DAHE

Scientific Notebook No. 141: Deformation Rig Plans, Materials, and Construction Details (07/11/1995 through 02/06/1997)

THE GEOLOGICAL SOCIETY OF AMERICA · 1888 ·

Bret Lake

CNWRA
CONTROLLED
COPY 141

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# Reference Disk

Disk for Page 1 of Scientific Notebook #141 was removed from its pocket during the scanning process, was misplaced, and cannot be located.

| Date | Scientist Making Update | Comments |
|---|---|---|
| 1. 6/27/95 | Bret Rahe | Initial transfer of Ref. list |
| 2. 8/11/95 | Bret Rahe | Addition References Added |
| 3. 12/19/95 | Bret Rahe | More updating of Ref. List |
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| 70. | | |

Brett Rahe
July 11, 1995

- The deformation table was designed by Bruno Vendeville from the Bureau of Economic Geology, Austin Texas.

Bruno Vendeville
Applied Geodynamics Laboratory
University Station, Box X
Austin, TX, 78713-8924

(512)471-1534
Fax: (512)471-0140
E-Mail: vendevillb@begv.beg.utexas.edu

- The following pages show all of the parts needed for the construction of the analogue modeling deformation frame and box and are from a series of faxes and drawings sent from B. Vendeville to David Ferrill (of the CNWRA). The deformation frame is the support for the deformation box. The deformation box is the portion of the unit which will deform the layered sand and silicone putty.

- The analogue modeling apparatus will be able to simulate a variety of structural deformation styles to include extension, strike-slip, transpressional, and transtensional situations.

DEF FRAME PLANS

*Mailing Address:*
University Station, Box X
Austin, Texas 78713-7508

*Delivery Address:*
10100 Burnet Road
Austin, Texas 78758-4497

Telephone: 512-471-7721 • Direct line:512-471-8334 • Telefax: 512-471-0140

*Date:* 03 02 1994

*To:* Dr. David Ferrill

*From:* Bruno Vendeville

*Affiliation:* SRI

*FAX:* (210) 522 5155

*Number of pages after this page:* 9

---

Hi David,

Here is the first part of the plans. These are for the deformation rig. The plans for the box itself will come tomorrow.

Here are a few things to indicate about the enclosed plans:

All the frame is made of 2 in x 2 in bars made of regular iron (to be painted after construction of the frame). All the bars need to be drilled every 2 inches so that we can insert screws, size 1/4 (allowing to add bars in the middle of the rig at the desired location). The small and large bars to be inserted also need to be drilled every 2 inches. The holes must be aligned with the corresponding holes in the main frame.

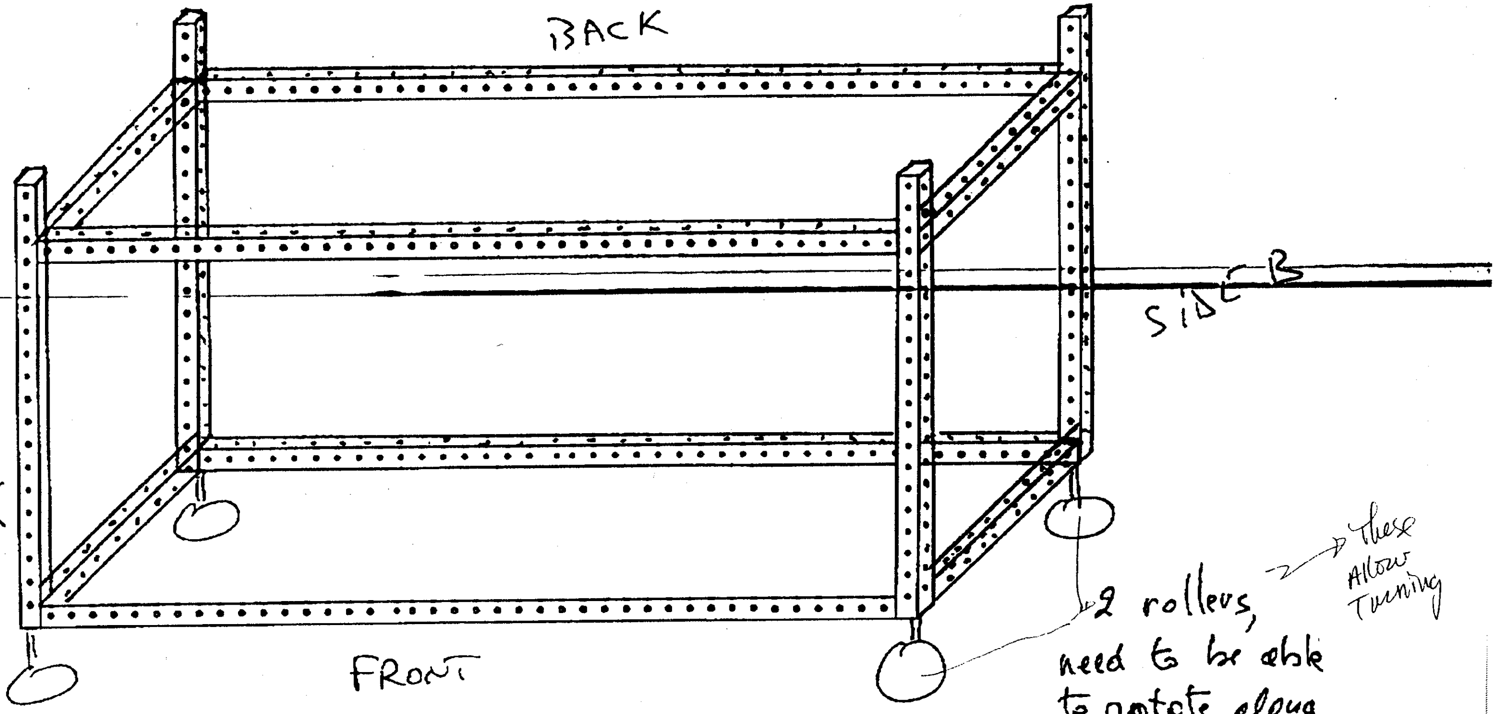
I suggest to give my telephone + fax number to which the machine shop you'll be asking for bids -

More to come tomorrow,

Bruno

# GENERAL VIEW

1



SIDE
A
2 rollers.
rotation
long
rtical
xis.
o
BRAKES

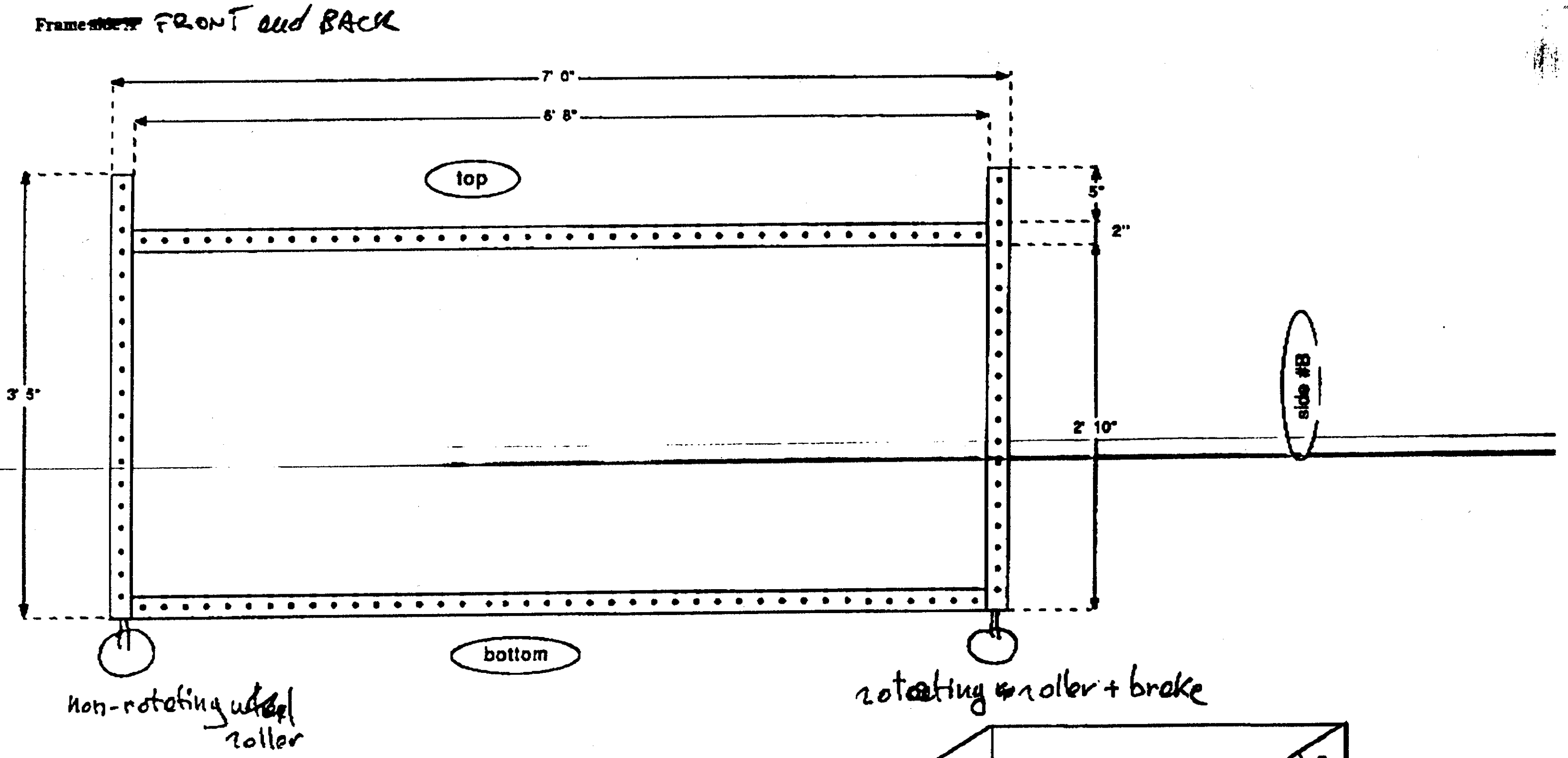
2 rollers, need to be able to rotate along vertical axis + BRAKES

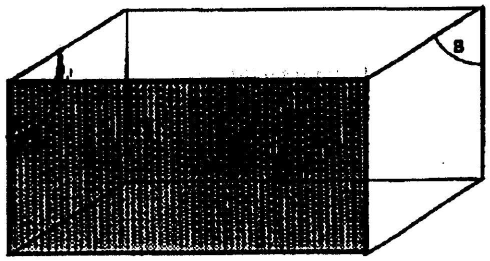
These Allow Turning

Side View

2

Frame ~~side #~~ FRONT and BACK





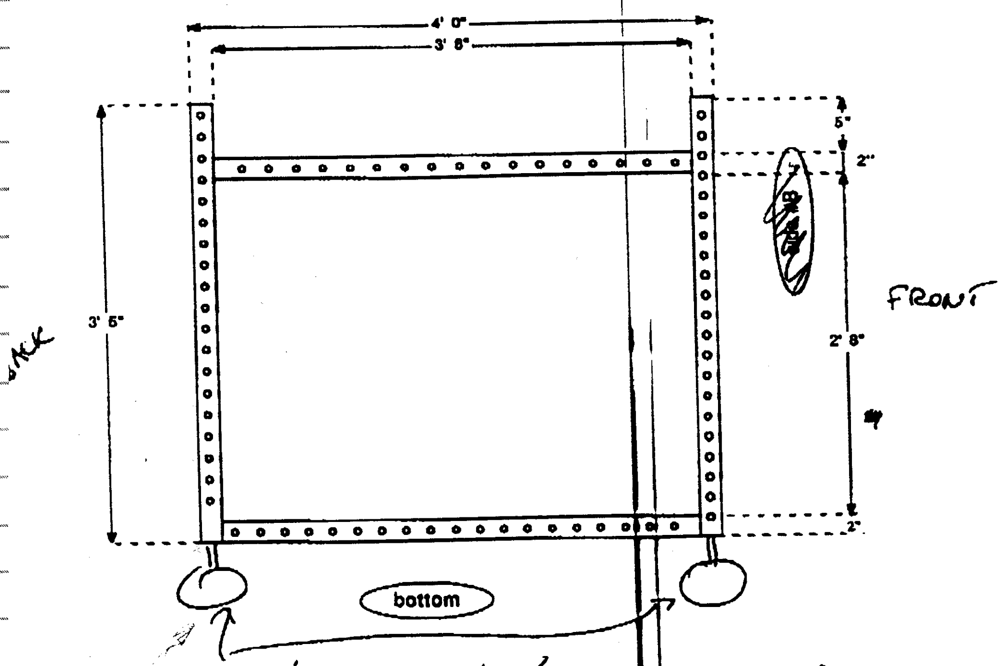
LOCATION

**Frame side A**

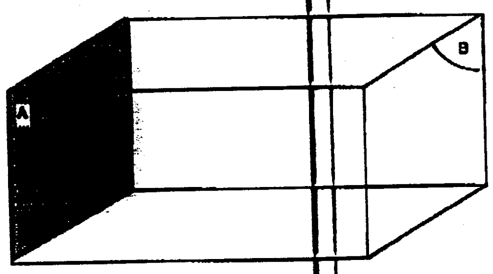
top

frame3

Head-On View



~~hou rotatrng~~ rollers (with ~~co~~ no brakes)
non-rotating



LOCATION

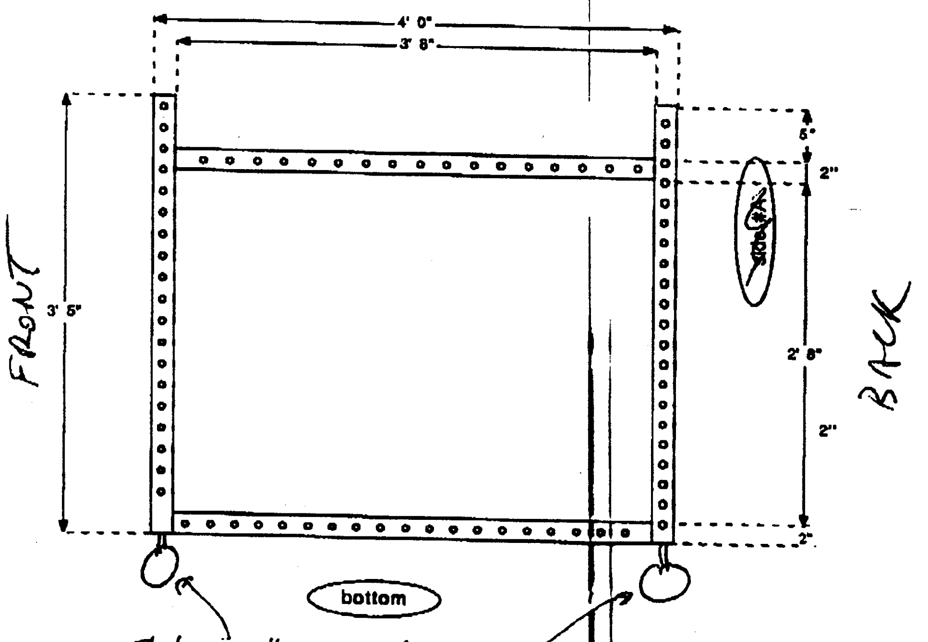
W.

8

**Frame side B**

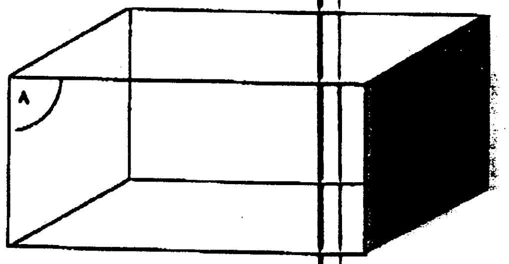
top

frame3



~~Rotating~~ Rollers ~~with brakes~~ ~~(No brakes)~~

Rotating Rollers with brakes

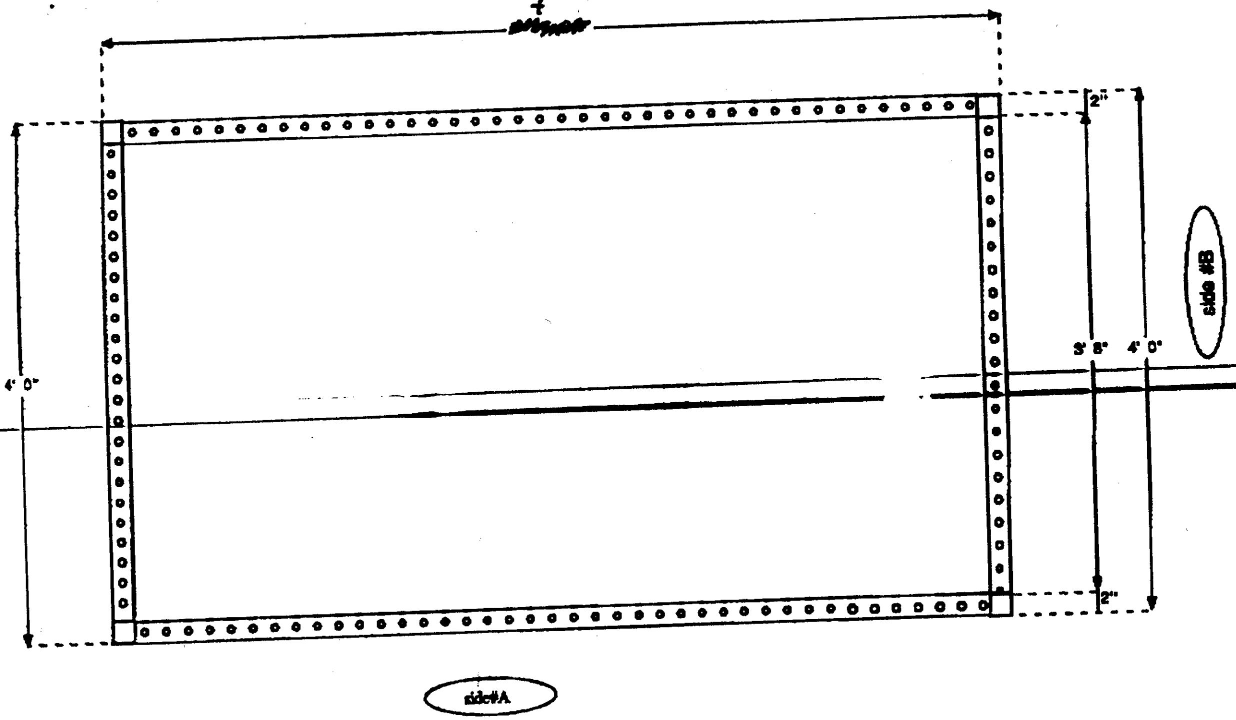


LOCATION

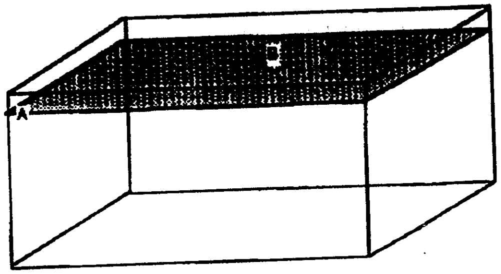
frame6

**Frame: top section**

Top View



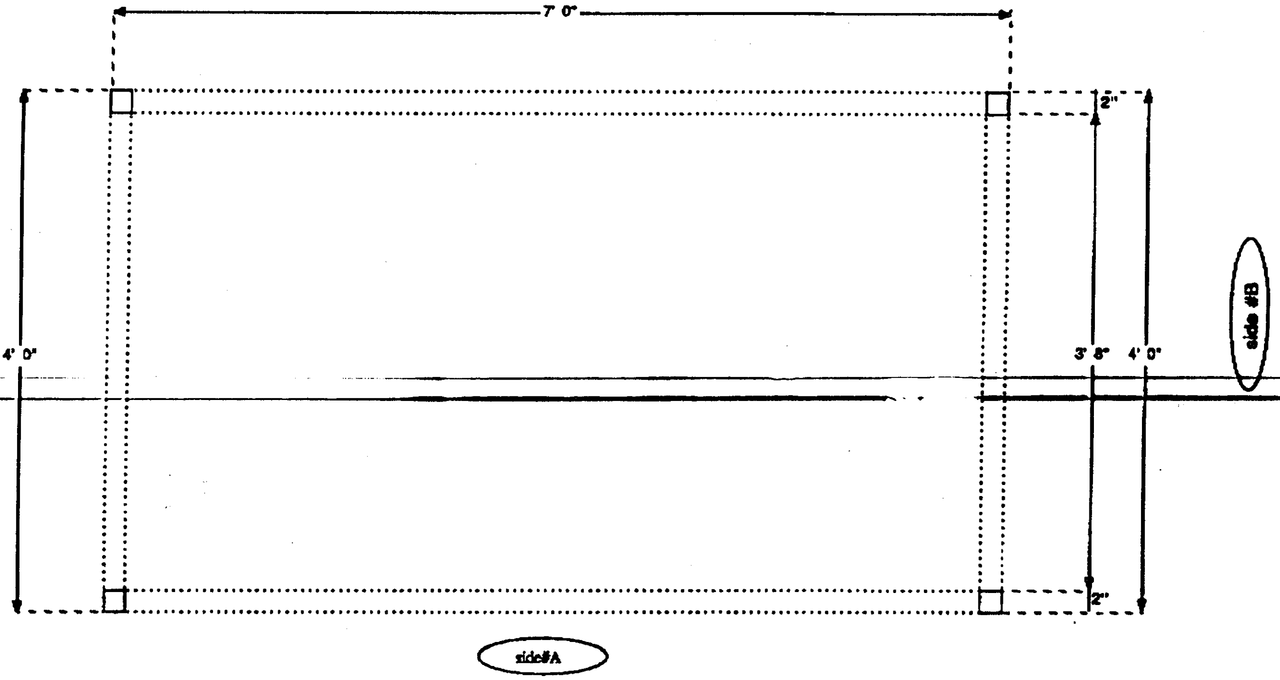
LOCATION

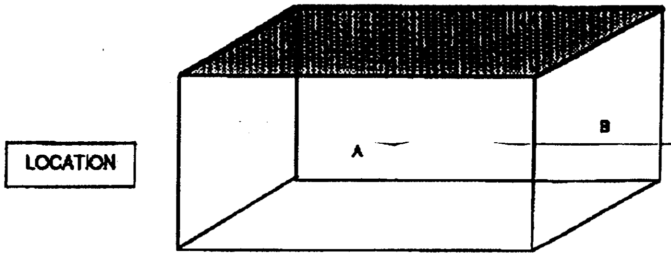


6

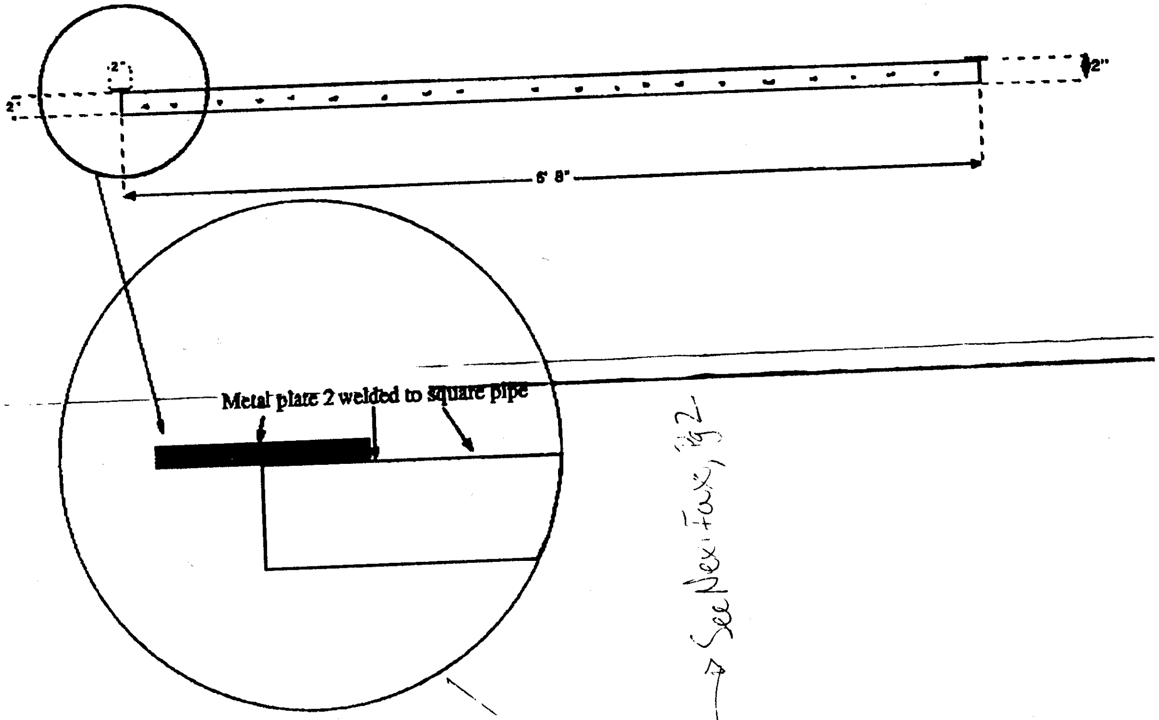
**Frame: top section**

Very top view





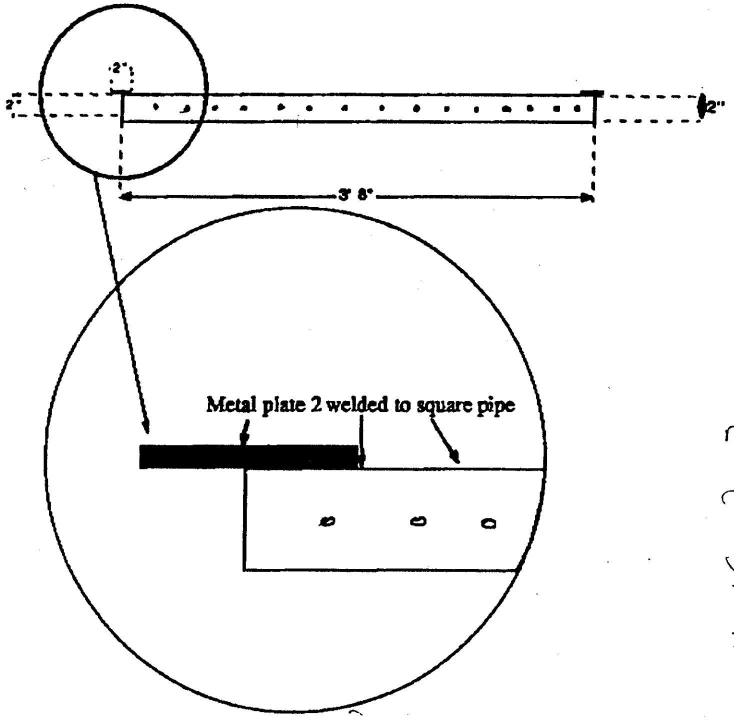
**Frame: large bars**



See Next Fax, fig 2

8

**Frame: small bars**

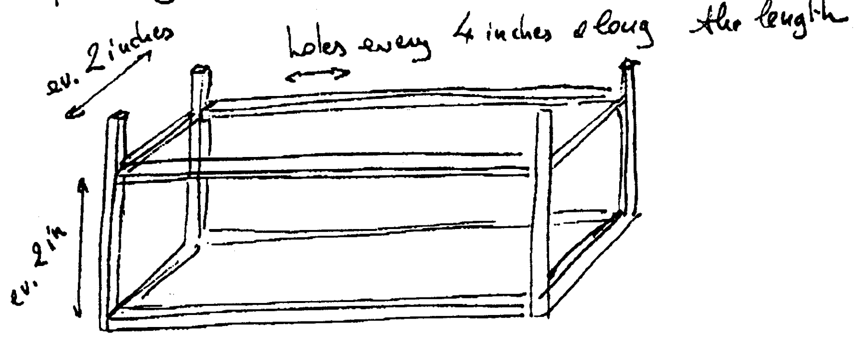


See Next Fax, Page 2

holes must be aligned with holes along the frame width.

## Additional note about the frame:

The spacing of the holes can be changed to the following:



The main frame needs to be welded, then the points of welding must be milled to provide a flat surface.

The additional bars (last two drawings of yesterday's fax, called "small bars" and "large bars") are built so that you can place them along the width, height, or length of the model.

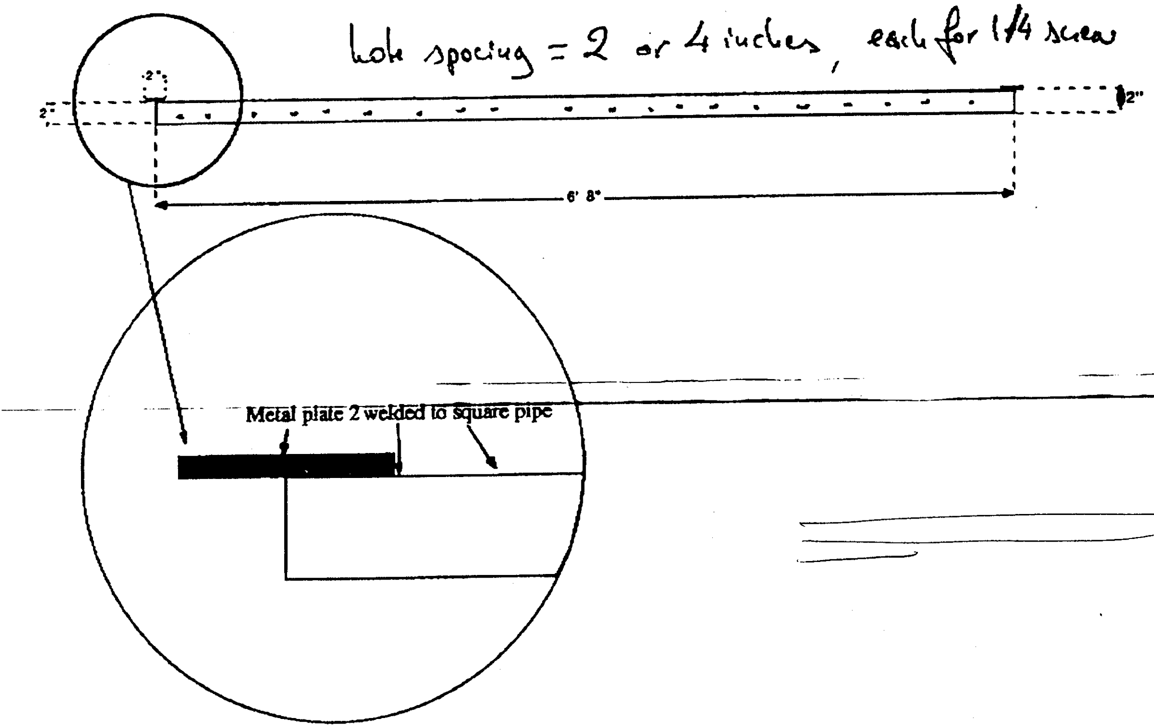
I'm enclosing a new version for them (new lengths ~~[illegible]~~ are 2'8", 3'8", and 6'8".

Number of 2'8" bars : 6
______ 3'8" — : 6
______ 6'8" — : 2

7 3

**Frame: large bars** 2eeh

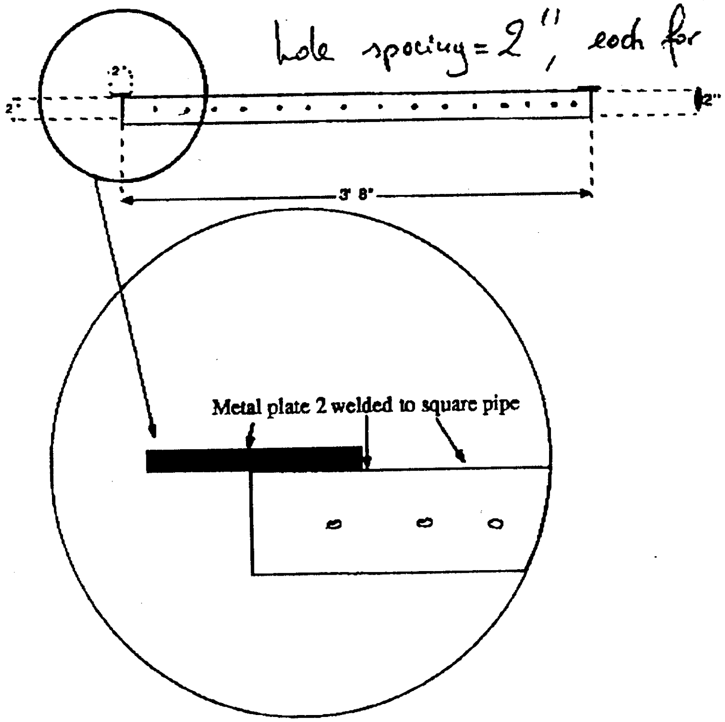
hole spocing = 2 or 4 inches, each for 1/4 sucw



8 ~

**Frame: ~~small~~ medium bars** 6 each

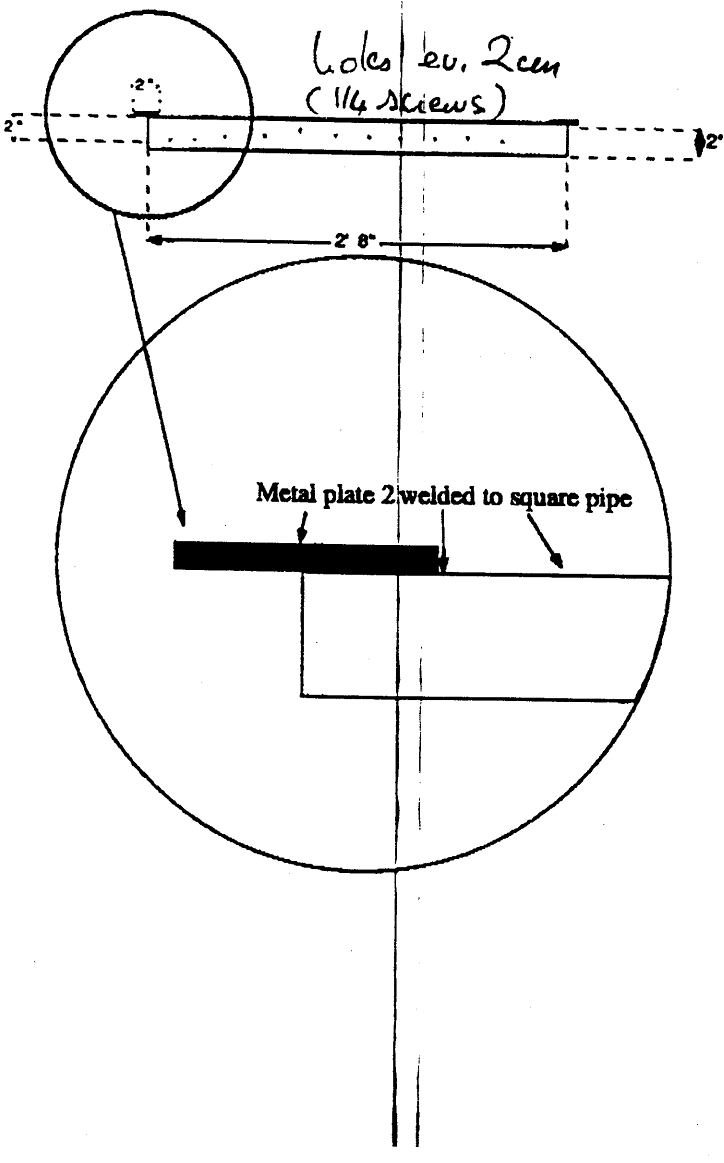
hole spacing = 2", each for 1/4 screws



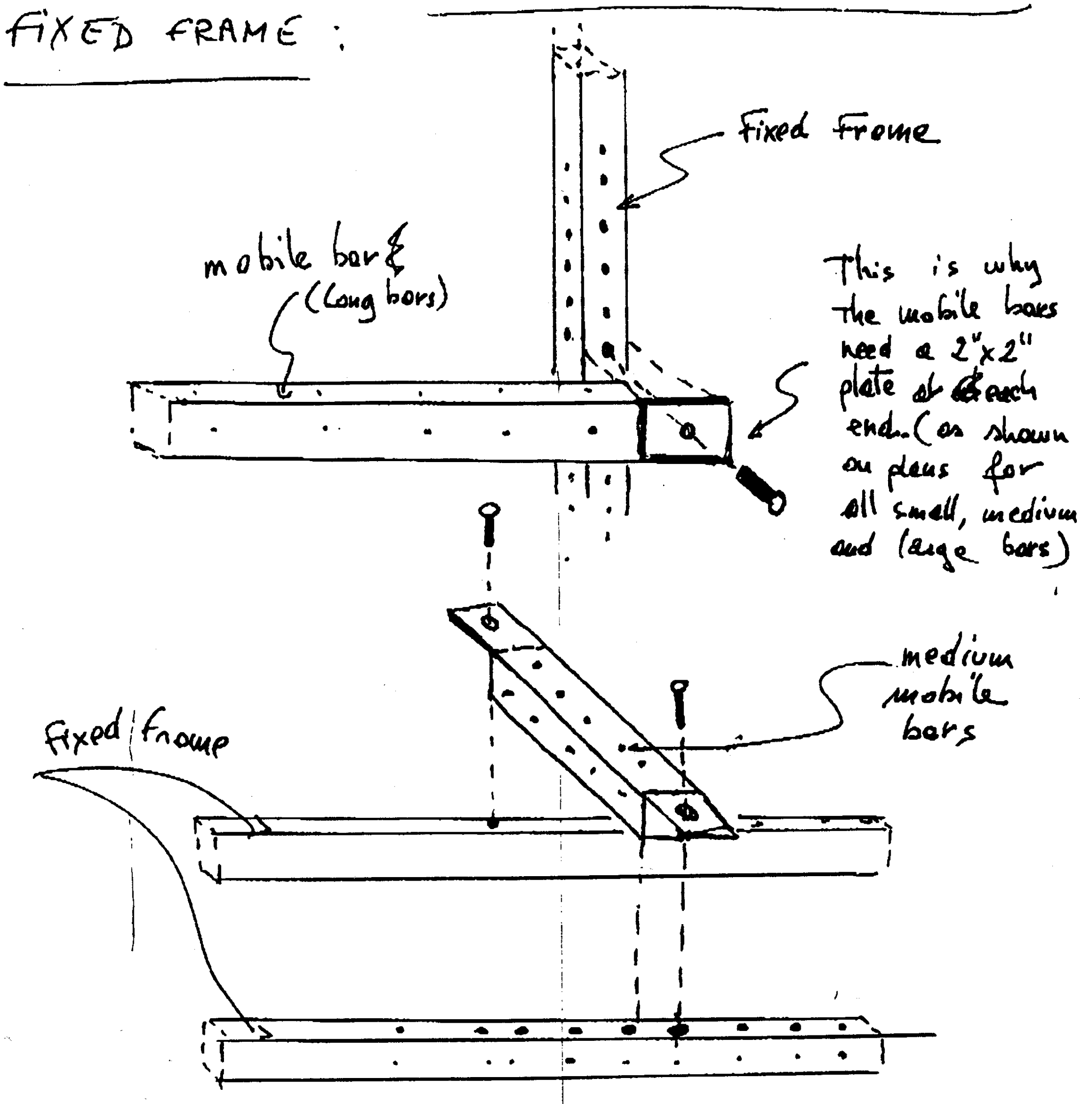
holes must be aligned with holes along the frame width.

small bars

6 each

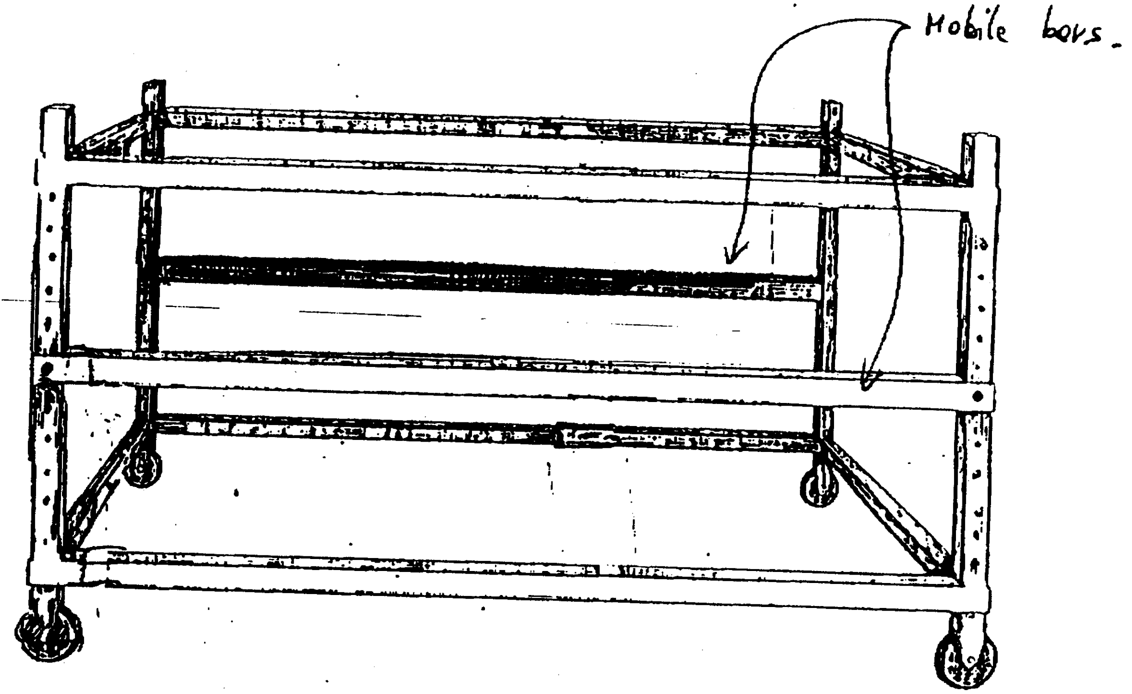


# TWO EXAMPLES ILLUSTRATING HOW THE MOBILE BARS ARE ATTACHED TO THE FIXED FRAME :

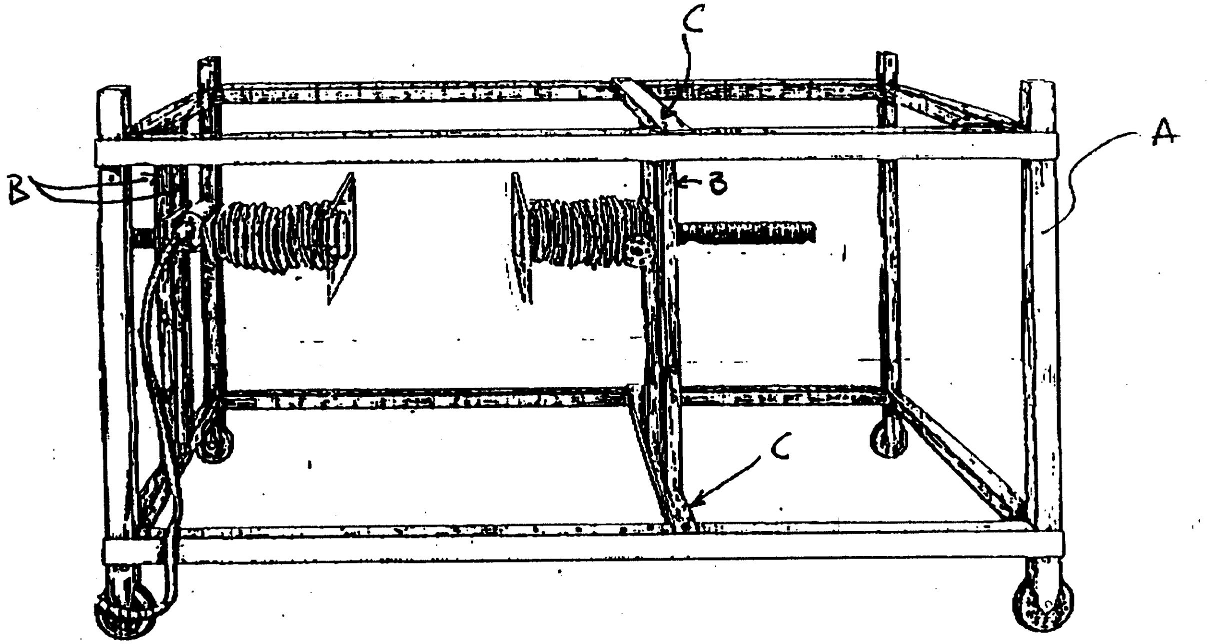


This is why the mobile bars need a 2"x2" plate at each end. (as shown on plans for all small, medium and large bars)

Fixed parts + 2, long mobile bars
attached on the sides.



Example with Fixed rig (A) + 4 ~~intermediate~~ medium mobile bars (B) and two small mobile bars (C)



UT B.E.G. ID:5124719800 DEC 23'94 14:53 No.006 P.01

Def. BOX PLANS

Bureau of Economic Geology

BUREAU OF ECONOMIC GEOLOGY
The University of Texas at Austin
University Station, Box X
Austin, TX 78713-7508
(512) 471-1534 or 471-7721
FAX (512) 471-0140

DATE: December 23, 94
TO: DAVID FERRILL
FROM: Vendeville
FAX #:
# of pages (including this cover page): 17

**MESSAGE**

Hi DAVID,

Enclosed are a few more comments about the frame, and the plans for the deformation Box.

Send me a fax if you have any questions. I'll be here Tuesday til FRIDAY.

Bruno

The deformation box comprises two main parts:

① - one part will remain attached to the moving screwjacks (6 Screw-jack fixed plates, and 6 Screw-jack sliding plates)

② - The other part comprises various plates forming the actual deformation box (4 Plates A, 2 Plates B1, 2 Plates B2, 2 Plate C1, 2 Plates C2). Plates B1 or B2 are connected to linear ball bearing, encased by an attachment block (8 each), itself bolt to Plates D (4 each). Plate D can be bolt to the Screw-jack sliding plate.

Total number of part:

| | | |
|---|---|---|
| - Screwjack fixed plates: | 6 | |
| - Screwjack sliding plates: | 6 | |
| - Plates A: | 4 | |
| - Plates B1: | 2 | |
| - Plates B2: | 2 | |
| - Plates C1:<br>(Plates C1 also include two 20"-long stainless-steel rods and two 20"-long wedge bars per plate. Total number of 20"-long rods: 4; Total number of 20"-wedge bars: 4) | 2 | |
| - Plates C2:<br>(Plates C2 also include two 40"-long stainless-steel rods and two 40"-long wedge bars per plate. Total number of 40"-long rods: 4; Total number of 40"-wedge bars: 4) | 2 | |
| - Attachment blocks (casing for linear ball bearings): | 8 | 4 on C1, |
| - Linear Ball Bearings: | 8 | 4 on C2 |
| - Waterproof Marine Plywood (Dimensions?) | 1 | |
| - 3 feet x 5 feet, 1/16"-thick aluminum plate (= base for the box) | 1 | |
| Total number of parts: | 41 | |

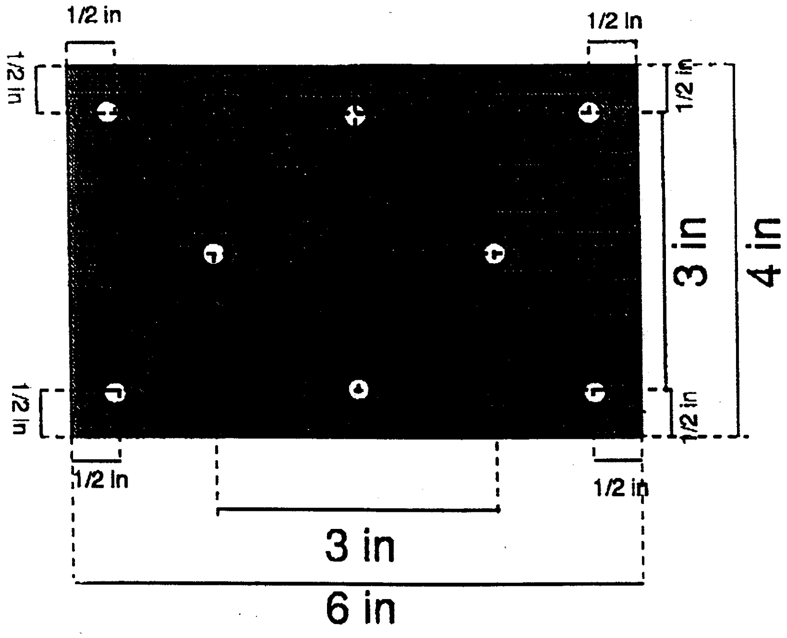
Please feel free to contact me if you have any questions:
Bruno Vendeville
Bureau of Economic Geology

Work phone: (512) 471 8334
Work Fax: (512) 471 9800
Answering message (home): (512) 476 4677

6

# Screw-jack fixed plate

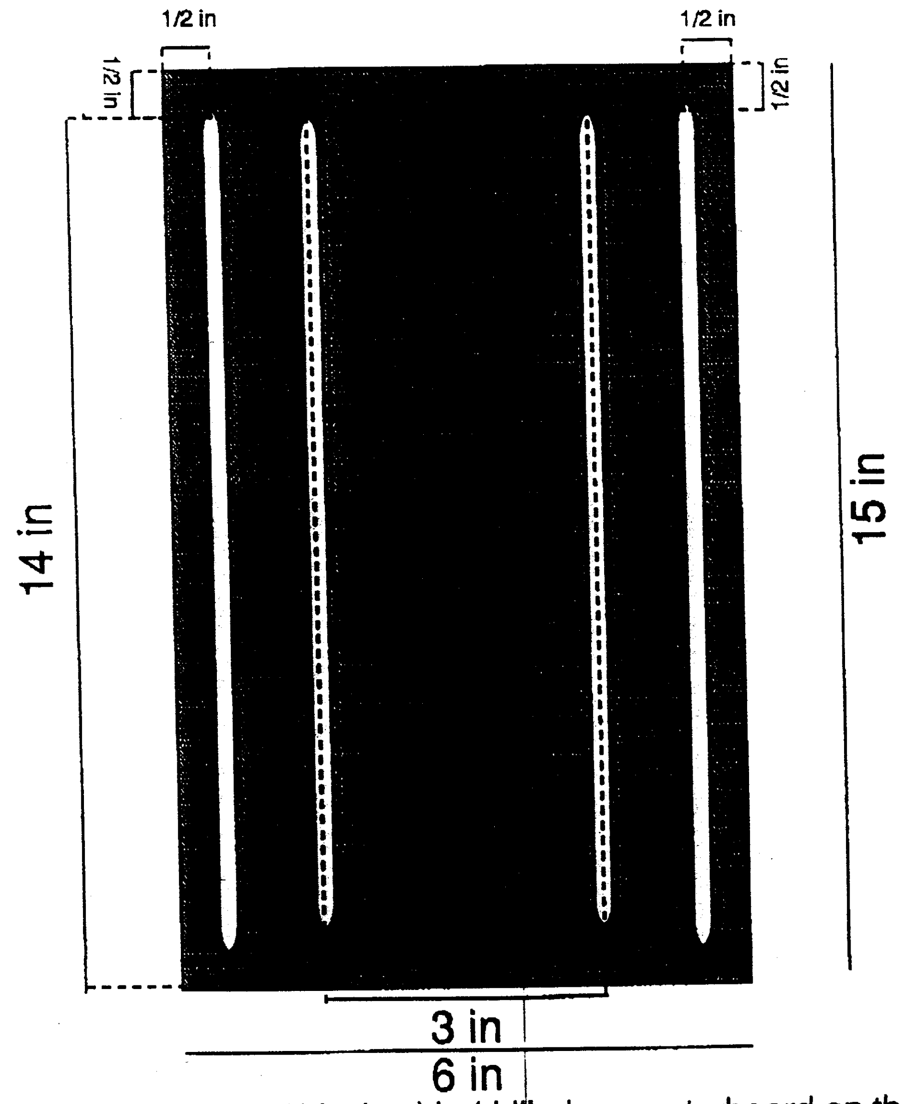
Aluminum, 1/2inch-thick.
6 each



○ Drilled for 1/4-20 bolts

◯ Drilled and counterbo~~ard~~red (on this side) for 1/4-20 cap-screws

Screw-jack sliding plate (6 each)
Aluminum, 3/4 inch-thick



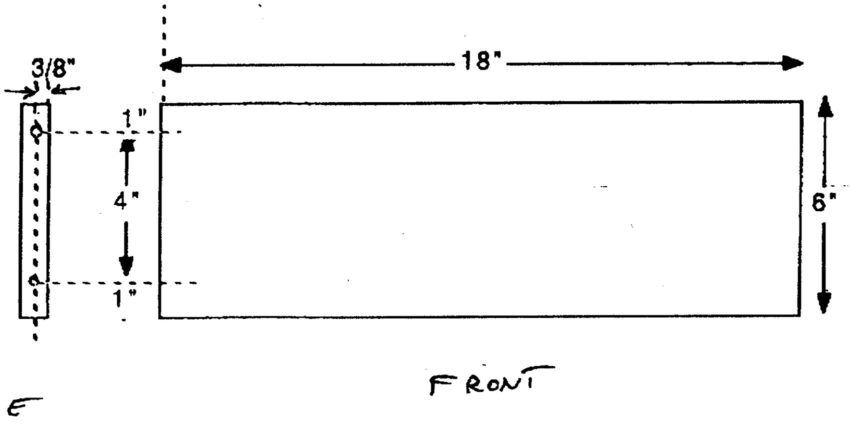
Two long slots 1/4 inch-wide (drilled + counterboard on this side)
Two short slots 1/4 inch-wide (drilled + counterboard on the **other** side)

8

10

**Box, Plate A**

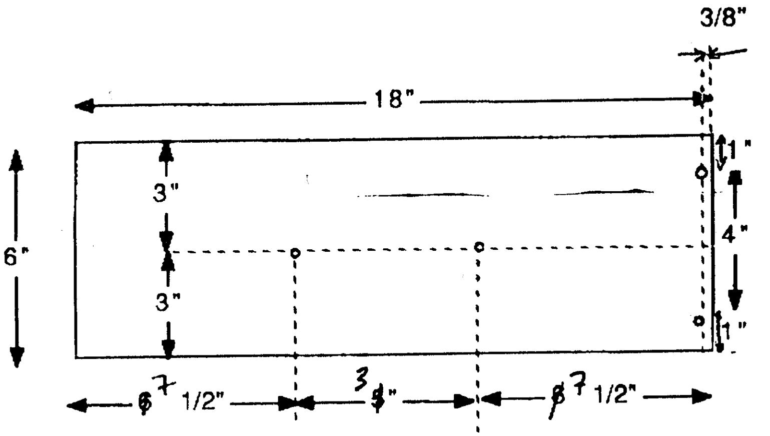
3/4" thick aluminum 4 each



All holes drilled and tapped for 1/4-20 cap screws

**Box, Plate B1**

3/4" thick aluminum 2 each

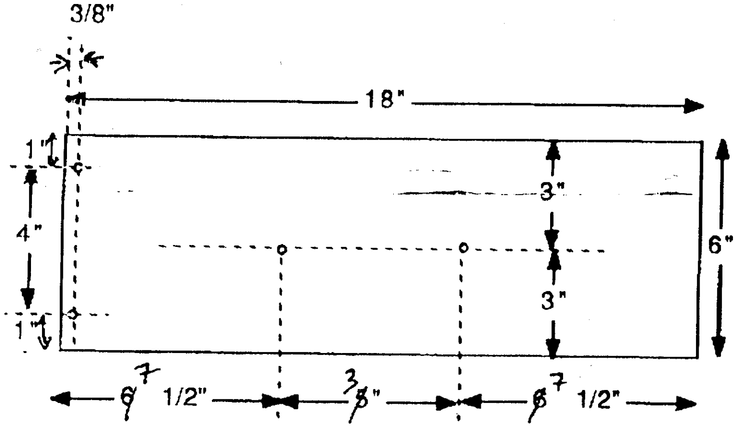


All holes drilled and counterboard (on this side) for 1/4-20 cap screws

21

**Box, Plate B2**

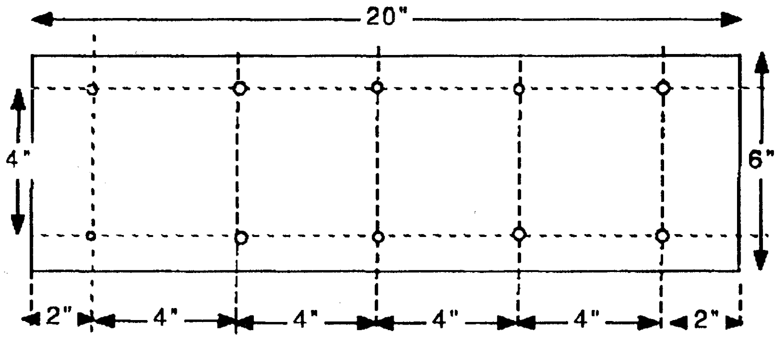
3/4" thick aluminum 2 each



All holes drilled and counterboard (on this side) for 1/4-20 cap screws

**Box, Plate C1**

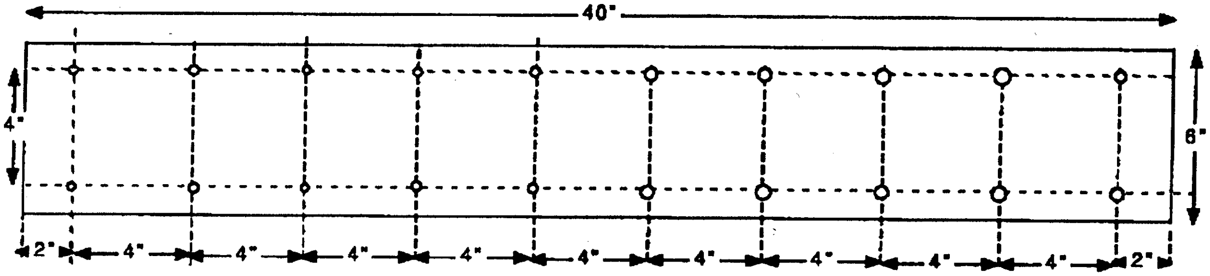
1" thick aluminum 2 each



All holes drilled (not tapped) and counterboard (on this side) for 10-32 cap screws

**Box, Plate C2**

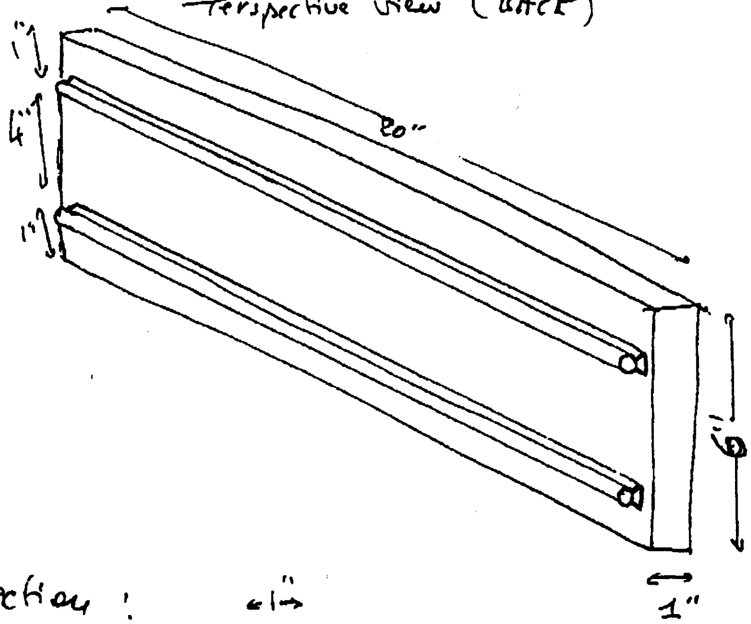
1" thick stainless steel 2 each



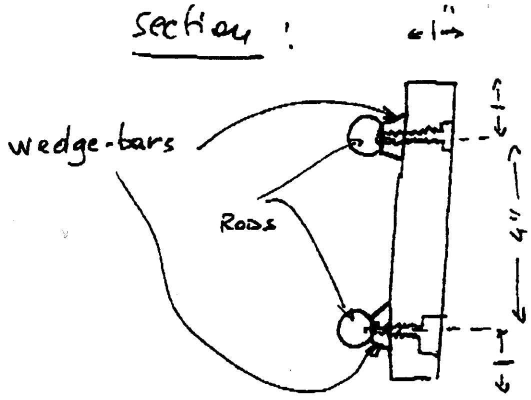
All holes drilled (not tapped) and counterboard (on this side) for 10-32 cap screws

Plate C1

Perspective view (BACK)

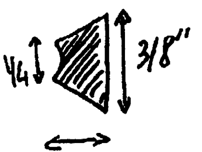


section :



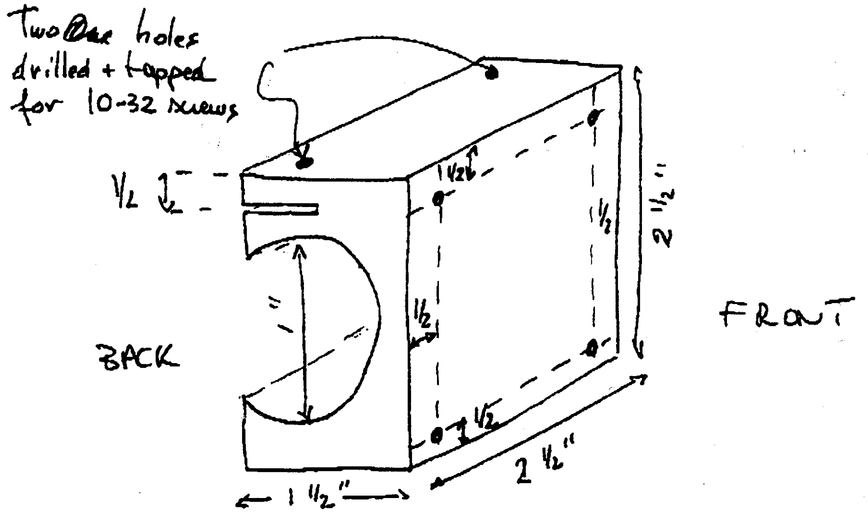
Rods are tapped for screws

2 stainless steel rods, each 20" long, 5/8" diameter,

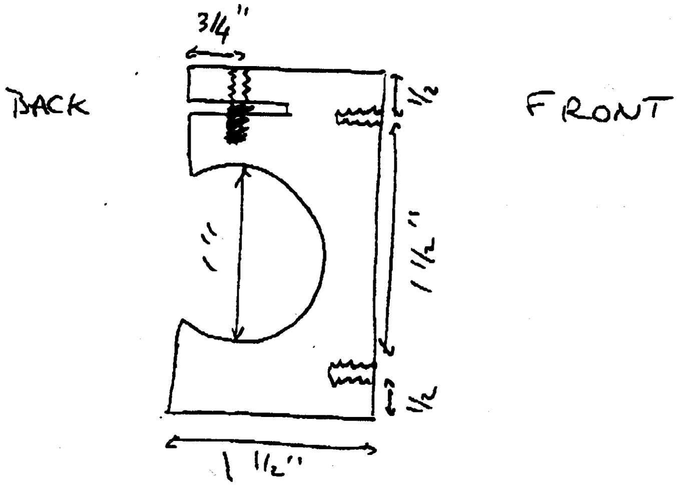
attached to two wedge bars (20" long ; 1/4  3/8" )

Both rods + wedge bars drilled + tapped to be attached to plate C1

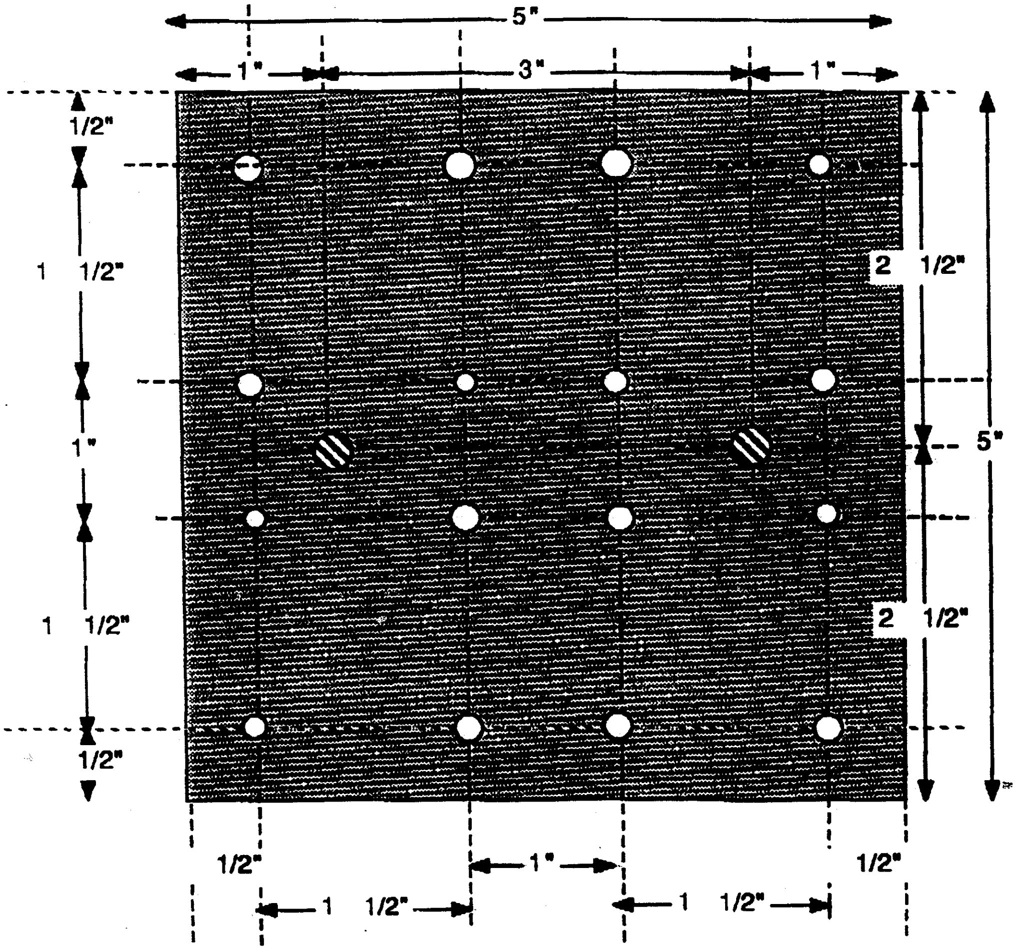
ATTACHMENT BLOCK (8 each).
= CASING FOR LINEAR BALL BEARINGS
Steinless Steel.



Section



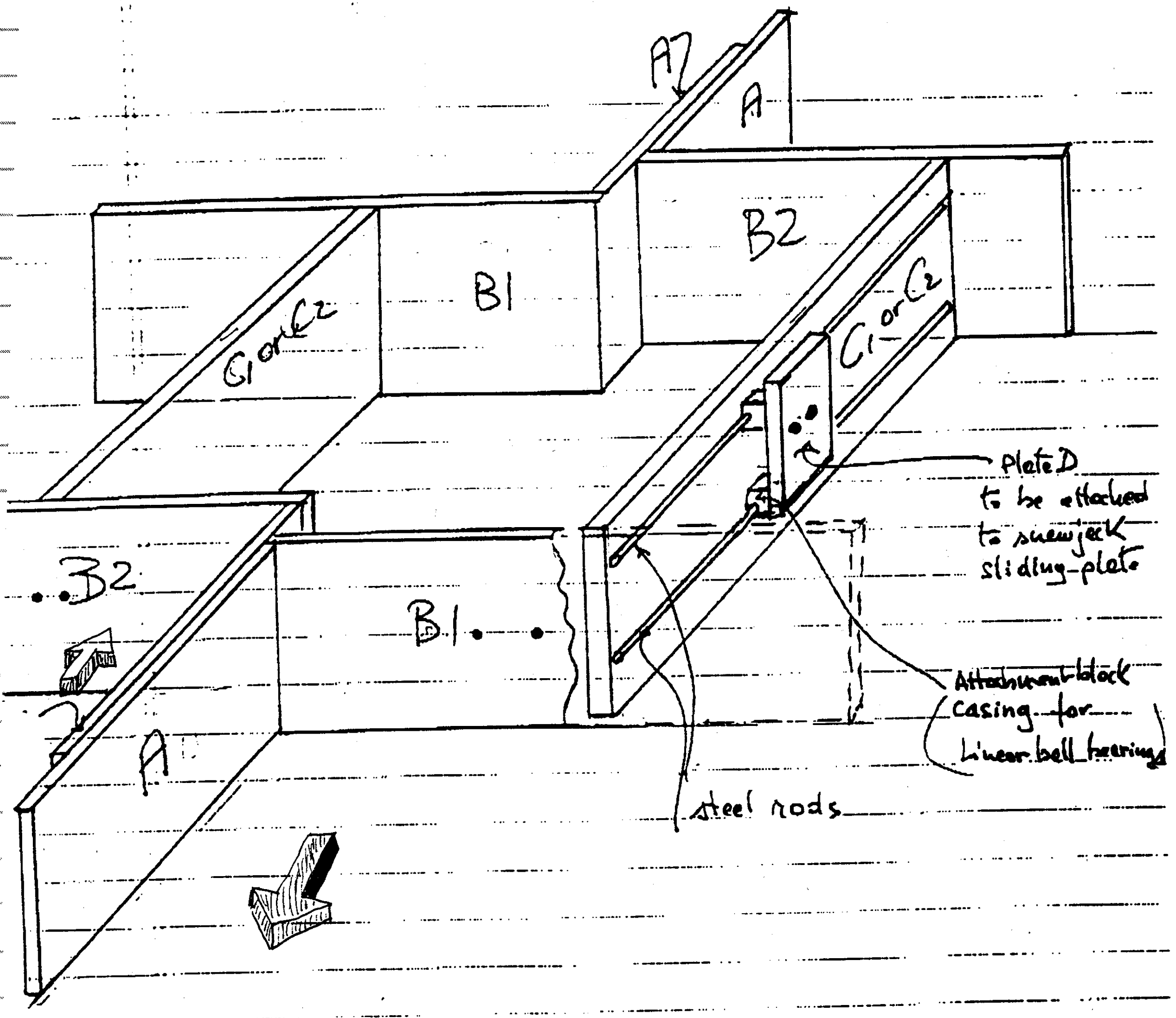
## Box, Plate D
4 each, 1/2 inch thick aluminum

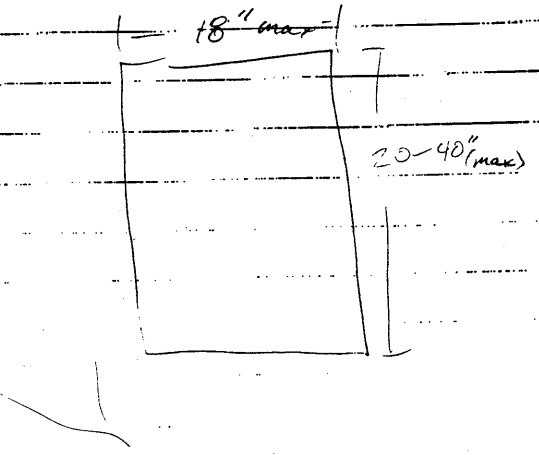


○ 16 holes drilled, not tapped,
and counterboard (on this side) for 10-32 cap screws

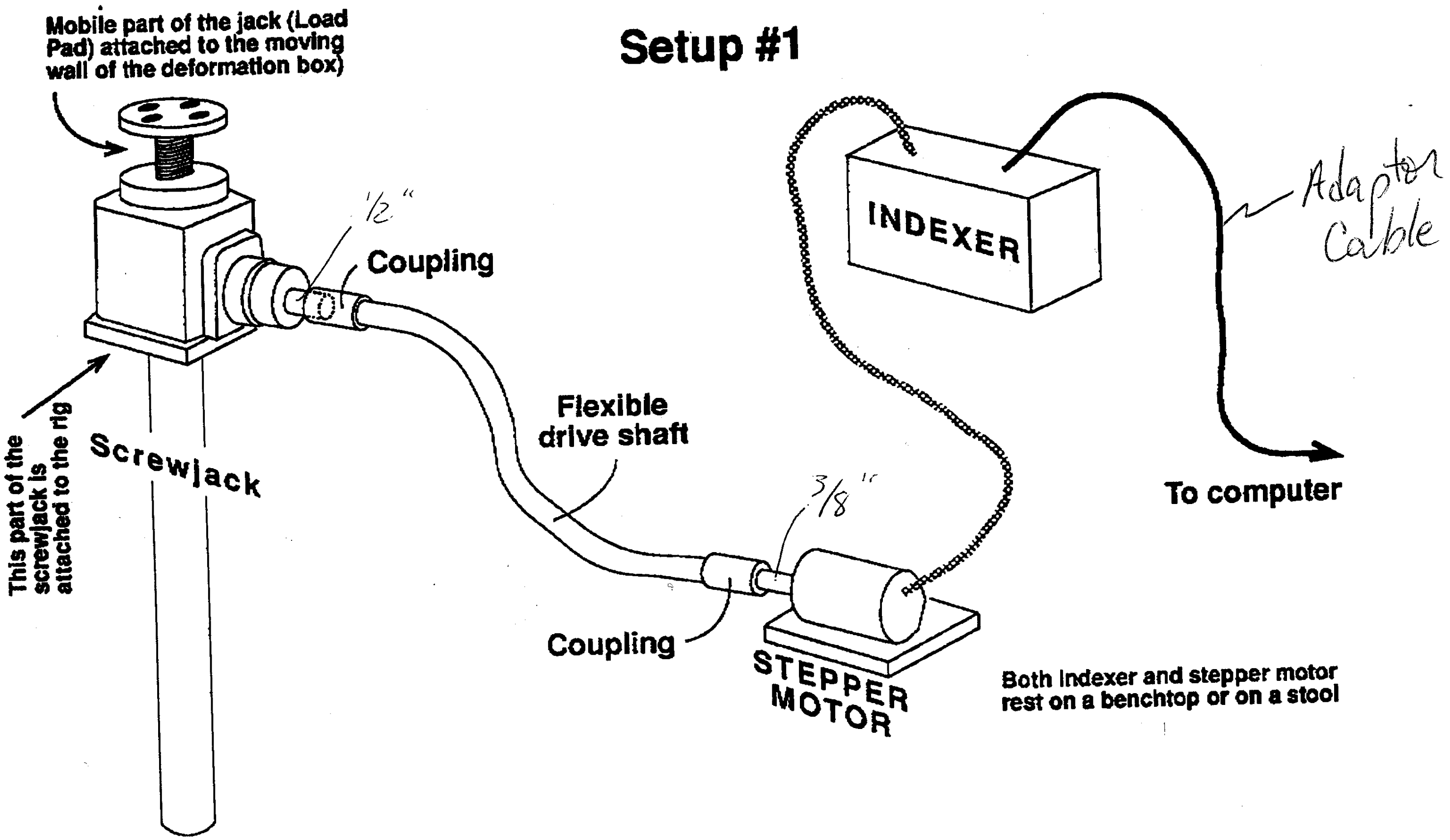
▨ 2 holes drilled, not tapped,
and counterboard (on this other side) for 1/4-20 cap screws

17

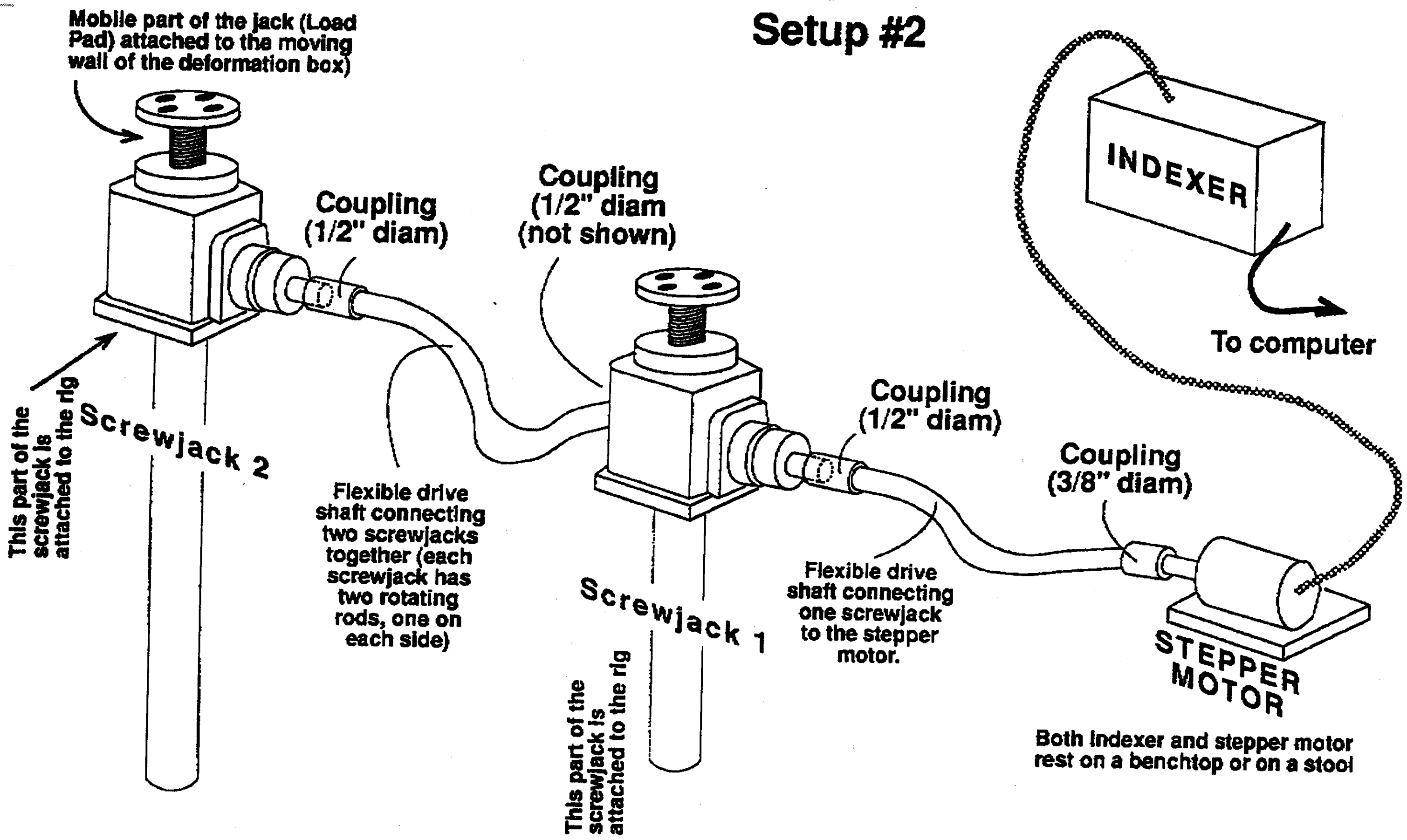

A2
A
B1
B2
C1 or C2
C1 or C2
B2
B1
A
Plate D to be attached to screwjack sliding-plate
Attachment block casing for Linear ball bearings
steel rods


18" max
20-40"(max)

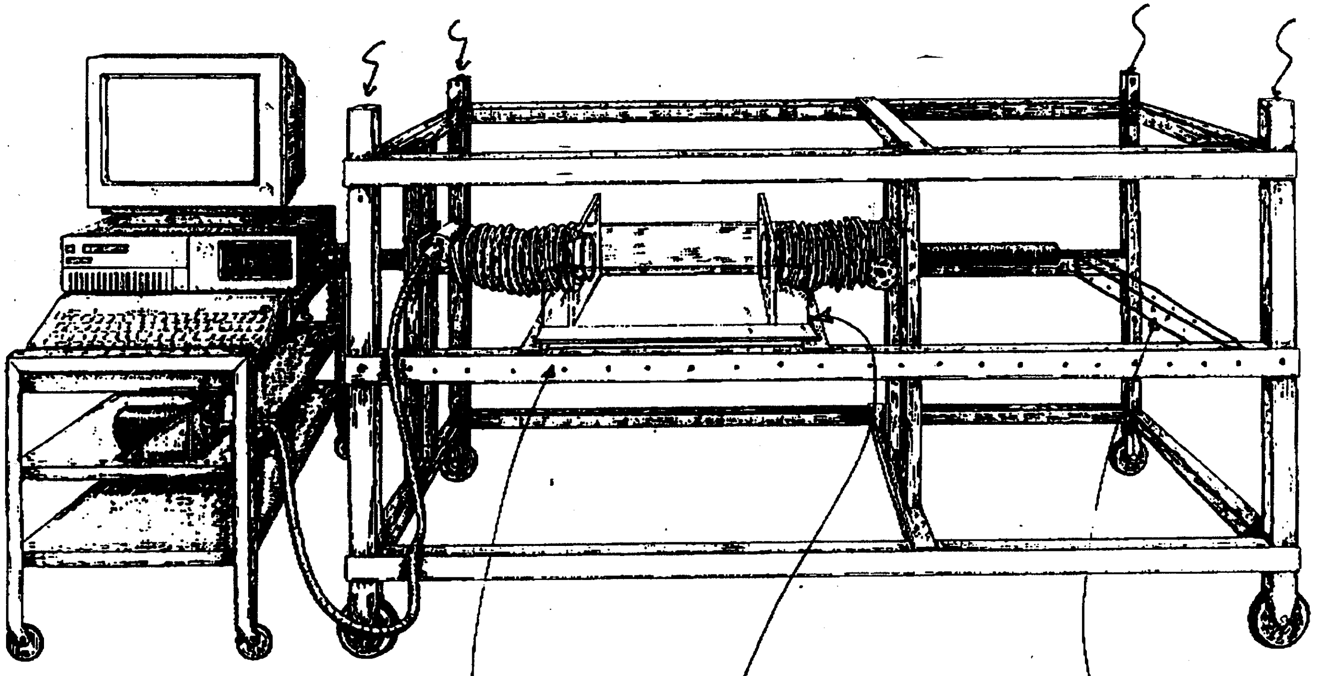
# Setup #1


Mobile part of the jack (Load Pad) attached to the moving wall of the deformation box)
1/2"
Coupling
INDEXER
Adaptor Cable
This part of the screwjack is attached to the rig
Screwjack
Flexible drive shaft
3/8"
To computer
Coupling
STEPPER MOTOR
Both indexer and stepper motor rest on a benchtop or on a stool

# Setup #2


Mobile part of the jack (Load Pad) attached to the moving wall of the deformation box)
Coupling (1/2" diam)
Coupling (1/2" diam (not shown)
INDEXER
To computer
This part of the screwjack is attached to the rig
Screwjack 2
Flexible drive shaft connecting two screwjacks together (each screwjack has two rotating rods, one on each side)
Screwjack 1
This part of the screwjack is attached to the rig
Coupling (1/2" diam)
Coupling (3/8" diam)
Flexible drive shaft connecting one screwjack to the stepper motor.
STEPPER MOTOR
Both indexer and stepper motor rest on a benchtop or on a stool

Arrows indicate hole to drill + tap at the center of the top of the posts.



July 11, 1995 Bret Kaho

## Other Parts, Accessories, and Materials Needed For The Completion of The Deformation Rig
(Aside From The Frame and Box)

- (4) 430-EPI Packages Stepper Drive Module & Microcontroller Indexer (Minarik Electronics, San Antonio)
- (4) M093-FC14 DC Stepper Motor (Minarik Electronics, San Antonio)
- (1) Adapter Cable from indexer to RS232 serial port of an IBM PC, 10' long (Minarik Electronics, San Antonio)
- (4) Motor/Drive cable, Ref # B215801-001 (Minarik Electronics, San Antonio)
- (3) Cable for daisy chaining multiple indexers "Y" Cable Ref # B216298-002 (Minarik Electronics, San Antonio)
- (2) Joyce worm gear screw jack, 2-ton capacity, 24:1 ratio, 20" rise, upright position, Load Pad end condition, Ref # WJT 242, 20", upright, type 2, with protection boot (Joyce Dayton Co. Dayton, Ohio).
- BK 4 (~~2~~) Joyce worm gear screw jack, 2-ton capacity, 24:1 ratio, 30" rise, upright position, Load Pad end condition, Ref # WJT 242, 30", upright, type 2, with protection boot(Joyce Dayton Co. Dayton, Ohio).
- (2) Bidrectional, flexible drive shaft, 1/4" diameter, #A=212-8146, 10 feet long, Plain-bearing, both couplings (#B-401-8553) Female with set screws, both ends connect to 1/2" diameter shafts (Elliot Manufacturing Co., Binghamton, NY).
- (2) Bidrectional, flexible drive shaft, 1/4" diameter, #A=212-8146, 8 feet long, Plain-bearing, both couplings (#B-401-8553) Female with set screws, one end to connect with 3/8" shaft, the other end to connect to 1/2" diameter shaft (Elliot Manufacturing Co., Binghamton, NY).
- (40) each of 1/4-20 Cap Screws in the following lenghts: 1/2", 3/4", 1", 1 1/2", 2", 2 1/4"
- (180) 10-24 Cap Screws, 1/2"
- (100) 3" long, 1/4-20 Hex Bolts
- (100) 1/2" diameter, 1/4" threaded hex nuts
- (50) flat washers
- (50 wing nuts
- Used Rustoleum primer and black finish spray paint for a final coating to protect the outer surfaces of the deformation rig from rust, chemicals, and normal use. This also facilitates easier cleaning of the rig.

July 11, 1995
Brett Rake

Other Equipment That Will Be Used During Experiments

- (3) Nikon F4s 35mm Cameras with Nikon MF-23 MultiControl Backs for taking pictures during progression of an analogue experiment. Each camera is equiped with a Nikor f/1.4 AF lens. (Wolff Camera and Video, San Antonio)
- (3) Bogen Salon 230 Studio camera stands with Bogen 3028 camera heads for camera attachment and positioning. (Wolff Camera and Video, San Antonio)
- (3) Calumet Mini-Compact light stands, MF3515. (Wolff Camera and Video, San Antonio)
- (3) Calumet A120 Light with 12" Reflector. (Wolff Camera and Video, San Antonio)
- (3) GE 500 watt ECT light bulbs. (Wolff Camera and Video, San Antonio)

July 20, 1995

Brett Rahe

# The Scaling of Analogue Models

The use of scale models in the field of geology has for over 60 years been a tool used to aid in making structural interpretations of the real world. In order to validate the use of such models of the real world, they must be scaled or reduced if you will, by appropriate factors that allow us to view the geologic processes on a level that is both smaller and faster in terms of time and dimensions. As such, scaling techniques have also shown scientists what modeling materials can be used to accurately represent the layers of the Earth.

Theories concerning the geometric, kinematic, and dynamic similarity between the physical model and the real world (from here on referred to as the 'prototype') must be talked about and understood before fundamental units and scale factors for the numerous dimensional quantities can be derived. From these then properties of the required media can be calculated, the next problem being to find a suitable media with those properties which is not always so easy. The vast knowledge of scaling used in conjunction with analogue models is attributed to the derivations of Hubbert (1937) and Ramberg (1967).

## Types of Similarity Between Models and Prototypes

There are three different degrees of similarity that are considered in the application of model scaling to the study of geologic structures. *Geometric similarity*, the first of the three, is satisfied when all corresponding lengths are proportional and all corresponding angles are equal between a prototype and its model (Hubbert, 1937). In simpler terms, this is just and extension of the law of similar triangles from geometry to bodies of varying shapes. Scale factors associated to geometric similarity include length, area, and volume.

If $l_1$ represents the length of the prototype and $l_2$ length of the model (Fig. 1), then a scale factor for the length ($\lambda$) can be obtained allowing any of the other lengths between the two to be calculated provided one of the corresponding lengths is known. Because scale models of geologic structures are smaller than the prototype, the scale

$$\lambda = l_2 / l_1 \text{, or } l_2 = \lambda\, l_1$$

factor for length will be less than unity (Hubbert, 1937).

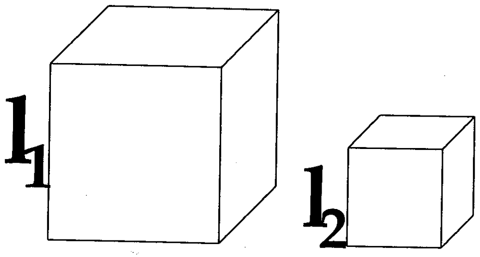


Figure 1. Two Geometrically Similar Bodies

The ratio of analogous areas between the model and prototype can be determined directly from the length ratio derived above. The same also applies for the calculation of the volumes between models and prototypes.

$$A_2/A_1 = \lambda^2 = l_2^2 / l_1^2$$

$$V_2/V_1 = \lambda^3$$

The next type of similarity between model and prototype is *kinematic similarity*. If two geometrically similar bodies have geometrically similar changes of shape and/or positions, the two bodies are said to be kinematically similar as long as the time needed for a change in the prototype is proportional to the time needed for a change in the model. As such the following relation is needed (Hubbert, 1937):

$$t_2/t_1 = \tau$$

where $t_2$ is the time necessary for the prototype to undergo a change in shape, $t_1$ the time for the model to undergo a proportional change, and $\tau$ is the model scale ratio for time. If the two bodies are kinematically similar, then velocities and accelerations for corresponding points must also be proportionally scaled as well.

$$v_2/v_1 = \eta = l_2/t_2 / l_1/t_1 = \lambda/\tau$$

$$a_2/a_1 = \gamma = l_2/t_2^2 / l_1/t_1^2 = \lambda/\tau^2$$

where $v_2$ and $v_1$ are the velocities of corresponding points, $a_2$ and $a_1$ accelerations, $\eta$ the model ratio for velocities, and $\gamma$ the model ratio of acceleration (Hubbert, 1937).

The third type is called *dynamic similarity*. With the previously discussed types of similarity, no mention of mass was referred to when the relations between the form and movement of the model and prototype were described. Dynamic similarity also brings into view the third elemental scale factor, mass ($\mu$) which allows us to evaluate the various forces that may act upon the prototype and scale them accordingly for the model. Because scaling laws necessitate that the shape and time span of deformation must scale proportionally from model to prototype, the response to each scaled force in the model must be both kinematically and geometrically similar to that of the prototype. This situation is satisfied if each force in the model is scaled down by the same factor as the corresponding force in the prototype (Twiss, 1992). If this is the case, then the model and prototype are said to be dynamically similar.

The three fundamental units that are brought about by geometric, kinematic, and dynamic similarity are time ($\tau$), length (l), and mass ($\mu$). From these three fundamental units all other pertinent mechanical quantities and their scale factors can be calculated (Fig. 2).

| Quantity | Dimensional Formula | Model Ratio |
|---|---|---|
| Area | $L^2$ | $\lambda^2$ |
| Volume | $L^3$ | $\lambda^3$ |
| Velocity | $LT^{-1}$ | $\lambda\tau^{-1}$ |
| Acceleration | $LT^{-2}$ | $\lambda\tau^{-2}$ |
| Density | $ML^3$ | $\mu\lambda^{-3}$ |
| Force | $MLT^{-2}$ | $\mu\lambda\tau^{-2}$ |
| Stress | $ML^{-1}T^{-2}$ | $\mu\lambda^{-1}\tau^{-2}$ |
| Strain | $L^0$ | 1 |
| Viscosity | $ML^{-1}T^{-1}$ | $\mu\lambda^{-1}\tau^{-1}$ |
| Gravitational Constant | $M^{-1}L^3T^{-2}$ | $\mu^{-1}\lambda^3\tau^{-2}$ |
| Strength | $ML^{-2}$ | $\delta\lambda$ |

Figure 2. Mechanical Quantities and Their Scale Factors

## Assumptions

These basic factors for the scaling and construction of scale models may cause one to think that modeling is straight forward and simple. There are, however, some problems that can develop and complicate the process. In creating the basic premise for dynamic similarity, that is that all forces of all types must be proportional, the ratio of the forces due to inertia , $\mu\lambda\tau^{-2}$, is chosen to be the standard to which all other forces have been made to rely on. This creates an immediate problem which needs a solution, or assumption, in order to solve. The problem is that when both the model and the prototype are subjected to the same gravitational force, it causes the model ratio for acceleration ($\gamma=\lambda\tau^{-2}$) to be equal to 1. This creates the situation where $\lambda$ and $\tau$ are no longer

$$\gamma = \lambda\tau^{-2} = 1, \text{ hence}$$
$$\lambda = \tau^2$$

independent ratios, but instead, one determines what the value of the other will directly be (Hubbert, 1937). Herein lies the problem. To illustrate, if a model is to simulate 200 million years of deformational history and also be completed within a few hours, a suitable time ratio would be on the order of $10^{-8}$. Because $\lambda$ equals $\tau^2$ in this case, the model ratio for length would then be $10^{-16}$, about the diameter of a molecule. On the other hand, if a suitable value for the model length ratio is chosen , $10^{-5}$ (McClay et al, 1987a; McClay et al, 1987b; McClay et al, 1988), then the corresponding model ratio for time would be $10^{-2}$. The time ratio would then reveal that the time needed to complete the model experiment would be 20 million years, not very realistic. So the thought comes to mind, how does the scientist solve this dilemma? According to Hubbert (1937), the key to solving this problem lies in the conditions that satisfy dynamic similarity as previously discussed. For dynamic similarity to be satisfied, the two body forces of inertia and gravity must be satisfied.

In order to solve our problem, suppose that in certain cases both of the body forces do not exist at the same time, or if they do, that one of them is so small that it is negligible compared to the other. Since analogues can represent millions of years of deformational history, movement is considered to progress very slowly and as such accelerations can essentially be thought of as negligible. A negligible acceleration equates to a negligible value for the inertial force as well. In such cases as this the controlling factor is clearly no longer inertia, but rather it is gravity which on the earth's surface is independent of the model ratio of time employed in the experiment. So to summarize, in cases where the acceleration is so small that inertial forces become negligible, the conditions of dynamic similarity are satisfied if the model ratios of length, time, and mass are chosen arbitrarily and all forces conform to the ratio:

$$F = \phi = \mu\gamma_g = ma$$

where $\gamma_g$ is the model ratio of gravitational acceleration which for the earth's surface may be set to equal one. This results in the following relationship:

$$\phi = \mu\gamma_g = \mu 1 = \mu = \delta\lambda^3$$

In order to keep geometric and kinematic similarity it is necessary that the strength of the modeling material and the model dimensions ($\lambda$) be scaled down by the same factor as well (Hubbert, 1937: Withjack, 1986; McClay and Ellis 1987b; Withjack, 1995).

## Properties of Modeling Materials

In modeling the geologic structures of the earth on a small scale, one must also consider the properties of the different media which are going to represent actual rock. To begin with, in choosing media for modeling the brittle crust, it is important to find a material that exhibits Coulomb behavior (Vendeville et al, 1987; Ellis and McClay, 1988; Davy and Cobbold, 1991). A Coulomb material, if you remember from introductory structural geology, is resistant to deformation unless the shear stress, $\tau_s$, on a given plane is greater than the critical shear stress value, $\tau_c$, whereby the material fails by faulting (Hubbert, 1981; Cobbold et al., 1989):

$$\tau_C = c + \mu(\sigma_n - p)$$

where c is the cohesion, $\sigma_n$ is the normal stress acting upon the plane, $\mu$ is the coefficient of internal friction, and p is the pore fluid pressure. In experiments, the pore fluid pressure is assumed to be negligible and the equation reduces to:

$$\tau_C = c + \mu(\sigma_n)$$

For rocks and loose soils, $\mu$ has been found to have a value of approximately 0.6 (Hubbert, 1981). The acute angle, $\theta$, between the maximum compressive stress ,$\sigma_1$, and the fracture plane, is predicted by (fig. 3):

$$\theta = 45^0 \pm \phi/2$$

where $\phi$ = arctan $\mu$ is the angle of internal friction.

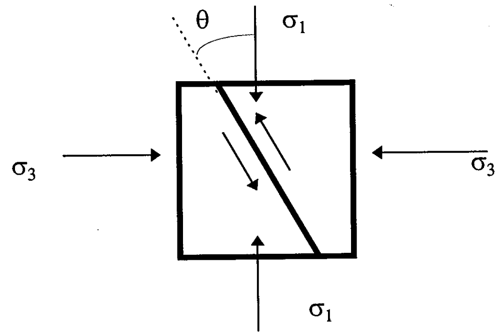


Figure 3. Orientation of Fault Plane to Maximum Compressive Stress

If the crust as a whole has an internal angle of friction = $30^0$, then one would expect to find normal faults with dips of 60 degrees ($45^0 + 30^0/2$); thrust fault with dips of $30^0$ ($45^0 - 30^0/2$); and strike-slip faults with vertical dips (Twiss, 1992). This results in the orientation of the maximum and minimum principle stresses being a key factor of what type of fault will develop, i.e. normal, reverse, or strike-slip (Cobbold et al., 1989; Davy and Cobbold, 1991; Twiss, 1992).

Some aspects of what are scaled are not represented by the use of sand. For instance, since sand is a granular material, one us usually not interested in the individual grain to grain relationship, but rather how the model as a whole represents the frictional and elastic behavior of the earth. Not accurately represented by analogue models are grain size and the dimensions of shear zones that develop between faults (Mandl, 1988). The effect of grain size is to cause the formation of narrow shear zones in the model instead of discrete fault planes (McClay and Ellis, 1987).

Sand is not the only modeling media used to represent layers of the earth as the brittle and ductile crust are two separate parts of the system. The viscous layers of the ductile lower crust and mantle must also be considered when trying to appropriately scale an analogue model representing multiple layers of the earth. Perhaps the most useful of materials used for this are the silicone putties made by Rhone-Poulenc in France, and DOW-Corning in Canada. One or both of these materials have been used extensively by many scientists to represent different aspects of extensional tectonic settings to include listric fault systems and the diapiric rise of salt domes (McClay and Ellis, 1987a; McClay and Ellis 1987b; Vendeville et al., 1987; Ellis and McClay, 1988; Vendeville and Jackson, 1992; Weijermars et al, 1993).

For an analogue model representing both the brittle and ductile portions of the crust, it would be convenient to choose length ($\lambda$), viscosity ($\psi$); and time ($\tau$) as the fundamental scale ratios to have. Earlier it was stated that the fundamental ratios were length, mass, and time while here the viscosity was used instead. From the scale equation for viscosity, however, the model ratio of mass can be obtained thus still satisfying dynamic similarity. If the viscosity of the lower crust is taken to be on the order

$$\text{viscosity} = \psi = \mu\lambda^{-1}\tau^{-2}, \text{ hence}$$

$$\mu = \psi\lambda\tau^{2}$$

of $10^{21}$ Pa•s (Mulugeta, 1985; Schreurs, 1994) then an appropriate viscosity for a modeling material would be on the order of $10^{4}$ Pa•s. This value is on the same order of magnitude as that of polydimethylsiloxane (PDMS), otherwise known as silicone putty. This is the reason that PDMS has been used extensively in the past decade to represent the ductile portions of the lower crust. Some varieties of PDMS, particularly those made by Rhone-Poulenc in France, have the ability to have their physical characteristics changed for more versatility. For example, both the density and viscosity of PDMS can be made larger by mixing powdered galena (PbS) with the putty; density increases by about .21 g/cm$^{3}$, viscosity increased by about a factor of 7. This property can allow for an even greater degree of realism imparted to analogue models.

Vendeville et al (1987) went even further by using honey to represent the asthenosphere in a multiple layer model of extensional regimes. The honey, like PDMS, behaves as an almost perfect Newtonian fluid meaning that it is linearly viscous. If a stress is applied to it, it will flow. When the stress subsides, the fluid flow stops as well but does not return to its original shape. Such deformation is termed nonrecoverable (Twiss, 1992). The viscosity ratio of silicone to honey is about 100:1, therefore making honey a suitable media for representing the asthenosphere as its density is also greater than that imparted to altered PDMS.

There are numerous other materials that have been used in the past to emulate the geologic processes in the real world. Though only some of the most important ones have been discussed here, the ones used in the past are still of use to researchers in the present. The same type of saturated clays, used as early as the 1950's by Ernst Cloos, are still being used in analogue experiments of 1995 (Withjack et al, 1995). Ongoing research in the fields of chemistry and chemical engineering will no doubt someday produce new materials which will be of use to geologists using analogue modeling as a tool. Figure 4 shows names and some characteristics of some past and present materials used for analogue modeling.

| | Sand | Garnet Sand | Glass Beads | Glass Powder | Pink Silicone | Gray Silicone | Honey | Clay |
|---|---|---|---|---|---|---|---|---|
| Density ($g/cm^3$) | 1.3 | 1.865 | ---- | ---- | 1.16 | 1.37 | 1.4 | 1.6 |
| Cohesion | very low | very low | very low | ? | ---- | ---- | ---- | $10^{-4}$MPa |
| Viscosity | ---- | ---- | ---- | ---- | $10^4$Pa•s | $10^4$Pa•s | $10^2$Pa•s | ---- |
| Material That It Models | Brittle Crust | Brittle Crust | Ductile Lower Crust | Brittle Crust | Viscous Lower Crust | Viscous Lower Crust | Asthen-osphere | Brittle Crust |

Figure 4. Analogue Modeling Materials

## Summary

In summarizing the various applications of scaling towards analogue modeling, it is first good to know how the model relates to the prototype in terms of similarity. The first two, geometric and kinematic, yield to us two of the three fundamental scale ratios, length ($\lambda$), and time ($\tau$). From dynamic similarity we obtained the third fundamental scale ratio that we needed, mass ($\mu$). From these three fundamental ratios, all other mechanical quantities and forces can be calculated.

The problem that arose where $\lambda$ and $\tau$ were no longer independent of one another as a result of inertial forces being used to satisfy dynamic similarity, was solved by making the assumption that because accelerations associated with tectonic movement are very small, except in the case of earthquakes, the associated inertial force is negligible (Hubbert, 1937). This resulted in gravity being the controlling factor, which on the surface of the earth is independent of the model ratio of time employed in the experiment. The most important statement made by several different authors was that in order to keep geometric and kinematic similarity, the strength of the modeling material must be scaled down by the same factor (Hubbert, 1937; Withjack et al, 1995). For this reason, sand has been chosen by many to represent the brittle layering of the upper crust. The characteristics of sand include a frictional coefficient of 0.6 and internal angle of friction equal to approximately 30 degrees which cause it to deform by faulting in discrete shear zones according to the

Coulomb fracture criterion. Scaling down the strength of the crust also requires a media that will deform under its own weight. In this respect, sand is also satisfactory because it possesses a negligible value of cohesion.

In addition to sand, numerous varieties of silicone putties have been used to model the ductile lower parts of the earth's crust. Those of particular interest are the ones produced by Rhone-Poulenc in France. These are significant because of their ability to have their physical characteristics of density and viscosity changed by the addition of powdered galena (PbS). Based on values from other authors, the viscosity of silicone has been shown to posses a viscosity on the appropriate order of magnitude which represents the viscosity of the lower ductile crust. Honey, with both a higher density and lower viscosity than PDMS, has been used to represent the asthenosphere. These three modeling materials used in various combinations are the ones dominantly used by most of the persons interested in what analogue modeling can provide. In no means however should one limit themselves to using the ones from the past, or in experimentation to develop new materials.

July 21, 1995

## Preparation Of Sand For Use In Analogue Modeling Experiments

- The sand that will be used for the structural analogue modeling project has the commercial name, Oklahoma #1. The sand was purchased in 100 lb bags from V.R. Hood Clays in San Antonio, Texas.

- Sand is an appropriate material for geologic analogue modeling because it is a Mohr Coulomb material meaning that it will generate faults when deformed which are similar in dip and orientation as those found in the brittle crust of the Earth according to the Andersonian Theory of Faulting

- The sand needs to be dyed using a non-toxic acrylic color (dye) which when dries becomes totally waterproof. Bye diluting the dye with ordinary tap water, it is easier to apply to the sand. The process is to fill 300 ml of water in a plastic beaker and mix with 3 tablespoons of dye. Once the dye has been totally dissolved into the water, the mixture is placed into a 3 gallon Rubbermaid storage container. To the container then is added white Oklahoma #1 sand, mixing by hand (rubber gloves are worn) and adding additional sand as necessary until the container is full and the sand is all coated with dye.

- The dyed sand is then placed into a circular metal container and put into the Grieve oven which is set at $300^0$ F. This process will dry the sand in a quick and timely manner.

- Periodically the sand must be stirred and mixed because the sand at the upper surface dries faster than that at the bottom. This further allows more moisture to escape and the sand to dry faster.

- Once the sand is dry, it is removed from the oven and sieved in order to remove any clumps or aggregates. The aggregates may then be broken apart and re-sieved so as to reduce waste.

- After sieving, the sand may be placed into a large storage container until it is needed for an experiment.

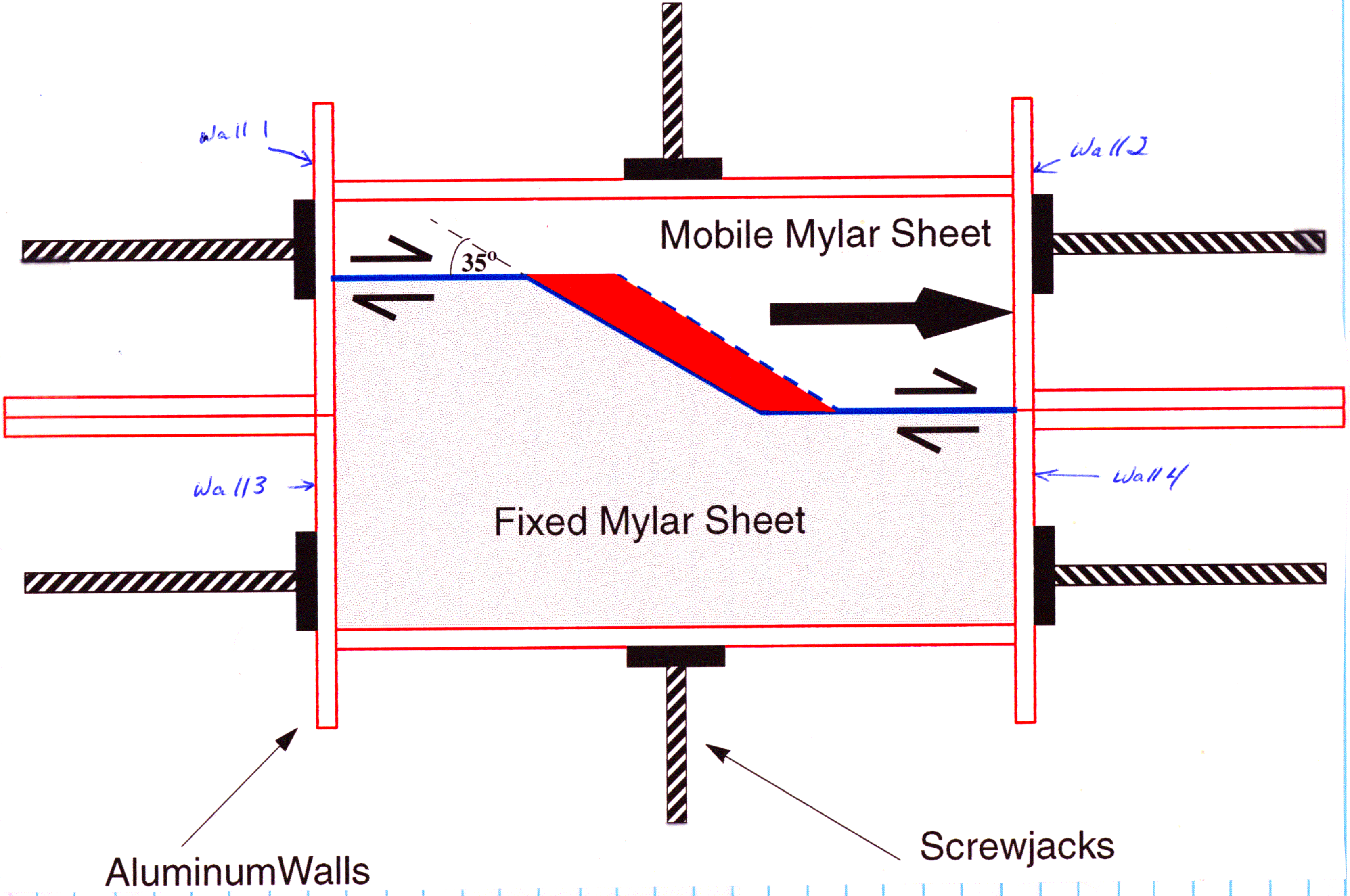
Use Procedure in
Ferguson/Sims Notebook #280
Page 141

August 1, 1995

Bret Rahe

- Objective: To model a simple dextral pull-apart basin approximating the dimensions of Death Valley, California. The initial series of models will also be used as learning tools for model setup, execution, scaling, and dissection. The model runs will be setup and run by Bret Rahe.
- The base of all of the initial models is cut from mylar and laid down on the formica floor of the deformation rig in the dimensions as shown in the diagram for each of the respective models. In the initial series of models there is one Fixed Mylar Sheet which underlies the Mobile Mylar Sheet (see picture next page). The Mobile Mylar Sheet is slid under wall 2 and fixed into position using masking tape so that no slippage will occurr and create insufficient displacement.
- The medium that will be used to simulate the brittle deformation of the crust is Oklahoma #1, dry quartz sand. Sand has been used extensively (see previous section on model scaling, pg. 38).
- A simple sketch of the deformation box is shown on the next page; it was created by Bret Rahe in Framemaker and shows what each of the model setups will in general look like.
- Factors for the scaling of each of the models will also be given for each individual model description.

# MAP OF SIMPLE PULL-APART MODEL



# EQUATIONS FOR DETERMINING THE DISPLACEMENT, VELOCITY, AND NUMBER OF PULSES IN A MODEL SIMULATION

V=linear velocity (cm/hr) (BR) 8/11/95
N=Number of pulses/per second

1. V(cm/hr)=(N(p/s)*3600*2.54)/(200*96)=N(p/s)*0.476
2. V(cm/min)=(N(p/s)*60*2.54)/(200*96)=N(p/s)*0.00794
3. N(p/s)=(V(cm/hr)*200*96)/(3600*2.54)=(V(cm/hr)*2.10
4. N(p/s)=(V(cm/min)*200*96)/(60*2.54)=V(cm/min)*126

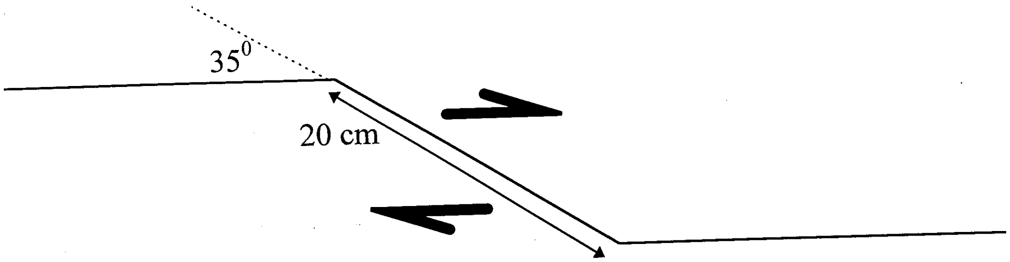
D=linear displacement (cm)
N=number of pulses

1. D(cm)=(N(p)*2.54)/(200*96)=N(p)*0.000132
2. N(p)=(D(cm)*200*96)/(2.54)=D(cm)*7559

These equations were received in an E-mail from Bruno Vendeville and are used to calculate linear displacement, number of pulses, and linear velocity. They take into account the pulses per second of the stepper motors and gearing and threading of the screwjacks. These will be used for model setup.

August 1, 1995

- Objective: First of the initial set of models simulating simple pull apart basins.
- The mylar configuration of the floor of the model will have the dimension as shown below. The fixed and mobile mylar sheets that will create the pull-apart basin will be mounted in the same configuration shown on page 47.



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$

$$\text{length ratio} = 1\ \text{cm}/321868\ \text{cm} = 3.10686 \cdot 10^{-6}$$

This means that 1 cm in the model represents approximately 3.21 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, next blue, and repeating the sequence for a total of six 1.25 cm layers. Total thickness of the model was 7.6 cm.
- The amount of strike-slip displacement that this model will undergo is 5.08 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 2.38 cm/hr |
| Number of pulses/second | 5 p/s |
| Displacement | 5.08 cm |
| Number of Pulses from the Stepper Motor | 38485 pulses |

- Therefore, at five (5) pulses per second, for a total of 38485 pulses, the model will take 2 hours, 8 minutes, and 17 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 34 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made every 10 minutes throughout the duration of the model run. These descriptions begin on the next page (pg. 50).

- The model will be started at 12:20 pm, August 1, 1995 and stopped at 2:28:17" pm the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS2000 software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.

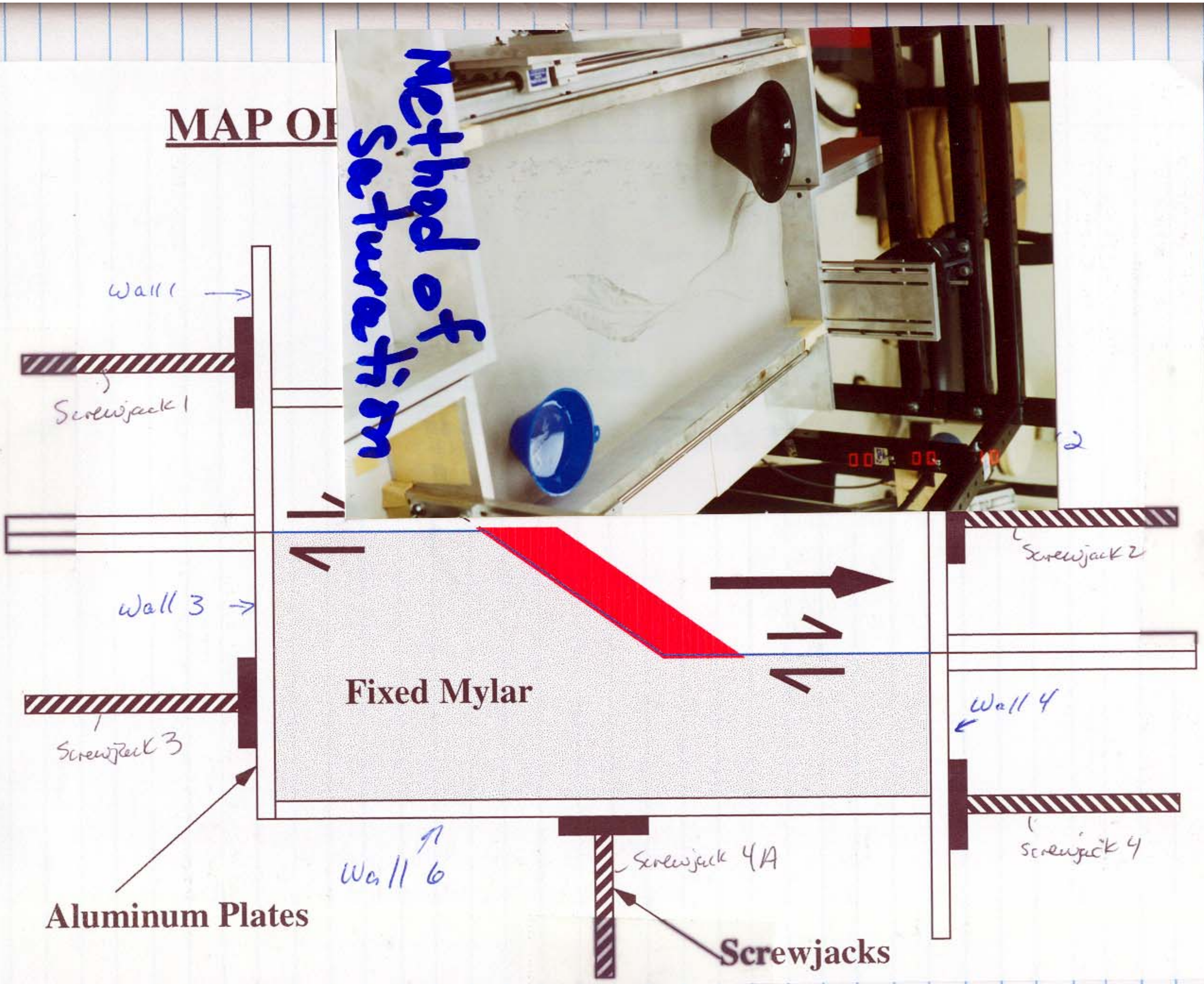
Description of Model Run, August1, 1995

| Time | Descriptions of Time Events |
|---|---|
| 12:20 pm | Model run started |
| 12:30 pm | Two symmetrical faults form which are bounding the graben formed by the stepping sections of strike-slip displacement. The graben has downdropped slightyly. |
| 12:40 pm | Riedel shears have developed along the pure strike-slip sections of the model at an angle of about $15^0$ to the main strike-slip faults. Two new faults have also formed as splays off of the two first formed graben bounding faults. The graben have dropped down further. |
| 12:50 pm | The Riedel shears have lengthened and are starting to show the sinusoidal shape predicted by Andersonian fault theory. They are synthetic to the main portion of the strike-slip fault and have the same sense of motion. The central graben has dropped down further and fault scarps are starting to be more pronounced along them. |
| 1:00 pm | The Riedel shears are lengthening further and beginning to join with two new bounding faults of the graben, outside of the two original faults. |

*****Descriptions at this point were interupted because of a tour by officials from the N.R.C. A short presentation was given by Dr. David Ferrill explaining to them the model that was in progress and why it was important to the investigation of the proposed repository at Yucca Mountain, Nevada. Photographic slides of the surface of the model were continually exposed for the total duration of the run up until 2:28:17" pm on August 1, 1995. They are contained in the notebook holding all of the photographic slides for all model runs.**

- In a attempt saturate the completed model, three plastic funnels were placed into the sand and filled with water allowing it to be introduced into the sand and cariied along by capillary action. The model filled from the bottom up and took approximately 8 hours to saturate. Following this, walls 2 and 4 (see pg. 47) were removed to allow cross-sections to be made.
- After removing the walls, it was determined that the model was too saturated with water as some of the sand oozed out of the lower layers, not able to stand in a vertical wall as is needed. By attempting to take further cross-sections however, a technique using two putty knives was used that still enabled cross-sections to be cut and faults to be made out. One putty knife is placed vertically into the sand, the second putty knife is then used to scoop away the unwanted sand from in front of the first. The first putty knife may then be carefully slid vertically upward along the face of the new cross-section, being careful not to remove additional material from behind the knife.
- It was decided that the next model should have the same dimensions and parameters as this one.

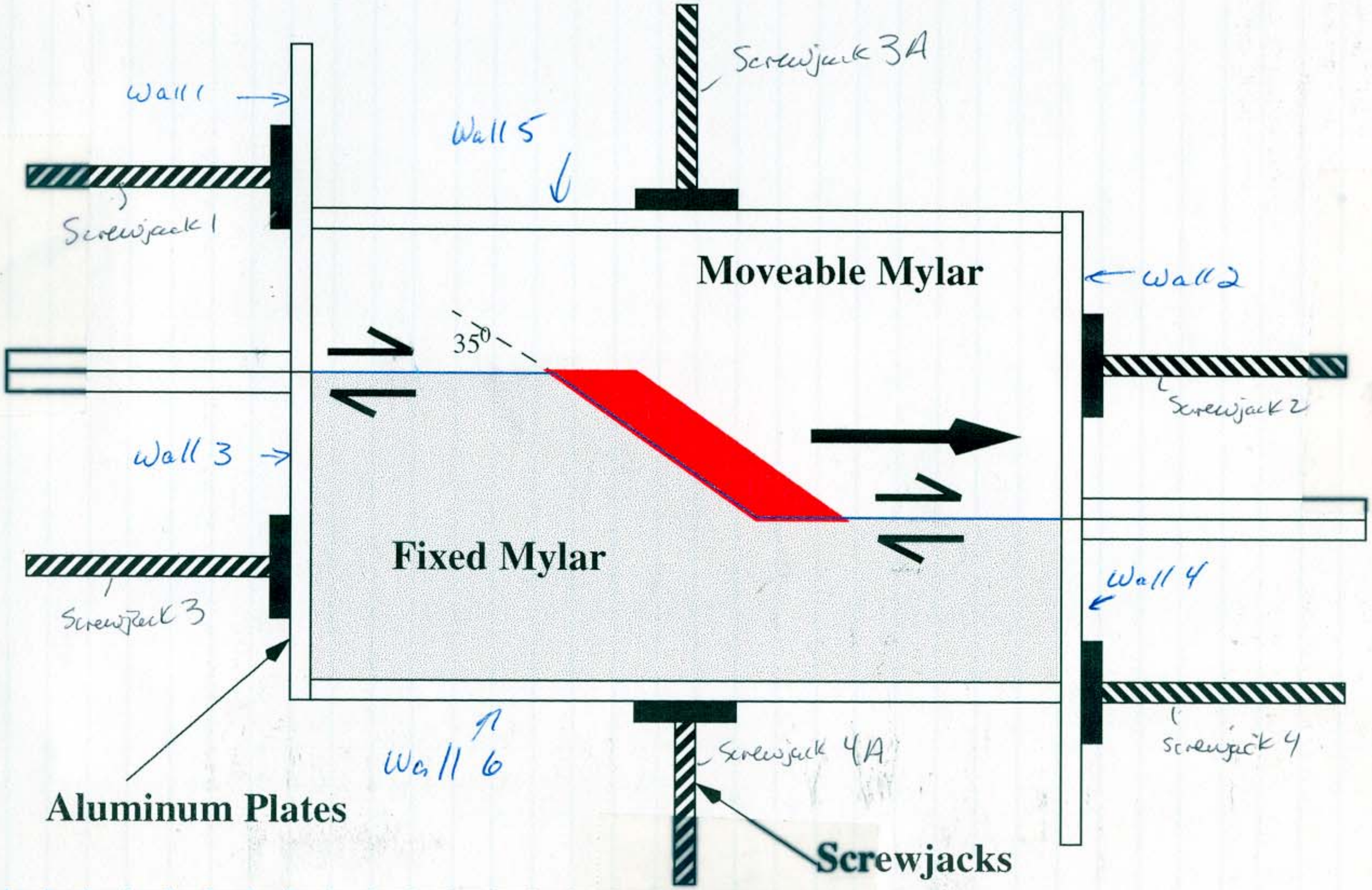
## MAP OF



This illustration shows how the screwjacks were repositioned to reduce the thrusting in the model next to wall #1.

8/4/95

# MAP OF SIMPLE PULL-APART MODEL

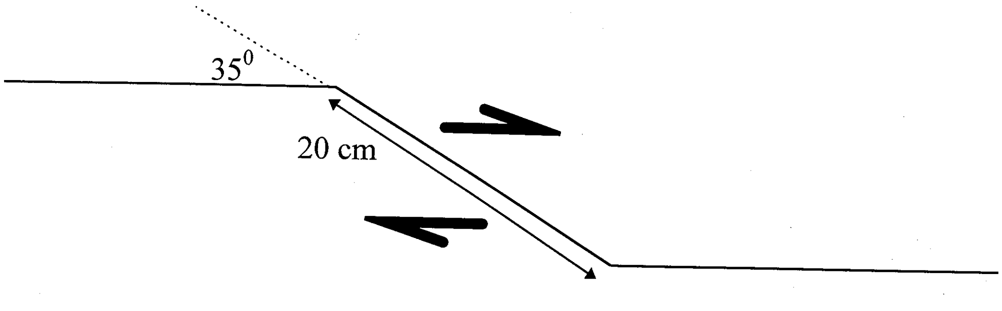


This illustration shows how the screwjacks were repositioned to reduce the thrusting in the model next to wall #1.

8/4/3

Brett Rahe August 3, 1995

- Objective: To model the same pull-apart as in the analogue model completed on August ~~1~~ 3, 1995. The new technique of creating cross-sections will be used to see if it works well enough or if some other method should be used.
- The mylar configuration of the floor of the model will have the dimension as shown below. The fixed and mobile mylar sheets that will create the pull-apart basin will be mounted in the same configuration shown on page 47.



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$

$$\text{length ratio} = 1\ \text{cm}/321868\ \text{cm} = 3.10686\cdot 10^{-6}$$

This means that 1 cm in the model represents approximately 3.21 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, next red, and repeating the sequence for a total of six 1.25 cm layers. Total thickness of the model was 7.6 cm.
- The amount of strike-slip displacement that this model will undergo is 5.08 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 2.38 cm/hr |
| Number of pulses/second | 5 p/s |
| Displacement | 5.08 cm |
| Number of Pulses from the Stepper Motor | 38485 pulses |

- Therefore, at five (5) pulses per second, for a total of 38485 pulses, the model will take 2 hours, 8 minutes, and 17 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 34 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.

- Description of the surface of the model will be made every 10 minutes throughout the duration of the model run. These descriptions begin on the next page (pg. 53).

- The model will be started at 12:40 p.m., August 3, 1995 and stopped at 2:48:17" p.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS2000 software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.

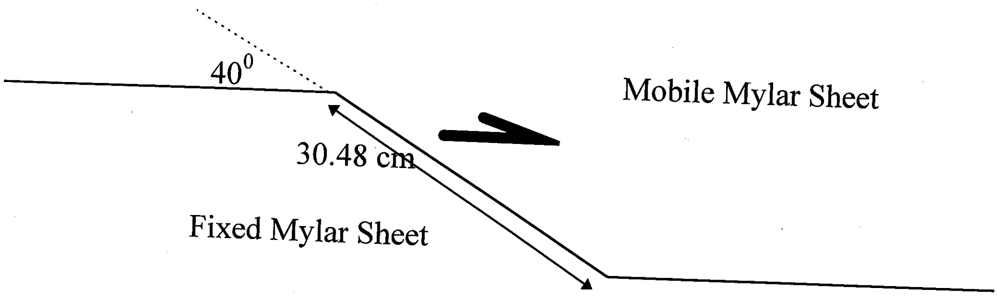
Description of Model Run, August 3, 1995

| Time | Descriptions of Time Events |
|---|---|
| 12:40 p.m. | • Model started |
| 12:50 p.m. | • Normal faults bounding the graben can be seen starting to form.<br>• They appear to be following the orientation of the step in the mylar between the two strike-slip sections. |
| 1:00 p.m. | • Riedel shears form.<br>• Additional normal fault appearing outside of the initial graben bounding faults. |
| 1:10 p.m. | • Riedel shears near the pull-apart have lengthened, one of them joining with the lower outside (newest) graben bounding fault.<br>• No rotation has appeared yet with the first faults that formed. |
| 1:20 p.m. | • The only noticeable change is the addition of more Riedel shears and the increased displacement of the already existing faults associated with the graben. |
| 1:30 p.m. | • Fault scarps on the bounding faults are becoming larger and the tips are lengthening outward. |
| 1:40 p.m. | • The graben is widening as sand slumps off of the scarp and fills the graben.<br>• The graben has become noticeably deeper.<br>• Some Riedel shears are linking together |
| 1:50 p.m. | • Riedel shears are becoming further linked together by additional faults |
| 2:00 p.m. | • The graben has further deepened.<br>• Tips of the bounding faults have lengthened further out away from the central graben |
| 2:10 p.m. | • Further deepening of the graben and slumping of sand from the fault scarps.<br>• Early formed Riedel shear has been cut and offset by a later Riedel shear |
| 2:20 p.m. | • Further deepening of the graben and slumping of sand from the fault scarps.<br>• The offset Riedel shear noted at 2:10 p.m. has been further offset. |
| 2:30 p.m. | • More slumping and downdropping of the graben. |
| 2:40 p.m. | • The fault scarps have become steeper and larger, though some sand still is slumping off of them |
| 2:48:17" p.m. | • The model was stopped<br>• Fault scarps along the edge of the graben are steep, and have a sigmoidal geometry.<br>• The Riedel shears have been linked together by several faults and offset in a dextral sense. |

- Boundary effects noted in this model, and the one that was executed on August 1, 1995, are a thrust fault system on one end of the model (adjacent to wall # 1) and are believed to be the result of the position of the mylar in relation to wall # 1 (pg. 47). To try and eliminate this boundary problem in the future, the screwjacks for the next model will be moved into a new position and offset from one another as shown in the illustration on page 51.
- The model was saturated with water using the method described in the previous model (pg. 50).
- Cross-section were made every 2cm and photographed accordingly. The cross-sections were cut perpendicular to the main direction of strike-slip displacement at 2 cm intervals. Developed slides will be placed into the folder holding slides for all models and will be kept in Bldg. 57, Lab L104. This model run is designated as '**8-3-95**'.

Brett Rake August 11, 1995

- Objective: This is the third model that will be run and is still considered to be within the learning period whereby the processes involved with creating flawless models, photos, and cross-sections can be perfected. This will ensure that later models will be of higher quality and yield better results.
- The mylar configuration of the floor of the model will have the dimension as shown below. The fixed and mobile mylar sheets that will create the pull-apart basin will be mounted in the same configuration shown on page 47.



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/321868\ \text{cm} = 3.10686\cdot10^{-6}$$

This means that 1 cm in the model represents approximately 3.21 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, next red, and repeating the sequence for a total of six 1.25 cm layers. Total thickness of the model was 10.16 cm.
- The amount of strike-slip displacement that this model will undergo is 7.62 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 2.38 cm/hr |
| Number of pulses/second | 5 p/s |
| Displacement | 7.62 cm |
| Number of Pulses from the Stepper Motor | 57600 pulses |

- Therefore, at five (5) pulses per second, for a total of 57600 pulses, the model will take 3 hours, 12 minutes, to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 5 minutes, 20 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.

- Description of the surface of the model will be made every 10 minutes throughout the duration of the model run. These descriptions begin on the next page (pg. 55).

- The model will be started at 1:20 p.m., August 11, 1995 and stopped at 4:32 p.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS2000 software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement. The first synsedimentary layer of sand will be yellow and will alternate with blue dyed sand. One centimeter of displacement will happen every 25 minutes, 12 seconds.

Description of Model Run, August 11, 1995

| Time | Descriptions of Time Events |
|---|---|
| 1:20 p.m. | • Model started |
| 1:30 p.m. | • No change was noted on the surface of the model. |
| 1:40 p.m. | • Two separate sets of faults bounding the graben have formed. An inner set and an outer set.<br>• The graben is beginning to drop down between the normal faults bounding it.<br>• The outer set of faults appear to be a series of discontinuous segments.<br>• Riedel shears have formed in the lower right end of the pull-apart and are joining with the outer set of faults. |
| 1:45:12" p.m. | • The first layer of yellow, synsedimentary, sand is added to the graben.<br>• 1 cm of displacement. |
| 1:50 p.m. | • Riedel shears beginning to form at both ends of the graben and starting to join with the outer bounding faults of the graben.<br>• The normal bounding faults have propagated up through the yellow layer of fill. |
| 2:00 p.m. | • Additional faults have developed linking Riedel shears together.<br>• Steep faults scarps have formed through the yellow layer of synsedimentary fill.<br>• The graben has dropped down further and still seems to be oriented the same as the step in the mylar basement. |
| 2:10 p.m. | • The outer bounding faults are very steep and still seem to be linked segmented faults.<br>• The main graben is continuing to subside.<br>• The two inner normal faults can be seen on the interior portion of the graben. |
| 2:10:24" p.m. | • The next layer of synsedimentary fill is added to the graben; blue sand was used.<br>• 2 cm strike-slip displacement. |
| 2:20 p.m. | • Faults have propagated up through the blue layer of synsedimentary fill |
| 2:30 p.m. | • Outer faults have again propagated through the second layer of synsedimentary fill.<br>• Steep walled normal faults.<br>• Normal faults cutting through from one side to the other along the lower portion of the graben.<br>• Left, outer bounding fault is curving around in a series of stepped segments at the lower end of the graben. Relay ramps have formed in between them. |
| 2:35:36" p.m. | • The third layer of synsedimentary fill is added to the graben, color.... yellow.<br>• 3 cm of displacement. |
| 2:40 p.m. | • Bounding faults and curved segments in the 2:20 description have propagated up through the third layer of fill. |
| 2:50 p.m. | • Faults have propagated up through the layers of fill.<br>• Array of Riedel shears have linked together.<br>• A newly formed normal faults has developed on the interior of the graben inside the left bounding fault. |

| | |
|---|---|
| | • Segmented curved portions of the lower region of the graben are lengthening. |
| 3:00 p.m. | • The graben has down-dropped further.<br>• Along the strike-slip portions of the model small push-ups and pull-aparts have developed between Riedel shears.<br>• Segmented and curved lower portion of the graben continues to form and lengthen. |
| 3:00:48" p.m. | • the fourth layer of synsedimentary fill is added, color... blue<br>• 4 cm of displacement. |
| 3:10 p.m. | • The graben bounding faults have once again propagated through the newest layer of fill (blue).<br>• Segmented faults also continue to propagate through the synsedimentary layers.<br>• Pull-aparts and push-up structures along the strike-slip portion of the model continue to deepen and rise respectively. |
| 3:20 p.m. | • Fault scarps have continued to remain very steep and also have grown up through the synsedimentary fill.<br>• Curved segments still show relay ramps between them.<br>• Push-ups and pull-aparts along the strike-slip sections of the model have continued to rise and fall respectively.<br>• Additional faults have formed in the central part of the graben. |
| 3:26:00" p.m. | • The fifth layer of fill is added to the graben, color..... yellow<br>• 5 cm of displacement. |
| 3:30 p.m. | • Bounding faults have propagated through the most recent layer of graben fill.<br>• Pull-apart between Riedel shears in the lower right of the model has deepened and faults have propagated through the yellow layer on the surface. |
| 3:40 p.m. | • The graben has now become noticeably wider.<br>• Faults in the central part of the graben have propagated up through the yellow and blue layers filling the graben.<br>• Curved segments are starting to link together.<br>• Bounding faults are still very steep.<br>• Push-up and pull-aparts along the strike-slip sections of the model continue to deform as previously and as expected. |
| 3:50 p.m. | • Rotation of the outer bounding faults can now be seen as they are oriented differently from the newly formed normal faults in the central graben.<br>• Faults are still very steep.<br>• Pull-apart along the lower strike-slip section has also deepened.<br>• A complex arrangement of faults has developed in the middle of the graben. |
| 3:50:12 p.m. | • Added the sixth layer of basin fill to the graben, color... blue.<br>• 6 cm displacement. |
| 4:00 p.m. | • Displacement along the left side of the graben seems to now be focused upon a newly developed fault in the middle of the graben.<br>• The right side of the graben is still mostly having displacement on the outer bounding faults of the graben. This may show an asymmetrical graben forming. |
| 4:10 p.m. | • A new normal fault has formed in the graben, it has the same sense of motion as the 2 to the left of it.<br>• Faults scarps on all bounding faults are all very steep. |
| 4:15:36" p.m. | • The last layer of synsedimentary fill is added to the graben, color.... yellow.<br>• 7 cm of displacement. |
| 4:20 p.m. | • Faults has propagated up through the layers of fill.<br>• All pull-aparts are actively downdropping. |
| 4:30 p.m. | • Normal faults bounding the graben have formed along the left side, dipping to the right.<br>• Faults propagate upward through the basin fill and keep very steep dips.<br>• The right side of the graben has appeared to hold only one major bounding fault during the duration of the model run.<br>• Segmented faults convert strike-slip to normal faults and are believed to be oblique slip in nature. |

| | |
|---|---|
| 4:32 p.m. | - The third model stops.<br>- A final layer of blue fill is added to the models surface in order to preserve the upper surface during saturation. |

- Because the first two models that were run took exceptionally long periods of time to saturate, an attempt will be made to shorten the time needed by pouring water onto a wet towel lying on the upper surface of the model.

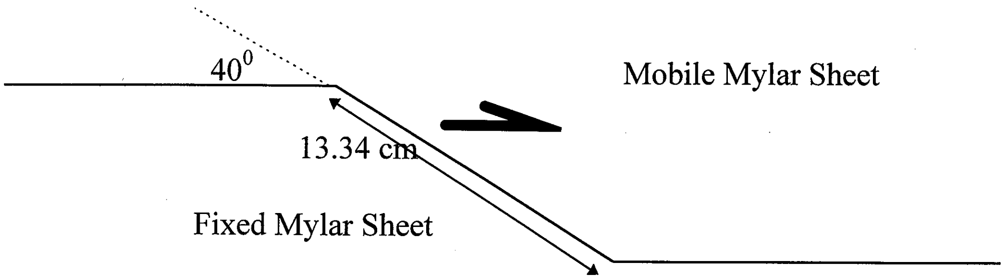
It was determined that the process described above will not work well. Air that is trapped between the grains of sand is not allowed to escape and results in pockets of dry sand in the lower layers. The vertical sections of sand do not stand and allow photos to be taken. The next models will use the prior process, even though it is more time consuming, which uses funnels placed into the sand. This should allow the sand to saturate from the bottom up, forcing out any air along the way.

8-17-95 (BR)

To make it easier to match the descriptions of the model to the appropriate slides, descriptions will be made to coincide with the photograph intervals from now on.

August 25, 1995
Brett Rahe

- Objective: This is the fourth model that will be run and is still considered to be within the learning period whereby the processes involved with creating flawless models, photos, and cross-sections can be perfected. This will ensure that later models will be of higher quality and yield better results. The small side-walls for the deformation apparatus will be used in this experiment.
- The mylar configuration of the floor of the model will have the dimension as shown below. The fixed and mobile mylar sheets that will create the pull-apart basin will be mounted in the same configuration shown on page 47.



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot 10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, next red, and repeating the sequence for a total of six layers each approximately 5 mm in thickness.. Total thickness of the model was 8.13 cm.
- The amount of strike-slip displacement that this model will undergo is 8 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 3.81 cm/hr |
| Number of pulses/second | 8 p/s |
| Displacement | 8 cm |
| Number of Pulses from the Stepper Motor | 60472 pulses |

- Therefore, at eight (8) pulses per second, for a total of 60472 pulses, the model will take 2 hours, 5 minutes, 59 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the.numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.

- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 59).

- The model will be started at 1:40 p.m., August ~~25~~ 24 BB, 1995 and stopped at 3:45:59" p.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS2000 software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 7 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 15 minutes, 45 seconds.

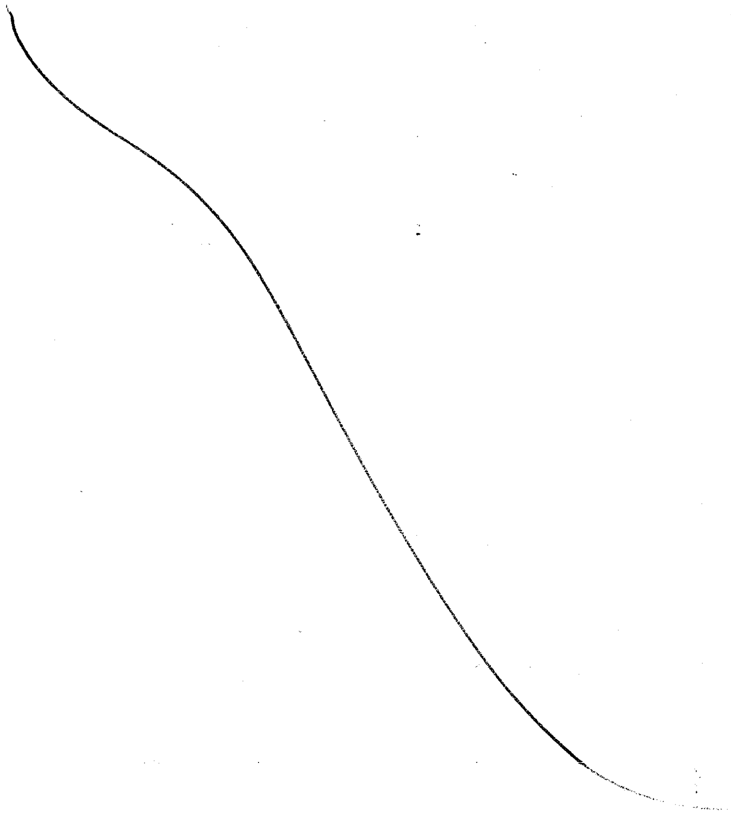
Description of Model Run, August ~~25~~ 24 BB, 1995

| Time | Descriptions of Time Events |
|---|---|
| 1:40 p.m. | • Model started |
| 1:47 p.m. | • The first two faults bounding the down-dropped portion of the graben can be faintly seen with the lowangle lighting. |
| 1:54 p.m. | • Normal displacement along the two initial graben bounding faults continuiing to take place.<br>• Curving along the left boundary fault into the strike-slip portion of the model is evident but does not look to be accomplished by a series of segmented faults. |
| 1:55:45" p.m. | • 1 cm of displacement.<br>• First layer synsedimentary fill added to the surface of the model.<br>• Color yellow. |
| 2:01 p.m. | • Boundary faults have propagated up through the yellow layer of fill.<br>• Along the edge of the right boundary fault, it is beginning to merge with the strike-slip portion of the model by what appear to be a series of segmented faults.<br>• Boundary faults appear to be rather steep, similar to the previous models that have been run.<br>• What appears to be a strike-slip fault has developed and runs through the interior of the graben in a diagonal fashion from the lower right of the pull-apart to the top left. It has dextral displacement. It is assumed to be strike-slip because it soes not dip to either side and is seen only as a zone of shear on the surface of the model. |
| 2:08 p.m. | • Reidel shears have developed along the strike-slip portion of the model.<br>• The faults bounding the graben have experienced further normal displacement and are trying to merge into the strike-slip part of the model by what appear to be segemented oblique-slip faults. |
| 2:11:30" p.m. | • 2 cm of displacement.<br>• Second layer of synsedimentary fill added to the surface of the model.<br>• Color blue. |
| 2:15 p.m. | • The two faults that formed first have propagated through the most recent layer of synsedimentary fill.<br>• No new bounding faults have formed yet, none at least that have appeared at the surface of the model.<br>• A small pull-apart has formed along the strike-slip portion of the model. |
| 2:22 p.m. | • Displacement continues along the two major bounding faults of the graben.<br>• The strike-slip section running through the middle of the graben has developed a small push-up structure. This seems rather strange and is hypothesized to be the result of walls 1 and 2 (pg. 47) being to xlose in proximity to the active portion of the pull-apart model. |
| 2:27:15" p.m. | • 3 cm of displacement. |

| | |
|---|---|
| | • Third layer of synsedimentary fill added to the surface of the model<br>• Color yellow. |
| 2:29 p.m. | • Bounding faults have propagated through the latest yellow layer of synsedimentary fill.<br>• Segmentation of the oblique-slip faults transferring normal to strike-slip displacement can be seen breaking through the upper layer of the model. |
| 2:36 p.m. | • A normal fault has developed in an odd orientation, almost parallel to the direction of strike-slip in the model. It is located in the center of the graben and runs from the left boundary fault to the right where it joins with the strike-slip section cutting through the center of the graben.<br>• Displacement along the faults bounding the graben appears to have increased because previous layers of blue synsedimentary fill can be seen along the edge of the graben.<br>• The segmented oblique-slip faults continue to transfer normal to strtike-slip displacement. |
| 2:43 p.m. | • Further displacement on all faults.<br>• Segmented oblique-slip faults are becoming easier to see. |
| 2:43 p.m. | • 4 cm of displacement.<br>• Fourth layer of syssedimentary fill added to the model.<br>• Color blue |
| 2:49 p.m. | • Faults have propagated through the layer of synsedimentary fill.<br>• The strike-slip fault has also propagated through the layer of sedimentary fill.<br>• The graben is now noticeably wider than at the beginning of the model. |
| 2:56 p.m. | • What was previously described as a strike-slip fault cutting through the central section of the graben now appears to be an oblique-slip normal fault which dips towards the right side of the model.<br>• An additional and similar fault has developed almost parallel to the fault described above.<br>• The graben is continuing to drop further. |
| 2:58:45" p.m. | • 5 cm of displacement.<br>• Fifth layer of synsedimentary fill added to the model.<br>• Color yellow. |
| 3:03 p.m. | • The faults bounding the graben have propagated through the top layer of graben fill.<br>• The oblique-slip faults cutting through the central section of the graben are barely discernable at the surface.<br>• The graben has become considerably wider now that at the beginning of the model simulation period. |
| 3:10 p.m. | • A complex array of linked faults has developed at the upper left portion of the model where the strike-slip section merges into the faults of the graben itself. This may be due boundary effects caused by wall 1 of the model being too close to the graben formed by the mylar basement. As wall 1 moves with dextral displacement it encounters the graben and causes faults not usually associated with a pull-apart basin to form. These faults resemble linked faults in the previous simulations that formed between Reidel shears along the strike-slip portion of the model. This boundary effect might be eliminatedeither by replacing the small side walls of the model with the longer ones, or, by creating a smaller offset with the mylar basement between the strike-slip sections of the model.<br>• Segmented oblique-slip faults can still be seen transferring normal to strike-slip slip displacement along the lower edge of the graben.<br>• The graben continues to widen although there does not seem to be as much normal displacement occurring on the bounding faults of the graben. |
| 3:14:30" p.m. | • 6 cm of displacement.<br>• Sixth layer of synsedimentary fill added to the model.<br>• Color blue.<br>• Error occurred, a divot was made in the model with the sieve used to place synsedimentary fill into the graben. This affect may be seen in the cross-sections. Care |

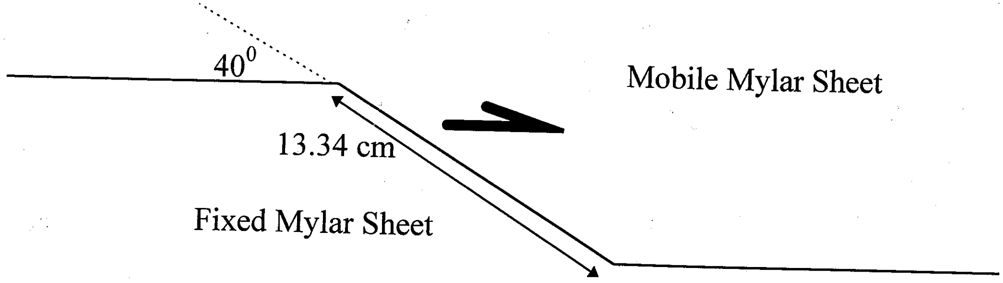
| | |
|---|---|
| | must be taken in the future to ensure that this does not happen again. |
| 3:17 p.m. | • Faults are just now beginning to propagate up through the surface of the model. |
| 3:24 p.m. | • Faults have propagated up through the last layer of blue synsedimentary fill but appear to have been affected by the error induced by dropping the seive onto the surface of the model. |
| 3:30:15" p.m. | • 7 cm of displacement.<br>• Seventh and last layer of synsedimentary fill added the the surface of the model.<br>• Color yellow. |
| 3:31 p.m. | • Nothing has propagated up through the layer of fill at this time. |
| 3:38 p.m. | • Faults have propagated through the layer of fill.<br>• The pull-apart basin appears to be assymetric, like the previous models, and is thought to be due to the mobile mylar sheet being on top of the fixed sheet. If the situation were reversed, it is thought that a more symmetrical pull-apart basin would develop. |
| 3:45 p.m. | • on the left side of the model, more displacement appears to be being taken up on the normal faults on the interior of the graben since displacement on the fault scarps on the outermost bounding fault has decreased.<br>• Dips of the faults still appear to be very steep.<br>• At least three and possibly four normal faults are present on the left side of the graben and dip towards the right. The right side of the graben is dominated by a single fault. |
| 3:45:59" p.m. | • Model was stopped |

- The strike-slip faults that developed through the central portion of the graben are similar to those described by Ken McClay (Geology, v. 23, pp. 711-714) which he called Cross-Basin Faults.
-



August 29, 1995

- Objective: This is the fifth model that will be run and is still considered to be within the learning period whereby the processes involved with creating flawless models, photos, and cross-sections can be perfected. This will ensure that later models will be of higher quality and yield better results. The small side-walls (20 inches each) for the deformation apparatus will be used in this experiment.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $40^0$ step measuring 13.34 cm, the Mobile Mylar Sheet will be placed underneath the Fixed Mylar Sheet. It is hypothesized that a more symmetrically shaped graben will form between the right-stepping strike-slip faults.



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot 10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by red, white, blue, and then repeating the sequence for a total of six layers, each approximately 1 cm in thickness.. Total thickness of the model was approximately 8.13 cm.
- The amount of strike-slip displacement that this model will undergo is 8 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 3.81 cm/hr |
| Number of pulses/second | 8 p/s |
| Displacement | 8 cm |
| Number of Pulses from the Stepper Motor | 60472 pulses |

- Therefore, at eight (8) pulses per second, for a total of 60472 pulses, the model will take 2 hours, 5 minutes, 59 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.

- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 63).

| | |
|---|---|
| | described by McClay (1995, see references).<br>• Segmented oblique-slip faults have propagated up through the layer of synsedimentary fill and are again clearly visible.<br>• The graben has dropped down further. |
| 1:47:15" p.m. | • 3 cm of displacement.<br>• Third layer of synsedimentary fill added to the surface of the model<br>• Color yellow. |
| 1:49 p.m. | • The only noticeable change in the model at this time is that the outermost normal faults on either side of the graben have propagated up through the second layer of synsedimentary fill (yellow layer). |
| 1:56 p.m. | • While both of the normal faults that bound the sides of the graben have propagated up through the blue layer of synsedimentary fill, the left side is continuous and smooth, the fault on the right side looks segmented into several smaller faults.<br>• The two normal faults crossing obliquely to the main axis of the graben have also propagated up through the layer of yellow fill. |
| 2:03:00" p.m. | • 4 cm of displacement.<br>• Fourth layer of synsedimentary fill added to the model.<br>• Color blue |
| 2:03 p.m. | • All faults appear to continuing to deform as before.<br>• A new normal fault appears to be forming along the lower portion of the graben in an orientation similar to the two faults cutting the main axis of the graben. |
| 2:10 p.m. | • Most of the faults associated with the main pull-apart basin have propagated through the latest layer of yellow synsedimentary fill.<br>• The graben is once again noticeably wider and the normal faults bounding it continue to dip steeply. |
| 2:17 p.m. | • The right side of the graben is composed of a couple of different normal faults.<br>• The two normal faults on the interior of the pull-apart, oblique to its axis are now easily visible of the surface of the model. |
| 2:18:45" p.m. | • 5 cm of displacement.<br>• Fifth layer of synsedimentary fill added to the model.<br>• Color yellow. |
| 2:24 p.m. | • Of the two normal faults bounding the right side of the graben, most of the displacement seems to now be being taken up by the one more towards the interior of the pull-apart and oblique to the main axis. This is because the size of the shadow cast from it is larger than the normal fault further from the center of the graben.<br>• Displacement on the left side of the graben is still dominated by a single normal fault though some displacement is being taken up on others. |
| 2:31 p.m. | • As described at 1:56 p.m., the fault on the right side of the pull-apart is segmented and is not smooth along the surface. The normal faults on the left side of the model is still smooth.<br>• The graben has further deepened and has become slightly wider.<br>• Most of the displacement is being taken up by the main bounding fault on the left side of the graben and the smaller normal fault closer to the interior of the basin on the right. |
| 2:34:30" p.m. | • 6 cm of displacement.<br>• Sixth layer of synsedimentary fill added to the model.<br>• Color blue.<br>• Error occurred, a divot was made in the model with the sieve used to place synsedimentary fill into the graben. This affect may be seen in the cross-sections. Care must be taken in the future to ensure that this does not happen again. |
| 2:38 p.m. | • The more active faults have propagated through the latest layer of blue synsedimentary fill. |
| 2:45 p.m. | • A peculiar normal fault has developed which dips towards the left. It begins in the lower interior portion of the graben and run almost parallel to the outermost fault. At about the midpoint of the graben its strike changes abruptly and makes a jog towards |

- The model will be started at 1:00 p.m., August 29, 1995 and stopped at 3:05:59" p.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS2000 software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 7 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 15 minutes, 45 seconds.

## Description of Model Run, August 29, 1995

| Time | Descriptions of Time Events |
|---|---|
| 1:00 p.m. | • Model started. |
| 1:07 p.m. | • Two faults have formed which are bounding the graben which has only dropped down a small amount.<br>• The left fault is showing a slight curvature where it changes from normal to strike-slip displacement along the left side of the model. |
| 1:14 p.m. | • Displacement on the left boundary fault of the graben progresses, the right side of the graben is now bounded by what seem to be two faults, the one that initially formed, and a splay coming off of it.<br>• Riedel shears are now faintly appearing along the strike-slip portions of the model. |
| 1:15:45" p.m. | • 1 cm of displacement.<br>• First layer synsedimentary fill added to the surface of the model.<br>• Color yellow. |
| 1:21 p.m. | • The two faults bounding the graben have propagated up through the yellow layer of synsedimentary fill.<br>• Both are curving into the strike-slip portions of the model by segmented sections of possible oblique-slip faults.<br>• A fault is now visible in the central portion of the graben oblique to its axis. It could be a strike-slip fault though in the last model that was run the same thing developed and eventually turned into a normal fault. |
| 1:28 p.m. | • Faults bounding the graben appear to be very steep.<br>• The fault that is cutting through the central part of the graben is a normal fault which is dipping towards the lower left of the model. It does not follow the orientation of the main axis of the graben.<br>• Oblique-slip faults that are transferring normal to strike-slip displacement are now easily seen to be segmented along the top edge of the pull-apart basin that has formed.<br>• The graben has both widened and deepened a large amount. |
| 1:31:30" p.m. | • 2 cm of displacement.<br>• Second layer of synsedimentary fill added to the surface of the model.<br>• Color blue. |
| 1:35 p.m. | • The only noticeable change in the model at this time is that the outermost normal faults on either side of the graben have propagated up through the second layer of synsedimentary fill (blue layer). |
| 1:42 p.m. | • The fault on the right side of the graben has become segmented into several faults at this time.<br>• Two new normal faults have formed within the interior of the graben forming a new depression that does not follow the orientation of the main graben. These faults run from one side of the graben to the other. They look like the Cross-Basin Faults |

| | |
|---|---|
| | the left side of the pull-apart. |
| 2:50:15" p.m. | • 7 cm of displacement.<br>• Seventh and last layer of synsedimentary fill added the surface of the model.<br>• Color yellow. |
| 2:52 p.m. | • Active faults have begun to propagate up through the last layer of synsedimentary fill which is yellow in color. |
| 2:59 p.m. | • The faults have further continued to propagate through the fill layer. No new faults have been noticed forming on the surface of the model.<br>• The graben has further deepened. |
| 3:05:59" p.m. | • Model stopped |

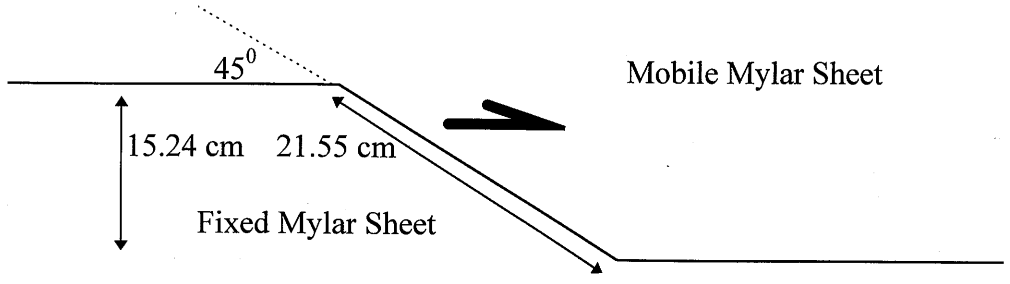
- It appears that the active part of the pull-apart model could have been influenced by boundary effects caused by the walls of the model being too close. To control these effects it is necessary to do one of two things: (1) continue using the small side walls (20 inch) and make the offset strike-slip faults in the mylar smaller, or (2), replace the smaller side walls with the longer ones that were used in the first three model runs. If the longer side walls are used, walls 5 and 6 (see pg 51) will be moved closer to the interior of the model. This will enable a smaller amount of sand to be used in the model and is thus not expected to increase the time needed to saturate the model by more than one or two hours.

- Cross-sections were made at 1cm increments & photographed. Slides are contained in the folder in Bldg. 57, C104.

September 11, 1995

9-11-95

- Objective: This model will be the first in a series of models, all of which will have the same basic scale factors and dimensions. In the set of models, only the step angle between the strike-slip sections of mylar will be changed ($45^0$ for this model). Upon competion of the suite of model a comparison will be made noting changes in fault geometries between faults that are stepped at different angles.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $45^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet. It is hypothesized that a more symmetrically shaped graben will form between the right-stepping strike-slip faults.



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$

$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot 10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 4.76 cm/hr |
| Number of pulses/second | 10 p/s |
| Displacement | 9 cm |
| Number of Pulses from the Stepper Motor | 68031 pulses |

- Therefore, at ten (10) pulses per second, for a total of 68031 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 67).

- The model will be started at 8:00 a.m., September 11, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1.5 cm of strike-slip displacement for the first 7.5 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One and one-half centimeter of displacement will happen every 19 minutes.

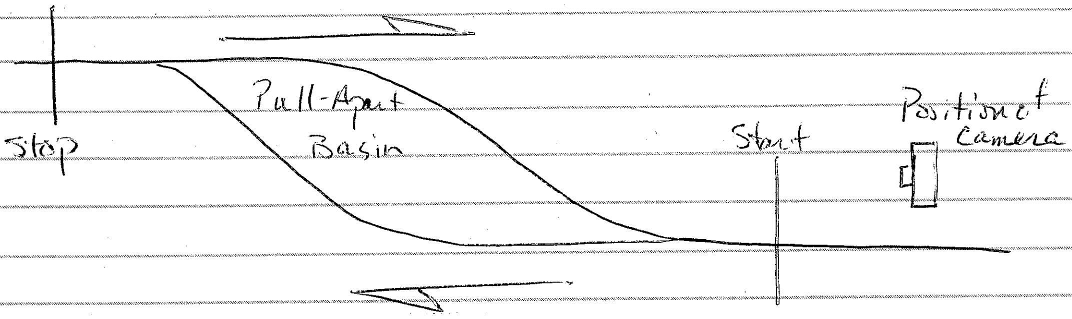
Description of Model Run, September 11, 1995

| Time | Descriptions of Time Events |
|---|---|
| 8:00 am | • Model run started |
| 8:07 am | • Bounding faults of the graben have formed, both have normal displacement.<br>• The fault on the left side of the graben appears to be segmented with an additional part of it forming further away from the center of the graben. |
| 8:14 am | • The normal faults bounding the graben have very irregular strikes.<br>• Riedel shears have formed along the strike-slip sections of the model, near the apex of the pull-apart on both ends.<br>• The graben appears to have widened and deepened.<br>• As with the last two models that were run, what appears to be a strike-slip fault has formed in the central part of the graben and runs across the entire length of the graben. This may be due to fault segmentation....when the deformation is for the pull-apart is controlled by normal and strike-slip faults only, no oblique faults. |
| 8:19 am | • First layer of synsedimentary fill was added to the surface of the model, 1.5 cm displacement.<br>• Color yellow. |
| 8:21 am | • Faults have propagated up through the yellow layer of fill.<br>• Riedel shears have formed more extensively throughout the strike-slip sections of the model. |
| 8:28 am | • A large amount of normal displacement has taken place along the bounding faults to the graben.<br>• The fault that runs through the central part of the graben has formed what looks like a right step. The faults have appeared to have switched from more strike-slip to normal displacement, both dipping towards the interior of the basin. This may also indicate that a more symmetrical graben is forming, unlike the asymmetric models that were previously created. |
| 8:35 am | • Normal displacement continues to occur on the two main faults bounding the graben causing it to both widen and deepen further.<br>• Displacement also continues to happen on the two stepped faults in the interior of the basin. |
| 8:38 am | • Second layer of synsedimentary fill is added to the graben, 3 cm displacement.<br>• Color, blue. |
| 8:42 am | • Based on the size of the fault scarps for the two major bounding faults of the graben, the fault on the right side appears to be experiencing a larger amount of displacement.<br>• Where the bounding faults merge into the strike-slip section of the model, they appear to be several stepped faults or a single fault with a very irregular strike.<br>• Some of the Riedel shears have been further linked together by additional shears.<br>• Several faults now make up the left hand side of the pull-apart, the right hand side |

| | |
|---|---|
| | appears to still be dominated by a single fault indicating that the graben may not be as symmetrical as was originally thought.<br>• Scarps associated with the normal faults are very steep. |
| 8:49 am | • Displacement on the left side of the graben is occurring on át least three different faults.<br>• Displacement on the right side of the pull-apart is still controlled by the bounding fault. |
| 8:52 am | • Third layer of synsedimentary fill is added to the pull-apart, 4 cm displacement.<br>• Color, yellow.<br>• The layer was added before it was scheduled because displacement was causing sand to slump off of the faults scarps and possibly distort them when cross-sections are made.<br>• From this point on, additional synsedimentary fill will be added at approximately every 1 cm displacement, up until 7 cm total strike-slip displacement. This will happen about every 12 minutes. |
| 8:56 am | • Faults have propagated up through the latest layer of sedimentary fill.<br>• Most noticeable at this point is a normal faults that has formed which runs from the right boundary fault towards the left side of the model. It has very irregular trace. |
| 9:03 am | • A small pull-apart may be forming along a section of Riedel shears just outside and to the left of the main pull-apart graben.<br>• The graben is continuing to widen |
| 9:04 am | • Fourth layer of synsedimentary fill is added to the pull-apart graben, 5 cm displacement.<br>• Color, blue |
| 9:10 am | • Most of the faults have propagated up through the layer of blue fill.<br>• The small pull-apart between Riedel shears has deepened considerably.<br>• Faults continue to be very irregular along their strike. |
| 9:17 am | • The graben has further widened.<br>• A new fault that appears to be mostly strike-slip is beginning to form as before, cutting through the central portion of the graben along its length. It might turn into a normal fault after more displacement.<br>• The other normal faults continue to deform as before.<br>• Irregularity along strike is still common as well as faults scarp being very steep along the boundary faults of the graben.<br>• Fifth layer of synsedimentary fill added to the graben, 6 cm displacement.<br>• Color, yellow. |
| 9:24 am | • Faults are propagating up through the latest layer of synsedimentary fill.<br>• The fault striking through the length of the graben does indeed now appear to be a normal fault. |
| 9:29 am | • Seventh and final layer of synsedimentary fill added to the surface of the model after 7 cm of displacement.<br>• Color, blue. |
| 9:31 am | • Faults are propagating through the last layer of blue fill. |
| 9:38 am | • No additional faults have formed and all previous are continuing as before. |
| 9:45 am | • While the right side of the pull-apart still appears to be dominated by the most part by a single fault, the left side of the model has displacement occurring on several faults. |
| 9:52 am | • The faults bounding the two sides of the graben differ in appearances. The faults making up the left boundary of the graben have very irregular strikes. The fault bounding the right side of the pull-apart has a more consistent strike, though there is some slight undulation along its strike as well.<br>• Several faults cut through the central portion of the graben though their amount of normal displacement is rather small at this point. They are mostly discernible from their shear zones which are visible on the surface of the model. |
| 9:53:20” am | • Model stopped |

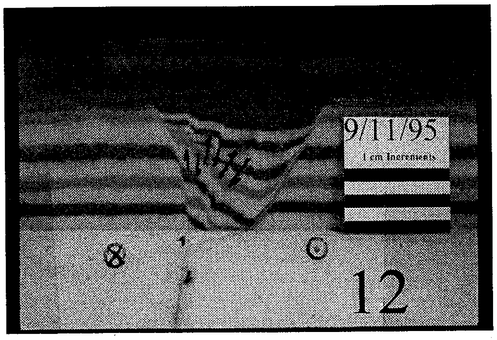
9-12-95
BR

- Cross-sections were made after saturating the model. Cross-sections were cut every 2 cm. ~~be~~ The drawing below shows approximately where cross-sections were begun & stopped.

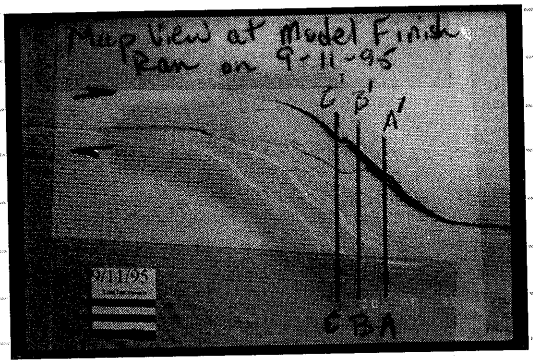


9-15-95 BR

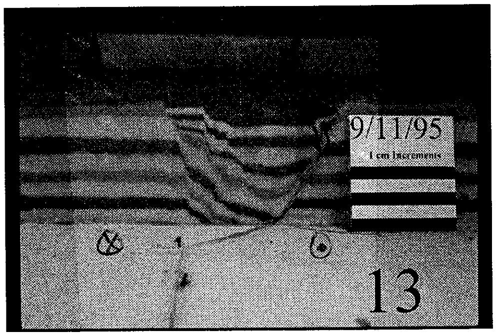
A



A'

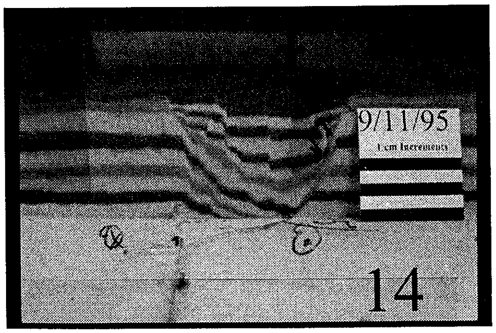


B



B'

C

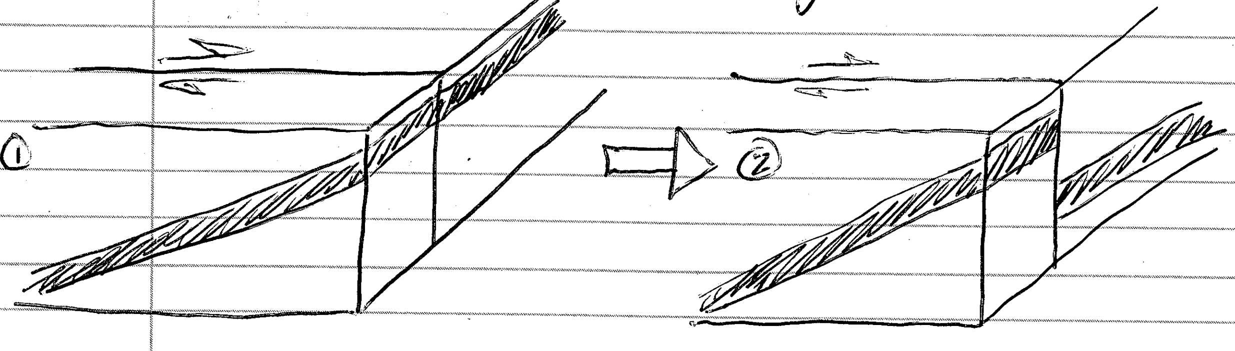


C'

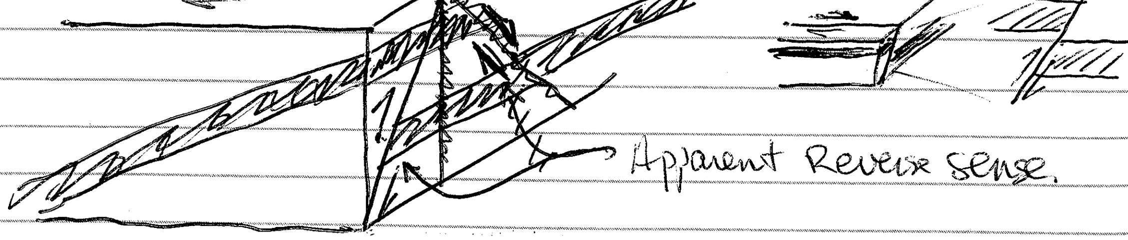
- Several unexpected faults were noted in the x-section slides. Slide 12, 13, & 14 are shown at left. Slide 12 has what appears to be 2 faults with a reverse sense of displacement. After talking about this with Dr. Alan Morris, he suggested that they may ~~be~~ have originally formed as strike-slip faults and then subsequently been rotated away from vertical.

- The faults in the upper right portion of the graben in slides 13 & 14 also show a reverse sense of motion. It is also noted that this fault, seen in both sections, occurs only in the synsedimentary fill above the graben.

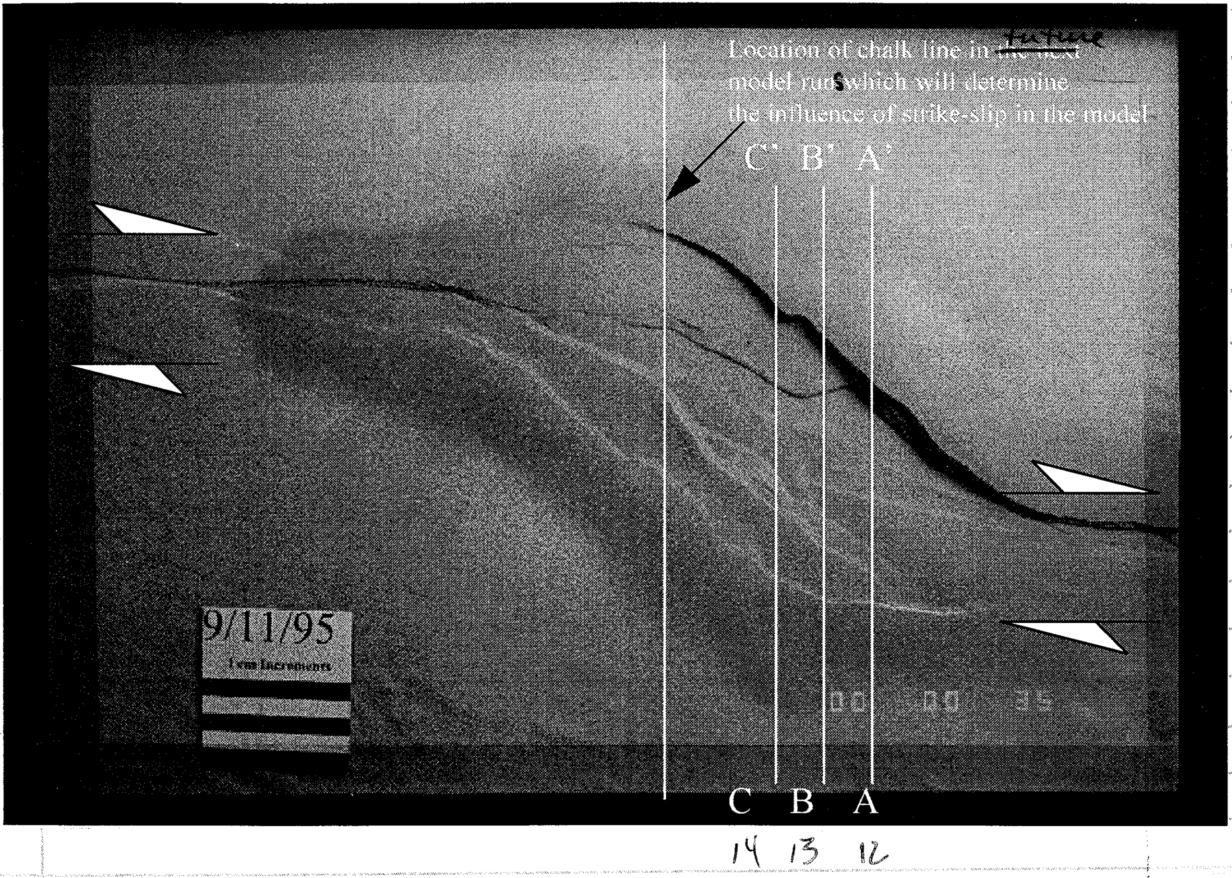
One possible explanation as to the origin of this fault is by strike-slip displacement. Different parts of the graben have different elevations along the surface. Because of this different portions of the same layer of synsedimentary fill may lie at different elevations. If a strike slip fault would cut a layer occupying different elevations, the observed offset could be confused with a reverse fault. A progression of simple block diagrams illustrating this would like the following:



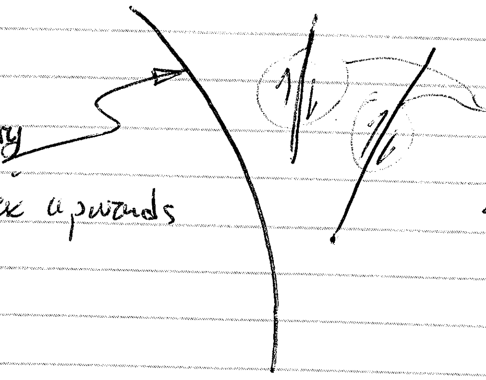
If the strike slip fault ~~is~~ in #② was rotated away from vertical, then this would/could be the final result showing an apparent reverse displacement.



- To see how much influence strike-slip is on this type of fault, a chalk line will be placed on the surface of ~~the next~~ future model at a fixed location. After every synsedimentary layer is added, the chalk line will be placed back onto the surface of the model at the same location ~~at~~ as the original. The approximate location will be similar in position to the drawing below.


Location of chalk line in ~~the next~~ future model runs which will determine the influence of strike-slip in the model

- Another possibility for the reverse sense of displacement came from a discussion with David Ferrill. As an example, if slide #12 (pg 69) is used, notice the shape of the main boundary fault on the left side of the cross-section. It is convex upwards.

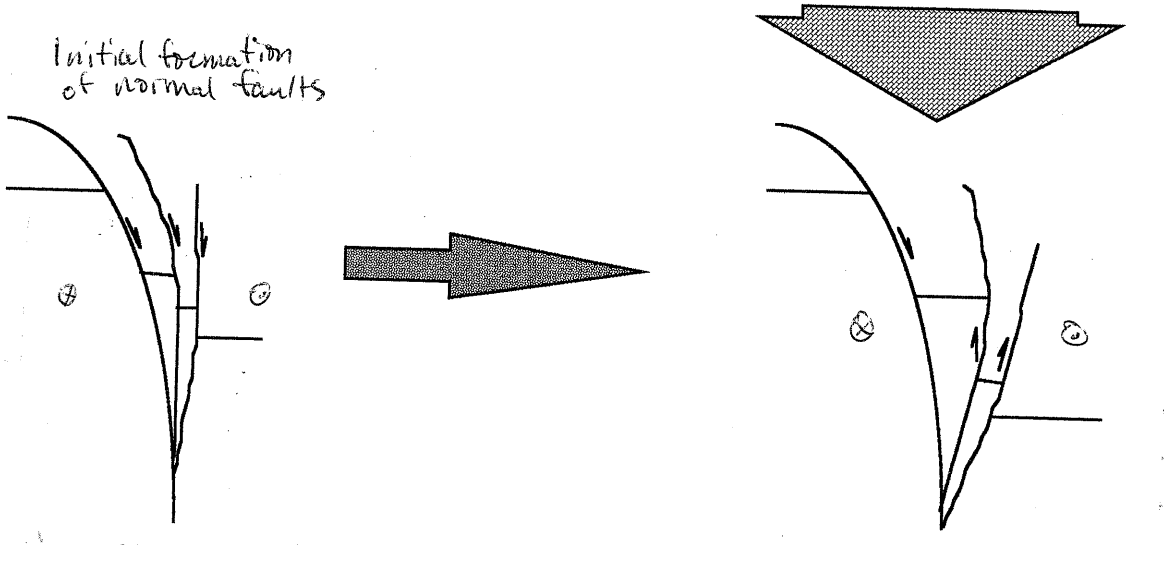


Left Boundary Fault... Convex upwards

Apparent reverse sense of motion on faults seen in slide #12, pg 69.

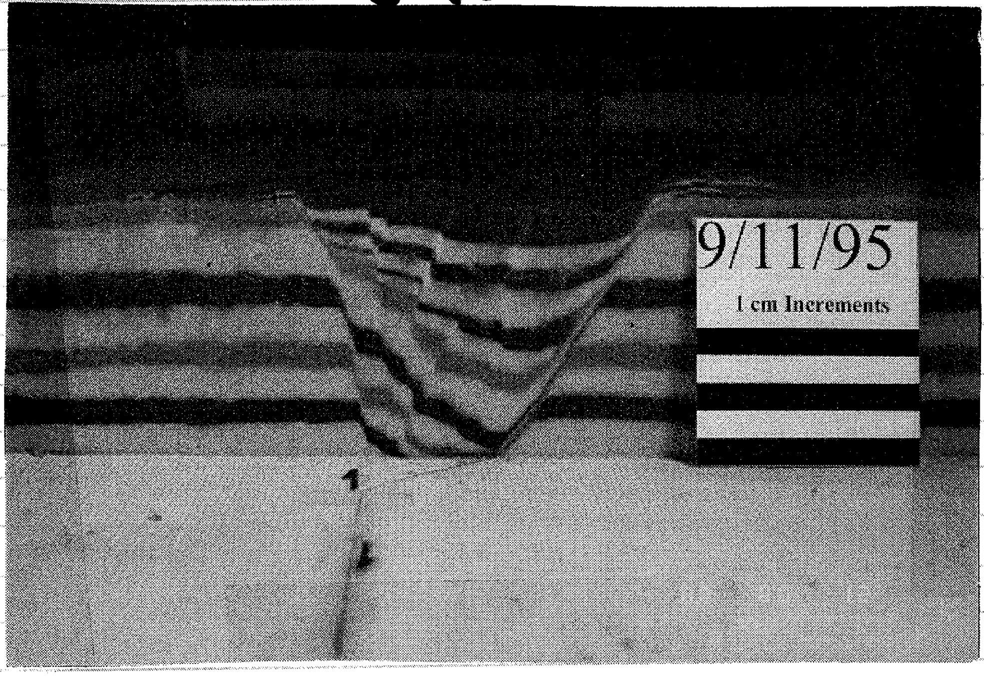
If the faults with reverse components had really formed as normal faults higher up, ~~and~~ then ~~to~~ they could have been rotated in a clockwise manner as extension continued and they were lowered into the graben, this due to the shape of the boundary fault on the left.

Final arrangement seen in slide #12 where the faults have been rotated and now appear to have a reverse sense of displacement



Initial formation of normal faults

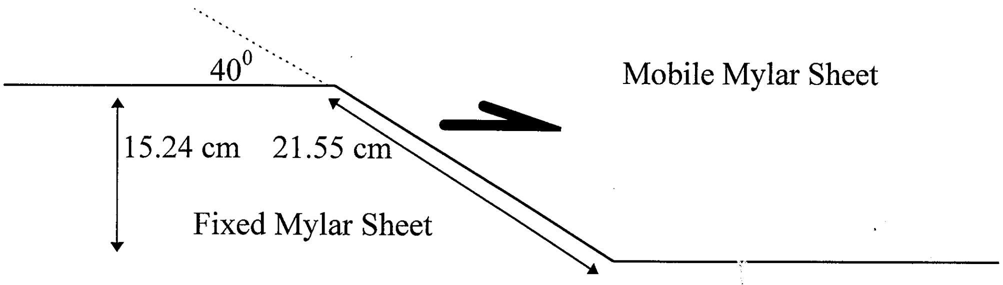
SLIDE 12



Brett Kale/
9-25-95

September 25, 1995

- Objective: This model will be the second model in a series of models, all of which will have the same basic scale factors and dimensions. In the set of models, only the step angle between the strike-slip sections of mylar will be changed ($40^0$ for this model). Upon completion of the suite of model a comparison will be made noting changes in fault geometries between faults that are stepped at different angles. Also noted will be features that are constant from one model to the next.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $40^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet..



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 4.76 cm/hr |
| Number of pulses/second | 10 p/s |
| Displacement | 9 cm |
| Number of Pulses from the Stepper Motor | 68031 pulses |

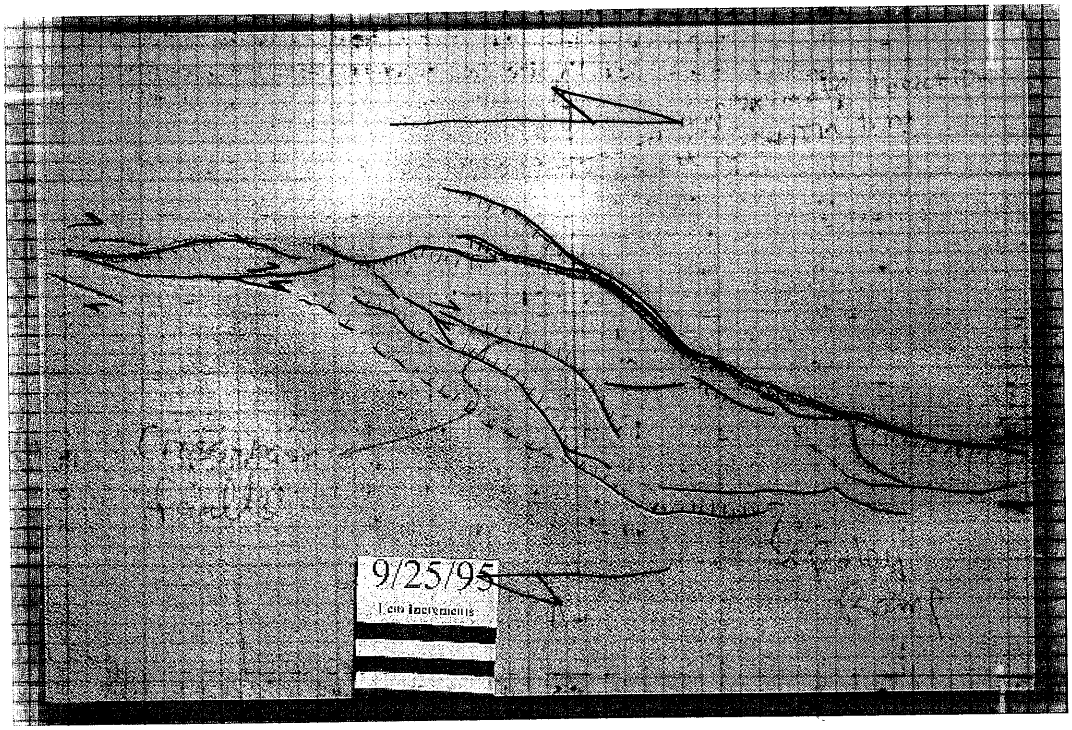
- Therefore, at ten (10) pulses per second, for a total of 68031 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 75).

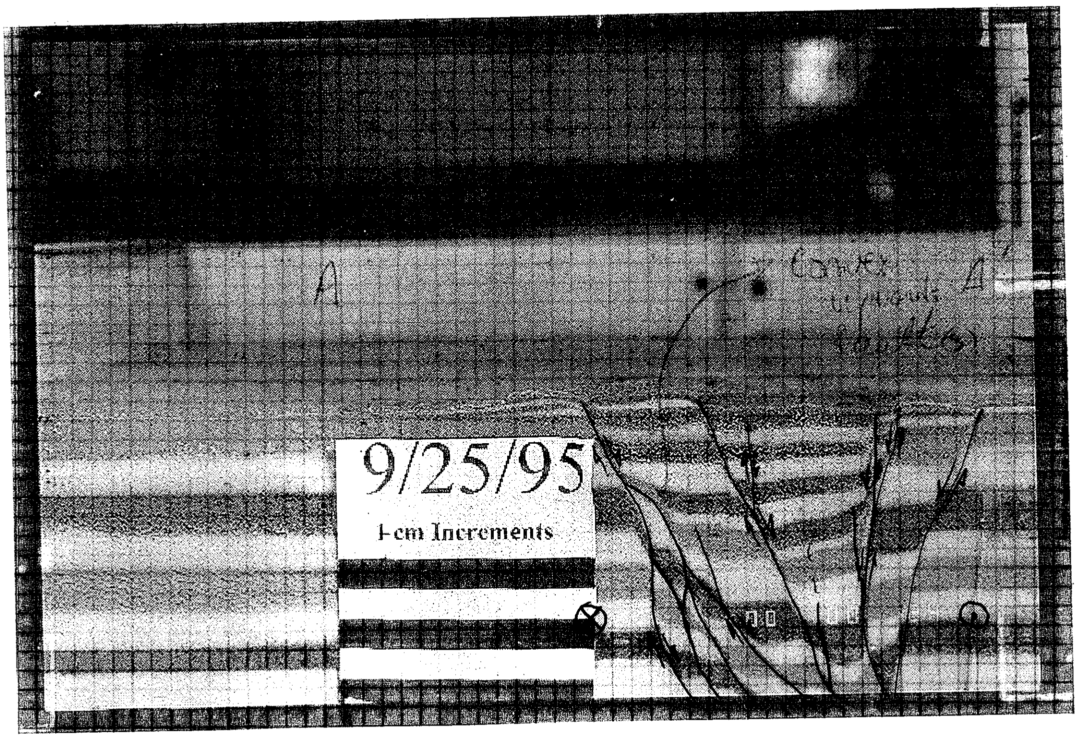
- The model will be started at 8:00 a.m., September 25, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes 36 seconds.

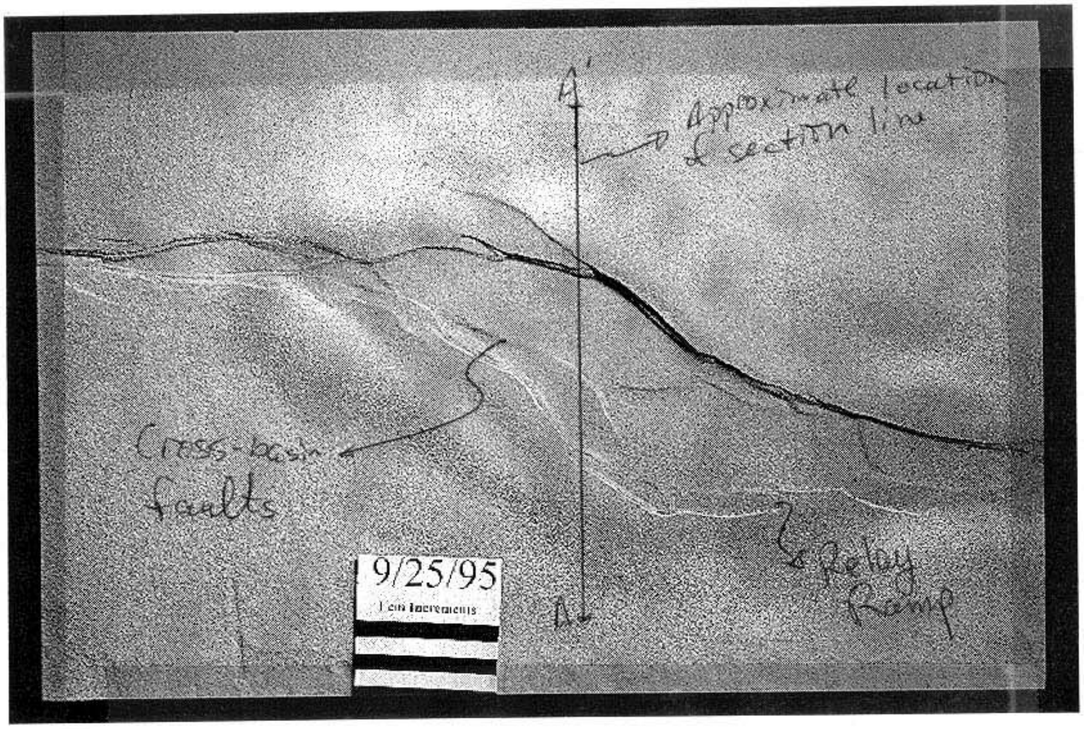
## Description of Model Run, September 25, 1995

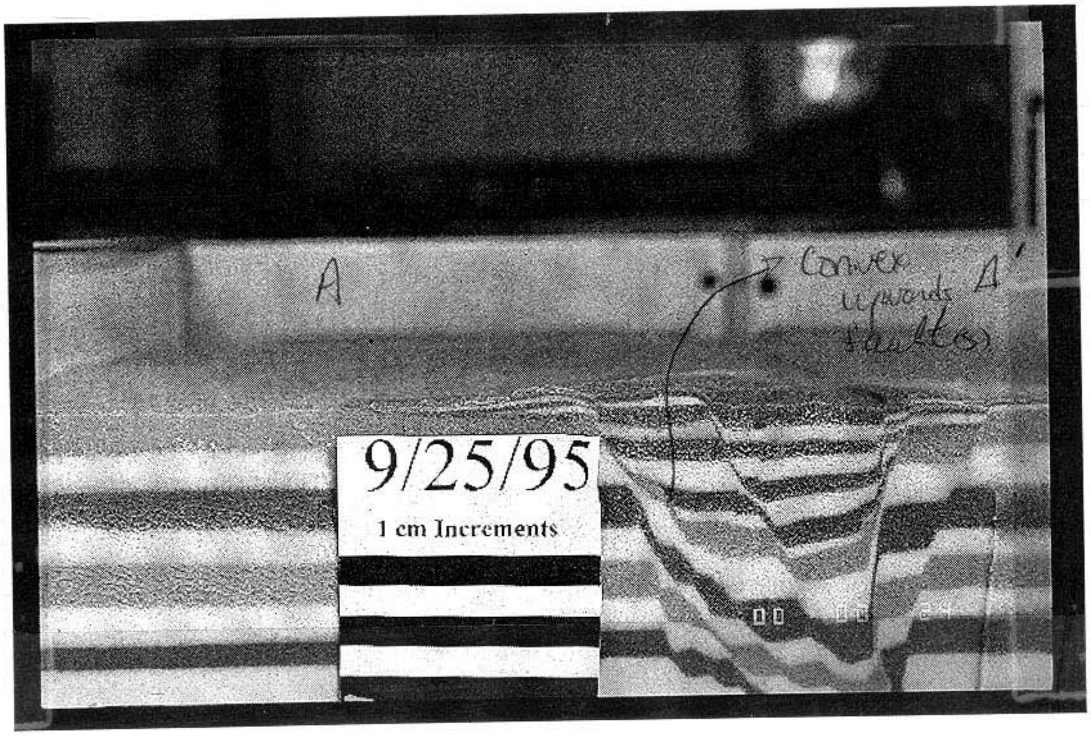
| Time | Descriptions of Time Events |
|---|---|
| 8:00 am | • Model run started. |
| 8:07 am | • Two normal faults, as in all of the other models, which bound either side of what will become the graben.<br>• The fault on the fixed side appears to be more irregular along its strike than the fault on the mobile side of the graben. |
| 8:12:36" am | • First layer of yellow synkinematic fill was added to the graben that has formed in the model. |
| 8:14 am | • Two en-echelon Riedel shears have formed along the lower strike-slip section of the model.<br>• The graben has widened and the boundary faults of the graben have propagated up through the yellow layer of fill.<br>• The hint of a strike-slip fault running from one apex of the graben diagonally across the interior to the other apex can faintly be seen. |
| 8:21 am | • The graben has continued deepen.<br>• The strike-slip fault running diagonally through the central part of the graben is continuing to experience displacement.<br>• An extensive system of Riedel shears have formed along both strike-slip sections of the model.<br>• Another strike-slip, or perhaps fault with reverse sense of displacement, is forming through the upper section of the graben. |
| 8:25:12" am | • Second layer of synsedimentary fill is added to the graben, color blue. |
| 8:28 am | • Faults have propagated up through the last layer of synsedimentary fill.<br>• The two strike-slip faults in the interior of the graben are continuing to experience displacement. |
| 8:35 am | • Another strike-slip fault has formed near the upper apex of the graben and may be linked to one of the nearby Riedel shears.<br>• The graben has further deepened.<br>• The trace of the strike-slip fault nearest the center of the graben appears to have become more irregular since its initial formation. |
| 8:37:48" am | • Third layer of synkinematic fill was added to the graben as fill.<br>• 3 cm displacement. |
| 8:42 am | • Boundary faults have propagated up through the latest layer of fill.<br>• The strike-slip faults near the upper interior portion of the graben have also reappeared. |
| 8:49 am | • The strike-slip fault at the upper apex of the graben appears that it may have now shifted in orientation to a reverse sense of displacement. Its strike has also become more irregular, not straight as it was when it initially formed.<br>• The strike-slip fault running through the center of the pull-apart has developed a bend |

| | |
|---|---|
| | along its strike but for the most part is still purely strike-slip.<br>• The faults bounding the graben have very steep dips associated with them. |
| 8:50:24" | • The fourth layer of synsedimentary fill was added to the pull-apart, color blue.<br>• 4 cm of strike-slip displacement. |
| 8:56 am | • The faults are continuing to undergo displacement as in the description of 8:49 am. |
| 9:03 am | • A new fault can now be noticed towards the interior of the graben from the left boundary fault. It appears to have a normal sense of displacement but if rotated as is suspected to have happened in the other models it may appear to have a reverse sense of displacement when cross-sections are cut.<br>• The strike-slip faults within the interior of the graben look as though they may possibly show a reverse sense of displacement when cross-sections are made.<br>• One of the strike-slip faults near the upper apex of the pull-apart has developed a splay at one end of its trace.<br>• The fifth layer of synsedimentary fill was added to the graben, color yellow.<br>• 5 cm of displacement. |
| 9:10 am | • Graben has widened and further deepened.<br>• The additional normal fault on the left interior side of the graben appears to be taking up more of the displacement for that section of the pull-apart. |
| 9:15:36" am | • The sixth layer of synkinematic fill was added to the pull-apart, color blue.<br>• 6 cm if displacement. |
| 9:17 am | • Faults have propagated up through the latest layer of fill. |
| 9:24 am | • Most of the normal displacement along the left side of the graben is now being taken up on a new fault, not the boundary fault that formed initially. It looks as though the fault taking up this displacement may join the strike-slip fault at the upper apex of the pull-apart. At some point along this fault then there must be taking place some form of oblique-slip shearing in the sand.<br>• As a result, a narrower section of the graben is only now actively being part of the pull-apart. In other words the active portion of the graben is not as wide as it was at previous times of the model run. |
| 9:28:12" am | • This being 7 cm of strike-slip displacement, another layer of synsedimentary fill was added to the interior of the pull-apart, color yellow. |
| 9:31 am | • Faults are just now starting to propagate through the last layer of yellow fill.<br>• The photograph at this time (# 28) should show the smaller active area of the pull-apart that is now active. |
| 9:38 am | • Both sides of the graben look have approximately equal displacement.<br>• Fault traces on the left side of the pull-apart are irregular.<br>• Several relay ramps can also be seen along the normal faults in the model.<br>• There is still a strike-slip fault cutting through the center of the graben, from one apex to the other. |
| 9:40:48" am | • The final layer of synkinematic fill was added to the surface of the pull-apart, color blue.<br>• 8 cm of displacement. |
| 9:45 am | • Faults have propagated up through the latest layer of fill.<br>• The active part of the pull-apart is still narrower than it once was. |
| 9:52 am | • Normal displacement at the upper section of the graben has shifted like the left side to a fault that is more towards the interior of the pull-apart.<br>• Other than this, all of the faults active in the previous description are still active. |
| 9:53:20" am | • The model run stopped. |


9/25/95
1-cm Increments


A
Convex
upwards
A
9/25/95
1-cm Increments

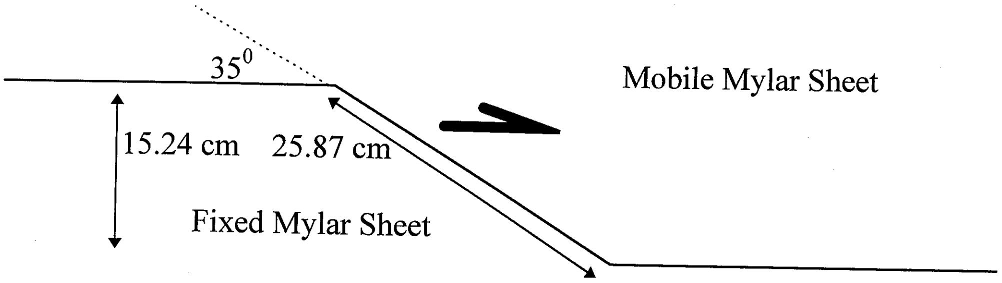

A'
Approximate location of section line
Cross-basin faults
Relay Ramp
9/25/95
1 cm Increments
A


A
Convex upwards fault(s)
A'
9/25/95
1 cm Increments

Brett Rahe
10-2-95

October 2, 1995

- Objective: This model will be the third model in a series of models, all of which will have the same basic scale factors and dimensions. In the set of models, only the step angle between the strike-slip sections of mylar will be changed ($35^0$ for this model). Upon completion of the suite of model a comparison will be made noting changes in fault geometries between faults that are stepped at different angles. Also noted will be features that are constant from one model to the next.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $35^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet..



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1 \text{ cm}/100{,}000 \text{ cm} = 1\cdot 10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 4.76 cm/hr |
| Number of pulses/second | 10 p/s |
| Displacement | 9 cm |
| Number of Pulses from the Stepper Motor | 68031 pulses |

- Therefore, at ten (10) pulses per second, for a total of 68031 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 79).

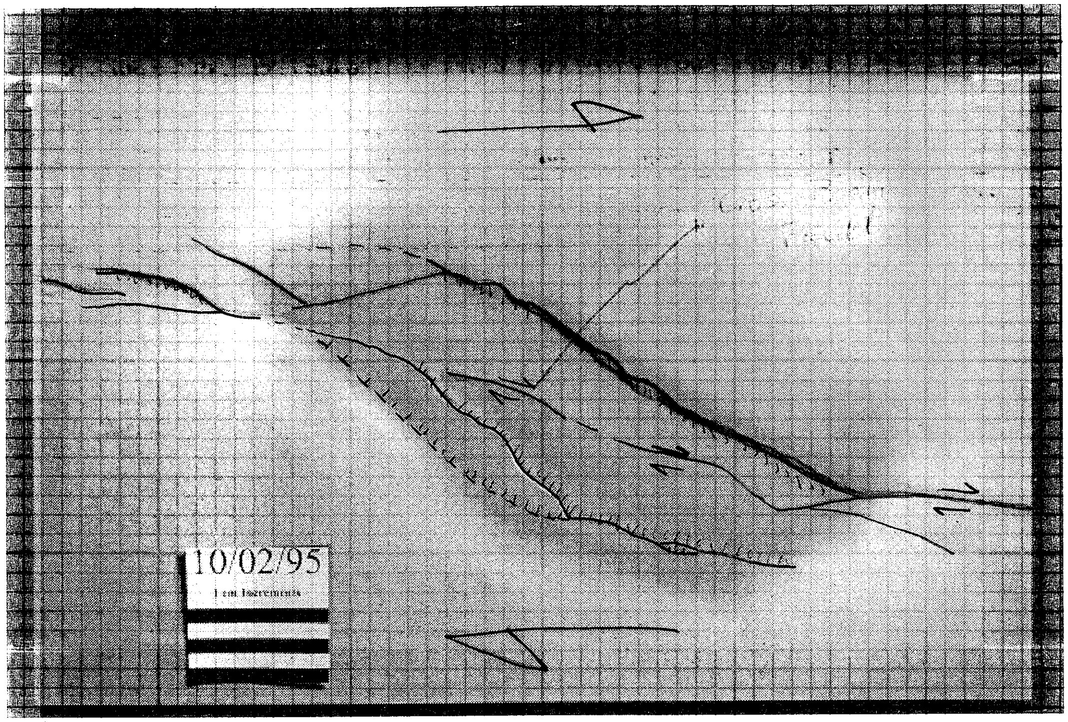
- The model will be started at 8:00 a.m., October 2, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes 36 seconds.

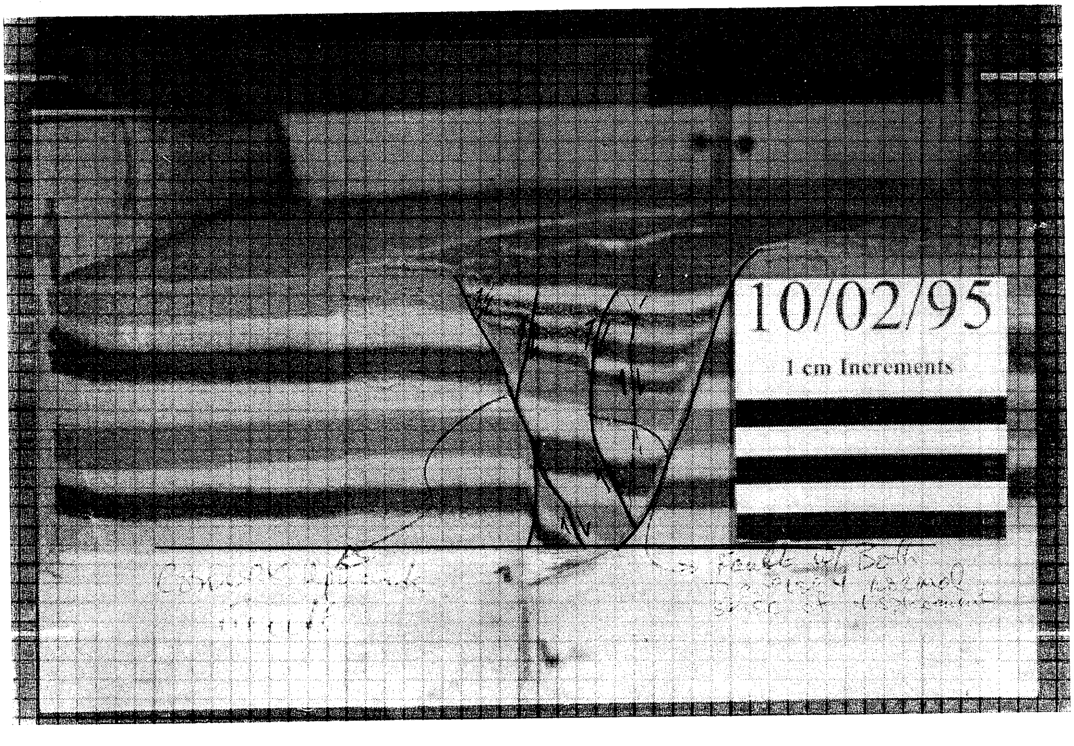
Description of Model Run, October 2, 1995

| Time | Descriptions of Time Events |
|---|---|
| 8:00 am | • Model run started. |
| 8:07 am | • The two major boundary faults of the graben have formed.<br>• They seem to be closer together than in previous models with higher degrees of offset between the strike-slip sections of the model. |
| 8:12:36" am | • First layer of synkinematic fill added to the graben, color yellow.<br>• 1 cm strike-slip displacement. |
| 8:14 am | • Two new faults have formed outside of the two initial ones. They now bound the graben on either side.<br>• A system of Riedel shears have begun to form on both strike-slip sections of the model. |
| 8:21 am | • The graben itself has become wider and what appears to be a strike-slip fault has formed near the upper-left portion of the model.<br>• Depth of the graben has also increased as well.<br>• The system of Riedel shears has also continued to form. |
| 8:25:12" am | • Second layer of synsedimentary fill is added to the graben, color blue.<br>• 2 cm of displacement. |
| 8:28 am | • Faults are propagating up through the layer of synsedimentary fill. |
| 8:35 am | • The graben is continuing to drop.<br>• The strike-slip faults in the interior of the graben are also continuing to form.<br>• No new active normal have formed as of yet. |
| 8:37:48" am | • The third layer of synkinematic fill was added to the graben, color yellow.<br>• 3 cm of displacement. |
| 8:42 am | • Faults have propagated up through the layer of fill just added to the graben.<br>• The strike-slip faults have also reformed through the fill layer. |
| 8:49 am | • The strike-slip faults seem to have moved further into the pull-apart |
| 8:50:24" | • The fourth layer of fill is added to the graben, color blue.<br>• 4 cm of displacement. |
| 8:56 am | • Faults have propagated up through the latest layer of blue fill. |
| 9:03 am | • The strike-slip faults have further developed in the interior of the basin are almost go from one apex to the other.<br>• The fifth layer of fill was added to the interior of the graben, color yellow.<br>• 5 cm of displacement. |
| 9:10 am | • The strike-slip faults seem to be the only ones that are visibly active in the interior of the basin. They may have some normal displacement taking place on them now. |
| 9:15:36" am | • The sixth layer of synkinematic fill was added to the pull-apart, color blue.<br>• 6 cm of displacement. |
| 9:17 am | • Faults are just now propagating up through the layer of synkinematic fill. |

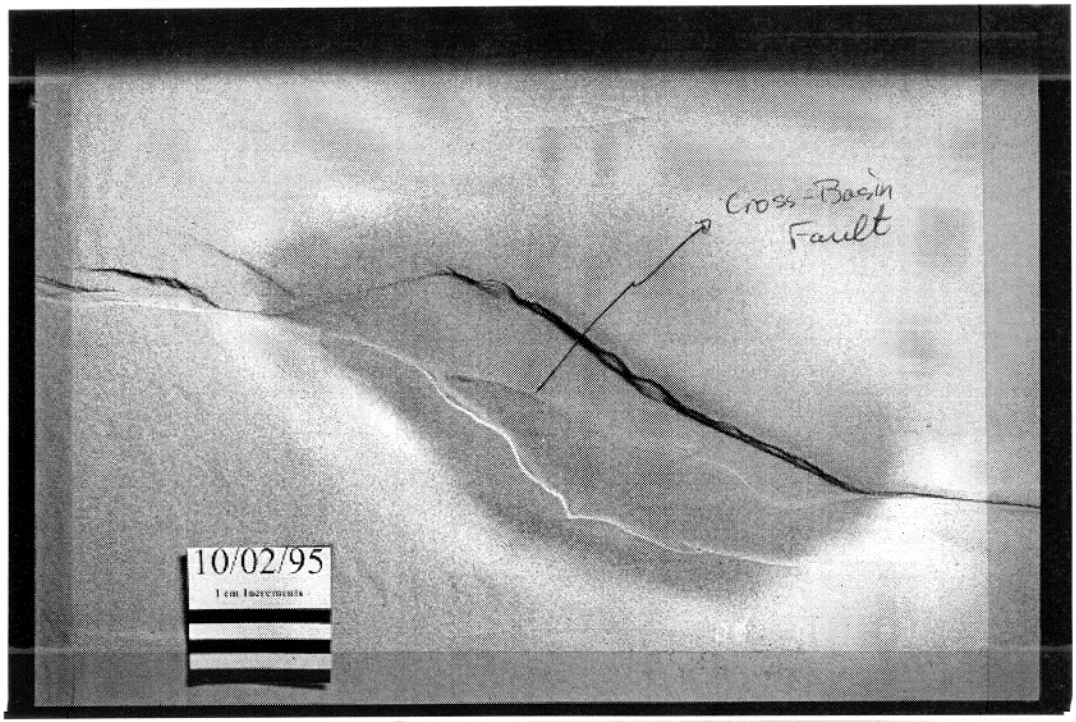
| | |
|---|---|
| 9:24 am | • The active part of the left side of the graben now appears to have shifted more to the interior of the pull-apart.<br>• A strike-slip fault has formed in the interior of the graben. |
| 9:28:12" am | • The seventh layer of synkinematic fill was added to the model.<br>• 7 cm of displacement. |
| 9:31 am | • Faults are just now propagating up through the layer of synkinematic fill. |
| 9:38 am | • The strike-slip faults in the interior of the graben are continuing to experience deformation. |
| 9:40:48" am | • The eighth and final layer of fill was added to the interior of the pull-apart.<br>• 8 cm displacement, color blue. |
| 9:45 am | • Faults are just now propagating up through the layer of synkinematic fill.<br>• The active portion of the pull-apart is much narrower. |
| 9:52 am | • |
| 9:53:20" am | • Model run stopped. |

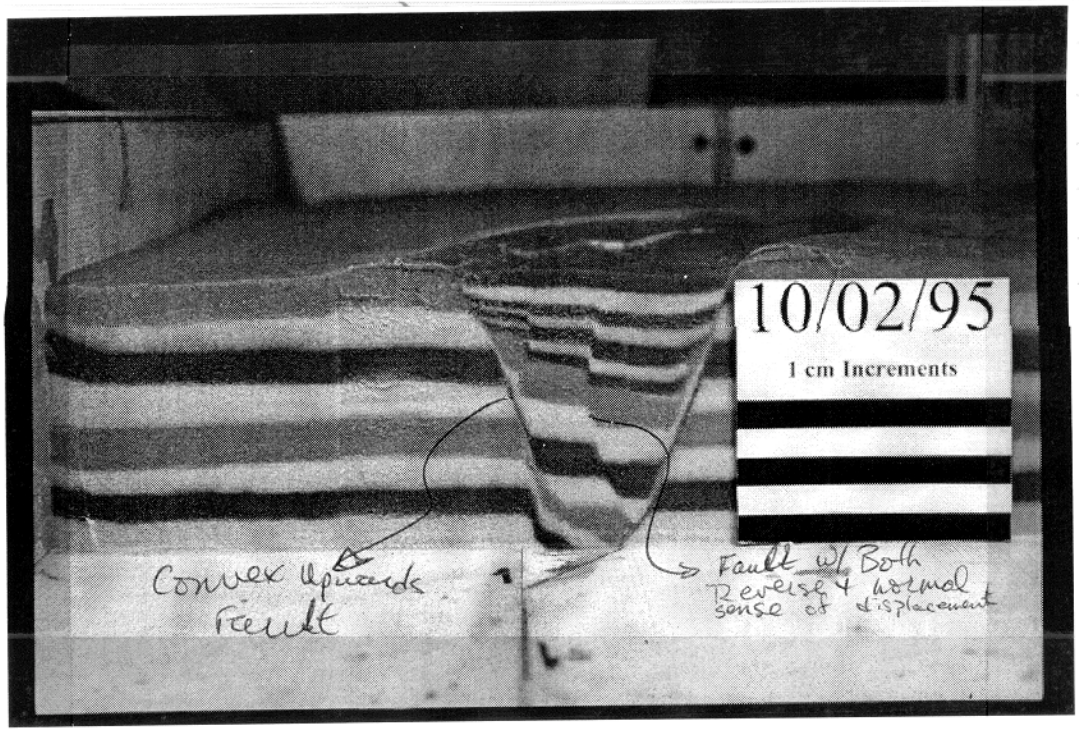
Cross-Sections made approximately every 1.5 cm





Cross-Sections made approximately every 1.5cm

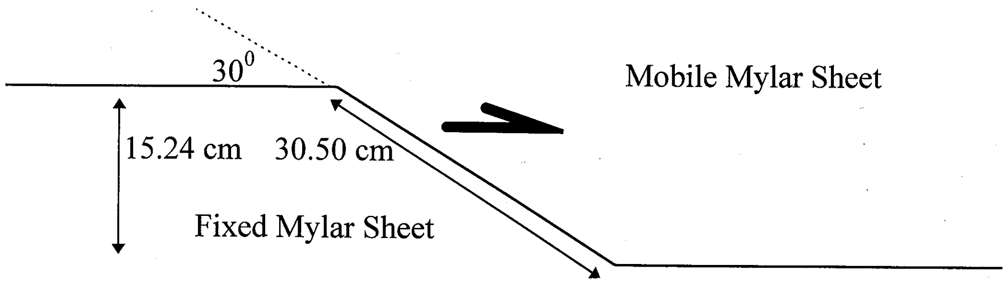




10-5-95

October 5, 1995

- Objective: This model will be the fourth model in a series of models, all of which will have the same basic scale factors and dimensions. In the set of models, only the step angle between the strike-slip sections of mylar will be changed ($30^0$ for this model). Upon completion of the suite of model a comparison will be made noting changes in fault geometries between faults that are stepped at different angles. Also noted will be features that are constant from one model to the next.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $30^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet..



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 4.76 cm/hr |
| Number of pulses/second | 10 p/s |
| Displacement | 9 cm |
| Number of Pulses from the Stepper Motor | 68031 pulses |

- Therefore, at ten (10) pulses per second, for a total of 68031 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 83).

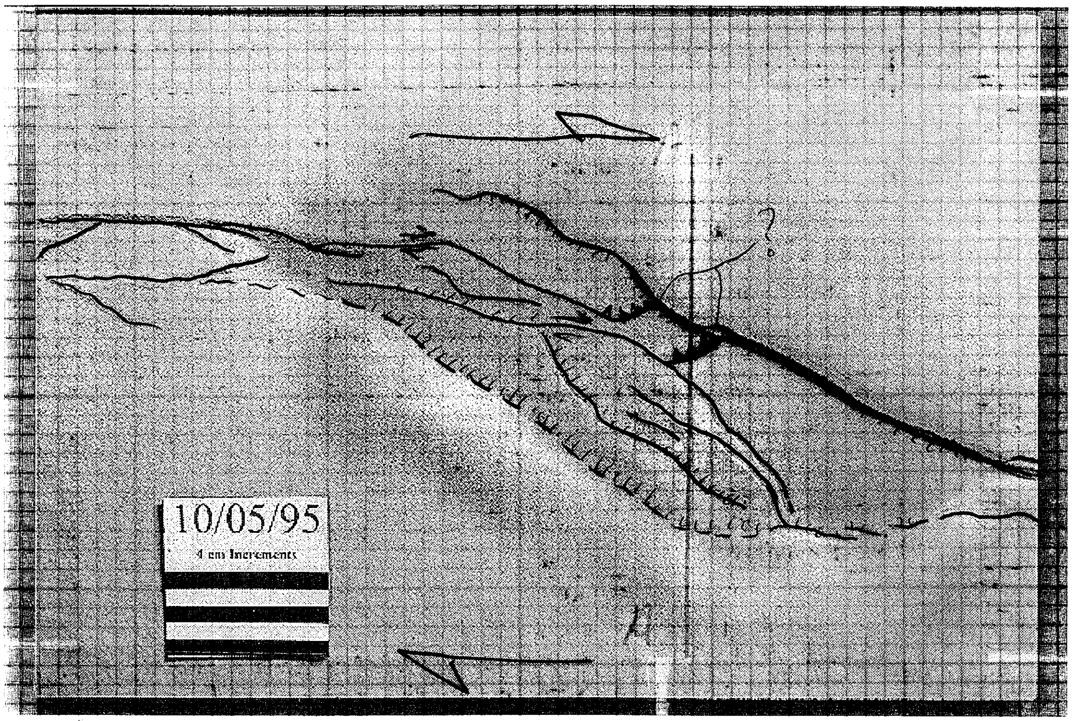
- The model will be started at 8:00 a.m., October 5, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes 36 seconds.

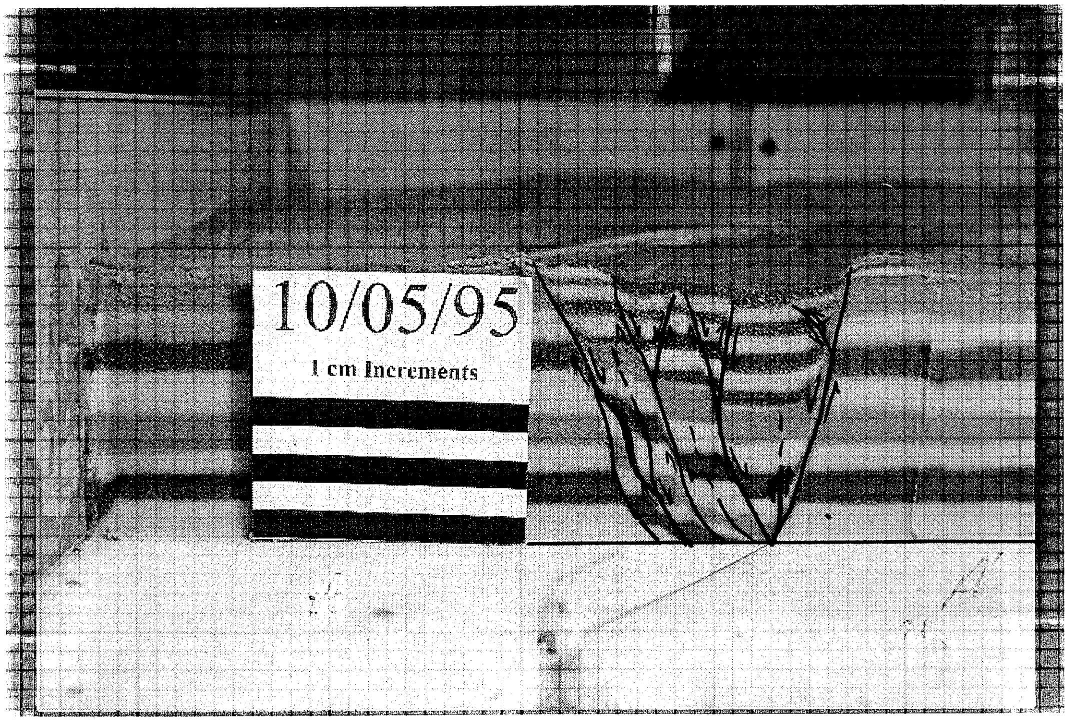
### Description of Model Run, October ~~7~~ 5, 1995

| Time | Descriptions of Time Events |
|---|---|
| 8:00 am | • Model run started. |
| 8:07 am | • The two faults bounding the outer edges of the pull-apart have started to form and are fairly close together.<br>• The two faults both consist of two en-echelon segments apparently following the step between the strike-slip sections of the model. |
| 8:12:36" am | • First layer of synkinematic fill added to the graben, color yellow.<br>• 1 cm strike-slip displacement. |
| 8:14 am | • A large Riedel-shear has formed near the lower apex of the pull-apart graben.<br>• The strike of the boundary faults are irregular and not straight. |
| 8:21 am | • The strike-slip faults (shear zones) seen in the other models have formed at the upper apex of the model and runs through the pull-apart, close to the right boundary fault.<br>• The graben seems to be deeper at its upper section compared to the portions near the lower apex of the pull-apart. |
| 8:25:12" am | • Second layer of synsedimentary fill is added to the graben, color blue.<br>• 2 cm of displacement. |
| 8:28 am | • Faults have propagated up through the layer of synsedimentary fill.<br>• The strike-slip fault cutting through the graben has continued to form and looks to be connected to a Riedel shear near the upper apex of the pull-apart.<br>• The boundary fault on the mobile side of the model has kept a very irregular appearance along strike while the boundary fault along the left side of the graben is straighter along strike.<br>• The lower part of the graben curves into the strike-slip section of the model by a series of en-echelon normal faults with relay ramps in between them. |
| 8:35 am | • No notable changes have occurred since the last description, faults continue to deform as before. |
| 8:37:48" am | • The third layer of synkinematic fill was added to the graben, color yellow.<br>• 3 cm of displacement. |
| 8:42 am | • Faults have propagated up through the layer of synsedimentary fill. |
| 8:49 am | • The strike-slip fault cutting through the top section of the pull-apart may be 'sandwiching' a part of the layered sand up against the boundary fault to the right and creating a small section with a reverse sense of displacement.<br>• No new faults seem to have formed in the interior of the pull-apart. |
| 8:50:24" | • The fourth layer of fill is added to the graben, color blue.<br>• 4 cm of displacement. |
| 8:56 am | • The strike-slip fault at the upper portion of the graben is still active and may transform into a fault with reverse displacement. |

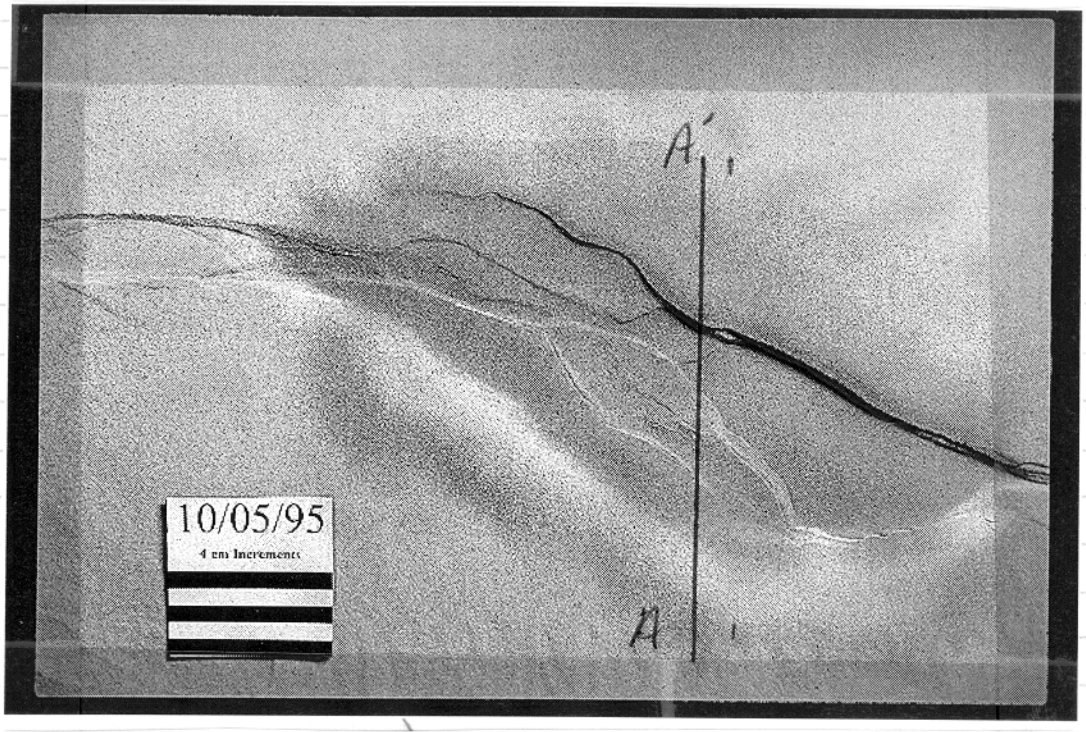
| | |
|---|---|
| 9:03 am | - The strike-slip fault at the upper portion of the graben is still active.<br>- The fifth layer of fill was added to the interior of the graben, color yellow.<br>- 5 cm of displacement. |
| 9:10 am | - A normal fault splaying from the left boundary fault now cuts through the interior of the graben. |
| 9:15:36" am | - The sixth layer of synkinematic fill was added to the pull-apart, color blue.<br>- 6 cm of displacement. |
| 9:17 am | - Faults have propagated up through the latest layer of fill. |
| 9:24 am | - The lower right section of the graben appears to still be deepening more than the portion near the top of the pull-apart.<br>- If there are more active faults, they must be active only in the subsurface as they do not reveal themselves on the surface of the model.<br>- There is another fault that has formed with strike-slip displacement close the first one that formed at the upper edge of the pull-apart. |
| 9:28:12" am | - The seventh layer of synkinematic fill was added to the model.<br>- 7 cm of displacement, color yellow. |
| 9:31 am | - Faults propagating up through the last layer of yellow fill. |
| 9:38 am | - Most of the displacement on the left edge of the pull-apart is now being taken up by the fault closer to the interior of the graben.<br>- A couple of very small normal faults have formed in the interior of the graben. |
| 9:40:48" am | - The eighth and final layer of fill was added to the interior of the pull-apart.<br>- 8 cm displacement, color blue. |
| 9:45 am | - Faults propagating up through the last layer of yellow fill. |
| 9:52 am | - Several small normal faults have reformed in the interior of the model.<br>- The strike-slip faults are also still present and may, when cross-sections are made, be related to a fault with reverse sense of displacement. |
| 9:53:20" am | - Model run stopped. |

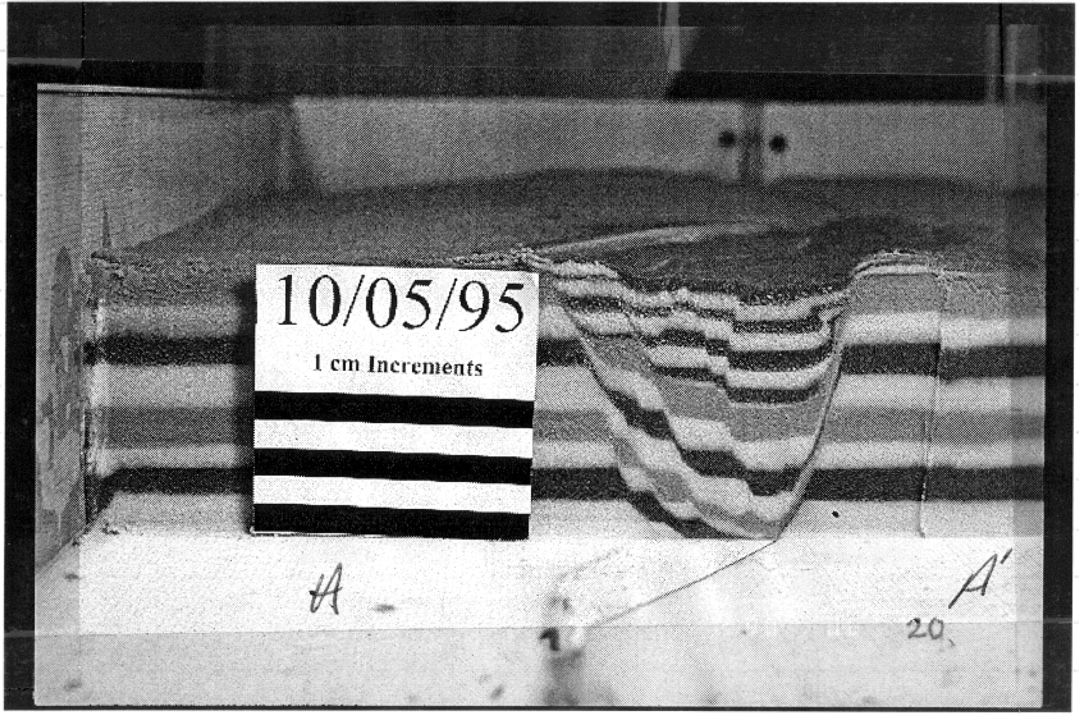
Cross-sections made approximatly every 1.5 cm



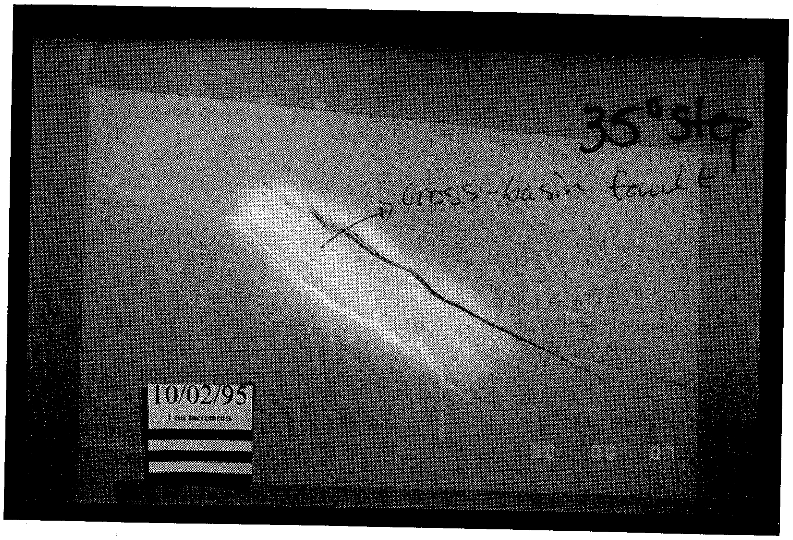


Cross-sections made approximately every 1.5 cm

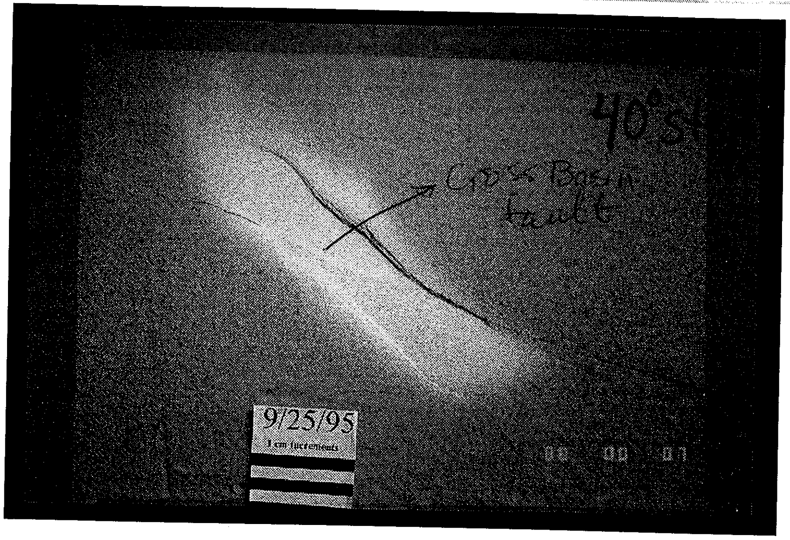




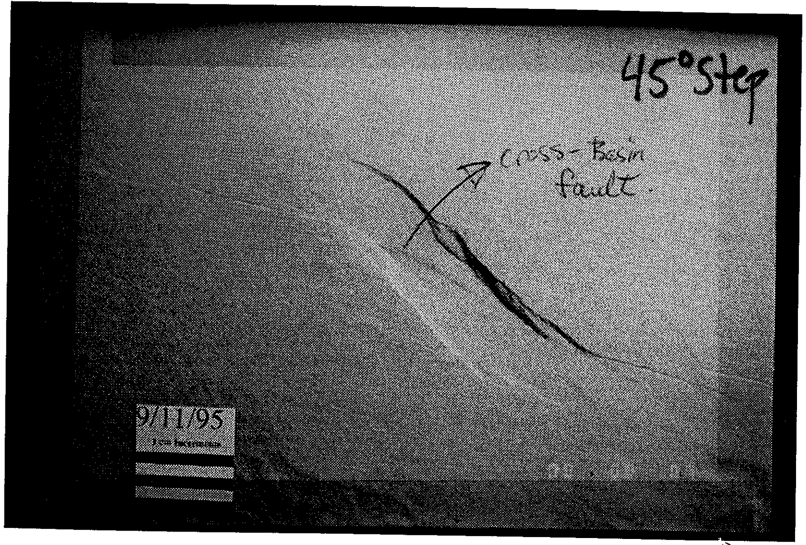
10-16-95
Bret Kale


35° step

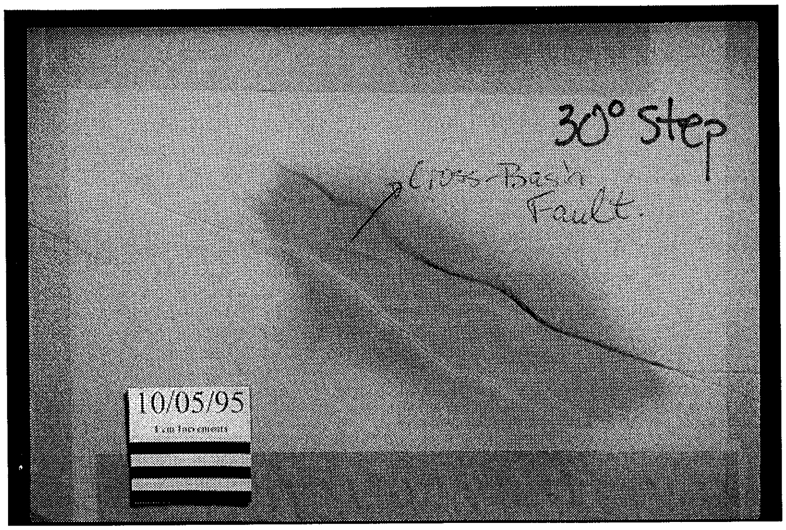
Cross-basin fault


40° st

Cross Basin fault


45° step

Cross-Basin fault.



- Similar in location and orientation between these models are strike-slip cross-basin faults. They all showed themselves at the same time step, frame 07 (24'30") into the model run.

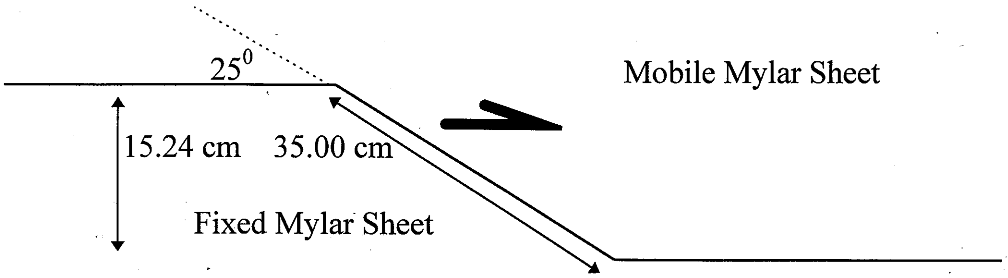
- Boundary faults on the mobile side of mylar tend to be more irregular along strike than boundary faults on the fixed side. Refer to page 51 for location of fixed and mobile sides.

- more normal displacement looks to be taking place on the mobile side of the pull-apart than on the fixed side.

October 23, 1995

BrettRake 10-23-95

- Objective: This model will be the fourth model in a series of models, all of which will have the same basic scale factors and dimensions. In the set of models, only the step angle between the strike-slip sections of mylar will be changed ($25^0$ for this model). Upon completion of the suite of model a comparison will be made noting changes in fault geometries between faults that are stepped at different angles. Also noted will be features that are constant from one model to the next.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $25^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet..



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot 10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 4.76 cm/hr |
| Number of pulses/second | 10 p/s |
| Displacement | 9 cm |
| Number of Pulses from the Stepper Motor | 68031 pulses |

- Therefore, at ten (10) pulses per second, for a total of 68031 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 89).

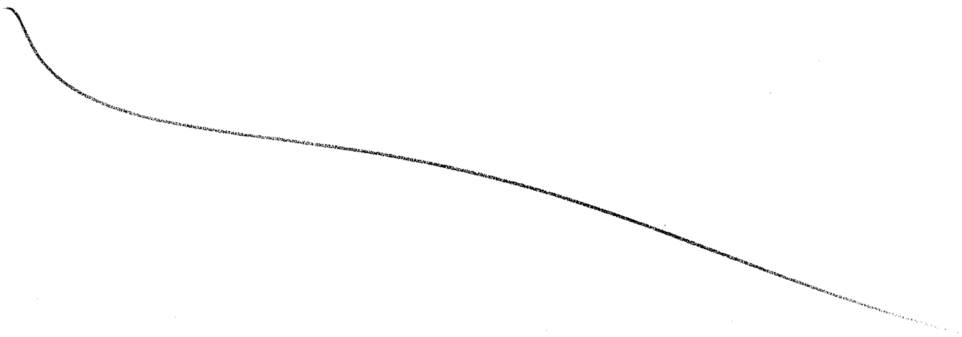
- The model will be started at 8:00 a.m., October 23, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes 36 seconds.

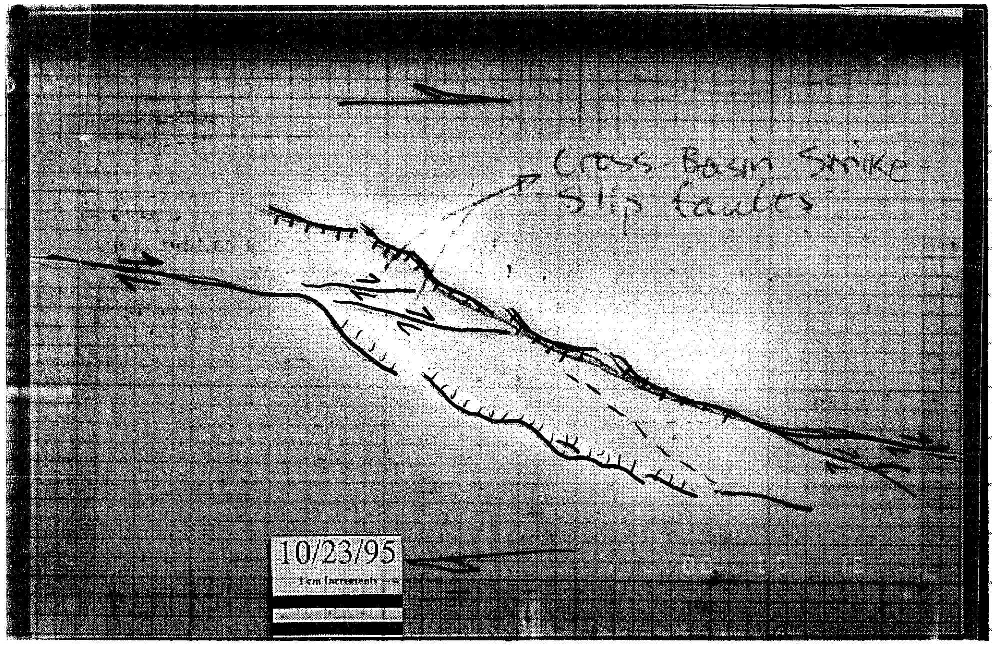
Description of Model Run, October 23, 1995

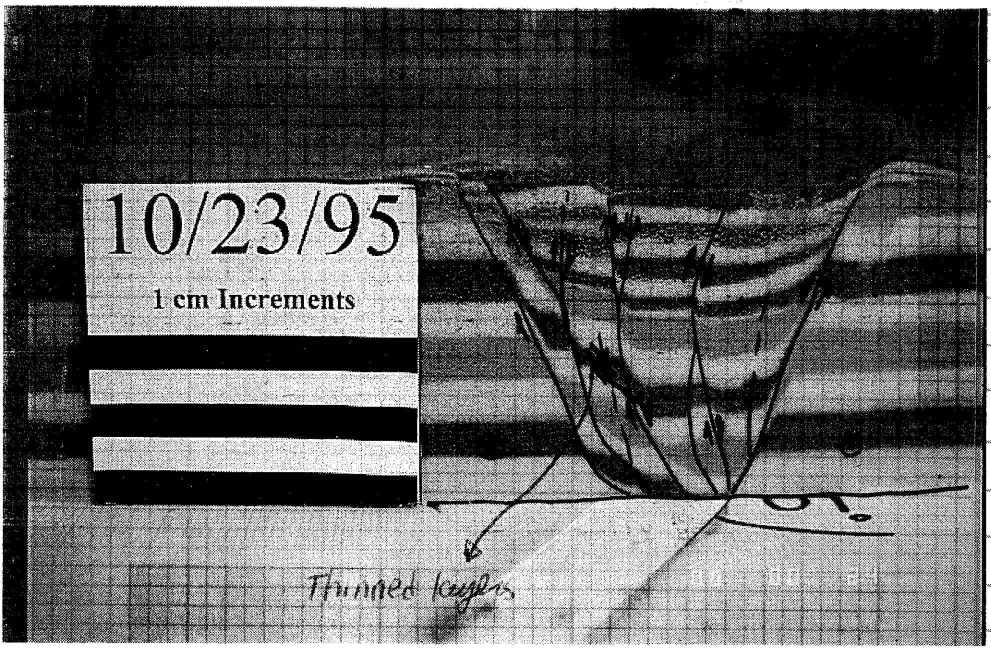
| Time | Descriptions of Time Events |
|---|---|
| 8:00 am | • Model run started. |
| 8:07 am | • No change on the surface of the model. |
| 8:12:36" am | • First layer of synkinematic fill added to the graben, color yellow.<br>• 1 cm strike-slip displacement. |
| 8:14 am | • The two faults that bound the graben have formed and are each segmented into two different en-echelon sections. |
| 8:21 am | • Two faults now bound the left side of the graben.<br>• The right side of the pull-apart is very irregular along strike.<br>• As in the other models, a cross-basin fault has formed cutting through the upper section of the pull-apart.<br>• Riedel shear systems have formed and some may merge into the boundary faults of the graben. |
| 8:25:12" am | • Second layer of synsedimentary fill is added to the graben, color blue.<br>• 2 cm of displacement. |
| 8:28 am | • The graben has dropped down via normal displacement on the faults bounding the graben. |
| 8:35 am | • The strike-slip fault that is cutting through the upper portion of the pull-apart has propagated through the second layer of synkinematic fill.<br>• The graben has also become wider.<br>• Relay ramps have formed along some sections of the two boundary faults. |
| 8:37:48" am | • The third layer of synkinematic fill was added to the graben, color yellow.<br>• 3 cm of displacement. |
| 8:42 am | • Faults are propagating up through the layer of fill that was just added to the interior of the graben.<br>• The strike-slip fault is also continuing to experience displacement, cutting through the upper section of the pull-apart. |
| 8:49 am | • The strike-slip fault has continued to deform and what appears to be another one is also visible further towards the top end of the pull-apart.<br>• The graben has become wider.<br>• The left side of the pull-apart is now more irregular along strike than when it first formed. The right side boundary fault has also changed and is now straighter. |
| 8:50:24" | • The fourth layer of fill is added to the graben, color blue.<br>• 4 cm of displacement. |
| 8:56 am | • All faults have just now propagated up through the last layer of synsedimentary fill. |
| 9:03 am | • The strike-slip faults continue to cut through the upper section of the graben though they do not appear to be 'dragging' material along with them which may be responsible |

| | |
|---|---|
| | for the observed reverse sense of displacement seen previous cross-sections.<br>• The fifth layer of fill was added to the interior of the graben, color yellow.<br>• 5 cm of displacement. |
| 9:10 am | • Displacement can be seen taking place on all of the faults that have formed thus far.<br>• The graben does not seem to have widened much in the past half hour or so.<br>• Different section of the interior of the pull-apart appear to be dropping more than others. The middle is dropping the most while the end sections are dropping down to a lesser degree. |
| 9:15:36" am | • The sixth layer of synkinematic fill was added to the pull-apart, color blue.<br>• 6 cm of displacement. |
| 9:17 am | • No notable change on the surface of the model. |
| 9:24 am | • There are still two strike-slip faults cutting through the upper section of the pull-apart. |
| 9:28:12" am | • The seventh layer of synkinematic fill was added to the model.<br>• 7 cm of displacement, color yellow. |
| 9:31 am | • No notable change on the surface of the model. |
| 9:38 am | • A new normal fault has formed on the left interior side of the pull-apart graben and now appears to be taking up most of the normal displacement on that side.<br>• Similar to other models also are the en-echelon normal to oblique faults located at the lower boundary of the graben that curve into the strike-slip section of the model.<br>• A Riedel shear has formed in between the two strike-slip faults in the upper portion of the pull-apart. |
| 9:40:48" am | • The eighth and final layer of fill was added to the interior of the pull-apart.<br>• 8 cm displacement, color blue. |
| 9:45 am | • Faults have propagated up through the latest layer of synsedimentary fill. |
| 9:52 am | • The right boundary fault of the model is very straight along strike while the left side of the pull-apart consists of an inner and outer system of normal faults that dip toward the interior of the model. |
| 9:53:20" am | • Model run stopped. |

- Because a 25° step makes the model of the pull-apart longer than the reach of the camera stand, cross-sections were made at 2 cm intervals.

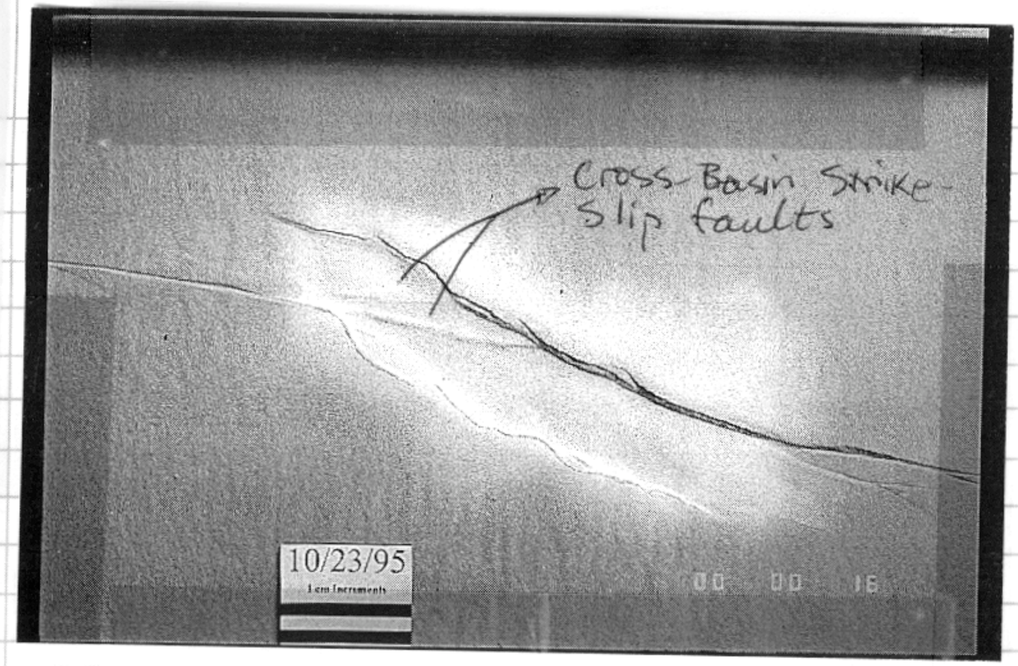


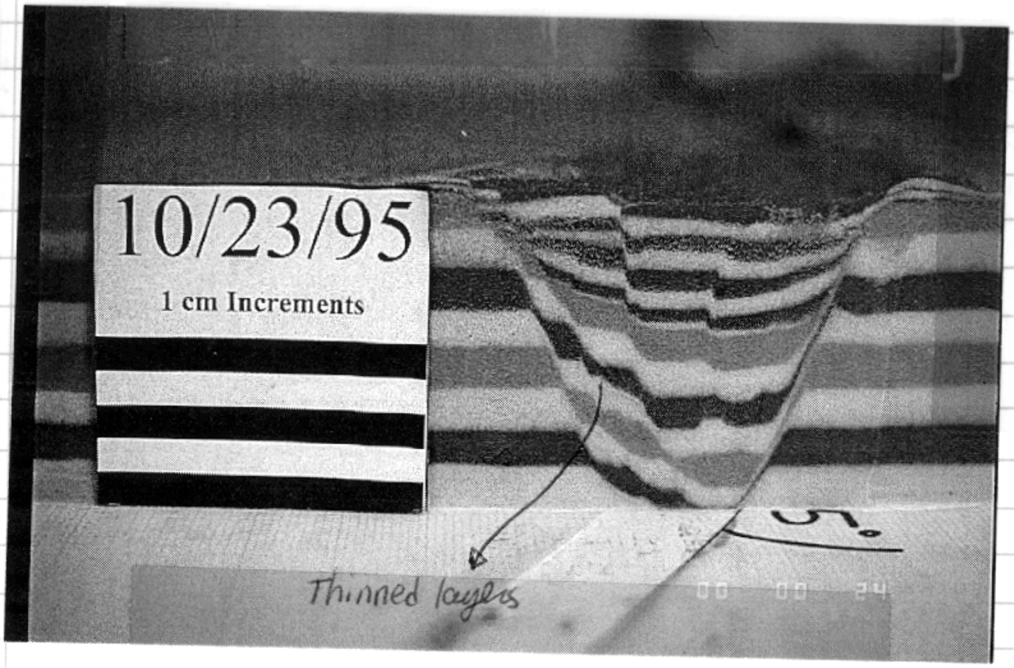




- This model also shows the 2 characteristc features found in previous models.
  1) Cross-Basin fault w/ strike-slip motion
  2) Faults with both reverse & normal displacement (seen in cross-section)

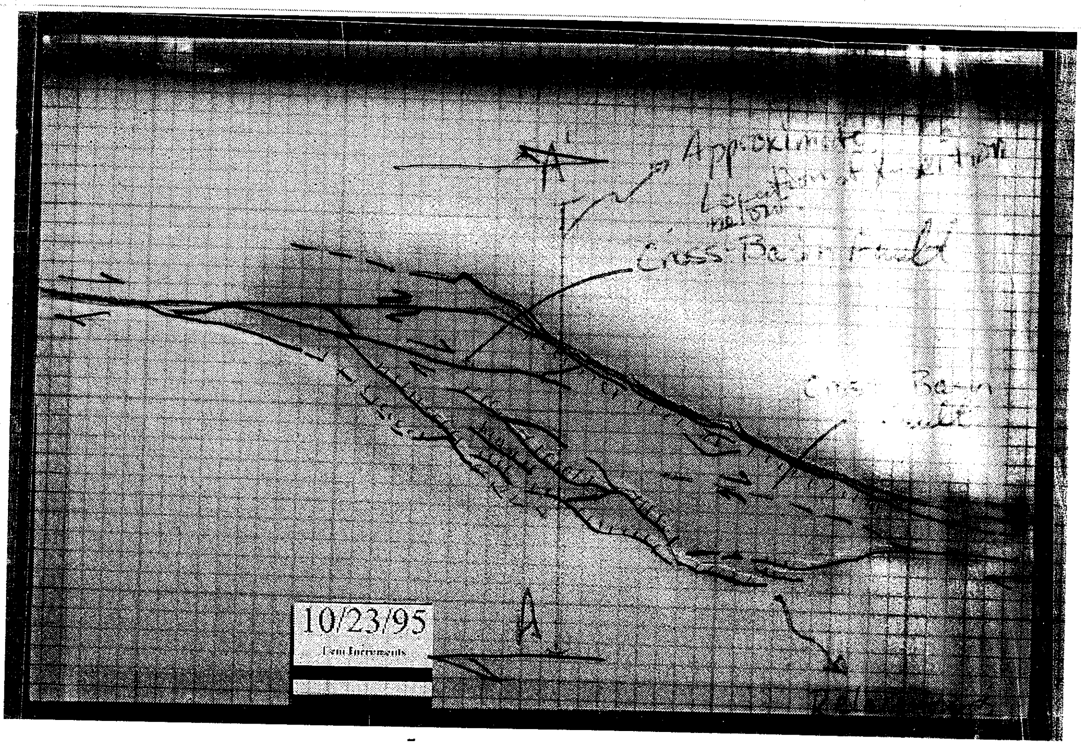
- Significant amounts of layer thinning can also be seen in this cross-section. Bedding within the graben dips towards the center of the cross-section, almost flat at the center.

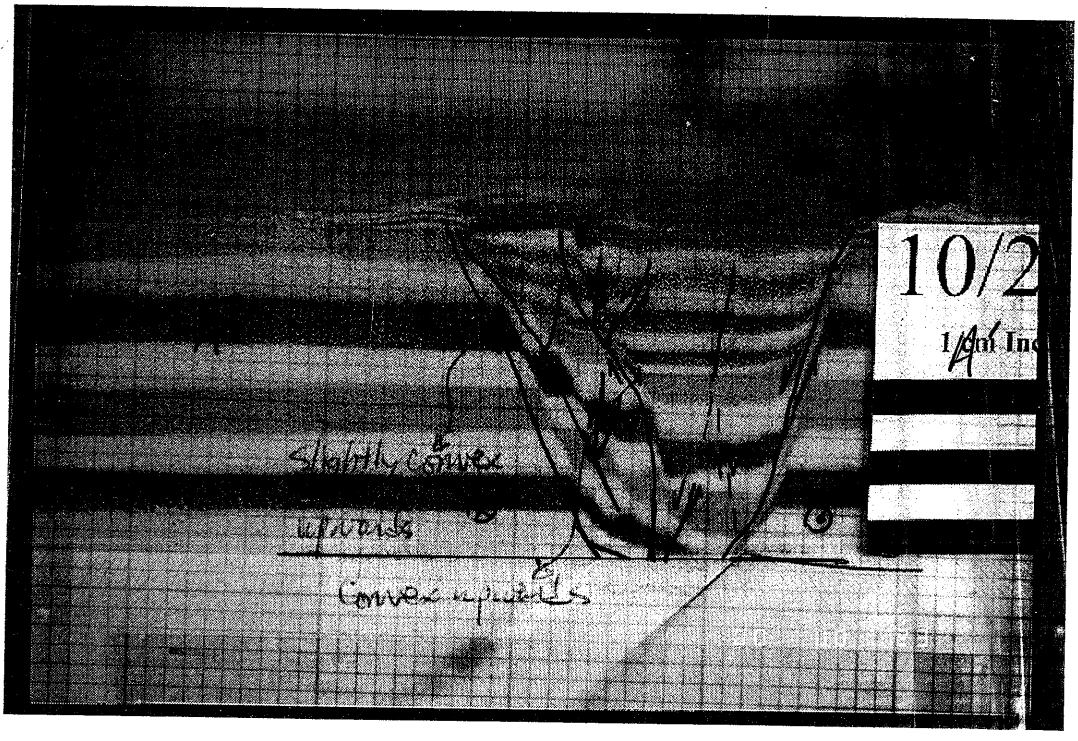




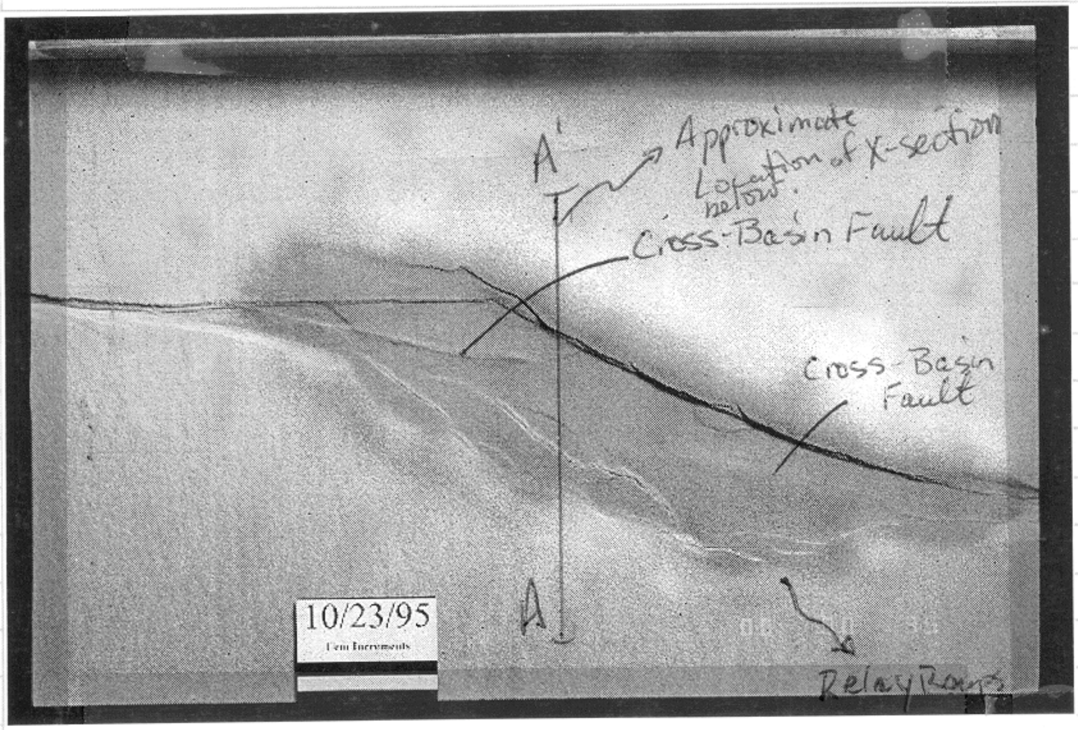
- This model also shows the 2 characteristic features found in previous models.
  1) Cross-Basin fault w/ strike-slip motion
  2) Faults with both reverse & normal displacement (seen in cross-section)

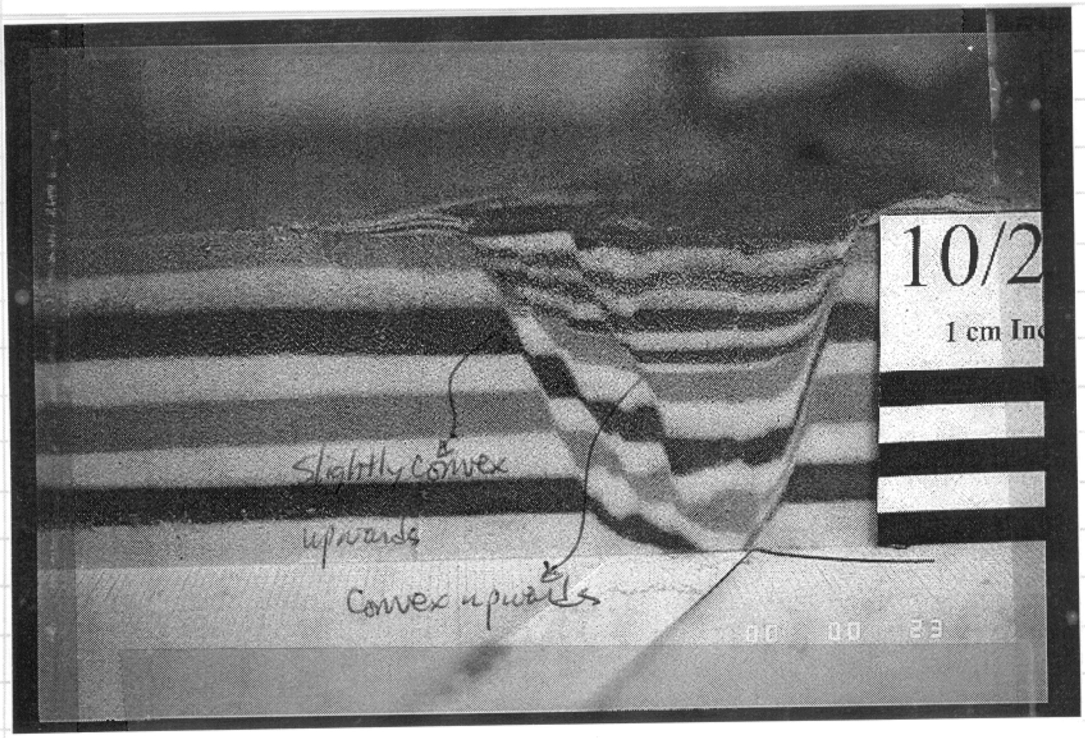
- Significant amounts of layer thinning can also be seen in this cross-section. Bedding within the graben dips towards the center of the cross-section, almost flat at the center.





- The faults on the left side of the graben sometimes show a convex upward configuration and has been seen ~~in~~ in prior model runs.



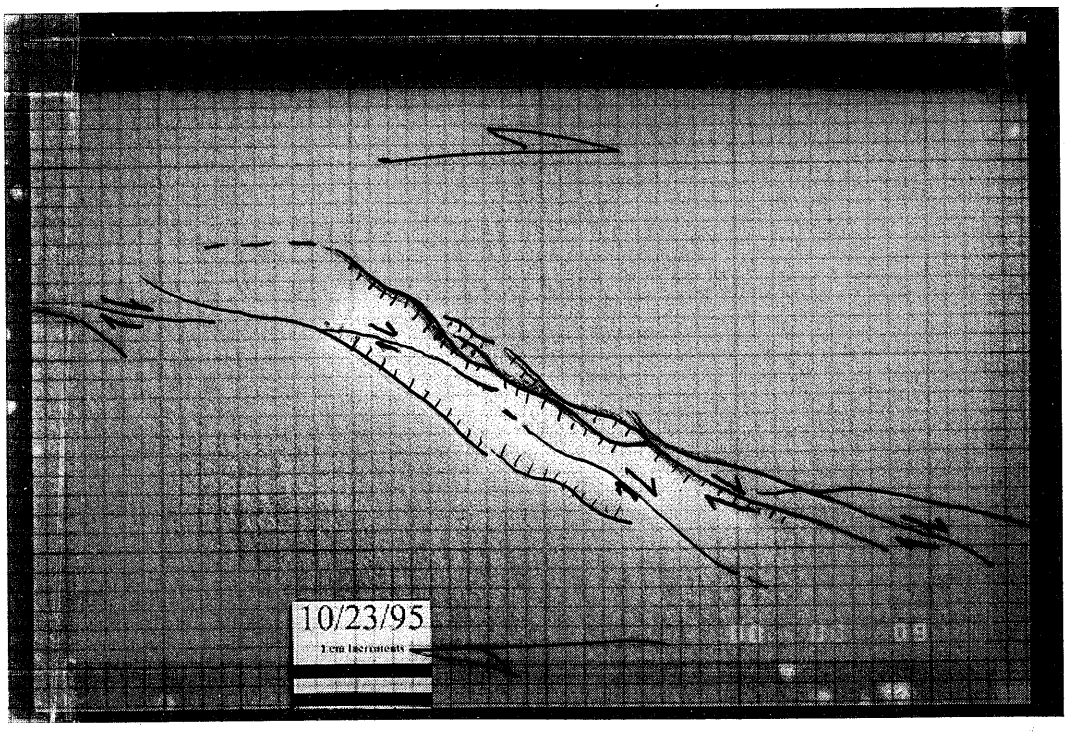


- The faults on the left side of the graben sometimes show a convex upward configuration and has been seen ~~up~~ in prior model runs.

- The upper image on the ~~opposite~~ facing page is the final map view photographed for model 10-23-95. I

It shows at least 2 cross-basin faults and ~~are~~ numerous normal faults, particularly along the left side of the pull-apart.

- The picture below is taken at an early stage in the model simulation. Note how the right side of the ~~mo~~ pull-apart is more

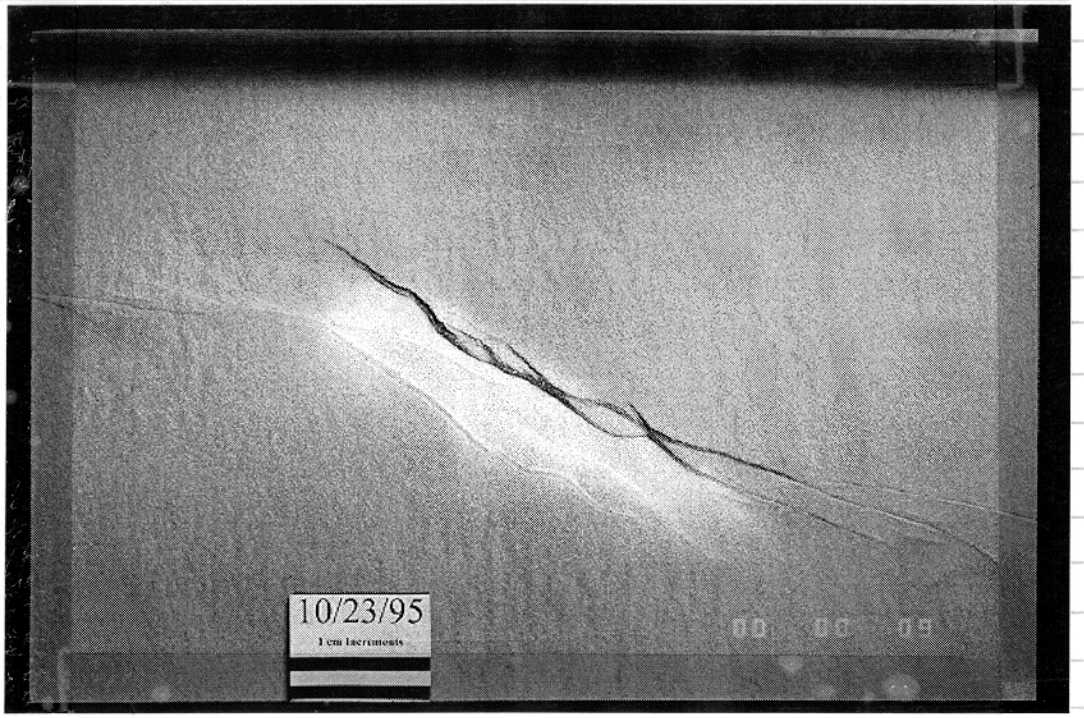


irregular along strike and is composed of several normal faults. This is ~~j~~ almost just opposite of the map view on the facing page (top).
=> over the course of the model simulation, complexity + number faults switched from more complex on the right + then later to the left side of the graben.

- The upper image on the ~~opposite~~ facing page is the final map view photographed for model 10-23-95. I

It shows at least 2 cross-basin faults and ~~ap~~ numerous normal faults, particularly along the left side of the pull-apart.

- The picture below is taken at an early stage in the model simulation. Note how the right side of the ~~mo~~ pull-apart is more

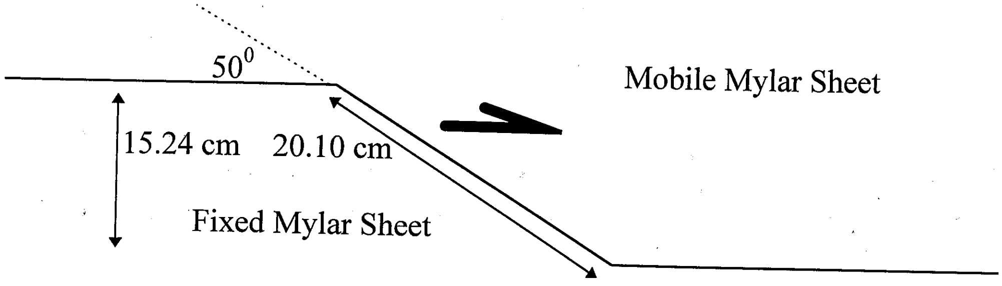


irregular along strike and is composed of several normal faults. This is ~~j~~ almost just opposite of the map view on the facing page (top). => over the course of the model simulation, complexity & number faults switched from more complex on the right & then later to the left side of the graben.

10-27-95

October 27, 1995

- Objective: This model will be the fourth model in a series of models, all of which will have the same basic scale factors and dimensions. In the set of models, only the step angle between the strike-slip sections of mylar will be changed ($50^0$ for this model). Upon completion of the suite of model a comparison will be made noting changes in fault geometries between faults that are stepped at different angles. Also noted will be features that are constant from one model to the next.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $50^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet..



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot 10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 4.76 cm/hr |
| Number of pulses/second | 10 p/s |
| Displacement | 9 cm |
| Number of Pulses from the Stepper Motor | 68031 pulses |

- Therefore, at ten (10) pulses per second, for a total of 68031 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. ~~93).~~ 95 BR

- The model will be started at 8:00 a.m., October 27, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- One step motor will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 1 and 2 (see pg. 47). The connections will look like those of setup #2 on page 34.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes 36 seconds.

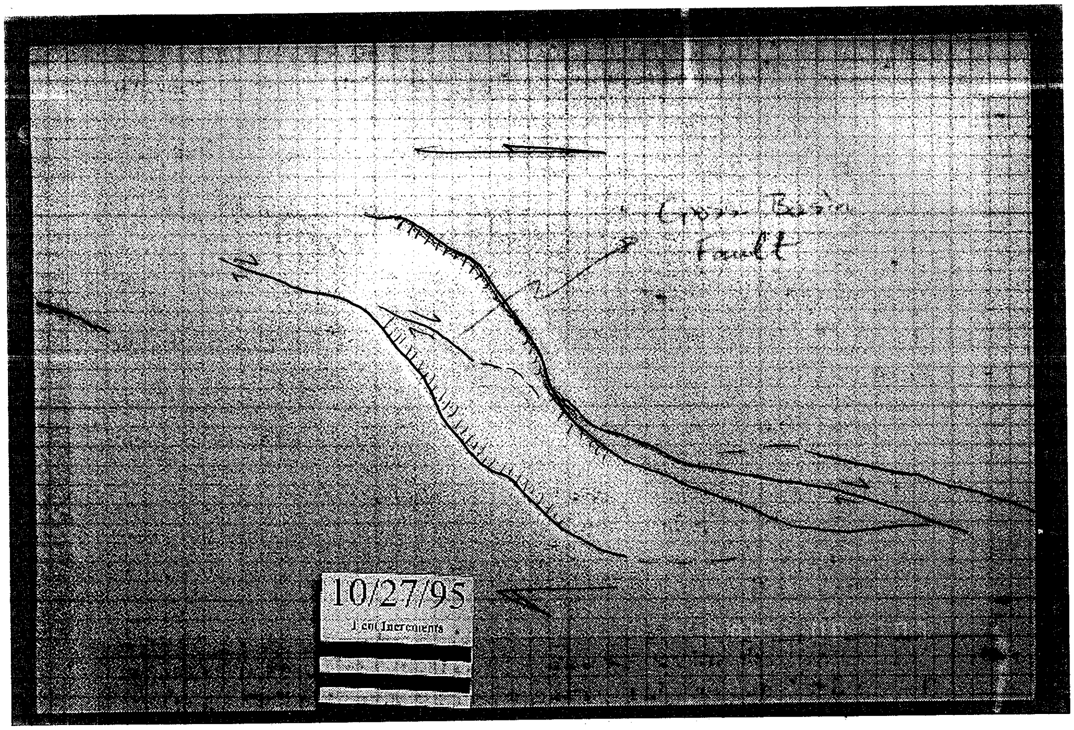
Description of Model Run, October 27, 1995

| Time | Descriptions of Time Events |
|---|---|
| 8:00 am | • Model run started. |
| 8:07 am | • Two outer faults have formed creating a graben; they appear to follow the orientation of the step cut into the mylar. |
| 8:12:36" am | • First layer of synkinematic fill added to the graben, color yellow.<br>• 1 cm strike-slip displacement. |
| 8:14 am | • The closer the step angle approaches 90 degrees, a greater amount of subsidence is noted in the graben.<br>• The right side of the pull-apart is very irregular while the left side is slightly more straight along strike.<br>• Riedel shears have also developed. |
| 8:21 am | • A cross-basin strike-slip fault has developed at the upper apex of the pull-apart, just like in many of the other models.<br>• The central portion of the pull-apart seems to be subsiding at a larger magnitude that either of the two ends.<br>• There may be a small push-up structure developing in the center of the basin along the small strike-slip fault cutting through the pull-apart.<br>• The systems of Riedel shears at either end of the model are becoming linked together by newly formed shears. |
| 8:25:12" am | • Second layer of synsedimentary fill is added to the graben, color blue.<br>• 2 cm of displacement. |
| 8:28 am | • Faults are just now starting to propagate up through the last layer of blue synkinematic fill in the interior of the pull-apart. |
| 8:35 am | • A new normal fault has formed just inside the left boundary of the graben. It has an irregularity along strike at its lower edge.<br>• The strike-slip fault at the upper apex of the graben is still active it appears.<br>• The center of the pull-apart still seems to be subsiding the most. |
| 8:37:48" am | • The third layer of synkinematic fill was added to the graben, color yellow.<br>• 3 cm of displacement. |
| 8:42 am | • All of the normal faults have propagated up through the last layer of synkinematic fill.<br>• One large relay ramp can be seen between the two normal faults on the left side of the pull-apart.<br>• Along the transition of the boundary faults on the left side of the model and the right hand section of strike-slip in the model are a series of en echelon normal faults separated by relay ramps. |
| 8:49 am | • An irregular fault has formed along the right side of the pull-apart, at its upper section, with almost an 'S' shaped appearance and may be reverse in orientation as the scarp does not really look like that of one of the normal faults. |

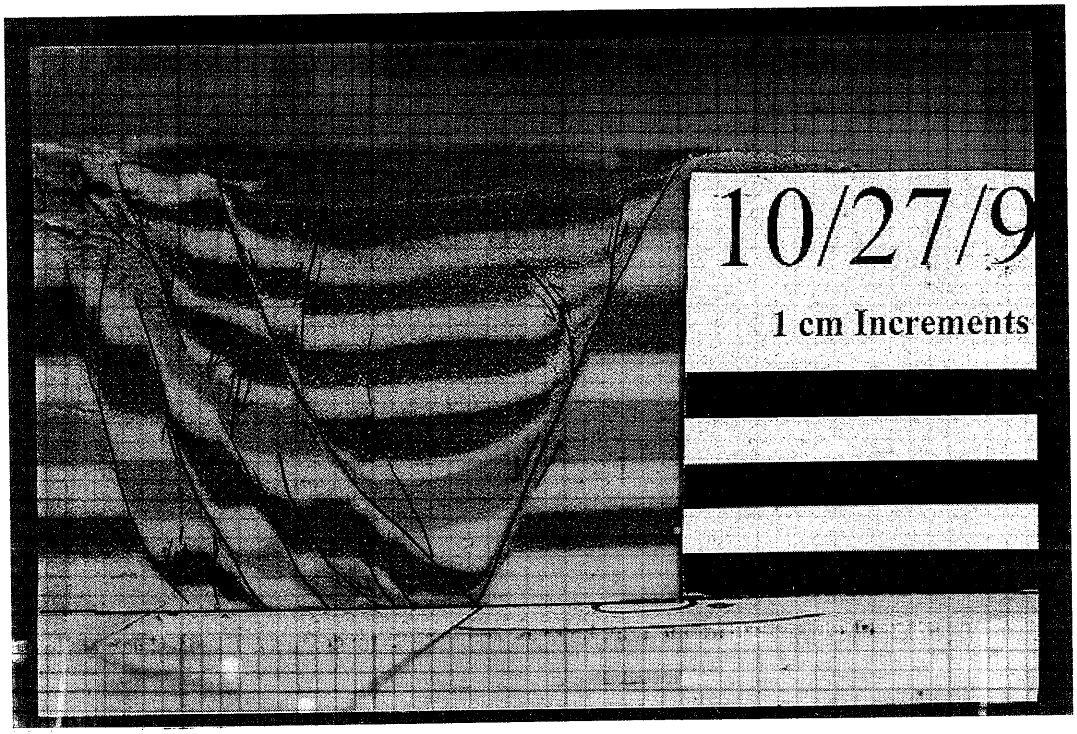
| | |
|---|---|
| | • The central portion of the graben is still the most actively subsiding. |
| 8:50:24" | • The fourth layer of fill is added to the graben, color blue.<br>• 4 cm of displacement. |
| 8:56 am | • There may be another strike-slip fault forming the in lower section of the pull-apart.<br>• All of the normal faults have propagated up through the layer of synsedimentary fill.<br>• The graben is noticeably wider than when the model was first started. |
| 9:03 am | • Most of the complexity in this model lies on the left side of the pull-apart where most of the normal faults are located.<br>• The two strike-slip faults are still active and may in cross-section be shown to be associated with some sort of reverse sense of displacement.<br>• Several relay ramps are also very prominent at more than one location along the boundary of the pull-apart.<br>• The fifth layer of fill was added to the interior of the graben, color yellow.<br>• 5 cm of displacement. |
| 9:10 am | • A smaller area is now active at the lower edge of the pull-apart and can be seen from portion of the new synsedimentary layer being faulted while adjacent areas are not.<br>• The strike-slip faults cutting through the graben are still active.<br>• The relay ramps are once again developing up through the last layer of fill.<br>• Two strike-slip faults now reside at the upper section of the pull-apart. |
| 9:15:36" am | • The sixth layer of synkinematic fill was added to the pull-apart, color blue.<br>• 6 cm of displacement. |
| 9:17 am | • Faults are beginning to propagate up through the last layer of synsedimentary fill. |
| 9:24 am | • The overall strike of the normal faults bounding the left side of the pull-apart has shifted from straight to a more irregular pattern. Similarly, the fault on the right side of the pull-apart is now straighter along strike than when it first formed.<br>• The strike-slip faults at the upper section of the graben is still very irregular along strike.<br>• The most actively subsiding portion of the pull-apart is still the central part. |
| 9:28:12" am | • The seventh layer of synkinematic fill was added to the model.<br>• 7 cm of displacement, color yellow. |
| 9:31 am | • Faults are beginning to propagate up through the last layer of synsedimentary fill. |
| 9:38 am | • By far most of the normal deformation is taking place along the left side of the pull-apart.<br>• Several normal faults are located along this side.<br>• The graben is now very much wider than at the beginning of the model simulation. |
| 9:40:48" am | • The eighth and final layer of fill was added to the interior of the pull-apart.<br>• 8 cm displacement, color blue. |
| 9:45 am | • Faults are beginning to propagate up through the last layer of synsedimentary fill.<br>• It can be seen from the outline of the last blue layer of fill that the active part of the lower section of the pull-apart is now much narrower than when at earlier times of the model simulation period.<br>• It will be interesting to see if the faults with reverse sense of displacement which developed in other model runs also develope in this one. |
| 9:52 am | • The left side of the pull-apart has the most normal faults and has an active portion that has become smaller over the course of the simulation.<br>• The right side of the model is dominated by one large normal fault.<br>• All normal faults have steep dips.<br>• There are still a few of the strike-slip faults visible that cut through the interior portions of the pull-apart and may be responsible for a reverse sense of displacement when the cross-sections are made. |
| 9:53:20" am | • Model run stopped. |

- Cross-sections for this model were made normal to the boundary faults of the pull-apart graben.

Cross-sections made approximately every 1 cm.

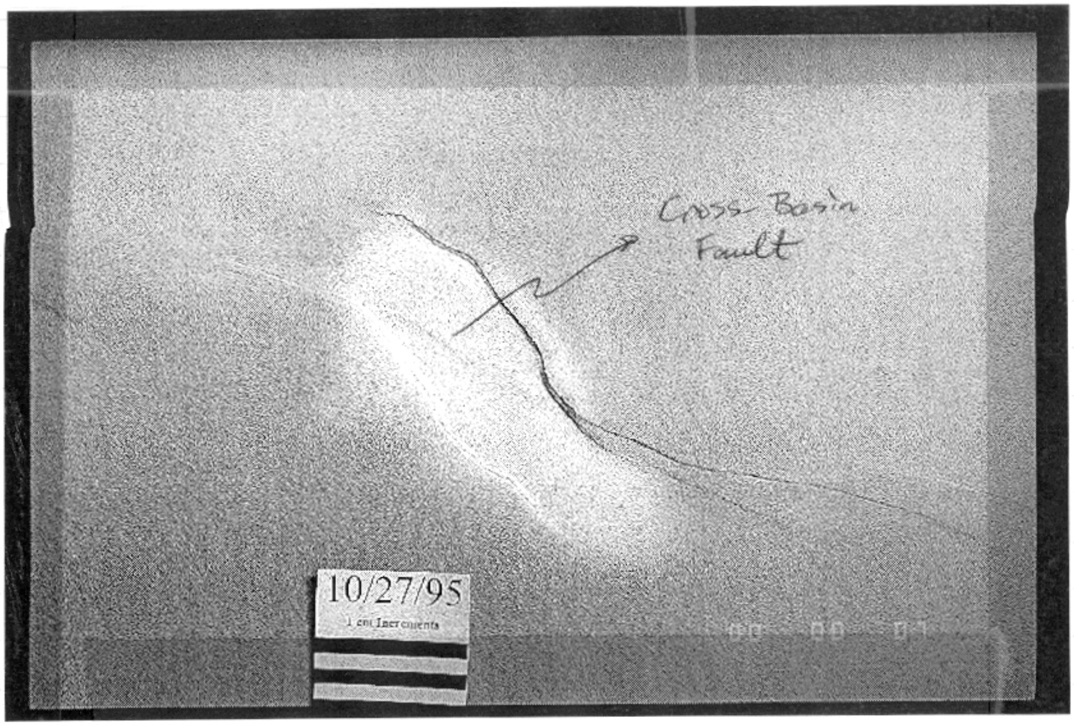


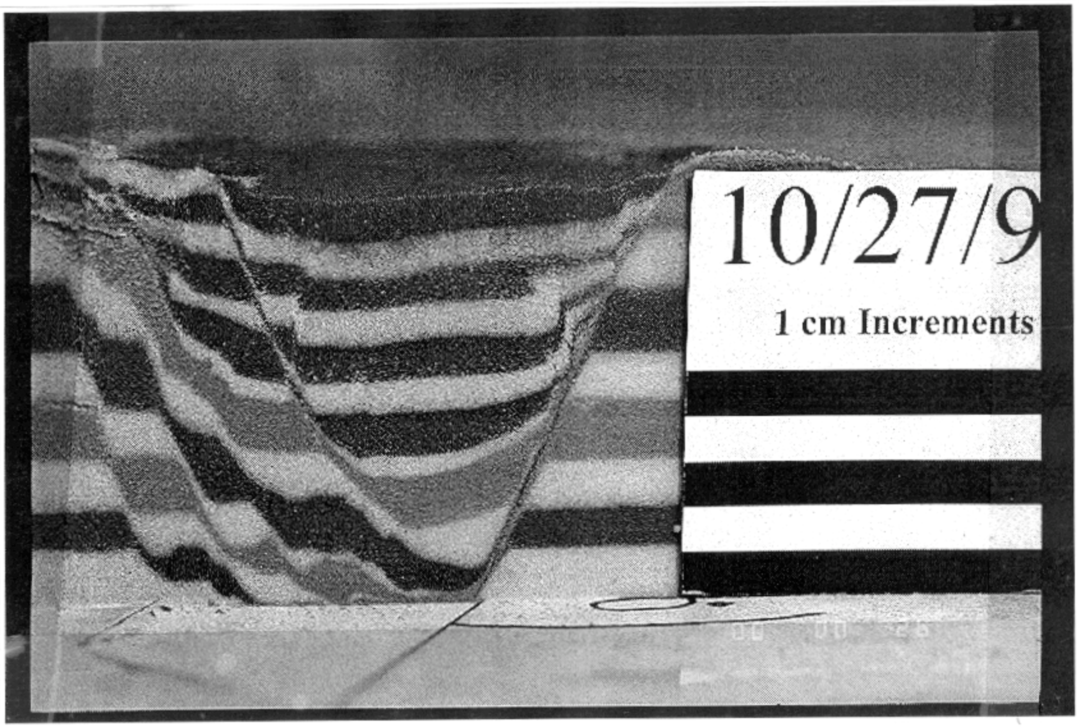
10/27/95
1 cm Increments

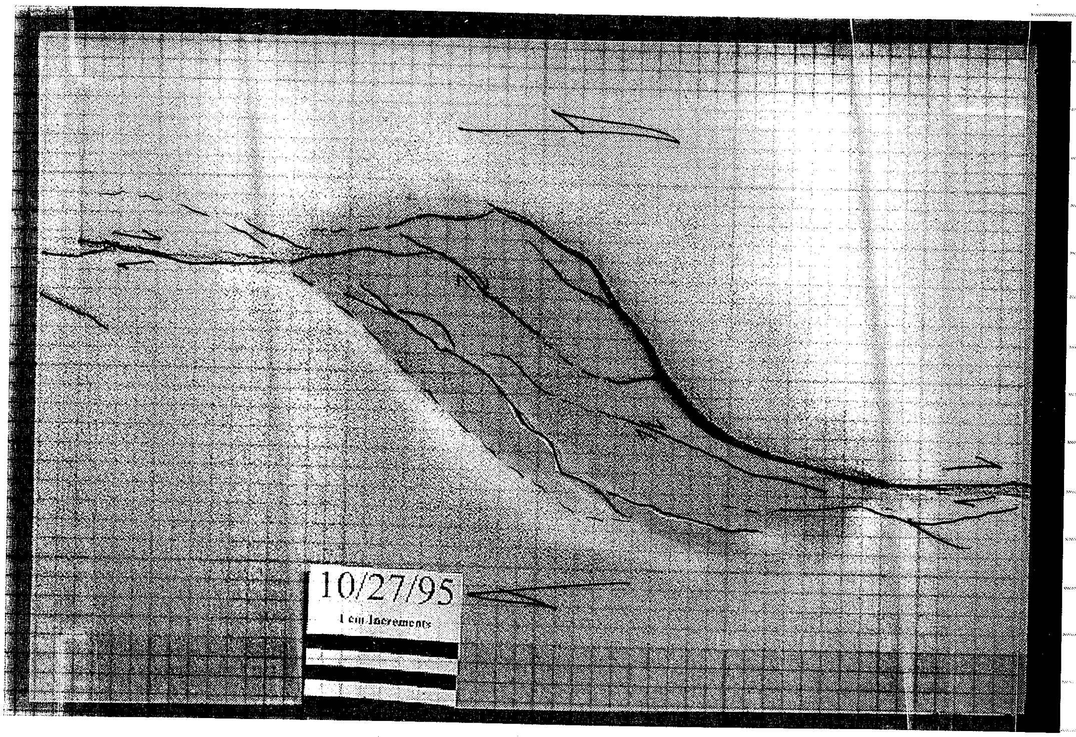


10/27/9
1 cm Increments

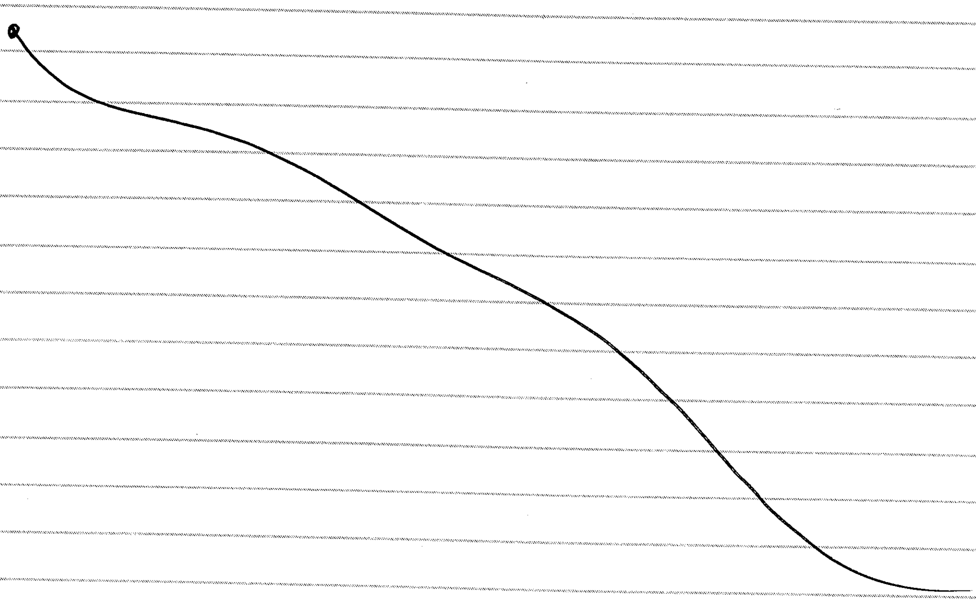
Cross-sections made approximately every 1 cm.

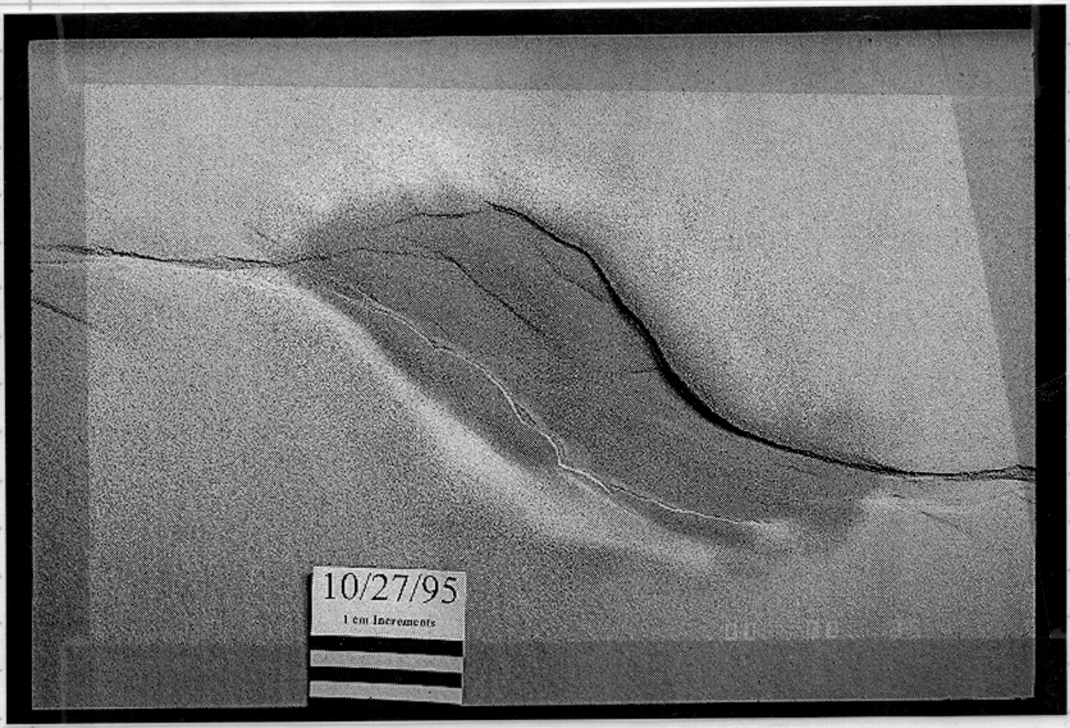




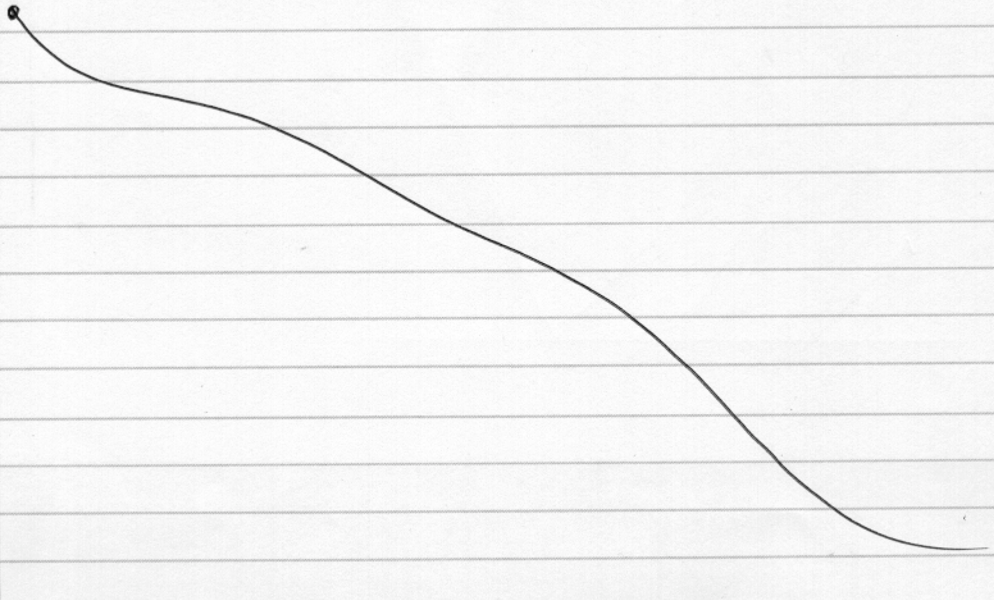


- Faults w/ both reverse & normal offset are still seen in cross-section.
- Cross-basin faults are still present





- Faults w/ both reverse & normal offset are still seen in cross-section.
- Cross-basin faults are still present



11-2-95
Bret Kahle

## Process for starting all indexers and therefore all step motors at the same time.

1) Write appropriate program and download into each indexer that will be used. Use the MSI.EXE software from Minarik. (use absolute mode when programming total # steps & pulses/sec)

2) Go into "Terminal Mode", then type in the following

```
<00      [ENTER]
1,2,3,4  [Enter]
H03      [Enter]    "Jog Mode"
H01      [Enter]    "Cycle Start" which
                    starts program execution
                    for all indexers at the
                    same time.
```

DP 11-2-95

3) Enter an "*" to stop all processes going on if something is not working properly.

4) Enter "H16" and c-codes should be displayed for the indexer in question.

5) Enter "H14" and it shows the program lines for the indexer in question.

11-8-95
Brent Rake

November 8, 1995

This entry into the scientific notebook explains the different programs that are used to control the indexers which are part of the deformation rig. The first programs described will be those used when one side of the model apparatus is fixed and the other mobile (like all models run thus far prior to this entry). The resulting motion of the mylar sheet will be the same as that of the arrows shown on page 47 of this scientific notebook.

- When Indexers 1 and 2 are to be used to control mobile walls 1 and 2 (page 47), use the following programs found in the c:\micro directory on the NEC Pentium computer in Lab L104, Building 57:

| | **Name** | **Result of program** |
|---|---|---|
| **Indexer 1:** | idx1cmbo.ms1 | Moves srcrewjack #1 68031 steps at 10 steps/second in a clockwise direction. |
| | idx1rtrn.ms1 | This returns wall 1 to its original position before the model was run. |

| | **Name** | **Result of program** |
|---|---|---|
| **Indexer 2:** | idx2cmbo.ms1 | Moves srcrewjack #2 68031 steps at 10 steps/second in a counter-clockwise direction. |
| | idx2rtrn.ms1 | This returns wall 1 to its original position before the model was run. |

BR 11-8-95

- When Indexers 3 and 4 are to be used to control mobile walls ~~1~~ 3 and ~~2~~ 4 (page 47), use the following programs found in the c:\micro directory on the NEC Pentium computer in Lab L104, Building 57:

| | **Name** | **Result of program** |
|---|---|---|
| **Indexer 3:** | idx3cmbo.ms1 | Moves srcrewjack #3 68031 steps at 10 steps/second in a counter-clockwise direction. |
| | idx3rtrn.ms1 | This returns wall 3 to its original position before the model was run. |

| | **Name** | **Result of program** |
|---|---|---|
| **Indexer 4:** | idx4cmbo.ms1 | Moves srcrewjack #4 68031 steps at 10 steps/second in a counter clockwise direction.<br>BR 11-8-95 |
| | idx4rtrn.ms1 | This returns wall 4 to its original position before the model was run. |

- When all 4 indexers are to be used at the same time for a single model simulation run the following 4 programs must be downloaded to each respective indexer for the appropriate motion to take place.

**Indexer 1:**

| **Name** | **Result of program** |
|---|---|
| idx1move.ms1 | Moves srcrewjack #1 34015 steps at 5 steps/second in a clockwise direction. |
| idx1bkup.ms1 | This returns wall 1 to its original position before the model was run. |

**Indexer 2:**

| **Name** | **Result of program** |
|---|---|
| idx2move.ms1 | Moves srcrewjack #2 34025 steps at 5 steps/second in a counter-clockwise direction. |
| idx2bkup.ms1 | This returns wall 2 to its original position before the model was run. |

**Indexer 3:**

| **Name** | **Result of program** |
|---|---|
| idx3move.ms1 | Moves srcrewjack #3 34015 steps at 5 steps/second in a counter-clockwise direction. |
| idx3bkup.ms1 | This returns wall 3 to its original position before the model was run. |

**Indexer 4:**

| **Name** | **Result of program** |
|---|---|
| idx4move.ms1 | Moves srcrewjack #4 34015 steps at 5 steps/second in a Counter clockwise direction.<br>(BP) 11-9-95 |
| idx4bkup.ms1 | This returns wall 4 to its original position before the model was run. |

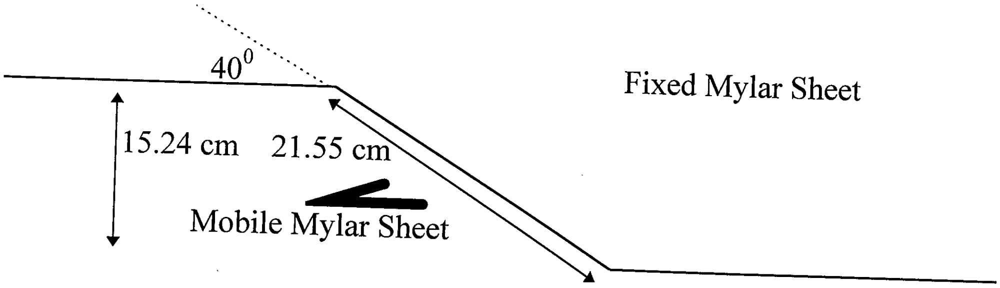
- For the second set of programs used for controlling all 4 of the indexers at the same time, the distance and speed each step motor is run at still ends up with 9 cm of overall strike-slip displacement and synkinematic fill can still be added at the same time intervals.

November 29, 1995

11-29-95
Brett Pole

Objective: This model will have the same basic scale factors and dimensions as the previous models, scale factors shown below. The step angle between the strike-slip sections of mylar in this model run is $40^0$. Different from previous model however are the wall which that shall be used to initiate the deformation. In prior models walls 1 and 2 were used (pg. 51). In this model walls 3 and 4 will be used for this purpose. The produced strike-slip offset will still be dextral (right-lateral). A description of the programs used are those at the bottom of page 100 for walls 3 and 4.

- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $40^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet..



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

length ratio = model/prototype

length ratio = 1 cm/100,000 cm = $1 \cdot 10^{-5}$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 4.76 cm/hr |
| Number of pulses/second | 10 p/s |
| Displacement | 9 cm |
| Number of Pulses from the Stepper Motor | 68031 pulses |

- Therefore, at ten (10) pulses per second, for a total of 68031 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- No descriptions will be made for this model because several other models have already been run at this step angle. Additionally, this is the first model that has been run using two step motors simulataneously, as such

unexpected problems could arise during the course of the simulation. Because of this, all observations will be made from the color slides taken of the model.

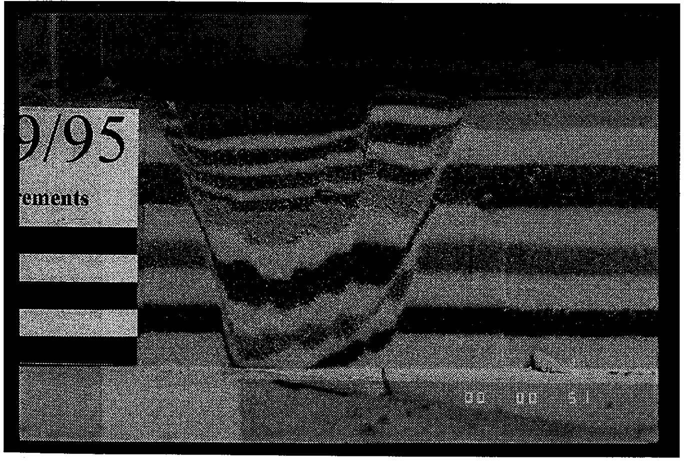
- The model will be started at 8:00 a.m., November 29, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio. The programs for the respective indexer and step motors are found on page 100 of this notebook.
- Two step motors will be used to drive the two screwjacks on the mobile walls of the deformation box which are walls 3 and 4 (see pg. 51). The connections will look like those of setup #1 on page 33.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes 36 seconds.

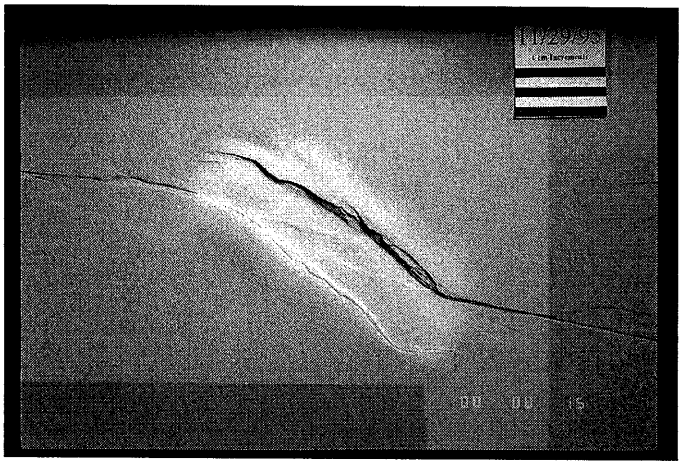
* Data backs were not reset to zero after areal photos were taken during the model run. As such, crossectional photos are numbered beginning with #34 and ending with # 79.

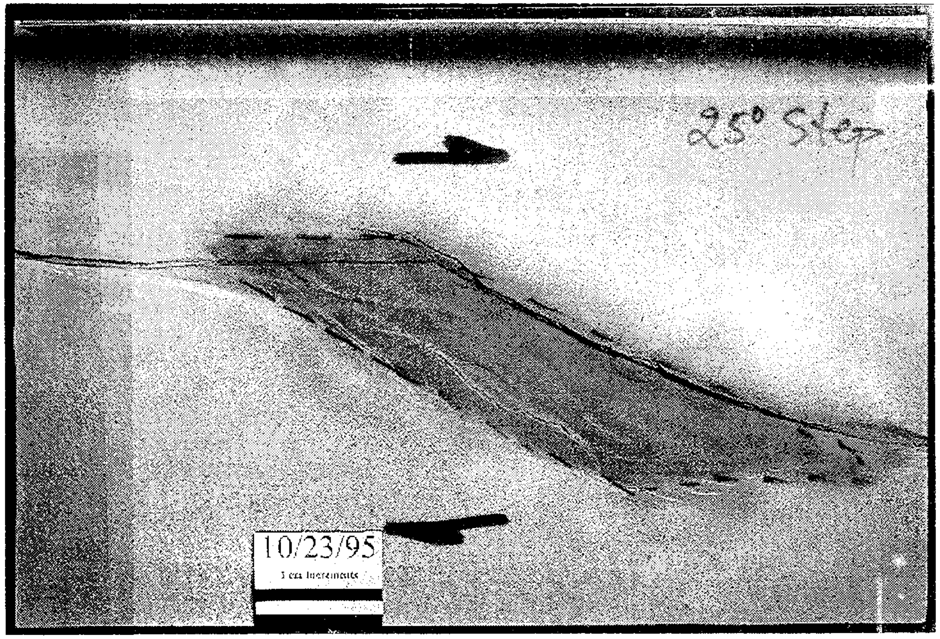
11-30-95 BF

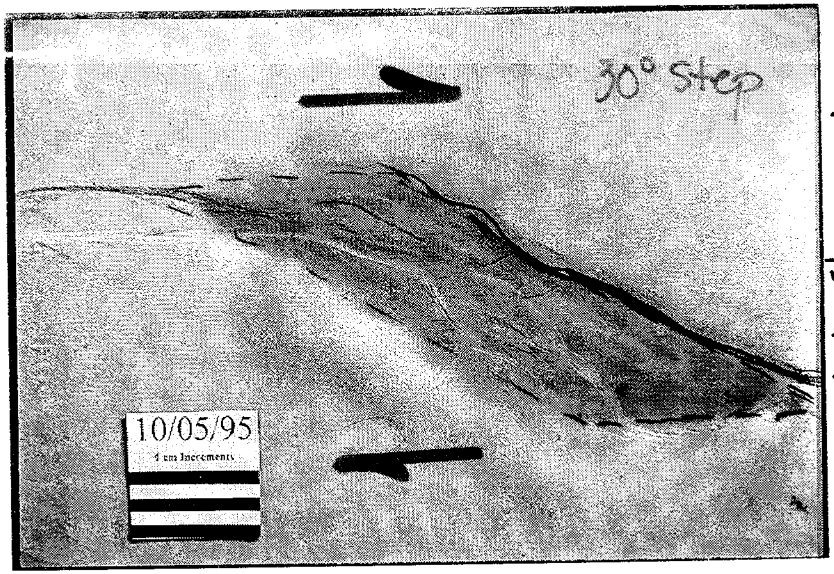
- Cross-sections made ~~e~~ every ~1cm.

- No unexpected errors were encountered.

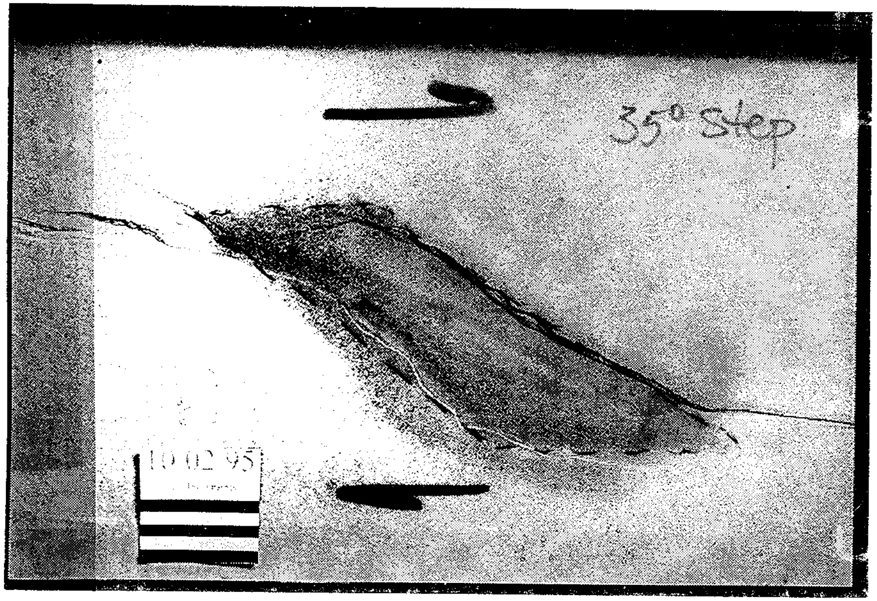


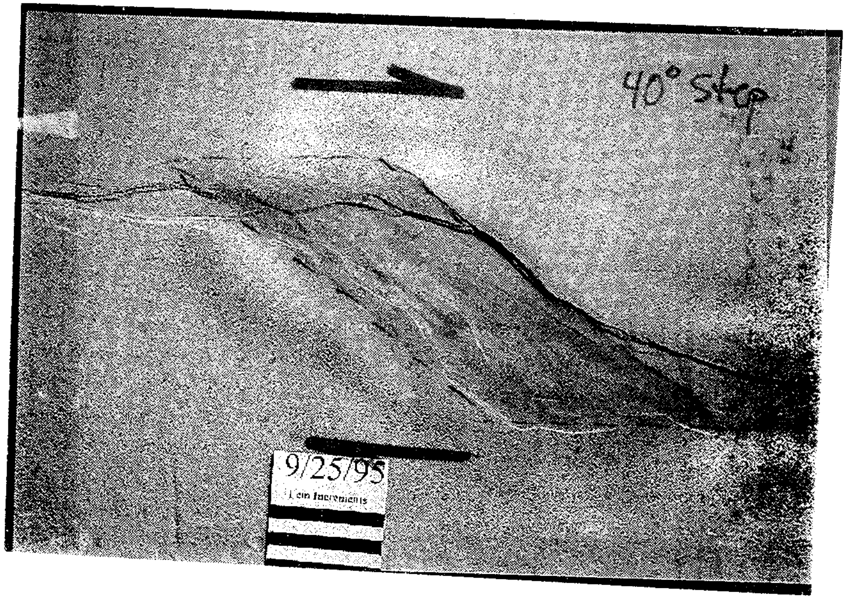


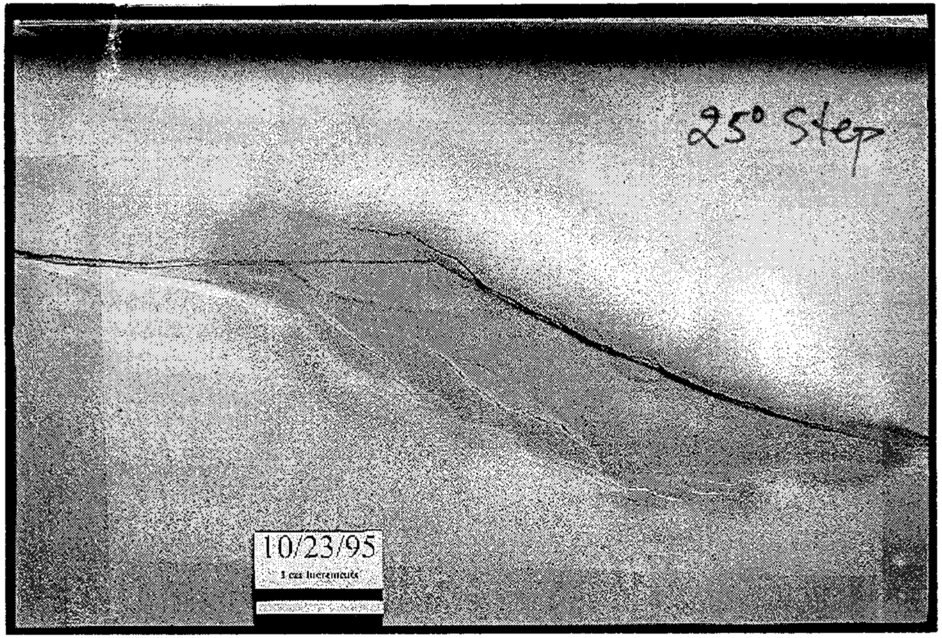

25° Step
10/23/95
1 cm Increments

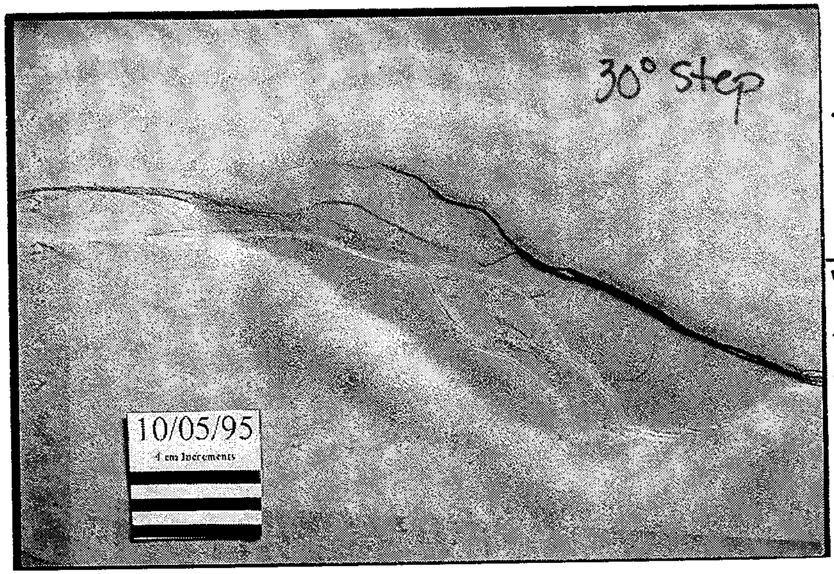

30° Step
10/05/95
1 cm Increments

12-1-95

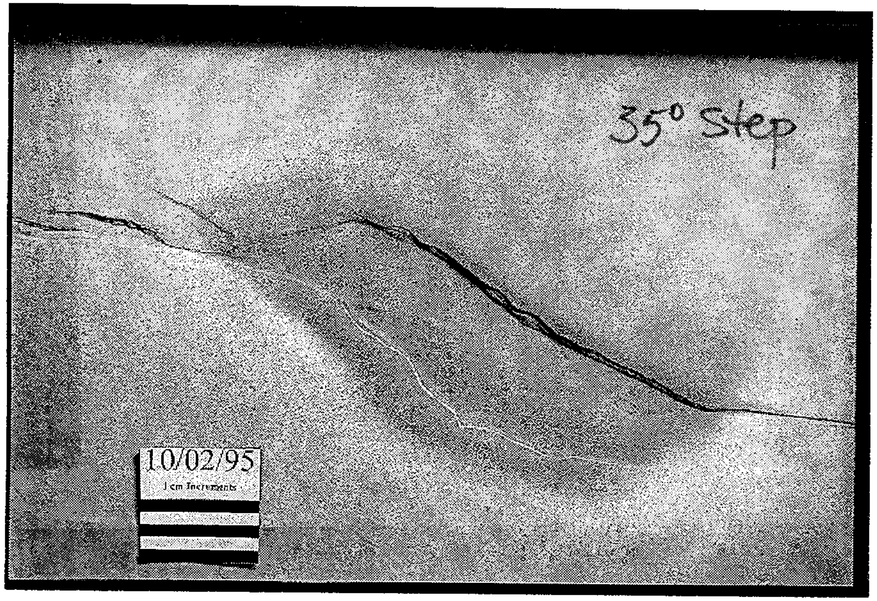

35° Step
10 02 95
1 cm Increments

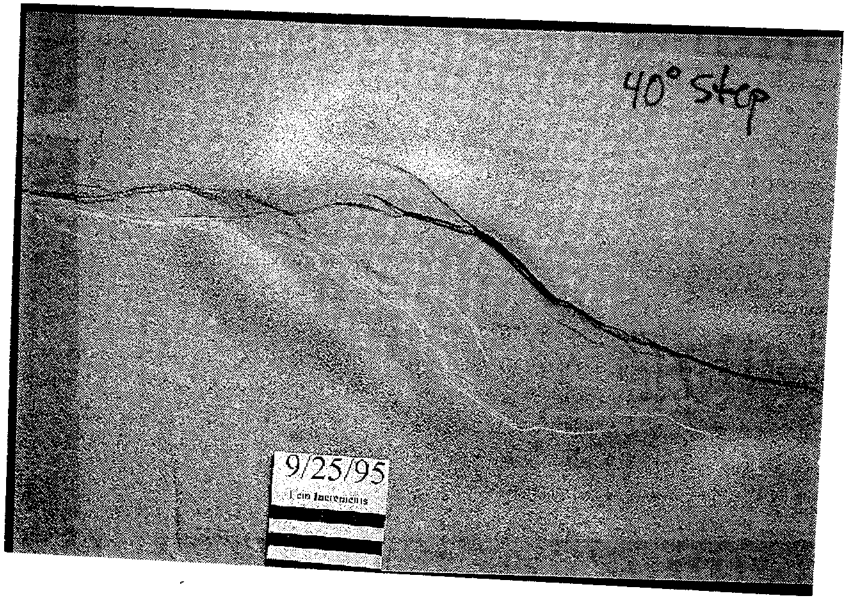

40° Step
9/25/95
1 cm Increments

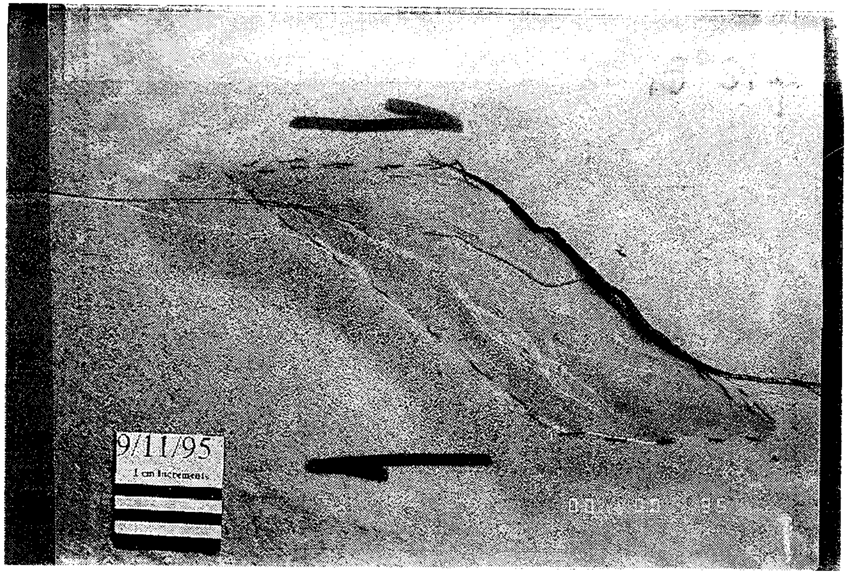

25° Step
10/23/95
1 cm Increments

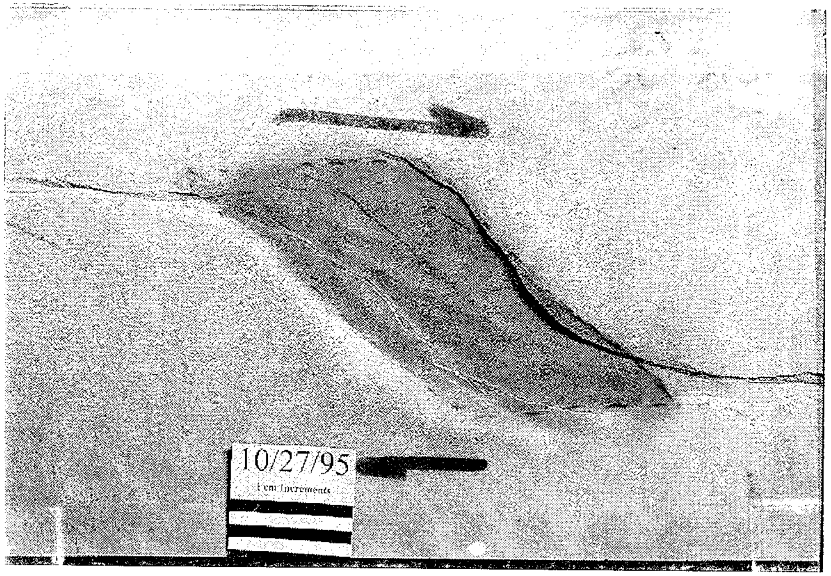

30° Step
10/05/95
1 cm Increments

12-1-95

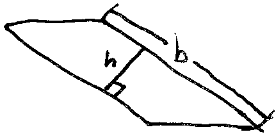

35° Step
10/02/95
1 cm Increments


40° Step
9/25/95
1 cm Increments



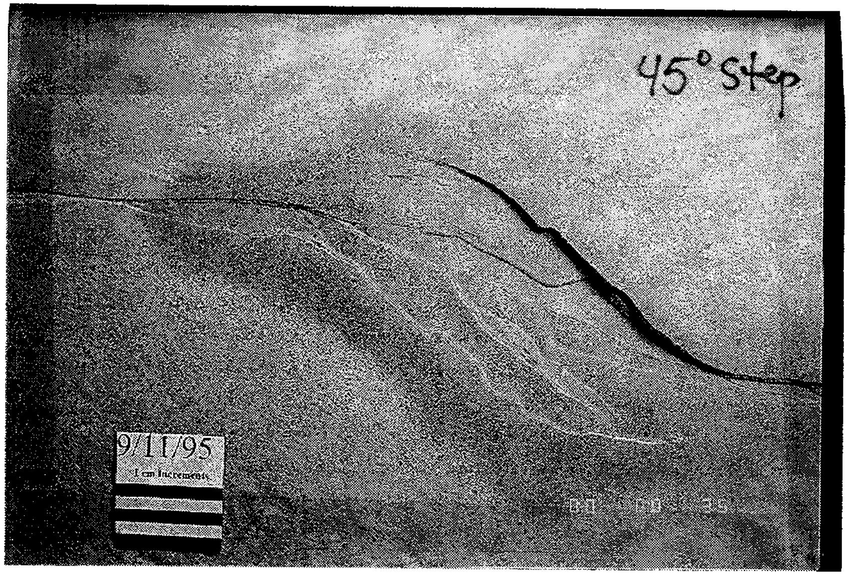


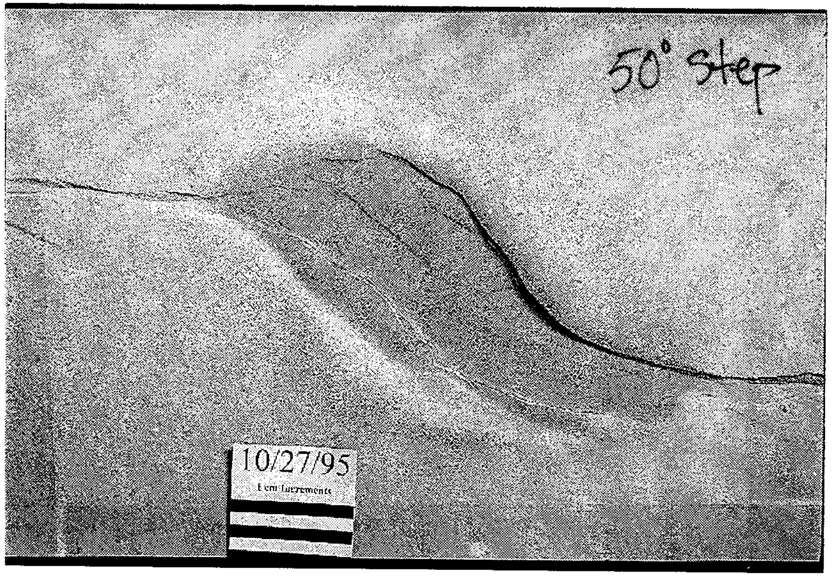
If the final shape of the pull-apart can be roughly estimated and compared to a parallelogram, then areas can be calculated using the formula: $\boxed{b \cdot h}$



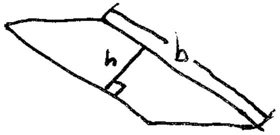
| Areas | |
|---|---|
| 25° | $10 \cdot 40 \approx 400\,\text{cm}^2$ |
| 30° | $11 \cdot 38 \approx 418\,\text{cm}^2$ |
| 35° | $11 \cdot 36 \approx 396\,\text{cm}^2$ |
| 40° | $11 \cdot 39 \approx 429\,\text{cm}^2$ |
| 45° | $12 \cdot 35 \approx 420\,\text{cm}^2$ |
| 50° | $13 \cdot 31 \approx 403\,\text{cm}^2$ |

$\Rightarrow$ Preliminary results would indicate that the change in step angle does not produce a large change in the area of pull-aparts.





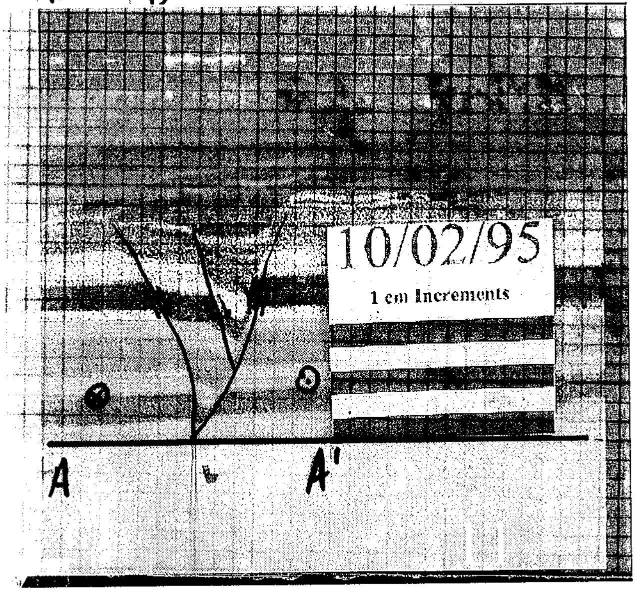
If the final shape of the pull-apart can be roughly estimated and compared to a parallelogram, then areas can be calculated using the formula: $\boxed{b \cdot h}$

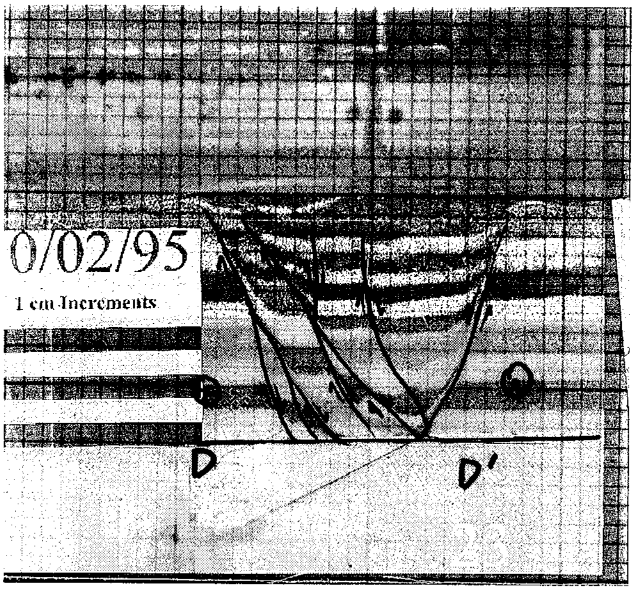


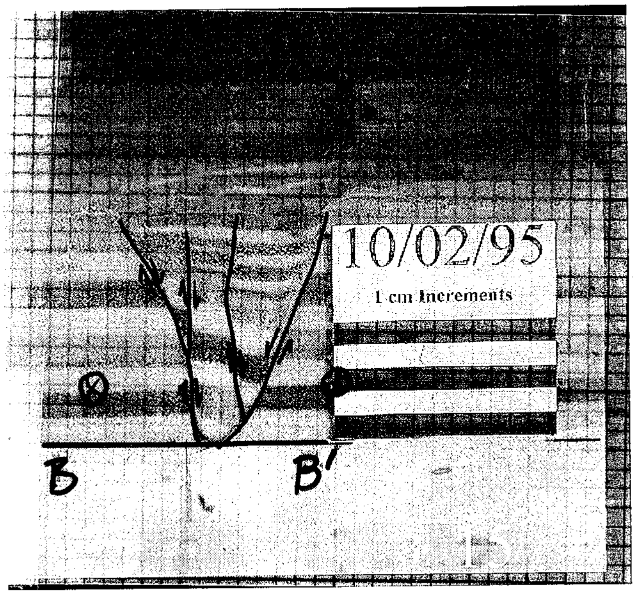
| Areas | |
|---|---|
| 25° | $10 \cdot 40 \approx 400\ cm^2$ |
| 30° | $11 \cdot 38 \approx 418\ cm^2$ |
| 35° | $11 \cdot 36 \approx 396\ cm^2$ |
| 40° | $11 \cdot 39 \approx 429\ cm^2$ |
| 45° | $12 \cdot 35 \approx 420\ cm^2$ |
| 50° | $13 \cdot 31 \approx 403\ cm^2$ |

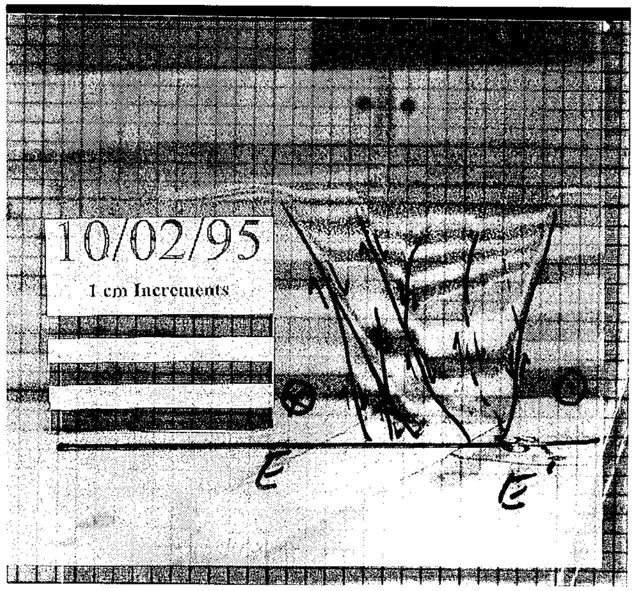
=> Preliminary results would indicate that the change in step angle does not produce a large change in the area of pull-aparts.

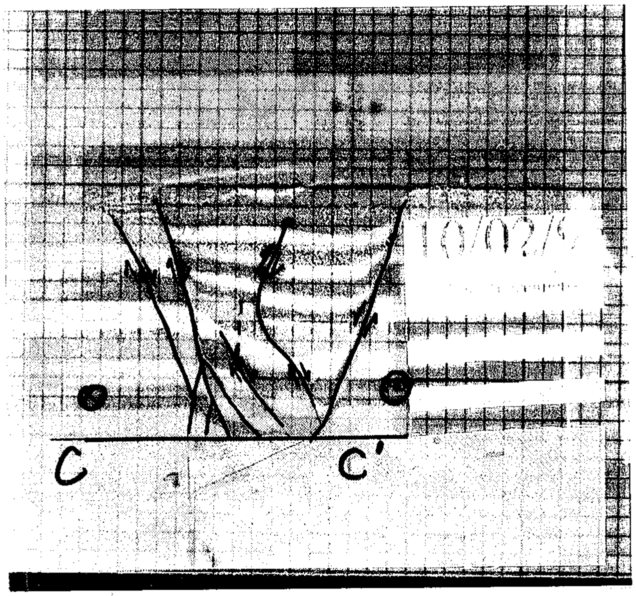
12-5-95 Bert Rahe

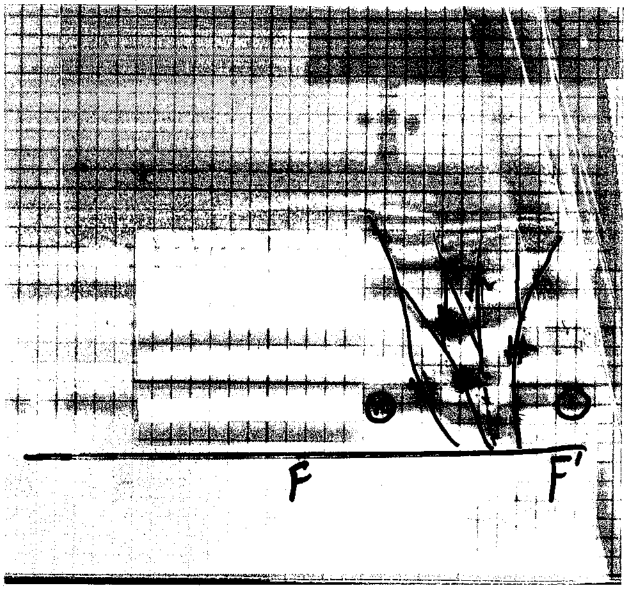




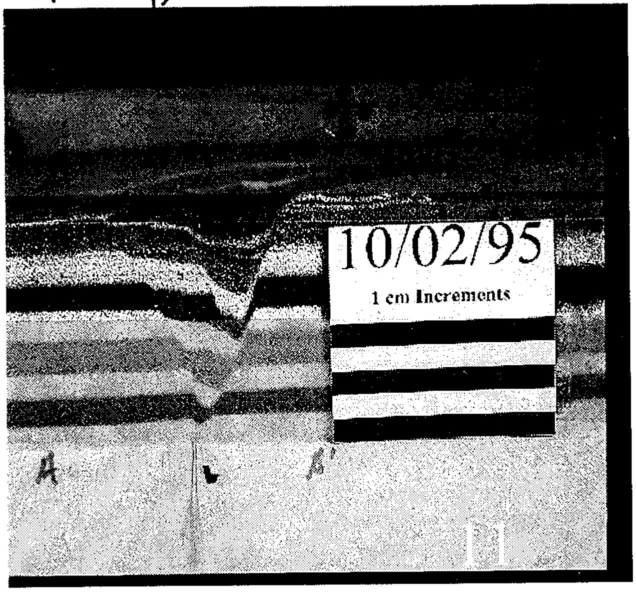


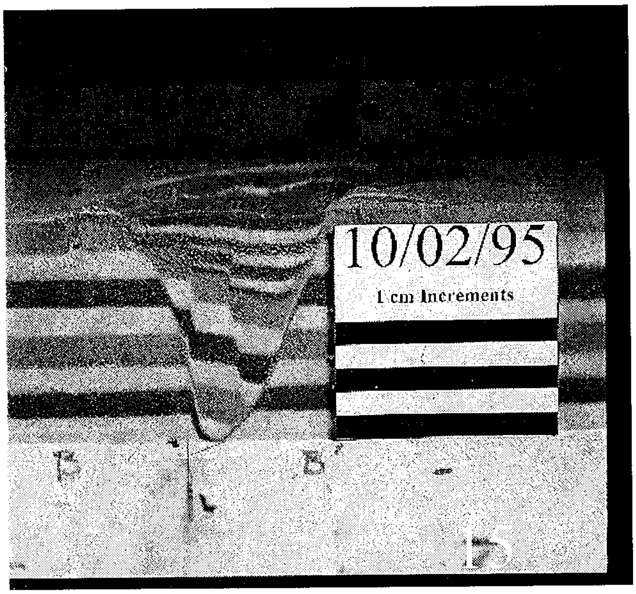


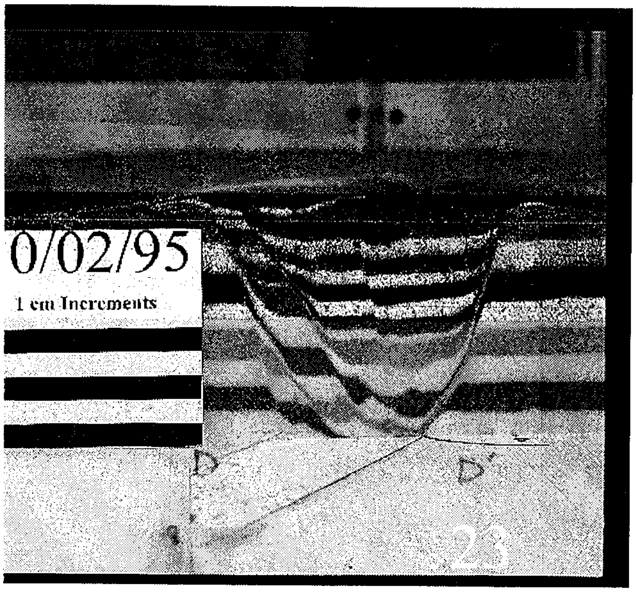


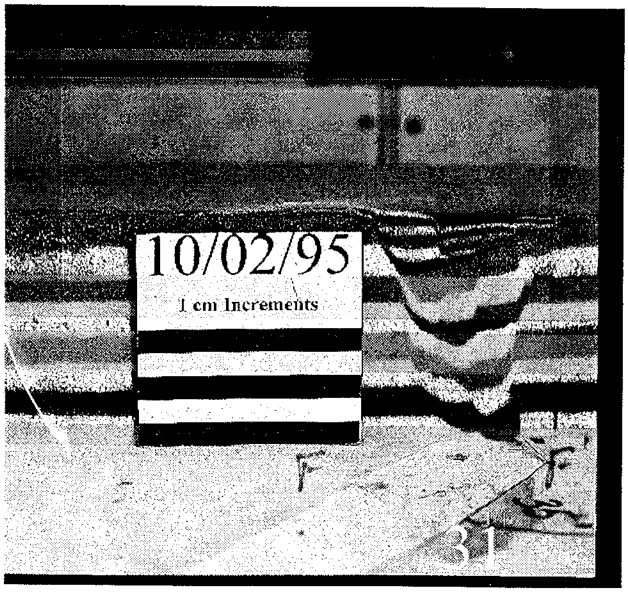


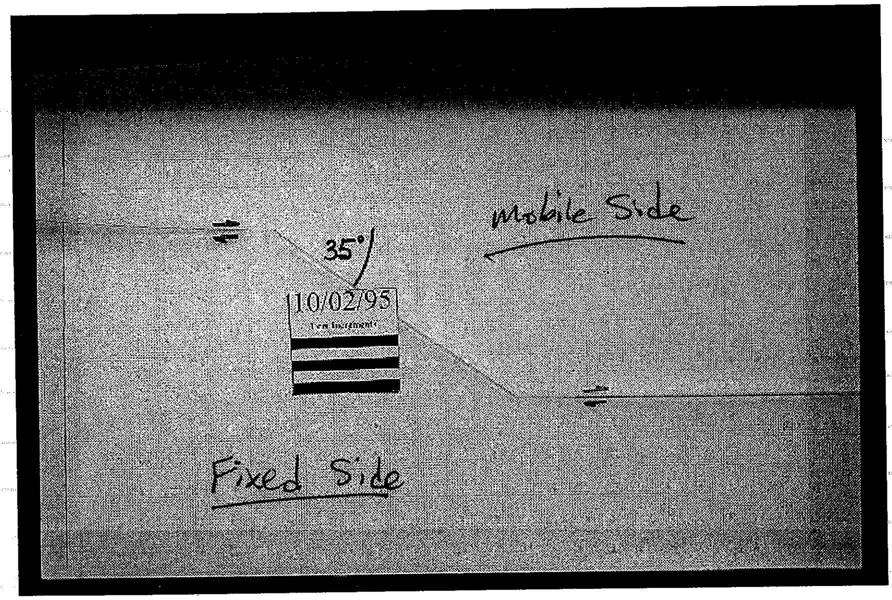
IL-5-95 Bathlake

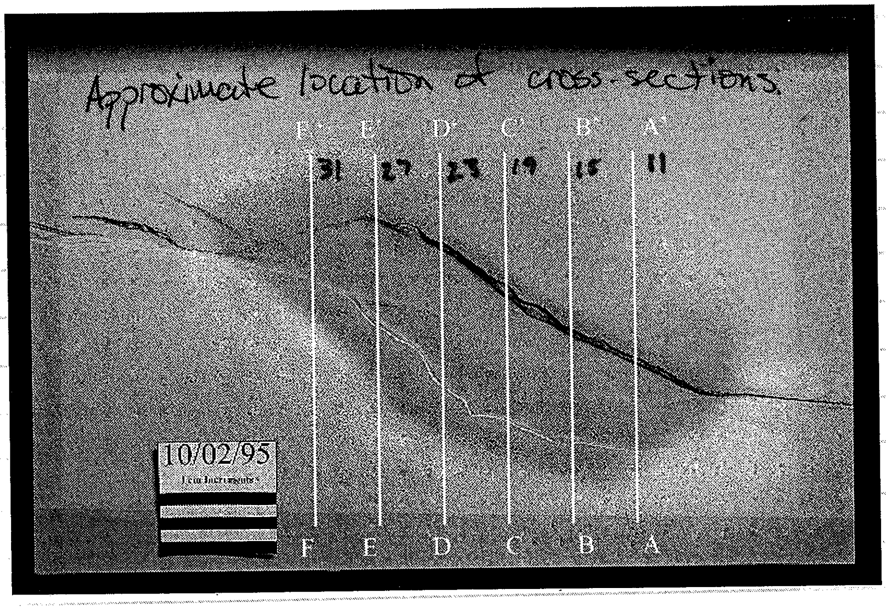












- Cross-sectional slides from model 10-02-95 show the following:

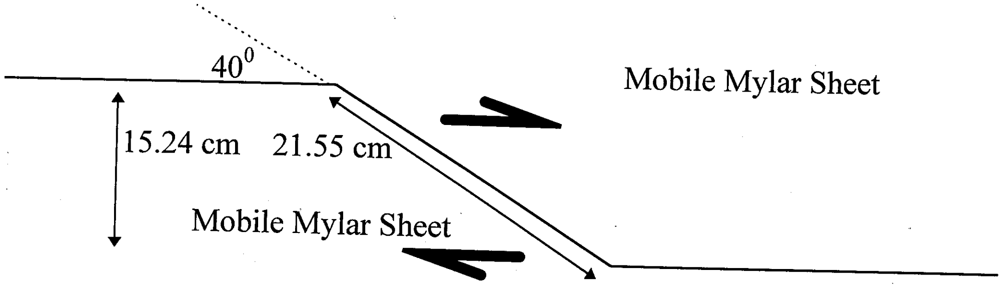
  * Single normal fault along mobile side of model.
  * Change in convexity of faults, particularly outer bounding faults on fixed side of model.
  * Relatively consistant throw with depth
  * faults with both a normal + reverse sense of displacement.
  * Bed thinning

2-15-95

Brett Rahe

December 15, 1995

- Objective: This model will have the same basic scale factors and dimensions as the prior model. During this model run, all of the walls will be moving in accordance with the programs on page 101 of this notebook. Comparisons and contrasts with previous models in which one side of the pull-apart was held fixed will be made.
- The mylar configuration of the floor of the model will have the dimension as shown below. Though this model will have the same dimensions, i.e. $40^0$ step measuring 21.55 cm, the Mobile Mylar Sheet will be placed just touching the Fixed Mylar Sheet..



- Models will be scaled for length, the resulting model to tectonic prototype ratio is:

$$\text{length ratio} = \text{model/prototype}$$
$$\text{length ratio} = 1\ \text{cm}/100{,}000\ \text{cm} = 1\cdot10^{-5}$$

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness.. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 9 cm. Using the equations on page 48 of this scientific notebook then the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr) | 2.38 cm/hr |
| Number of pulses/second | 5 p/s |
| Displacement | 4.5 cm in both directions (a total of 9 cm) |
| Number of Pulses from the Stepper Motor | 34015 pulses |

- Therefore, at five (5) pulses per second, for a total of 34015 pulses, the model will take 1 hour, 53 minutes, 23 seconds to complete.
- Each role of film that is used contains 36 exposures, as such 36 may be divided into the time needed to run each model to obtain the interval time needed to program the Nikon F4 camera which will record the model as it progresses from start to finish. This will be done for every model. For this model it resulted in an interval time of 3 minutes, 30 seconds. Additionally, by using the data backs, each slide will be imprinted with the date and a number, the numbers beginning with '1' and increasing by the same factor so that the final picture has imprinted upon it the number '36'. The cameras are started simultaneously with the computer program controlling the motion of the deformation box.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken (every 7 minutes) throughout the duration of the model run. These descriptions begin on the next page (pg. 109).

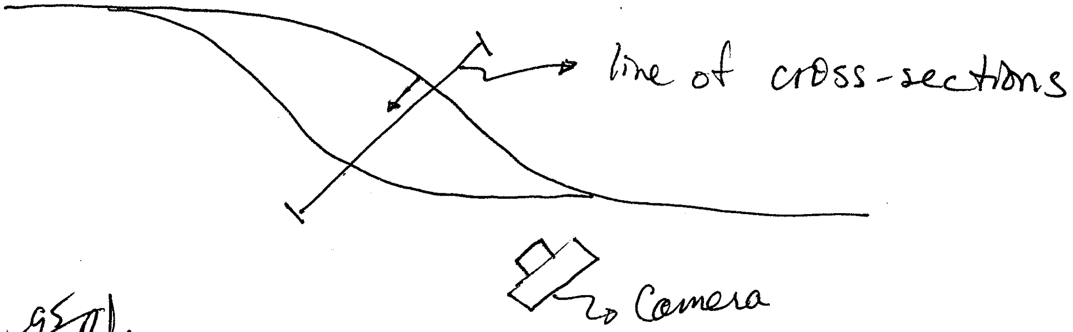
- The model will be started at 8:00 a.m., December 15, 1995 and stopped automatically at 9:53:23 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- All step motors will be used to each control an individual wall of the model. The connections will look like those of setup #1 on page 33.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 7 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes 36 seconds.

Description of Model Run, December 15, 1995

| Time | Descriptions of Time Events |
|---|---|
| 8:00 am | • Model run started. |
| 8:07 am | • As expected, the two boundary faults of what will become the graben are just now becoming visible on the surface of the upper layer of the model. |
| 8:12:36” am | • First layer of synkinematic fill added to the graben, color yellow.<br>• 1 cm strike-slip displacement. |
| 8:14 am | • Riedel shear systems have started to develop along the portion of the model overlying the pure strike-slip sections of the model.<br>• Additional normal faults appear to be forming outside of the two original graben bounding faults.<br>• The graben is becoming wider. |
| 8:21 am | • The graben had widened and also deepened.<br>• The Riedel shear systems have further developed.<br>• The presence of cross-basin faults can also be seen developing trending through the basin.<br>• The normal faults bounding the graben do not appear to be as steeply dipping as faults bounding pull-aparts in model where one side was fixed relative to a mobile side. |
| 8:25:12” am | • Second layer of synsedimentary fill is added to the graben, color blue.<br>• 2 cm of displacement. |
| 8:28 am | • Faults are propagating up through the second layer of synkinematic fill. |
| 8:35 am | • The right side of the pull-apart is very irregular along strike.<br>• Cross-basin fault has reappeared in the middle of the graben.<br>• Relay ramps can be seen starting to form between faults merging bounding faults into the strike-slip sections of the model. |
| 8:37:48” am | • The third layer of synkinematic fill was added to the graben, color yellow.<br>• 3 cm of displacement. |
| 8:42 am | • Faults are propagating up through the second layer of synkinematic fill. |
| 8:49 am | • The cross-basin fault easily seen through the center of the pull-apart.<br>• The graben is further widened and deepened. |
| 8:50:24” | • The fourth layer of fill is added to the graben, color blue.<br>• 4 cm of displacement. |
| 8:56 am | • Graben bounding normal faults have propagated up through the uppermost layer of synsedimentary fill. |
| 9:03 am | • Graben continues to widen and deepen.<br>• Relay ramps continue to develop in the areas mentioned earlier.<br>• The fifth layer of fill was added to the interior of the graben, color yellow.<br>• 5 cm of displacement. |

| | |
|---|---|
| 9:10 am | • The cross-basin fault trends across the entire pull-apart from one apex to the other.<br>• No new normal faults have been detected. |
| 9:15:36" am | • The sixth layer of synkinematic fill was added to the pull-apart, color blue.<br>• 6 cm of displacement. |
| 9:17 am | • Faults are propagating up through the sixth layer of synkinematic fill. |
| 9:24 am | • Two cross-basin faults are now visible on the surface of the model trending through the interior of the pull-apart. |
| 9:28:12" am | • The seventh and final layer of synkinematic fill was added to the model.<br>• 7 cm of displacement, color yellow. |
| 9:31 am | • Faults are propagating up through the seventh layer of synkinematic fill. |
| 9:38 am | • The nicely formed pull-apart is noticeably wider and deeper.<br>• Cross-basin faults are still present. |
| 9:45 am | • The model is continuing to experience strike-slip displacement.<br>• Bounding faults to the graben are now dipping more steeply than they appeared to earlier. |
| 9:52 am | • An area between the cross-basin faults is now subsiding. It appears to be a smaller graben within the larger pull-apart.<br>• All of the other faults have continued to deform as before. |
| 9:53:20" am | • Model run stopped. |

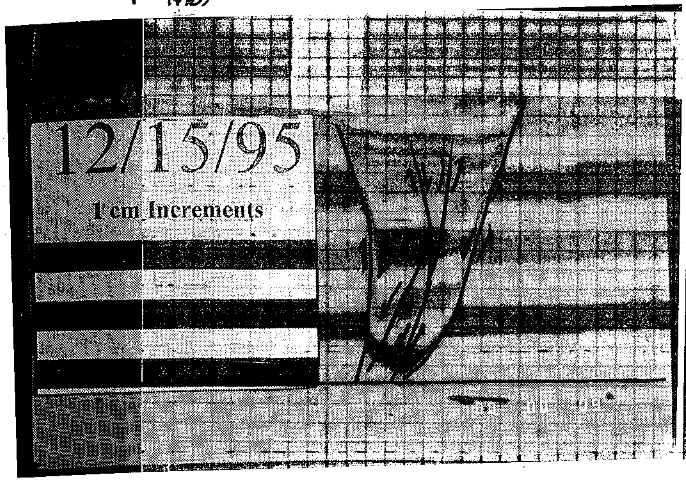
- Cross-sections to be taken every approximately 1cm.
- Cross-sections were cut perpendicular to the dip direction of the normal faults bounding the pull-apart!

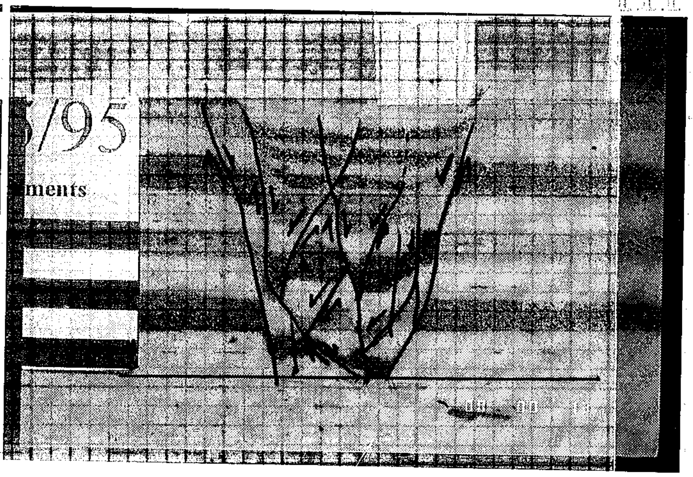


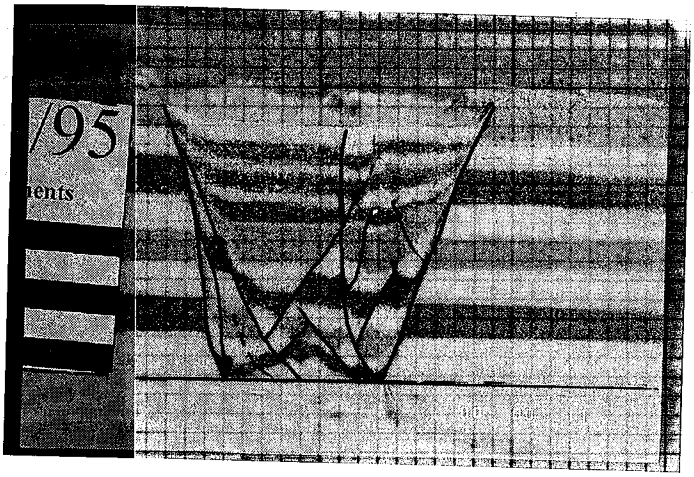
12-21-95
Bret Rahe

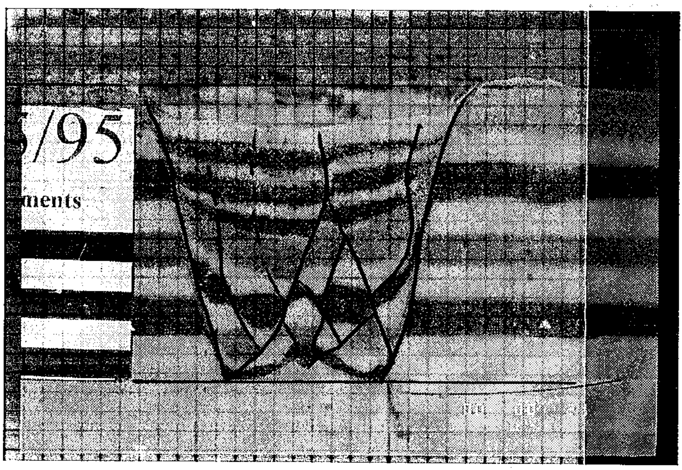
- Problems with the Nikon camera responsible for taking photos in plan view resulted in no photos at all for this model run. As such only the descriptions made during the simulation are available for interpretations. The photos of the cross-sections are ~~still~~ all O.K.

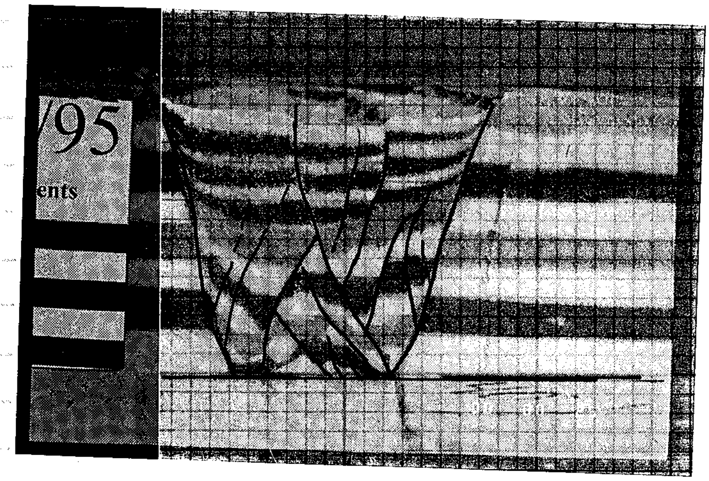
12-22-95

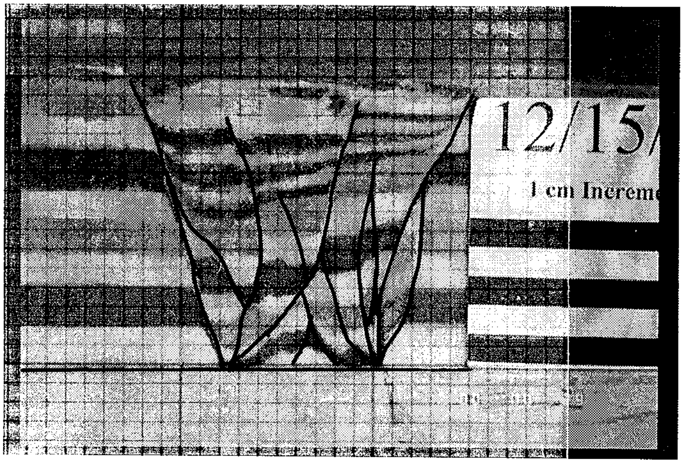




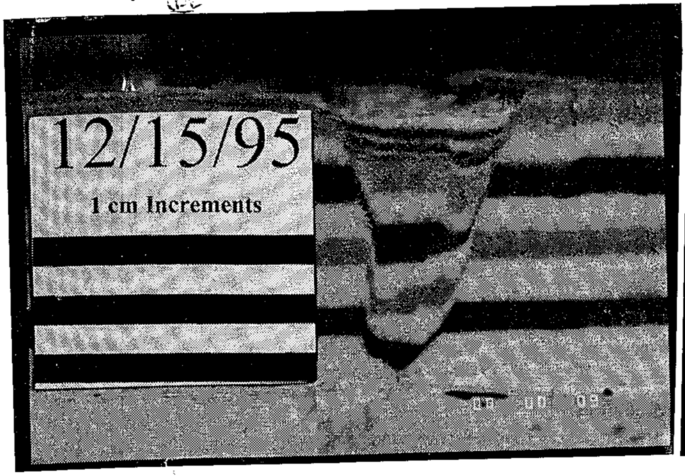


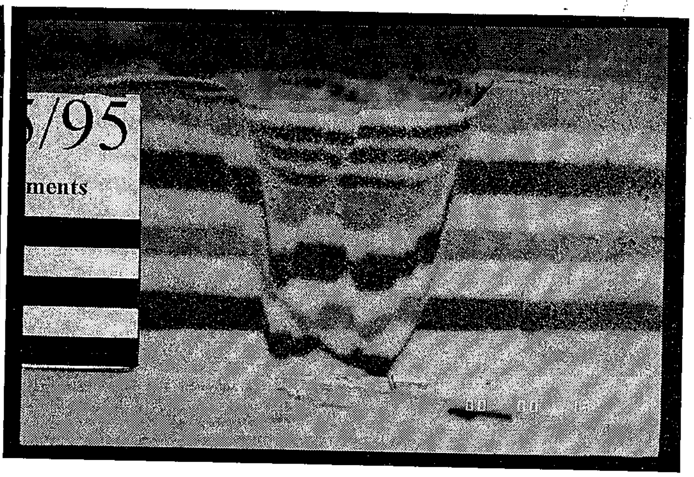


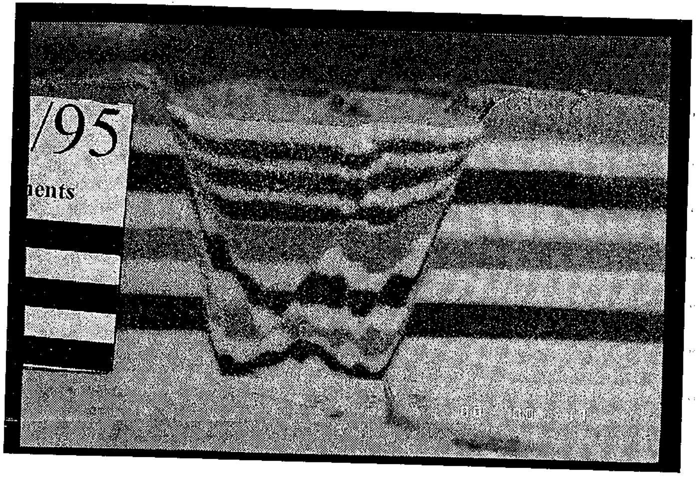


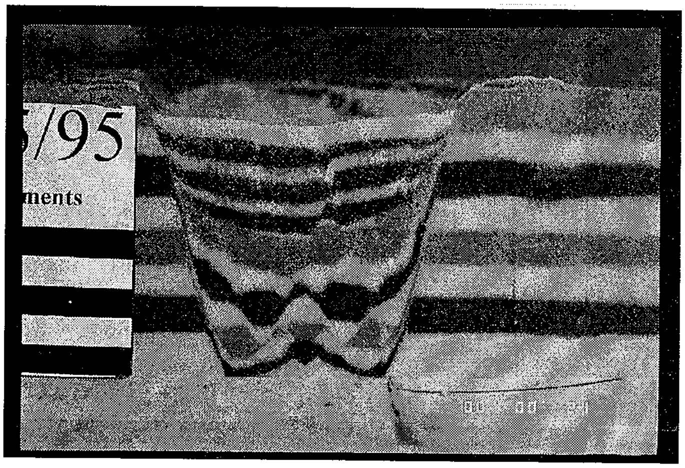


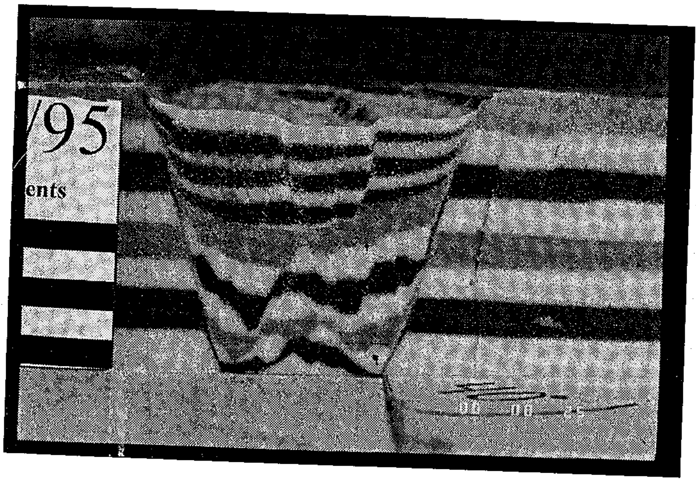
- Most notable is the symmetry of the graben unlike the models with one fixed side.
- Similar to previous models are fault morphologies that change along strike from convex up to convex down (compare boundary fault shape on right side of graben in slide 09 + 29 above).
- Consistant throw with depth on individual faults.











- Most notable is the symmetry of the graben unlike the models with one fixed side.
- Similar to previous models are fault morphologies that change along strike from convex up to convex down (compare boundary fault shape on right side of graben in slide 09 & 29 above).
- Consistant throw with depth on individual faults.

BR

BR

BR

Bret Rahe

January 3, 1996

- Previous pull-apart models have consistantly shown the developement of cross-basin strike-slip faults. These faults develope in both models with one fixed side and in models where both sides of the model are moving away from one another at the same rate. In models where one side of the pull-apart was held fixed by not moving the mylar substrate, cross-basin faults commonly demonstrated in cross-section both a reverse and normal sense of displament. Preliminary results from models in which both sections of the mylar substrate are moving away from one another do not develope faults with a reverse displacement sense, but do result in symmetric pull-aparts. The next suite of models will attempt to determine the parameters and controlling factors that affect the development of the reverse displacments between the two end members ( one fixed and one mobile side <u>vs.</u> both sides mobile).
- The importance of the determining these parameters are as follows:

1. Structural interpretations
2. Seismic interpretations
3. Stratigraphy
4. Reasons pertaining to the seismic risk assessment for Yucca Mountain and the surrounding region.

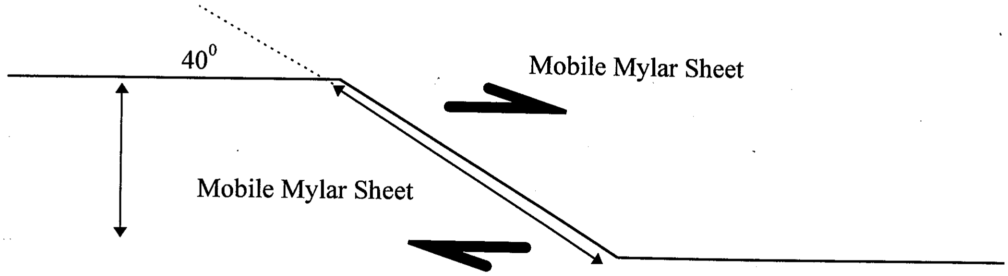
- On the following page is a description of the models that will be run. The different amount of displacement that each side of the model will experience are shown. The necessary number of pulses were calculated using the equations on page 48 of this scientific notebook.
- Models will be scaled the same as the previous models, 1 cm = 1 km. Thickness of the models will be ~10cm. Recording of models will be like before as well with the use of the photographic equipment in the lab (Bldg. 57, L104). Specific details will accompany the description of each model simulation before it is run.

| Model # | Wall Combo | Amount (cm) | Amount (pulses) | Pulses per Second (#pulses/7200sec) | |
|---|---|---|---|---|---|
| ✓1. | Walls 1 and 2 | ~~10.0~~ 0.0 cm | ~~75590~~ 0 pulses | ~~10.50~~ 0.00 p/s | BR 1-4-96 |
| | Walls 3 and 4 | ~~0~~ 10.0 | ~~0~~ 75590 | ~~0.00~~ 10.50 p/s | |
| ✓2. | Walls 1 and 2 | 1.00 cm | 7559 pulses | 1.04 p/s | |
| | Walls 3 and 4 | 9.00 cm | 68031 pulses | 9.45 p/s | |
| ✓3. | Walls 1 and 2 | 1.50 cm | 11339 pulses | 1.57 p/s | |
| | Walls 3 and 4 | 8.50 cm | 64251 pulses | 8.92 p/s | |
| ✓4. | Walls 1 and 2 | 2.00 cm | 15118 pulses | 2.10 p/s | |
| | Walls 3 and 4 | 8.00 cm | 60472 pulses | 8.40 p/s | |
| ✓5. | Walls 1 and 2 | 2.25 cm | 17008 pulses | 2.36 p/s | |
| | Walls 3 and 4 | 7.75 cm | 58582 pulses | 8.14 p/s | |
| ✓6. | Walls 1 and 2 | 2.50 cm | 18898 pulses | 2.62 p/s | |
| | Walls 3 and 4 | 7.50 cm | 56692 pulses | 7.87 p/s | |
| ✓7. | Walls 1 and 2 | 2.75 cm | 20787 pulses | 2.89 p/s | |
| | Walls 3 and 4 | 7.25 cm | 54803 pulses | 7.61 p/s | |
| ✓8. | Walls 1 and 2 | 3.00 cm | 22677 pulses | 3.15 p/s | |
| | Walls 3 and 4 | 7.00 cm | 52913 pulses | 7.35 p/s | |
| ✓9. | Walls 1 and 2 | 3.50 cm | 26457 pulses | 3.67 p/s | |
| | Walls 3 and 4 | 6.50 cm | 49133 pulses | 6.82 p/s | |
| ✓10. | Walls 1 and 2 | 4.00 cm | 30236 pulses | 4.20 p/s | |
| | Walls 3 and 4 | 6.00 cm | 45354 pulses | 6.30 p/s | |
| ✓11. | Walls 1 and 2 | 5 cm | 37795 pulses | 5.25 p/s | |
| | Walls 3 and 4 | 5 cm | 37795 pulses | 5.25 p/s | |

- Each model simulation to last for 2 hours.
- Step motors 1,3, and 4 turn counter-clockwise to move walls during simulation.
- Step motor 2 turns clockwise to move walls during simulation.

January 16, 1996

- Objective: This model is part of the second suite of simulations aimed at determining controlling factors associated with the formation of the cross-basin fault. For this simulation programs will be used to obtain the displacements for model #6, pg. 117 of this scientific notebook. The specific programs to be used are st2_6_01.ms1, st2_6_02.ms1, st2_6_03.ms1, and st2_6_04.ms1 which are stored on the NEC computer in Lab L104, Bldg. 57. The programs are in the c:\micro directory.



- Models are all to be scaled for length, resulting in the following tectonic prototype ratio:

length ratio = model/prototype = 1 cm/100,000 cm = $1\cdot10^{-5}$.

This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 10 cm. Using the equations on page 48 of this scientific notebook the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr): | |
| wall 1 | 1.25 cm/hr |
| wall 2 | 1.25 cm/hr |
| wall 3 | 3.75 cm/hr |
| wall 4 | 3.75 cm/hr |
| Number of pulses/second | |
| wall 1 | 2.62 p/s |
| wall 2 | 2.62 p/s |
| wall 3 | 7.87 p/s |
| wall 4 | 7.87 p/s |
| Displacement | |
| wall 1 | 2.50 cm |
| wall 2 | 2.50 cm |
| wall 3 | 7.50 cm |
| wall 4 | 7.50 cm |
| Number of Pulses from the Stepper Motor | |
| walls 1 and 2 | 18898 pulses |
| walls 3 and 4 | 56692 pulses |

- Each model should take approximately 2 hours to complete from start to finish.
- Each model will be photographed from start to finish in plan view using the Nikon F4s cameras in the lab. Each slide will be imprinted with a sequential number in the lower right corner. Exposures will be taken every 4 minutes.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken throughout the duration of the model run in 8 minute intervals and whenever else it is deemed important. These descriptions begin on the next page (pg. 119).

- The model will be started at 8:00 a.m., January 16, 1996 and stopped automatically at 10:00 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- All step motors will be used to each control an individual wall of the model. The connections will look like those of setup #1 on page 33.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes.

BL

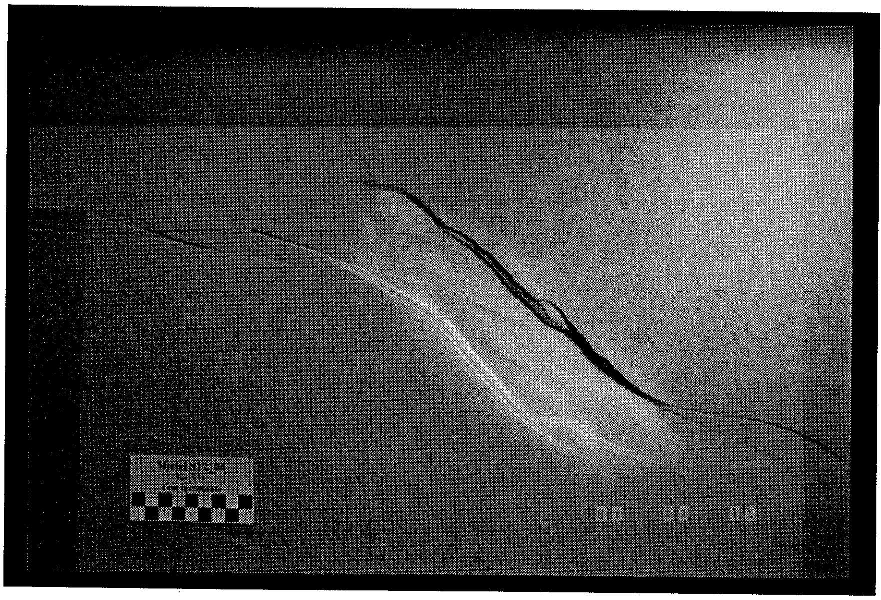
## Description of Model Run, January 16, 199~~7~~6

| Time | Descriptions of Time Events |
|---|---|
| 8:00 | • Model simulation started |
| 8:08 | • Two outer bounding faults have formed and the central section of the pull-apart is beginning to subside. |
| 8:12 | • Yellow synkinematic fill was added to the interior section of the pull-apart. At this time the model has experienced 1 cm of dextral displacement. |
| 8:16 | • Systems of Riedel shears have developed above the pure strike-slip sections of the mylar substrate.<br>• The outer boundary faults of the graben have propagated up through the layer of yellow fill. The graben has also widened and further subsided. Normal displacement is dominant.<br>• One relay ramp exists at the lower section of the pull-apart where the boundary fault is merging into the strike-slip section of mylar. |
| 8:24 | • The cross-basin faults have begun to form and can be seen cutting through the interior of the pull-apart basin. It cannot yet be determined if they will show any reverse sense of displacement. These faults may be extensions of Riedel shears near the graben itself.<br>• Riedel shear systems have become further linked together.<br>• Blue layer of synsedimentary fill was added to the interior of the pull-apart. This after 2 cm of strike-slip displacement in the model. |
| 8:32 | • The graben has further subsided.<br>• Riedel shears continue to form and cut one another.<br>• Cross-basin faults are propagating up through the layer of blue fill in the interior of the graben.<br>• Relay ramps have formed at both ends of the pull-apart where normal boundary faults are merging into the strike-slip sections of the model. |
| 8:36 | • The third layer of synsedimentary fill was added to the graben. Color yellow and after 3 cm of total dextral strike-slip displacement. |
| 8:40 | • Graben continues to widen and deepen.<br>• Faults are propagating up through the most recent layer of fill within the interior of the pull-apart. |
| 8:48 | • Relay ramps have reformed at either end of the graben.<br>• Cross-basin faults have also reformed and cut through the interior of the pull-apart.<br>• Fourth layer of syndeformational fill added to the model, color blue. This done after 4 cm of total strike-slip displacement. |
| 8:56 | • Some faults bounding the pull-apart seem to have become less active. One noted example is found at the upper apex of the pull-apart where faults change from normal to strike-slip displacement.<br>• Graben widening and deepening. |
| 9:00 | • Fifth layer of fill was added to the graben after 5 cm of dextral displacement. Yellow. |

| | |
|---|---|
| 9:04 | • Graben continues to widen and deepen.<br>• Faults are propagating up through the most recent layer of fill within the interior of the pull-apart. |
| 9:12 | • Faults propagating up through the layers of fill.<br>• Further widening and deepening.<br>• Cross-basin faults can be seen on the surface but their sense of displacement in the subsurface cannot be determined.<br>• Sixth layer of synsedimentary fill added to the pull-apart, color blue. This after 6 cm of dextral displacement. |
| 9:20 | • Faults are propagating up through the most recent layer of fill within the interior of the pull-apart.<br>• More normal faults appear to have formed on either side of the interior of the pull-apart. |
| 9:24 | • Seventh layer of synsedimentary fill added to the pull-apart. 7 cm of displacement. Color is yellow. |
| 9:28 | • Faults are propagating up through the layer of synkinematic fill.<br>• Graben continues to widen and deepen. |
| 9:36 | • A section along the right side of the graben is now not as active and extension is being taken up by normal faults closer to the interior of the pull-apart. This normal fault is very irregular along strike.<br>• Another small pull-apart has formed between linked sections of Riedel shears towards the upper edge of the graben.<br>• Eighth and final layer of syndeformational fill added to the interior of the pull-apart after a total of 8 cm of dextral displacement. Color blue. |
| 9:44 | • Faults are propagating up through the most recent layer of fill within the interior of the pull-apart.<br>• Graben continues to widen and deepen but not as rapidly as during earlier in the simulation. |
| 9:52 | • Most subsidence was just noted to have been taking place along the left side of the pull-apart.<br>• There is now a complex system of normal faults within the interior of the pull-apart.<br>• The orientation of the cross-basin faults cannot be determined, much less their subsurface sense of motion. |
| 10:00 | • Model simulation stopped<br>• The final surface of the model shows a complex arrangement of predominantly normal faults that accommodate extension within the pull-apart. The faults are variable along strike and can be seen to have different amounts of displacement.<br>• Cross-basin faults where noted to have formed early in the model simulation but are now only barely visible on the surface of the model. |

- Cross-sections will be made normal to the boundary faults of the graben at approximately 1 cm intervals

*{Note: An error was made concerning the date printed on the scale on photo-slides. the date read 12/15/95 when in reality it was 1/16/96.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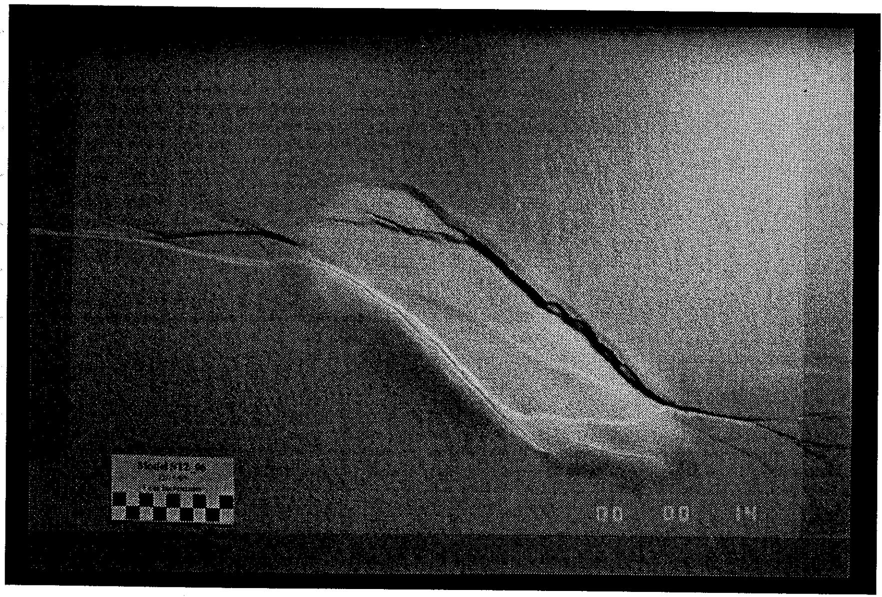
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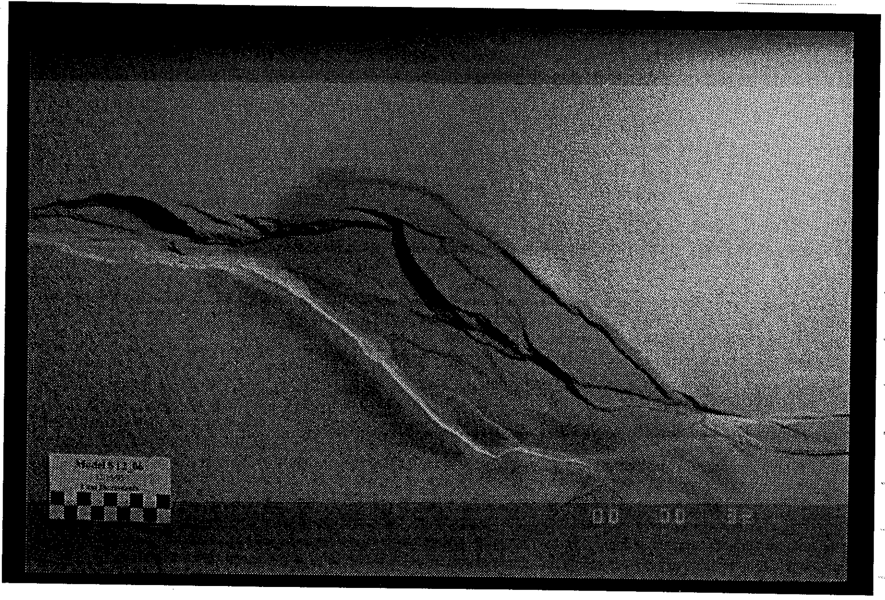
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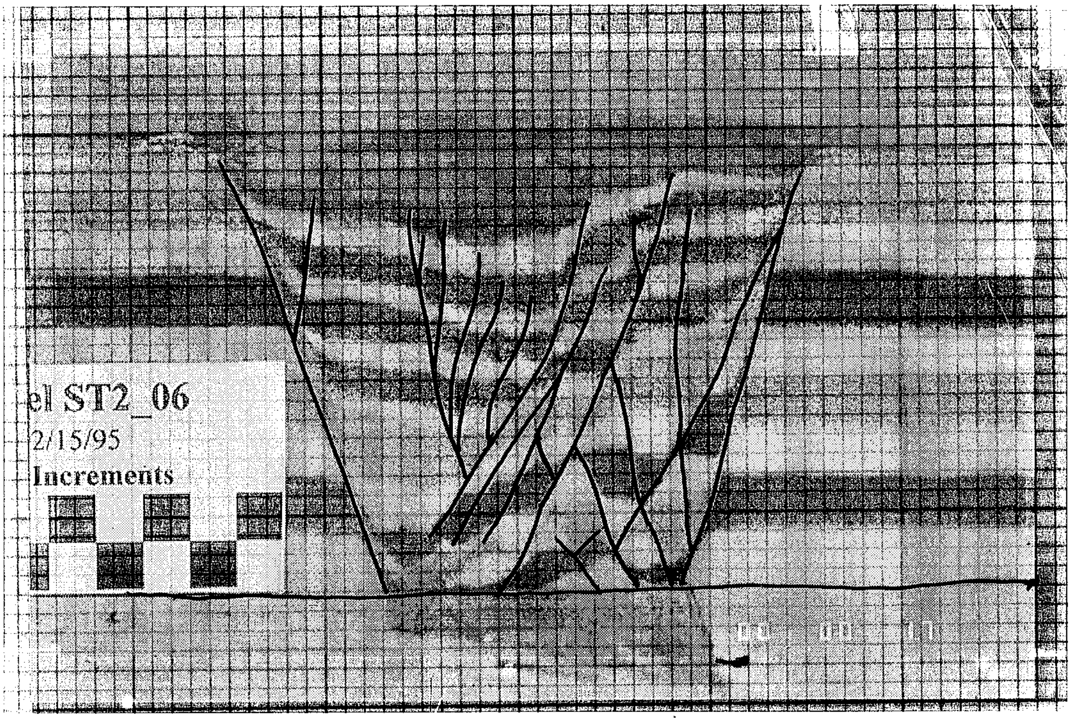
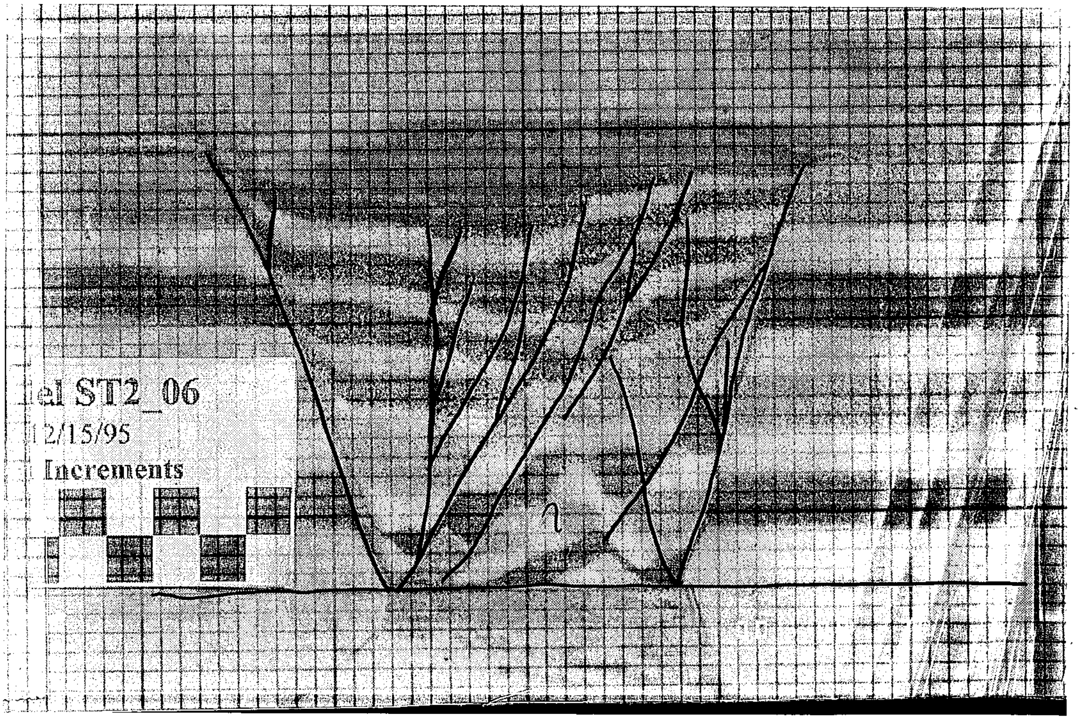

el ST2_06
2/15/95
Increments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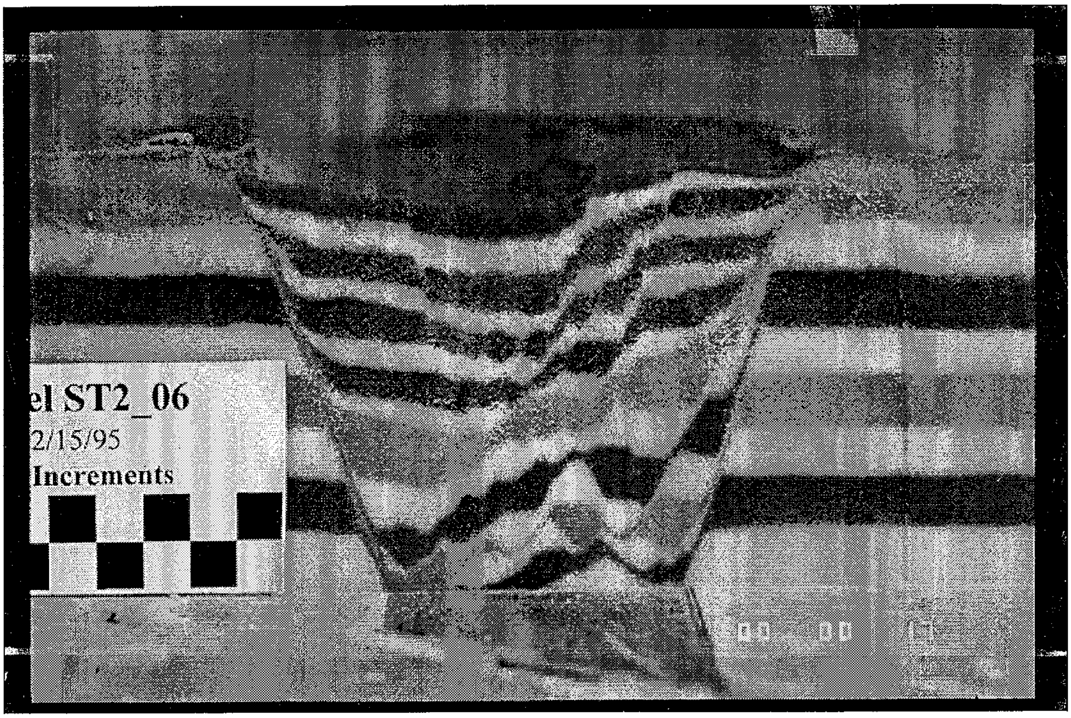
Increments
?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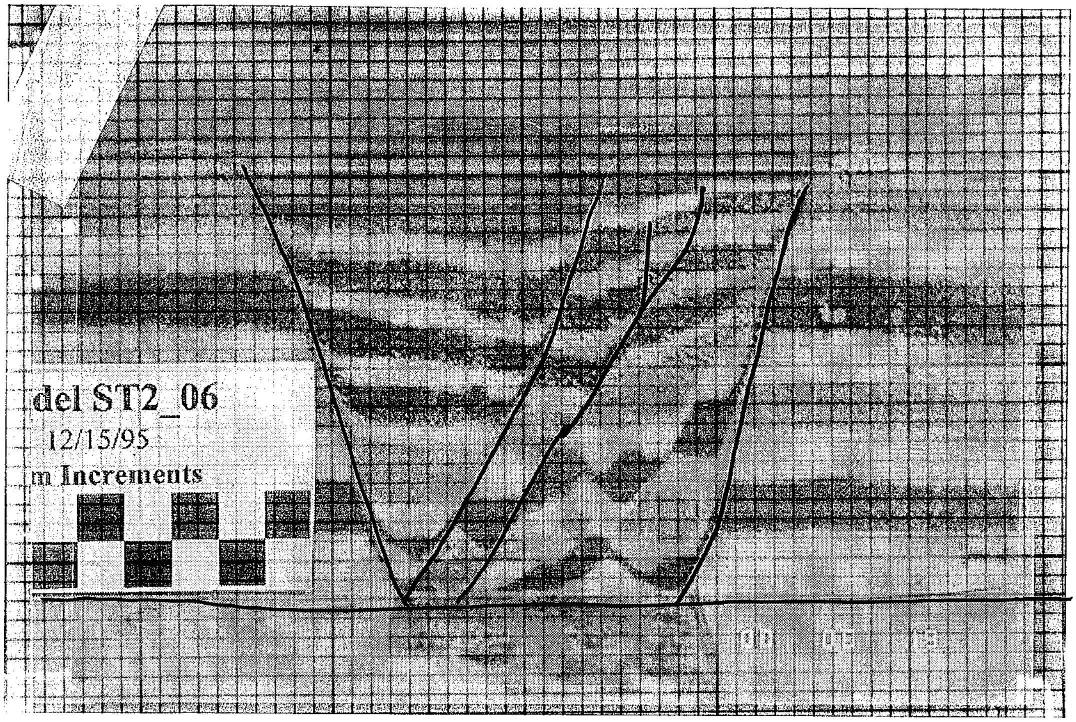
Increments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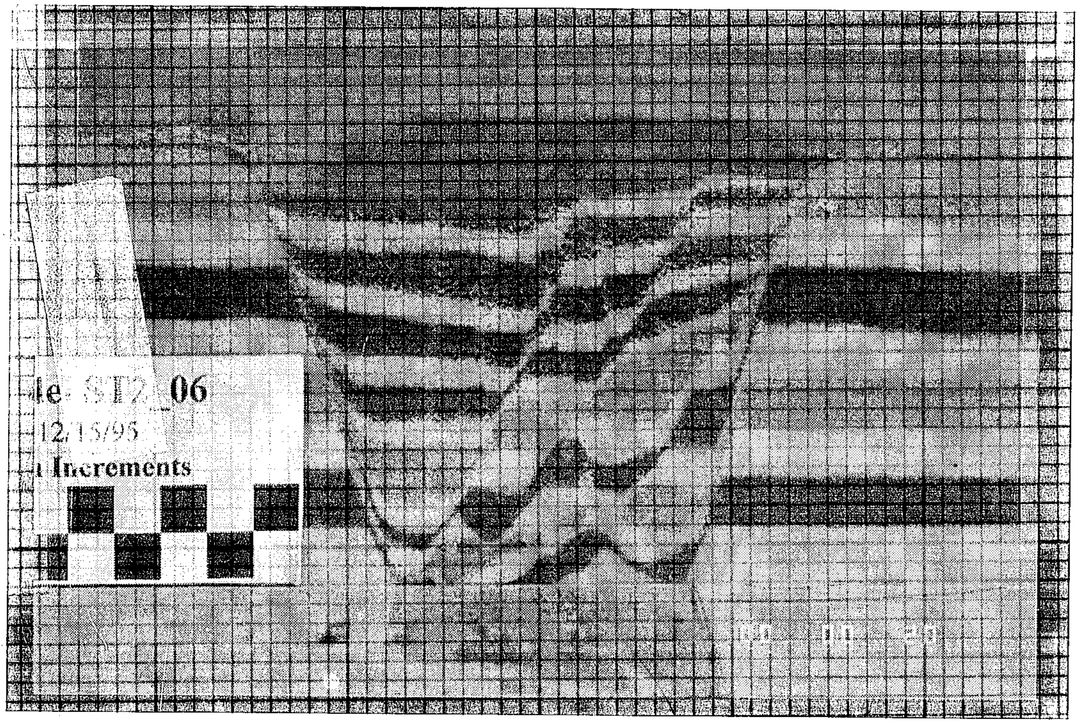
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n Increments
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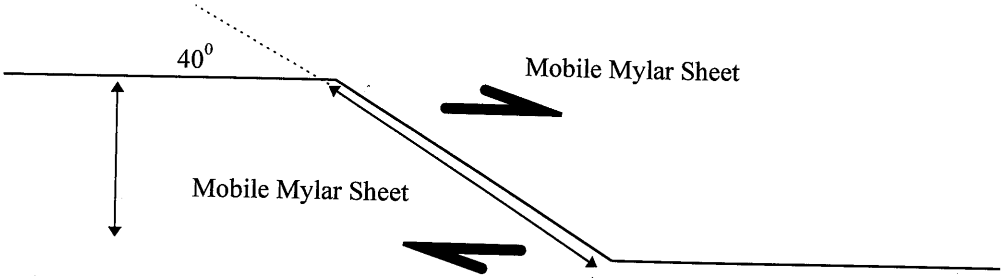
Bret Hale

January 18, 1996

Objective: This model is part of the second suite of simulations aimed at determining controlling factors associated with the formation of the cross-basin fault. For this simulation programs will be used to obtain the displacements for model #~~6~~5, pg. 117 of this scientific notebook. The specific programs to be used are st2_5_01.ms1, st2_5_02.ms1, st2_5_03.ms1, and st2_5_04.ms1 which are stored on the NEC computer in Lab L104, Bldg. 57. The programs are in the c:\micro directory.



- Models are all to be scaled for length, resulting in the following tectonic prototype ratio:

  length ratio = model/prototype = 1 cm/100,000 cm = $1 \cdot 10^{-5}$.

  This means that 1 cm in the model represents approximately 1.0 km in the prototype.

- Once the mylar had been cut into the appropriate dimension as shown above and placed into the bottom of the deformation box, then the dyed and undyed sand (see pg. 45 for preparation technique) was placed into the model in alternating layers beginning with white on the bottom, followed by blue, white, red, and then repeating the sequence for a total of eight layers, each approximately 1.25 cm in thickness. Total thickness of the model was approximately 10 cm.
- The amount of strike-slip displacement that this model will undergo is 10 cm. Using the equations on page 48 of this scientific notebook the following parameters were determined for the model.

| | |
|---|---|
| Linear Velocity (cm/hr): | |
| wall 1 | 1.12 cm/hr |
| wall 2 | 1.12 cm/hr |
| wall 3 | 3.87 cm/hr |
| wall 4 | 3.87 cm/hr |
| Number of pulses/second | |
| wall 1 | 2.36 p/s |
| wall 2 | 2.36 p/s |
| wall 3 | 8.14 p/s |
| wall 4 | 8.14 p/s |
| Displacement | |
| wall 1 | 2.25 cm |
| wall 2 | 2.25 cm |
| wall 3 | 7.75 cm |
| wall 4 | 7.75 cm |
| Number of Pulses from the Stepper Motor | |
| walls 1 and 2 | 17008 pulses |
| walls 3 and 4 | 58582 pulses |

- Each model should take approximately 2 hours to complete from start to finish.
- Each model will be photographed from start to finish in plan view using the Nikon F4s cameras in the lab. Each slide will be imprinted with a sequential number in the lower right corner. Exposures will be taken every 4 minutes.
- Description of the surface of the model will be made to coincide with every other photograph as it is taken throughout the duration of the model run in 8 minute intervals and whenever else it is deemed important. These descriptions begin on the next page (pg. 125).

- The model will be started at 8:00 a.m., January 18, 1996 and stopped automatically at 10:00 a.m. the same day. The indexers and stepper motors that will be used to move the walls of the model are controlled by the NEC computer and MS1.EXE software provided by Minarik Electronics of San Antonio.
- All step motors will be used to each control an individual wall of the model. The connections will look like those of setup #1 on page 33.
- In an attempt to better preserve the fault scarps that form along the normal faults bounding the pull-apart, synsedimentary layers will be added to the downdropped portion of the graben with every 1 cm of strike-slip displacement for the first 8 centimeters of displacement. The first synsedimentary layer of sand will be yellow and will alternate with sand that has been dyed blue. One centimeter of displacement will happen every 12 minutes.

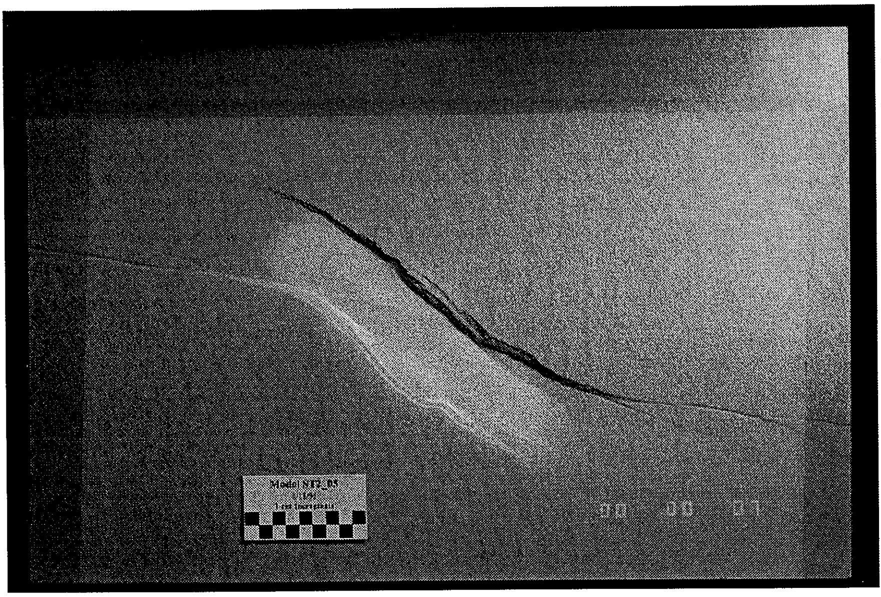
BP

## Description of Model Run, January 18, 199~~5~~6

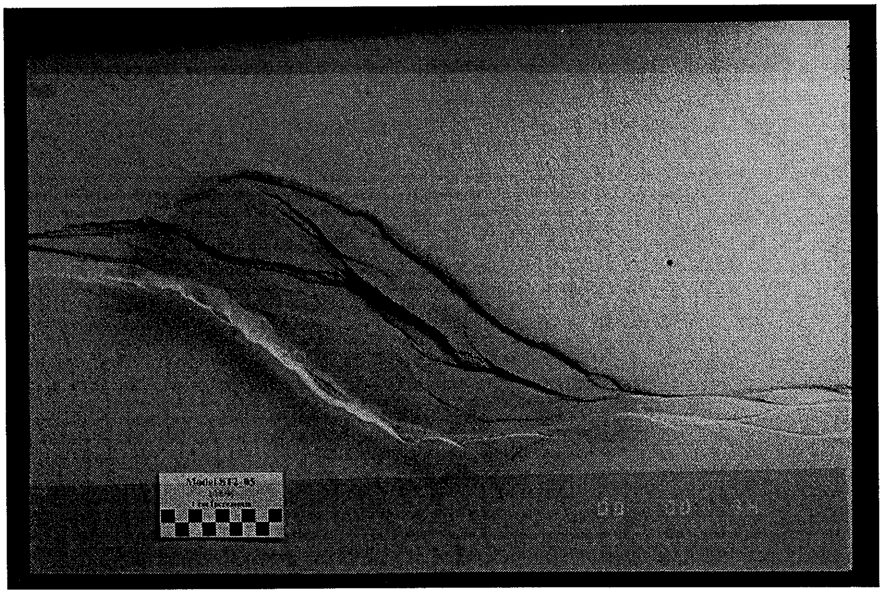
| Time | Descriptions of Time Events |
|---|---|
| 8:00 | • Model run started. |
| 8:08 | • Boundary faults have begun to form what will become the central graben of the pull-apart. |
| 8:12 | • First layer of yellow synsedimentary fill was added to the graben after 1 cm of displacement. |
| 8:16 | • Riedel shear systems have started forming above the sections of mylar experiencing pure strike-slip displacement.<br>• The floor of the pull-apart is widening and deepening.<br>• No indication of the cross-basin faults is yet evident. |
| 8:24 | • Cross-basin faults are now appearing on the surface of the model and cut through the central section of the model.<br>• The subsurface sense of displacement is not evident.<br>• Graben widening and deepening.<br>• Relay ramps are showing up were the normal boundary faults merge into the strike-slip sections of the model.<br>• Second layer of fill added to the graben after 2 cm of displacement. Color blue. |
| 8:32 | • Faults are propagating upward through the fill.<br>• Additional normal faults seem to be forming. All faults with normal displacement directions appear to have very steep dips.<br>• The systems of Riedel shears are becoming further linked together. |
| 8:36 | • Third layer of synkinematic fill is added to the graben as fill. 3 cm of dextral displacement. Color yellow. |
| 8:40 | • Faults are propagating upward through the fill. |
| 8:48 | • The graben has become further enlarged due to displacement along the normal faults bounding the pull-apart.<br>• Cross-basin faults have reappeared through the fill and cut across the central area of the graben.<br>• Relay ramps also are continuing to reform through the fill layers. Additional ramps are also showing up.<br>• Fourth layer of synkinematic fill is added to the graben as fill. 4 cm of dextral displacement. Color blue. |
| 8:56 | • Faults are propagating upward through the fill.<br>• Cross-basin fault cutting through the graben is irregular along strike and may cause a reverse displacement in the subsurface. |
| 9:00 | • Fifth layer of fill added to the pull-apart. 5 cm total displacement, color yellow. |
| 9:04 | • Faults are propagating upward through the fill. |
| 9:12 | • Cross-basin faults are still irregular along strike as seen in plan view. A single large one cuts from one apex of the graben to the other. |

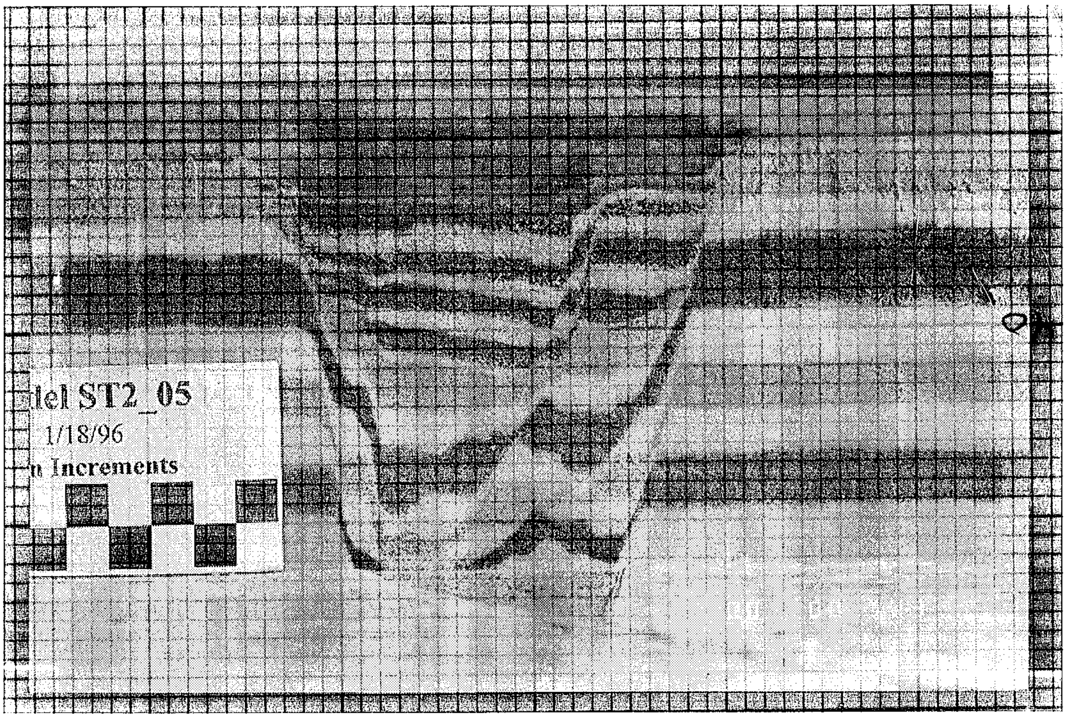
| | |
|---|---|
| | • The area comprising the pull-apart is getting larger.<br>• Sixth layer of fill added to the interior of the pull-apart. 6 cm displacement, color blue. |
| 9:20 | • Faults are propagating upward through the fill.<br>• Additional normal faults are forming inside the outermost boundary faults.<br>• Cross-basin faults have reappeared through the fill. |
| 9:24 | • Seventh layer of synkinematic fill added to the pull-apart, 7 cm dextral displacement, color yellow. |
| 9:28 | • Faults are propagating upward through the fill. |
| 9:36 | • The pull-apart basin is now nicely formed and fully developed.<br>• A complex array of faults resides in the subsided sections comprising the graben.<br>• Cross-basin faults are easily seen on the surface in map view.<br>• As in the previous model of suite two, most displacement is taking place along the normal faults associated with the side of the pull-apart moving at the faster rate.<br>• Parts of the graben near the side moving more slowly are not as active.<br>• One of the normal faults lying inside the right boundary fault is seen to change to strike-slip displacement near the grabens lower apex. This is noted by the presence of a discrete shear zone.<br>• Eighth layer of fill added to the graben, 8 cm displacement, color blue. |
| 9:44 | • Faults are propagating upward through the fill.<br>• Normal and cross-basinal faults are reappearing. |
| 9:52 | • Most displacement is taking place along the outermost boundary fault along the left side of the pull-apart.<br>• A large section along the right side is now pretty much inactive.<br>• Several cross-basin faults can be seen on the surface of the model.<br>• Numerous normal faults can be seen. |
| 10:00 | • Model simulation stopped. |

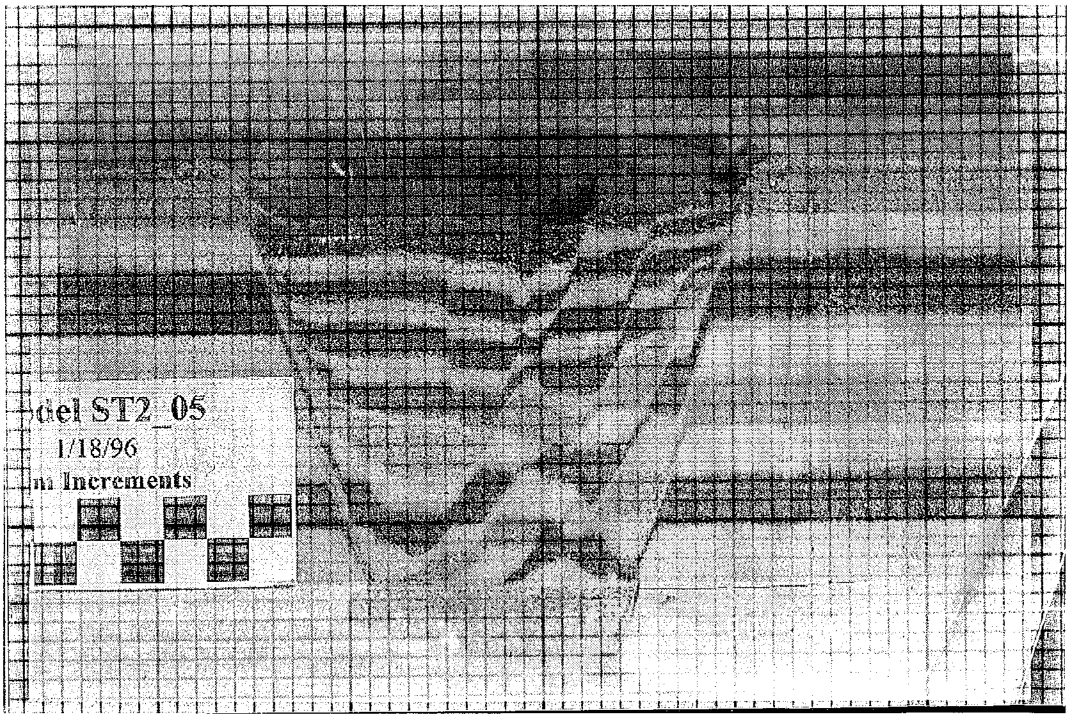
- Cross-sections ~~model~~ made normal to boundary faults of graben at 1 cm intervals.


Model ST2_05
1 cm Increments


Model ST2_05
1 cm Increments


Model ST2_05
1 cm Increments


del ST2_05
1/18/96
n Increments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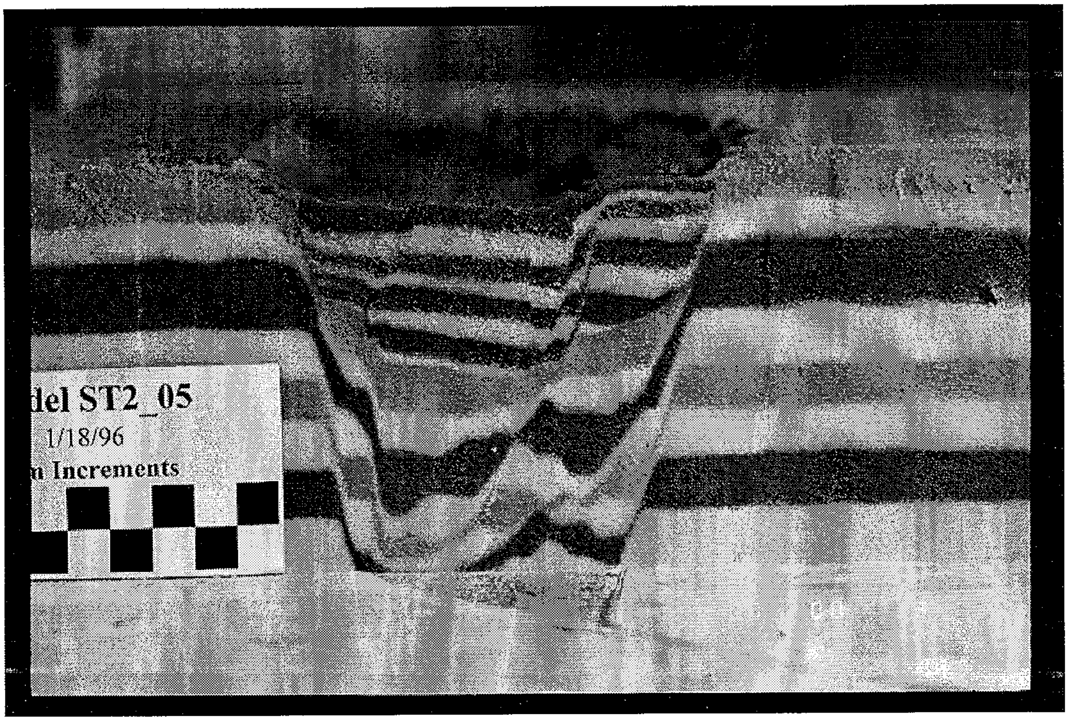
m Increments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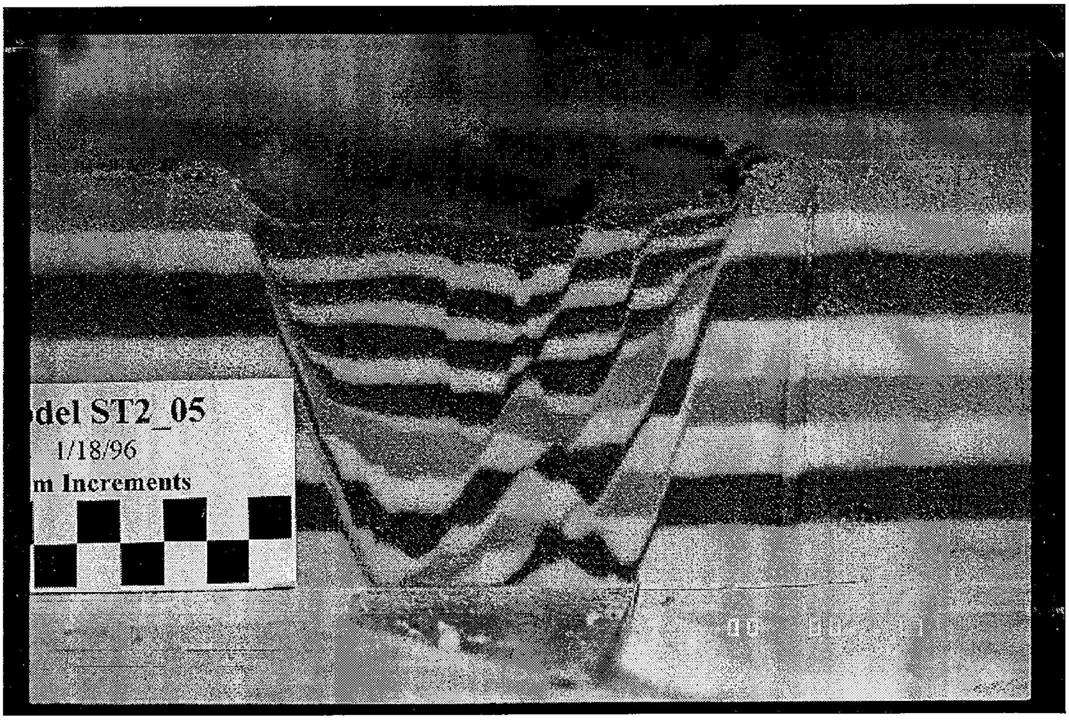
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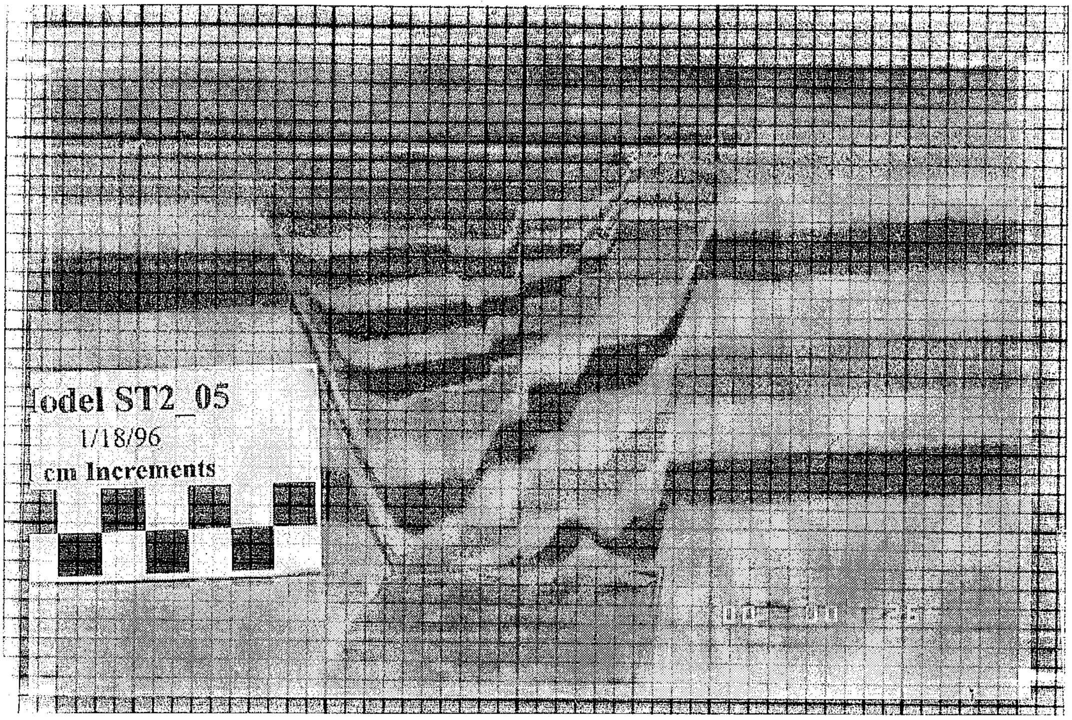
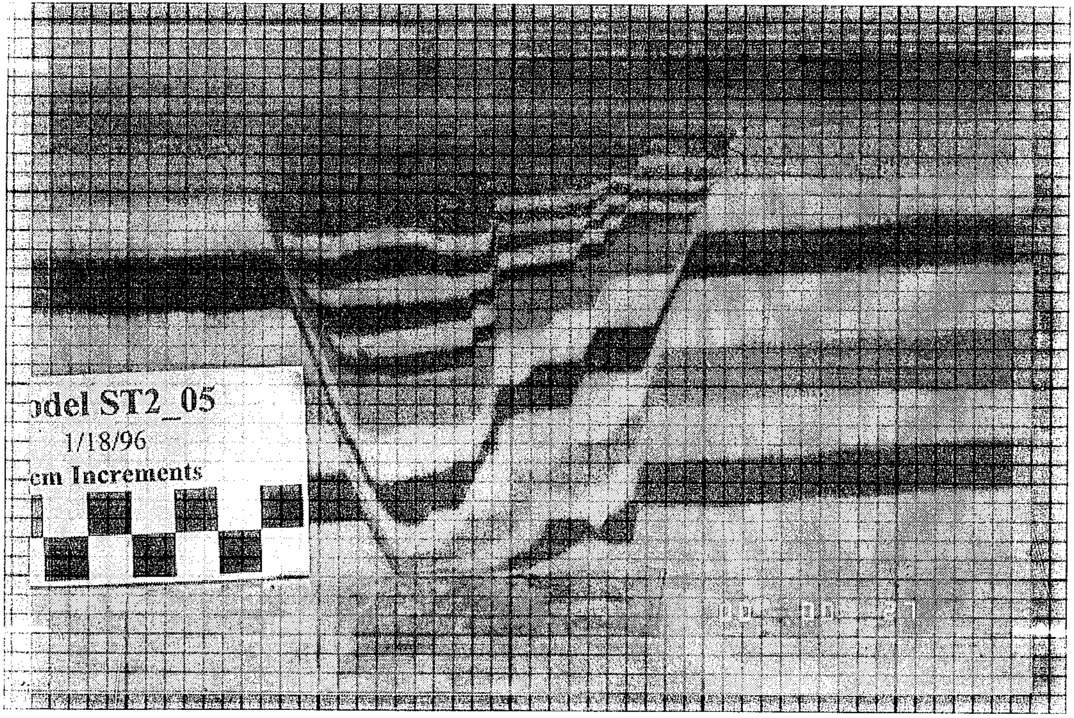
1/18/96
m Increments



odel ST2_05
1/18/96
cm Increments
00 00 26



odel ST2_05
1/18/96
cm Increments
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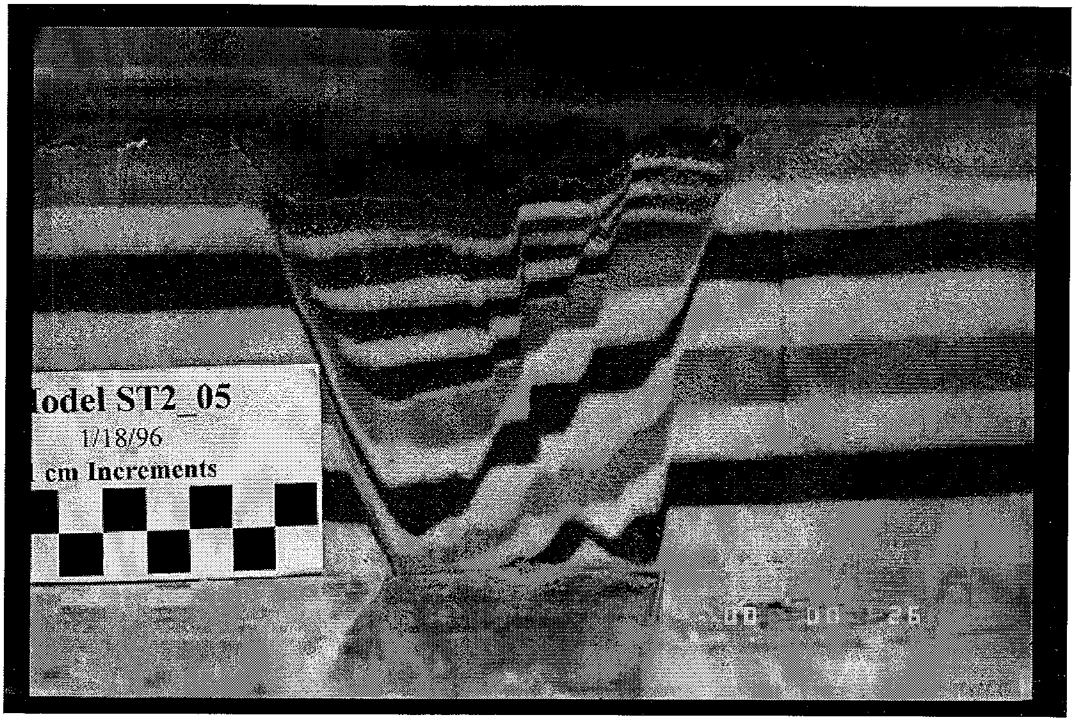
odel ST2_05
1/18/96
cm Increments
00 00 26


odel ST2_05
1/18/96
cm Increments
00 00 27