Start: 9:00am
Finish: 6:00pm

Thursday 7th. May 1992

Oblique slip?

Scott R.B. 1990

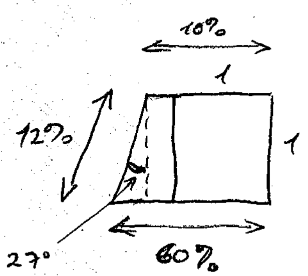
IF N. Yucca Mtn. extended 10%
AND S. Yucca Mtn extended 60%

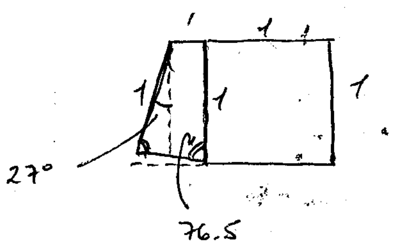
THEN this cannot be achieved by simple rotation

AND

Either: ⊕ Longitudinal strain along Yucca Mtn. (027°) is + 12%

OR: ⊕ Oblique slip direction to negate long. extension is directed 283° (N77W)





Alan Morris

We need:

+ Data from Bob Scott for his 1990 paper
+ Data from new study (John Russell has the name) done by USGS on faults at Yucca Mtn.

● We can use this fault orientation and slickenline data for a fault analysis à la Krantz + Reches.

Alan Morris

Start 9:30am
Finish 1:30pm

Monday 11 May 1992

Figures for Stirewalt paper.

Alan

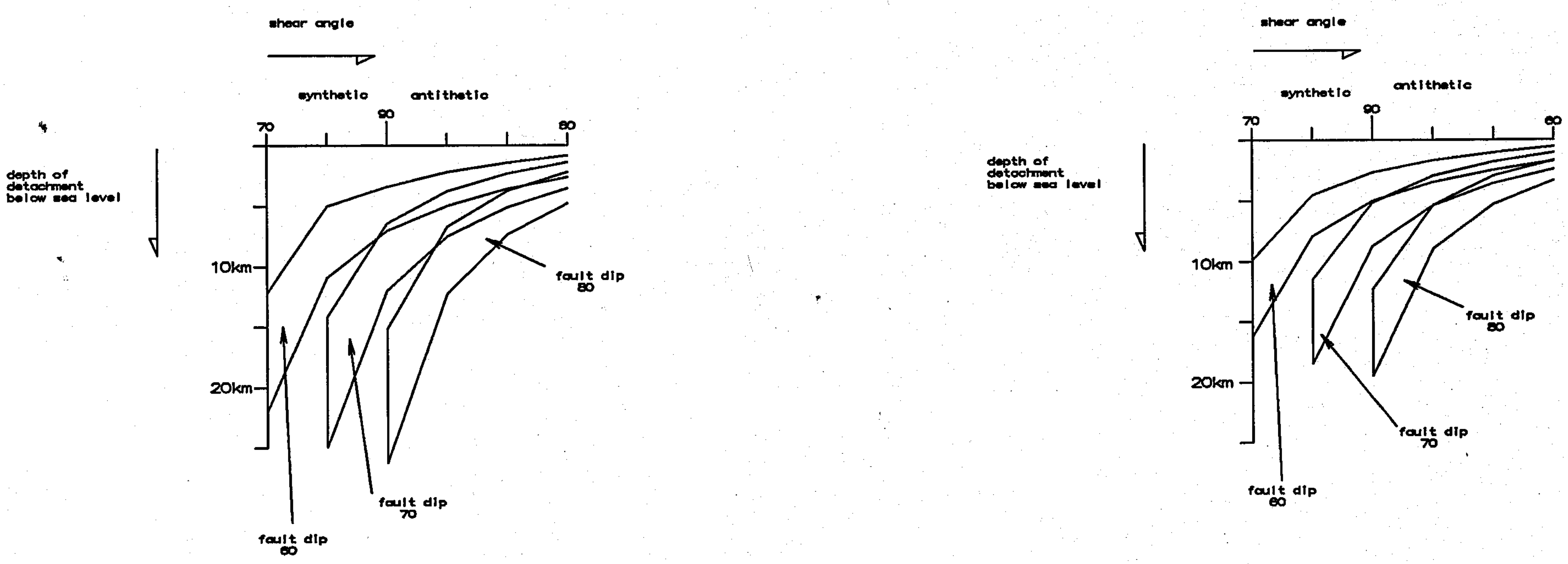
Massi

Start 12:30pm.
Finish 1:30pm.

Tues 12 May 1992

Plotting for report.

vertical/oblique shear solutions



higher regional

lower regional

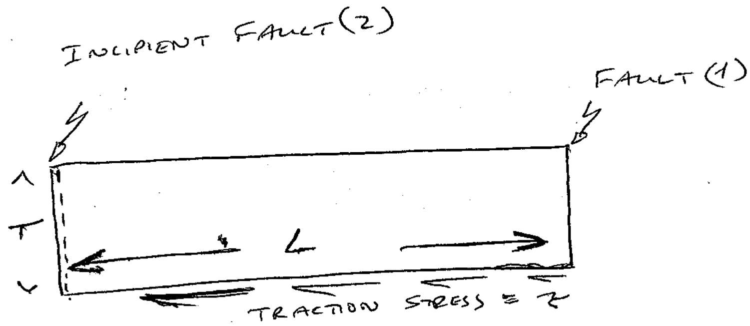
... into a single detachment level (Figure). This is especially true ...

124
Start 1:30pm
Finish 6:00pm

Thursday 14 May 1992

Alan Morris

CHARACTERISTIC WAVELENGTH (1)



WHEN DRIVING ~~STRESS~~ FORCE = RESISTING FORCE

THEN FAULT (2) DEVELOPS

DRIVING FORCE = $\tau . L$

RESISTING FORCE = CRITICAL STRESS (FAILURE) × T

$= \sigma_c . T$

$$\tau . L = \sigma_c . T$$

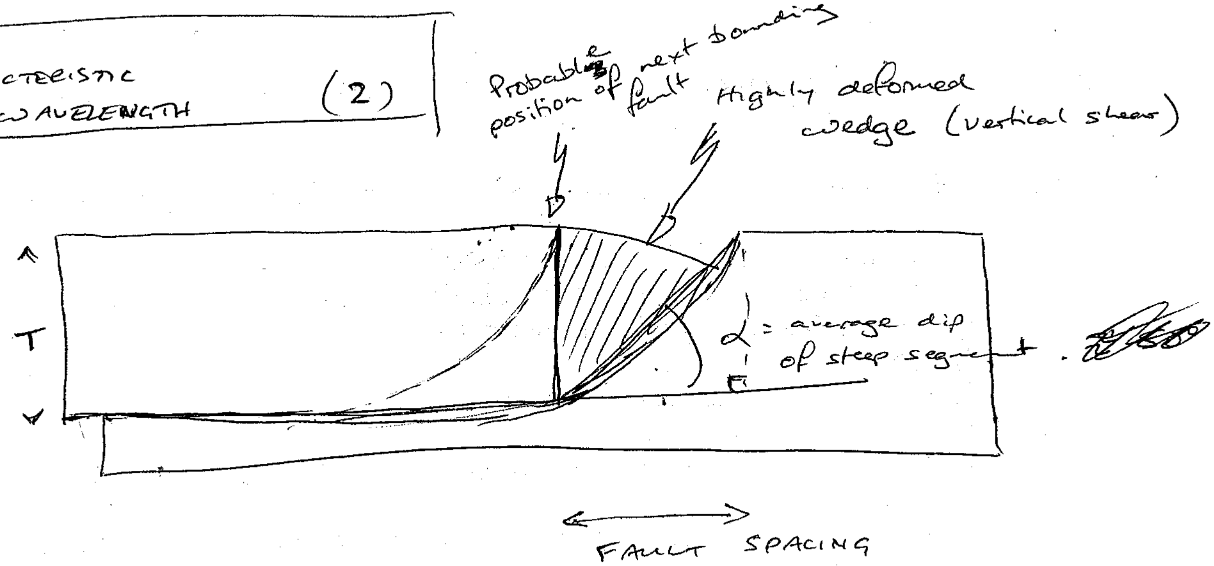
$$\frac{L}{T} = \frac{\sigma_c}{\tau}$$

$\therefore$ Fault spacing $L = \dfrac{T . \sigma_c}{\tau}$

Report preparation

Alan Morris

CHARACTERISTIC WAVELENGTH (2)



$$\text{FAULT SPACING} = \frac{T}{\tan \alpha}$$

Alan Morris

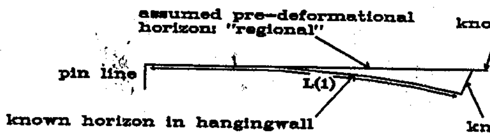
Start: 10:30am

Finish: 7:00pm

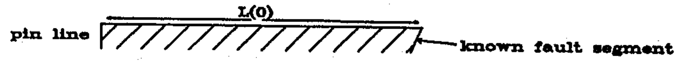
Friday 15 May 1992

Report preparation

Flexural slip fault trajectory prediction

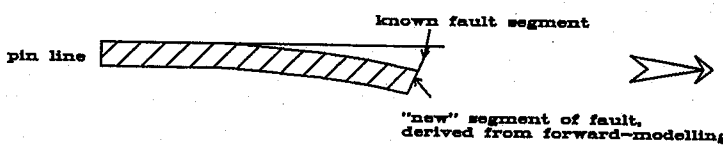


assuming the undeformed regional is thus:



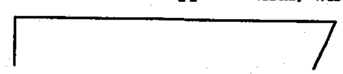
a bedding-parallel unit can be defined for the undeformed state, bounded by the known fault segment, and by th pin line.
Line length L(0) must equal L(1).

This block can be "forward-modelled" into the deformed state, using the known geometry of the hangingwall as a template, and the hangingwall pin.



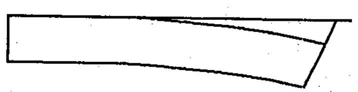
"new" segment of fault, derived from forward-modelling

The fault now appears thus, when restored:

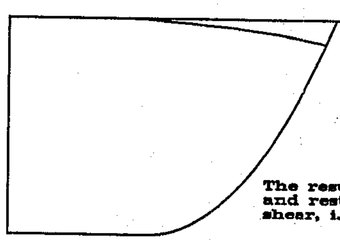


and a new bedding-parallel unit can be defined for the undeformed state, bounded by the extended fault segment, and by the pin line.

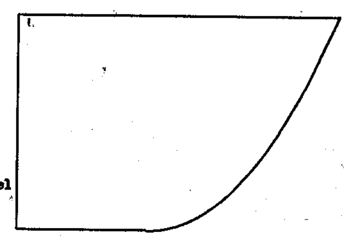
As before, this block can be "forward-modelled" into the deformed state, using the known geometry of the hangingwall as a template, and the hangingwall pin.



Successive iterations of this process permit the fault trajectory to be predicted to a depth at which it becomes horizontal:



The resulting interpretation is balanced and restorable assuming bedding-parallel shear, i.e. flexural slip.



Start: 11:30am

Finish: 3:00pm

Mon 25 May 1992

Plotting for report

Start 11:30am

Tues 26 May 1992

Plotting 11:30 - 2:30

MILEAGE SwRI → Home 12.5 miles, one way

1 hour on AV-1 @ UTSA

Alan

Macozi

3hrs @ UTSA

Alan Morris

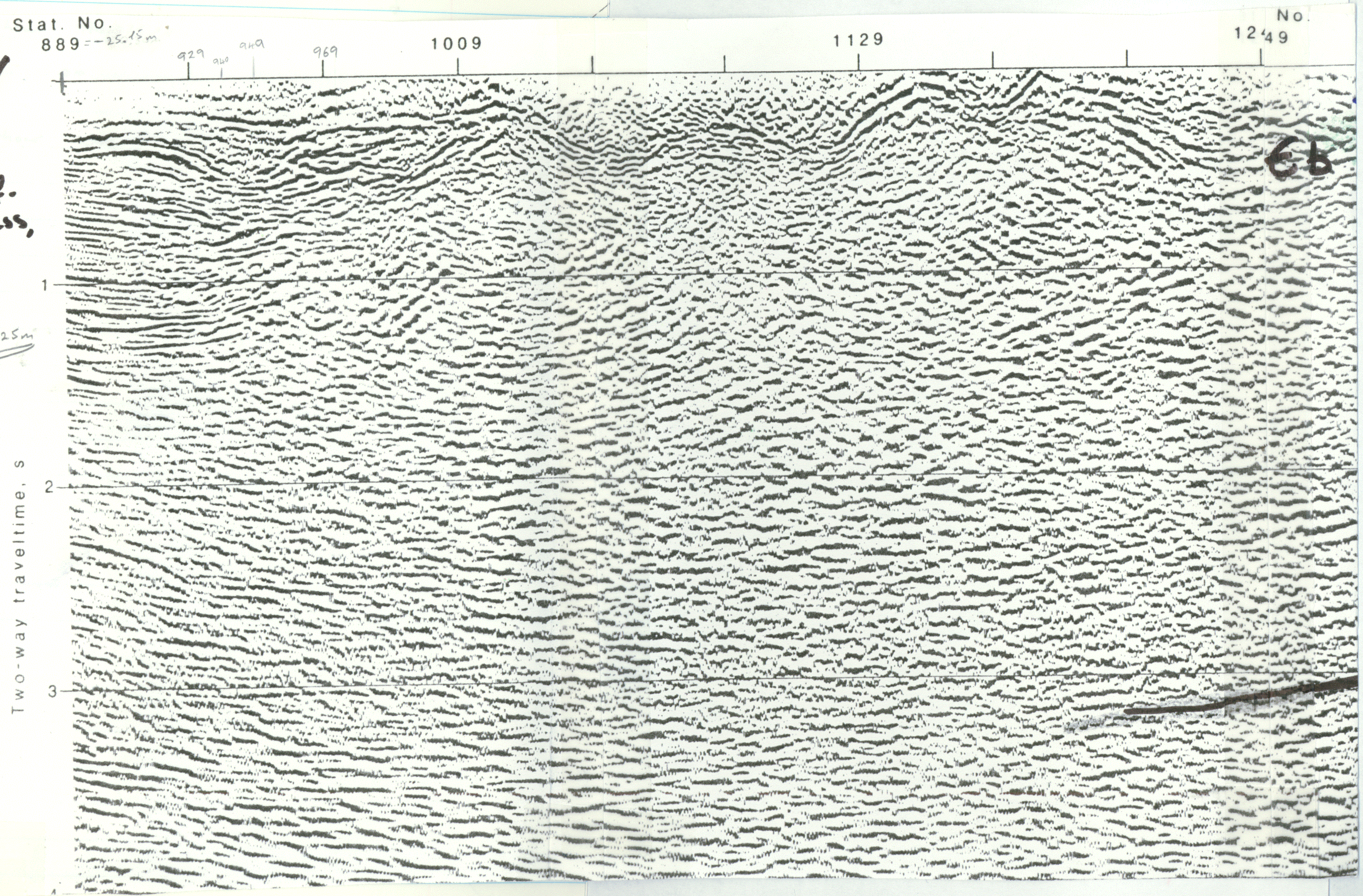
129

Tuesday 2nd June 1992

W

First, - stream-of-consciousness, attempt

Seismic datum = 825m



Alan Morris

3hrs @ UTSA

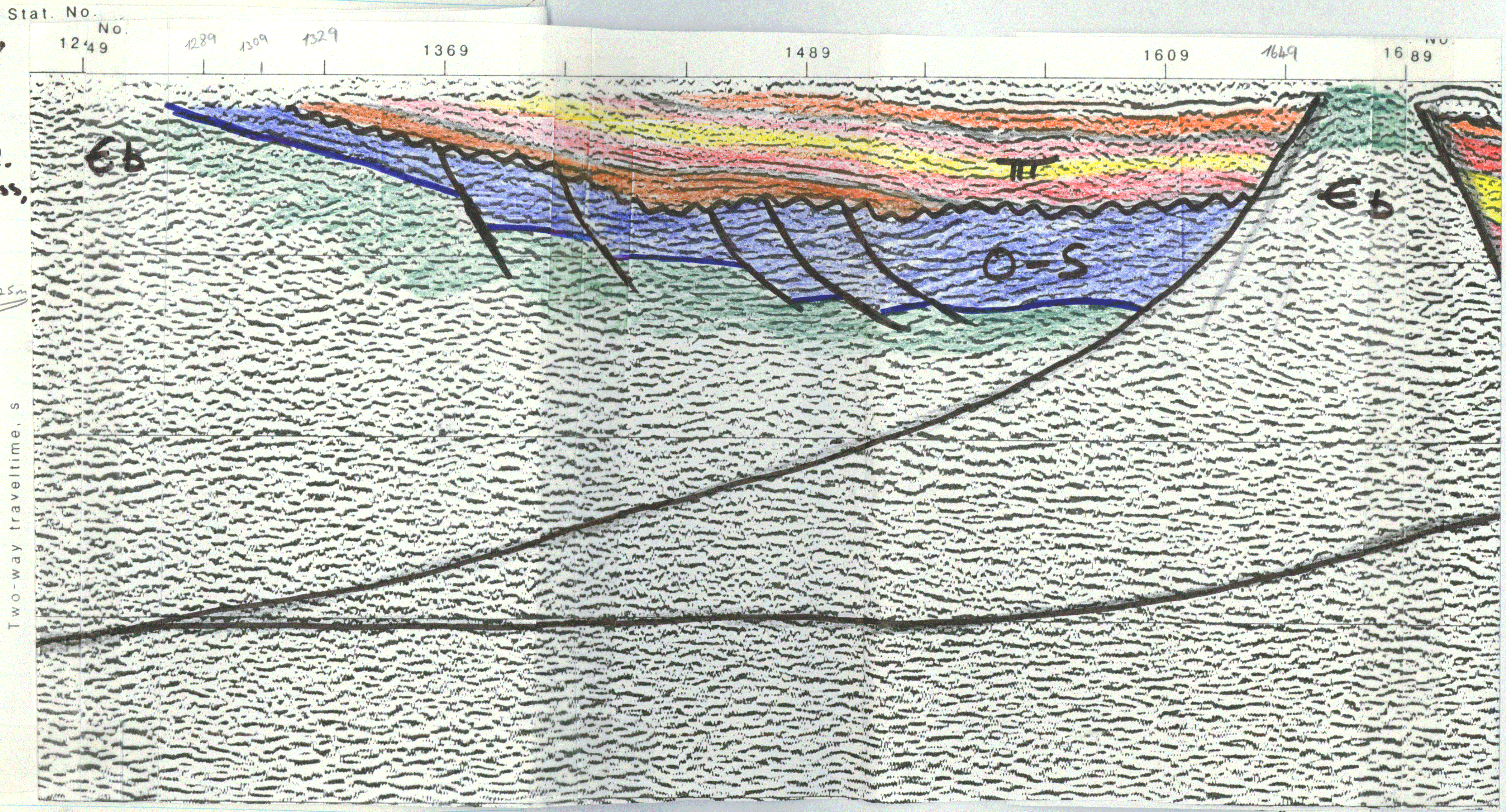
Alex Maltman

Tuesday 2nd June 1992

W

First, - stream-of-consciousness, attempt

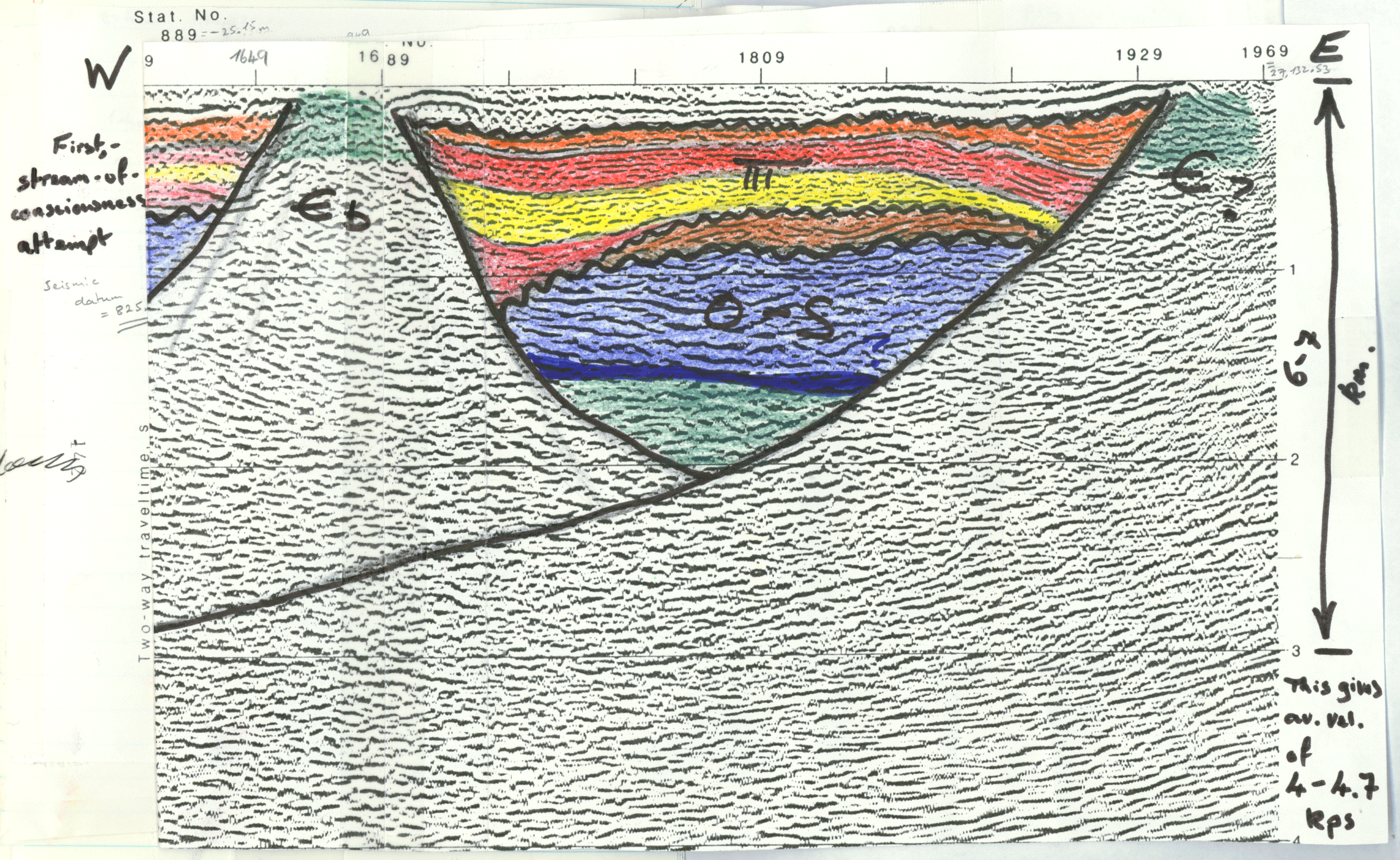
Seismic datum = 825m



3hrs @ UTSA

Alan Morris

Tuesday 2nd June 1992



Alan Morris

into a single detachment level (Figure). This is especially true for smaller faults, which do not have sufficient displacement to reach the detachment level

SwRI
Start 8:30am.
Finish 11:30am.

Wednesday 3rd June 1992

"Quality Assurance" meeting.

AV-1 work continues.

Alan

Massi

Friday 5th June 1992

2 hours AV-1 @ UTSA

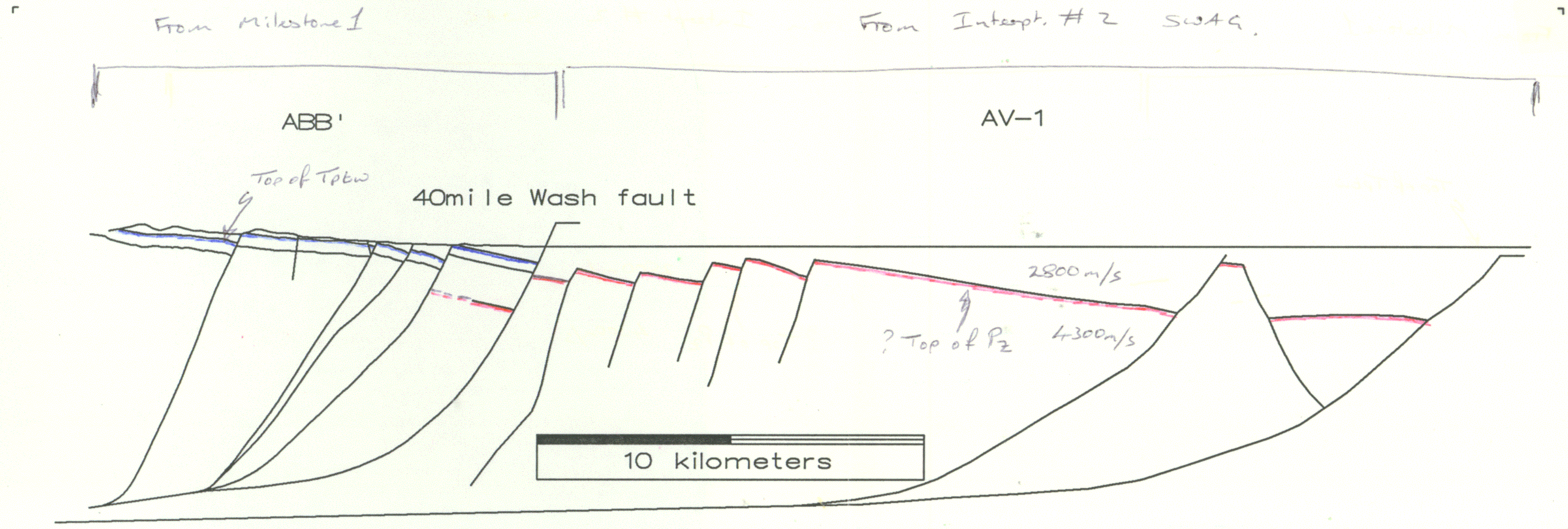
Alan

Massi

Start: 9:30am
Finish: 4:00pm

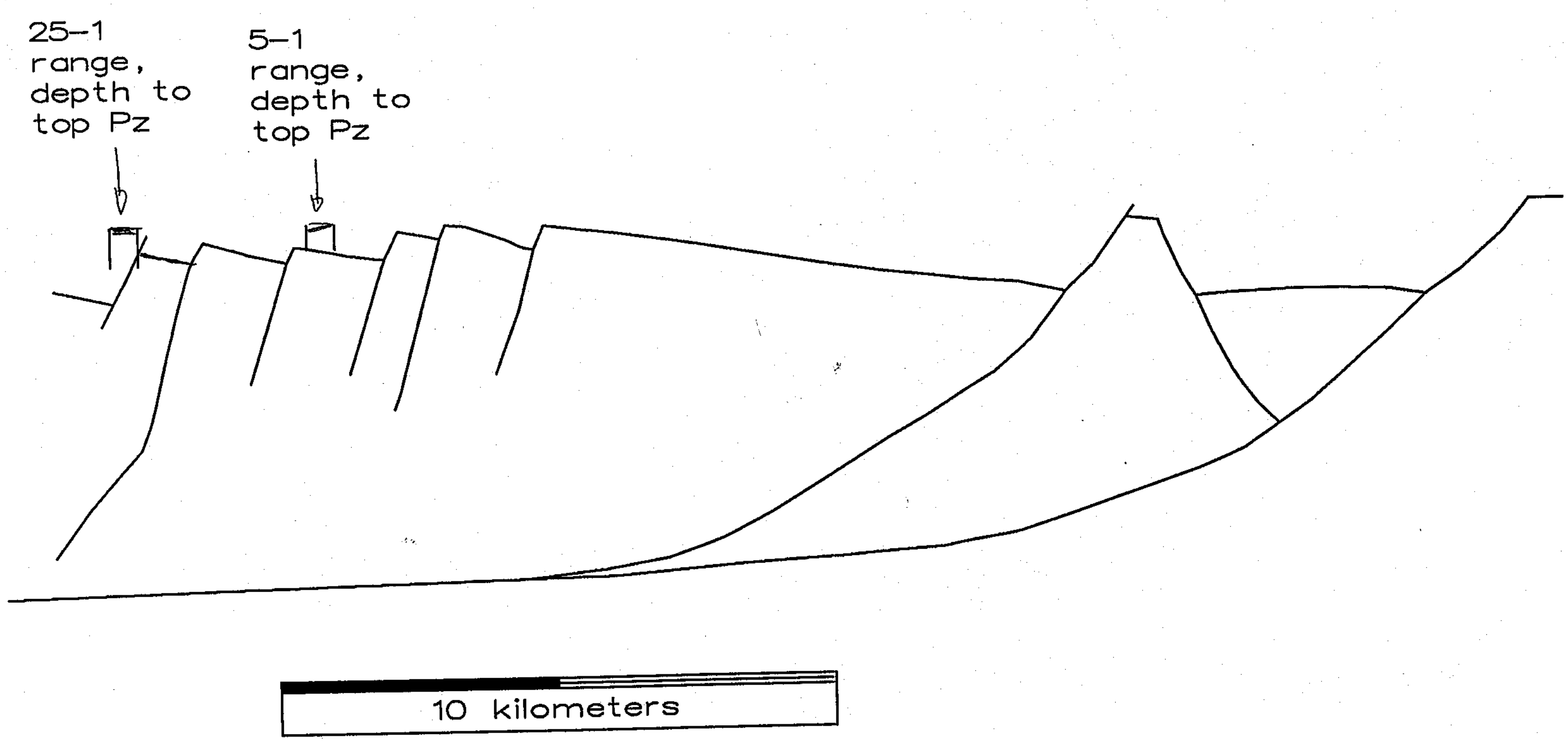
Monday 8th June

AV-1 - Geosec work



Alan Morris

AV-1


25-1 range, depth to top Pz
5-1 range, depth to top Pz
10 kilometers

Start 12:00pm.
Finish 6:45pm

Tuesday 9th June

AV-1 TRUTH POINTS

(1) Well 25-1

Based on NE-SW structural trends 25-1 probably projects between stations 940 and 960.

Depth to top of Pz in this well ≈ 690m

Using a velocity of 2750m/s for the Tertiary + valley-fill (see AV-1 refraction velocity profile) combined this gives a TWTT of 0.50s for this reflector.

(2) Well 5-1

As with 25-1 (above) this well should project between 1080 and 1100.

Depth to top of Pz in this well ≈ 433m.

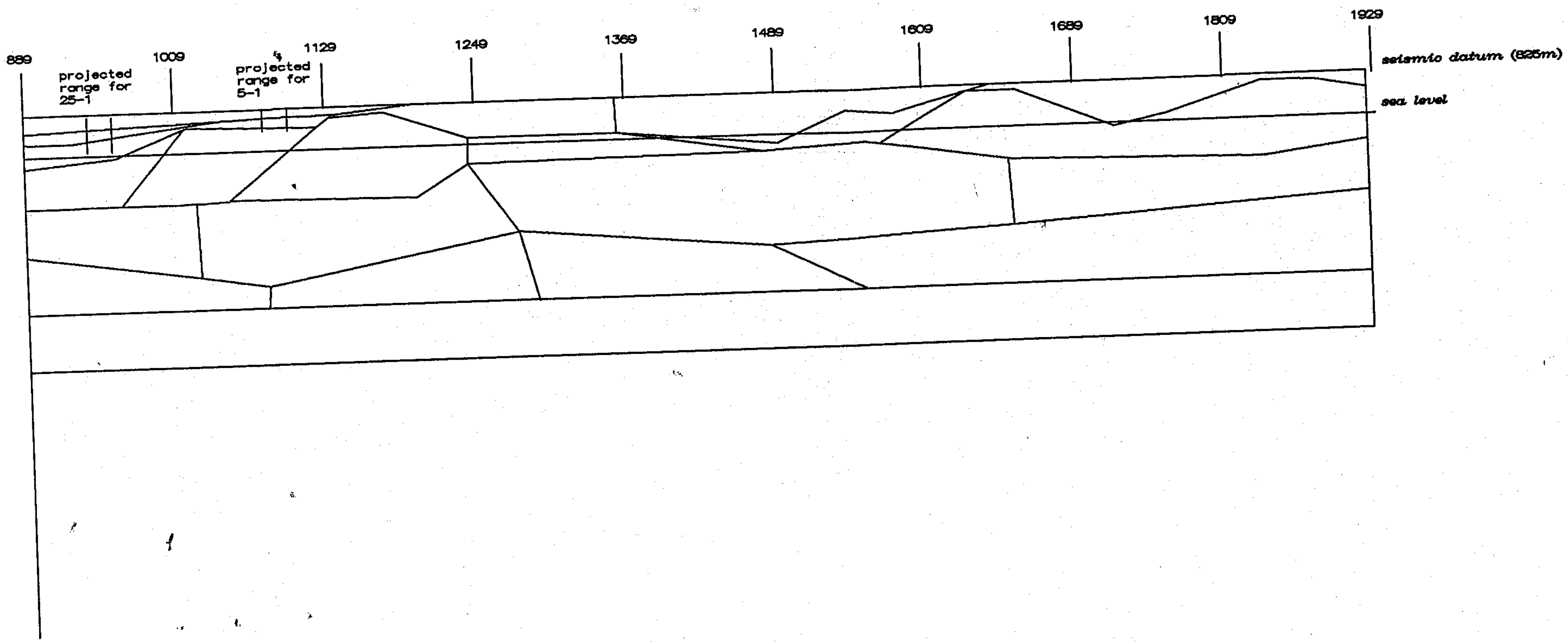
Using velocity of 2750m/s for Tert + valley fill (again see AV-1 refraction profile) this gives a TWTT of 0.31s for this reflector.

Alan Mussi

Interpretations #2 and #3 give excellent depths to detachments - see plots

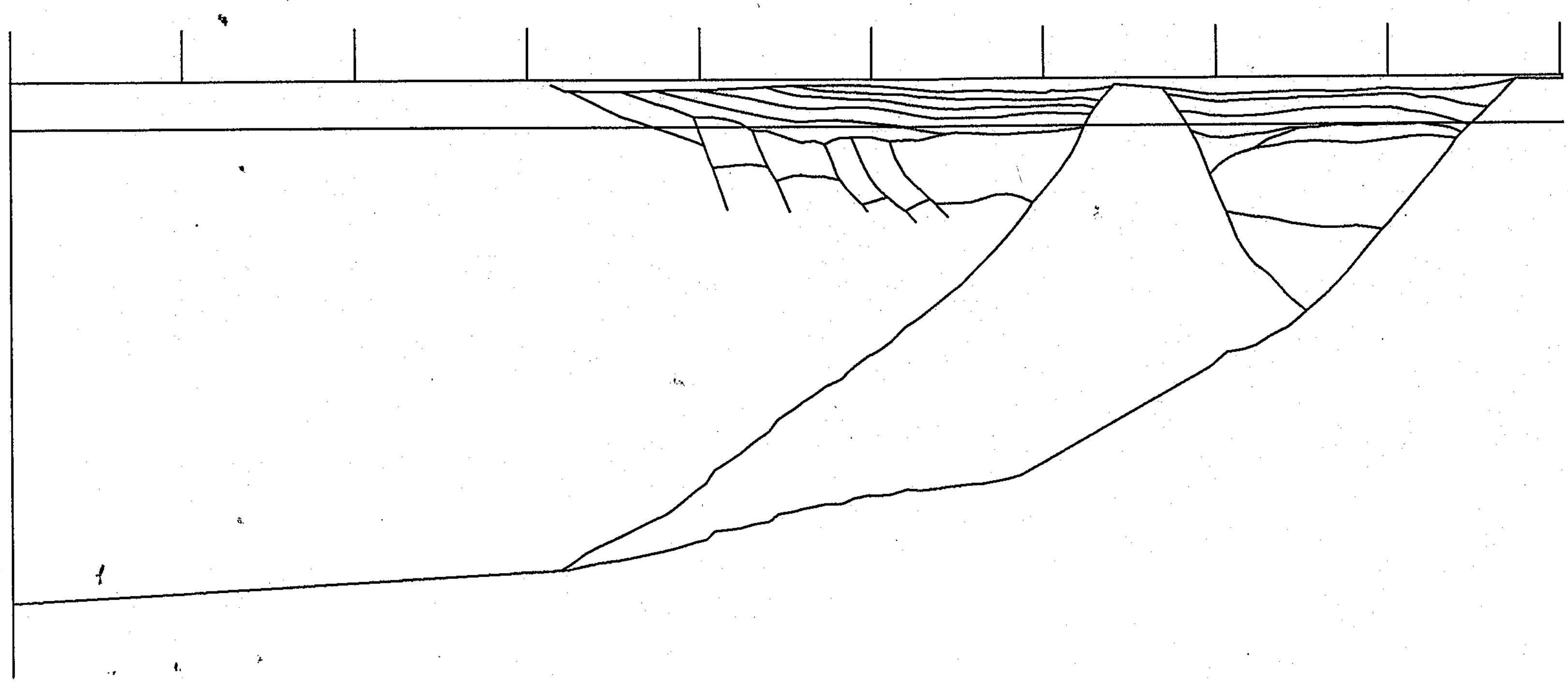
Alan Moore

AV-1 REFRACTION VELOCITY MODEL (DEPTH)



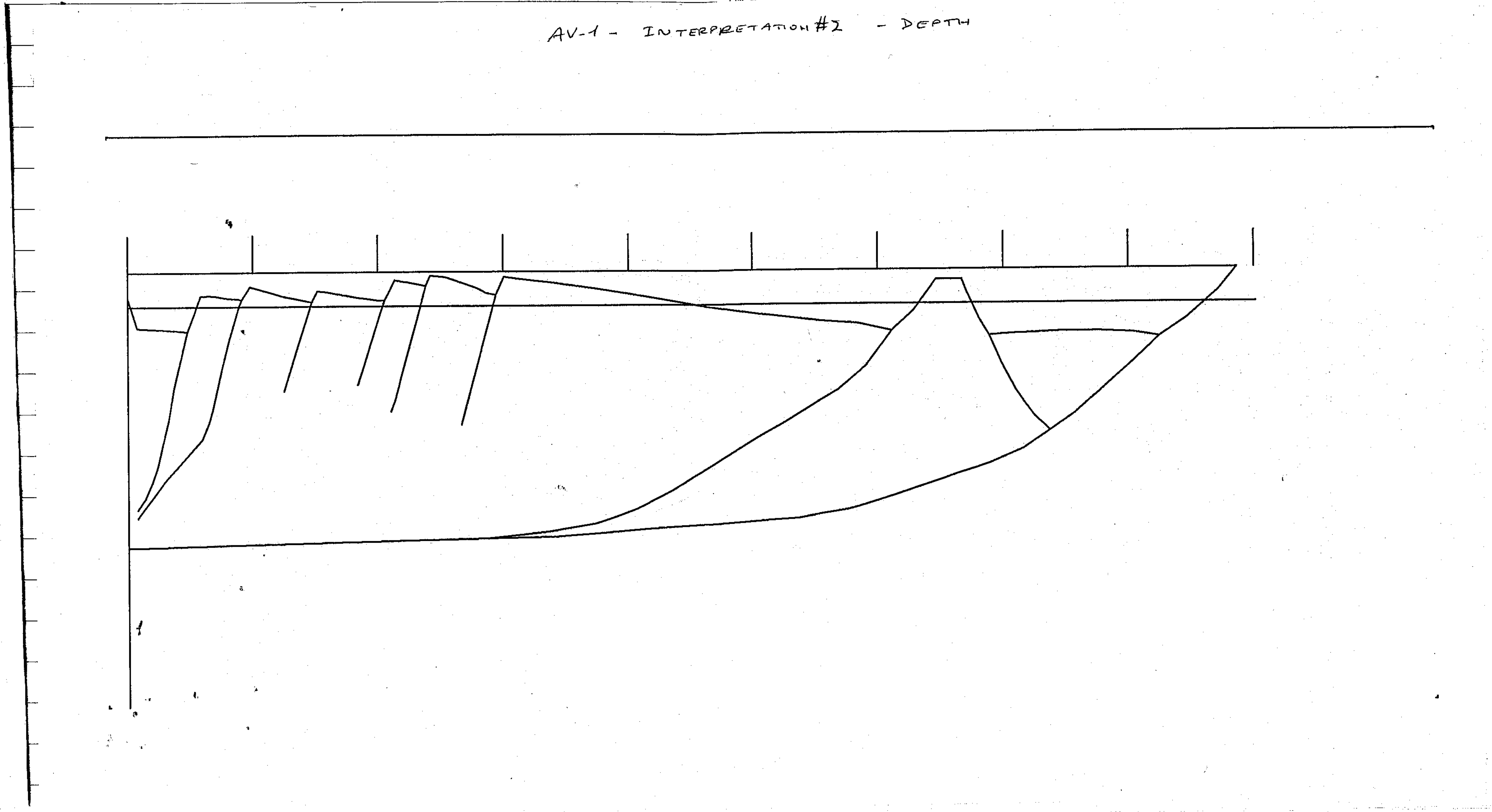
Interpretations #2 and #3 give excellent depths to detachments - see plots.

Alan



Interpretations #2 and #3 give excellent depths to detachments - see plots.

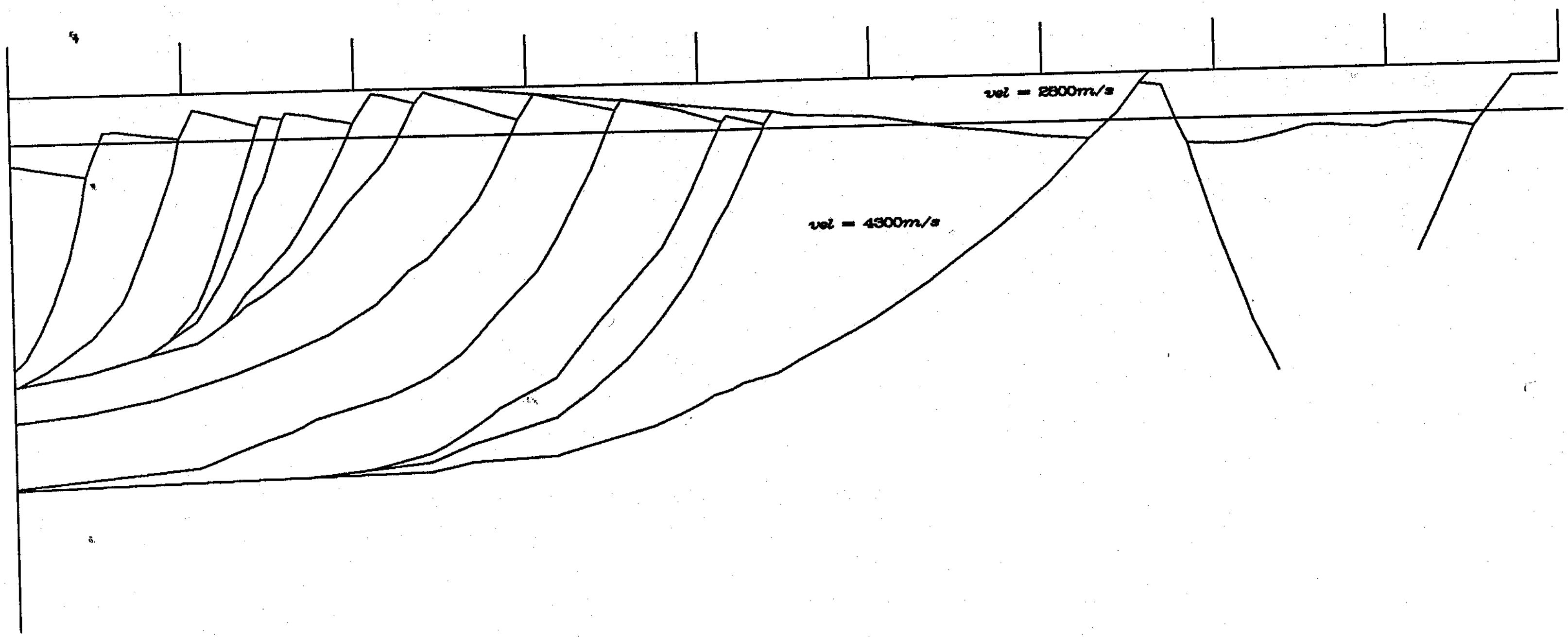
Alan



Interpretations #2 and #3 give excellent depths to detachments - see plots.

Alan

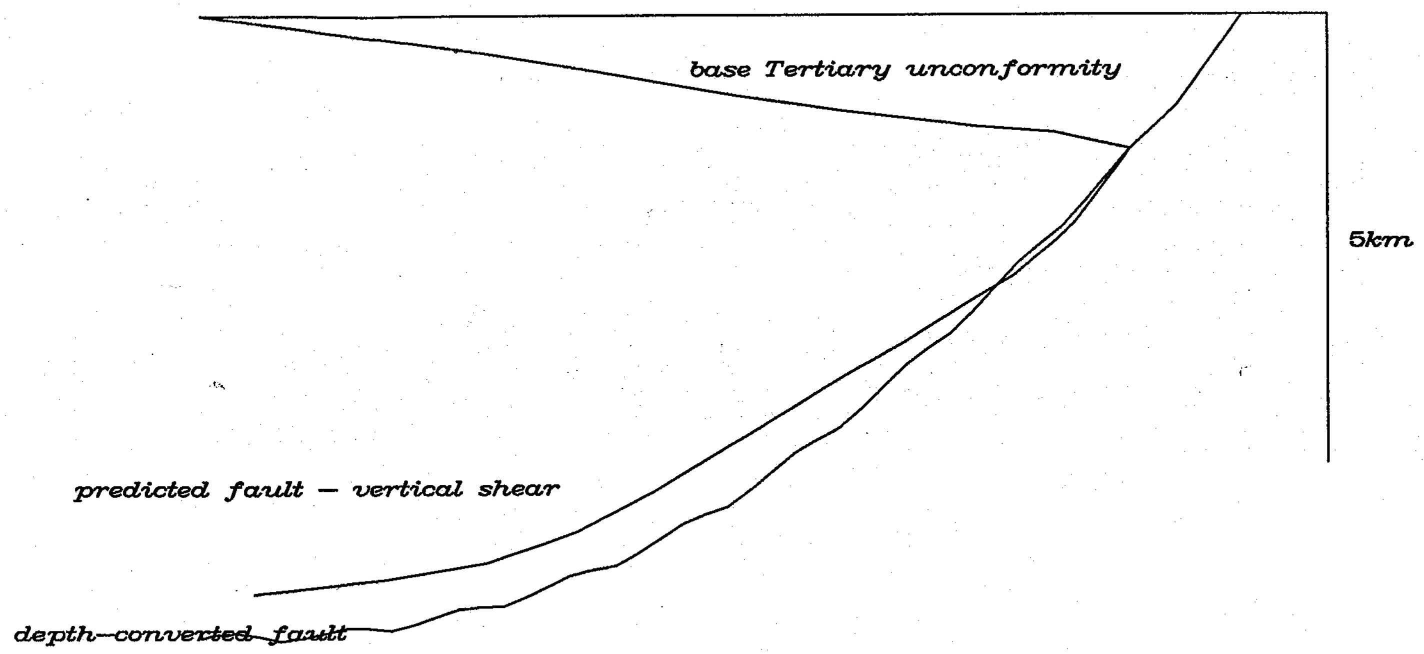
AV-1 Interp#3 depth.



Interpretations #2 and #3 give excellent depths to detachments - see plots.

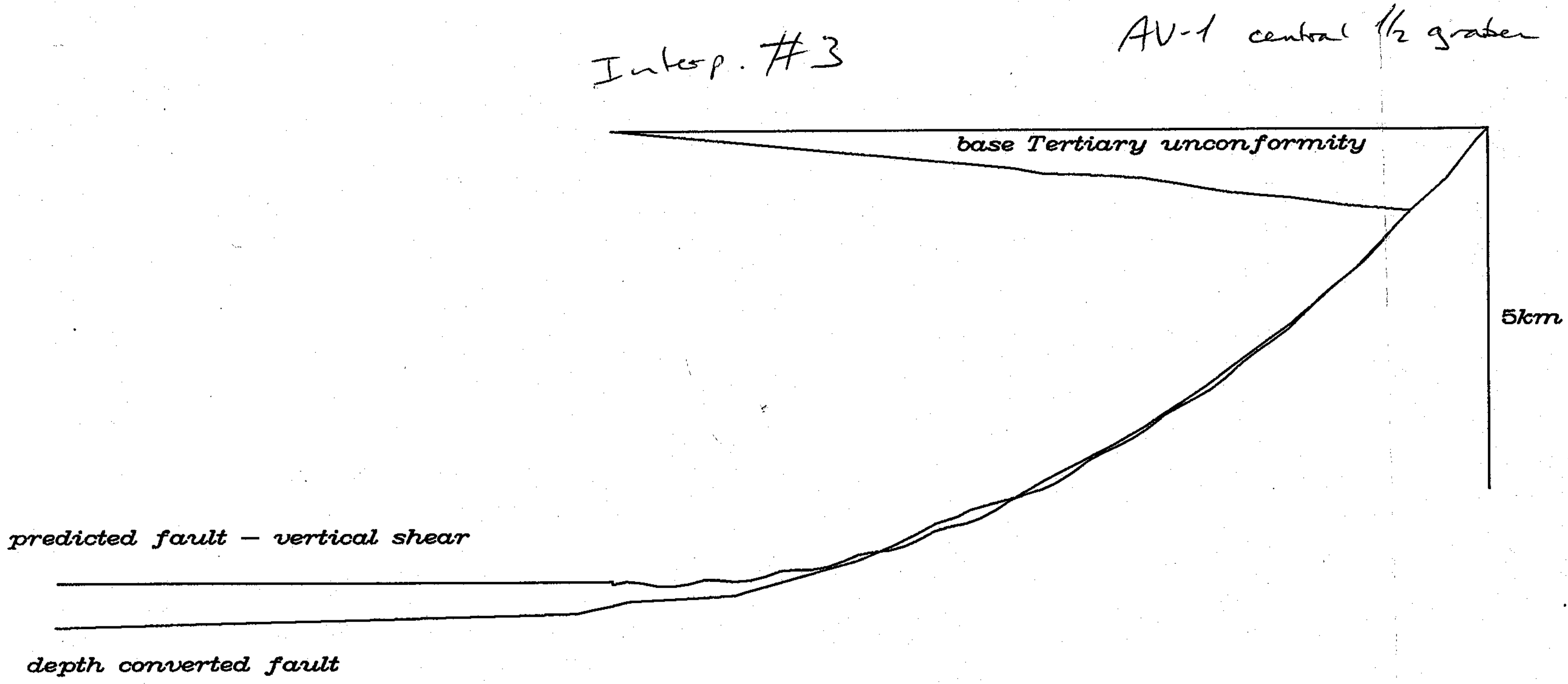
Alan

Interp. #2 AV-1 central 1/2 graben



Interpretations #2 and #3 give excellent depths to detachments - see plots.

Alan



Start: 11:00am | SwRI
Finish 3:00pm
+ 2hrs @ UTSA

10 June 1992

Fault predictions shown on previous page are OK BUT: Although 2800 m/s is OK for TII rocks the depth-converted faults were obtained using 4300 m/s for all sub-TII rocks. This is too slow. I need to time-convert (using faster vel) the predicted trajectories to see if the seismic record section can be reinterpreted to fit those.

Central Half-Graben Time-Depth Analysis

Interp.#	Vertical shear Depth to detach.	Sub-TII vel.	TWTT to detach.
2	6445	4300 m/s	3 s
		4500	2.87 s
		4700	2.76 s
		4900	2.65 s
		5100	2.6 s
		5300	2.46 s
		5500	2.38 s

Alan Morris

Interp #	Depth to detachment	Shear angle	Sub-TII vel	TWTT to detach
2	8250	82 syn.	5500	3 s
	7950	84 syn.	5300	3 s
	7650	85.5 syn	5100	3 s
	7350	87.25 syn	4900	3 s
	7050	89.2 syn.	4700	3 s
	6750	89.9	4500	3 s
	6450	90° (vert)	4300	3 s

CONCLUSION

To have the detachment at 3 sec TWTT the geometry of the rollover in the central half-graben indicates that for reasonable sub-TII velocities (i.e. 5100 - 5500 m/s) the shear angle must be 85.5 - 82° synthetic.

Alternatively, if the shear angle is assumed to be vertical (90°) then for reasonable sub-TII velocities the detachment should appear between 2.38 and 2.6 s TWTT.

Whichever of the above two explanations is preferred the depth range of the detachment is 6.45 km – 8.25 km (5.63 – 7.43 km sub-sea)

11 June 1992

AV-1 gives good shallow information:

1) It is clear what the geometries of the central half-graben are. Provided that a good shallow (< 1.5 sec TWTT) velocity model can be applied this will allow accurate prediction of deeper fault trajectories

2) 40Mile Wash Fault is real, but difficult to fully constrain, there is insufficient hw data at west end of line to model the fault

3) Graben at east end of AV-1 has indeterminate polarity - difficult to interpret data below 1.5s TWTT and there is insufficient hw data to do fault prediction.

4) Possibility of domino-block should be considered but because of the size and extent of central half-graben this will require multiple detachment levels. Also the geometry of smaller fault blocks to west of central half-graben is poorly constrained from the seismic data.

Start: 12:15 pm
Finish: 6:15 pm - at SwRI

GEOSEC work on AV-1

Alan

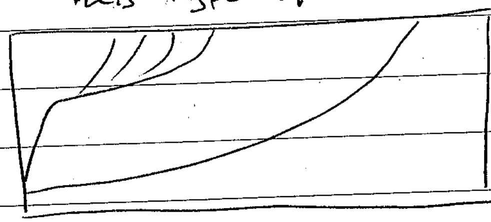
Morris

Start: 2:00pm
Finish 6:00pm

12 June 1992

New AU-1 interpretation - double-decker detachments

Note:
This type of detachment produces an

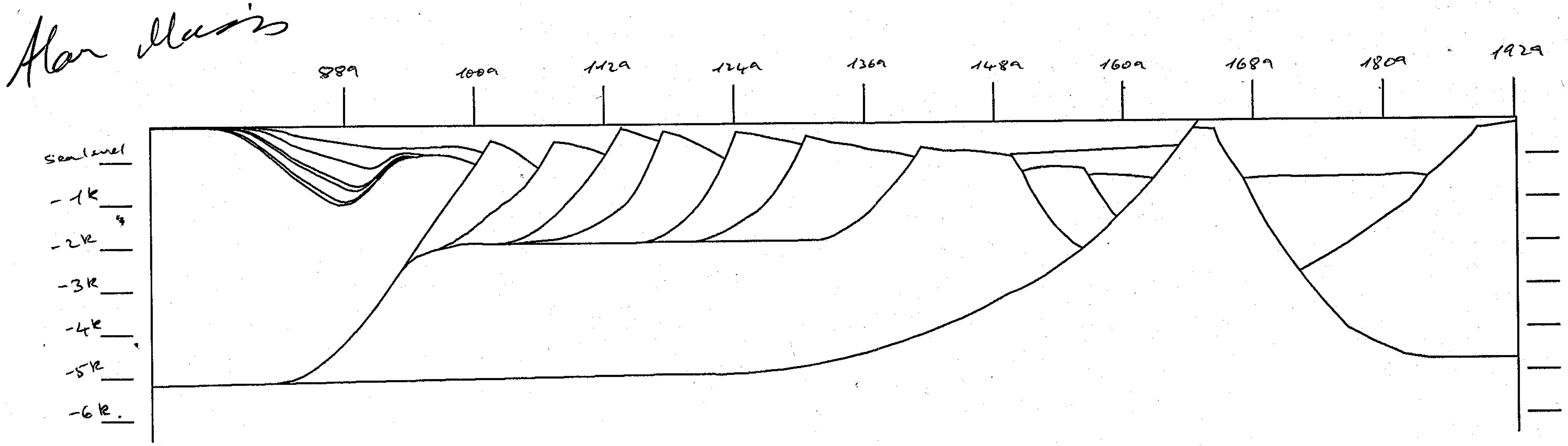


asymmetrical basin at the W. end of the line w/out a major fault - see plot: p141 →

ARCHIVE GEOSEC FILES
/u4/geosecarc

Alan

Mazi


Alan Morris
889
1009
1129
1249
1369
1489
1609
1689
1809
1929
sea level
-1k
-2k
-3k
-4k
-5k
-6k

Start: 10:30am
Finish 5:30pm

15 June 1992

TO OBTAIN A FILE MANAGER IN GEOSEC USER,
/usr/openwin/bin/openwin : - launches openwindows from geosec after login.

Wordperfect is in: /home/bren/alan

Alan

Mani

Start: 11:00am
Finish: 5:30pm

16 June 1992

AV-1-depth-modelling.db

Alan

Depth to detach.

Interp	Vel. Profile	Vert. Shear	60° shear
4	2800 / 3400	8 km.	19
3	"	8 km.	18
2	"	7.2	17.3
1	"	9.4	34

Alan

Potential seismic reflectors as candidates for detachment surfaces.

1.1 - 1.2 s
2.4 - 2.6 s } twtt.
~ 3 s

Alan

Mani

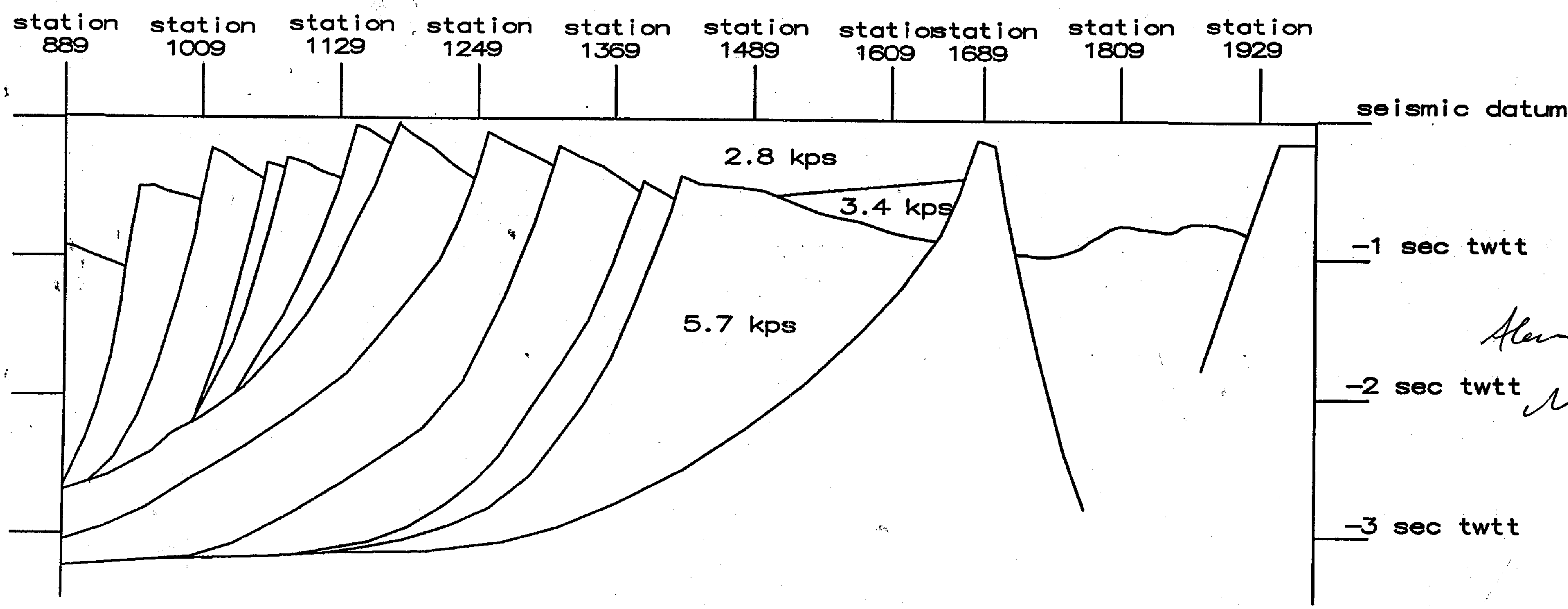
144

Start : 10:30am

Finish : 6:30pm

17th June 1992

AV-1 Report



Digitized, interpreted velocity model, AV-1
Deeper detachment

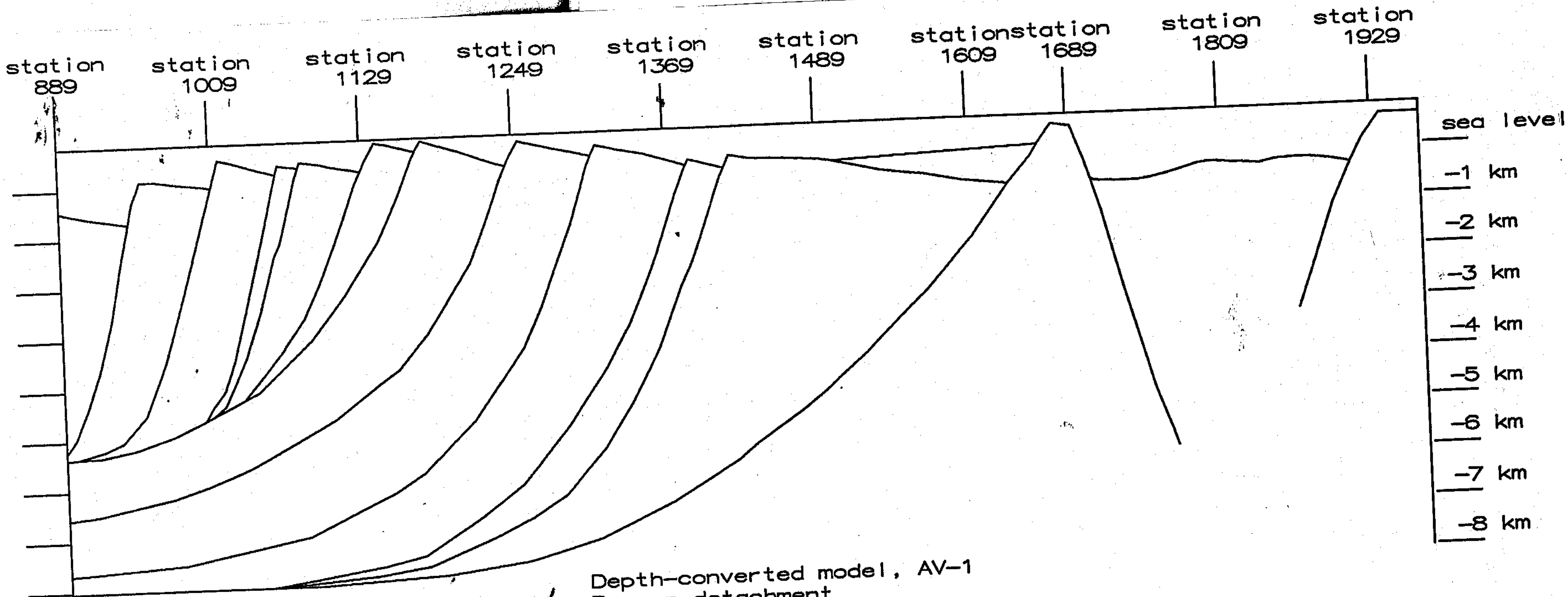
Alan Meeks

Start : 10:30am

Finish : 6:30pm

17th June 1992

AV-1 Report



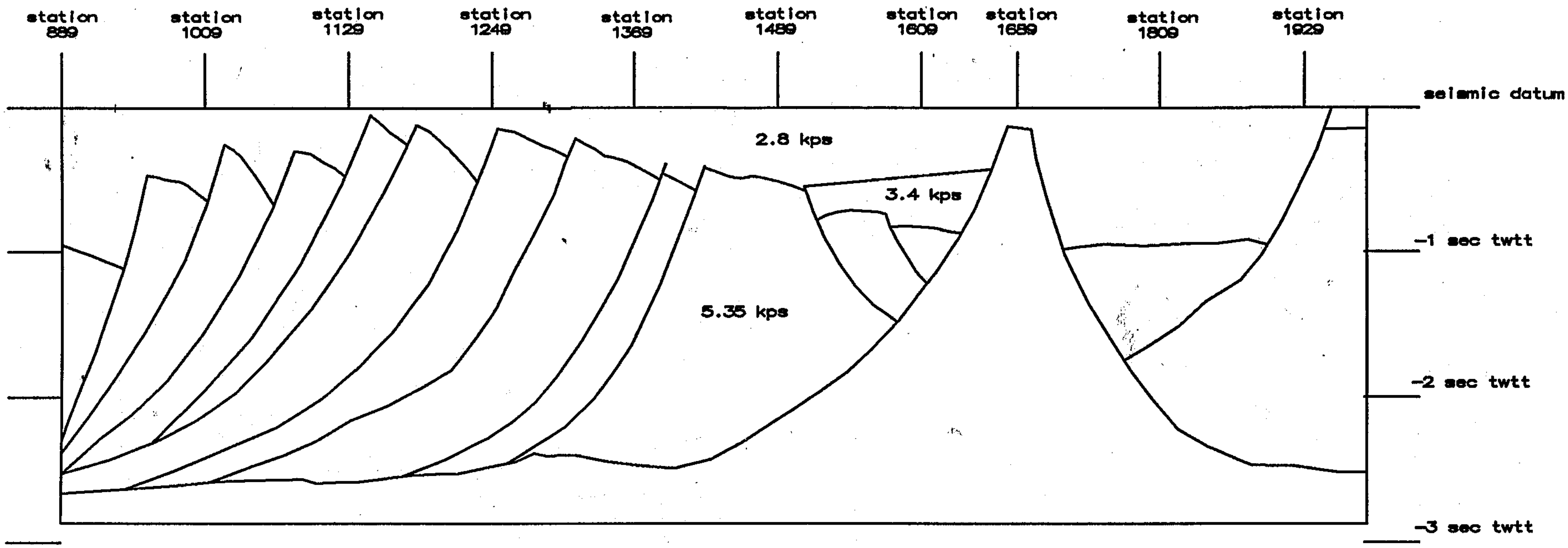
Depth-converted model, AV-1
Deeper detachment

Start : 10:30am

Finish : 6:30pm

17th June 1992

AV-1 Report



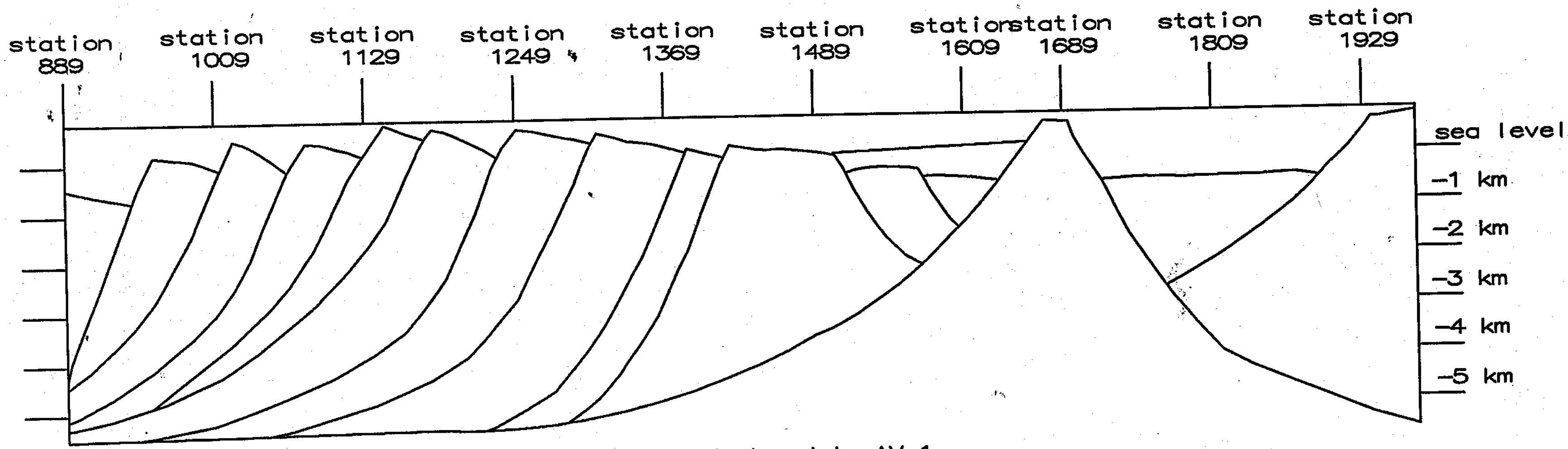
Digitized, interpreted velocity model, AV-1
Shallow detachment

Start: 10:30am

Finish: 6:30pm

17th June 1992

AV-1 Report



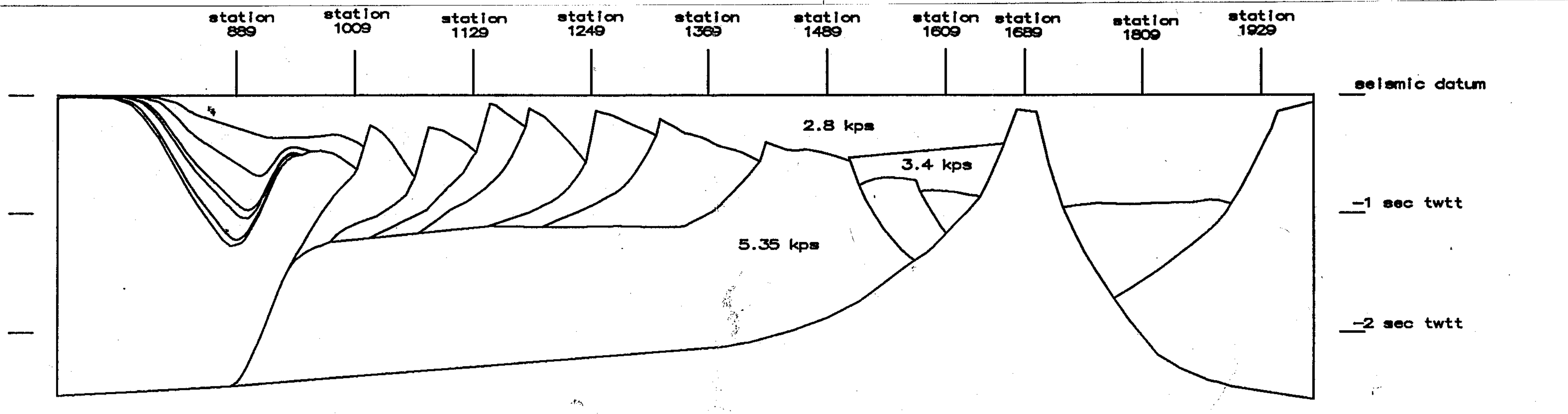
Depth-converted model, AV-1
Shallow detachment

Start 8:30am
Finish 5:30pm

18th June 1992

AV-1 Report production - 50% GED 50% non-GED

[signature]



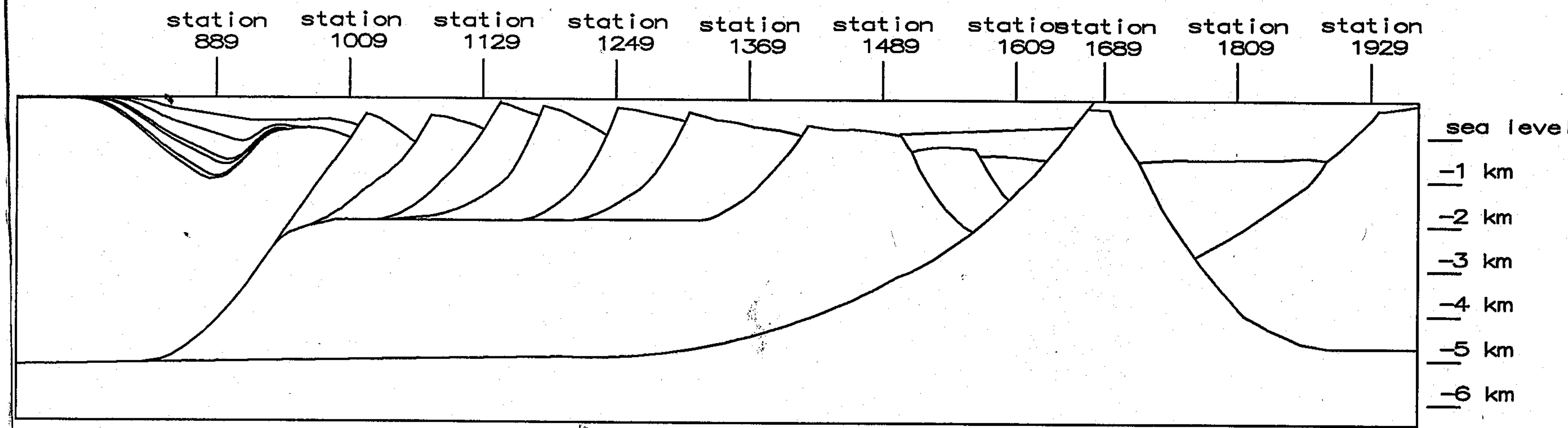
Time-converted, multiple detachment model

Start 8:30am
Finish 5:30pm

18 June 1992

AV-1 Report production - 50% GEO 50% non-GEO

Alan Moss

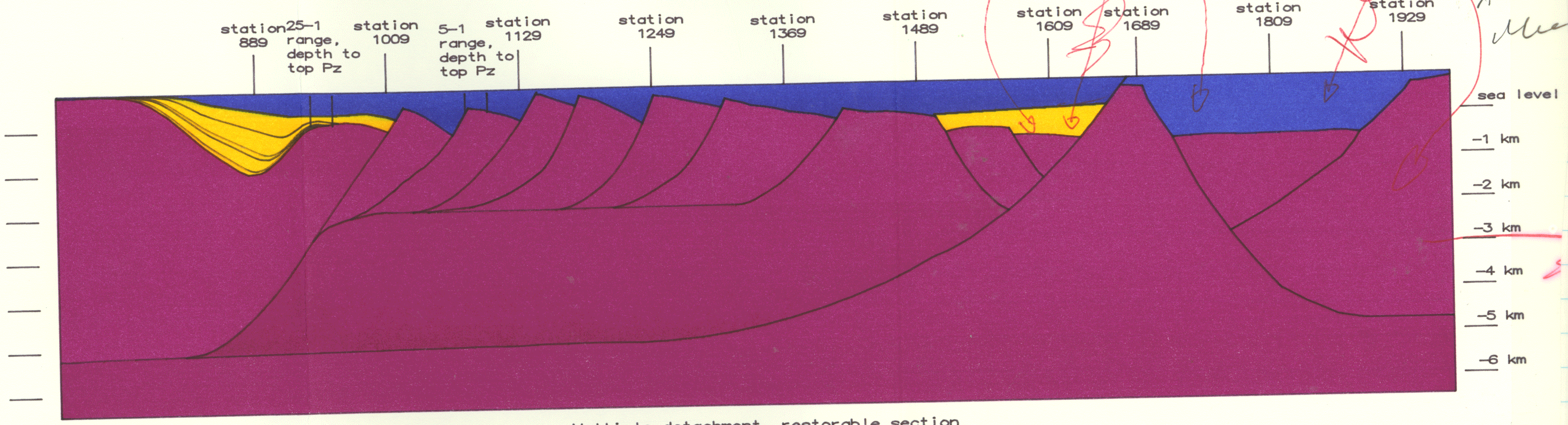


Multiple detachment, restorable section

Start: 9:00am
Finish: 11:30am

19 June 1992

Finish AV-1 report



Multiple detachment, restorable section

Start: 9:30 am
Finish: 10:30 am

14th. July 1992

Talked to Steve - focus on methodology and give guidelines for interpreting models & sections.

Alan

Marij

Start: 8:30am.
Finish: 5:30pm

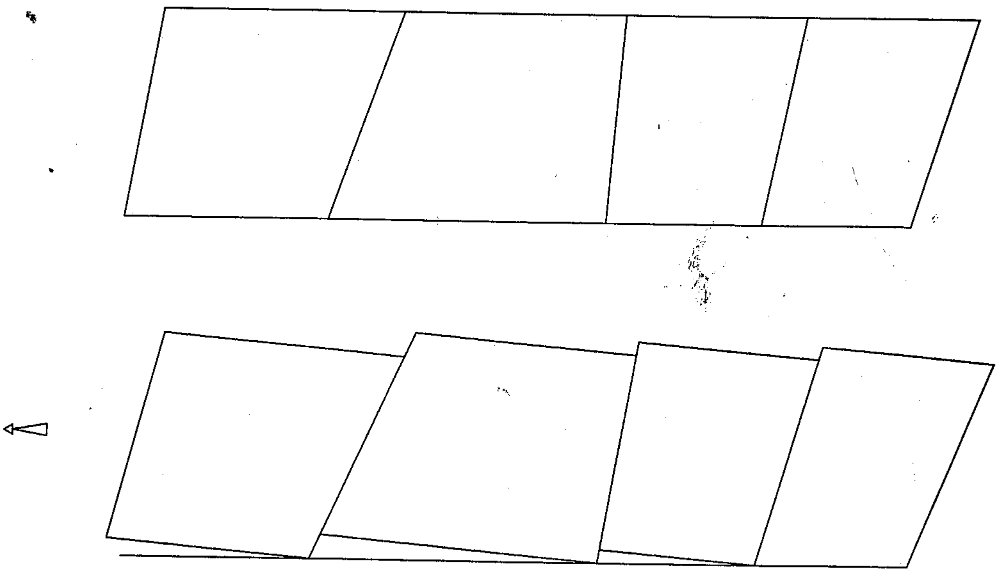
1st July 1992

Report is due 7th. Sept., needs to be ready for review 31st. Aug.

Worked on "alternative models" report and

PROJECT Altmodel1.db

domino



148

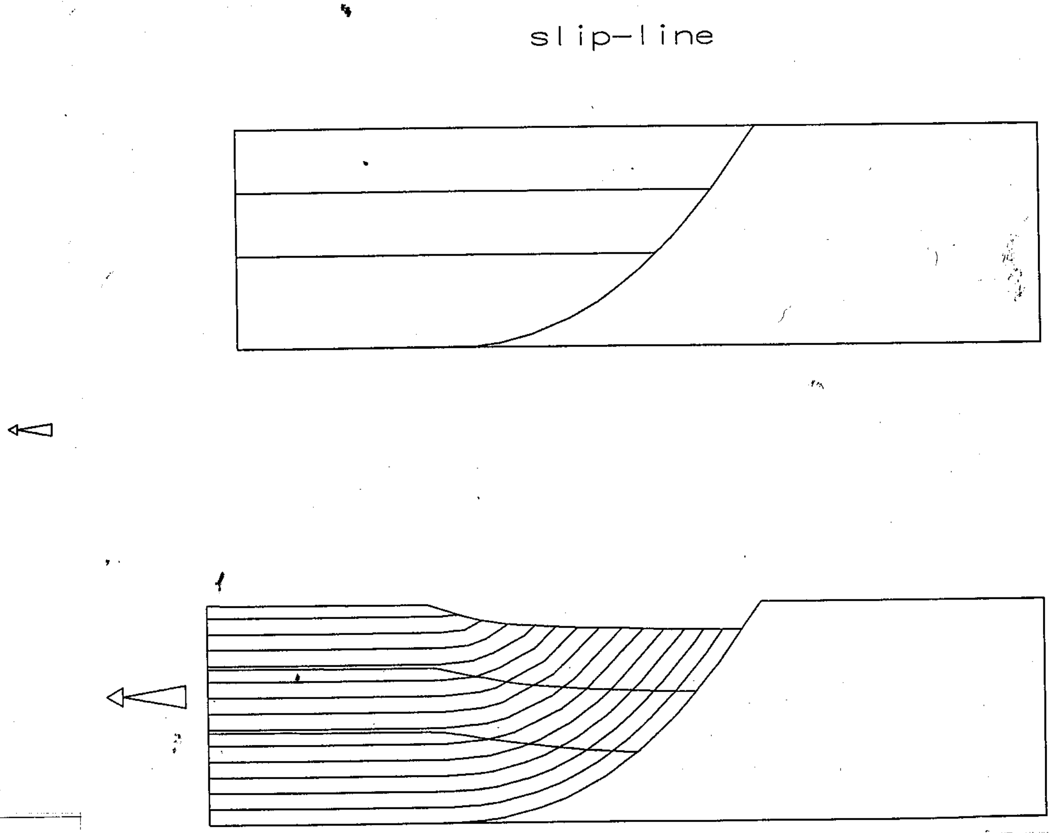
Start: 8:30am.
Finish: 5:30pm

1st July 1992

Report is due 7th Sept., needs to be ready for review 31st. Aug.

Worked on "alternative models" report and volcan[illegible]

PROJECT Altmodel 1.db

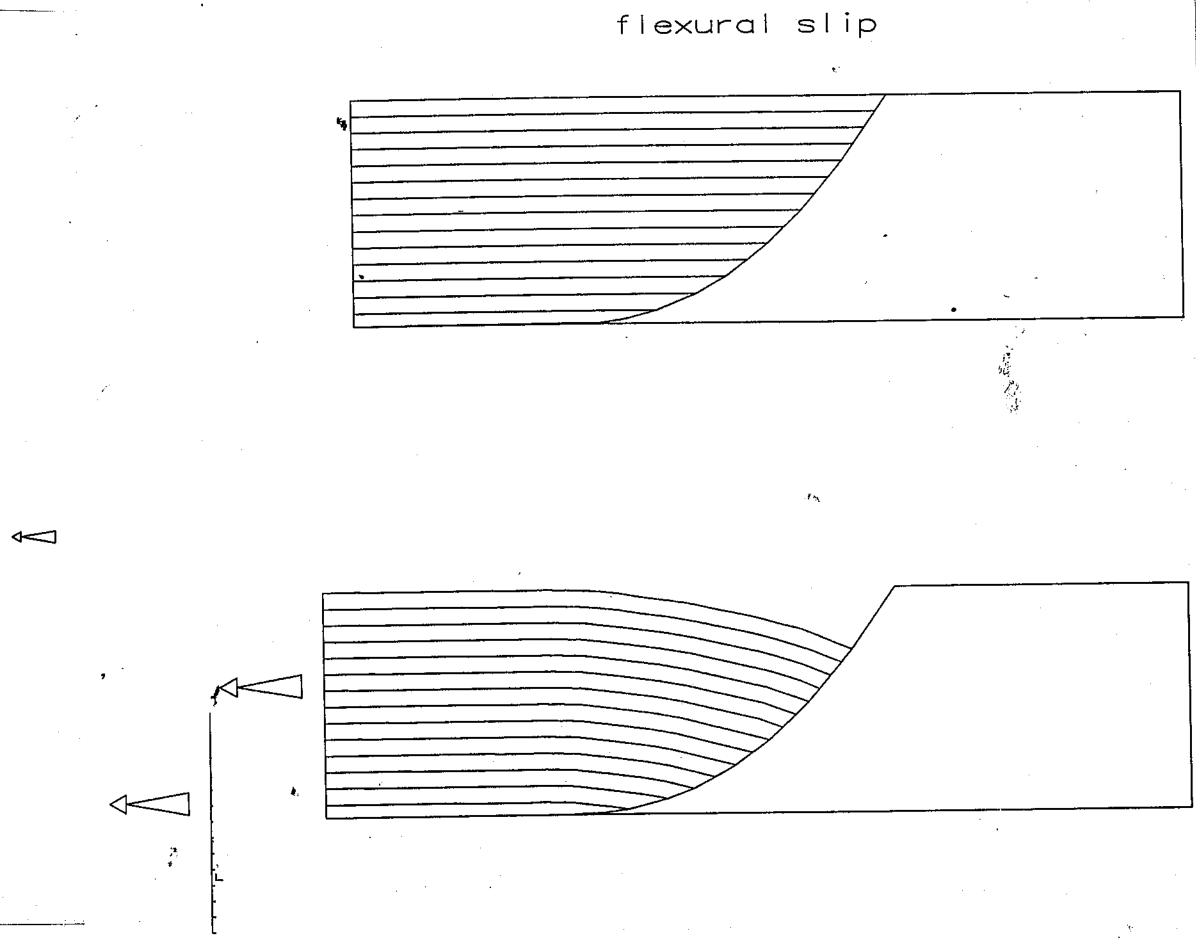


Start: 8:30am.
Finish: 5:30 pm

1st July 1992

Report is due 7th. Sept., needs to be ready for review 31st. Aug.

Worked on "alternative models" report and volcanics
PROJECT Altmodel 1.db



Start: 8:30am.
Finish: 5:30pm

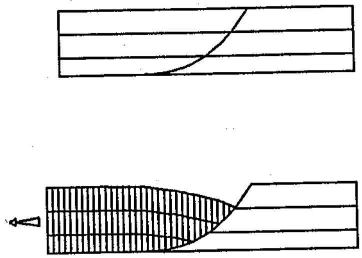
15th July 1992

Report is due 7th, Sept., needs to be ready for review 31st, Aug.

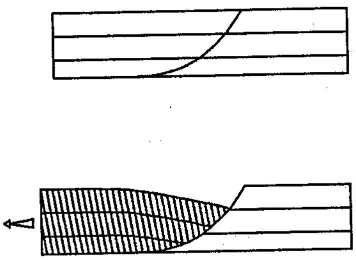
Worked on "alternative models" report and volcanism ~~review~~.

PROJECT Altmodel1.db

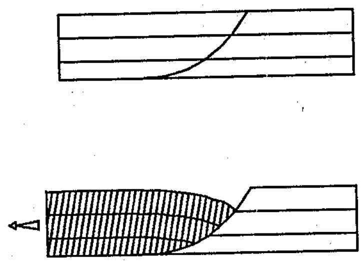
vertical shear



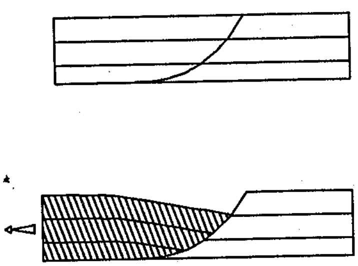
80-degree antithetic, oblique shear



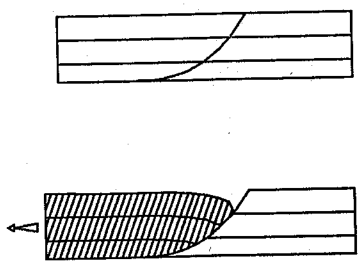
80-degree synthetic, oblique shear



70-degree antithetic, oblique shear



70-degree synthetic, oblique shear



Start: 8:30am
Finish: 3:30pm

16th. July 1992

Alan Moss

INTRODUCTION

BALANCE AND RESTORABILITY

Geological cross-sections of deformed terrains are drawn using a variety of input data, for example, surface geology, seismic reflection and refraction information, and well data. These windows of reality leave large portions of the section to the geologist's imagination. Reliance upon cross-sectional interpretations in the petroleum exploration of the Canadian Rocky Mountain Foothills during the 1950's forced geologists to formulate geometric rules to apply to the interpretation of blank areas on their sections. Dahlstrom's classic 1977 paper is often referred to as a milestone in this thought process.

For a geological cross section of a deformed state to be realistic (i.e., a credible approximation to reality) it must be **balanced** or **restorable** to an undeformed state that is geologically reasonable. This philosophical constraint reduces the range of interpretations but does not necessarily provide a unique solution.

In practice the restorability or otherwise of a cross-section is established using the principle of conservation of material, which for a two-dimensional representation of geological structures requires that the cross-section plane contain the relative movement vector(s) of the features being depicted, and that the deformed and restored states must have equal areas (**"area-balanced"**). Departures from this principle frequently occur, but must be accounted for by geologically reasonable processes. For example, in areas of extensional deformation deposition may be synchronous with fault movement (so-called "growth" faults), as faulting and sediment accumulation proceed the sediment is progressively compacted as it is buried more deeply. When restoring a section drawn through such structures it is necessary to account for this change in cross-sectional area by decompacting each sedimentary layer sequentially according to its lithological character (refs).

Within the last ten years the principle of restorability has been taken a step further to encompass the idea of **retrodeformability**. This has grown out of an improved understanding of the mechanisms by which rocks deform. It is no longer sufficient that a section be area-balanced but it must be shown that the geometries in the deformed state can have formed from the restored state by the application of kinematically viable deformation mechanisms. The range of acceptable interpretations of the data is further narrowed by this additional constraint.

A balanced, or restorable, cross-section can be arrived at in a number of ways, and confidence in the interpretation will be greater if it is retrodeformable rather than merely restorable. A balanced section, whatever the means by which it was produced, is not necessarily truth, it is, however, more believable than a non-balanced section and all geological cross-sections should be examined with the concept of balance in mind.

Quick checks for restorability

DEFINITIONS AND BACKGROUND

DEFORMATION MECHANISM

Vertical/oblique shear

Vertical shear and shear oblique to bedding with a consistent angle are mechanisms that have been applied to extensional structures in the Gulf of Mexico with a great deal of success (refs). As the crust is extended, listric normal faults develop that are steep near to the surface, and shallow with depth, often becoming sub-horizontal in a zone of shale or evaporitic beds (refs). The hangingwall block as it moves over the fault surface maintains contact with the fault by internal collapse. This collapse is accommodated by penetrative slip on vertical or inclined shear planes (Figure) as if the hangingwall were composed of a deck of cards with a consistent orientation. In reality these shear planes may be manifest as quasi-pervasive fault systems, or as arrays of synthetic and antithetic faults within the hangingwall.

Flexural slip

Layering in some form is the most common primary anisotropy in rocks. Sedimentary and volcanic rocks are particularly exemplary of this, dominated as they are by bedding, or flow banding. Lithological layering is also (almost invariably) a mechanical anisotropy which controls deformation behavior. This is especially true for contractional deformation but may also apply to certain instances of extension. Because the layers represent mechanically homogeneous units large scale shape changes are accommodated by sliding between layers (the bending telephone directory analogue). This is flexural slip. Flexural slip can also occur by more pervasive slip within units but still along surfaces parallel to layering. In the case of an extensional listric fault (Figure) hangingwall collapse is accommodated by bending of the layers within the hangingwall block, and this bending is in turn accommodated by layer-parallel slip.

Slip-line

Some workers have invoked shear parallel to fault surfaces as a mechanism for deformation. This may be applicable in some high grade metamorphic terrains, and within close proximity to the major fault surface, it does not give reasonable geometries for larger scale deformation.

Domino

The tendency for deforming crust to behave as rigid or semi-rigid blocks has been recognized in a number of tectonic settings, notably where extension has affected crystalline crustal material. Deformation in such a setting has been described in terms of "domino" blocks. Each block undergoes a rotation, and faults are either planar or arcs of circles (Figure).

GEOMETRY

Single detachment

Multiple detachment

TECTONIC SETTING

Simple extension

Transtension

KEY CHARACTERISTICS

DEFORMATION MECHANISM

Vertical/oblique shear

Flexural slip

Domino

Slip-line

GEOMETRY

Single detachment

Single detachment models are the simplest conceptual method for interpreting extensional structures. They suffer from the limitation that not all faults can be forced to "sole" into a single detachment level (Figure). This is especially true for smaller faults, which do not have sufficient displacement to reach the detachment level required by larger faults in the system. This can be resolved by assuming that the smaller faults are downwardly blind (Figure) and represent a manifestation of the pervasive shear mechanism within the hangingwall.

Multiple detachment

Both contractional and extensional tectonic systems are known to exhibit multiple detachments (refs) these can be active at different times or they may be active synchronously.

Alan Morris

TECTONIC SETTING

Simple extension
Simple E-W extension

Transtension
N60W extension superimposed on a NS normal fault system causes oblique slip - "transtension"

APPLICABILITY TO YUCCA MOUNTAIN

DEFORMATION MECHANISM

- Vertical/oblique shear
- Flexural slip
- Domino
- Slip-line

GEOMETRY

- Single detachment
- Multiple detachment

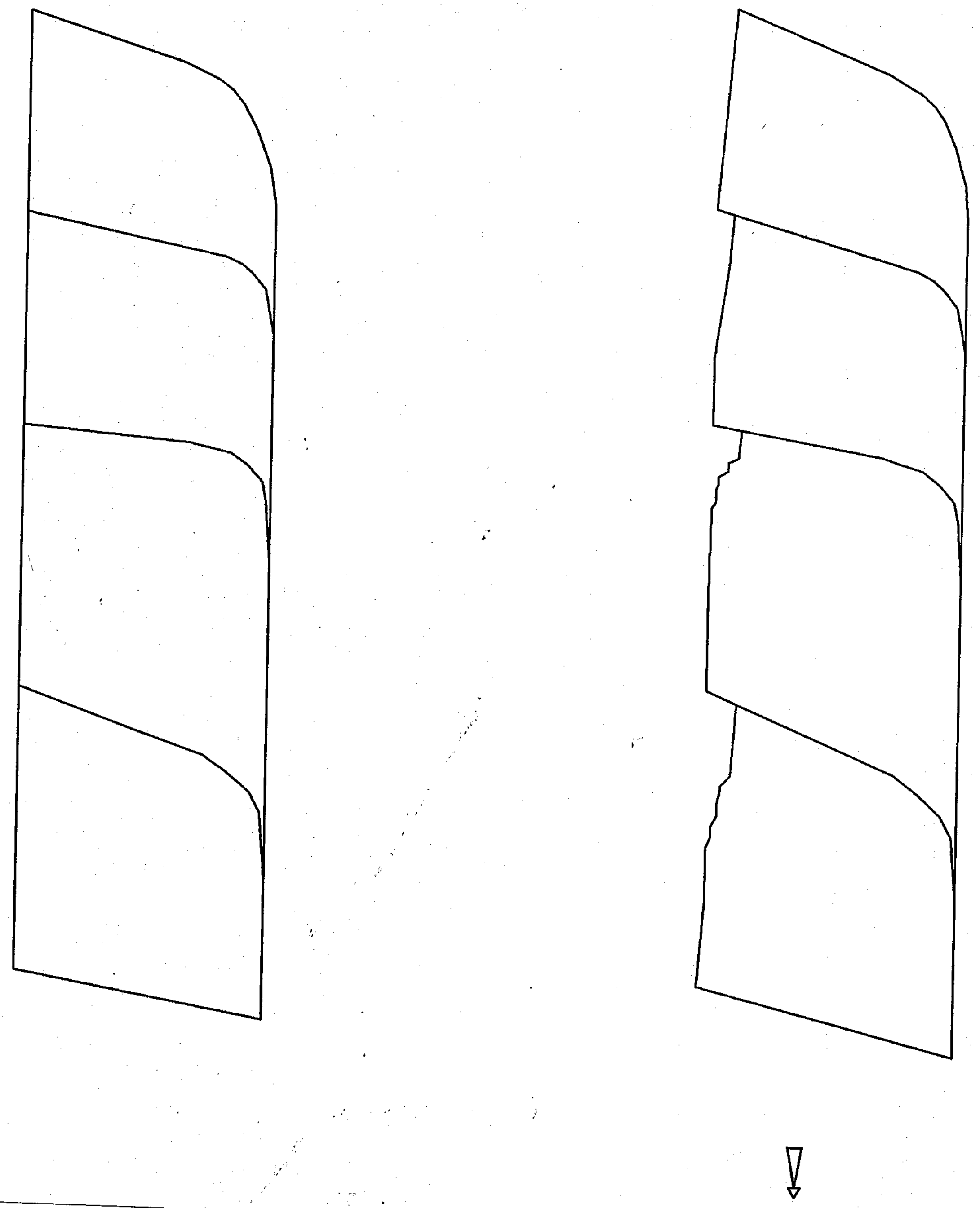
TECTONIC SETTING

- Simple extension
- Transtension

? Hybrids

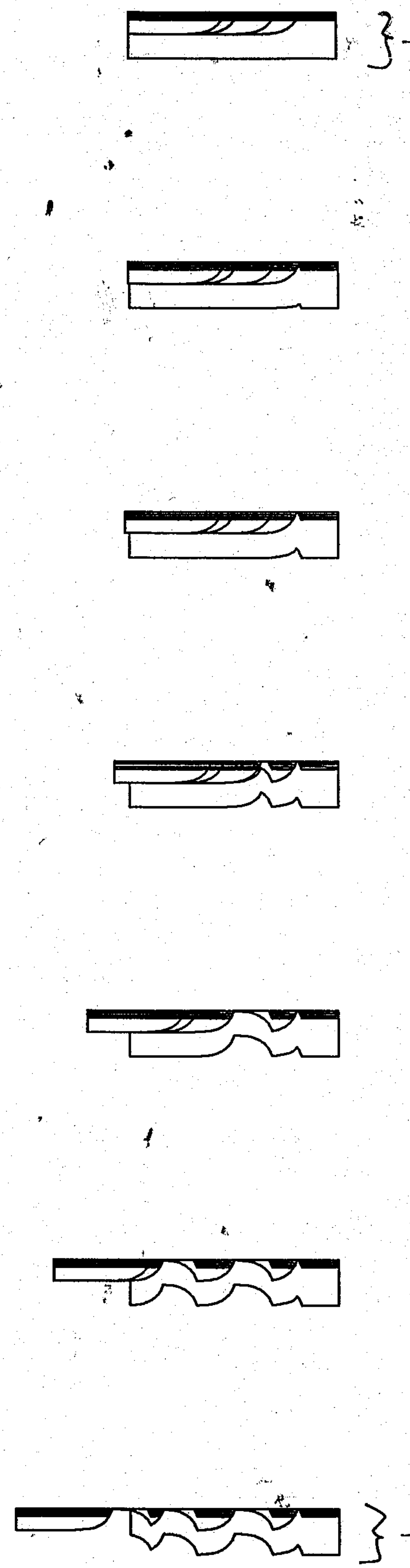
? "Rolling hinge" deformation

Alan Morris

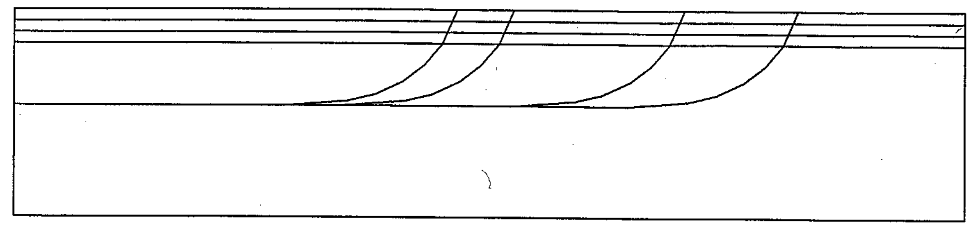


hybrid - domino block rotation and vertical shear

ROLLING HINGE

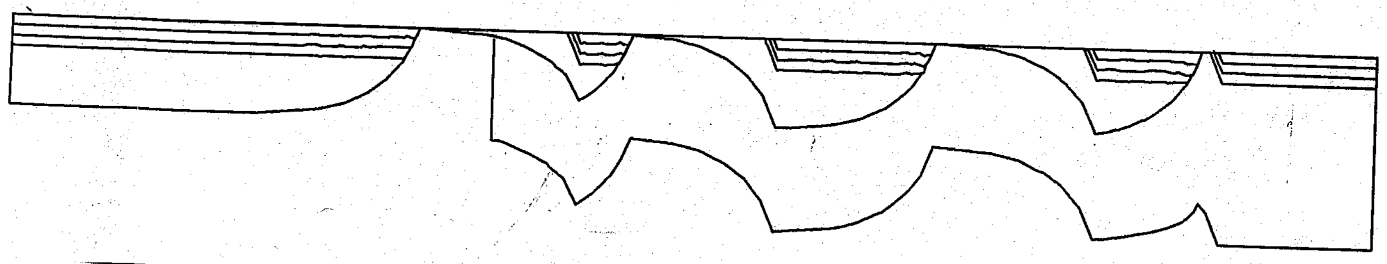


Alan Morris



Alan

Alan Morris

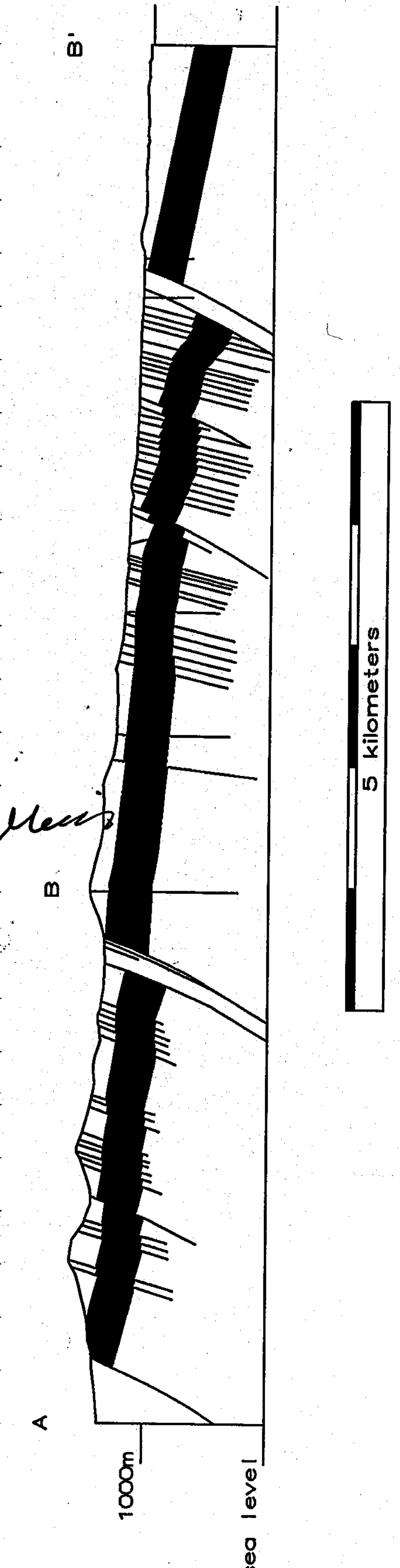


Start 8:30am } SoRI
Finish 11:45am

17th July 1992

Re-Digitised ABB'
plotting for alternative models work in SantaFe.

Alan [illegible]



Alan [illegible]

156

Note: Miscellaneous Reading 17 July – 6 Aug. approx 15 hours

6th. August – Santa Fe

Alternatives:

Vertical/oblique shear

Flex. slip

Domino

"Soft domino"

Hybrid-domino (vert/obl. + rigid rotation)

Multiple detachments (synch. in space)

Multiple detachments (time + space transgressive)

Rotating regional stress fields.

Far-travelled terraines (Zeke Snow / Brian Wernicke)

Slip-line

Alu

Mui

Shrs — 7th. August - Santa Fe. Alan Morris

DOMINO

It is possible to "balance" the Yucca Mt.ⁿ section using the domino model, but there is a wide range of solutions:

Prerequisites

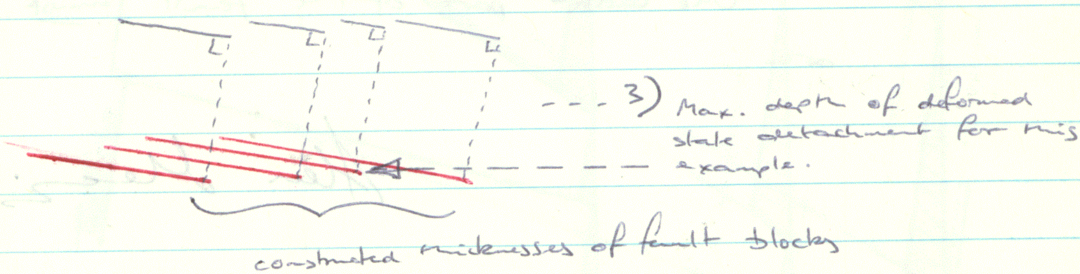
1) Simplify all fault blocks to an uniform (and consistent) dip

Assumptions

1) Simplest case - horizontal detachment
2) No antithetic faults
3) Max. initial fault dip = 90°

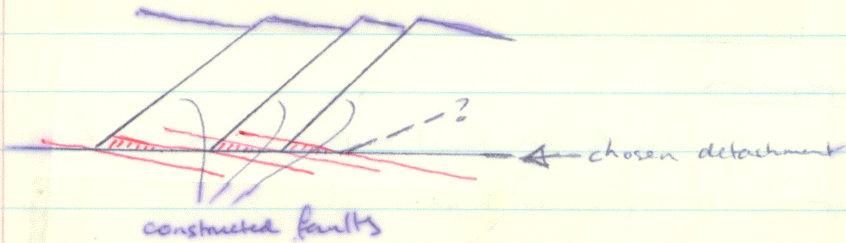
Procedure

1) Choose an initial depth to detachment.
2) Construct this thickness for each deformed state fault block: This gives ---



4) Choose a detachment at or above this level then construct the faults:

This method requires no knowledge of fault orientation.



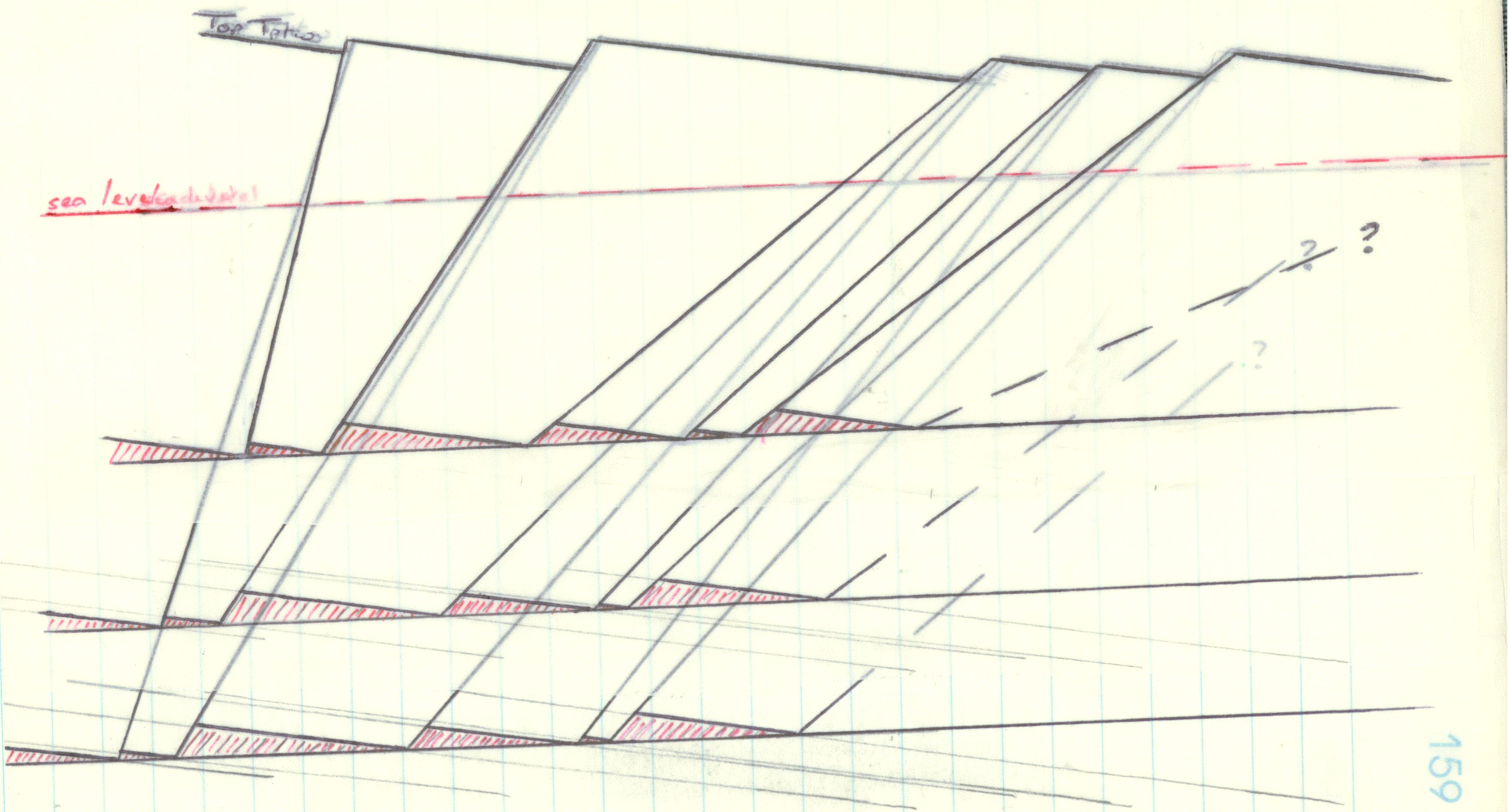
For Yucca Mt: this produces a series of solutions that give steepening faults with increasing depth to detachment (no surprise!) (page 159) →

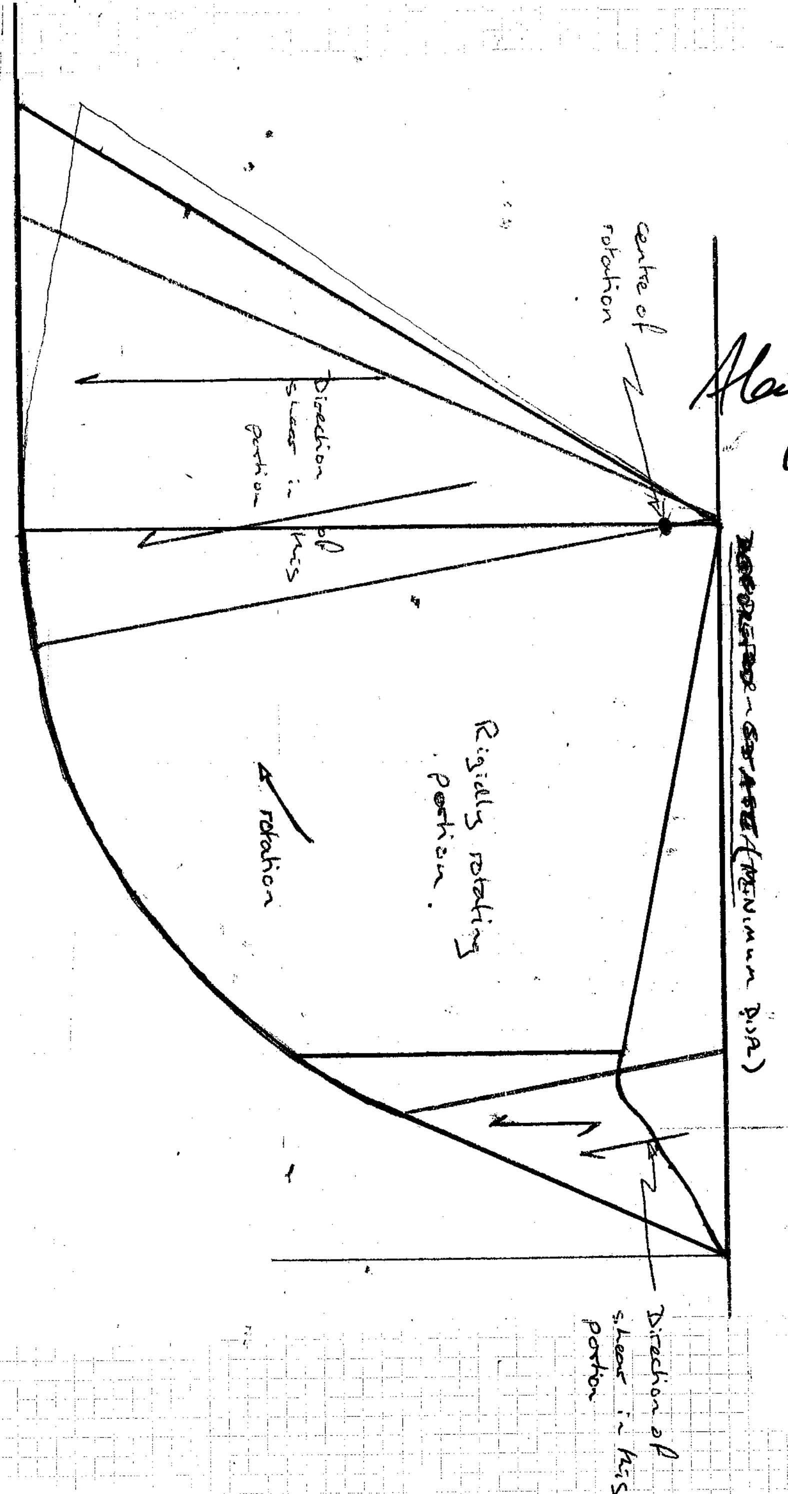
HYBRID DOMINO

Part rigid rotation and part oblique shear (see p. 180)
The size of the hw-cutoff "collapse" region ~~and~~ the dip of the rigidly rotated portion of the hw. uniquely determine the depth to detachment.

One catch - part of the fault must be a circular arc

Alan Menzies


Top
sea level
?
?
?



Alan Moss

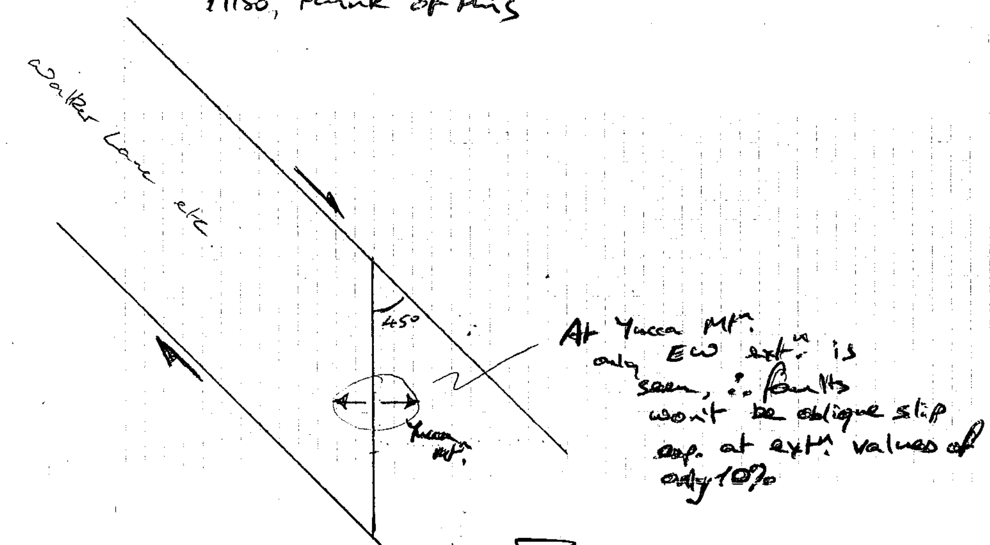
2hrs

10th. August

From Jackson + McKenzie, 1983 - JSG p.471-482:

Try interpreting most of the faults at Yucca as shallow detachment and then 40mile Wash/Canyon fault as deep and younger, effectively killing the older, shallow faults - test this by looking at aftershocks from recent e'quake.

Also, think of this



Alan Moss

Alan Morris

12-13 Aug 1992 : 2 hrs

Called Steve - deadline for alternative models is now late Sept.

More details on Little Skull Mt. Equake:

5.6 magnitude
9-11 km depth
dip-slip
fault plane strikes N45E

Aftershocks - strike-slip
mag. 4

fault plane / aux plane
one dips 30° W the other 60°E (?)

The California Landers earthquake may be a stepping into the continent of the San Andreas system?

Alan Morris

Monday 24 Aug 1992 5 hrs

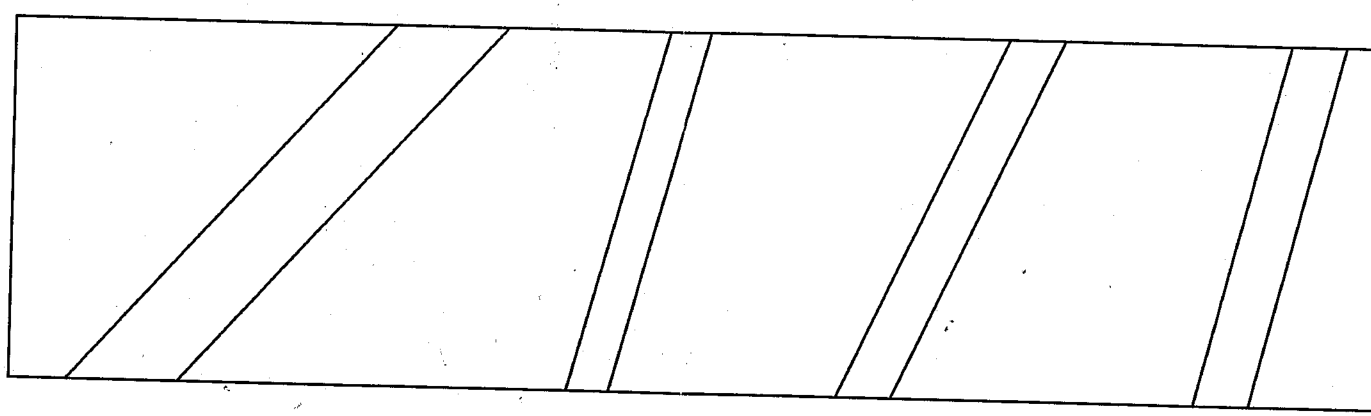
start 9:00am
Finish 2:00pm

Alternatives report.

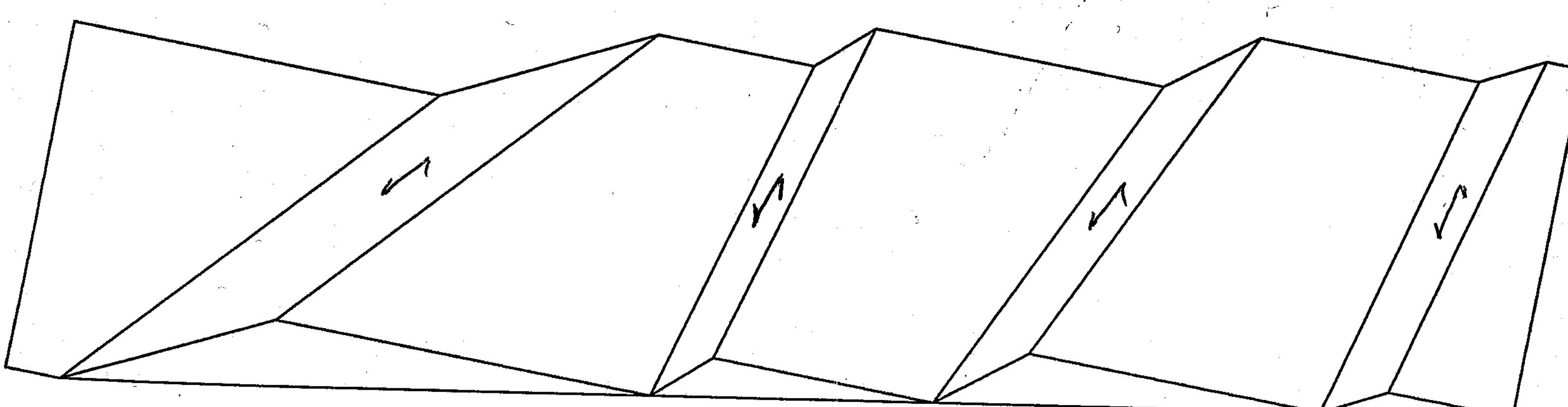
508 972 3000 x 2083
INTERLOGIC

21st Aug 1992 ScoRI Start: 9:00am
Finish: 5:00pm

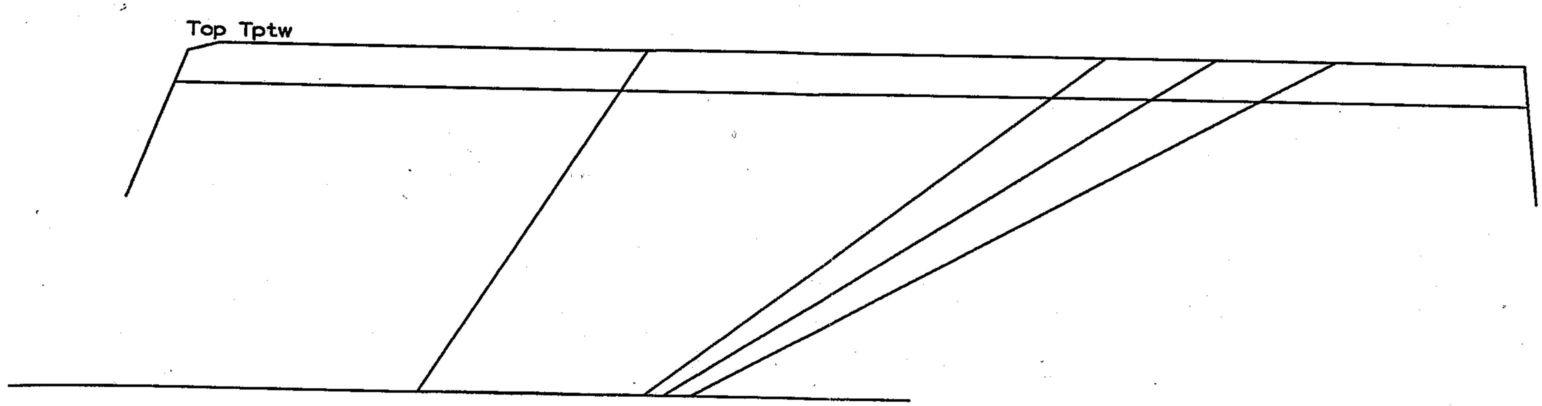
APM



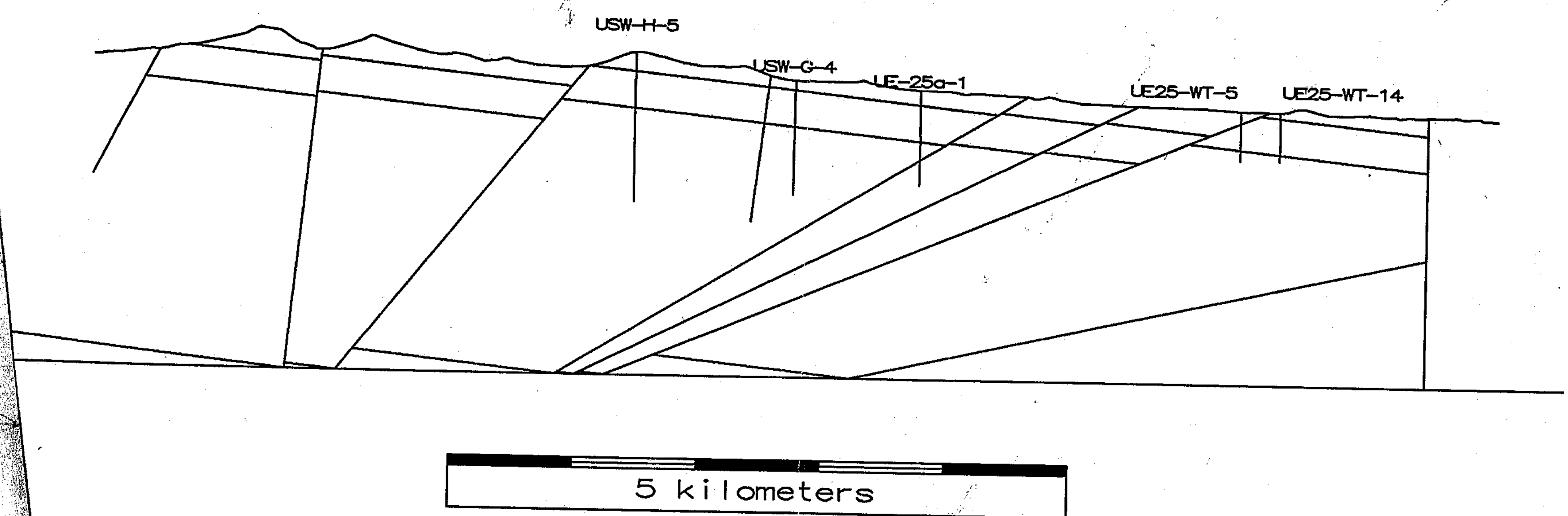
Hybrid-domino
(The real thing)



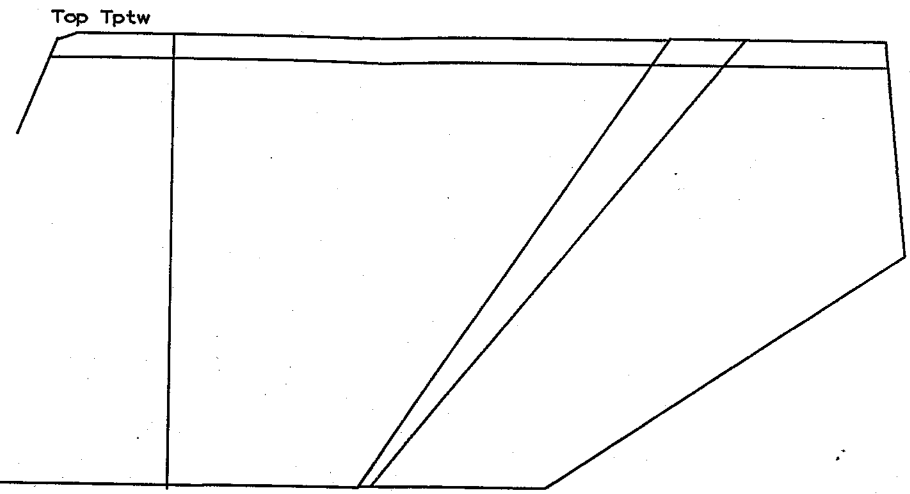
21st Aug 1992 SwRI Start: 9:00am Finish: 8:00pm.
APM



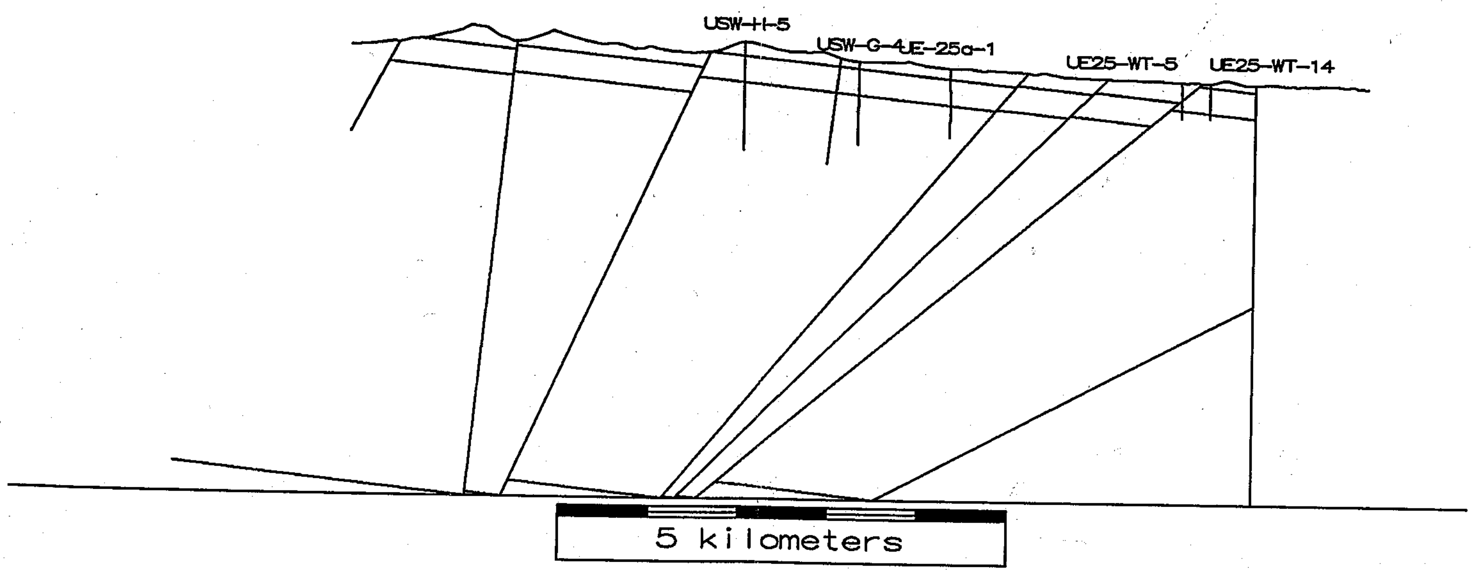
Domino model, thickness = 2.5km
section ABB'



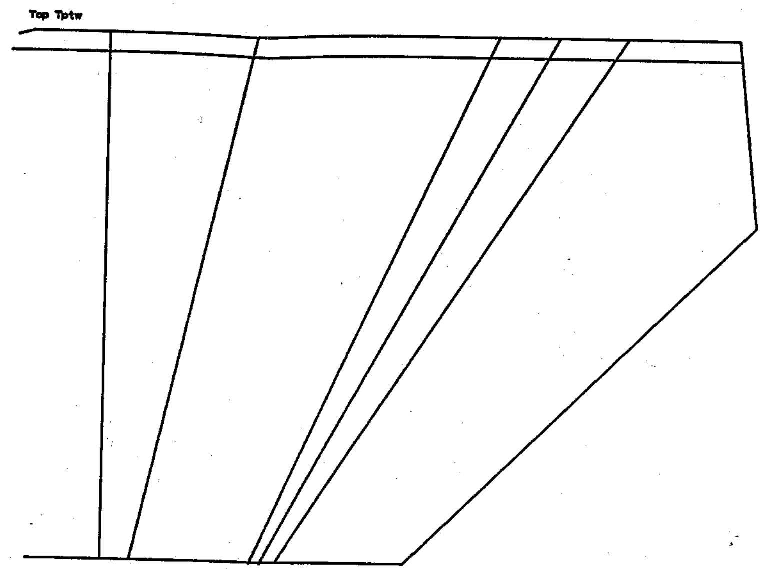
21st Aug 1992 SwRI Start: 9:00am
Finish: 5:00pm
APM



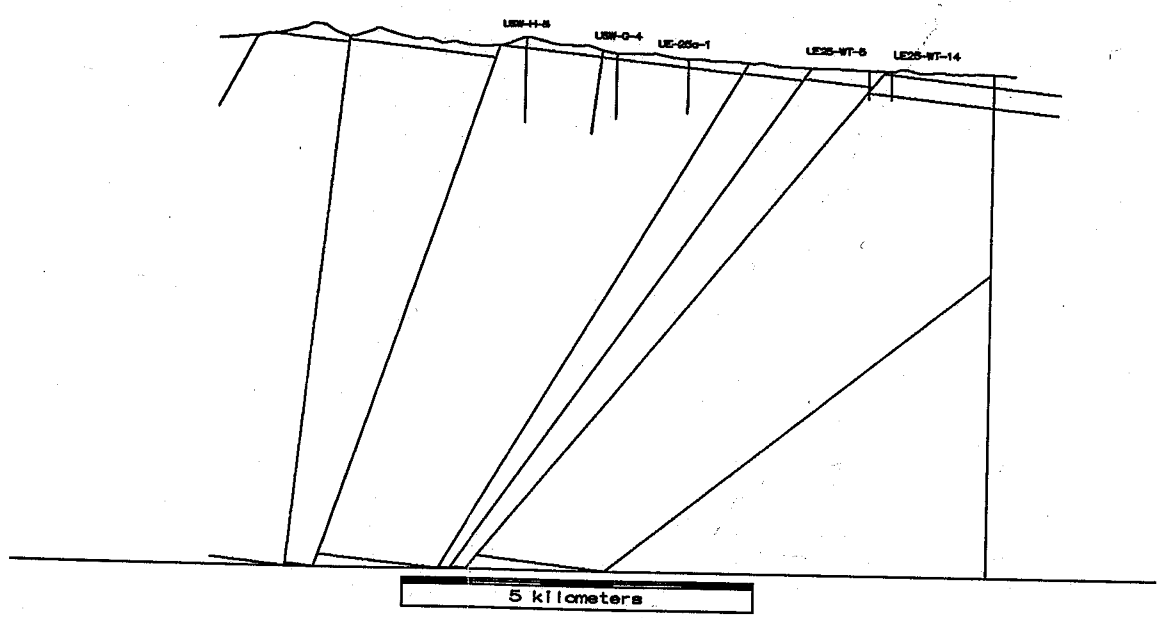
Domino model, thickness = 5km
section ABB'



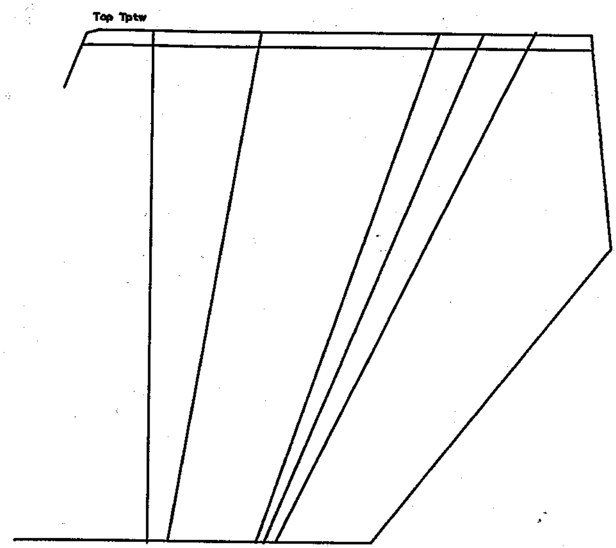
21st Aug 1992 SwRI Start: 9:00am
Finish: 5:00pm
APM



Domino model, thickness = ~~8~~ 7.5km
section ABB'



21st Aug 1992 SwRI Start: 9:00am
Finish: 5:00pm



Domino model, thickness = 10km
section ABB'