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Scientific Notebook No. 051: Familiarization with Geometrical Models of Extension in Basin and Range Province (07/19/1992 through 04/21/1997)

21
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R

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CNWRA
CONTROLLED
COPY 051

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This notebook contains descriptions of the preliminary scoping work done on physical analog models at UTSA for CNWRA. Work was preformed by Alan Morris. This notebook is superceded by notebook 141 and 189. Work recorded in those notebooks was carried out in the physical analog model laboratory by Bret Rahe and Darrell Simms. This scientific notebook is archived effective 4/21/97.

A Lozano McKague
4/21/97

Alan Morris

Contents

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Alan Morris

JOHN MARK HAMILTON

- INITIAL WORK CONSISTS OF FAMILIARIZATION with GEOMETRICAL MODELS of EXTENSION IN BASIN AND RANGE PROVINCE.

"DOMINO model"

" FLEXURAL slip"

" OBLIQUE/VERTICAL SHEAR

Alan Morris

READ through "GEOMETRIC MODELS OF FAULTING AT YUCCA MOUNTAIN"

After a brief discussion of ABOVE mention models with DR. MORRIS, including a 'TUTORIAL' using "GEOSEC".

- CURRENT OBJECTIVE IS TO FIND LITERATURE ON VARIOUS FAULT MODELS AND AREA SPECIFIC WORKS IF AVAILABLE FOR B[illegible] ALTERNATIVE MODELS REPORT.

- 7/17/92 -

Alan Morris

SPENT LITERATURE SEARCH [illegible] - 4:00)

working on lit. search, w/ the help of JOYCE. obtained several articles to review.

Alan

- 7/19/92 -

Alan Morris

spent REVIEW day, articles obtained on 7/17.

~~7/20/92~~ -
~~WORKED AT UTSA. LIBRARY from 11:00 to 5:00 reviewing and making copies~~ of relevant literature. (5 hrs tot.)

Alan Morris

7/21/92
~~REVIEWED articles~~ at home, began ~~write-up for comparison of models,~~
10:30 - 3:00 @ home (3. hrs. time)] - 5.5
4:00 - 6:30 @ school (2.5 hrs time)

Alan Morris

7/22/92
2:00 - ~~REVIEWED ARTICLES~~ @ Home
~~4:00 - 6:00 worked on summary @ school~~
TOT. 3hrs.

Alan Morris

7/23/92
9:00 - ~~WROTE~~ writing on SUMMARY
~~1:00 - 5:00 " " "~~
8:00 - " " "

Alan Morris

8/13/92 - UTSA LIBRARY - LOOKING UP References from 11:00 - 4:00 (5hrs)

Alan Morris

8/14/92 - SWRI - ~~TAKE~~ REFERENCE BACK K/AR
found a few more references.
2:00 - 3:30 (1.5 hrs)

Alan Morris

8/18/92 - Review References
2 hrs

ABM

8/22/92 - Review References
2hrs

ABM

8/23/92 - Review References
2 hrs

ABM

8/24/92 - write summary II.
2.5hrs.

ABM

8/25/92 - WORKED ON SUMMARY
~2 hrs

ABM

8/26/92 - WORKED ON SUMMARY
~2 hrs.

ABM

8/27/92 - FINISHED SUMMARY
finished up today
~3 hrs

Alan Morris

Alan Morris

Fault Modeling Project

June 1993 (START DATE)

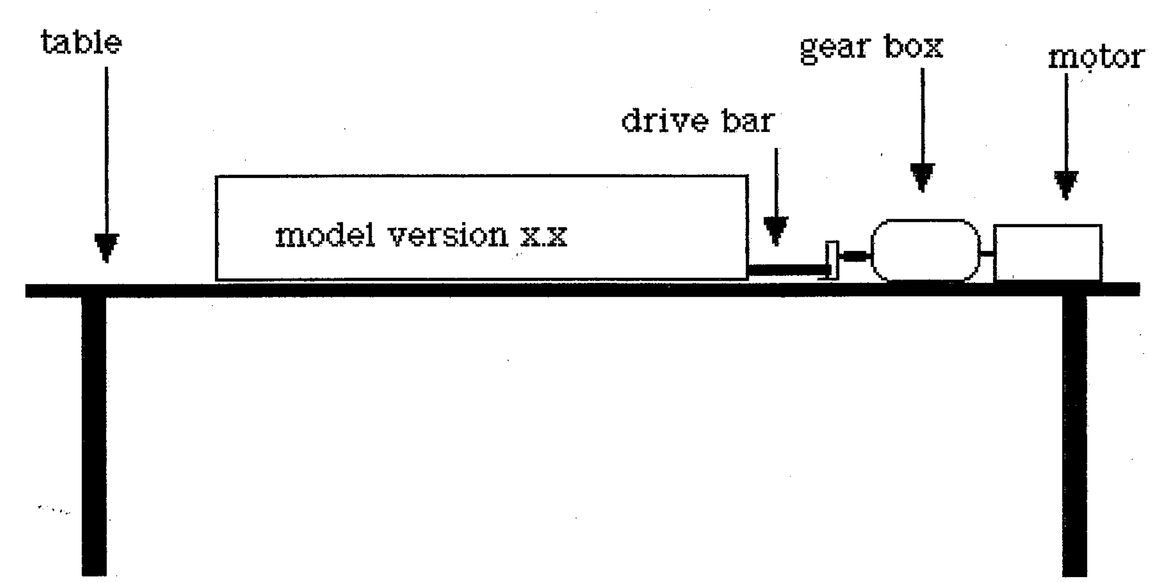
Project Began in JUNE 93, expected completion date Aug. 94.

OBJECTIVES: Construct physical, analog model of listric normal faults, such that fault geometry may be examined in three dimensions.

Equipment: Drive motor, gear-reduction box, solid TABLE.

-Equipment to be constructed: modeling Apparatus.

Figure below provides a basic sketch of layout



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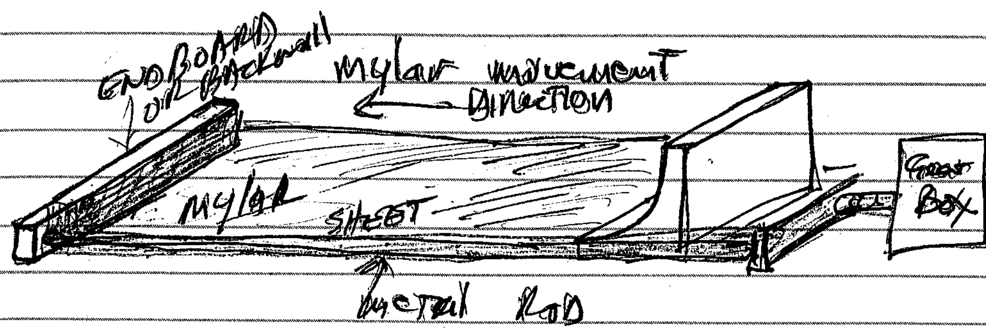
MODEL VERSION 1,

Model Apparatus was constructed using:

1) CLAY AS A FOOTWALL
2) MYLAR AS A TRANSPORT surface
3) METAL RODS AS EXTENSIONS FOR DRIVE SYSTEM



The metal RODS ARE CONNECTED TO THE BACKWALL. Movement is Accomplished by connecting the gearbox to the other end of the metal RODS, This results in pulling the mylar OUT from under the footwall.

—RESULTS—

PRIMARY RESULT IS - A GREAT DEAL of MODIFICATION AND Refinement is required.

1) MOTOR-to-gearBox coupling needs replacement
2) TRACK OR GUIDE system is needed to prevent Apparatus from torque related movements
3) Footwall is too small
4) Need SIDEwalls to layer SAND properly.

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MODEL VERSION 2

JULY 1993

-CHANGES MADE-

1) FOOTWALL was modified, AND is now more representative geometrically of "real world" listric faults. Construction material is still clay.

2) SIDEWALLS were ADDED
3) TRACK was ADDED to prevent torque related movement.

— RESULTS of MODEL VERSION 2 —

* MORE MODIFICATIONS ARE NEEDED BEFORE Apparatus IS VIABLE

1) The DRIVE mechanism needs revamping

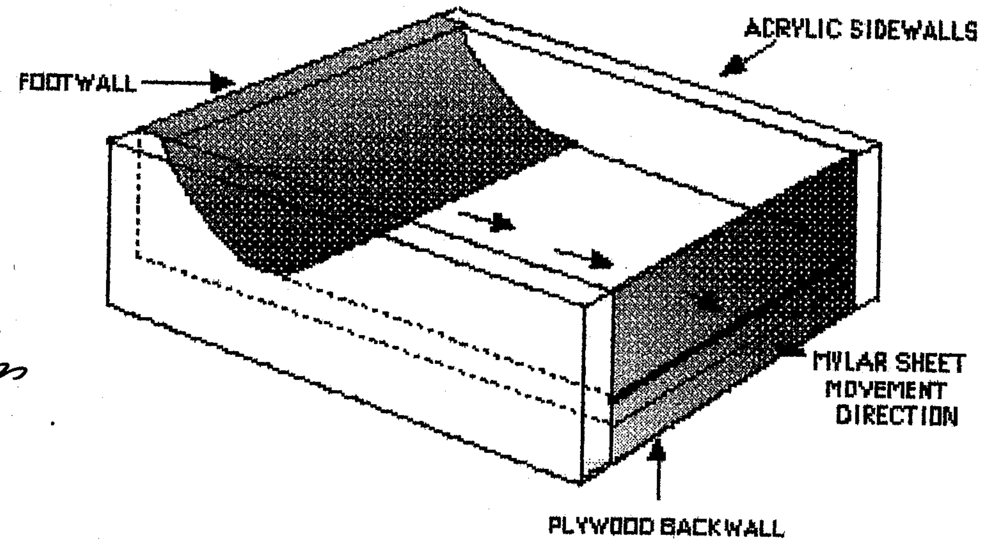
2) FOOTWALL MUST be CONSTRUCTED of some other material rather than clay DUE to Shrinkage FACTOR inherent with clay.

Alan Morris

SEPT 1993

MODEL VERSION 3

VERSION 3 represents AN ENTIRELY NEW APPARATUSS.



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Apparatus now exist essentially As one unit contained w/in a box-like STRUCTURE, Composed of components,

DESCRIPTION of components.

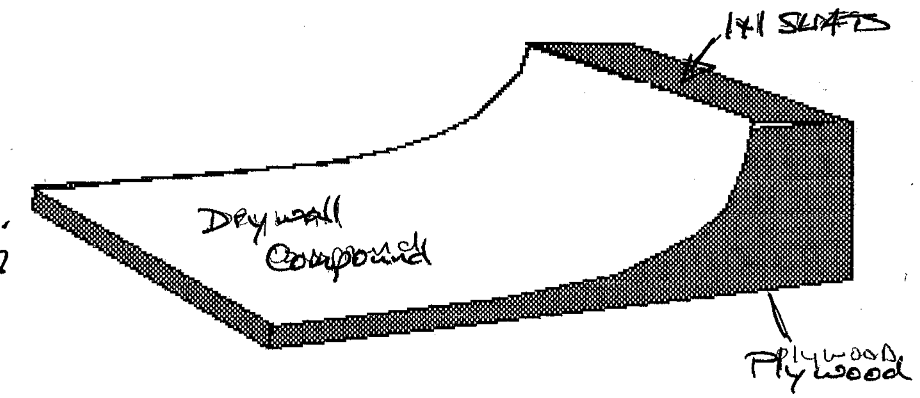
1) FOOTWALL- CONSTRUCTED OF plywood AND Drywall Compound.

Geometrically Realistic cut-outs were constructed from 1/4" plywood, THESE PROVIDED "endcaps" for the fault surface. The endcaps were then Joined together using A plywood Base, AND 1x1 ~~across~~ SLATS Across the top.

With the "shell" constructed, A FAULT SURFACE was created By Filling

in the shell with drywall or joint compound (USED IN SHEETROCK WALL CONSTRUCTION) to remove irregularities). The compound was ADDED, allowed to DRY, SANDED, & shaped, this process was repeated, until the desired geometry was achieved.

Footwall is shown Below



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NEXT- the Footwall is contained within a Box w/ Acrylic SIDEWALLS, AND A plywood BACKWALL. (SEE Drawing pg. 8)

A Mylar sheet is then cut to fit over the footwall, AND Between the sidewalls This sheet provides A Detachment surface when it is pulled away from the footwall through a slit in the Base of the Back wall.

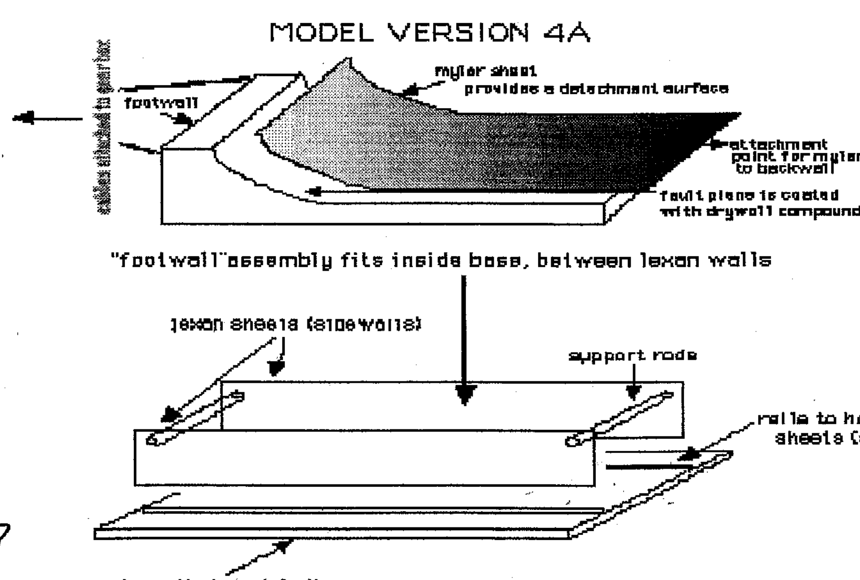
AM

Model VERSION 4 Oct. 1993

MODEL VERSIONS 4A & 4B

Significant modifications to version 3 were performed to construct version 4A. The footwall from version 3 was used to save time in the construction of version 4A. First the basic footwall was extended by addition of a flat that effectively lengthened the footwall by several inches. The two footwall portions were attached by two iron rails that were polished on their base and used as a sliding surface. The basic operation of the model was intended to allow the gearbox to pull the footwall assembly away from the backwall. The backwall would have the mylar sheet attached to it, which effectively acted as the detachment surface as the footwall was pulled away from the backwall. Movement was guided by placing the footwall between the sidewalls, which were held in place by rails at their base, and threaded rods at their tops. The non moving backwall was also attached to the sidewalls. Thus a three sided box was formed using the backwall, and two sidewalls. The footwall assembly was the added inside the box, and effectively formed the fourth side of the box. Small diameter cables were then attached to the footwall assembly at one end, and to the gearbox at the other end. This arrangement was designed to alleviate the formation of inversion, and compression structures within the model. Model version 4A is pictured below in figure 2.

Figure 2



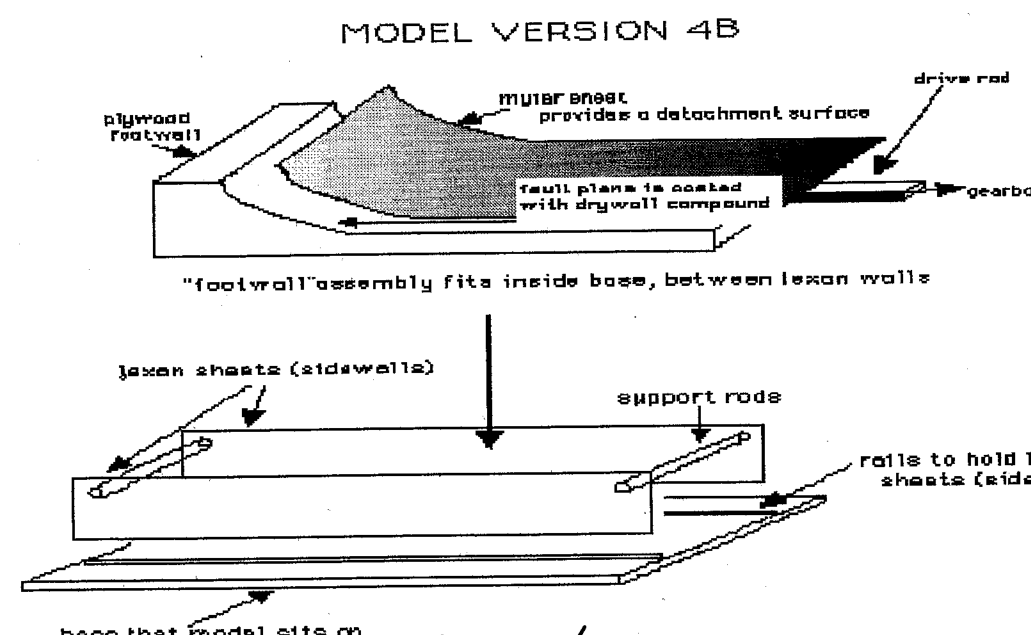
Results version 4A

The basic design of this version was viable, the problem-it was discovered lies in the gear-box. During the first (and only) run attempt with this version, the drive coupling for the gearbox came apart. After investigating the problem it was found that without extensive modification to the drive equipment the model must be pushed to achieve extension rather than pulled out from under the detachment. Therefore version 4A was modified to operate under the reverse direction and renamed version 4B.

MODEL VERSION 4B

Modification was achieved by essentially turning the model 180 ° and constructing a ridged drive rod to push the footwall assembly out from under the detachment surface. This version is pictured in figure 3 below.

Figure 3



Oct - Nov
1993

Model 4B, Run # 1, 6.7% extension

- Results: A small rollover anticline was produced in the hangingwall of Run #1.

- Run resulted in additional information used for further development of apparatus.

Changes to apparatus that need consideration are:
1) Need to get around using a mylar detachment surface
2) model needs to be wider to reduce edge effects
3) Footwall assembly moves in a "stick-slip" fashion, this needs to be fixed.

- Primary results from model 4B, are modifications required to construct a better apparatus

See next page (pg. 13) for photograph of model 4B Run # 1, (only one run was performed with model 4B)

Alan Morris

Model 4B, Run # 1, 9-11-93

Alan Morris 1993

- Development & Construction of Model 5

Version 5 incorporates some features of model version 4. Features such as plywood and drywall footwall construction, sidewalls, and a backwall are similar to version 4.

However, this version is larger, and contains several features not found in earlier versions. The basic design uses a stationary footwall contained between two acrylic sidewalls. The hanging wall portion is constructed by using a acrylic sheet below the footwall, which is the same width as the footwall, and is also contained between the sidewalls. Movement is provided by pushing the hanging wall out from under the footwall.

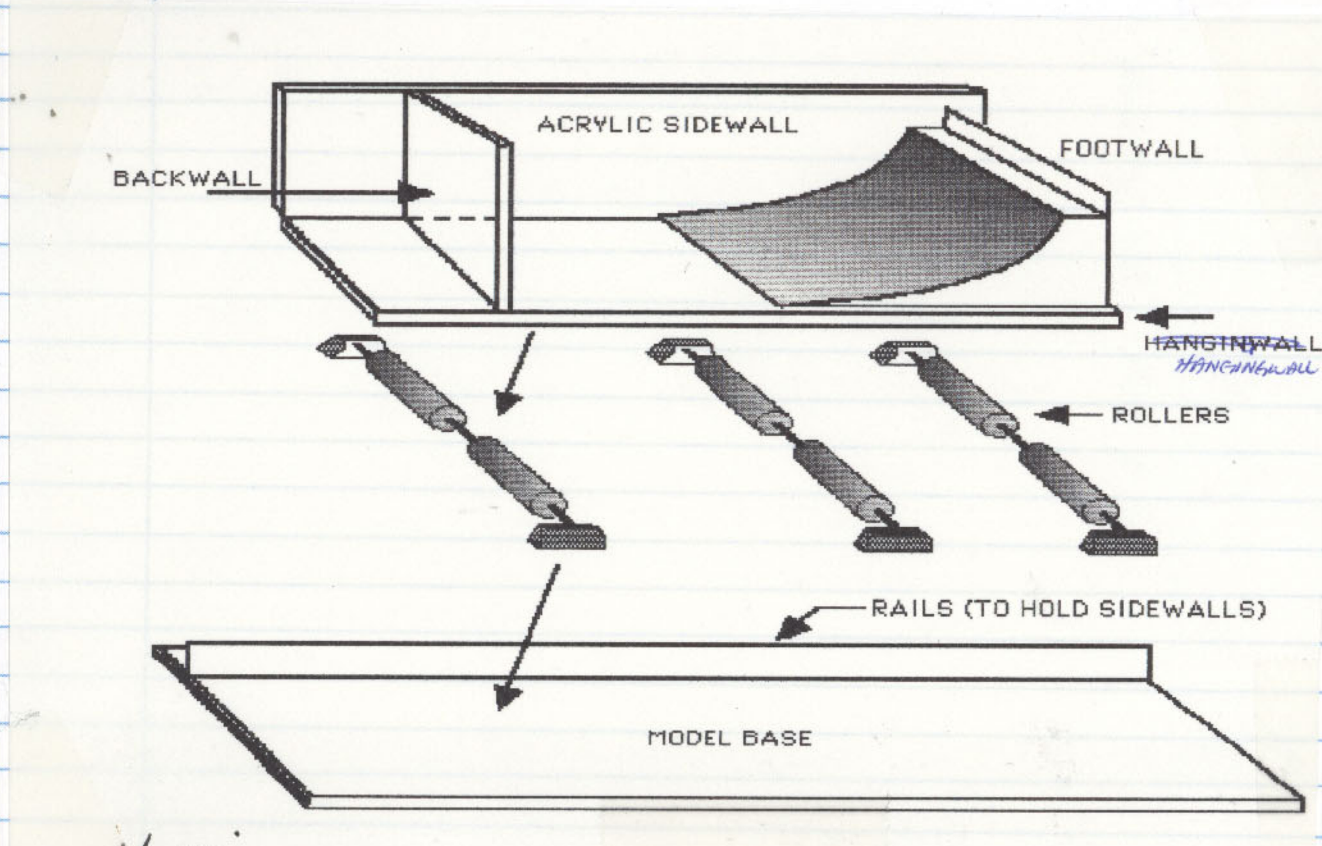
Stick, slip movement is alleviated by allowing the hanging wall to roll along on a set of rollers constructed of washers and steel rods.

Alan Morris

Nov 1993

Model Version 5,

Drawing below shows model with the sidewalls removed on one side, (cut-away view)



Alan M[illegible]

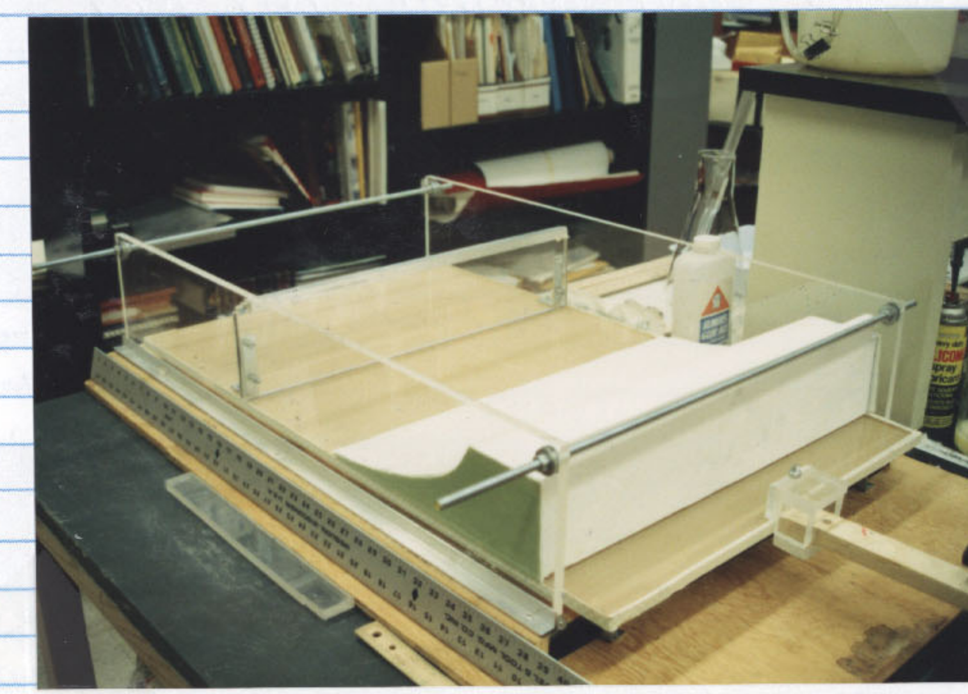
With the exceptions of minor modifications model version 5 has remained essentially the same with each run.

Some modifications made to Model 5 consist of:

1) Coating footwall (drywall compound) with plastic laminate to lower friction, and prevent degradation of the drywall compound.

- Other changes include, addition of foam rubber to sides of footwall to serve as gaskets to prevent sand leakage.

Photo: Model version 5, with laminate material in footwall, + foam rubber gaskets, below.



← Drive bar

↑ scale is in inches

Alan M[illegible]

At this point, the apparatus is viable, with the exception that minor modifications between runs will need to be made.

Nov - Dec 1993

MODEL RUNS FOR VERSION 5

Run #1,
Run was performed using dry sieved sand, grain sizes were ≤0.5mm. This particular sand contained a moderately high fraction of fines.
Extension amount was 6%

Results: formation of a rift, at the toe, or base of the footwall. Rift formation resulted due to sand cohesion values being lower than anticipated. Very little slip along the "face" of the footwall occurred, deformation was limited to the rift walls.

Significant aspects of this run.
1) importance of cohesion values became evident
2) obvious friction (edge) effects occur between the sand and side walls, thus the importance of a wide model.

Page 17, photographs

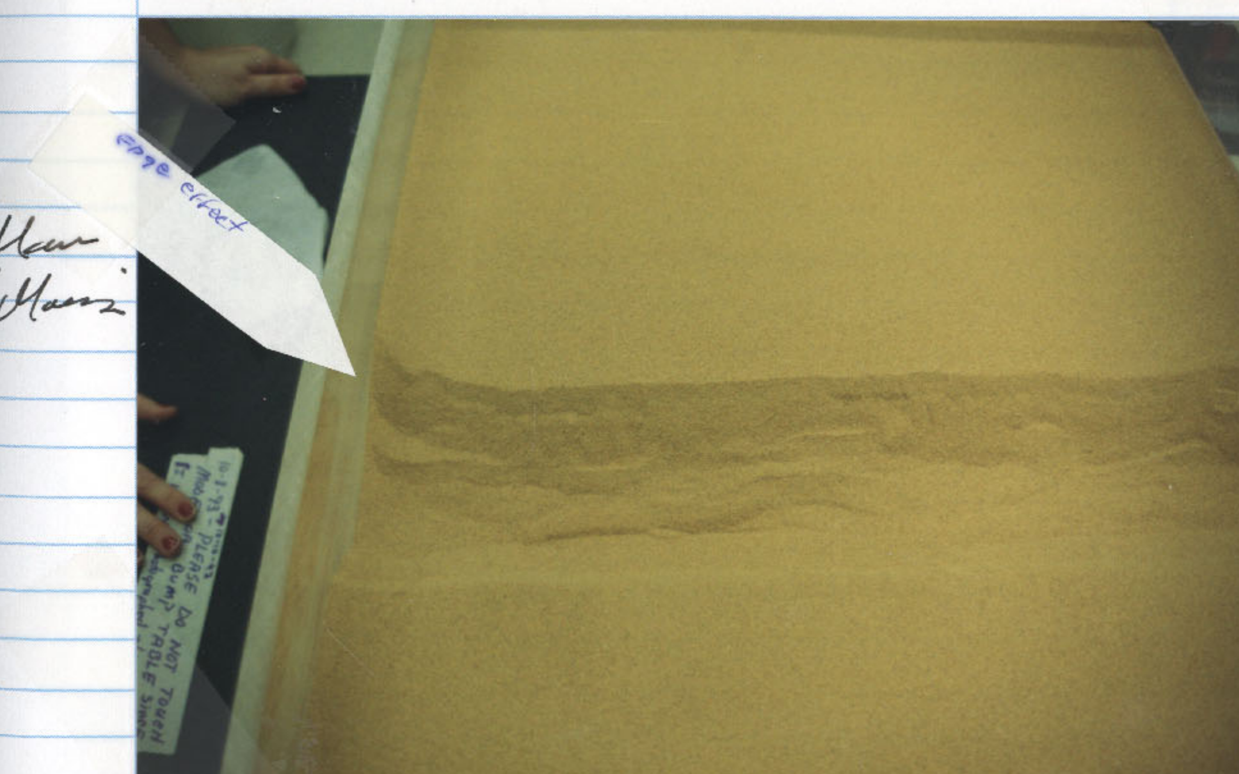
TOP photo: shows fault zones associated with rift.

Bottom photo: shows the friction or edge effects between sand & sidewalls

Alan Masi

Alan Masi

Alan Masi



Run #2.

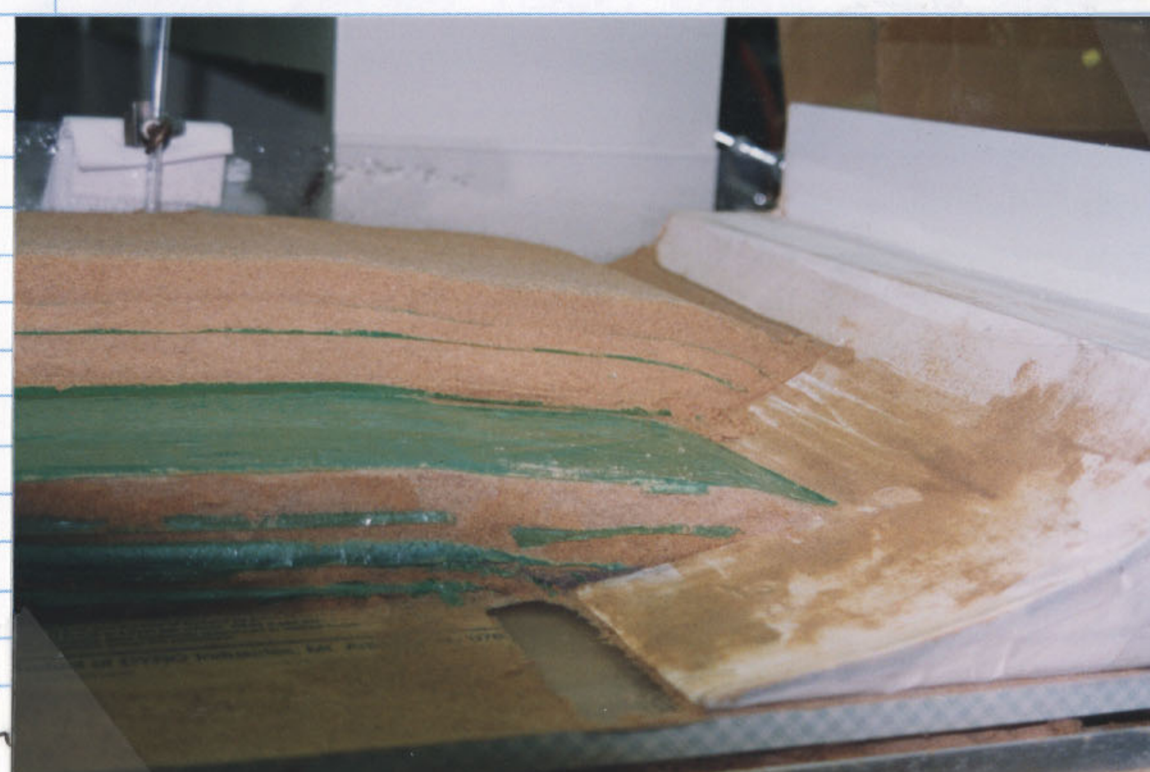
This run was performed using the same sand as run #1. The major difference in this attempt was the introduction of thin plastic sheets between sand layers in order to increase the cohesion values of the sand. The model run effectively modeled the case for flexural slip.

After extension was performed, the model deformed uniformly, creating a rollover anticline in the hanging wall as expected. The drawback to this technique lies in the plastic preventing formation of any faults, (vertical or oblique shear). However, the run proved useful for investigation of flexural slip.

Photographs were taken in sections by saturating the model with water and slicing it apart along the center line to avoid edge effects.

Photograph

Model 5 Run #2 Flexural Slip



Run #3

This run was performed using "Oklahoma #1" sand, which is a fine, pure silica sand available as sandblasting aggregate. Run 3 was aimed at testing the behavior of the new footwall (with a plastic laminate coating plus teflon), and investigation of the behavior of the new sand.

The run set employed the use of a partial decollement in the form of a plastic sheet that extended only to the top of the flat portion of the footwall. Once again a rift was formed, this time at the top of the decollement. Some slip did occur along the top of the footwall, however the model still did not behave as hoped. This run did produce evidence that the modeling material needs to be more cohesive.

- An additional objective of this run was testing the new method for staining sand. Sand was stained from pure white (natural color) to purple using 'Rit' clothes dye (black or Navy blue) both seem to produce purple sand.
This method is superior to using methylene blue since clothes dye is less toxic.

- No photographs of this run were taken.

Nov-Dec
1993

Model Run #4

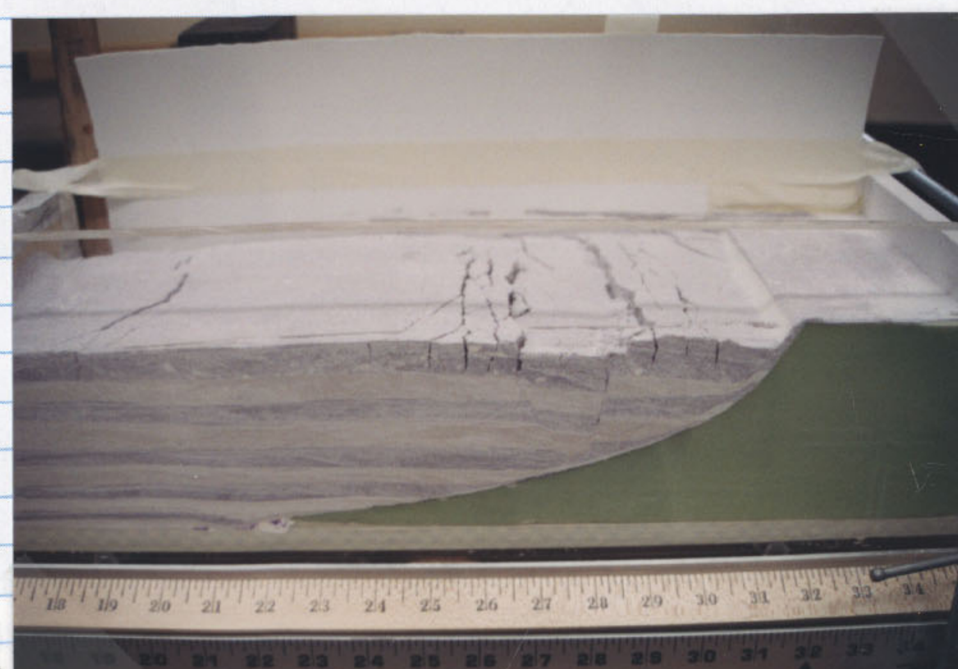
This attempt was aimed at experimenting with the effects of wheat flour on the cohesive properties of sand. This run was primarily intended to be a "check" on this effect and not a well analyzed look at the exact properties of the material that resulted from mixing sand and flour.

Oklahoma #1 was mixed at approximately 1:1 with ordinary (bleached) wheat flour, then layered into the model apparatus. The model apparatus was specially set up for this run such that less material would be needed to perform the analysis. This was accomplished by changing the location of the backwall in relation to the footwall, and addition of a divider panel to decrease the width of the model. The net result was a model with the same mechanical function, on a much smaller scale.

Modeling results for this run were quite spectacular. Extension was accommodated by formation of a rollover anticline containing a graben produced by antithetic and synthetic shear. Slip along the fault surface occurred, along wi~~d~~th ~~the~~ formation of several vertical faults.

- Run #4 contains no plastic sheet (decollement) other than the model itself

Photograph Run #4



Current status of project (January 27, 1994)

At this time it seems the method has been refined to the point that viable model results can be achieved. It is imperative however that the sand flour mixture be tested for its material properties. This mixture needs to be perfected and used at what may be referred to as an equilibrium point. In other words the mixture ratio should result in a cohesion value that is just high enough to allow deformation to occur in the manner described in run #4, but low enough that the model is still geologically reasonable at model scale (i.e. the rock being modeled is not infinitely strong).

The current plan is to perform a full model scale run by February 2, 1994 again using the sand flour mixture. The mixture will be measured this run and currently plans are for a mixture of 30% flour, and 70% sand.

In addition a cohesion testing device has been designed, and will be constructed as soon as possible in order to obtain numerical values for the mixture.

One last item planned for run # 5 is the addition of a discontinuity in the fault plane. This is to allow examination of three dimensional changes in fault shape due to irregularities in the footwall.

Model Run #5 JAN. 29, 1994

SAND: FLOUR Ratio is 10:1

SET UP

- Detachment surface is a plastic sheet attached to the ~~footwall~~ hanging wall and running up the "flat" of footwall.

- a small irregularity is located in the footwall (A positive relief bump)

- SAND is OK #2

- model is full width

- SAND layers are approximately 1cm thick

Alan Morris

RESULTS: the decollement (plastic sheet) is controlling deformation. A Rift formed at the top of the plastic sheet.

Model was photographed extensively and sectioned after being saturated with H_2O. Multiple section photographs were taken.

The main problem seems to be a need for quantitative information concerning cohesion values for model materials.!

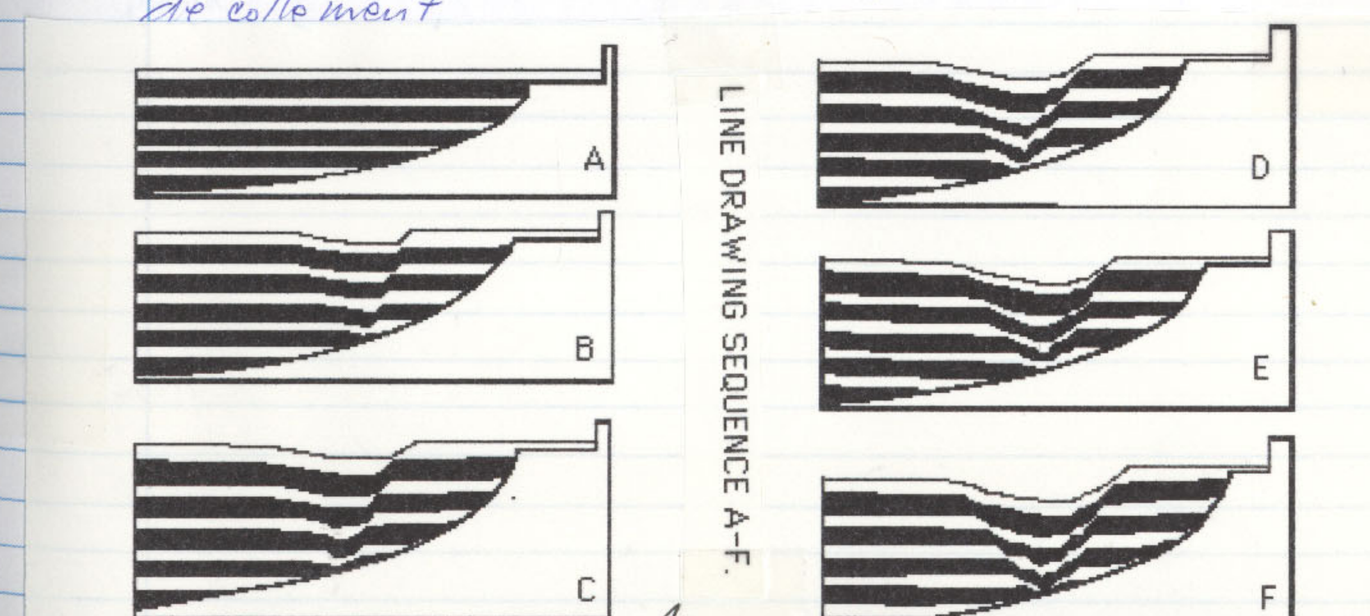
Results are pictured on pages 23 & 24 for run #5.

Alan Morris

Photograph above is Model Version 5, Run #5 JAN. 29, 1994.

photo taken 2" inside of sidewall (section photo)

graben initiates at the top of the decollement.



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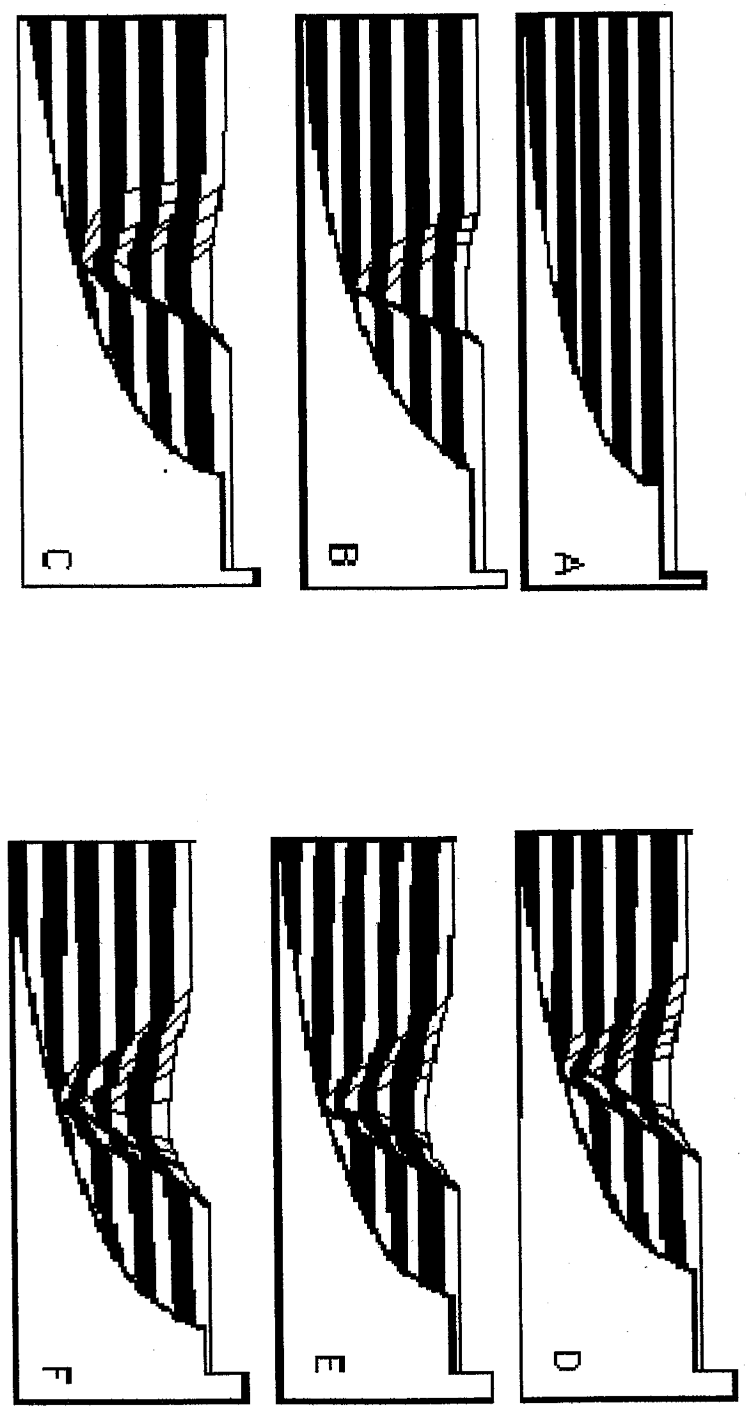


MODEL VERSION 5 RUN 5, LINE DRAWINGS WITH FAULT TRACES DRAWN IN.

February 3, 1994
Model notes.

Thoughts resulting from Run # 5

The following is a list of possible ways to produce true listric geometries in analog sand models.

1) Vertical model depth should play an important role, since the model imitates the full listric system, significant rheologic changes occur with depth in the natural system. This should be accounted for in the model in some fashion. The question is how?

A) Construct a deep model, this may allow the faults to develop into a listric shape.

B) Increase the cohesion values of the modeling material with depth, along a some scale that imitates the change in rock behavior related to increases in lithostatic pressure, and increased temperature (i.e. more plastic behavior). Consider the effects of decrease in porosity with depth in the natural system, this is not accounted for in the model.

C) Create a basil detachment layer in the model that mimics an active decollement.

D) Reduce the transistional "bump" between the footwall and hanging wall in the model to obtain a continuous (or reasonably continuous) fault plane.

E) My understanding is that listric faults develop at depth and splay up into the brittle portion of the crust giving rise to a steeping upwards fault. Therefore it seems plausible to have a partial decollement horizon extending along the flat portions of the footwall.

D) Make modifications to the active detachment surface, i.e. scale it to model specifications rather than having an infinitely strong (plastic) sheet as a detachment.

E) Continue with efforts to reduce the adhesion values between the footwall and model material where the two are in contact.

F) Build another discontinuity that is slightly larger than the one used in run #5. With the goal of modeling non-cylindrical geometry.

G) Examine the possibilities of introducing an element of oblique slip into the model. It may be that this element plays a role in the development of listric geometry.

H) Consider the use of different model materials that are relatively non-cohesive, or switch to a sand with smaller grain size.

I) Finally, some comparative quantitative cohesion values need to be obtained, suggestion is to construct a cohesion testing device.

Numbers related to grain size, depth, addition of flour etc. would provide additional relevant information concerning model behavior.

Alan Morris

Alan Morris

Run 6, summary

RESULTS OF MODEL RUN #6
(RUN DATE 2/12/93) 4 APR

MODEL 5, RUN #6.

CONSTRUCTION:

This run is primarily aimed at investigating the effects of some of the considerations mentioned in model notes of 2/3/93 ("ways to produce listric geometry").

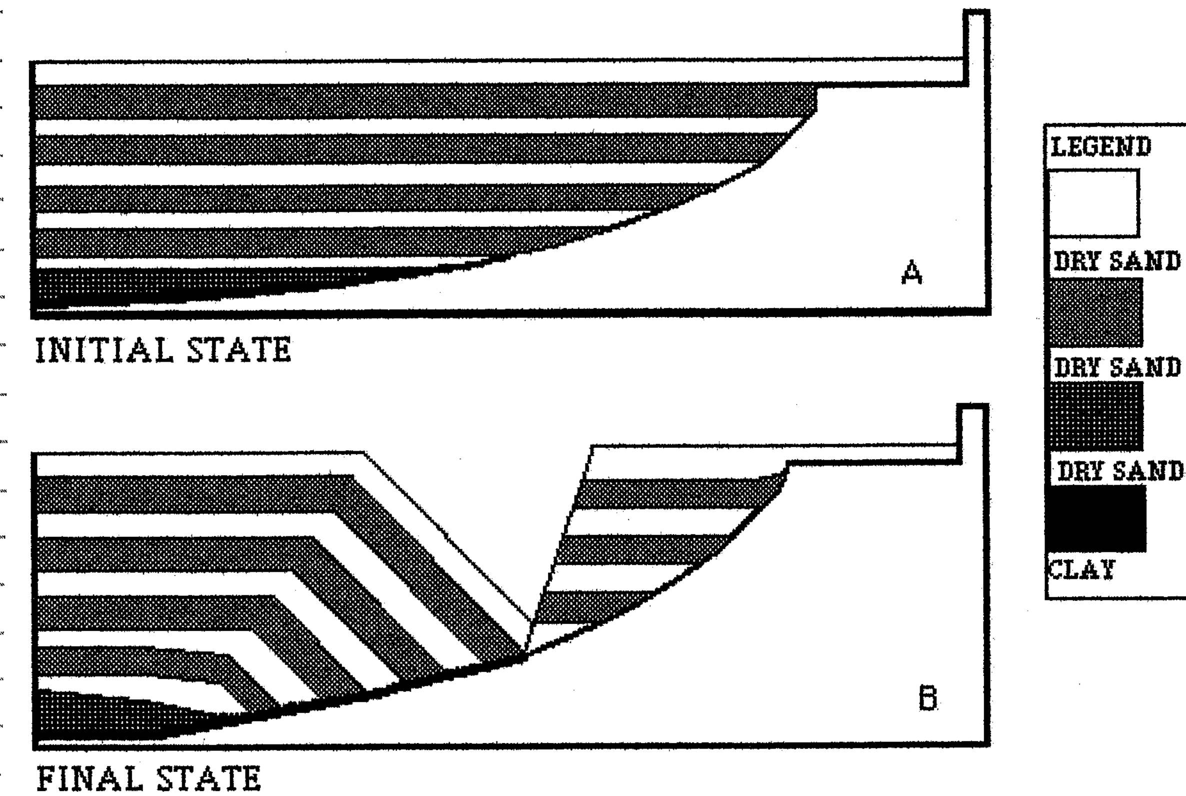
Base of model was designed to emulate a brittle ductile transition by using a clay layer saturated with water. Above this clay layer a single sand layer was saturated with water, then sprayed with lightweight oil at its top to slow water migration by capillary rise into overlying layers. The clay layer extends up through the flat portion of the footwall, and is underlain by a plastic sheet acting as a decollement. Ideally this arrangement would produce internal shear within the clay, and cause fault formation to emanate from the base of the model and "fire" up to the surface.

Next, sand was layered into the model above these two basil layers in 1cm increments (one cm thick layers). The top layer was slightly thicker than this, and constructed from a slightly larger grain size sand than the other layers. Lower layers (sand) were composed of Oklahoma #1 sand, while the uppermost layer was composed of sieved construction sand. The reason for this arrangement was to simulate progressively more brittle behavior toward the model top.

RESULTS:

Results were not as anticipated, however, they were informative. Hangingwall deformation initiated at the top of the decollement as usual, unique to this run however was the rotation of a portion of the hangingwall as extension proceeded. Deformation was accommodated by formation of a rift and its associated antithetic / synthetic shear, or fault zones, along with minor block rotation within the hangingwall. The drawing below depicts model run 6 as described above.

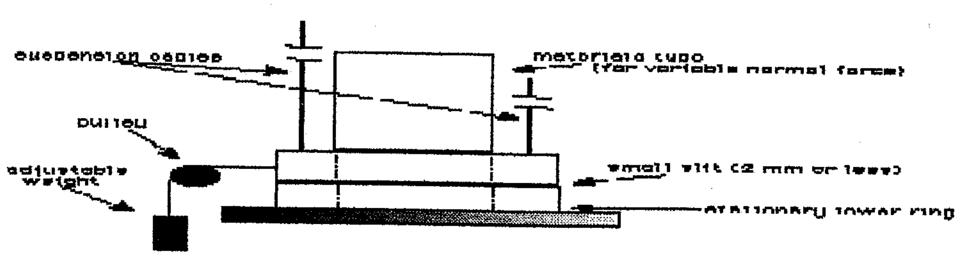
MODEL VERSION 5, RUN #6
FEBRUARY 12, 1993 4 APR



Cohesion Testing
2/27/94

Based on work published by Krantz 1991, I elected to further investigate the role of cohesion in sand as it pertains to physical analog models.

This procedure began with construction of a testing apparatus designed after the device described in Krantz's paper. The device consist of two plastic cylinders. One cylinder sits atop the other, into which sand is loaded, and a shear stress applied until the sand fails. The device is made slightly more sensitive by suspending the upper cylinder by cables to negate friction between the cylinders. The upper cylinder is only slightly separated from the lower one, allowing all the applied shear stress to be transmitted to the sand. See the drawing below.



Cohesion testing device after Krantz,1991

After constructing the device, it proved to be of less use than I had hoped. It seems the device is not "sensitive" enough to detect small values of cohesion (i.e. near zero). For this reason the data from the cohesion testing is not included.

Testing did seem to indicate that cohesion values for dry sand are extremely small, (this may be confirmed in published data).

Thoughts on this subject are as follows:
I. Sand when well sorted, homogeneous, containing very few "fines", and above all dry, exhibits cohesion values of approximately zero.

II. Considering model scale, (see next section for more on scale) cohesion values should fall in the range of 0 to 0.5 pascals. In addition, model scale is at best an order of magnitude science, the current values are certain to be low enough (possibly too low) to fall within the scaling limits.

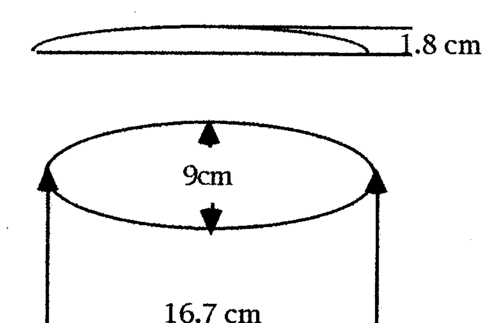
(Primary reference Krantz, 1991)

Significant Developments / Changes
(since last model run)

3/8/94

After further research it seems that the sand sold to me as Oklahoma #1 used in model run #5, was NOT OKLAHOMA #1.
The mean grain size was too large, and the overall homogeneity (roundness, sphereicity, and sorting) were too varied.
Currently I am able to obtain true O.K. #1 sand from a local reputable supplier. This is a very nice modeling sand, it is well sorted, clean, homogeneous quartz sand. The grains are well rounded, and spherical.

Other changes include a modification in the footwall discontinuity that should have a more pronounced effect on the geometry of faults developed in the model. In other words the new "bump" will be a more drastic departure from cylindrical footwall geometry.
The new bump measures 16.7 cm by 9 cm by 1.8 cm



Notes on
MODEL SCALE:

MARCH
1994

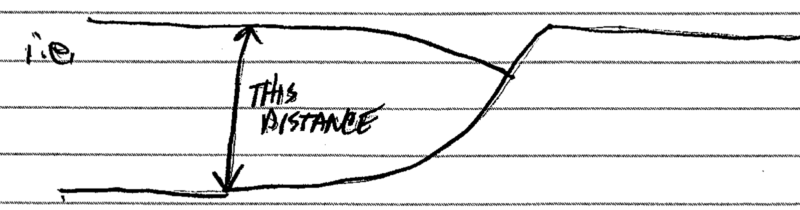
BASIC DIMENSIONS: LENGTH, MASS, (TIME IS NOT A significant FACTOR in Brittle Behavior)

Length SCALE, or proportionality CONSTANT = λ

$\lambda = L_{model}/L_{prototype}$ (L=Length)

Therefore for a scale of 10 cm = 10 Kilometers

i.e.



If DISTANCE ABOVE IS 10 Km in prototype, AND 10 cm in model, then

$10\,cm/10\,Km = \lambda \Rightarrow 1\,cm/1\,Km \Rightarrow 1\,cm/1\times10^{5}\,cm$

$\lambda = 10^{-5}$

Area $= \lambda^2 = 10^{-10}$ Volume $= \lambda^3 = 10^{-15}$

If Lengths And Angles Are preserved the model is Geometrically similar

Density Scale

- Prototype Average Density = 2.02 g/cm³
- Average Model Density = 1.7 g/cm³

$\delta = \rho_{model}/\rho_{prototype} \Rightarrow 1.7/2.02 = 0.84$ = Ratio of Density

NOTE: This Value May Range Between 0.8 And ≅ 1.0

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MASS RATIO: $\eta = \delta\lambda^3$ (Density · Volume)
$\cong 8.42\times10^{-16}$

TIME = τ $t_{model}/t_{prototype}$ ≅ $\tau \cong$ [illegible]

model ratio of stress

$\sigma = \sigma_{prototype}/\sigma_{model}$ ⇒ CONSIDERING inertial Forces negligible

$\Rightarrow \sigma = \eta/\lambda = 8.42\times10^{-6}$

THIS VALUE MAY RANGE Dependent upon η ⇒ Reasonable values Are Between $1\times10^{-5} - 9\times10^{-6}$

THESE VALUES YIELD A Required model cohesion of Approximately 0.5 → 0.05 Pascals.

0.00005

Alan Morris

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Alan Morris

Model Runs 7 & 8

Run #7 (3-11-94)
- Using the footwall discontinuity described on page 29, and O.K. #1 sand. Model was set up with approximately 1 cm thick sand layers.
- Extension amount 7%.
- Model was sectioned vertically after running.

Run #8 (3-29-94)
- This run is designed specifically to provide data on the repeatability of run number 7.
- All parameters for the run are identical with the exception of sand color. Black sand is used rather than purple to enhance contrast in photographs.
- The post run sectioning technique differs somewhat from run 7 also. After cutting 3 vertical sections, and seeing that geometries were comparable to run 7, it was decided to pursue a horizontal sectioning technique for the remainder of the model. Based on information gained from this technique it may be advisable to run a minimum of two identical experiments for any given scenario, and section the results in both the vertical and horizontal planes.

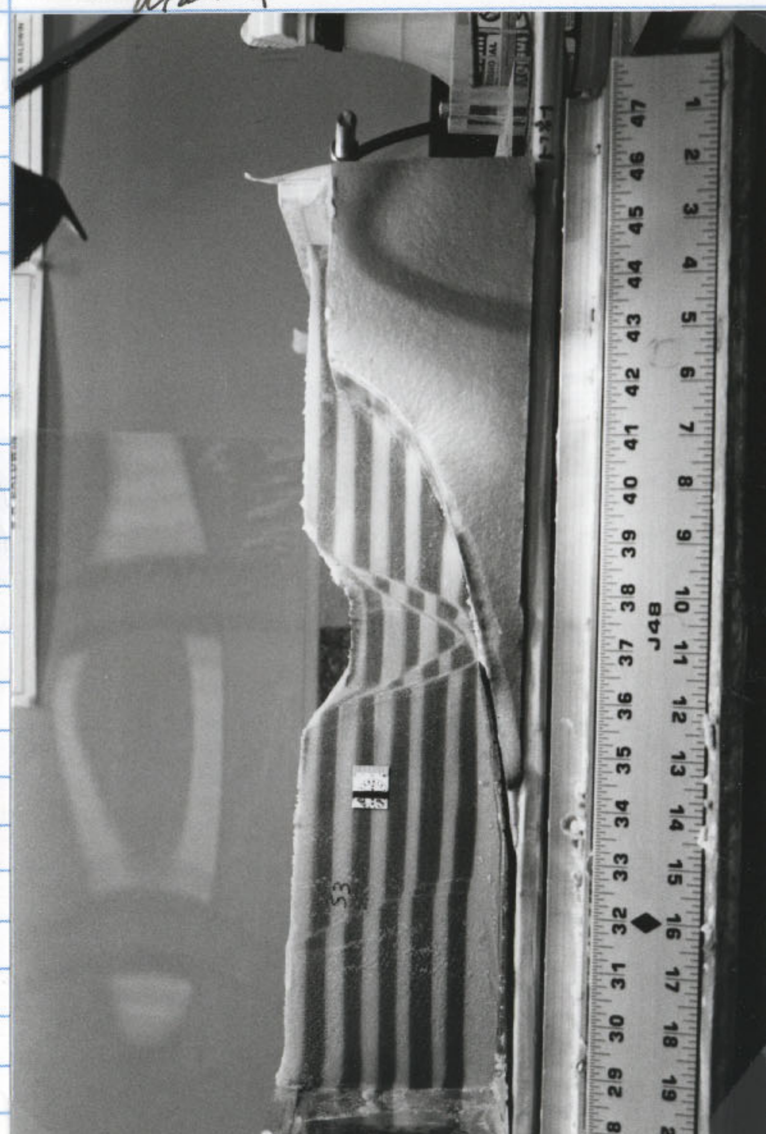
Alan Morris

SEE PHOTOGRAPHS pgs. 34, 35 & 36, 37

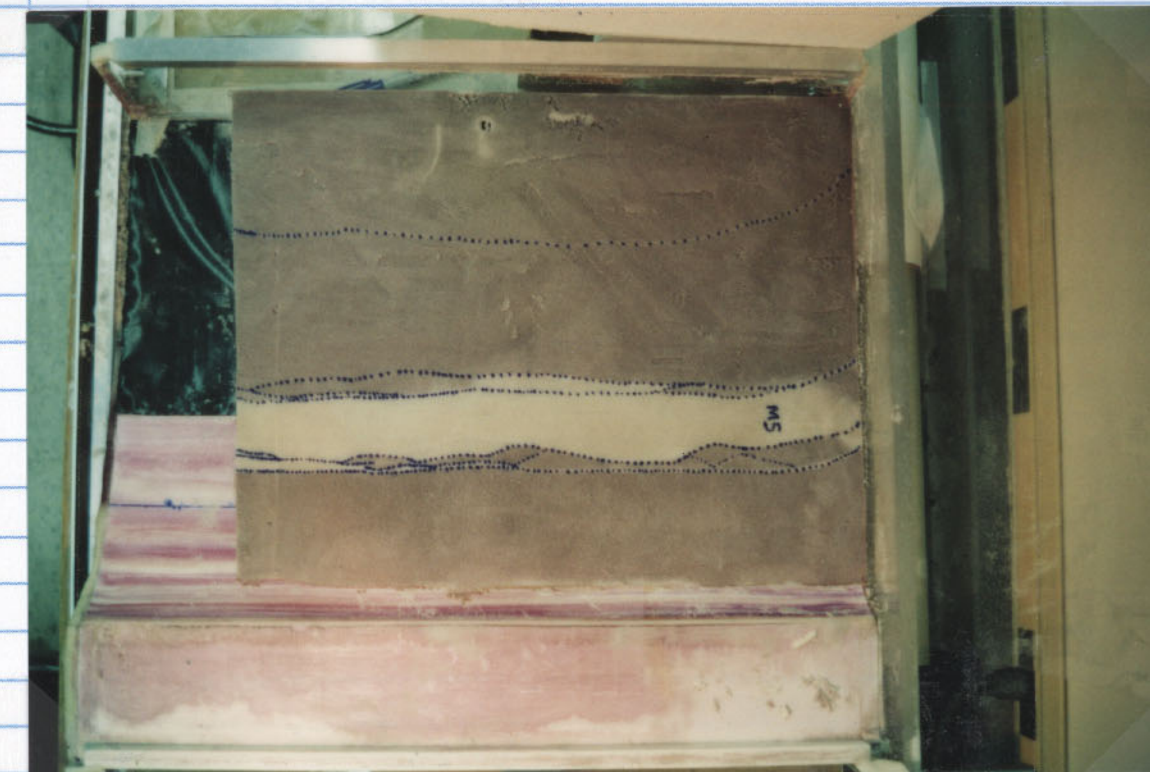
Model V.5, Run #7

Model V.5, Run #8

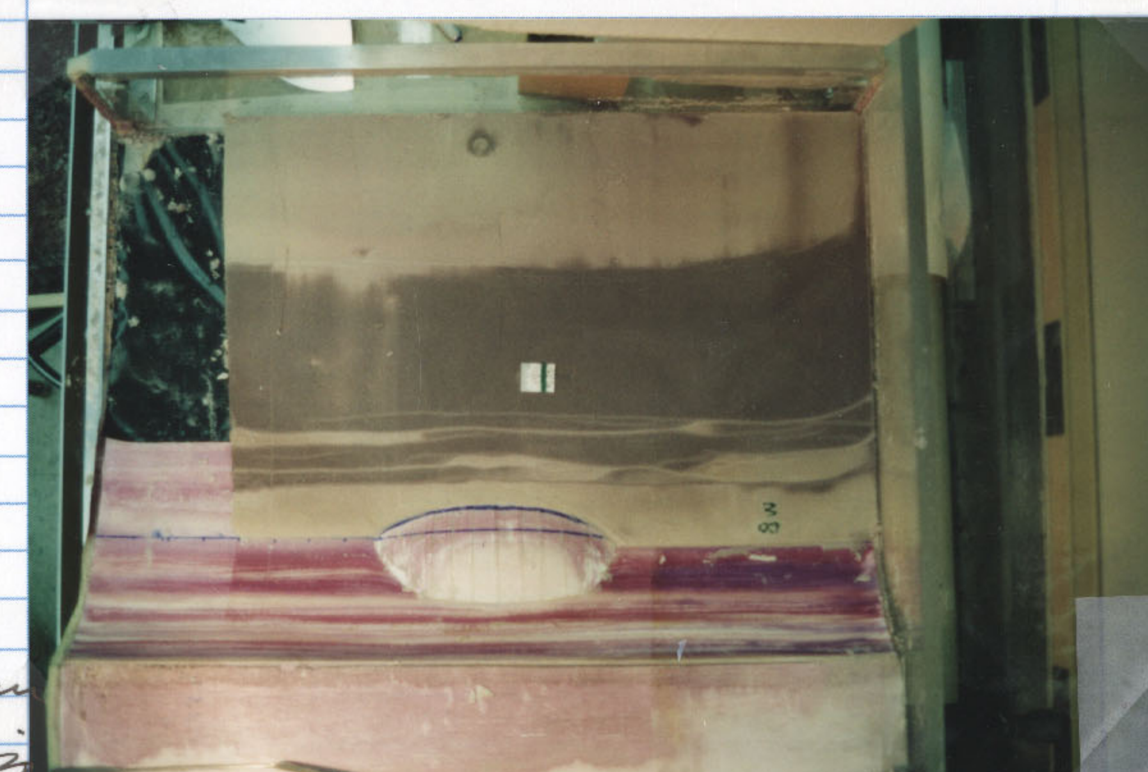
Alan Massi



HORIZONTAL SECTIONS



Alan Massi



Alan Massi

APRIL 1994

Alan Morris Alan Morris

Model Run #9

Run #9 was designed as a cylindrical geometry fault model. This was done in order to investigate results of cylindrical versus non-cylindrical model runs when all parameters except the footwall discontinuity were the same. In this run the decollement sheet was located in the same position as in the non-cylindrical runs, sand was the same (O.K. #1), in addition all other aspects of the model run were identical to runs 7 and 8.

Results:

- Fault geometries were still very complex.
- Fault geometries were almost identical to non-cylindrical geometries.
- The only significant difference in geometry consist of apparently fewer antithetic fault splays in this run. The antithetic splays here are limited to one dominant splay, with a antithetic "transfer zone" located in the middle of the model.

Thoughts:

- It is now quite obvious the plastic sheet decollement is controlling the dynamics of the model.
- This indicates a need for development of some other type of detachment surface in the model.

Possible solutions:

- Use Dow-Corning SGM 36 as a detachment
- See notes of 4/24/94. pg. 41

MODEL RUN #9
CYLINDRICAL GEOMETRY

Photos. pgs 39 & 40

Alan Morris

Notes 4/24/94

Sand behavior in the model

After reading through and thinking about the scaling aspects of modeling, I think that the flour added to the sand may be the way to go after all. Upon examination of the photos from run #4, (the sand flour run) the fault scarps are not that unrealistic, at a length ratio of 10^{-5} the fault scarps are only about 4000 feet high. While this may be unrealistic, it is closer than what I previously thought. The thing that is a bit disturbing is the shape of the fault scarps, i.e. near 90 degree angles on them. I believe however that if the new sand were combined with flour, at some reasonable ratio, and tested for cohesion values by doing an angle of repose test, combined with a cohesion test using the testing device at values that are measurable it may turn out to be justifiable.

Other thoughts include trying to modify the model such that it represents a smaller area (SCALE CHANGE). The result here being if we change lambda to something an couple of orders of magnitude larger, then we may be able to use significantly different values for cohesion with the most interesting thing being that those values would still have Hubberts sanction.

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(This is a PARTIAL list of reference material on hand)
(papers with a check-mark in the margin have been read and are)
(relevant to the thesis project)

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Twiss & Moores

SAND COHESION TESTS
5/3/94

Using angle of repose and scarp height tests, a sand/flour mixture was sought out with that would have the correct properties for the model. Several mixtures were tested ranging from 100% sand to 100% flour, with values incremented by 10% between the two end members. The results indicated that a mixture of 20% flour and 80% sand used for model run #10.

MODEL RUN #10
20% FLOUR 80% O.K. #1 SAND
5/4/94

Cylindrical geometry with no detachment surface (in order to see if slippage will occur along the footwall without inducement from an artificial detachment surface).

Results: Graben formation at "toe" of footwall at point where hangingwall was active. In summary the results were not ~~different~~ significantly different from previous runs using O.K. #1 sand with no flour added. Exceptions to the above statement relate to scarp heights, they were far too large, i.e. out of scale (at 2-2.5 Km high when multiplied by the scale factor for the model).

Alan Moore

PHOTOS OF ABOVE WERE TAKEN, BUT not developed due to results of model run w/ the 80%-20% mixture.

MODEL DESIGN CHANGES DUE TO RESULTS OF SAND TESTING
5/5/94 - 5/20/94

Based on the multiple attempts at obtaining variable fault geometries, and initiation of listric faults without use of an "induced" or artificial detachment layer (over both cylindrical and non-cylindrical surfaces) the basic function the modeling apparatus was changed to accommodate a viscous substrate. The design change occurred in two stages. The first stage made use of a passive footwall design with honey as a viscous layer at the base, and sand as a brittle layer above. The result of this experiment was useful- in the sense that flaws with the gasket design for the model revealed themselves immediately.

As a result of the first modification the modeling apparatus was redesigned. The second version incorporated an active footwall and a much better gasket system. The results of this model design are far better than expected. This model version is referred to in the notes as 5B.

Model version 5B run #1

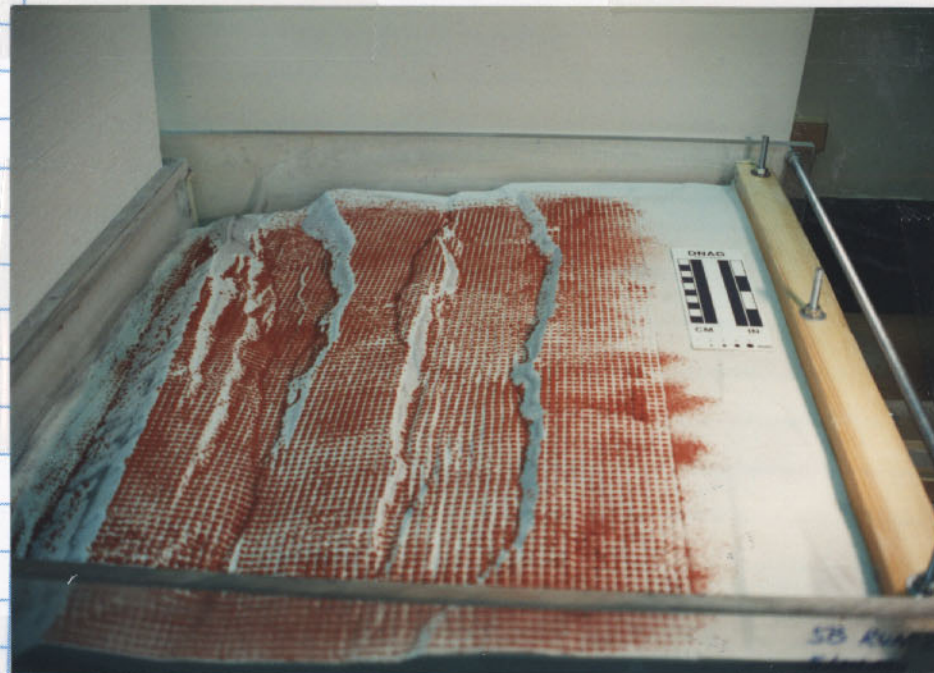
The result of this run revealed a problem at the honey / sand interface. The top of the honey layer was coated with a layer a fairly strong gelatin and allowed to congeal. After congealing the sand layers were added to the model. The end result was over-pressuring the lower layers (primarily the gelatin layer) which allowed diapiric breakthroughs to occur in the sand layers. This was quite interesting but not the desired result. As a result the modeling apparatus was kept the same with only a change in media for the next run.

Model version 5B run #2

The interface layer was coated with a stronger material that would alleviate breakthrough yet still provide a gradual strength change between the lowermost and uppermost layers of the model. In addition the new interface material appears to be within the scale requirements for strength.

Media changes resulted in the most spectacular, and geologically reasonable model results to date. Results of this run include concave up, concave down, and approximately planar fault geometries. Even more interesting it appears that some fault reactivation and cut-off did occur in the model. This modeling media, and apparatus arrangement appears to provide geologically reasonable, easily reproducible results. Other attractive features of this version is the relative ease with which the footwall may be changed both geometrically and dynamically.

SEE photographs pg. 46 & 47.



MODEL VERSION 5B
Run # 2
(ACTIVE FOOTWALL + non-cylindrical FW geom.)

Pages 1 through 47 of this Scientific Notebook were reviewed for compliance with QAP-001 in response to Corrective Action Request 94-02. Corrections and clarifications were made as appropriate. In some cases, the date of a change will reflect the date of this review rather than the date of the original Scientific Notebook entry. Randy Folck

SwRI - QA

12/02/94

I HAVE REVIEWED THIS SCIENTIFIC NOTEBOOK AND FIND IT IN GENERAL COMPLIANCE WITH QAP-001 AND THERE IS SUFFICIENT TECHNICAL INFORMATION SO THAT ANOTHER QUALIFIED INDIVIDUAL COULD REPEAT THE ACTIVITY

H. Lawrence McKague

9/21/97