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Fedors
#336
close-out

Randy Fedors

20-1402-661 Thermal Effects

TEF KTI → USFIC KTI

Contents | Page

DRIPPING & CONSTITUTIVE RELATIONS FRACTURE/MATRIX

5/17/99

DRIPPING INTO SUBTERRANEAN CAVITIES FROM UNSATURATED CAVITIES

Collaborators: Dani Or (paid consultant, Utah State Univ.)
Teamrat Ghezzehei (unpaid collaborator, Utah State Univ)
Ron Green (over-seeing seepage into drift studies under ambient and thermal pulse conditions)
Melissa Hill (logistic help in lab, etc..)

Objective: Investigate dripping and along-wall flow of water in unsaturated fractures intersecting a cavity.
Create a basis for the F_{ow} and F_{mult}, and/or F_{wet}, as appropriate, factors used in the TPA code

F_{ow} = drift seepage focusing factor.
F_{mult} = fraction of dripping that contacts canisters.
F_{wet} = fraction of canisters that receive dripping

History: Dani Or was encouraged to extend the work of Or and Tuller on capillary and film flow along a fracture face to the phenomena of drip detachment from the edge of the fracture face. Green was invited to an USFIC meeting as an introduction to Dani's work and subsequently, Dani was asked to present his work at Green's Seepage Workshop later in Dec 1998. Since then, sensitivity analysis and evaporation have been added (simple chemistry change also)

Machining: Marion x 2042
Larry Bishop x 2349 (Range) beeper # 715-3009
Main shop (Gilbert Rodriguez or Harold King) x 5704

6/17/99
RF

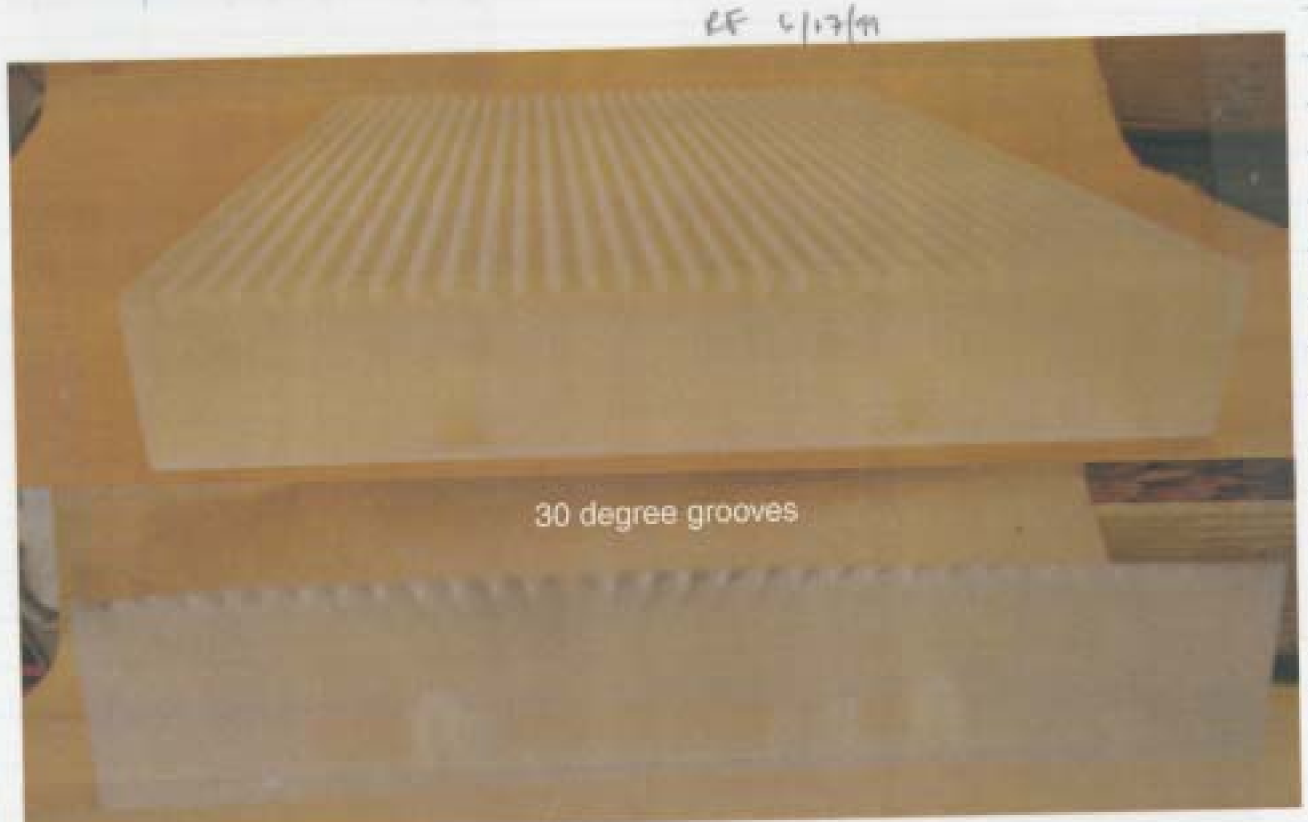
Observations of Dripping from Plexiglass & Glass Plates

Plexiglass "fracture" surfaces were fabricated in the machine shop of building 178 (George Geleta, Supervisor, Model Shop, Dept. of Space Systems, Instrumentation & Space Research Division, x3239) using the thick (~3/4 inch) plexiglass from Ron Green's lab. The fabricated plexiglass "fractures" were 4 x 6 in (long dimension in direction of flow) with grooves to test Dani Or's model. Only the grooves, no planes between grooves were fabricated; see photos this page and following page. Two groove sizes were fabricated, 30 deg and 120 deg. Depths for the grooves was restricted to 2 mm. The machine shop requires ~~are~~ measurements in english (inches, feet, etc...). Glass plates were 4x6 in and 2 mm thick, frosted and unfrosted. Plexiglass was also frosted & unfrosted.

RF 6/17/99

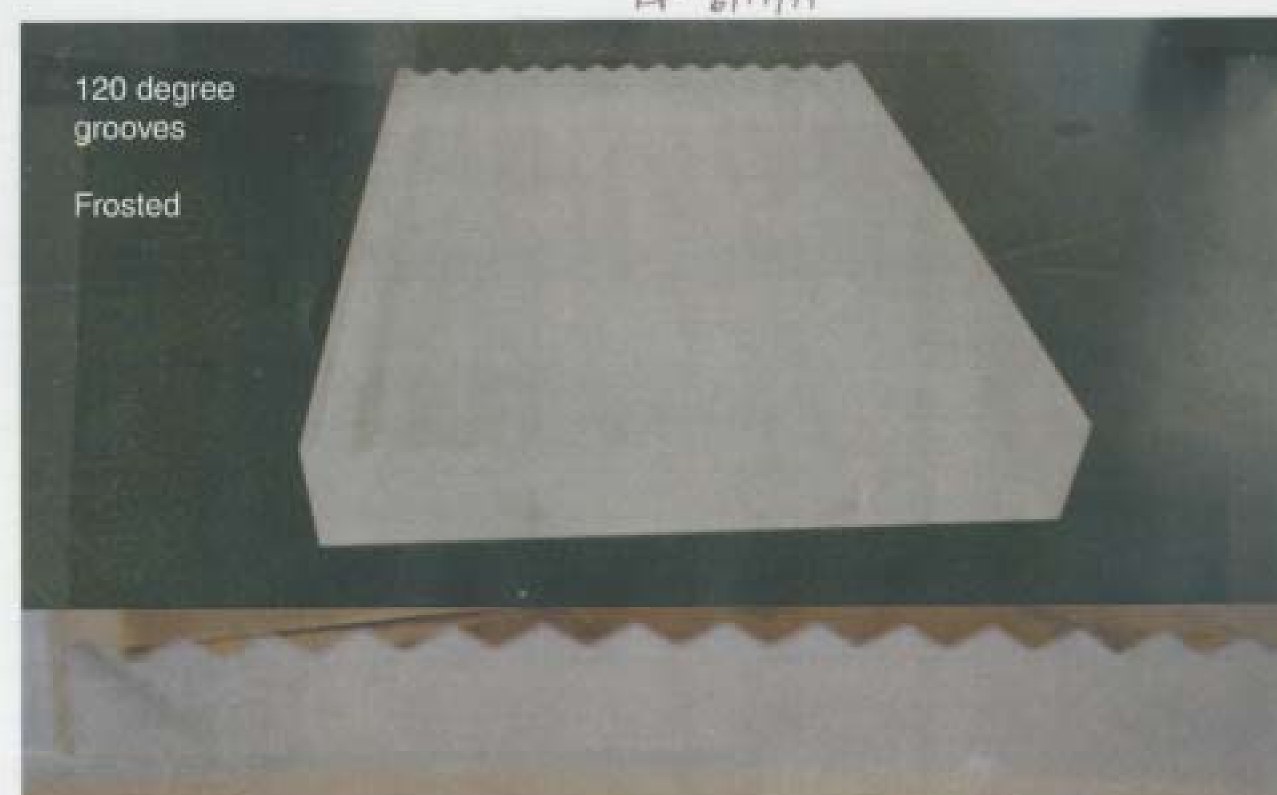
Holders for the plexiglass & glass fabricated fractures were designed and made by myself and Tony Mazaro, a student employee of the lab.

RF 6/17/99



RF 6/17/99

RF 6/17/99



 6/17/99 PF

Results of Observations on grooved plexiglass & smooth glass

From the onset, it was known that plexiglass did not have a wettability with respect to water/air similar to that expected for natural rock fractures; the surface tension is expected to differ markedly. However, this experiment served two purposes. (1) To refine the logistics of the dripping setup in terms of supplying water to the top of block, collecting water from the drips, and covering the entire experiment to reduce any evaporative effect (which was expected to be minimal at the high rates of influx to be used); and (2) observations of physical aspects of dripping that might be incorporated into the dripping model of Dani Or (see his scientific notebook).

The first objective was satisfied. The only modification will be a stronger holder for the natural fracture surfaces (Apache Leap Tuff) to be used later.

The second objective, observations of drips, had one significant surprise. Dani, using grooved aluminum, also noted the "transition zone" for his 45 degree grooves. The zone is the transition from negative pressures in the groove to positive pressures in the drops. For large angle grooves this transition zone is small to negligible (120 deg plexiglass block); but for small angled-grooves, it is significant. I noted 1½ cm long transition zone for the 30 degree grooves expressed as a build-up of water at the bottom of groove, just before the lip where the drop detaches. As expected, capillarity effects are reduced for the 120 deg angle grooves and no transition zone is readily observed. The build-up of water in the transition zone is observed as the filling of the groove with water — and the length of the transition zone (or filled groove above drop) did not appear to vary when the flux was changed

10/22/99 PF

Drips from Natural Fractures

bubo D:\Randy\DriftSeepage\NaturalFractures*

Tony Magaro used the rock saw in Bldg. 51 to cut 3 fracture surfaces, all about 1¼ to 1½ inches thick

RS-1	~ 6 x 7 inches
RS-2	~ 6 x 7 inches
RS-3	~ 6 x 6 inches

Tony also cut blocks with smooth (saw-cut) surfaces so that grooves could be cut in tuff (to address question of surface tension and wettability differences between water on aluminum versus tuff).

The fracture surfaces are from a large diameter borehole core from the Apache Leap Tuff in Arizona

The experimental setup includes:

- a cylindrical ceramic input source for water along the top of the fracture surface (photo on next page shows a long tube, this tube was cut to match the width of the rock for all measurements).
- Filter paper to better distribute water coming from ceramic tube onto entire width of rock (uneven surface)
- rock support structure built by Tony Magaro
- drip collection done with 10 ml (tic marks to 0.2 ml) burette/beaker. [graduated cylinder]
- Fisher Scientific stop watch (blue-faced one); 14-648
- peristaltic pump: Monostat Cassette Pump Serial # 3024 catalog # 72 500 000
- box enclosure (plexiglass) to ensure no ventilation effect,

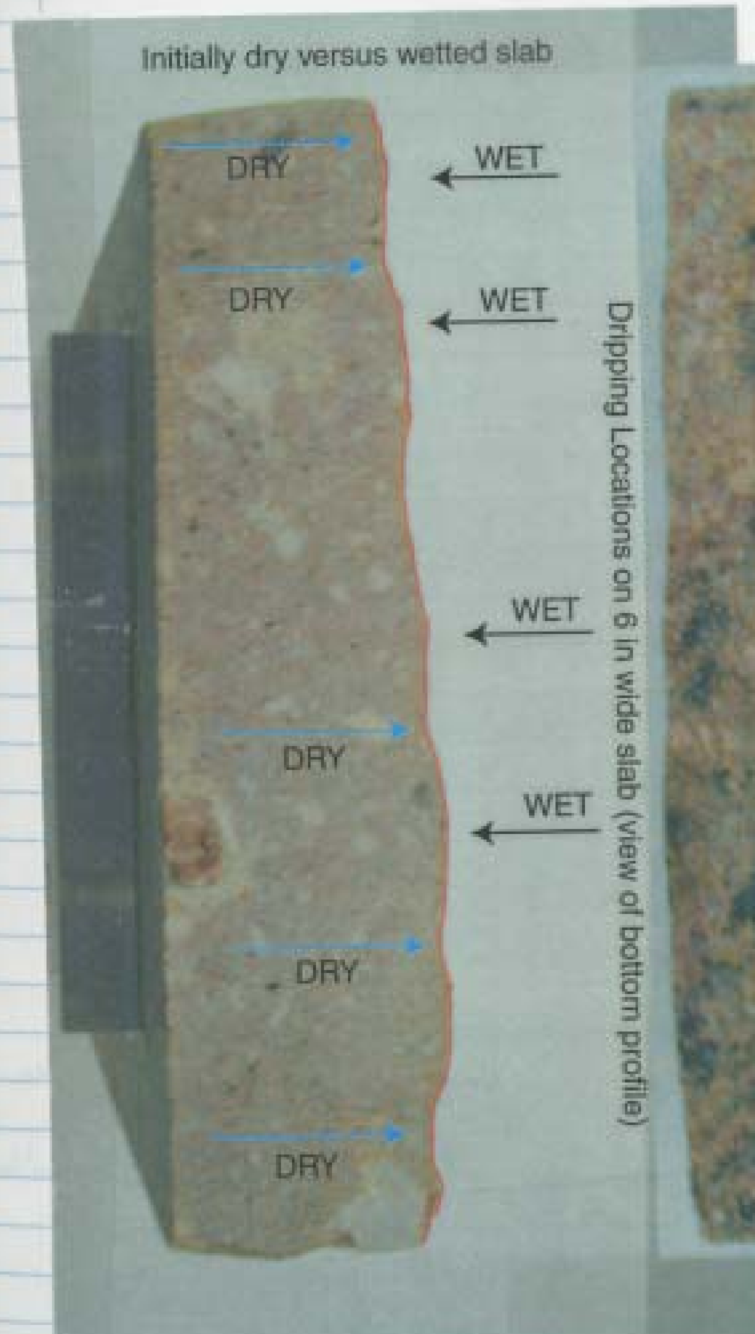
Initial setup is depicted in a photo on the next page. The only significant difference for actual runs was to use the shortened ceramic tube (to match width of rock)

Support Apparatus

RF 10/22/09

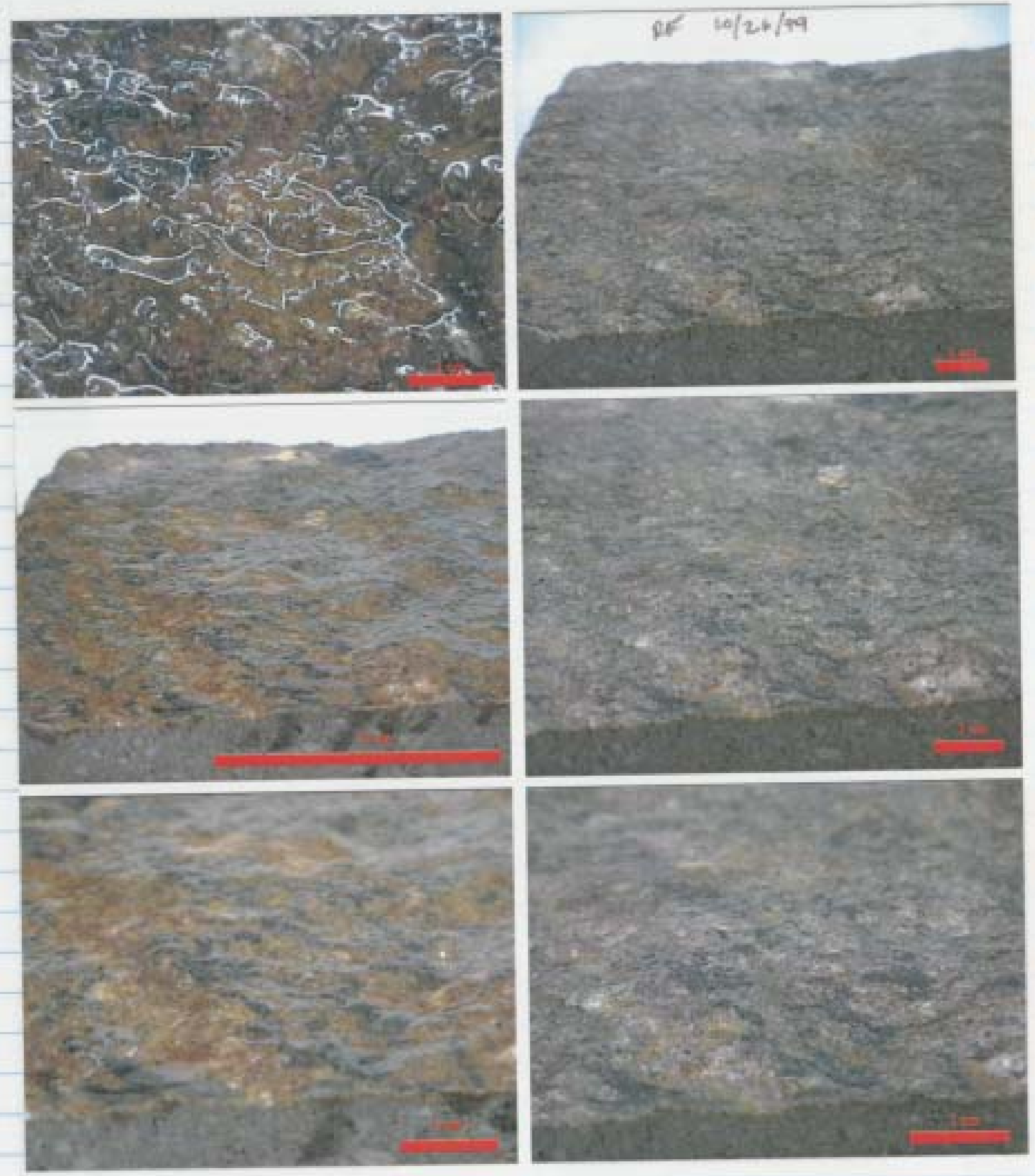
Drip Location - Wet versus Dry Initial Condition

The drip locations changed location depending on whether the experiment was started with a dry fracture surface or a wet fracture surface. When dry initially, rivulet flow along fracture face feeds the low points (depressions) in the profile of fracture lip. When wet initially (spray misted to wet entire surface), the drip locations shifted to the high points in the profile



RF 10/26/99

RF 10/26/99



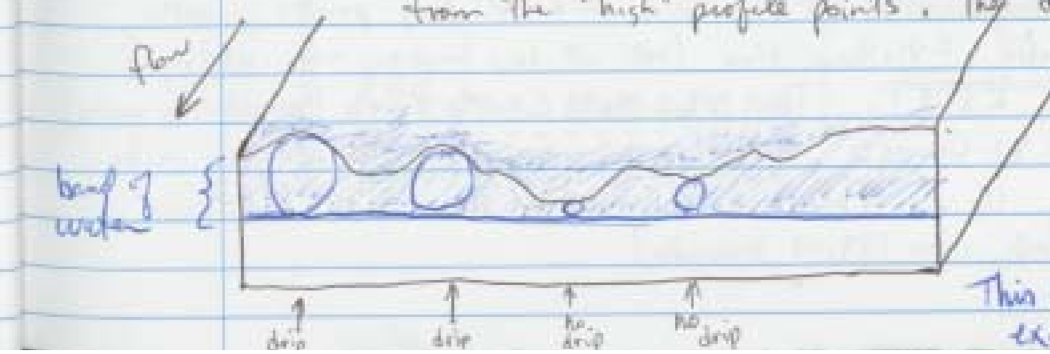
Photos of wet and dry surfaces taken at various scales. The channels for water flow down the fracture face are evident in these photos. Also "storage" depressions, places where water has no through pathway are present

NOTE: The appropriateness of the plane, pit and groove geometric simplification in the photo below (RS-1' block).

flow direction

RF 10/26/99

Also evident in the photo (middle one) is the build-up at the bottom of fracture block where drips fall from. This build-up occurs along the entire bottom portion of the fracture block and it allows water to re-distribute laterally! Hence the drip locations may not occur where the channel/groove locations feed the bottom of the fracture block. There is also a continuous band on the bottom (saw cut) side of the block (view shown in right photo, but not with water present). The sketch below illustrates why drips detach from the "high" profile points. The drips search out areas where they can maximize the attachment area (illustrated by blue circles).



This is relevant to an excavated drift!!!

10/26/99

Counting Drops → RS-1 & RS-2
Fracture Blocks

The apparatus shown on page 6 was set up for both blocks (RS-1 & RS-2). The blocks were pre-wet and the plexiglass enclosure was used (lighting misting introduced initially to get RH approaching 100%). The graduated cylinders (page 6) were placed under drip locations after the flow had been going for an hour. The number of drips into each graduated cylinder was counted for a measured length of time (stopwatch). Hence, the number of drops, the total volume, and the time period were all recorded to spreadsheet

* RF 10/26/99 was D:drive switched to J:drive 3/10/00

* bubo: J:\DriftSeepage\NaturalFractures\dripping.xls

Note that the photos from the previous pages, plus other photos are stored as directories \Plexiglass*, .\Set-1*, .\Set-2*, .\Set-3*, and .\Set-4*; the photos Dani Or used in his publications came from .\Set-4\

The drip flux, drip period (time between drips), and drip volume, and drops per 10 minute period were all calculated from the measured # of drips, total volume, and time. A print-out of the spreadsheet with graphs is attached to page 11. The record identifier includes the fracture block number followed by a comma, then a "1" or "2" to denote repeated experiments, then "a", "b", or "c" to denote drip locations on the fracture blocks.

exactly reversed !! "1" & "2" refer to drip locations; "a", "b", "c" refer to subsequent experiments repeated at different fluxes

9/3/00 RF

For experiments with RS-2, there were 2 drip points; both were collected at the same time (not all drip locations were utilized for block RS-1). The Manostat Cassette Pump (peristaltic pump) Catalogue # 72 500 000, Serial # 3024 was set to a flow rate setting of 10. This was calibrated to 3.2087 ml/min [9.8 ml over 183.25 seconds]

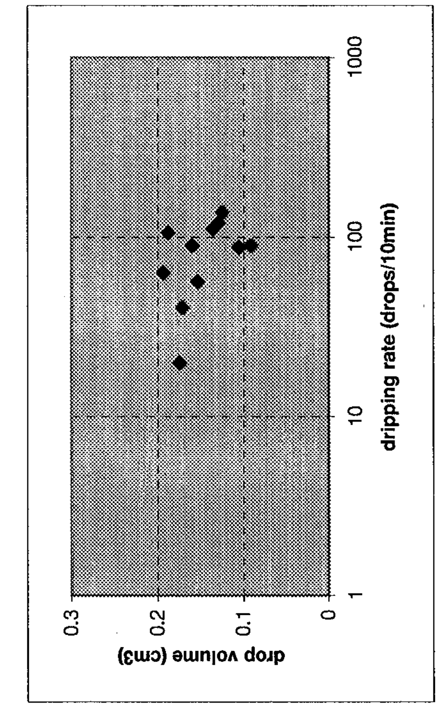
RF 10/26/99

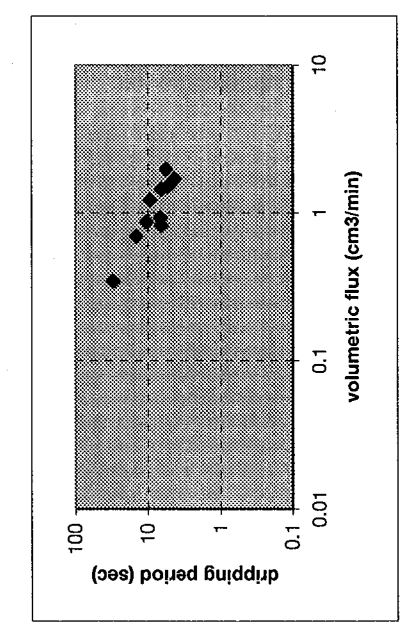
dripping.xls print-out

Dripping Laboratory Experiments

slab #, then drip location denoted by number	date	drips	volume ml	time sec	comments, quality	drip flux cm3/min	drip period sec	drip volume cm3	drops per 10 min
RS-1,1a	21-Oct-99	48	4.4	320	?	0.8250	6.67	0.0917	90.0
RS-1,2a	21-Oct-99	73	9.1	320	?	1.7063	4.38	0.1247	136.9
RS-1,1b	21-Oct-99	36	3.8	245		0.9306	6.81	0.1056	88.2
RS-1,2b	21-Oct-99	40	5.2	200		1.5600	5.00	0.1300	120.0
RS-1,2c	21-Oct-99	39	5.3	210		1.5143	5.38	0.1359	111.4
RS-1,3a	22-Oct-99	30	4.8	200		1.4419	6.66	0.1600	90.1
RS-1,4a	26-Oct-99	30	4.6	317		0.8718	10.55	0.1533	56.9
RS-2,1a	26-Oct-99	30	5.8	284	total input 3.2 cm3/min	1.2265	9.46	0.1933	63.4
RS-2,2a	26-Oct-99	50	9.4	284	total input 3.2 cm3/min	1.9878	5.67	0.1880	105.7
RS-2,1b	26-Oct-99	27	4.7	814	total input 1.0 cm3/min	0.3465	30.14	0.1741	19.9
RS-2,2b	26-Oct-99	55	9.4	814	total input 1.0 cm3/min	0.6930	14.80	0.1709	40.5

RF 10/26/99





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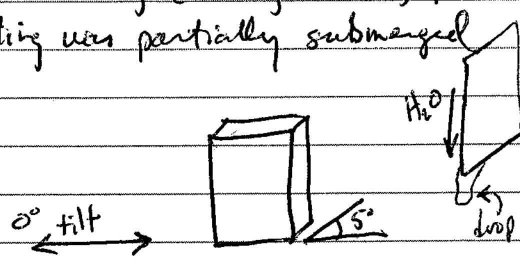
Dripping from RS-2 slab (Apache Leap)

Building 51

Set up apparatus for supplying steady, uniform flux to top of slab while covered by plexiglass case. After dripping had gone on for a long time, and was going too slow, it dawned on me that I forgot to pre-wet the samples. Hence, the dripping rate was significantly slowed because of sorption into the rock slab. Dripping rates were on the order of 25-30 seconds (dripping period) instead of the expected 5-15 seconds.

9/1/00
PF

Set up RS-2 slab again after wetting (soaking in tub) the rock all night. 1st hour of wetting was partially submerged to reduce trapping of water.



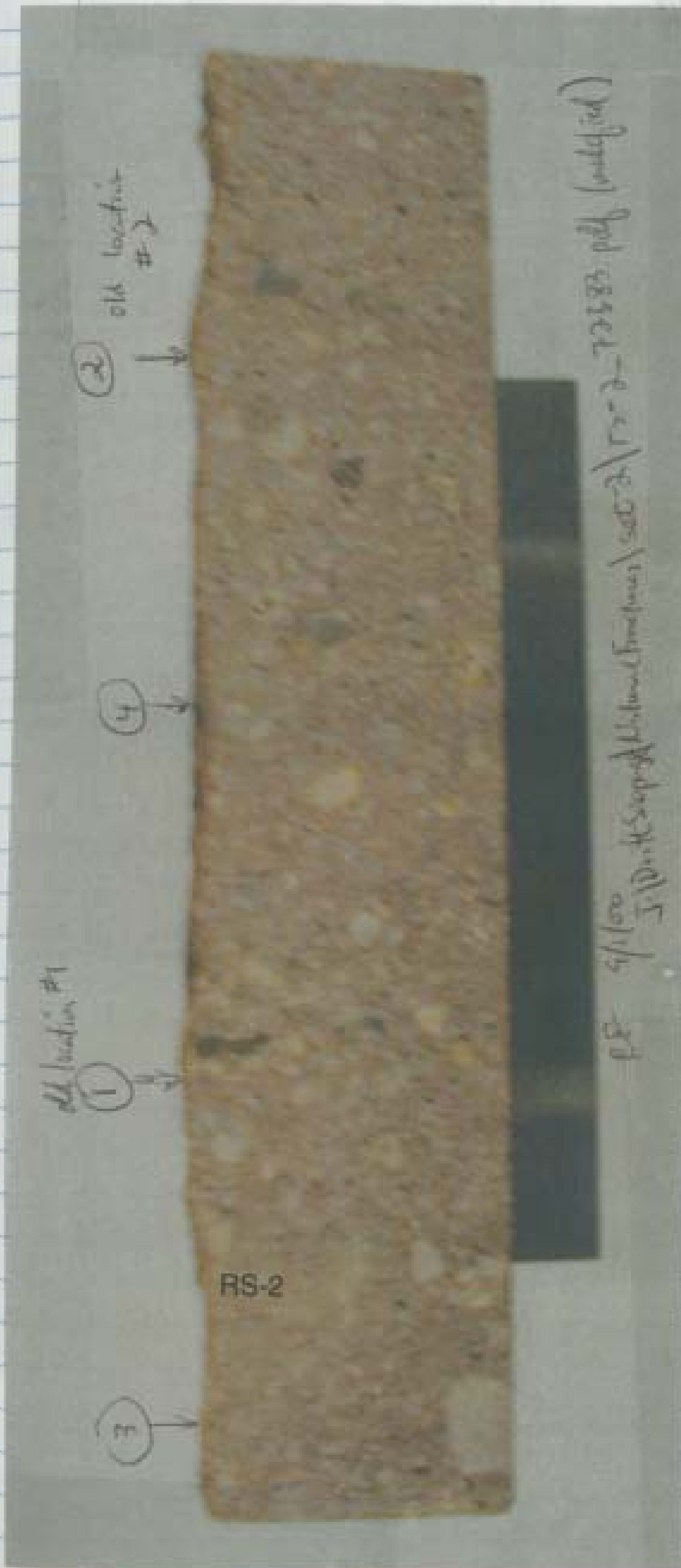
Used Brunton to check angles of bottom of slab. Aligned the bottom face to 5° to keep water from flowing to back of slab. Also made sure that water wouldn't flow side to side by making sure there was no tilt.

Used small hose on peristaltic pump w/ setting to "10". [I will check pump output rate after the system has been running awhile, so it doesn't really matter what the setting starts at & what hose is used]

See set-up on pages 5-6 for further details

Since earlier work indicated that the drip points were controlled by profile "high" points when the slab is initially wet (grooves feed the dripping, grooves w/in slab are "low" channels), I noted the drip locations for this particular flux (supplied) rate. There were 4 drip locations, two of which were the same locations as noted in previous testing

Locations #1 and #2 match old locations #1 & #2 (page 11 chart)



Bottom photo of RS-2 slab ("profile") with drip locations noted. Numbers are used in table on following location

9/1/00
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As before, drops from each location are collected in separate graduated beakers/cylinder (0.2 ml resolution tic marks), same as previously used.

location	drops counted	total volume collected	time
3	22	3.6 ml	768.4 seconds
1	39	6.5 ml	"
4	42	6.95 ml	"
2	59	9.4	"

The base of the drop (#1 location) was measured to be ~6.5 mm But the drop diameter at the base contracts just as the drop is collecting prior to detachment. Photos taken of drips at locations #1 and #2 (early sequence of close ups) will help determine drop anchoring diameter. Unfortunately, the computer that has the video card and software for viewing the videocam images (and saving) is not functional (the mouse is broke). IMS was called in for repair so I will come back when it's fixed to get the images off the camera.

Peristaltic pump output = 60 ml in 28 min & 15 seconds

$$\frac{60 \text{ ml}}{28.25 \text{ min}} = 2.124 \frac{\text{ml}}{\text{min}}$$

Total from table above (calculated in spreadsheet
J:\DriftSeepage\NaturalFractures\dripping.xls) is 2.065 ml/min
The rate calculated from dripping is close to that measured from pump, therefore, the mass balance is pretty good.

not radius! RF 9/1/00

	date	drips	volume ml	time sec	comments, quality	drip flux cm3/min	drip period sec	drip volume cm3	drops per 10 min	estimated drop diam, mm
RS-2,3	01-Sep-00	22	3.6	768	influx for all 4 drips = 2.124 ml/min	0.2811	34.93	0.1636	17.2	
RS-2,1	01-Sep-00	39	6.5	768	influx for all 4 drips = 2.124 ml/min	0.5076	19.70	0.1667	30.5	6.5
RS-2,4	01-Sep-00	42	6.95	768	influx for all 4 drips = 2.124 ml/min	0.5427	18.29	0.1655	32.8	
RS-2,2	01-Sep-00	59	9.4	768	influx for all 4 drips = 2.124 ml/min	0.7340	13.02	0.1593	46.1	
					sum of individual fluxes =	2.0654				

RF 9/1/00

12/9/00
RF

Write-up sent to Teamrat & Dani
bubo J:\DriftSeepage\NaturalFractures\drip-fracture.doc

RF 12/9/00

Natural Fracture

A natural rock fracture surface was obtained from a large-diameter core of the Apache Leap Tuff in New Mexico. This material is a moderate to densely welded air fall tuff. Samples were cut using a rock saw to the dimensions of 3 cm thick, 18 cm long, and 15 cm wide. The bottom saw-cut edge emulates a drift wall surface in a tunnel. The use of a natural rock fracture face eliminates uncertainty caused by wettability characteristics and surface morphology (roughness) as compared with the fabricated aluminum fracture model. Additional levels of complexity, however, are added when studying dripping from the natural fracture face as compared to the more strictly controlled aluminum fracture model.

The natural fracture slab was saturated prior to being mounted with the surface of the fracture face vertically oriented inside a closed plexiglass chamber maintained at a high humidity. Prior to starting the experiments, the fracture slabs were nominally saturated by slow submergence in a water-filled bucket. Water was supplied to the top of the fracture slab using a peristaltic pump operated at several flow rates. The water was injected into to a ceramic tube resting along the entire top edge of the fracture face; fine filter paper was used to help distribute the water influx evenly across the top of the fracture slab. When a steady state dripping rate was attained, glass beakers were placed under each drip location, and the number of drops collected in each beaker during a specified length of time was counted. At the end of each experiment, the volume of each beaker was determined. The volumetric flux Q (m^3s^{-1}) for each experiment was calculated from the volume V (cm^3) of water accumulated in the beakers as,

$$Q = \frac{V}{t}$$

where t (s) is duration of test. The time-averaged dripping period P (s) of individual drops is calculated from the number of drops N as,

$$P = \frac{t}{N}$$

for the specified time duration of test.

Observations

Drip locations are a function on several features of the natural fracture slab. The location of drips changes for initially dry fracture faces versus wetted faces. For initially dry fracture faces, the drip locations are dictated by the rivulet channel locations on the face of the rock slab. At the bottom of the rock slab, these locations correspond with low points in the cross-sectional profile along the bottom edge. For the completely wetted rock fracture face experiments, the drops detach from beneath high points on the fracture face profile at the bottom edge of the slab, even though the drops were fed by flow through the low channels ("grooves") on the fracture face. This means that water migrates laterally along the bottom of the fracture slab, both in the capillary fringe on the fracture face and in the similarly continuous band of water on the underneath (saw-cut) surface at the edge of the slab. The drip locations at the high points of the profile suggest a tendency for the drops to maximize the drip anchoring area. However, there was no correlation noted between the measured drop volume and magnitude of profile height. All data reported here are from experiments using a completely wetted fracture slab; data from initially dry fractures are only expected to be relevant for shallow, near-surface natural systems with prominent air flow well-connected to the atmosphere.

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continued from page 15

Experimental data of the dripping period at variable flow rates and different drip locations on the natural fracture surface of the Apache Leap Tuff follow a trend that is consistent with an assumption of constant drop volume. Figure 1 confirms the assumption of constant drop volume for the applied flux rates though there is some scatter in the data possibly due to measurement errors. Overall, the data indicate that the drop volumes from natural fractures with the smooth (rock saw-cut) bottom surface were of similar magnitude to the drop volumes in natural caves within the broad region of intermediate flux rates measured by Genty and Deflandre (1998). The drop volumes from the natural fracture face are larger than those measured from the grooved aluminum plate. This may be due to the rough surfaces of natural fractures and subterranean cavities.

Experimental data of the dripping period as a function of volumetric flux (figure 1) at different drip locations on the natural fracture surface of the Apache Leap Tuff follow closely predictions made using a constant drop volume and the equations developed in Or and Ghezzehei (2000).

The anchoring area of the drop (A_o) was visually estimated during the experiments and confirmed using measured drop diameters from video digital photographs (see figure 3). The anchoring area varies during the drop formation period. Early drop anchoring area is large but as the weight of the water in the drop increases during the last few tenths of a second prior to drop detachment, the radius of the anchoring area decreases by 35 percent. The asymptotic surface from which the drop-anchoring radius is approximated is clearly visible in figure 3; the shape of this asymptotic surface changes during the formation of the drop. In addition, the drop radius a (see figure A2, Or and Ghezzehei, 2000) does not become distinct until late in the drop period when the weight of the water causes the drop to begin to elongate. The drop radius a is slightly smaller than the drop anchoring radius R; the former radius was included in the equation for drop volume to refine the development (Or and Ghezzehei, 2000).

AF 12/9/00

The figure on page 17 was assembled from images taken with Chuck Connor's digital video camcorder
[Cano Mini DV, ZR Digital Video Camcorder]

Frames were chosen, frozen, and saved as jpegs
bubo I:\DriftSeepage\NaturalFractures\Images-Aug2000\
files ⇒ drp0????.jpg where the question marks are the times in seconds

The scale bar was estimated by measuring known features on sample

Drip sequence bubo: J:\Driftseepage\NaturalFractures\Images-Aug2000\
.\dripSequence.pdf

RF 12/9/00

12/9/00
RF

Summary of data sent to Teamrat & Dan.

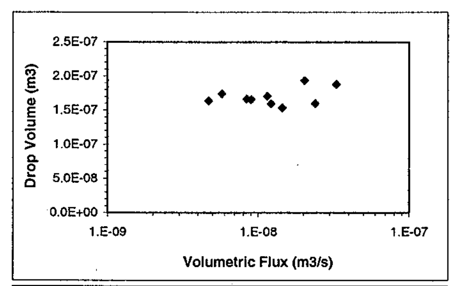
J:\DriftSeepage\Natural Fractures\dripping.xls
Excel spreadsheet (Excel 97 SR-2)

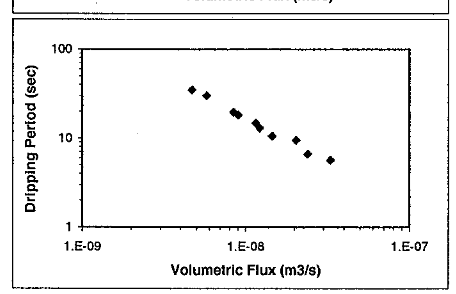
Dripping Laboratory Experiments

slab #, then drip location denoted by number	date	drips	volume ml	time sec	drip flux cm3/min	drip period sec	drip volume cm3	drops per 10 min	qualitative visually estimated drop diam, mm	comments, quality
RS-1,1a	21-Oct-99	48	4.4	320	0.8250	6.67	0.0917	90.0		?
RS-1,2a	21-Oct-99	73	9.1	320	1.7063	4.38	0.1247	136.9		?
RS-1,1b	21-Oct-99	36	3.8	245	0.9306	6.81	0.1056	88.2		Ao wetted diameter= 11mm; ?
RS-1,2b	21-Oct-99	40	5.2	200	1.5600	5.00	0.1300	120.0		wetted dia.(mm)=13, 12.5,11, 12; ?
RS-1,2c	21-Oct-99	39	5.3	210	1.5143	5.38	0.1359	111.4		?
Eliminate 1st day of experiments from analysis due to questionable procedures and data collection techniques										
RS-1,3a	22-Oct-99	30	4.8	200	1.4419	6.66	0.1600	90.1		
RS-1,4a	22-Oct-99	30	4.6	317	0.8718	10.55	0.1533	56.9		
RS-2,1a	26-Oct-99	30	5.8	284	1.2265	9.46	0.1933	63.4		total input 3.2 cm3/min
RS-2,2a	26-Oct-99	50	9.4	284	1.9878	5.67	0.1880	105.7		total input 3.2 cm3/min
RS-2,1b	26-Oct-99	27	4.7	814	0.3465	30.14	0.1741	19.9		total input 1.0 cm3/min
RS-2,2b	26-Oct-99	55	9.4	814	0.6930	14.80	0.1709	40.5		total input 1.0 cm3/min
RS-2,3	01-Sep-00	22	3.6	768	0.2811	34.93	0.1636	17.2		influx for all 4 drips = 2.124 ml/min
RS-2,1	01-Sep-00	39	6.5	768	0.5076	19.70	0.1667	30.5	6.5	Locations #1 and #2 match up with locations of drippin
RS-2,4	01-Sep-00	42	6.95	768	0.5427	18.29	0.1655	32.8		influx for all 4 drips = 2.124 ml/min
RS-2,2	01-Sep-00	59	9.4	768	0.7340	13.02	0.1593	46.1		Locations #1 and #2 match up with locations of drippin
	sum of individual fluxes (9/01/00 only)=				2.0654					

Measurements made on RS-2,2 from images 11/22/00
R is associated with the anchoring area,
and "a" is associated with the semiellipsoid of the drop
0.564 = ratio of slab to photo scale (print out)

Clock Time (sec)	photo scale diameter base (cm)	photo scale diameter drop (cm)	R (cm) radius	a (cm) radius
15.14	2.2		0.621	
16.23	2.1		0.592	
17.2	2.1		0.592	
18.07	2		0.564	
18.16	2	1.6	0.564	0.451
18.22	1.7	1.4	0.479	0.395
18.23	1.55	1.2	0.437	0.338
18.24	1.3		0.367	





RF 12/9/00

Last Entry RF 10/4/02

I have reviewed this scientific notebook and find it in agreement with QAP-001. There is sufficient information regarding methods used for conducting tests, acquiring and analyzing data so that another qualified individual could repeat the activity.

E. C. Pearcy
10/4/2002

ADDITIONAL INFORMATION FOR SCIENTIFIC NOTEBOOK #: 336

Document Date:	05/17/1999
Availability:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, Texas 78228
Contact:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, TX 78228-5166 Attn.: Director of Administration 210.522.5054
Data Sensitivity:	■"Non-Sensitive" □ Sensitive □"Non-Sensitive - Copyright" □ Sensitive - Copyright
Date Generated:	10/21/1999 through 01/01/2001
Operating System: (including version number)	Windows NT 4.0
Application Used: (including version number)	Various
Media Type: (CDs, 3 1/2, 5 1/4 disks, etc.)	1 CD
File Types: (.exe, .bat, .zip, etc.)	jpg, pdf, xls, ppt, txt, doc
Remarks: (computer runs, etc.)	Media contains drift seepage/natural fractures: various binary, ASCII files