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6220 Culebra Road • San Antonio, Texas, U.S.A. 78228-5166
(210) 522-5160 • Fax (210) 522-5155

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U.S. Nuclear Regulatory Commission
ATTN: Mrs. Deborah A. DeMarco
Office of Nuclear Material Safety and Safeguards
Program Management, Policy Development, and Staff
Office of the Director
TWFN, Mail Stop 8D–37
Washington, DC 20555

Subject: Programmatic Review of Poster

Dear Mrs. DeMarco:

The enclosed poster is being submitted for programmatic review. This poster will be submitted for presentation at the AGU Fall Meeting to be held December 10–14, 2001, in San Francisco, California. The title of this poster is:

> "Unsaturated Flow Through Fractured and Unfractured Nonwelded Tuffs"
> by Randall W. Fedors, James Evans, Dani Or, Craig Forster, Jason Heath, and Kelly K. Bradbury

This poster is a product of the Center for Nuclear Waste Regulatory Analyses and does not necessarily reflect the view(s) or regulatory position of the U.S. Nuclear Regulatory Commission.

Please advise me of the results of your programmatic review. Your cooperation in this matter is appreciated.

Sincerely,

Budhi Sagar
Technical Director

ECP/BS/ph
Enclosure

cc:	J. Linehan	K. Stablein	W. Patrick
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	E. Whitt	B. Leslie	CNWRA Element Managers
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	W. Reamer	N. Coleman	P. Maldonado
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Unsaturated Flow Through Fractured and Unfractured Nonwelded Tuffs

Randall W. Fedors[1], James Evans[2], Dani Or[2], Craig Forster[3], Jason Heath[2], and Kelly K. Bradbury[2]

[1. CNWRA, 6220 Culebra Road, San Antonio, TX 78238; 210-522-6818; e-mail: rfedors@swri.org; 2. Utah State University; 3. University of Utah].

UtahState UNIVERSITY

1. Introduction

Why study flow through nonwelded tuffs?

The nonwelded tuff units at Yucca Mountain (YM), the site of the proposed high-level radioactive waste repository, play a prominent role in percolation through the unsaturated zone to the repository horizon:

- The nonwelded Paintbrush Tuff (PTn) unit, which overlies the repository, is assumed to spatially and temporally dampen episodic pulses moving downward through the moderately welded tuffs of the Tiva Canyon Unit;
- Numerical model simulations (CRWMS M&O, 2000) show that a porous, permeable nonwelded tuff matrix (PTn) may attenuate rapid, transient fracture flow from the moderately welded Tiva Canyon tuff; hence, a steady state assumption is often made for unsaturated flow through the fractured tuffs of YM.

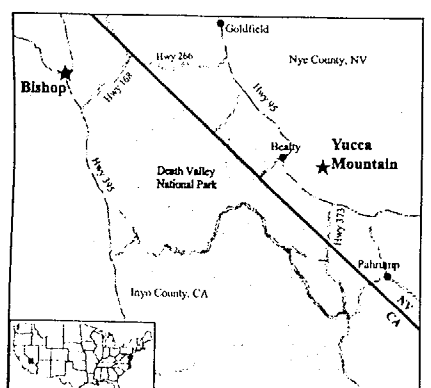
What is the evidence for fast flow at YM and how?

Evidence for non-uniform flow, either spatially or temporally as episodic percolation suggests that a significant percentage of episodic infiltration follows fast pathways through the PTn:

- Presence of bomb-pulse chlorine-36 below the PTn
- Dilute chemical composition of the perched water below the proposed repository
- Large faults likely participate, but these cover a relatively small area overall
- Primary heterogeneity or secondary discontinuities (e.g., fractures and small faults), however, could lead to preferential flow paths through the PTn and into the Topopah Spring welded tuff (TSw) below

Objectives

- Evaluate the reasonableness of the Bishop Tuff as a credible analog for the PTn at Yucca Mountain, on the basis of flow processes through the rocks at each site
- Perform field and laboratory tests to address the flow of water through fractured and unfractured nonwelded tuffs
- Translate the field and laboratory data into a continuum numerical model representation



Acknowledgments

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The authors would also like to acknowledge the assistance of Aaron Steinwand of the Inyo County Water Department, both for the water tank and assistance in the field.

Further thanks to D. Ferrill for the photographs from the Exploratory Studies Facility tunnel at Yucca Mountain (Figures 2d and 2e)

2. Nonwelded Paintbrush Tuff, Yucca Mountain

Poorly exposed rhyolitic tuff sequence at Yucca Mountain, Nevada, USA

- Surface exposures on west flank of YM
- ESF tunnel exposures
- Borehole data

Figure 2a

Stratigraphic Section

- Alternating massive ignimbrite and bedded tuffs
- All subunits of nonwelded tuffs not present at all locations
- Idealized section (4 subunits visible in figure 2a):
  - basal Tiva Canyon grades from densely welded to nonwelded
  - upper bedded unit (Tpbt4)
  - massive ignimbrite, partially to moderately welded (Tpy) (figure 2b)
  - middle bedded unit (Tpbt3), sharp upper boundary (figure 2c)
  - massive ignimbrite (Tpp)
  - lower bedded unit (Tpbt2)
  - upper Topopah Springs vitric tuff, grades nonwelded to densely welded downward
- Contacts vary from gradational to sharp unconformities

Figure 2b

Figure 2c

Structure

- Multiple structural deformation orientations
- Conjugate faults (figure 2d) and small offset fault in ESF tunnel (figure 2e, rock bolt used for scale)
- Surface exposure of fault in bedded unit (Tpbt3) (figure 2f)

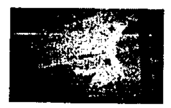

Figure 2d

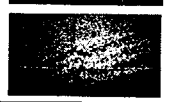

Figure 2e

Figure 2f

3. Nonwelded Basal Bishop Tuff, An Analog Site

Rhyolitic nonwelded tuff at base of Bishop Tuff near Bishop CA, USA

Figure 3a

Stratigraphic Section

- Unit D, densely welded tuff capping the Tablelands (figure 3a,d)
- Unit C, massive ignimbrite, moderately welded, grades to densely welded at top (figure 3a)
- Unit B, moderately welded grading to nonwelded at bottom massive ignimbrite, matrix-supported texture with lithic and pumice fragments (figure 3a,b and top of 3c)
- Pumice-rich, well bedded air fall deposits; pumice-clast supported texture (figure 3c,e) and locally finely laminated with evidence of fluvial reworking (figure 3g)

Figure 3b

Structure

- Single structural deformational event, extensional
- Fractures:
  - Fracture density increases with degree of welding (figure 3d)
  - Fractures still evident in nonwelded massive ignimbrite (figure 3e)
  - Though fractures not evident in bedded deposits, weathering likely occurred along fracture planes (figure 3c)

Figure 3c

Figure 3d

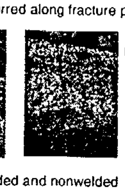

Figure 3e

- Faulting
  - Fault juxtaposing bedded and nonwelded massive ignimbrite (figure 3f)
  - Conjugate normal faults in laminated airfall tuff (figure 3g)

Figure 3f

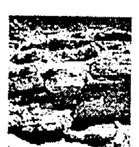

Figure 3g

9. References

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Tokunaga, T.K. and J. Wan, 1997. Water film flow along fracture surfaces of porous rock, Water Resources Research 33(6), pp. 1287-1295.

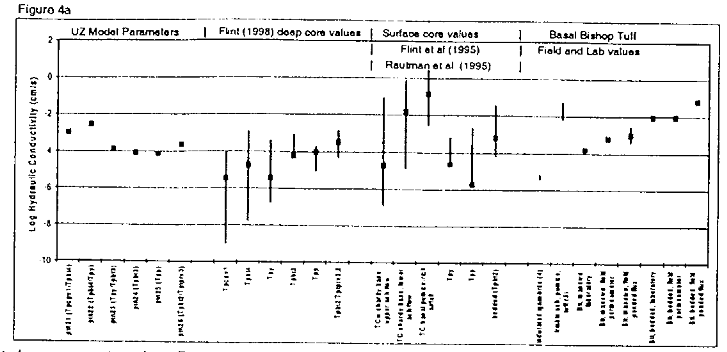
4. Hydrologic Properties of the PTn and Basal Bishop Tuff

Hydrologic data from the PTn at Yucca Mountain is summarized from a number of literature sources. Sparse hydrologic data from the nonwelded basal units of the Bishop Tuff have been supplemented as part of this work with both field and laboratory tests.

Figure 4a plots the mean and range of PTn permeabilities on left. Literature values and our measurements of hydraulic conductivity (field and laboratory) and field flux rates (simple infiltration tests) for the Bishop Tuff are on right. The range of values for the basal Bishop Tuff falls in the range of laboratory values reported for the PTn at Yucca Mountain.

Note: Literature values ((1) and (2) in figure 4a) of permeability for the Bishop Tuff are from Tokunaga and Wan (1997) and Hollet et al. (1991), respectively

Figure 4a



Tables 4a and 4b contain field and laboratory derived unsaturated zone parameter values. Porosity values for both the massive ignimbrite (matrix-supported texture) and bedded airfall (pumice clast-supported texture) were measured to be 0.47 while the moderately welded ignimbrite porosity was 0.35. Particle density for the nonwelded tuff was estimated to be 2.18 g/cm³. Field bulk densities of the clast-supported bedded and matrix-supported tuffs were 1.02 and 1.12 g/cm³.

Table 4a. Summary of Gardner relation parameter values from field measurements

Site	K_s (cm/s)	α (1/cm)	S (cm/s$^{1/2}$)	Comments
1. massive nonwelded ignimbrite	0.0006	0.09	0.06	disk permeameter
2. fractured, nonwelded tuff	0.0008	0.35	0.035	disk permeameter
2a. fractured, nonwelded tuff	0.0008	0.06	0.08	Guelph permeameter
3. fault area	0.0025	0.6	0.05	disk permeameter
3a. fault area	0.0022	0.4	0.055	2nd set of measurements
4. bedded clast-supported airfall tuff	N/A	N/A	N/A	No feasible measurements
5. moderately welded tuff	0.002	0.19	0.06	disk permeameter

Table 4b. van Genuchten water characteristic parameters measured in the laboratory (average of 4 asmples)

Sample type	θ_s (cm³/cm³)	θ_r (cm³/cm³)	α (1/cm)	n (-)	ρ_b (g/cm³)	Comments
matrix-supported, nonwelded	0.47	0.01	0.0068	1.79	1.1	disturbed
clast-supported, nonwelded	0.478	0	0.03	1.68	0.98	disturbed
moderately welded	0.355	0.12	0.00062	3.33	1.44	cores

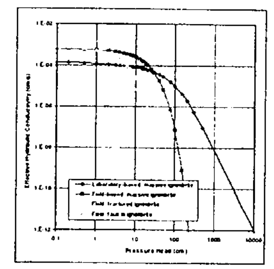


Figure 4b illustrates the differences in effective permeability as a function of tension head for all of the materials in the basal Bishop Tuff. Where data are available, field and laboratory estimates are compared.

5. Dye Tracer Tests in Nonwelded Bishop Tuff

Three ponded water tracer tests (line source) were performed using pulses of Brilliant Blue dye at 4 locations

Test 1

Paired test two sites, with and without fractures [figure 5a and 5b]. Site 2, the fractured tuff site, is on line with a large fault extending to the north [figure 5a].

- ~125 gallons infiltrated into each of two pits over 38 hour period
- Two pulses of dye tracer at hour=0.5 and hour=25
- Float valves to control pond height in pits
- 38 hours ponded infiltration

Figure 5a

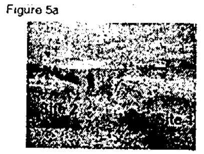


Figure 5b

Site 2: Flow is not preferential through the fractures, but rather, the fractures enhance matrix flow by constraining the flow paths. Depth to half-width ratio is 2:1. [figure 5c,d]. Sub-vertical fractures noted during early stages of excavation were noted to further focus the flow and transport.

Site 1: No vertical fractures at onset of test; 1 sub-horizontal fracture evident during excavation. Depth to half-width ratio is 1:1. [figure 5e,f]. Sub-horizontal fracture on right side caused significant lateral migration.

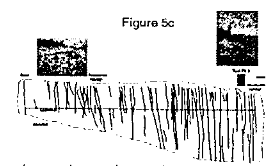


Figure 5c

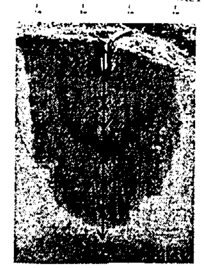


Figure 5d

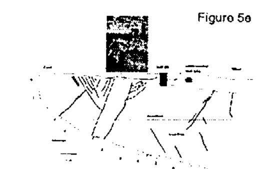
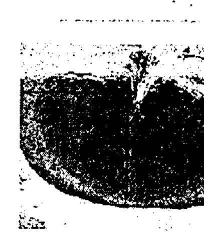


Figure 5e



Site 1

Figure 5f

Test 2

Small fault with gouge in massive nonwelded ignimbrite of Barrow Pit noted in figure 5a.

- Line source ponding parallel to ledge face (figure 5g)
- Single pulse dye tracer
- Short duration test, <5 gallons after tracer

Observations:

- Gouge was finer grained than the surrounding matrix (figure 5g)
- Flow and transport through the gouge was slower (figure 5h)

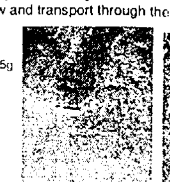


Figure 5g

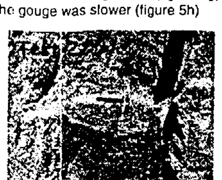


Figure 5h

Test 3

Bedded airfall tuff (pumice-clast supported) with prominent horizontal textural horizon

- Horton Creek site
- Line source ponding and single pulse dye tracer
- Short duration test, ~10 gallons after tracer

Observations:

- Anticipated unstable flow not exhibited by dye tracer
- Stable front indicative of uniform properties and capillarity-dominated flow and transport
- Flow and transport near prominent textural horizon exhibited little lateral movement [fig 5i]
- Iron-stained pathway exhibited no preferential flow and transport [figure 5j]

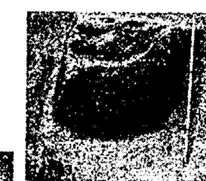


Figure 5i

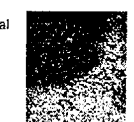


Figure 5j

6. Modeling of Dye Tracer Test

Two conceptualizations of Dye Tracer Test 1 were simulated using HYDRUS2D (v2.02):

- Homogeneous media with isotropic permeability for non-fractured site and anisotropic permeability for fractured tuff site
- Heterogeneous with fractures modeled as discrete features assigned a lower permeability than surrounding matrix

Hydrologic properties of nonwelded massive ignimbrite were based on field and laboratory data, fracture-fill properties were based on literature values typical of caliche, and initial conditions were qualitatively inferred from the field and further defined by calibration.

Homogeneous Representation

The effect of fractures can be modeled using anisotropic homogeneous media. Figure 6a represents Site 1 (unfractures) and figure 6b represents Site 2 (fractured).

Figure 6a

Site 1, unfractured

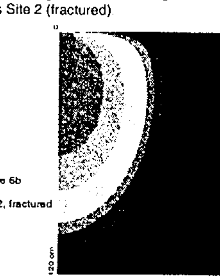


Figure 6b

Site 2, fractured

Discrete Feature Representation

Discrete fractures in the model are vertical and include a narrow filling of caliche and a narrow envelope where matrix pores are assumed to be partially filled by caliche. Figure 6c shows the filled fractures in the field. An excavated face at the end of the ponded line source of the dye tracer test Site 2 (fractured tuff) in Figure 6d shows the constraining of flow caused by the fractures. An expanded view of the modeled plume (figure 6e) exhibits the same separation of dye from the fractures as seen in figure 6d. A plot of pressure head distribution in figure 6f shows strong similarities to actual vertical flow features that result from filled fractures constraining lateral movement of water.

Figure 6c. Caliche-filled fractures

Figure 6d. Excavation face at edge of ponded pit, Site 2

Figure 6e. Modeled dye tracer, enlarged view from box drawn in figure 6f

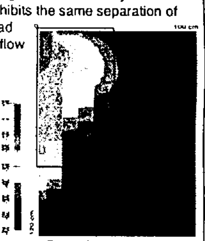


Figure 6f. Modeled pressure head (cm) distribution for discrete feature representation

7. Summary

The influence of primary lithology, texture, and faults/fractures on fluid flow through nonwelded tuffs was assessed using data from in situ infiltrometer, permeameter, and tracer tests and laboratory hydrologic tests.

Important observations are:

- The basal Bishop Tuff sequence includes many of the same features noted in the PTn at Yucca Mountain, and hence would be an excellent analog site for tests to help understand flow processes in fractured and unfractured nonwelded to partially welded tuffs;
- The line-source ponded dye trace test provides a realistic condition for focused water flow from fractures of welded rocks into nonwelded horizons of the nonwelded PTn;
- In the massive ignimbrites, flow constrained by filled fractures in the nonwelded tuff led to a two-fold increase in the vertical-to-horizontal anisotropic bulk permeability ratio over flow in non-fractured tuffs;
- Anisotropy can be used to represent the general effect of fractures on flow in simulations;
- Specific features of flow and transport can be simulated using discrete feature representations;
- No preferential flow was noted in the tracer test profiles completed in the highly permeable and porous bedded tuffs. This was an unexpected result.

8. Future Work

Further work is needed for detailed hydrologic characterization of flow in fractured nonwelded tuffs.

- Evaluation of the nature of fracturing and faulting as a function of texture in the tuffs (grain size and packing, degree of welding)
- Laboratory tests of flow through nonwelded tuffs, with and without fractures
- Field tests of infiltration in nonwelded tuffs with open fractures (fractures without secondary mineralization)
- Evaluation of the effect of fracture dip angle on the focusing of flow
- Field or laboratory infiltration tests in fractured tuffs with varying degrees of welding

Do fractures promote preferential flow or are they barriers to flow under unsaturated conditions?