LABORATORY NOTEBOOK

CNWRA/SwRI

NOTEBOOK NO. 302

ISSUED TO Troy Maxwell T.M.

ON 1-5 **19**99

DEPARTMENT Div. 20 CNWRA

RETURNED **19**

CNWRA CONTROLLED COPY 302

Entries made by: Troy Maxwell T.M.

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INSTRUCTIONS

1. **The primary purpose of this notebook is to protect your and the Company's Patent-Rights by keeping records of all original work in a form acceptable as evidence if any legal conflict arises.**

2. • When starting a page, enter the title, project number, and book number.
   • Use ink for permanence -- avoid pencil.
   • Record your work as you progress, including any spur-of-the-moment ideas which may be developed later.
   • Avoid making notes on loose paper to be recopied.
   • Record your work in such a manner that a co-worker can continue from where you stop. You might be ill and to protect your priority it could be urgent that the work continue while you are absent.

3. • Give a complete account of your experiments and the results, both positive and negative, including your observations.
   • Record all diagrams, layouts, plans, procedures, new ideas, or anything pertinent to your work including the details of any discussions with suppliers, or other people outside the Company.
   • Do not try to erase any incorrect entries; draw lines deleting them, note the corrections, sign and date the changes. This extra care is worthwhile because of the necessity of original data to prove priority of new discoveries.

4. • After entering your data, sign and date the entries.
   • Explain your work to at least two witnesses who are not co-inventors, and have them sign and date the pages in the place provided.
   • Record the names of operators and witnesses present during any demonstration and have at least two witnesses sign the page. If no witnesses are present during an experiment of importance, repeat it in the presence of two witnesses.

5. Since computer programs can be patented these instructions apply to the development of computer software. In this case a description of the structure and operation of the program should be recorded in the notebook, together with a basic flow diagram which illustrates the essential features of the program. In the course of developing the code, the number of lines of code written each day should be recorded in the notebook, together with a statement of the portion of the flow diagram to which the section of code is directed.

6. This notebook and its contents are the exclusive property of the Company. It is confidential and the contents are not to be disclosed to anyone unless authorized by the Company. You must return it when completed, upon request, or upon termination of employment. It should be kept in a protected place. **If loss occurs, notify your supervisor immediately, and make a written report describing the circumstances of the loss.**

Form 590

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Introduction: (Also see CNWRA notebook 301)

This notebook is to be used for laboratory experiments for modeling water flow through rock fracture. An artificial fracture will be contructed out of sand blasted glass panes pressed together. The experiment was suggested by Debra Hughson on December 11, 1998.

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12-30-98

Debra and I purchased two 12" x 15" glass plates from Glass Service located on Bandera road. Each plate is approximately 3/8" thick and weighs 2.7 kg (≈ 6 lbs).

T.M. 12-30-98

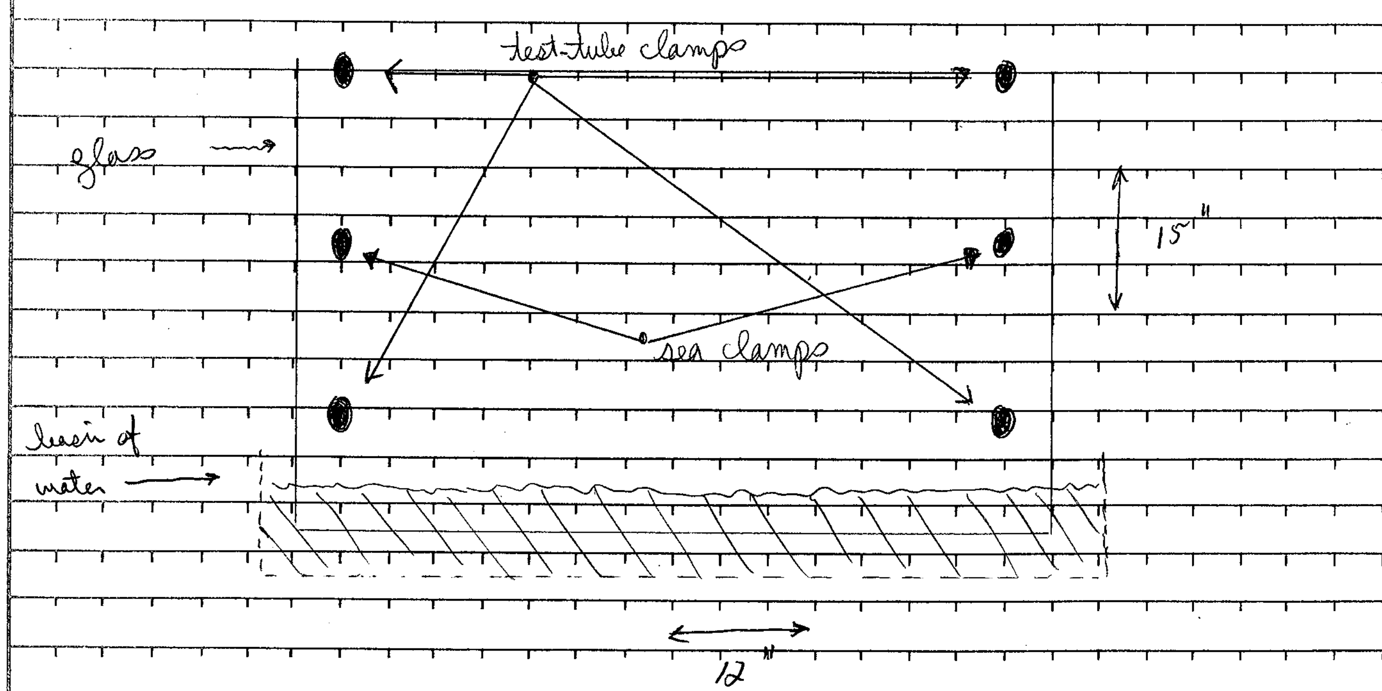
1-4-99

One side of each glass plate was sand blasted with fine grade 4 sand. Bldg. 137 was responsible. The glass was blasted at an ~~80 ft~~ 80 in distance. T.M. 1-4-99

T.M. 1-4-99

1-6-99

The glass plates were clamped together and held to a ring stand. To measure the capillary pressure, the plates were dipped into 3/4" of room temp. water. A large ~~tin~~ metal pan was used to hold the water.



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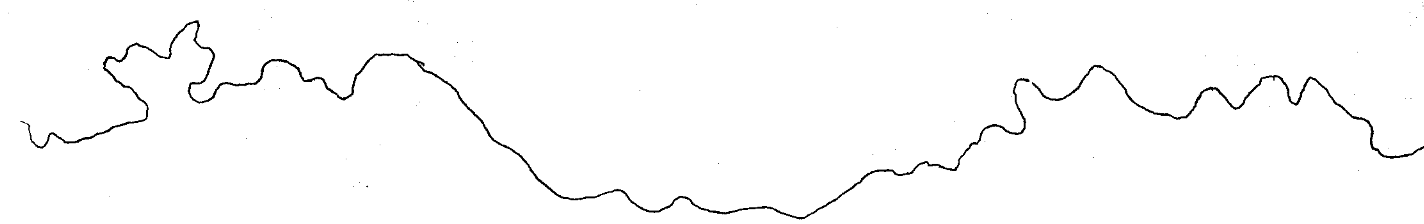
(reduced sketch)



Results from capillary pressure test:

depth of water : 3/4 in
max height (left): 2 1/8 in
max height (right): 1 7/8 in
min : 5/8 in

The experiment was conducted at 77°F in an open environment. Four test-tube clamps were used to hold the glass plates to the ~~ring~~ ring stands while two sea-clamps ~~clamps~~ were used to hold the plates together. No clamps were placed on the short (12") side of the glass.

T.M. 1-6-99

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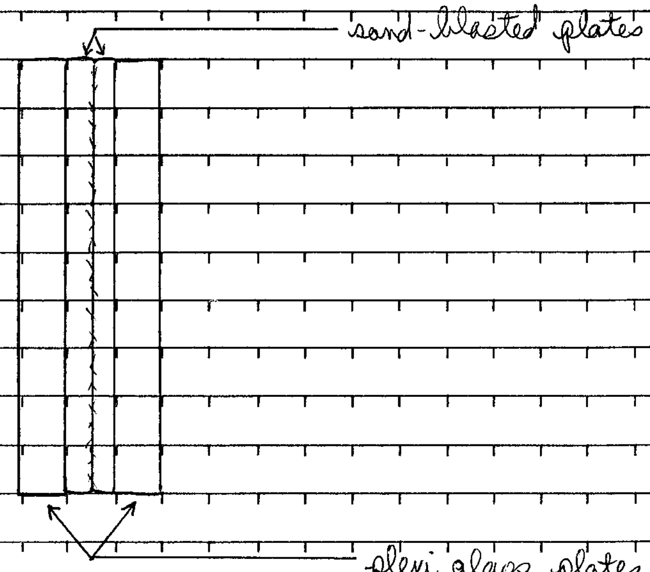
1-13-99

The results from the capillary pressure test revealed that the pressure was greater on the right and left sides of the glass. This was expected since no clamps were placed in the middle of the glass. Ron Green suggested the use of plexi glass to distribute the load of the clamps. On 1-12-99, two 12 × 15 in plates of plexi glass were cut. The plates were about 1/2 inch thick. The capillary pressure test was repeated with the two plexi glass plates sandwiching the two glass plates.



The added plexi glass increased the weight of experiment (two glass plates, two plexi glass plates, two sea-clamps) to about 20 lbs. Therefor an additional set of test tube clamps were added. Hence the experiment was conducted under the same conditions as on page three of this notebook with the added test tube clamps.

☆ Note: The dotted line represents the water rise between the plexi glass and sand-blasted glass.

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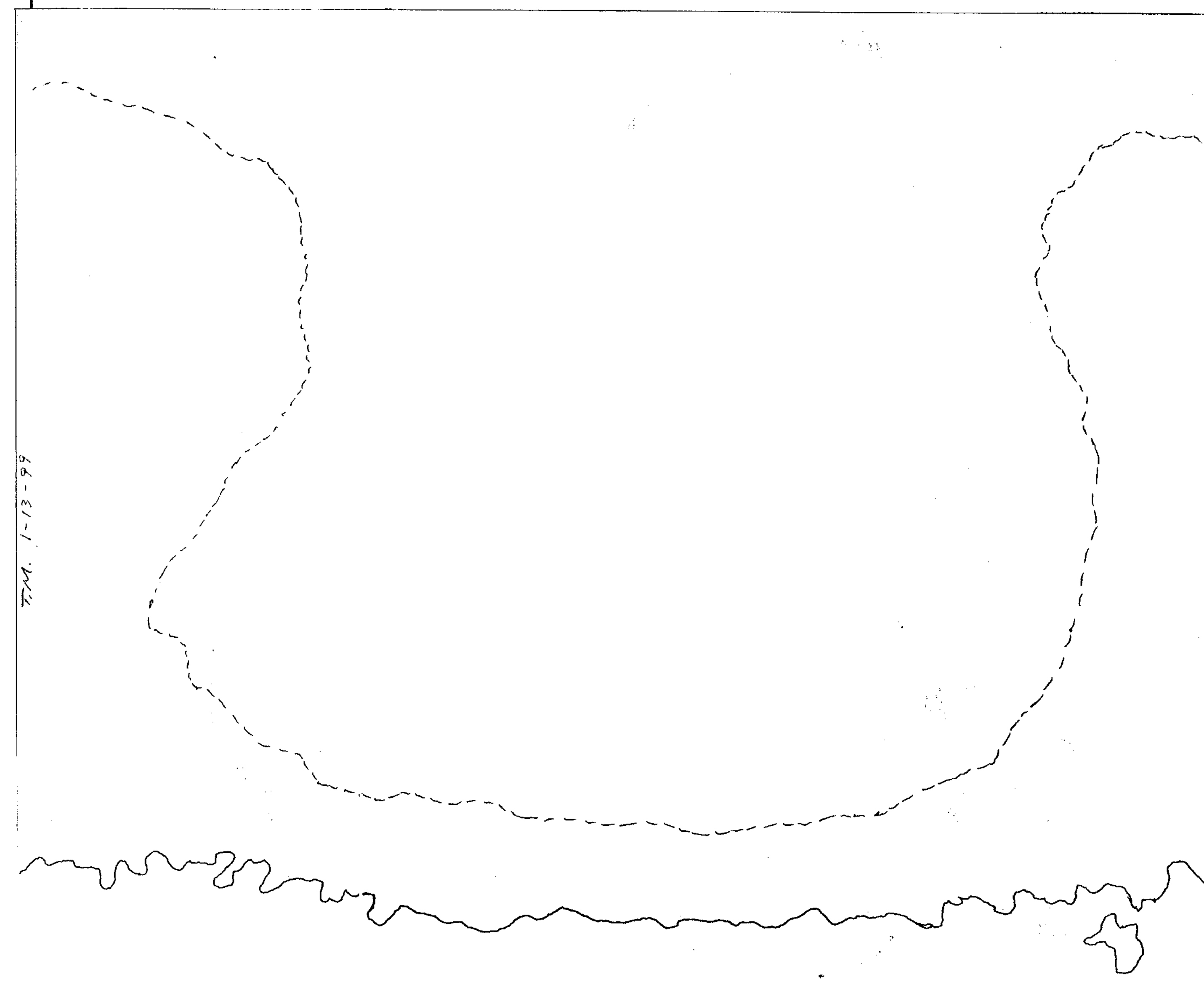
(reduced sketch)



Results from capillary pressure test (with additional plexi glass)

depth of water	: 3/4 in	☆(dotted line) depth of water	: 3/4 in
max height (left)	: 1 5/16 in	max. height (left)	: 8 3/4 in
max height (right)	: 1 5/16 in	max height (right)	: 8 1/4 in
min.	: 9/16 in	min.	: 1 1/2 in

T.M. 1-13-99

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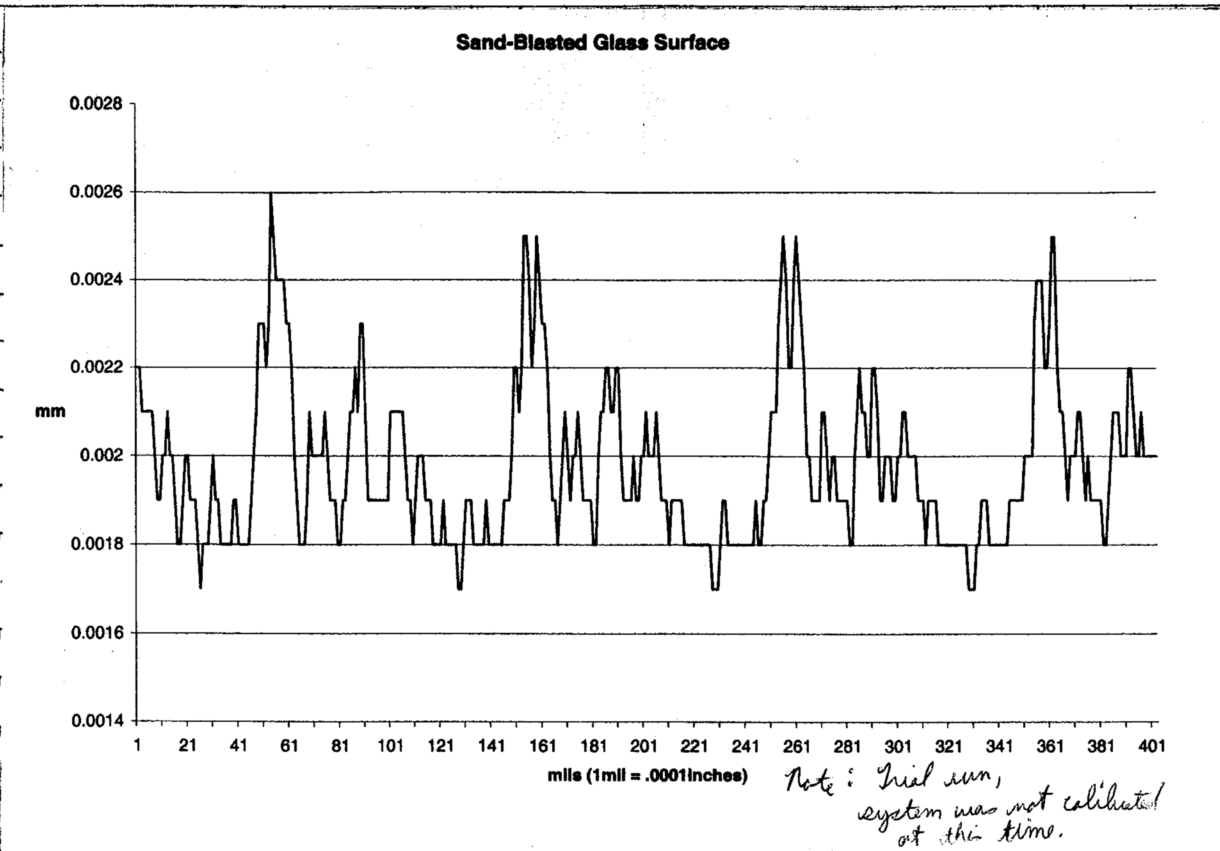

T.M. 2-9-99

This is a trial run of the profile of one of the sand-blasted plates. The "Rock Profiler" was used to scan the sand-blasted surface with a LC 2100 Laser Displacement Meter. Along with the LC2100 Laser, the profilometer uses an Asymtek A-102B Benchtop Gantry type X-Y-Z positioner. The LC2100 is made by Keyence. The laser scans the surface similar to the motion of a typewriter which is illustrated on pg. 7 of this notebook.

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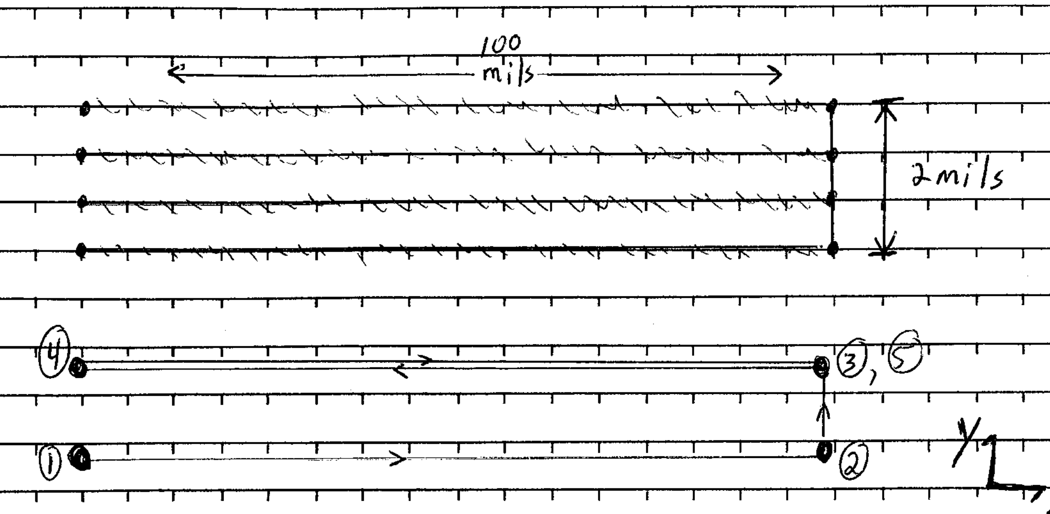
Illustration of how the data from the chart on page 6 was recorded.



① → ② : The laser moves in the x-direction while scanning the height difference in the surface. For this run, a x-distance of 100 mils (0.1 in) was used. The laser moves in increments of 1 mil.

② → ③ : The laser moves in the y-direction 1 increment, or 0.001 in.

③ → ④ : The laser moves 100 mils in the x-direction without scanning.

④ → ⑤ : Repeat the process of ① → ②

The steps are repeated until the laser moves 2 mils in the y-direction.

T.M. 2-9-99

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4-16-99

On the plot on page 6 of this book, the height is labeled in mm. From the "Laser Displacement Meter LC-2100" instruction manual, the laser has a factory-set condition. On the face of the controller panel, select cal and press the entry key. Setting a calibration set value to "3.0000 mm" or "8.0000 mm" returns the system to the factory-set condition. Using Starrett Webber gage blocks, a test revealed that the height is recorded in inches. Using 0.101, 0.102, and 0.111 inch gage blocks, plots of these test revealed the factory-setting to be accurate. These test were performed similar to the step from ① to ② on page 7 of this notebook. This process was performed at a temperature of 22±2°C. The coefficient of expansion of steel gage blocks is approximately 6.5 millionths of an inch per inch of ~~ft~~ T.M. 4-16-99 length per degree Farenheit.

Change = Length of Block × (Temperature of block − 68) × Coeff. of exp.

change = (0.111) × (71.6 − 68) × 0.0000065

change ≈ 2.60E-6

Hence any thermal changes in the gage blocks may be neglected.

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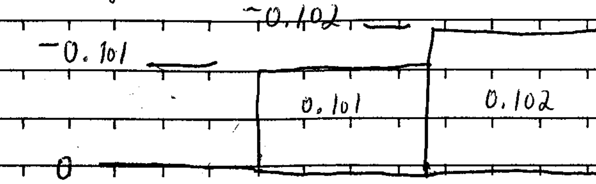
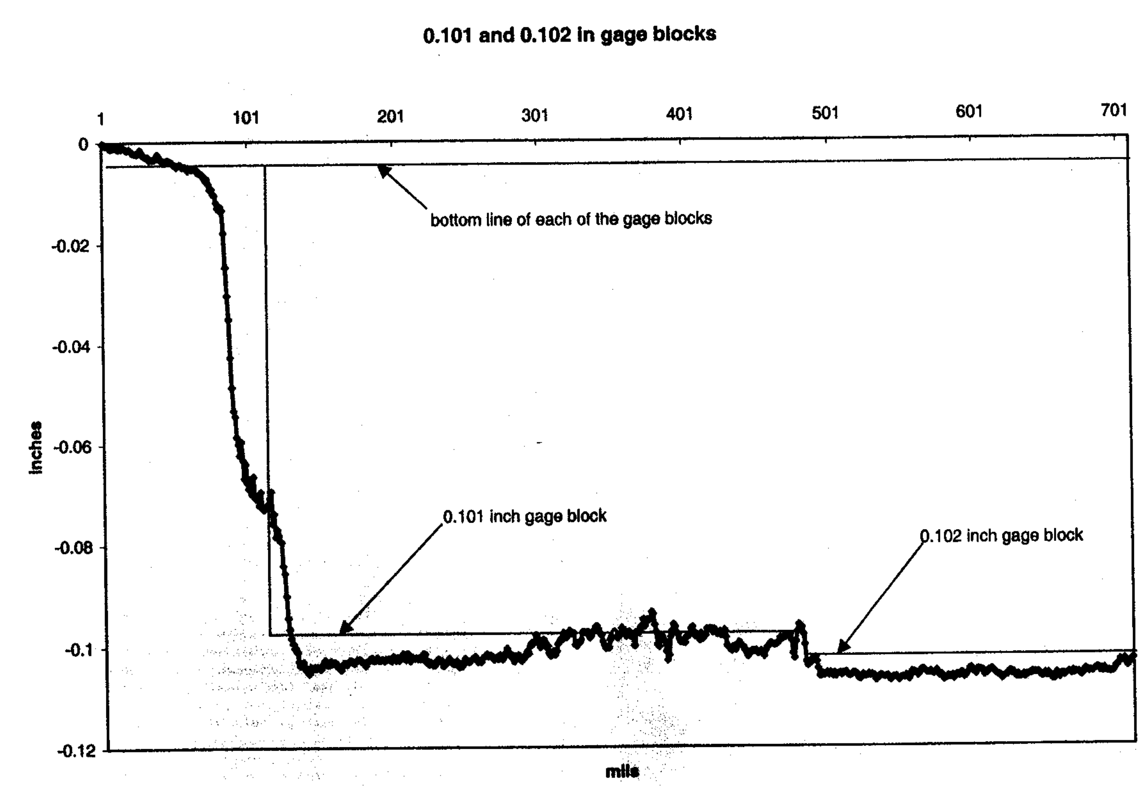
Note: The laser reads the height of the blocks as a negative number, while it will read a pit as a positive number.



Hence the plot is inverted.

T.M. 4-16-99



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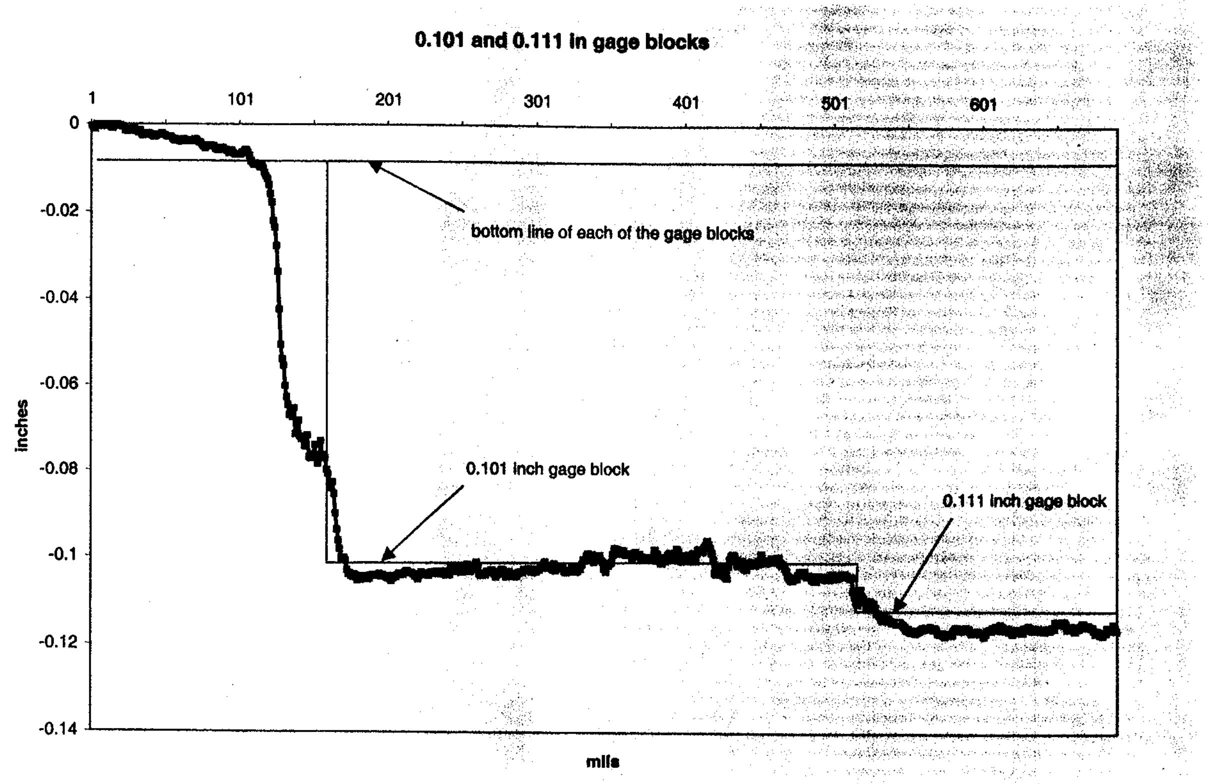

T.M. 4-16-99

The test revealed the profilameter readings to be accurate to 0.01 and 0.001 inches.

T.M. 4/16/99

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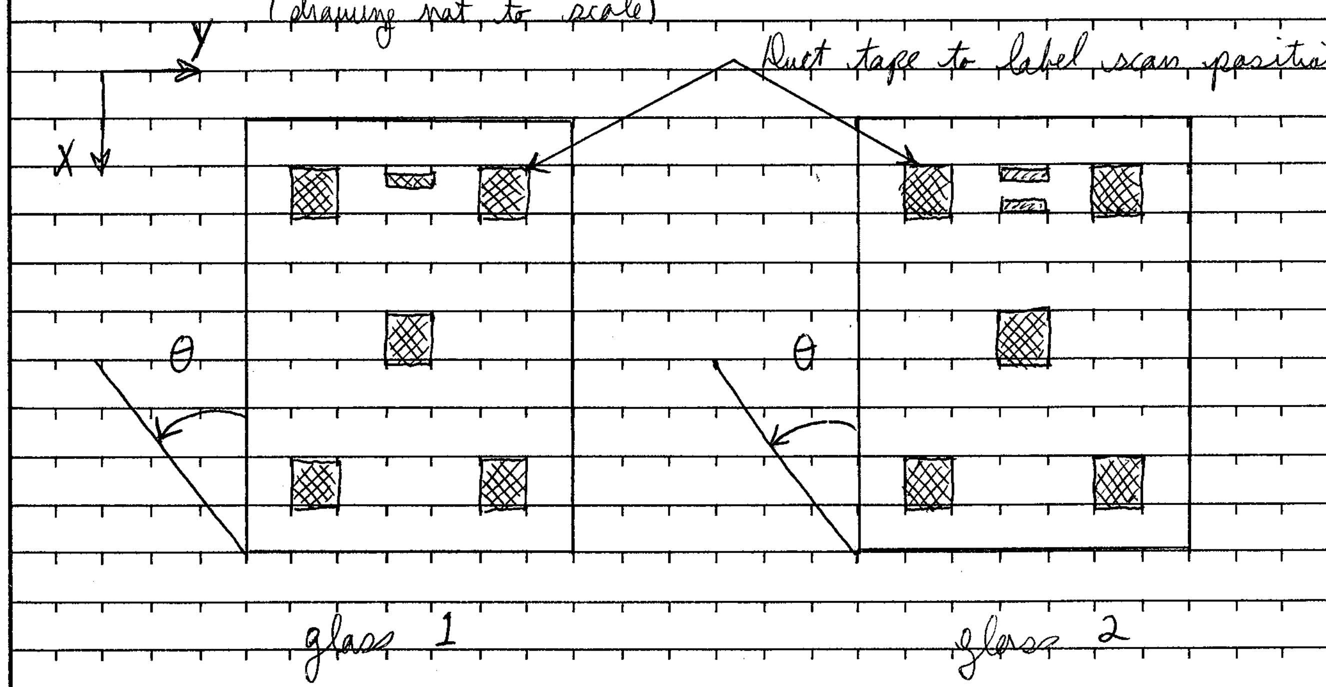
4-22-99

The purpose of the profilameter in this experiment, is to measure the height and width of the groves in the sand-blasted glass surface. The measurements are taken at each of the four corners and the center of each glass plate. Each measurement is a 150 mil square. Once a 150 mil square is recorded, the glass is rotated 45° and the same square is recorded at a 45° different orientation. This process is repeated four times for each square. Duct tape was placed on the smooth side of each glass to label the positions to be scanned and label "glass 1" and "glass 2".

Illustration of labels and glass orientation.
(drawing not to scale)



In the orientation above, this position will be labeled "straight". When θ is rotated 45° in the direction shown, the position is 45° of straight. When θ equals 90°, the position is perpendicular and at 135° the position is 45° of perpendicular.

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The data is recorded onto 3.5" floppy disk where each position scanned has a title for that specific location.

M : middle
T : top R : right S : straight
B : bottom L : left P : perpendicular

1 : glass one 45 : forty five degrees
2 : glass two

For example:

TR1S = top right corner of glass one in the straight position.
BL2P45 = bottom left corner of glass two forty five degrees of the perpendicular position.

The number of disk used to record what amounted to 40 different scans was 20. The disk are numbered 1-20 and have the above mentioned titling system.

T.M. 4/22/99

4-23-99

The following plots illustrate just one area of interest, the groove depth. Also shown is a top layout of the laser profiles showing the scan parameters. For the following plots, the Max-x is 100 mils while the Max-y is 0.00. The plots were recorded in a similar manner to the step from ① to ② on page 7 of this notebook.

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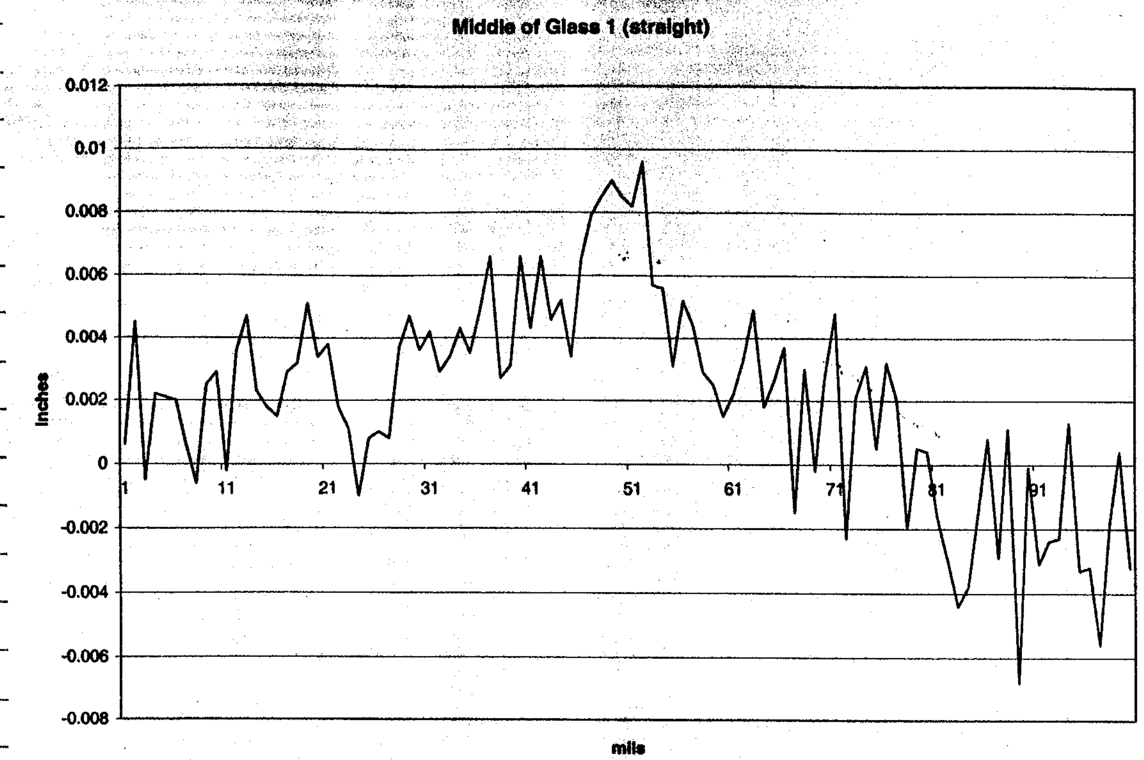
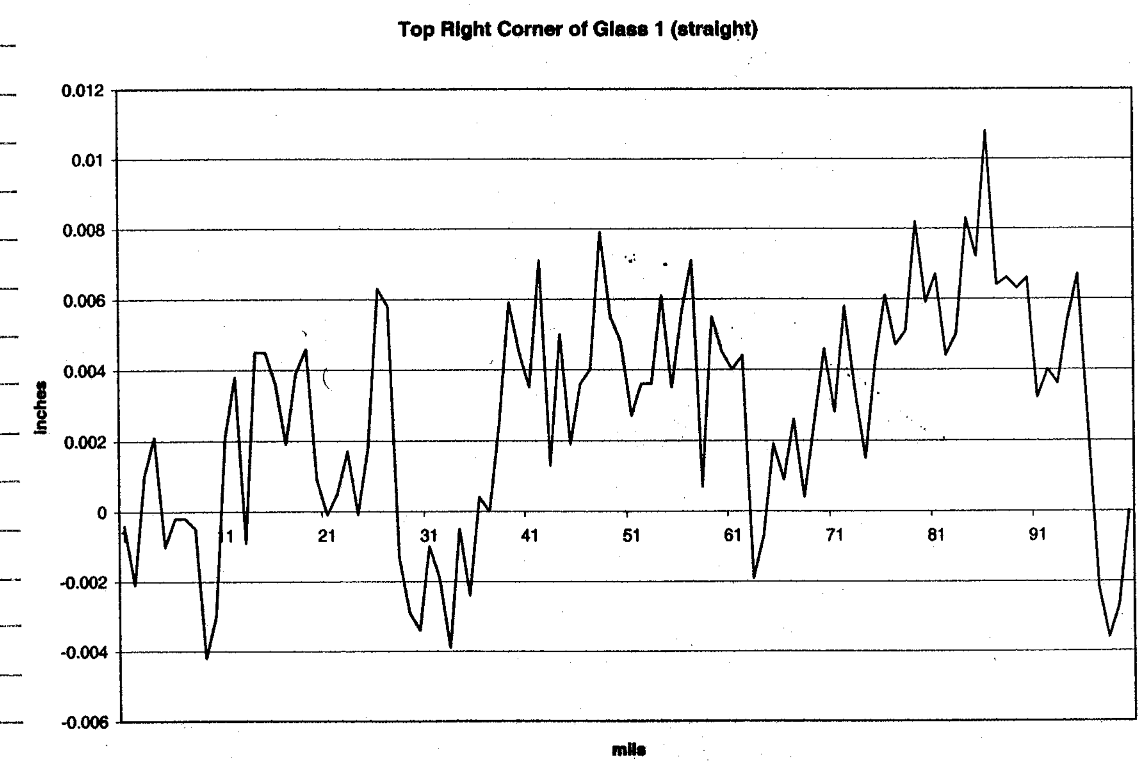


T.M. 4-23-99



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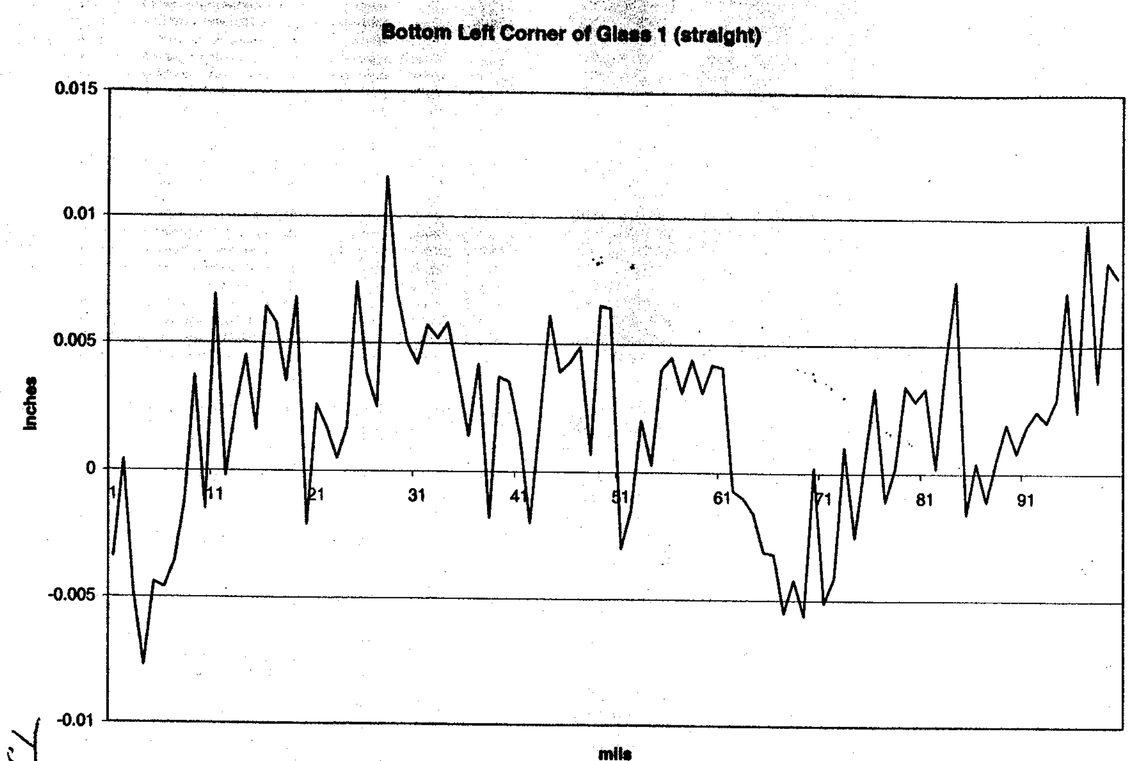

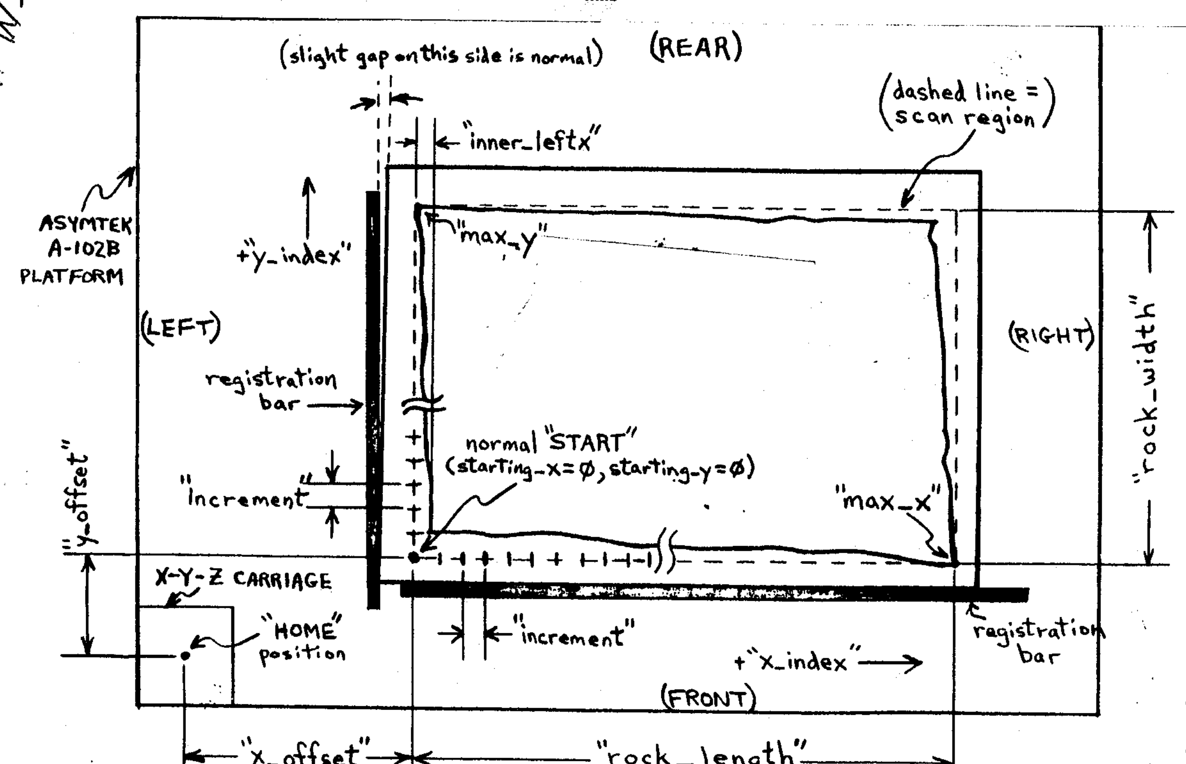

— TOP LAYOUT VIEW OF "ROCK PROFILER" SHOWING SCAN PARAMETERS —

T.M. 4-23-99

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The plates revealed, for the small area in the graph, that the average grave depth is about 0.005 inches deep.

T.M. 4-23-99

4-27-99

Preliminary test for rock fracture flow

The glass plates were arranged in a manner similar to that of the ~~capp~~ capillary pressure test on pages 2-5 of this notebook. T.M. 4-27 The glass plates were held together by 4 small sea clamps. Like the capillary test, two plexi glass plates sandwiched the sand-blasted glass plates. Unlike the capillary pressure test, four test tube clamps were used to hold the model erect and not to hold the glass together. The test tube clamps were not used to hold the glass model above the ground as in the capillary test. Two 1½ inch thick metal plates were used to hold the model so it would remain level during testing. The test tube holders would bend because of the weight of our model. A porous ceramic cylinder with a one inch diameter was placed at the top of the model. The cylinder was held in place by wrapping parafilm around it, and using the plexi glass and sand-blasted glass interface to hold the parafilm. This also acted as a boundary keeping the flow of water into the fracture simulation. "Cheese cloth" was placed between the cylinder and the model to attempt to acheive uniform flow. In a similar manner as the parafilm at the top, parafilm was placed at the bottom of the model to receive the exit flow and channel it into a container. A Manostat cassette pump was used to pump nano-pure water into the cylinder.

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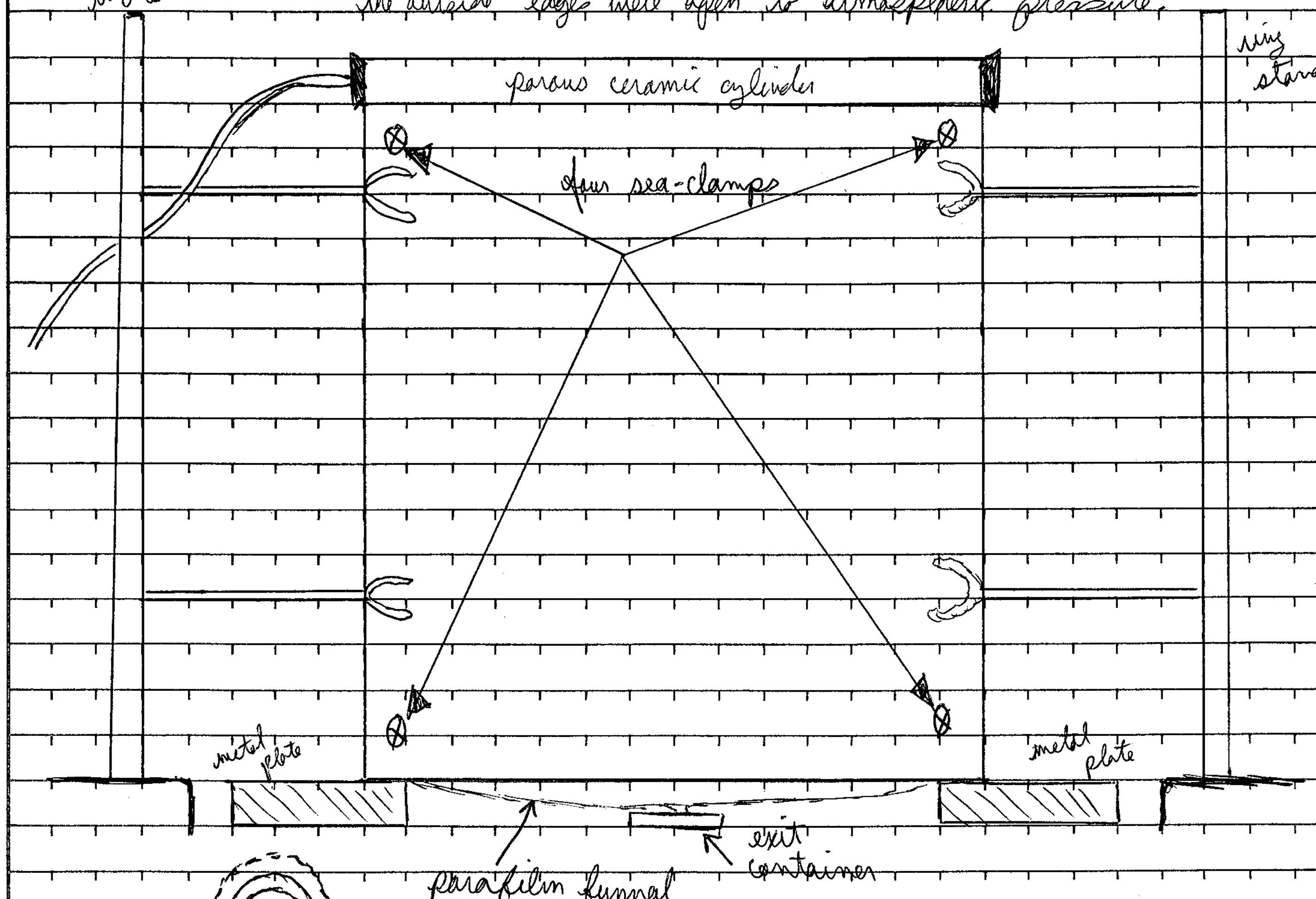
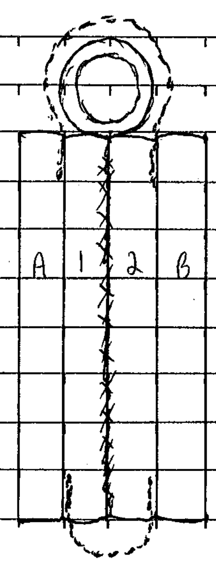
From Page No. 15

Preliminary model for rock fracture flow
(drawing not to scale)

Note: There was no sealant on the edges for this experiment, the outside edges were open to atmospheric pressure.





Side view of model where A and B are plexi glass and 1 and 2 are the sand-blasted glass plates with the rock fracture simulation is the 1 and 2 interface. The dotted lines represent the location of the parafilm boundaries.

T.M. 4-27-99

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4-29-99

Results from experiment on pages 15 and 16 of this notebook. Before the pump was started, the ceramic cylinder and cheesecloth were saturated with nano-pure water. The pump ran for approximately 4½ minutes before the water started down the fracture model. The pump was set constant flow rate at 0.0322 mL/s. The fracture replica was unsaturated before the experiment.

Results:

Seepage Velocity: 0.635 cm/s

(Q_{out}) Volumetric flow rate exit: 0.0278 mL/s

Calculations:

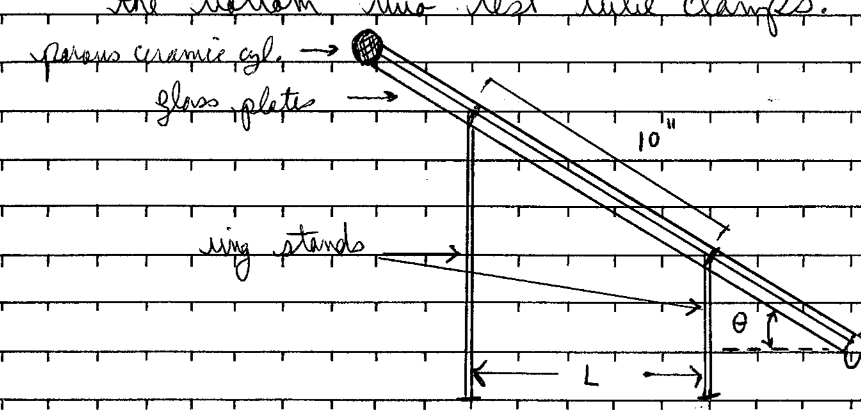
$$\text{Seepage Velocity} = \frac{\text{length}}{\text{time}} = \frac{15\text{ in}}{60\text{ s}}$$

$$Q_{out} = \frac{\text{exit water}}{\text{time}} = \frac{75\text{ mL}}{2325\text{ s}}$$

T.M. 4-29-99

4-30-99

To measure the intrinsic permeability of the rock fracture model, the test on page 15 of this notebook will be repeated at an angle θ. The set up of the experiment remains the same except another set of ring stands will be used to create an angle θ. One set of ring stands will hold the top two test tube clamps while the second set of ring stands will hold the bottom two test tube clamps.



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If the test tube clamps are placed 10 inches apart on the glass, and the ring stands are placed at a distance L apart, then the desired angle θ will be a function of the distance L.

$$\theta = \cos^{-1}\left(\frac{10}{L}\right)$$

For this experiment, an angle of 45° will be arbitrarily chosen as our first run. This angle corresponds, from the equation above, to a distance of 14 inches.

Results: T.M. 4-30-99

The results of this experiment are ~~of~~ neglected due to a leak at the top of the fracture model. Water flowing from the porous ceramic cylinder leaked in between the plexi glass and the sand-blasted glass plate on the back side of the model.

T.M. 4-30-99

5-4-99

When disassembling the experiment on 4-30-99 of this notebook, a small crack was detected at the top left corner of glass 2. The crack is internal and does not appear to affect the model. However a replacement glass was purchased and the process on 1-4-99 of this notebook (pg 2) will be repeated. The replacement glass was purchased should the crack propagate.

T.M. 5-4-99

5-14-99

A possible cause of the crack in glass 2 is the weight and set up of the model. In the experiment on 4-27-99 the weight of the model was sustained by metal plates 1/2 inch on each side of the model. On the experiment on 4-30-99, the weight of the glass was sustained by the test tube clamps. The compression of the sea-clamps and test tube clamps held the plates together and held the model up. This proved to be too much pressure on the glass. A new procedure will be

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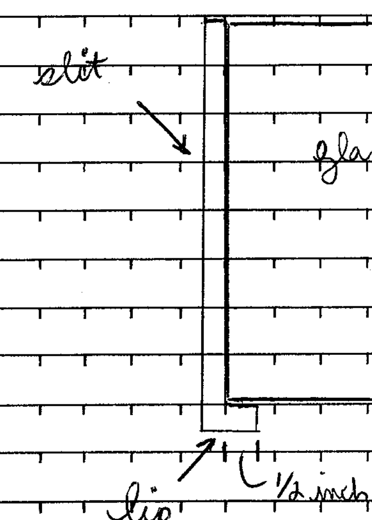
implemented to set up the rock fracture replica.

T.M. 5-14-99

5-17-99

The construction of the new procedure will consist of the following. The two 12"x15" plexi glass plates from the previous procedure will be replaced by two 15"x15" plexi glass plates. Six 1/4 inch bolts with wing nuts will replace the four sea clamps previously used. The sand-blasted glass plates are held between to two square plexi glass plates as before except the six bolts hold the glass together and not the sea clamps. To allow for the weight of the glass, and the glass not to be under high compression, two slits with 1/2 inch lips are placed in between the two plexi glass plates. The weight of the sand-blasted glass plates will rest on the 1/2 inch lips. The lips are similar in theory to the metal plates on pgs. 15 and 16 of this notebook.



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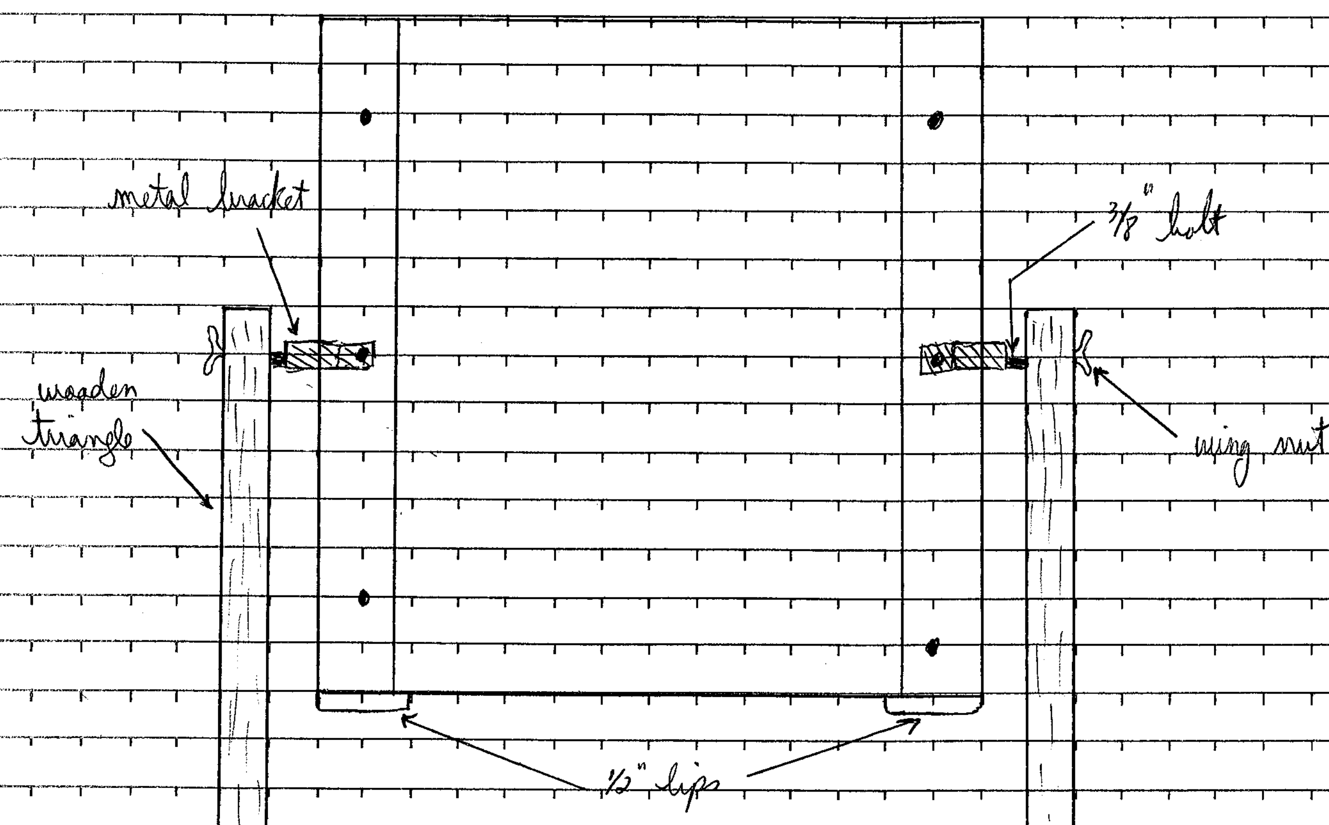
5-19-99

The new design of the plexi glass will be held up by two triangles on each side of the glass. Pieces 16" long are cut from a 2"x4" pine board. The pieces are cut in a manner that every angle on each triangle is 60°. The glass plates are held to the triangles by two 3/8" bolts on each side of the glass. A metal bracket 3/4" wide connects the bolt to the glass plates on each side of the glass. Wing nuts are placed on the outside edge of the wooden triangles. The glass plates may be rotated and their position may be fixed by tightening the wing nuts. This new procedure allows the model to have a fixed angle θ while the glass plates are not under high compression because of the 1/2" lips on the plexi glass slits (pg. 19).

(Note: • denotes 1/4" bolts as stated on pg 19 of this notebook)



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From Page No. 20

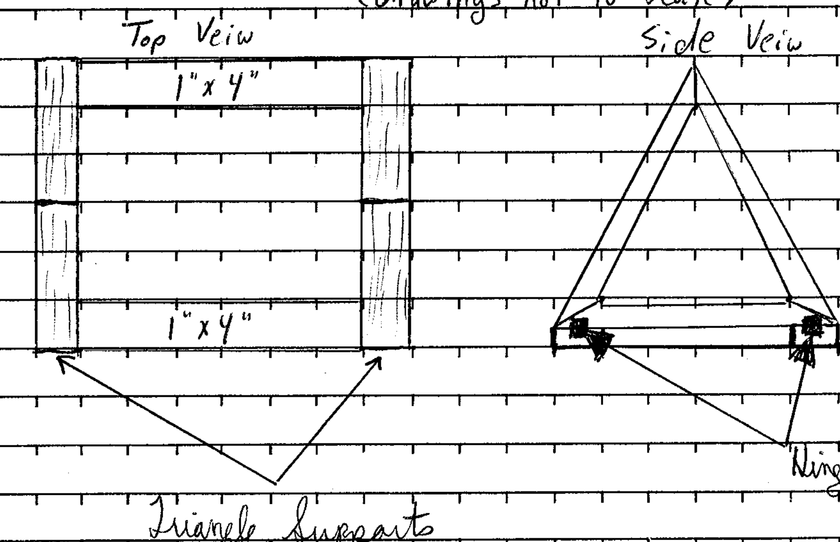
Note: Not shown on page 20 of this notebook in the drawing, is the brace at the bottom of the triangles. A 2"x4" block is placed at the bottom corner of each triangle to prevent side to side movement of the model.

T.M. 5-19-99

5-21-99

Instead of a 2"x4" block of wood, a 1"x4" piece of pine is used to support side to side movement of the model. Two 19" strips were screwed to the front and back base of each triangle stabilizing the base. Hinges were connected to each strip to allow one of the triangle supports to fold out. This allows for quick construction or dissasembling of each experiment.

(drawings not to scale)



T.M. 5-21-99

5-24-99

To increase flow visibility, a 300 watt halogen light was purchased along with a dimmer switch to adjust the brightness. A wooden box was built to act as housing to the wiring of the ~~lit~~ T.M. 5-24 switch and light. The light is placed 13 inches behind the glass for good fracture flow visibility.

T.M. 5-24-99

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5-26-99

The preliminary experiment on 4-30-99 of this notebook was repeated using the new frame design explained in the previous pages of this notebook. An arbitrary angle of 57° was chosen for the first run. Before the pump was started, the cheesecloth and ceramic cylinder were both saturated with nanopure water. The pump was set at a constant flow rate at 0.0125 mL/s. The fracture replica was unsaturated before the experiment.

Results:

Seepage Velocity: 0.318 cm/s

(Q_{out}) Volumetric flow rate exit: 0.0114 mL/s

T.M. 5-26-99

6-1-99

The preliminary experiment on 5-21-99 of this notebook was repeated using an angle of 65°. The conditions were the same except the constant flow rate was increased to approximately 0.0333 mL/s.

Results:

Seepage Velocity: 0.465 cm/s

(Q_{out}) Volumetric flow rate exit: 0.0327 mL/s

T.M. 6-1-99

6-2-99

The process on page 11 of this notebook is repeated for the replacement glass mentioned on 5-4-99 of this notebook. The replacement glass data will have the same titling sceme as on page 12 of this notebook with the exception that the replacement glass is labeled "glass 3".

T.M. 6-2-99

6-4-99

The fracture in glass 2 was examined using the profilometer to see if the sand-blasted side of the glass was affected. From the results, the fracture is approximatly 100 mils wide and ~~1.5 inches~~ T.M. 6-4-99 0.15 inches deep. The fracture is 4 inches long.

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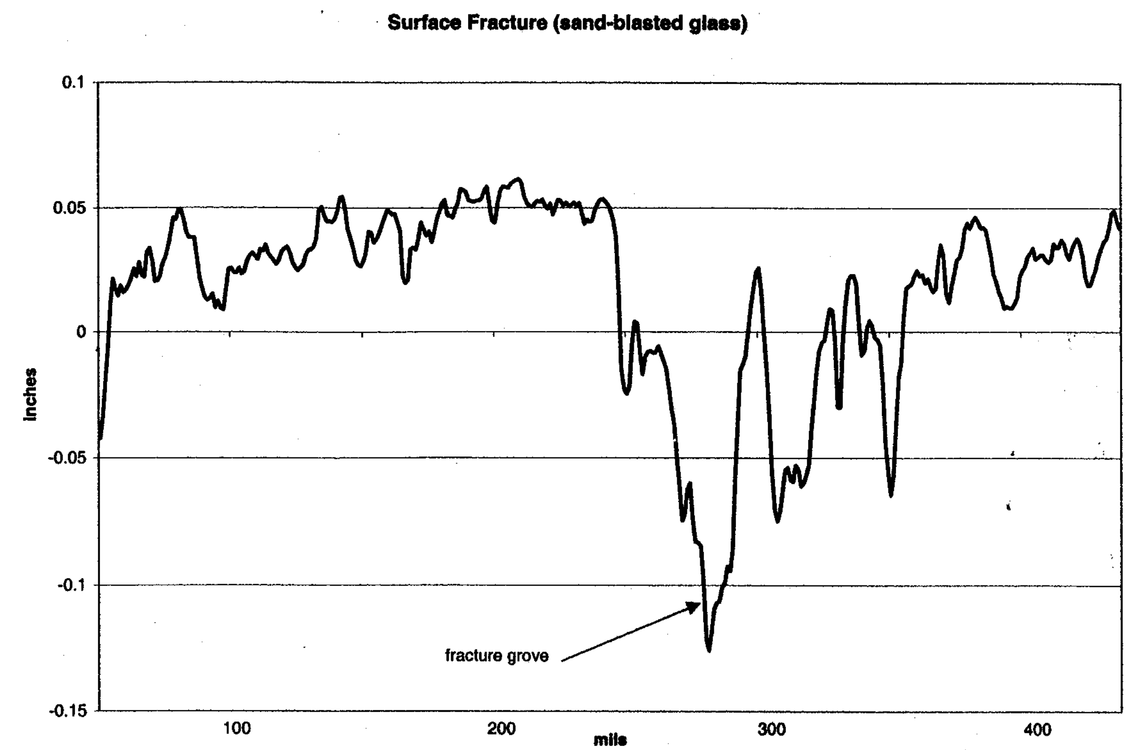

T.M. 6-4-99

T.M. 6-4-99

6-10-99

The following pictures are illustrations of the design introduced on pages 20-21 of this notebook. Instead of a pump and porous ceramic cylinder, the de-aired water was manually injected with a syringe. A digital camera with a 144 pixel per inch resolution was used to take the pictures. The dimmer switch to the 300 watt halogen light was adjusted to its maximum brightness. On the back side of the model, a blue translucent sheet of thin plastic was added to create a greater contrast between the saturated and unsaturaed areas of the model. The results of the photos illustrate the need for a more even distribution of light over the glass surface area.

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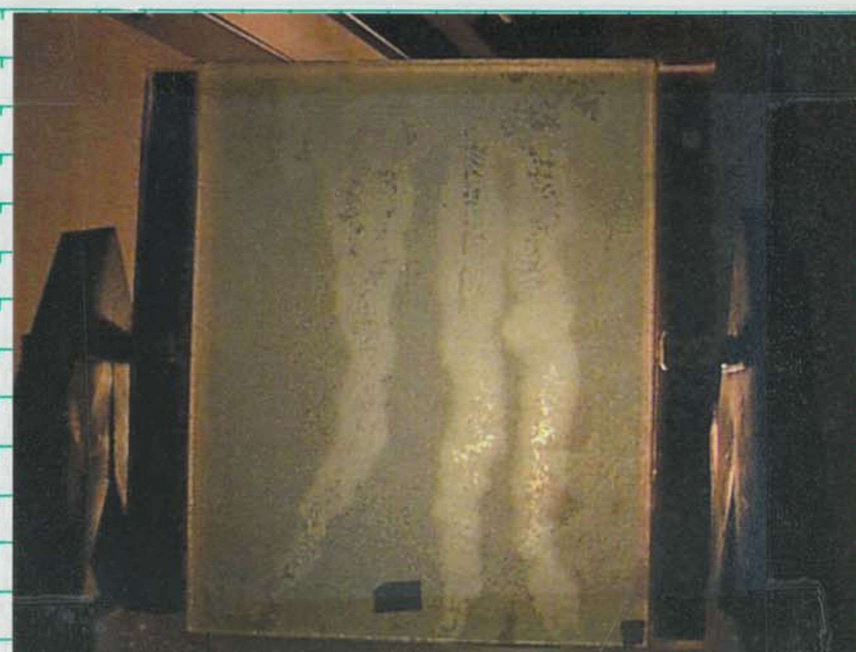

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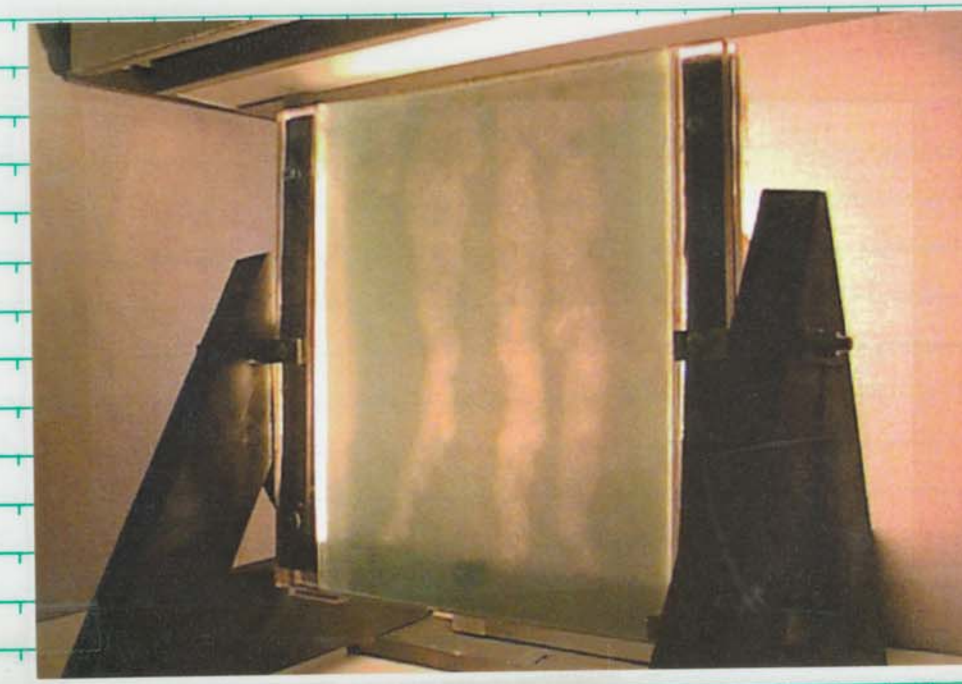

T.M. 6-10-99

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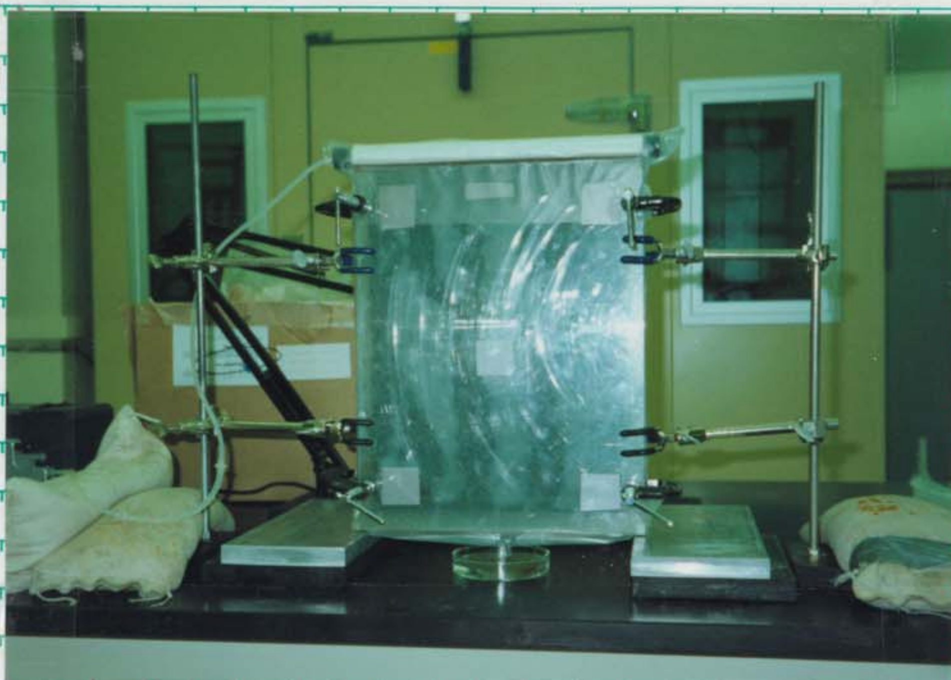
6-15-99

The following picture is a visual illustration of the equipment used in the experiment on page 16 of this notebook.



T.M. 6-15-99

6-21-99

To measure the intrinsic permeability of the fracture model, the process described previously in this notebook does not provide enough accuracy. An experiment using a Quizix SP-5200 Pump system must be applied. The glass plates must be horizontal with a differential pressure transducer connected at the inlet and exit. The ceramic cylinder set up will not work for this application, therefore another process (set up) must be implemented.

T.M. 6-21-99

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6-23-99

A differential pressure transducer was available from building 131. The plots to calibrate the transducer will come from experimental data from this notebook combined with Darcy's law $K = \frac{Q\,dL}{dh\,A}$

Q = volumetric flow rate
dL = length of glass
dh = pressure
A = cross sectional area
K = hydraulic conductivity

Solving for a range for dh, the transducer will be calibrated over a range of 0-5 psi over 10 points at 0.5 increments. The data used to estimate this range is $A = 0.387\ cm^2$

$K = 0.1 \rightarrow 0.01\ cm/s$

$dL = 38.1\ cm$

$Q = 0.0351\ mL/s$

T.M. 6-23-99

6-25-99

Received from building 131 a Rosemount D/P cell differential pressure transducer. The model number is 1151DP4522B1. The voltage is 0-10 VDC.

T.M. 6-25-99

6-28-99

The experiment on 6-10-99 of this notebook was repeated with the exception the pump and ceramic cylinder was used. The 300 watt halogen light was adjusted to its maximum brightness, and was placed one meter behind the glass model. Instead of one blue translucent sheet, three were used for this experiment to increase the contrast between the saturated and unsaturated areas of the glass. A digital camera with a 144 pixel per inch resolution was used to take the pictures.

T.M. 6-28-99

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6-30-99

Photos from the experiment on 6-28-99 of this notebook revealed a lighting problem. The light was not evenly distributed. Before the water started down the fracture, the light appeared to be evenly distributed, but as the photos illustrate the light became brighter as the water approached the exit.

T.M. 6-30-99

#1

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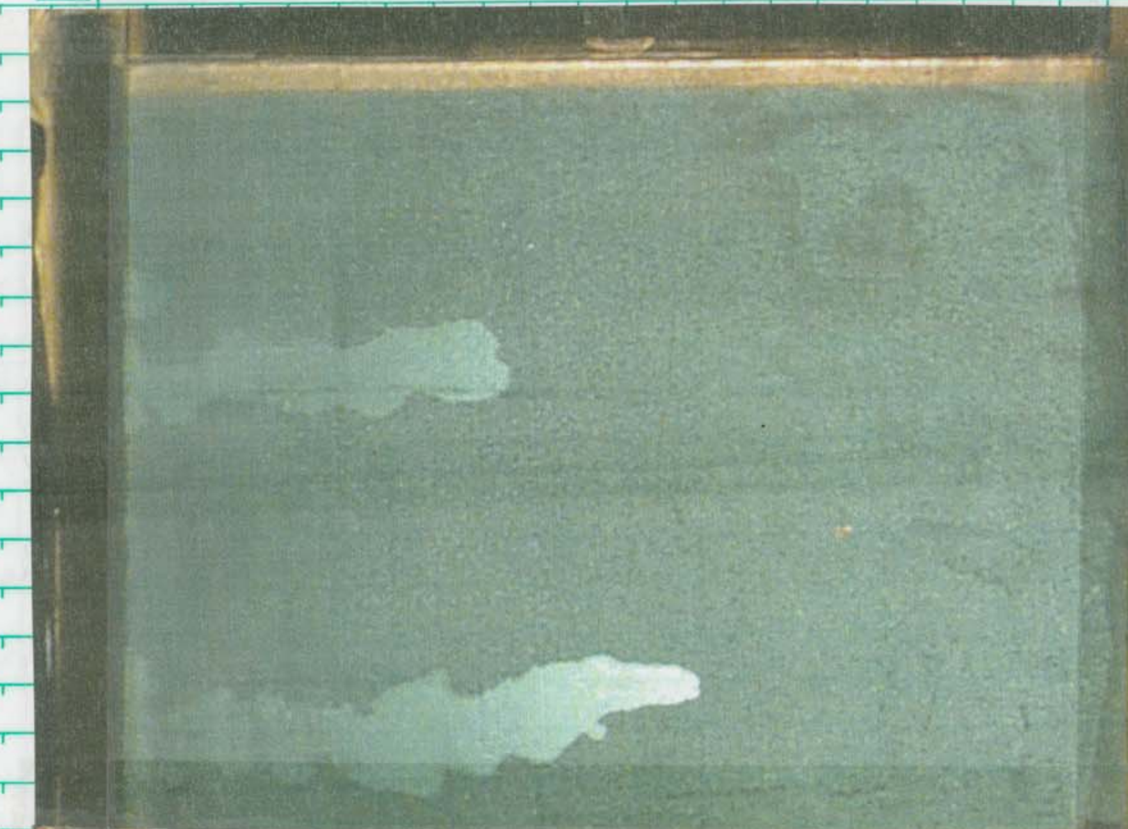
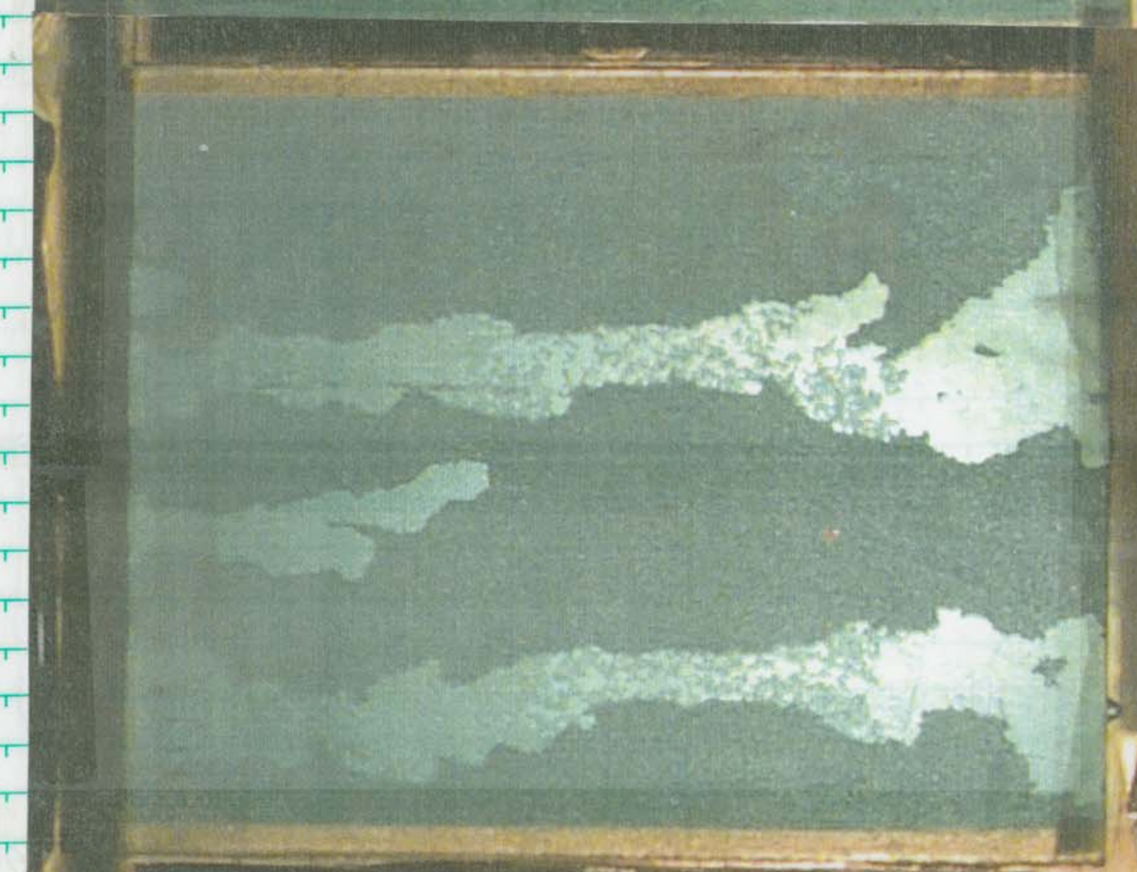


#2



#3

T.M. 6-30-99

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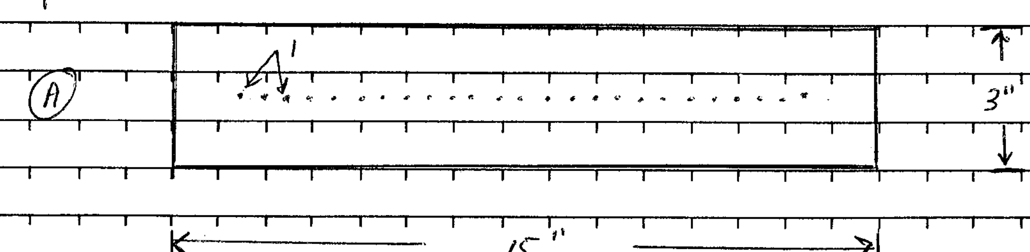
7-6-99

To find the mean aperature of the fracture, the experiment must have constant laminar flow. To create constant laminar flow, two aluminium manifolds will be machined for the experiment. An entrance and exit manifold that are exactly alike. The manifolds are needed because the present condition of the experiment will not work well for horizontal flow with any accuracy.

T.M. 7-6-99

7-7-99

A description of the manifolds mentioned above follows below.



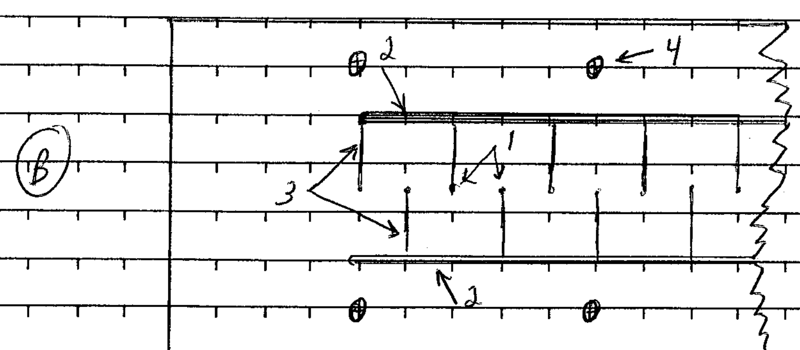


Figure (A) : Front view of manifold ; A-1 : 1/32" inch holes
Figure (B) : Inside view of manifold
B-1 is same as A-1
B-2 is main channel groove 1/8" x 1/8"
B-3 is grooves between main channels 1/32" x 1/32"
B-4 is 1/4" holes threaded

T.M. 7-7-99

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7-9-99

The manifolds will be held together with 14 1/4" x 3/4" course thread bolts. Not shown on the figures on page 30 of this notebook, are the entrance and exit holes on the manifolds. There are two 1/8" high pressure tube fittings going into each main channel of each manifold.

T.M. 7-9-99

7-12-99

The manifolds were machined here at South West Research. Before bolting them together, a thin strip of silicon was placed inside of each one to act as a gasket.

T.M. 7-12-99

7-14-99

The differential pressure transducer will be used to measure the pressure drop across the fracture to determine the permeability. The pressure differential will be measured at the inlet and exit manifolds. For this experiment, the frame used from page 20 of this notebook will not be adequate. A frame must be designed that is capable of adjusting the aperture of the fracture while sealing to the manifolds.

T.M. 7-14-99

7-15-99

The new frame consist of two 15" x 15" sheets of plexi glass 1/2" thick that sandwich the glass plate with six 1/4" dia. bolts similar to the previous experiments. The plexi glass is sealed to the aluminium manifold with 732 Multi Purpose Silicone. Water is delivered to the inlet manifold with a Quizix 1040-A constant-flow dual piston pump and software.

T.M. 7-15-99

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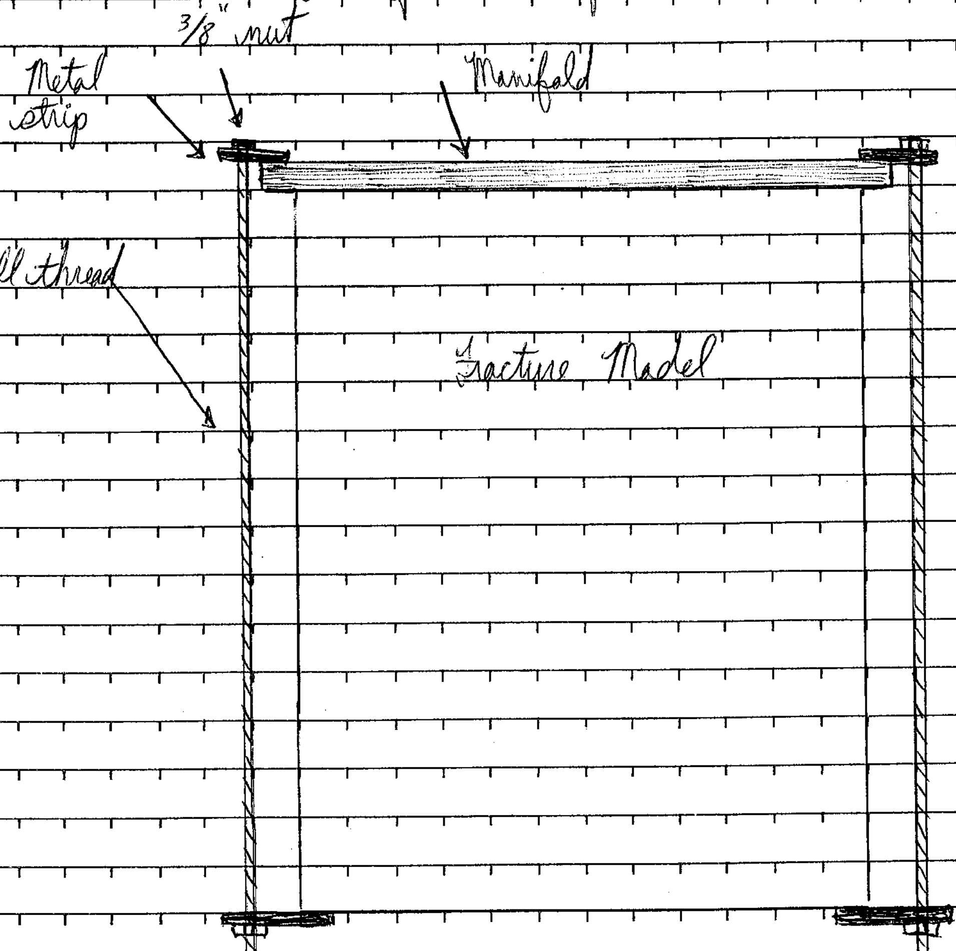
7-19-99

After several runs at different flow rates, the silicone did not prevent leaks on its own. Clamps were created and added to the experiment to create a better seal between the plexi glass and the aluminum manifold.

Note: Drawing not to scale, the purpose is the illumination of the clamps.



T.M. 7-19-99

7-20-99

Further testing revealed the clamps did stop the leaks.

T.M. 7-20-99

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7-22-99

Before the fracture permeability can be determined, the mean fracture aperture must be found. The mean fracture aperture can be obtained using the constant volume pycnometer method. The pycnometer methodology is based on Boyle's gas law, which states that the product of the pressure and volume of a gas for a contained system is constant at constant temperature. If a quantity of gas of known volume and pressure is allowed to expand into a larger volume, the resulting pressure can be used to calculate the fracture volume. The volume of the gas can be calculated as follows:

$$V_c = (P_r - P_f)V_r / P_r$$

V_c = volume of gas in the fracture
P_r = initial known gas pressure of the reservoir
P_f = final gas pressure of the combined reservoir and fracture
V_r = initial known volume of gas in the reservoir

T.M. 7-22-99

7-27-99

The plexi glass frame used to adjust the aperature of the fracture has a flaw. The plexi glass tends to bow in the middle due to the load of the bolts. This causes an uneven distribution on the glass fracture model.

T.M. 7-27-99

7-28-99

Instead of ½" plexi glass, 1" plexi glass was ordered from the machine shop here on the SWRI campus with the same dimensions as the ½".

T.M. 7-28-99

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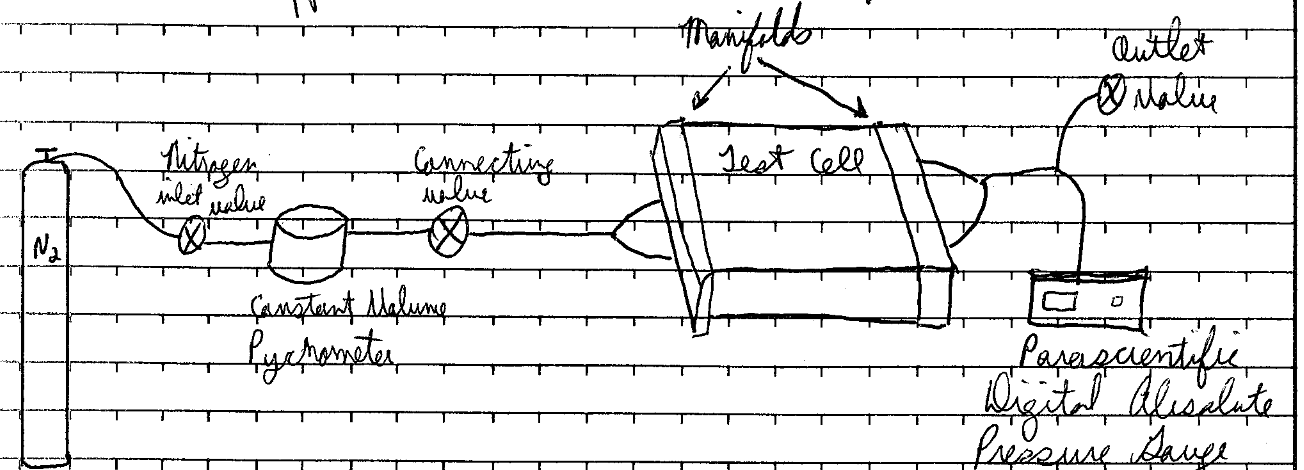
8-2-99

The following is a schematic of positive pressure experimental apparatus used to measure aperature volume.



T.M. 8-2-99

8-3-99

Methodology for volume measurement from schematic above. The valve between the test cell and the reservoir was opened, and gas (nitrogen) was introduced to a known positive initial pressure. The inflow valve was closed, and the system was stabilized for about 3 to 5 min to reach thermal equilibrium and to check for leaks. The valve between the reservoir and the test cell was closed, isolating the reservoir at the initial pressure. The relief valve was opened, allowing the test cell to attain atmospheric pressure. The relief valve was then closed, and the two chambers were connected by opening the connecting valve. Once again, the system was allowed to attain equilibrium after which the final pressure was recorded. The aperature is calculated using

$$b = V_c / A_f$$

where A_f is the area of the fracture.

T.M. 8-3-99

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8-5-99

For the aperture measurement, the two glass plates were sealed to the manifolds and their edges were sealed with 732 silicone. There were no leaks between the inlet valve and the connecting valve however the experiment had many leaks between the connecting valve and the outlet valve.

T.M. 8-5-99

8-9-99

The experiment continues to leak between the connecting and exit valve. A stronger sealant is required. Instead of 732 silicone, 748 silicone will be used.

T.M. 8-9-99

8-16-99

The equation from pg. 33 for the aperture volume measurement is wrong. The equation should be

$$V_c = \frac{V_r (P_i - P_f)}{P_f}$$

To account for possible reading errors of pressure within the fracture before the nitrogen is introduced, the following equation was suggested by Delia Hughson

P_a = Pressure in the fracture before the nitrogen is introduced

if $P_a \neq 0$

then $P_i V_r = P_f (V_r + V_c^*)$

where $V_c^* = V_c - V_{0a}$; V_{0a} = volume occupied by compressed gas initially in the fracture

then $P_a V_c = P_f V_{0a}$

$$V^* = V_c - \frac{P_a V_c}{P_f}$$

$$P_i V_r = P_f \left(V_r + V_c - \frac{P_a V_c}{P_f}\right)$$

$$V_r (P_i - P_f) = V_c (P_f - P_a)$$

$$V_c = \frac{V_r (P_i - P_f)}{P_f - P_a}$$

T.M. 8-16-99

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8-19-99

The following is an aperture measurement using the pycnometer method.

Torque on bolts : T
Initial Pressure : P_i
Final Pressure : P_f
Pressure in fracture : P_a

$T = 6$ ft*lb

Run	P_i	P_f	P_a
1	14.278	14.996	—
2	14.2757	15.0338	0.0014
3	14.2755	14.9853	0.0035
4	14.2758	15.0028	0.007
5	14.2763	14.9072	0.0044
avg.	14.2763	14.985	0.0163

$$V_c = \frac{V_r(P_i - P_f)}{P_f - P_a} \qquad b = V_c / A_f$$

V_r = volume of reservoir + volume of connecting lines = 781.87 + 3.468
V_r = 785.338 cm^3
A_f = 12in x 15in = 1161.28 cm^2

$$V_c = \frac{785.338(14.2713 - 14.985)}{14.985 - 0.0163}$$

V_c = 319.06
b = 0.275 cm

T.M. 8-19-99

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8-23-99

The aperture measurement is larger than expected. The model still has a slow leak.

T.M. 8-23-99

8-26-99

The focus of this experiment, due to the request of supervisor Debra Hughson, will change to capillary rise and dripping. What governs the waters actions along the capillary fringe? The focus of this experiment now looks to answer this question.

T.M. 8-26-99

8-30-99

The experiment on 6-28-99 of this notebook was repeated. The water met no resistance as it seeped between the glass plates and there was no capillary rise before the water dripped from the bottom. It is suspect that the rough surface of the glass became smooth due to the continuous assembling of experiments. New glass plates will be ordered and sand-blasted.

T.M. 8-30-99

9-1-99

Eight sheets of 12"x15" glass ~~[illegible]~~ (T.M. 9-1-99) plates, 3/8" thick, were ordered from the SWRI Buildings and Grounds.

T.M. 9-1-99

9-6-99

The glass plates arrived. Two sheets were taken to the SWRI machine shop to be sand-blasted as the previous set. Except the sand was "Ex Fine" and not grade 4. The distance was 80 in as before.

T.M. 9-6-99

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9-8-99

Using a 0.3 ml/min flowrate, the experiment on 6-28-99 was repeated. The water dripped only after the water creeped along the bottom of the glass and did not drip until about 13 min after the water entered the fracture.

T.M. 9-8-99

9-13-99

Results from 8-30-99

The water dripped instantaneously as the water reached the bottom of the fracture.

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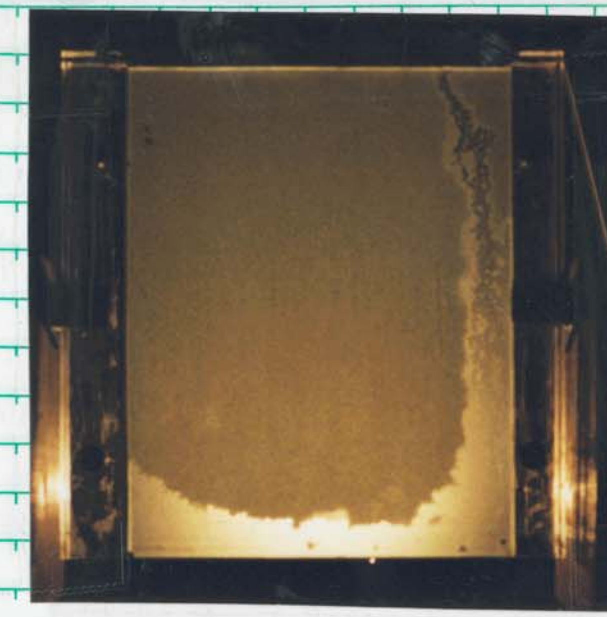
Results from 9-8-99



The water dripped only after the water reached level of capillary rise as shown in this picture.

T.M. 9-13-99

9-17-99

In order to simulate the same experiment every time, the glass will no longer be taken apart to dry. 8 sheets of 1" thick 12" x 15" plexi glass was ordered from SWRI machine shop. There will be four different sets of models for fracture flow.

T.M. 9-17-99

9-21-99

The glass will be dried after each experiment by blowing air into the fracture and cleaning out the water. It is suspect that taking apart the model repeatedly changes the surface texture of the glass plates.

T.M. 9-21-99

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9-27-99

Instead of a 35mm camera, a "Win TV model 400" video camera was used to observe the fracture flow. The dripping can now be recorded and viewed on a computer monitor.

T.M. 9-27-99

10-4-99

The experiment from 9-8-99 was repeated at 0.7 mL/min. the water only diverted half away along the capillary fringe before it dripped. The water entered in the center of the glass.

T.M. 10-4-99

10-5-99

The experiment was repeated for 10-4-99 at a 0.5 ml/min flowrate. The water diverted a little more than half along the capillary fringe before it dripped. The focus of the experiment to this point is to find out what governs the action of the water along the capillary fringe. The goal is to understand what conditions need to be met in order to create an experiment that is repeatable. That is to say we can make the water do the same thing everytime hence understanding what governs it. The suspect factors are flowrate, surface texture, entrance conditions, humidity, and the ceramic cylinder.

T.M. 10-5-99

10-11-99

Somewhat of a trial and error test was run. The name given to the previous experiments run will be "Dripping". Dripping refers to experiments were water is released into the glass fracture using a Quizix Pump and ceramic cylinder. Today four "trial and error" dripping experiments were run at rates of 1 ml/min, 0.3 ml/min, and 0.1 ml/min. With the cheesecloth, the water seemed to run through the fracture in one channel, but without it many channels formed quickly. As the flowrates lowered, the dripping slowed. In fact, at 0.3 ml/min and below, a drop would fully form and when the water moved along the capillary fringe slowly, the drop would be pulled back up.

T.M. 10-11-99

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10-15-99

To analyze the flow in this experiment, a chart has been developed. The glass plate will be identified as follows

Model:

A: Glass Plate sand-blasted with fine grit at 80 inches.
B: Glass Plate sand-blasted with fine grit at 60 inches.
C: Glass Plate sand-blasted with grade 4 at 80 inches.
D: Glass Plate sand-blasted with grade 4 at 60 inches.
#: Number of times the model has been run.

Experiment:

1: Regular dripping experiment with water
2: Same as 1, but the fracture is saturated
3: Same as 1, but alcohol is used.

Drop Length & Width:

The length and width of the falling fluid measured after it passes the half way point on the glass. This gives the drop a chance to form.

Width along fringe:

The lateral distance the fluid travels along the capillary fringe

Capillary Rise:

The maximum height the fluid reaches measured from the bottom of the glass.

Capillary Rise above Drip:

The height of the fluid directly above the point where the fluid drips.

T.M. 10-15-99

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10-19-99

Dripping Experiment
(Glass Fracture)

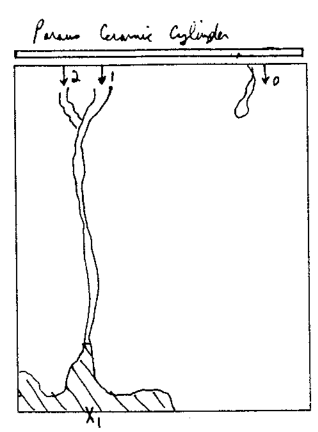
Date: 10-19-99
Model: A-1
Experiment: 1
Flow Rate: 0.025 mL/min
Torque: 10 ft-lb
Start Time: 13:30

Time	14:05	14:15	14:45	15:20					
Drop Length	5.0	?	—	—					
Drop Width	1.3	?	—	—					
Width Along Fringe	—	—	—	15.2					
Capillary Rise (high)	—	3.8	1.6	3.8					
Capillary Rise Above Drip	—	—	—	3.8					

(all measurements in cm)

Unsaturated Velocity: —
Saturated Velocity: —

Notes:



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10-20-99

Dripping Experiment
(Glass Fracture)

Date: 10-20-99
Model: A-2
Experiment: 1
Flow Rate: 0.05 mL/min
Torque: 10 ft-lb
Start Time: 13:15

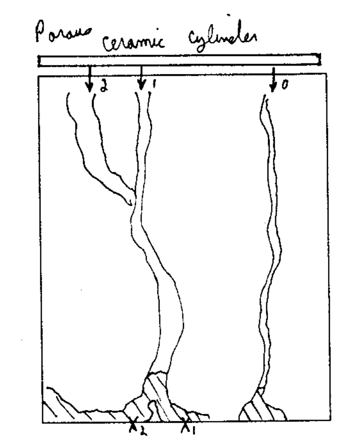
Time	13:28	13:30	14:00	14:20	14:23	14:31			
Drop Length	7.6	4.4	—	5.1	10.2	—			
Drop Width	1.3	1.3	—	0.81	0.81	—			
Width Along Fringe	—	—	4.4	12.7	15	24			
Capillary Rise (high)	—	3.8	3.2	4.4	4.4	3.2			
Capillary Rise Above Drip	—	—	—	5.1	5.1	—			

(all measurements in cm)

Unsaturated Velocity: 0.25 cm/s
Saturated Velocity: —

Notes:

About one hour into the experiment, a large amount of water gushed towards the middle of the glass. The water did not crawl along the bottom but dripped from X_1 as shown. Three minutes later another large amount fell from left center, marked 2, and joined the first, marked 1, half way down. It dripped from X_2 and crawled at the same time.



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11-5-99

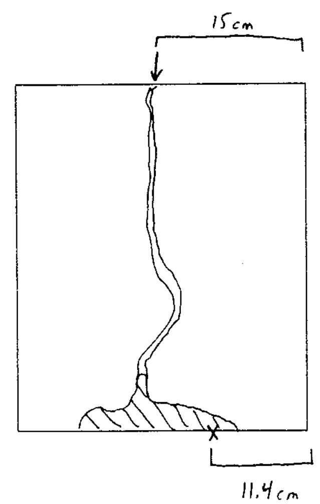
Dripping Experiment
(Glass Fracture)

Date: 11-5-99
Model: A-B-1
Experiment: 1
Flow Rate: 0.025 mL/min
Torque: 8 ft·lb
Start Time: 10:13

Time	10:17	10:33	10:37	10:47	10:52	13:21	14:10		
Drop Length	3.2	3.2	2.5	1.9	1.9	?	?		
Drop Width	0.95	0.95	0.64	0.64	0.64	?	?		
Width Along Fringe	—	6.4	6.4	10.2	11.4	16.5	18.4		
Capillary Rise (high)	—	2.5	2.5	2.5	2.5	?	?		
Capillary Rise Above Drip	—	—	—	—	1.3	?	?.		

(all measurements in cm)

Unsaturated Velocity: 0.04 cm/s
Saturated Velocity: ———



Notes:

After the first drop fell, the system comes to a kind of equilibrium. That is the drop that exits is almost equal to the drop that enters. The capillary fringe only moved 7 cm in about 3 hours.

11-5-99

The ceramic cylinder was removed from the experiment. The fluid will now enter the fracture directly from the pump tube.
T.M. 11-5-99

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11-8-99

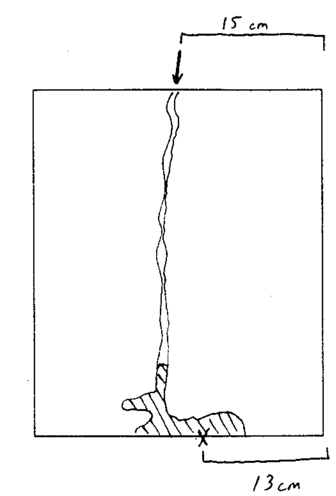
Dripping Experiment
(Glass Fracture)

Date: 11-8-99
Model: A-B-2
Experiment: 1
Flow Rate: 0.05 mL/min
Torque: 8 ft·lb
Start Time: 13:30

Time	13:35	13:40	13:42	13:44					
Drop Length	3.8	2.5	2.5	2.5					
Drop Width	0.64	0.32	0.32	0.32					
Width Along Fringe	—	3.8	5.7	5.7					
Capillary Rise (high)	—	1.3	2.5	2.5					
Capillary Rise Above Drip	—	—	—	1.9					

(all measurements in cm)

Unsaturated Velocity: 0.10 cm/s
Saturated Velocity: —



Notes:

The drop length and width appeared to reach equilibrium.

11-8-99

T.M. 11-8-99

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11-8-99

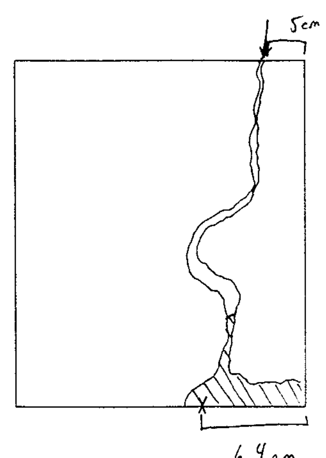
Dripping Experiment
(Glass Fracture)

Date: 11-8-99
Model: A-B-3
Experiment: 1
Flow Rate: 0.05 mL/min
Torque: 8 ft-lb
Start Time: 14:30

Time	14:36	14:42	14:46						
Drop Length	7.6	*	*						
Drop Width	0.64	*	*						
Width Along Fringe	—	6.4	8.9						
Capillary Rise (high)	—	2.5	2.5						
Capillary Rise Above Drip	—	—	1.3						

(all measurements in cm)

Unsaturated Velocity: 0.11 cm/s
Saturated Velocity: —



Notes:

* The drop length and drop width were not clear enough to measure. The drip through the fracture never formed individual drops. It stayed in patches and streams. The water traveled from patch to patch but wouldn't form a definable drop.

11-8-99

T.M. 11-8-99

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11-10-99

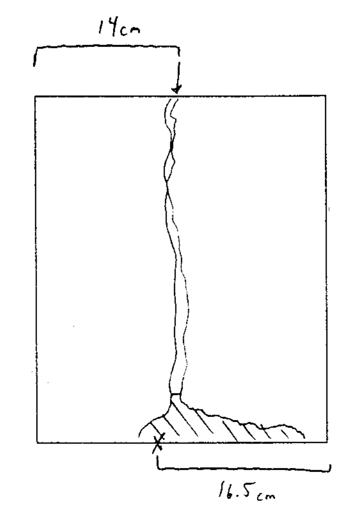
Dripping Experiment
(Glass Fracture)

Date: 11-10-99
Model: A-B-4
Experiment: 1
Flow Rate: 0.05 mL/min
Torque: 9 ft-lb
Start Time: 10:00

Time	10:05	10:11	10:13	10:17	10:25				
Drop Length	3.8	2.5	2.5	2.5	2.5				
Drop Width	0.64	0.32	0.32	0.32	0.32				
Width Along Fringe	—	4.4	6.4	9.5	12.7				
Capillary Rise (high)	—	1.3	2.5	2.5	2.5				
Capillary Rise Above Drip	—	—	—	—	1.3				

(all measurements in cm)

Unsaturated Velocity: 0.12 cm/s
Saturated Velocity: 1.0 cm/s



Notes:

The drop width and length appeared to reach equilibrium.

11-10-99

T.M. 11-10-99

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11-11-99

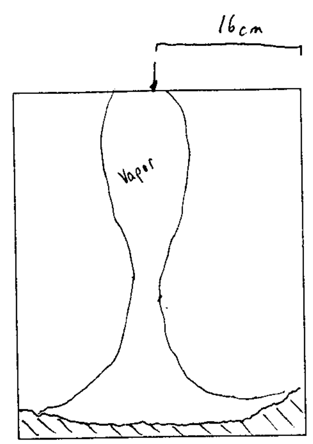
Dripping Experiment
(Glass Fracture)

Date: 11-11-99
Model: A-B-5
Experiment: 3
Flow Rate: 0.05 mL/min
Torque: 8 ft-lb
Start Time: 12:17

Time	12:27	12:32	12:42	12:49	12:54	12:58	—		
Drop Length	1	2	*	—	—	—	—		
Drop Width	0.5	0.5	*	—	—	—	—		
Width Along Fringe	—	12	14	16	19.5	Full	—		
Capillary Rise (high)	—	0.5	*	—	—	—	—		
Capillary Rise Above Drip	—	—	—	—	—	—	3.5		

(all measurements in cm)

Unsaturated Velocity: 0.08 cm/s
Saturated Velocity: 0.967 cm/s



Notes:

* The drop length and width fell in irregular shapes and streams sometimes dividing as it fell due to the large vapor (sat.) area as shown.

* The capillary rise started on the left and moved to the right.

11-11-99

T.M. 11-11-99

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11-15-99

As noted on page 39 of this notebook, the glass plates are not taken apart to clean. However it is suspect that the fracture after many runs becomes hydrophobic. The width along the capillary fringe is expected to be full before it drips. A cleaning solution is needed to remove the contaminants that are making the fracture hydrophobic.

T.M. 11-15-99

11-17-99

The glass plates were taken apart and cleaned with a 10% Nitric acid solution. The Nitric Acid was applied to the glass surface and quickly rinsed with tap water. The plates were allowed to dry in open atmosphere and then reassembled. The acid was unsuccessful. A capillary rise test resulted in no rise at all. The water never entered the fracture.

T.M. 11-17-99

11-19-99

The glass was cleaned with Alconox detergent powder. The glass plates were taken apart and Alconox was sprinkled on the surface. Water was applied and a tooth-brush was used to scrub the glass. The glass was rinsed clean with tap water. The process was repeated except the final step the glass was rinsed with deionized water. Alconox proved to be the most successful cleaner thus far because of the good capillary rise achieved after the cleaning.

T.M. 11-19-99

11-22-99

Two new glass plates were sand-blasted with ex-fine (T.M. 11-22-99) sand at 80 inches. The plates were cleaned with the same process described on 11-19-99 of this notebook.

T.M. 11-22-99

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11-29-99

Glass plate model A-B was run through a capillary rise test with nano-pure water. The rise was marked on the model with an erasable marker. Dripping test number one was performed at different flow rates. The test was recorded with "Win TV model 400" video camera. A still shot of when the water dripped was recored to a 3.5 inch floppy disk.

T.M. 11-29-99

11-30-99

The experiment procedure performed on 11-29-99 of this notebook was repeated for tap-water and alcohol in that order. The glass plates were not taken apart and were dried by blowing air through the fixture. Again the moment of drip was recorded to 3.5 inch floppy.

T.M. 11-30-99

12-2-99

The experiment procedure performed on 11-29-99 of this notebook was repeated for model A-A. Which were the two new plates from 11-22-99 of this notebook. The test were performed in the order of nano-pure, tap water, then alcohol. Again the moment of drip was recorded to 3.5 inch floppy.

T.M. 12-2-99

12-3-99

The data from the above experiments was given to Delia Hughson.

T.M. 12-3-99

12-8-99

The contact angle for the two different models was roughly measured. Five drops of each fluid (nano-pure, tap water, alcohol) were placed on each glass surface, with the plates taken apart. The drops were placed on the different rough surfaces and measured with the naked eye. The drops were placed on the glass with a sirenge. The highest and lowest of the drops were recorded to give a range. The contact angle is defined on page 51 of this notebook.

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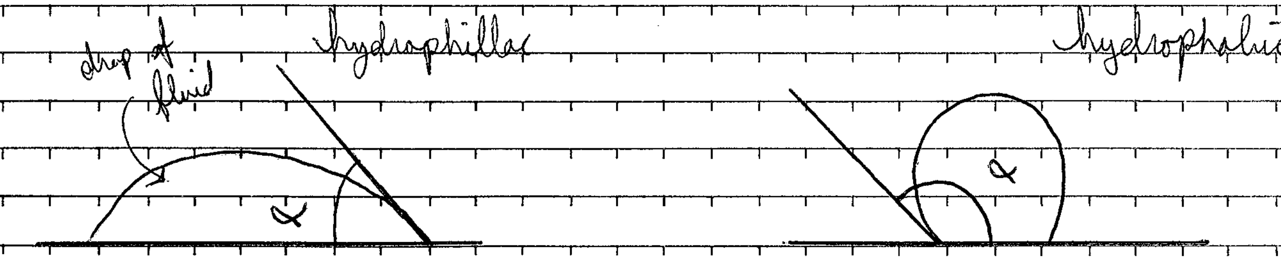

α = contact angle

Recorded Data

Model A-B	Nano	Tap	alcohol
α(A):	65°-75°	70°-80°	0°
α(B):	70°-80°	70°-80°	0°

Model A-A	Nano	Tap	Alcohol
α (A):	25°-45°	15°-35°	0
α(A):	15°-40°	20°-45°	0

The drops were placed in the area where the capillary fringe is formed.

T.M. 12-8-99

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The Remainder of
this Notebook,
from here to the
end is BLANK

This Notebook
appears to comply
with QAP-001.

I have reviewed this notebook. It is still generally in compliance with QAP-001. There is sufficient information so that another qualified individual could repeat the activity. E.C. Roy 8/28/2002

E.C. Roy 3/9/2001

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Recorded by DH | Feb 11 2000

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