

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

Thursday 7th May 1992

Oblique slip?

SCOTT R.B. 1990

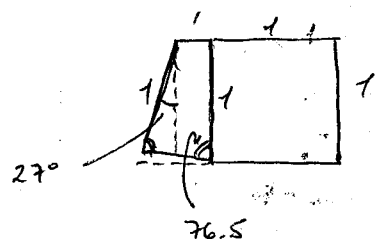
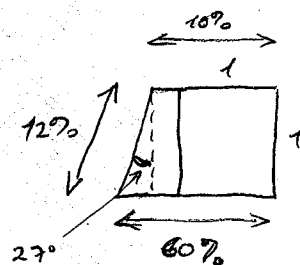
IF N. YUCCA MTN. EXTENDED 10%
AND S. YUCCA MTN EXTENDED 60%

THEN THIS CANNOT BE ACHIEVED BY SIMPLE ROTATION

AND

EITHER: (A) LONGITUDINAL STRAIN ALONG YUCCA MTN.
(027°) IS +12%

OR: (B) OBLIQUE SLIP DIRECTION TO NEGATE LONG.
EXTENSION IS DIRECTED 283° (N77W)



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 slickenside
data for a fault analysis à la Krentz + Reches

Hen

Masini

122

Start 9:30am
Finish 1:30pm

Monday 11 May 1992

Figures for Stirewalt paper.

Alan

Maria

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

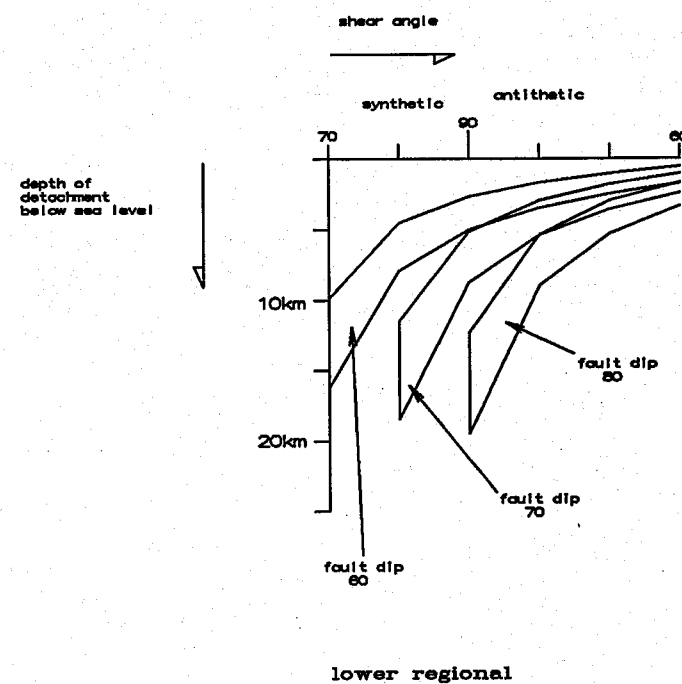
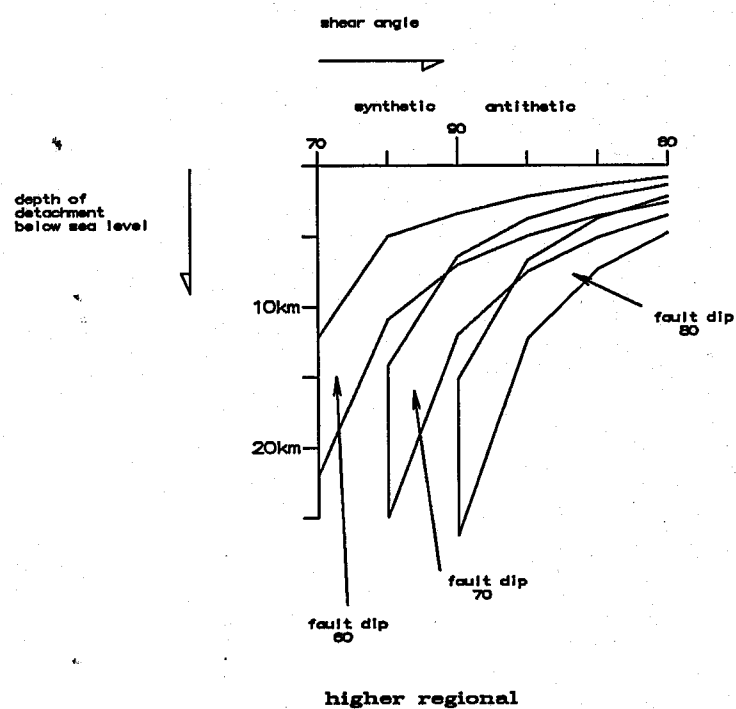
123

Tues 12 May 1992

Plotting for report

Alan Mason

vertical/oblique shear solutions



124

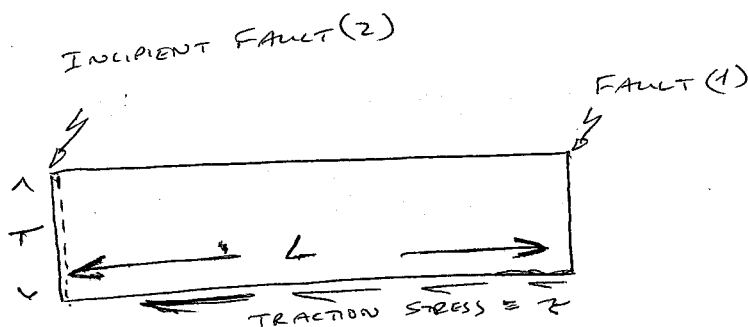
Start 1:30 PM
Finish 6:00 PM

Thursday 14 May 1992

Ken Mason

CHARACTERISTIC
WAVELENGTH

(1)

WHEN

$$\text{DRIVING FORCE} = \text{RESISTING FORCE}$$

THEN

FAULT (2)

DEVELOPS

$$\text{DRIVING FORCE} = \tau \cdot L$$

$$\begin{aligned} \text{RESISTING FORCE} &= \text{CRITICAL STRESS (FAILURE)} \times T \\ &= \sigma_c \cdot T \end{aligned}$$

$$\tau \cdot L = \sigma_c \cdot T$$

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

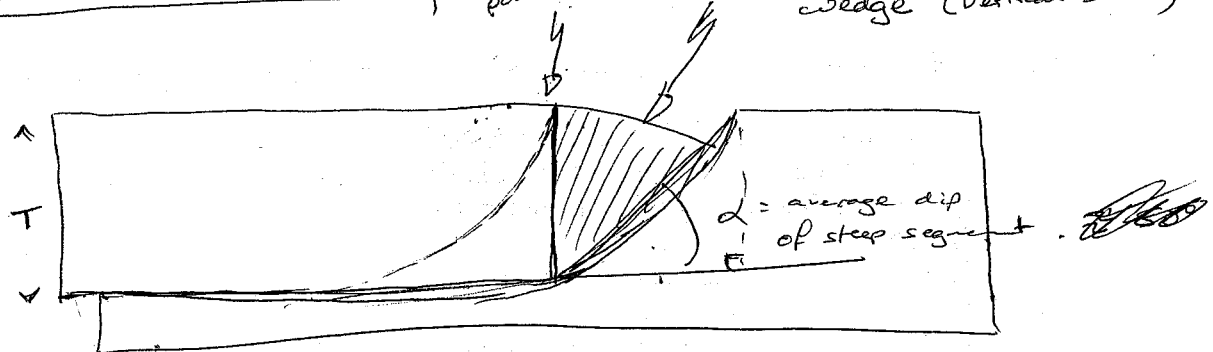
$$\therefore \text{Fault spacing } L = \frac{T \cdot \sigma_c}{\tau}$$

Report preparation

Hoe Hoe's

CHARACTERISTIC
WAVELENGTH

(2)

Probable
position of next boundingHighly deformed
wedge (vertical shear)

← →
FAULT SPACING

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

Hoe
Hoe's

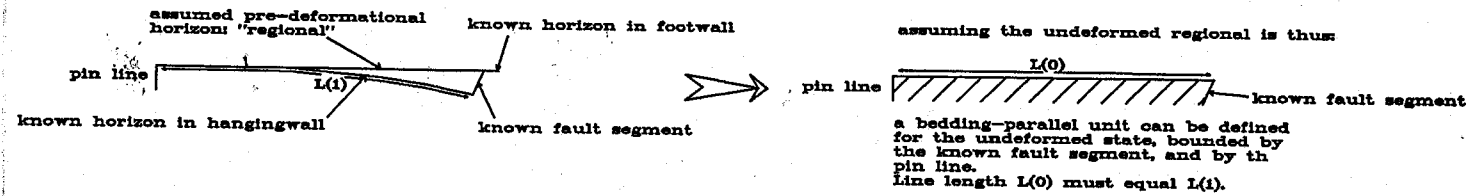
Start: 10:30am

Finish: 7:00pm

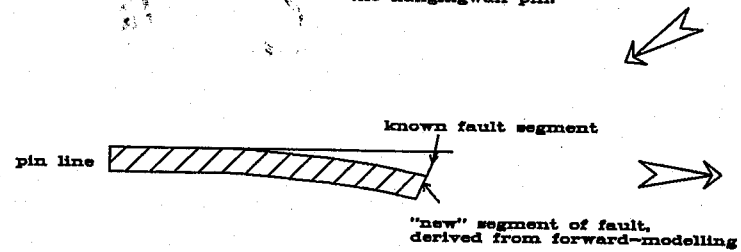
Friday 15 May 1992

Report preparation

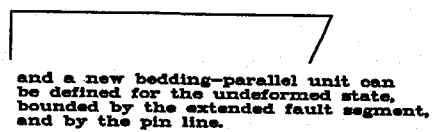
Flexural slip fault trajectory prediction



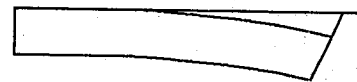
This block can be "forward-modelled" into the deformed state, using the known geometry of the hangingwall as a template, and the hangingwall pin.



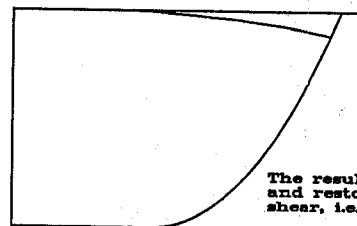
The fault now appears thus, when restored:



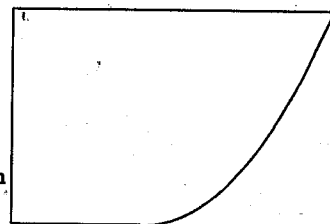
As before, this block can be "forward-modelled" into the deformed state, using the known geometry of the hangingwall as a template, and the hangingwall pin.



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: 11:30a.

Finish: 3:00pm

Mon 25 May 1992

Plotting for report

Alan

Moss

Alan

Moss

128

Start 11:30am

Tues 26 May 1992

Plotting

11:30 - 2:30

MILEAGE SARTI → Home 12.5 miles, one way

1 hour on AV-1 @ UTSA

Alan

Marion

3 hrs @ 475 A

Ken Massis

129

Tuesday 2nd June 1992

Stat. No.

889 -- 25.15m

929 940 949

969

1009

1129

No.

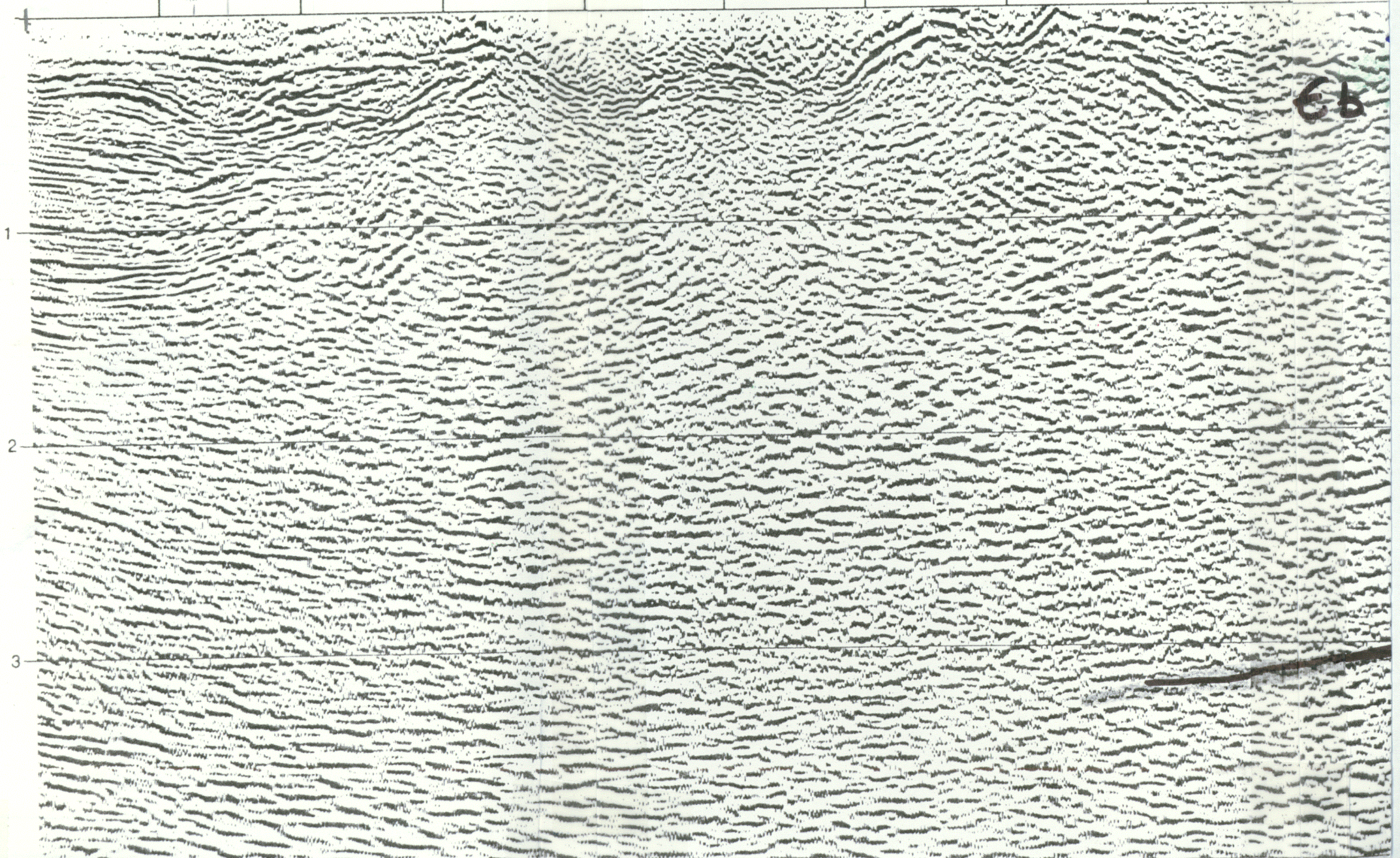
1249

W

First-
stream-of-
consciousness,
attempt

Seismic
datum
= 825m

Two-way traveltimes, s



EB

Ken
Massis

3 hrs @ 475 A

Alan Macis

129

Tuesday 2nd June 1992

Stat. No.

No.

1249

1289

1309

1329

1369

1489

1609

1649

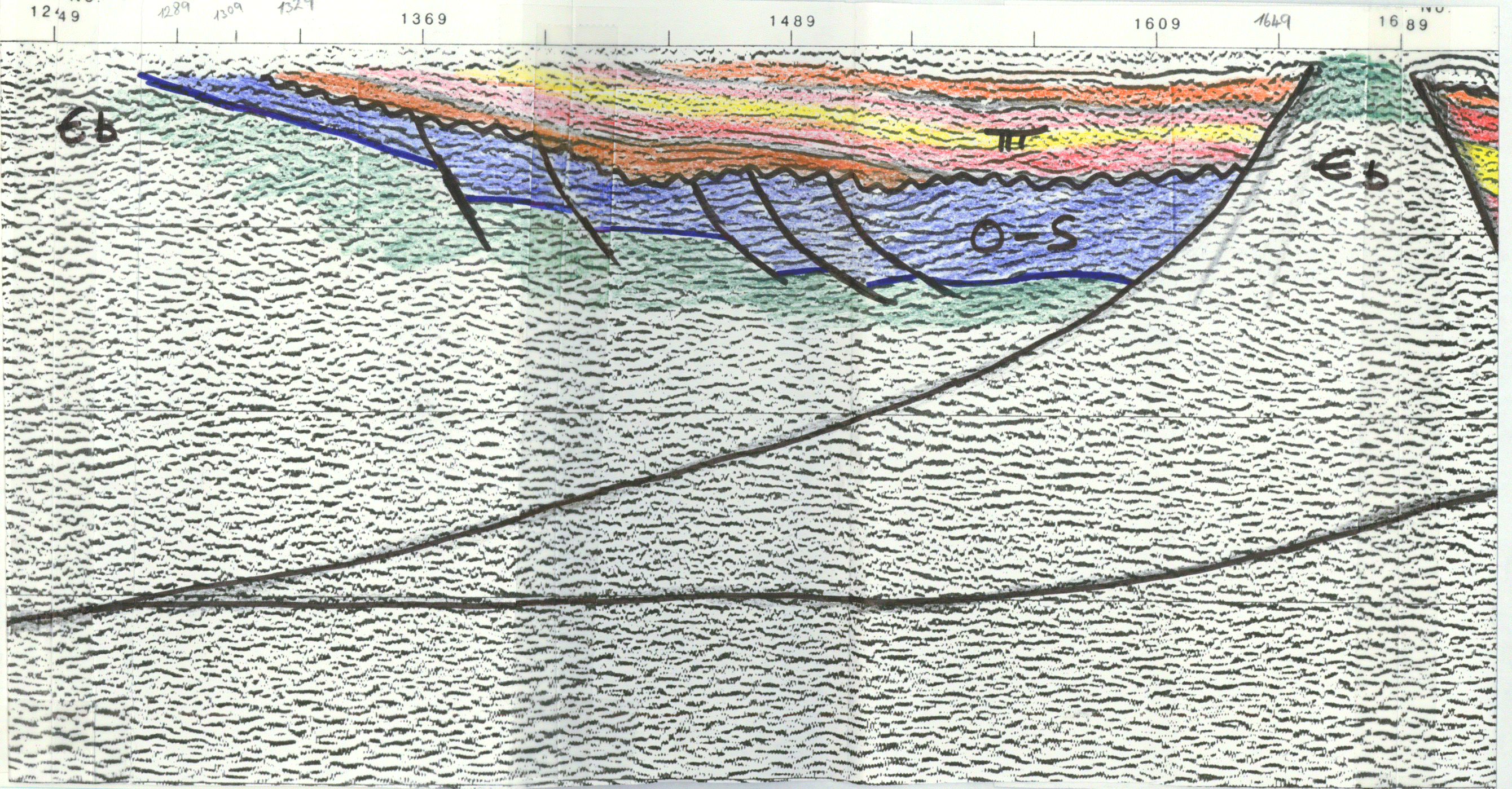
1689

W

First-
stream-of-
consciousness,
attempt

Seismic
datum
= 825m

Two-way traveltimes, s



Eb

III

O-S

Eb

Macis

Tuesday 2nd June 1992

Stat. No.

889 = -25.15m

W

1649

1689

1809

1929

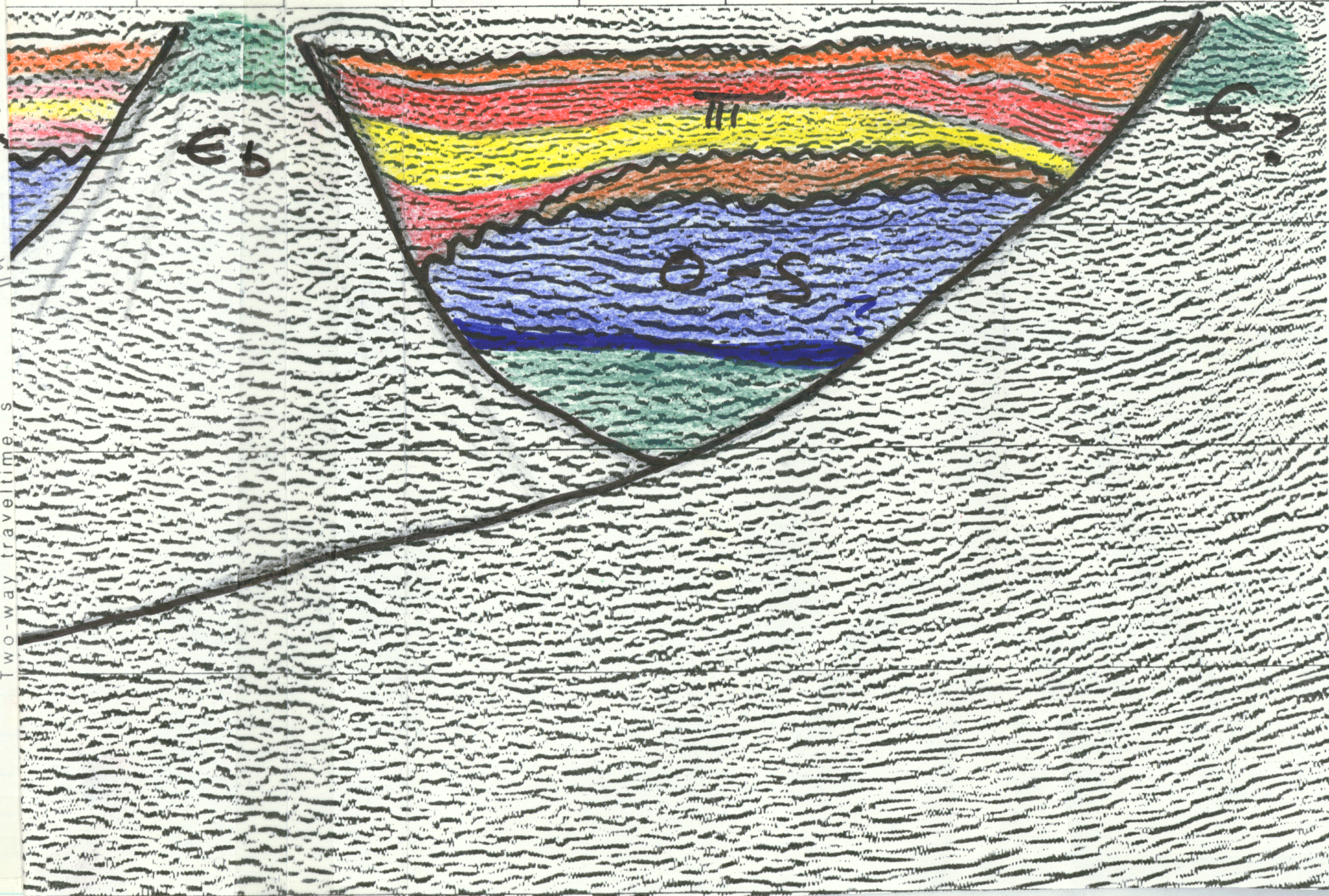
1969

E

First-
stream-of-
consciousness
attempt

Seismic
datum
= 825

Two-way traveltimes



6-7
km.

This gives
av. vel.
of
4-4.7
kps

130

Start 8:30am
Finish 11:30am

Wednesday 3rd June 1992

"Quality Assurance" meeting

AV-1 work continues

Alan

Masri

131

Friday 5th June 1992

2 hours AV-1 @ UTSA

Alan

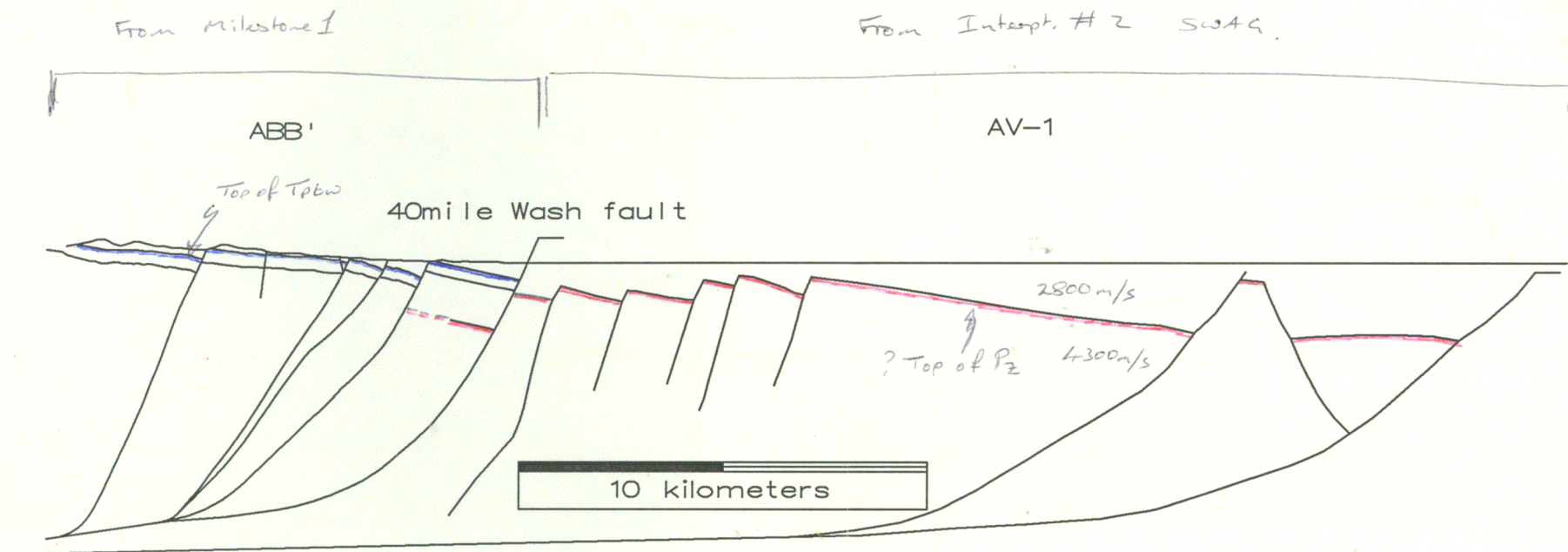
Masri

132

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

Monday 8th June

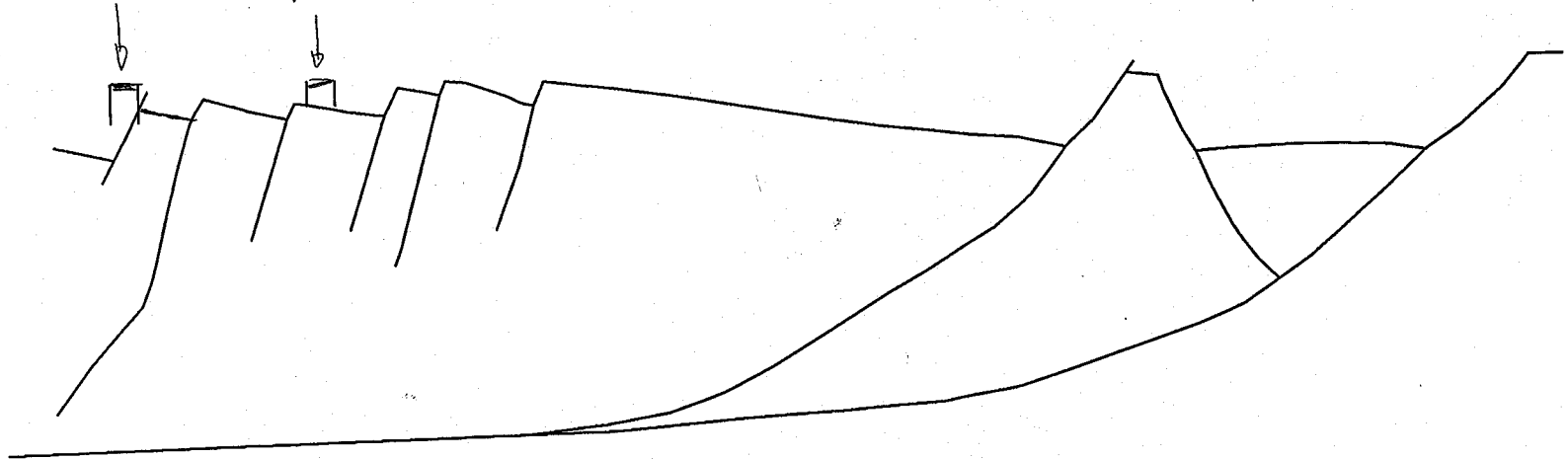
AV-1 - Geosec work



Alan Macdonald

Plan View

AV-1

25-1
range,
depth to
top Pz5-1
range,
depth to
top Pz

10 kilometers

Start 12:00 PM
Finish 6:45 PM

Tuesday 9/12 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 ≈ 690 m

Using a velocity of 2750 m/s for the Tertiary + valley-fill (see AV-1 refraction velocity profile) combined this gives a TWT of 0.50 s 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 ≈ 433 m.

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

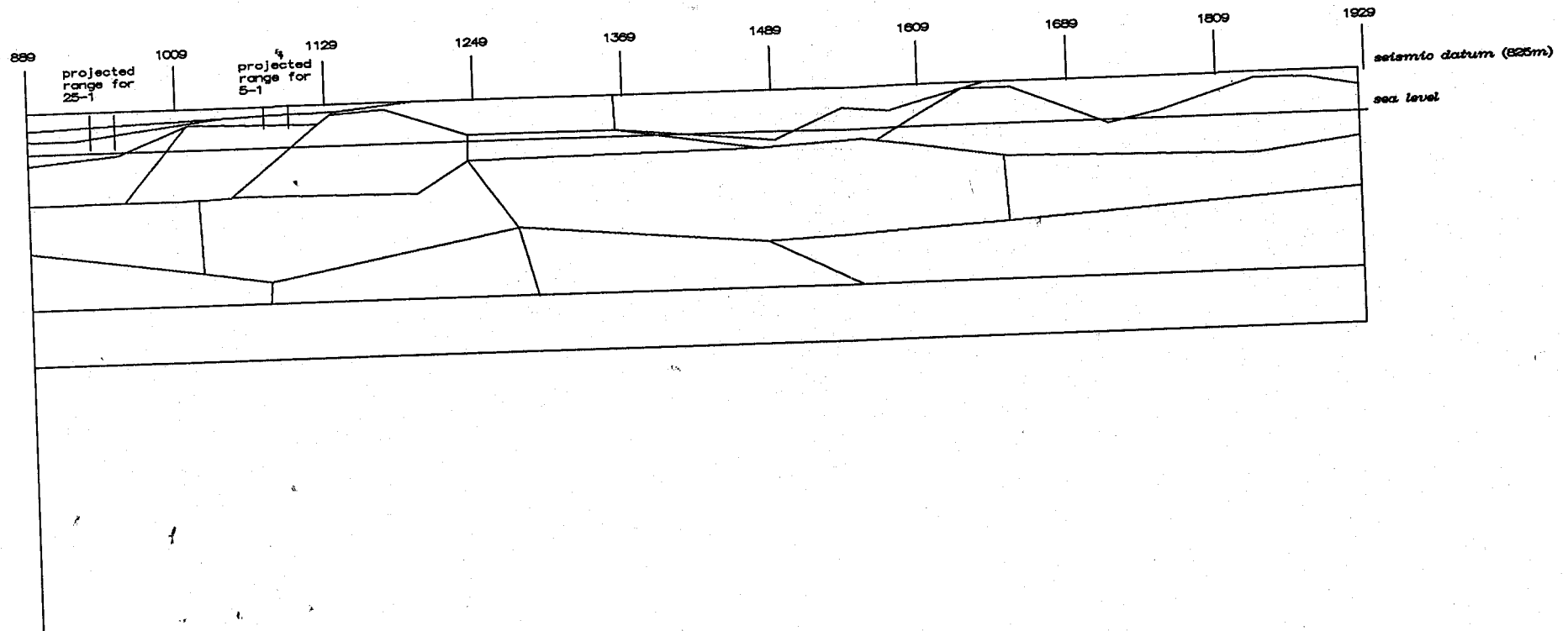
Alan Musi

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

Alan

W. L. M.

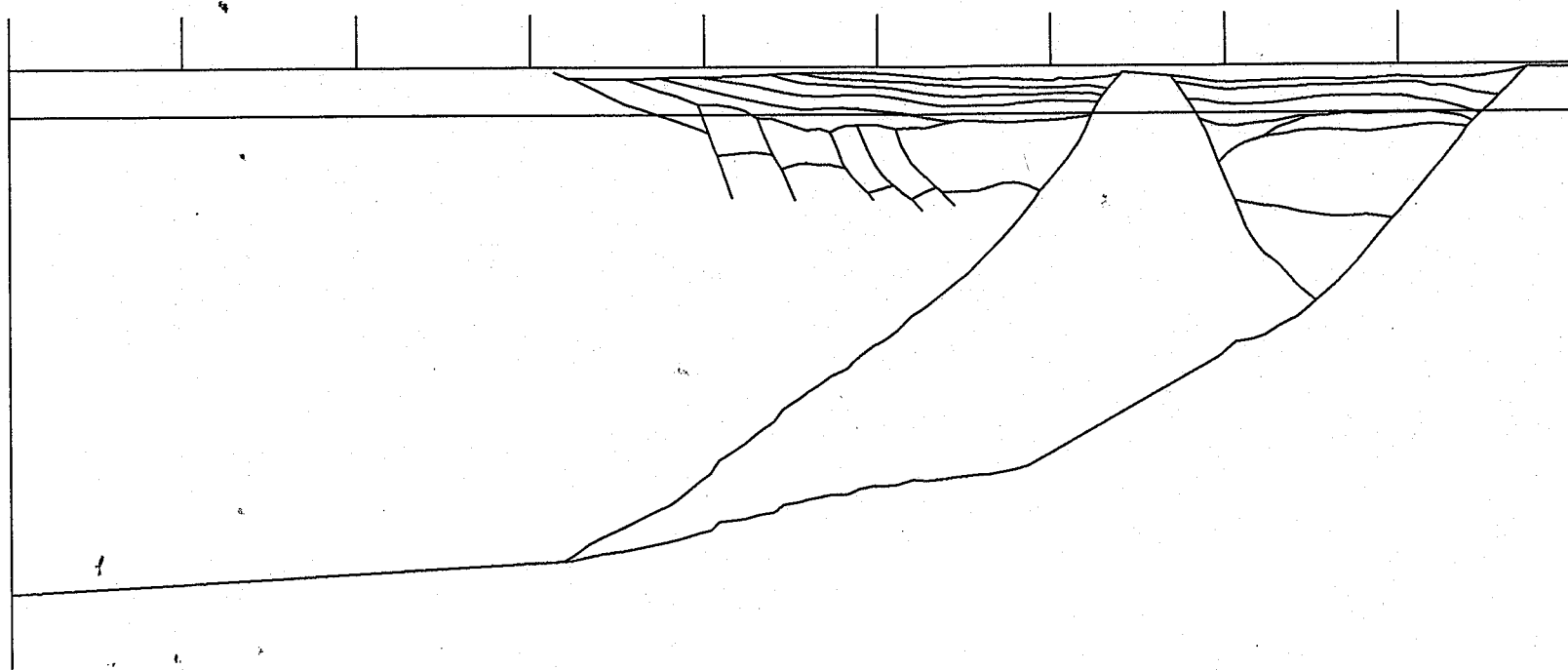
AV-1 REFRACTION VELOCITY MODEL (DEPTH)



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

Alan

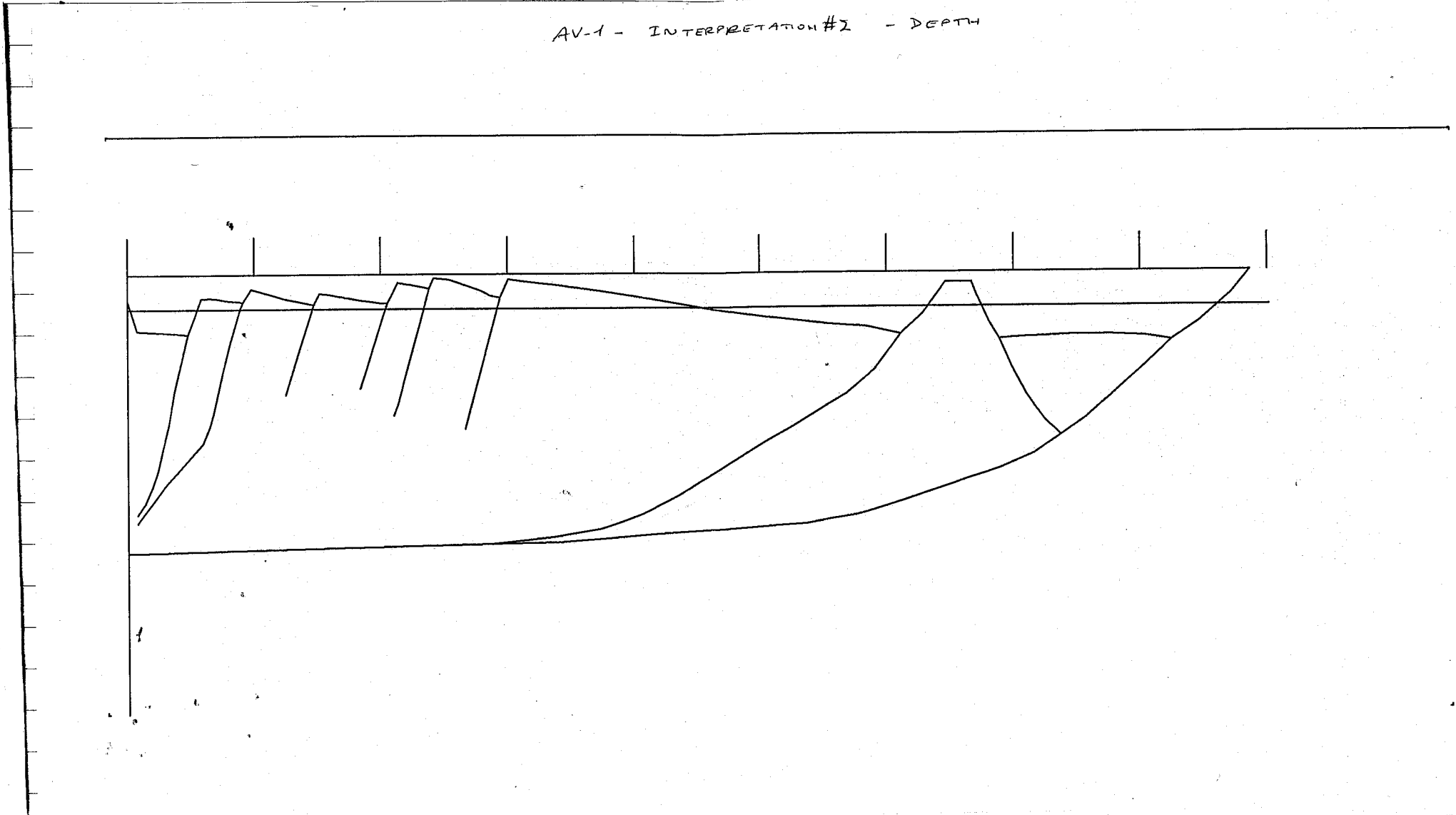
AV-1 - INTERPRETATION #1 - DEPTH



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

Alan

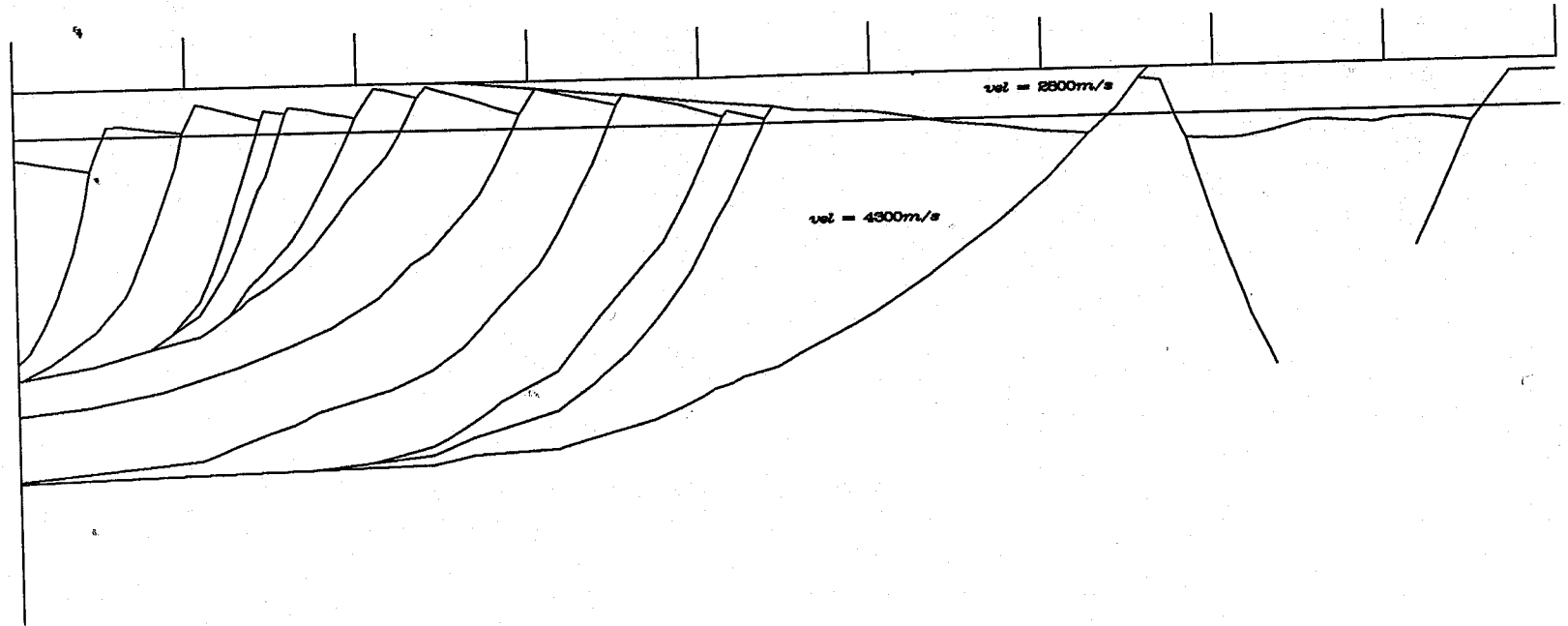
AV-1 - INTERPRETATION #2 - DEPTH



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

Alan

AV-1 Interp#3 depth.

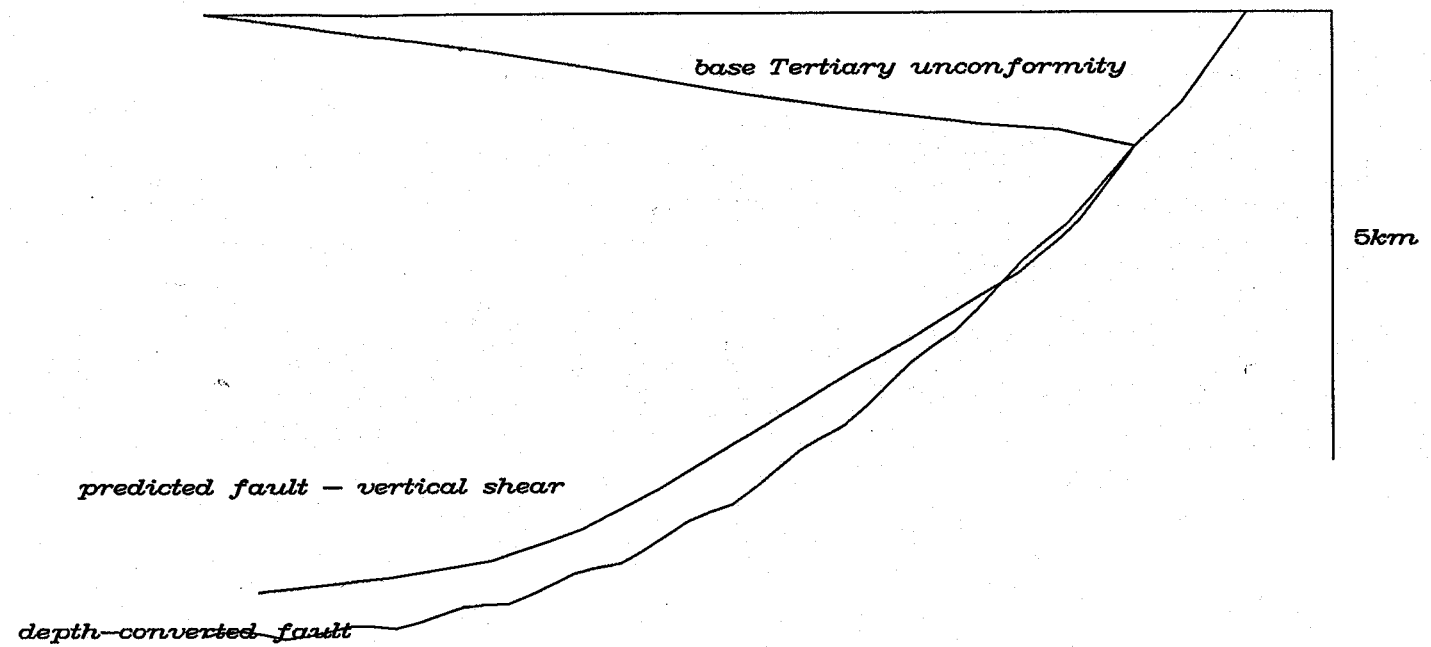


Interpretations #2 and #3 give excellent depths to
detachment - see plots

Alan

Interp. #2

AV-1 central 1/2 graben

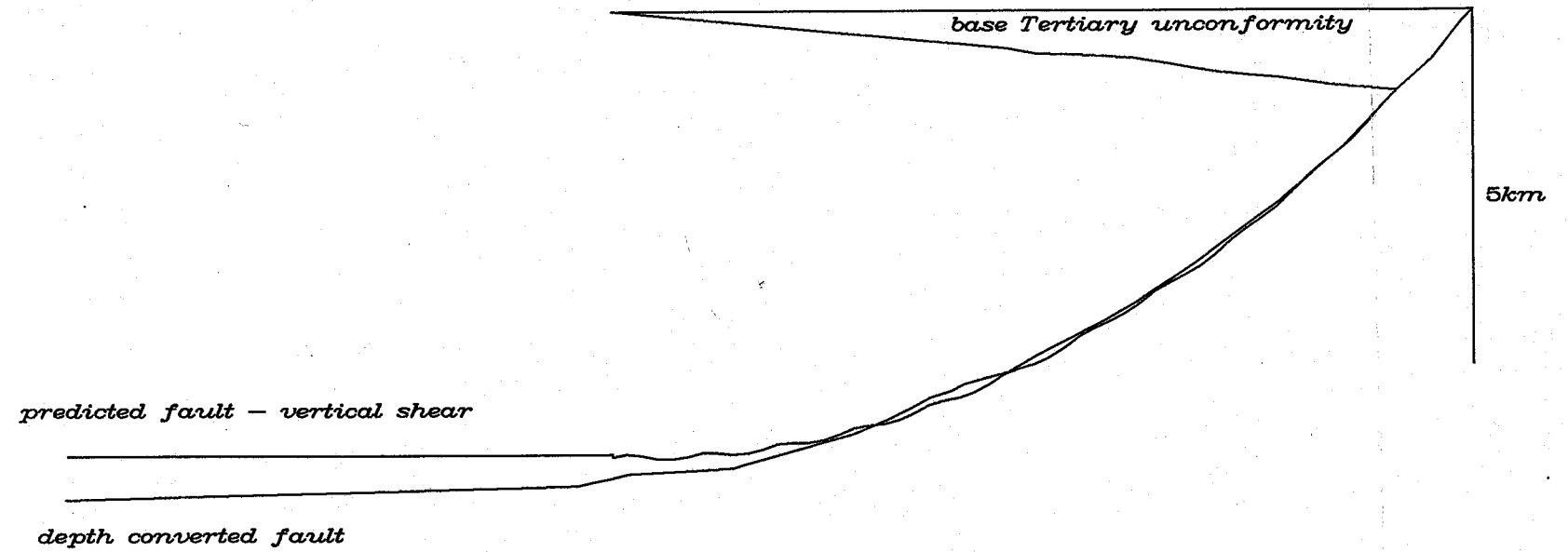


Interpretations #2 and #3 give excellent depths to
detachment - see plots

Alan

Interp. #3

AV-1 central 1/2 graben



Start: 11:00am / SWRS
Finish: 3:00pm

+ 2 hrs DUTSA

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 (using faster vel). I need to time-convert 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	3.5
		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 Harris

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 6445 km - 8.25 km (5.63 - 7.43 km sub-sea)

11 June 1992

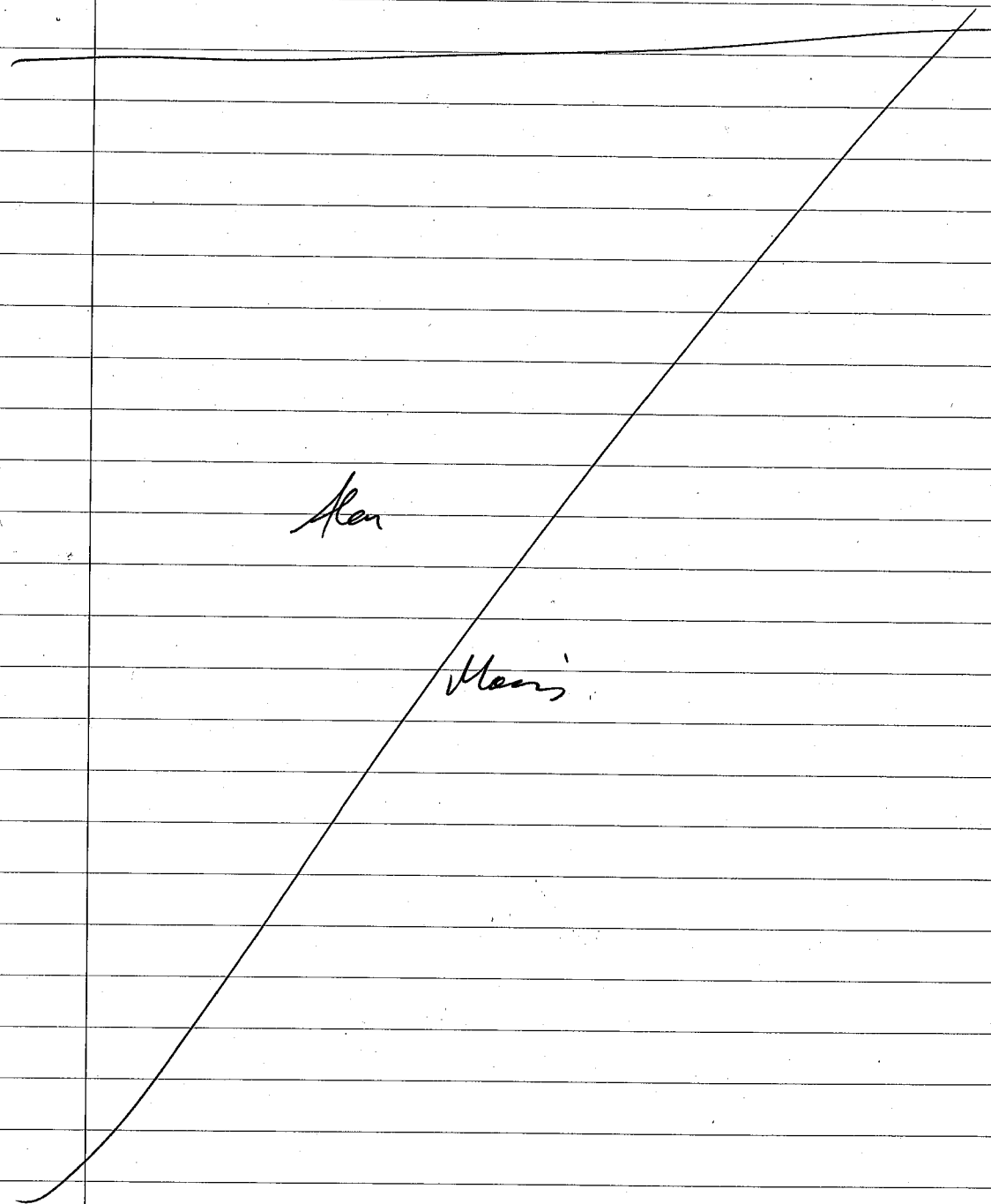
AV-1 gives good shallow information:

- 1) It is clear what the geometries of the central half-graben are. Provided that a good shallow ($< 1.5 \text{ sec TWT}$) velocity model can be applied this will allow accurate prediction of deeper fault trajectories.
- 2) 40 mile Wash Fault is real, but difficult to fully constrain. There is insufficient two 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 1.5 s TWT and there is insufficient two 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 at SRI

Finish: 6:15 pm

SEDSPEC made on AV-1



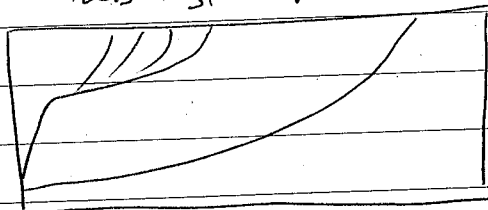
Start: 2:00pm
Finish: 6:00pm

12 June 1992

New AV-1 interpretation - double-decker detachment

Nok:

This type of detachment produces an



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

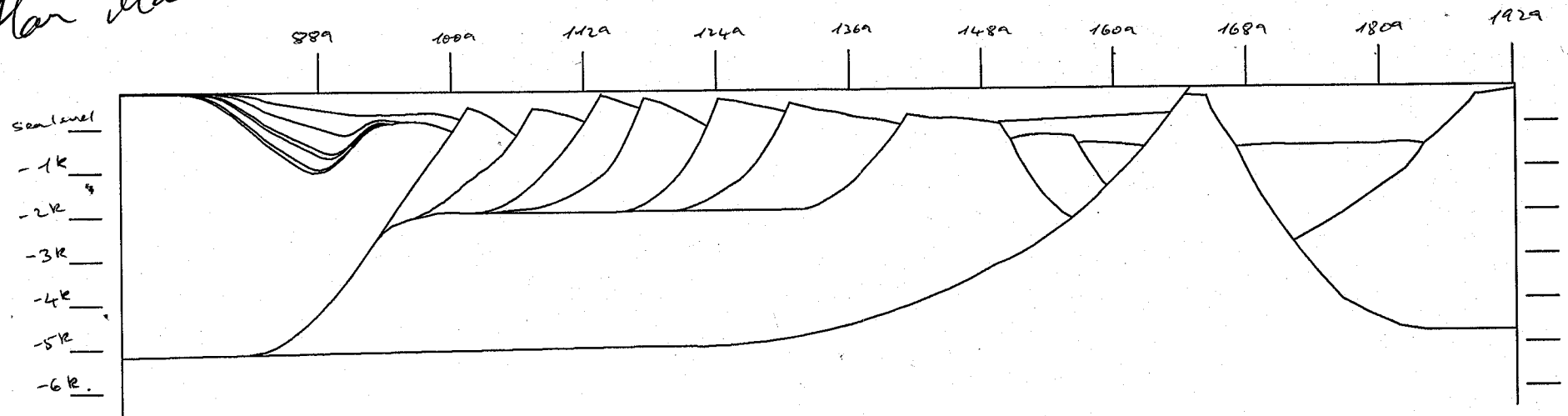
Archive GEOSSEC FILES

/ut4/geosecsrc

Alan

Masi

Alan Massis



Start: 10:30am
End: 5:30pm

15 June 1992

TO OBTAIN A FILE MANAGER IN GEOSPEC USER,

/usr/openwin/bin/openwin - launches openwindows from
geospec after login.

Wordperfect is in: /home/bren/alan

Alan

Alan

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

16 June 1992

AV-1 depth-modelling, etc.

Interp	Vel. Profile	Vert. Shear	Depth to detach
			66° shear
4	$\frac{2800}{3400}$	8 km	19
3	"	8 km	18
2	"	7.2	17.3
1	"	9.4	34

Potential seismic reflectors as candidates for detachment
surfaces.

1.1 - 1.2 s

2.4 - 2.6 s

2.3 s

best

Alan

Alan

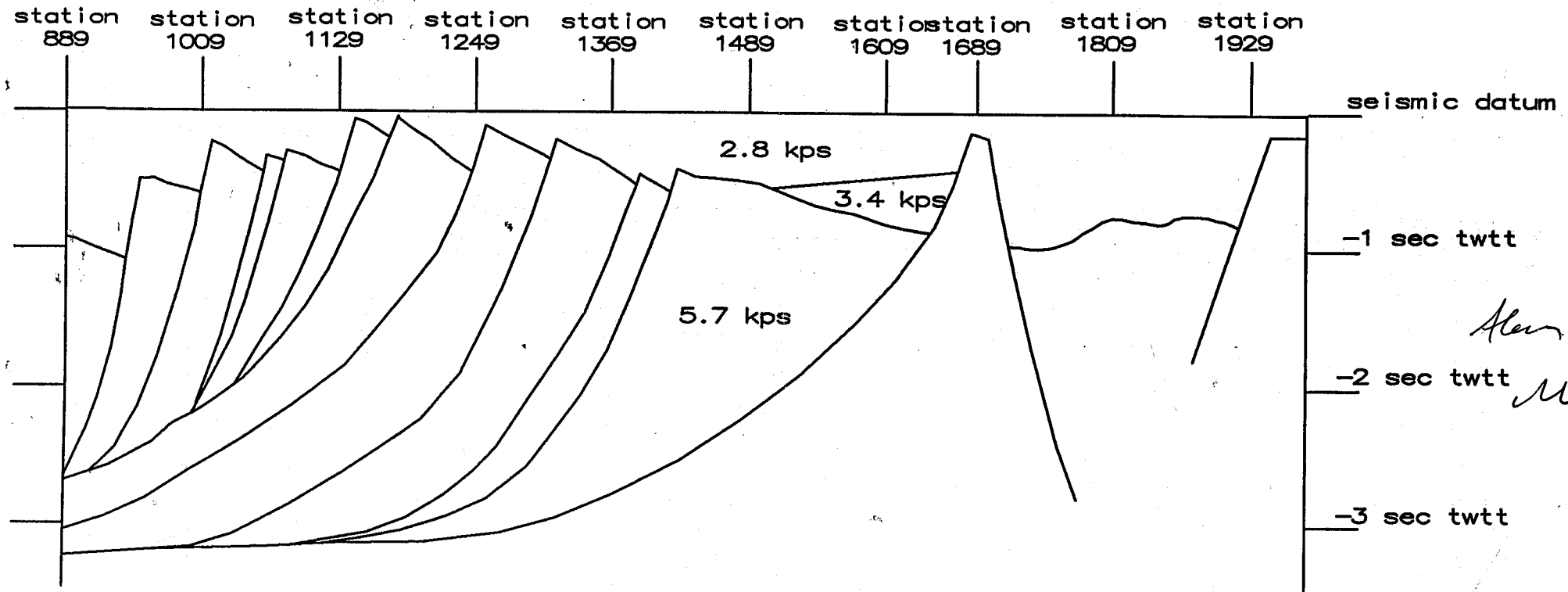
144

Start: 10:30am

Finish: 6:30pm

17th June 1992

AV-1 Report



Digitized, interpreted velocity model, AV-1
Deeper detachment

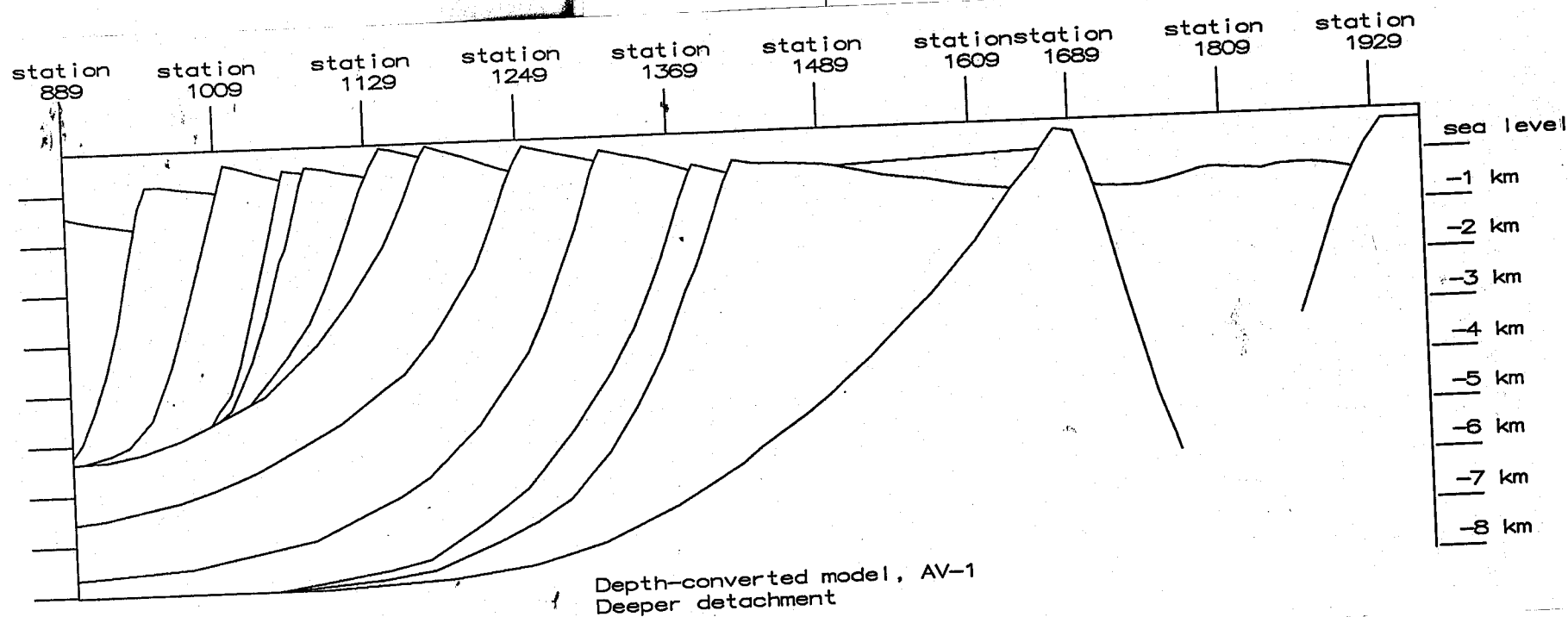
144

Start: 10:30am

Finish: 6:30pm

17th June 1992

AV-1 Report



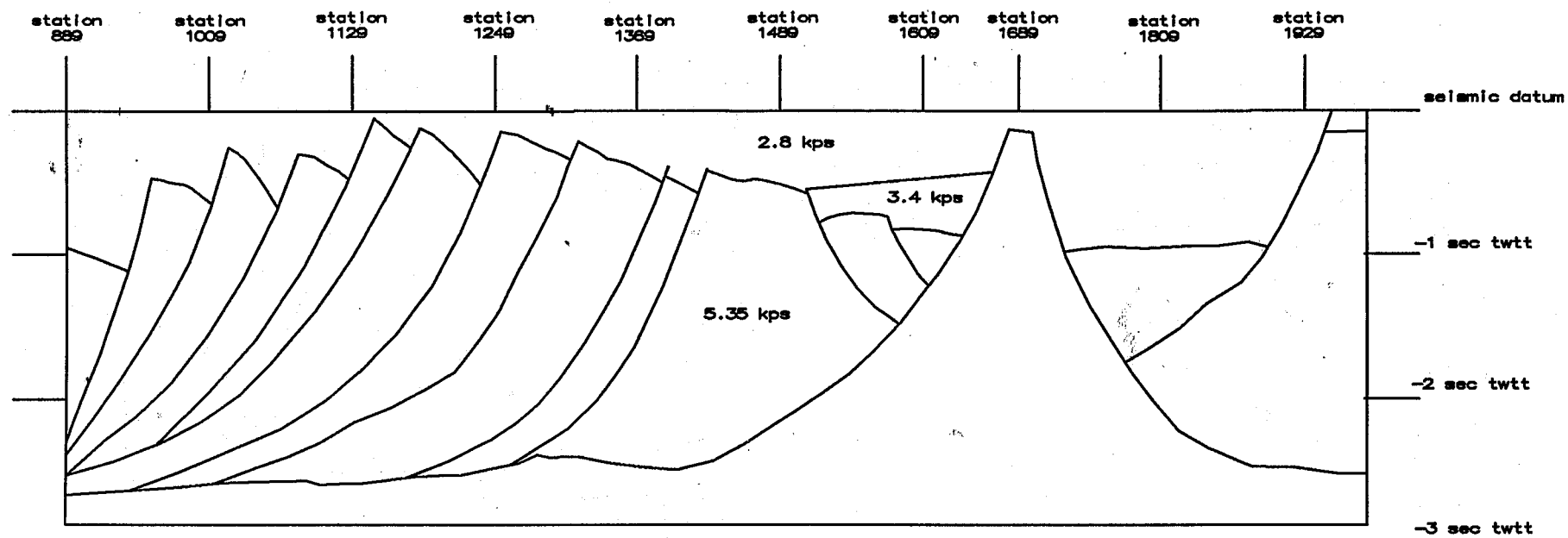
144

Start: 10:30am

Finish: 6:30pm

17th June 1992

AV-1 Report



Digitized, interpreted velocity model, AV-1
Shallow detachment

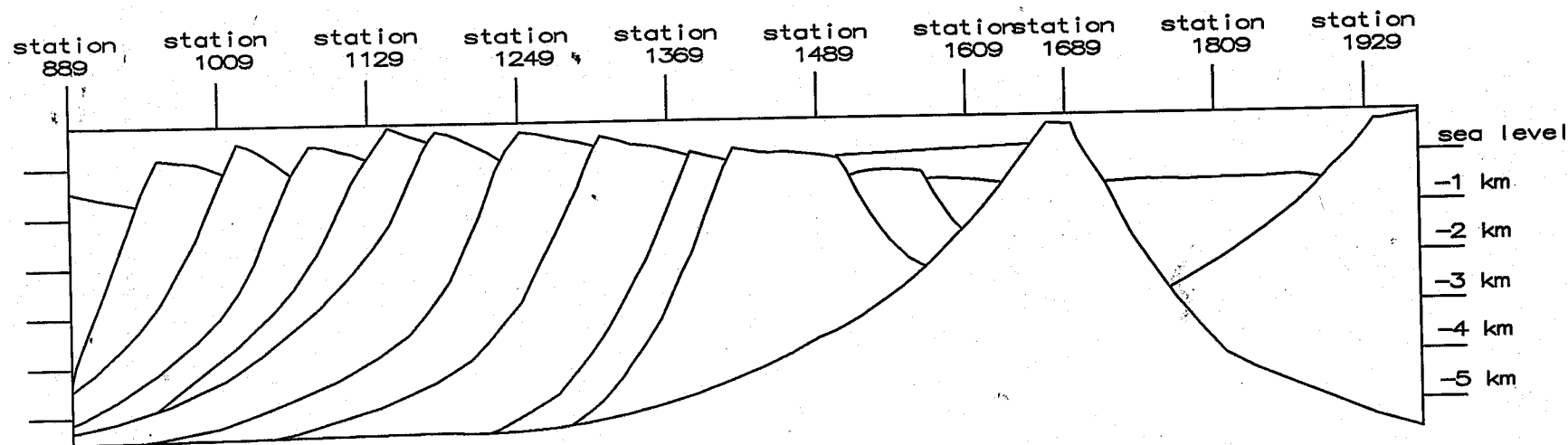
144

Start: 10:30am

Finish: 6:30pm

17th June 1992

AV-1 Report



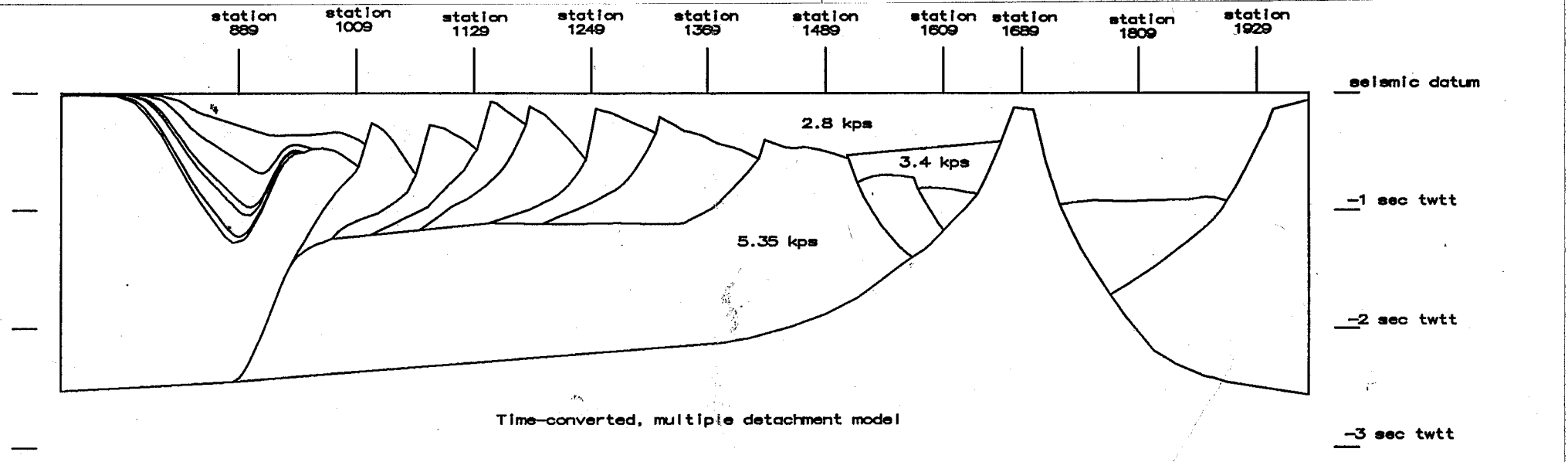
Depth-converted model, AV-1
Shallow detachment

Shot 8:30am
End 5:30pm

18th June 1992

AV-1 Report production - 50% SED 50% - SED

Alan Harris



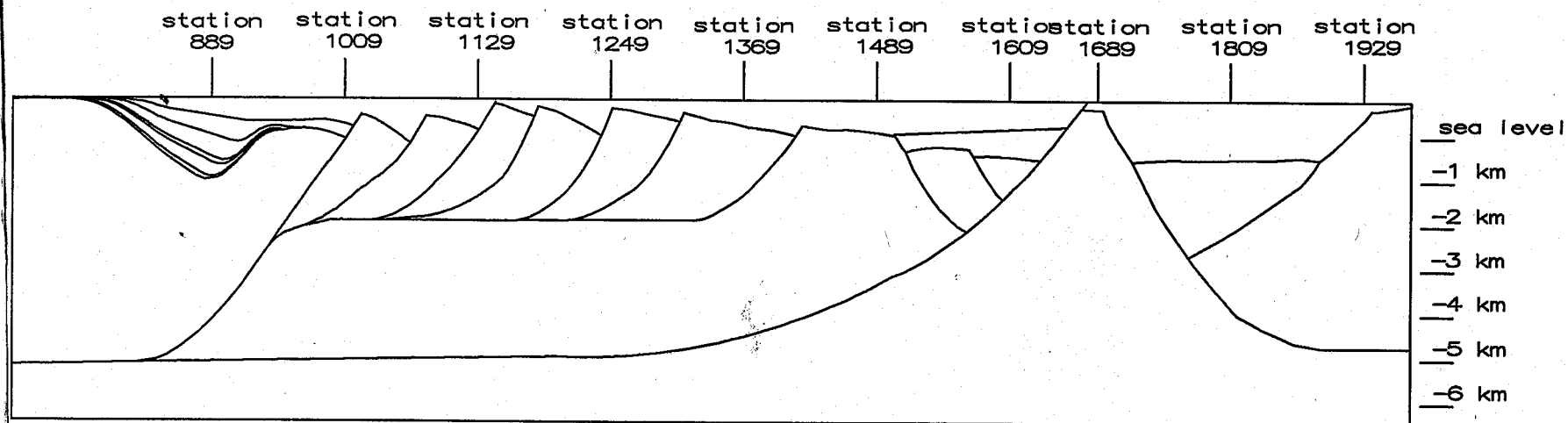
Shot 8:30am

Finish 5:30pm

18 June 1992

AV-1 Report production - 50% SED 50% un-sed

for Mass



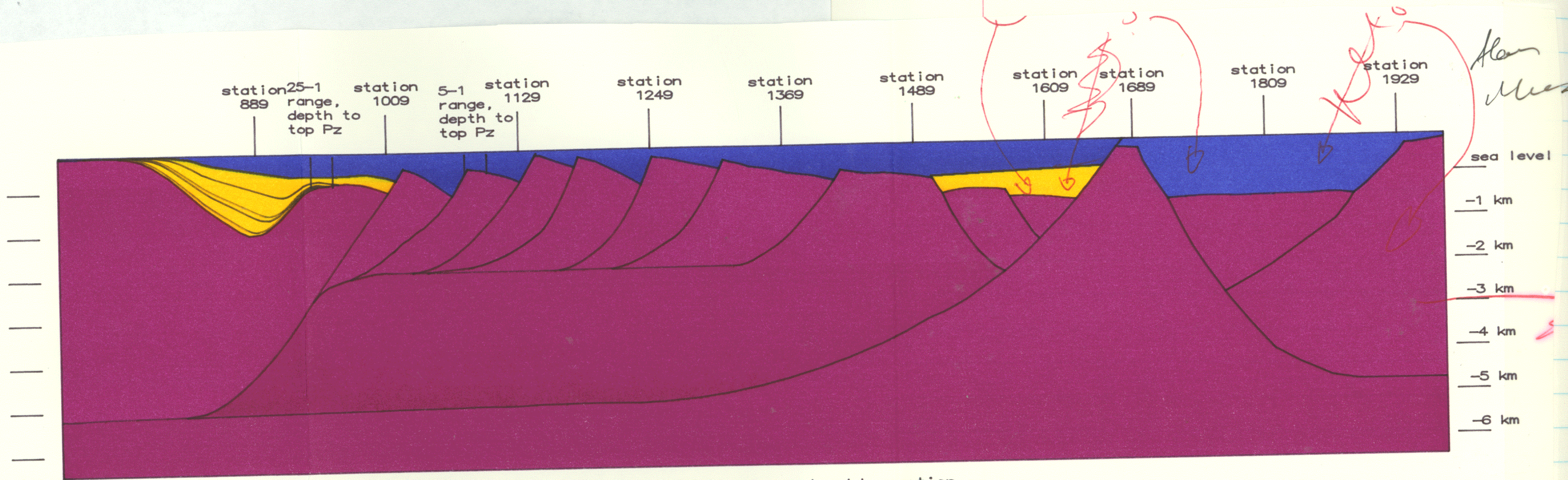
Multiple detachment, restorable section

146

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

147

14th July 1992

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

Alan

Mavis

148

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

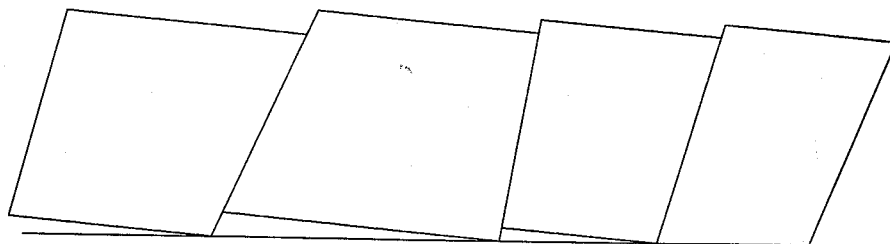
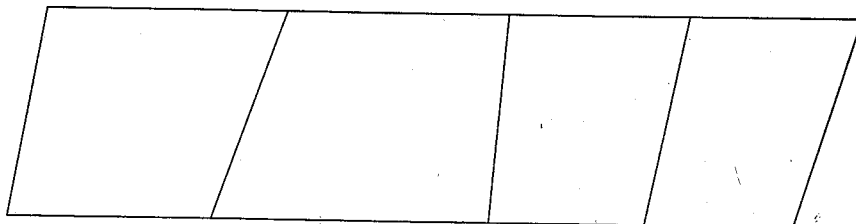
15th July 1992

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

Worked on "alternative models" report and

PROTECT Altmodel 1. db

domino



148

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

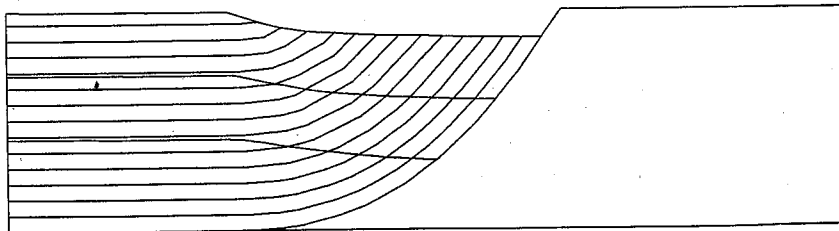
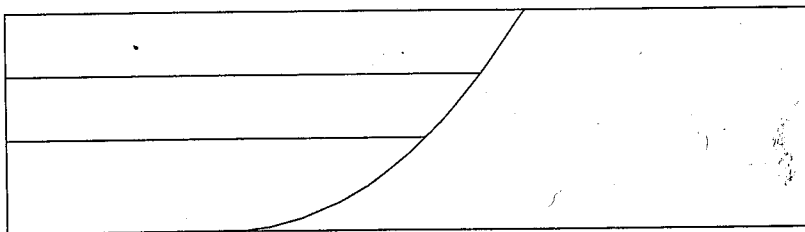
15th July 1992

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

Worked on "alternative models" report and volcanism

PROTECT Altmodel 1. db

slip-line



148

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

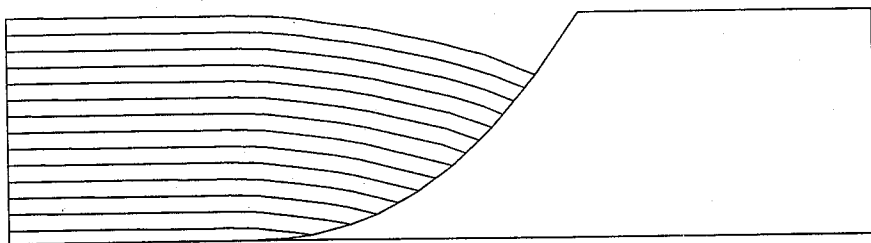
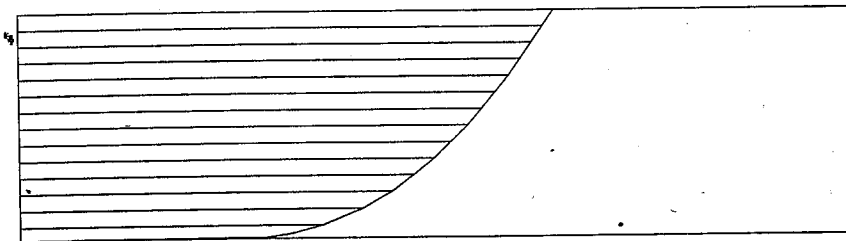
15th July 1992

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

Worked on "alternative models" report and volcanism

PROJECT Altmodel 1. db

flexural slip



148

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

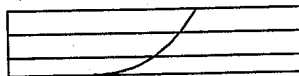
15th July 1992

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

Worked on "alternative models" report and ~~colours~~ ~~models~~

PROTECT Alt model 1. db

vertical shear

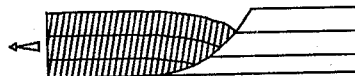
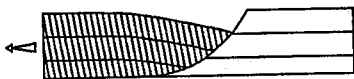
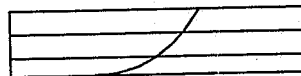
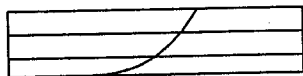


How

Meaning

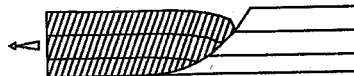
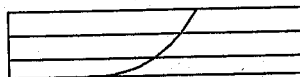
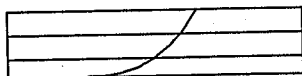
80-degree antithetic, oblique shear

80-degree synthetic, oblique shear



70-degree antithetic, oblique shear

70-degree synthetic, oblique shear



Start: 8:30am
 End: 3:30pm

16th. July 1992

Alan Wilson

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

Transension

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 Harris

TECTONIC SETTING

Simple extension

Simple E-W extension

Transension

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

APPLICABILITY TO YUCCA MOUNTAIN

DEFORMATION MECHANISM

Vertical/oblique shear

Flexural slip

Domino

Slip-line

GEOMETRY

Single detachment

Multiple detachment

TECTONIC SETTING

Simple extension

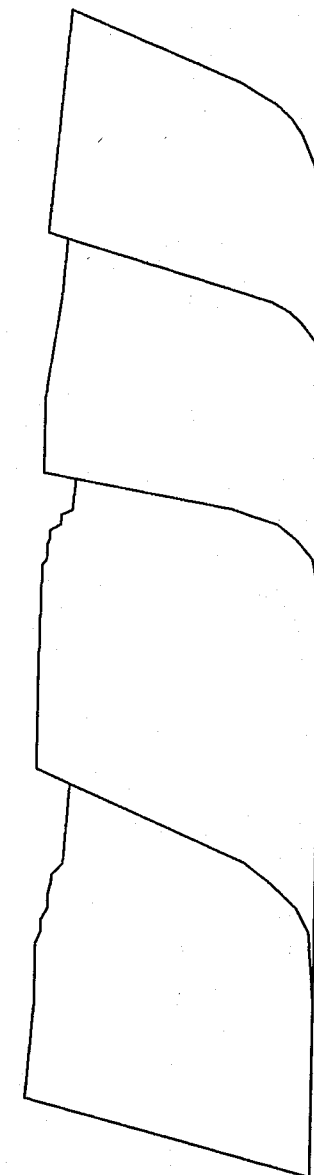
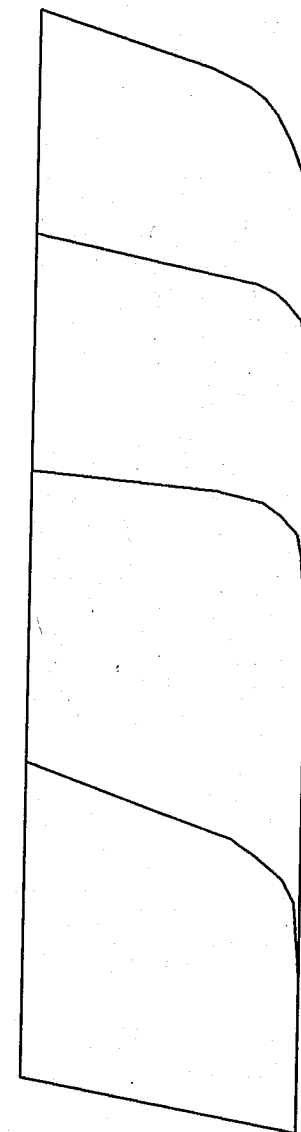
Transension

? Hybrids

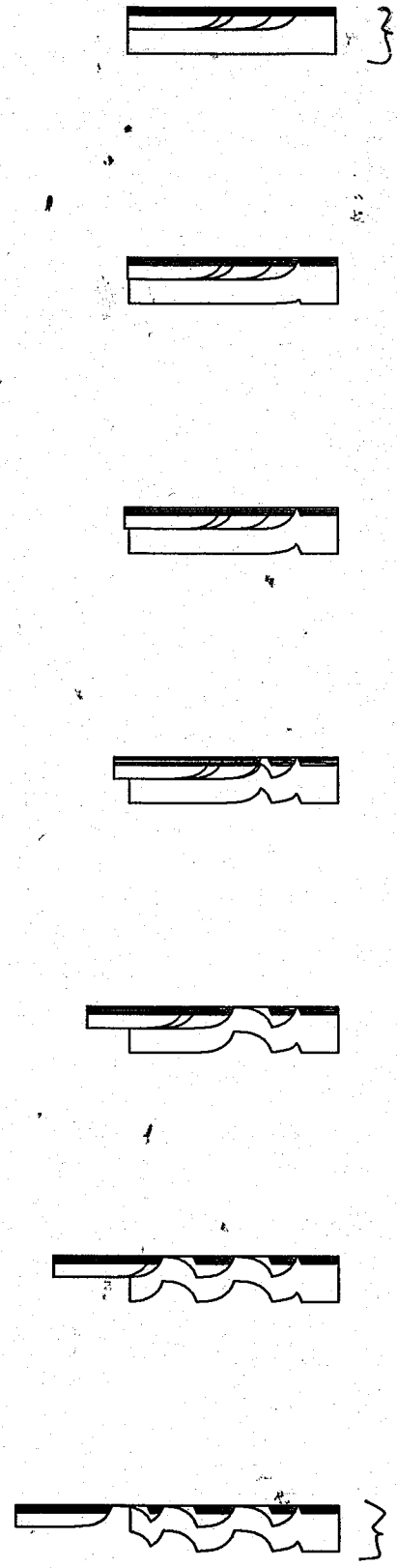
? "Rolling hinge" deformation

Alan Harris

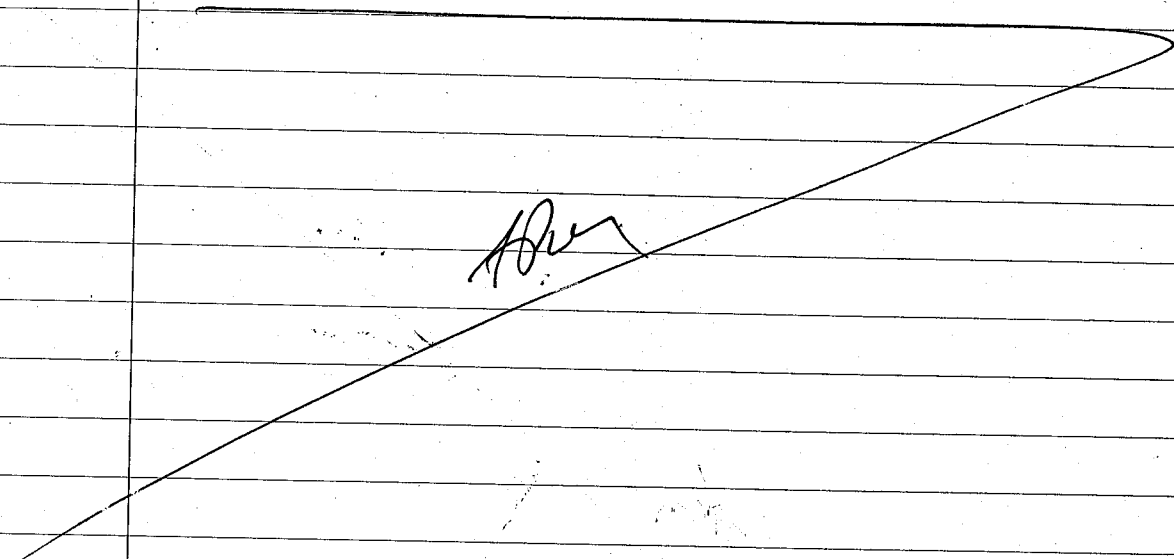
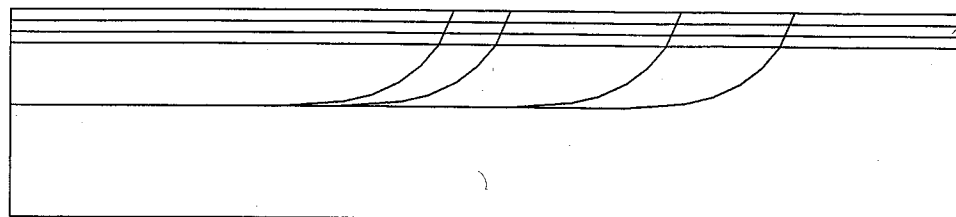
hybrid - domino block rotation and vertical shear



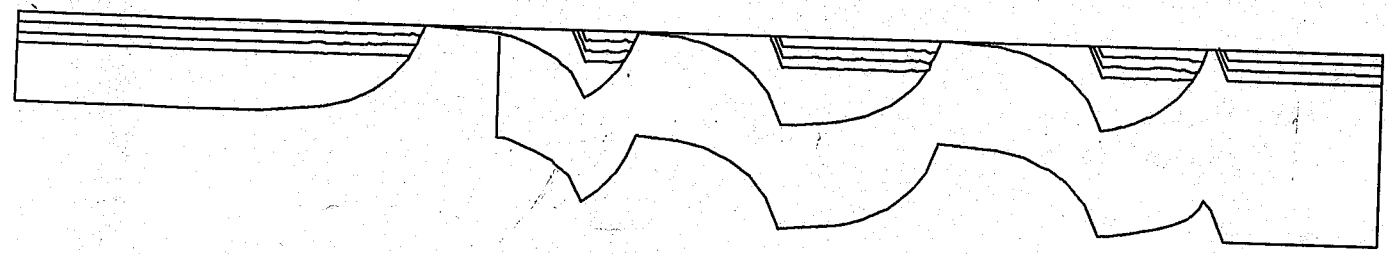
Rolling
Hinge



Plan
View



Plan View



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

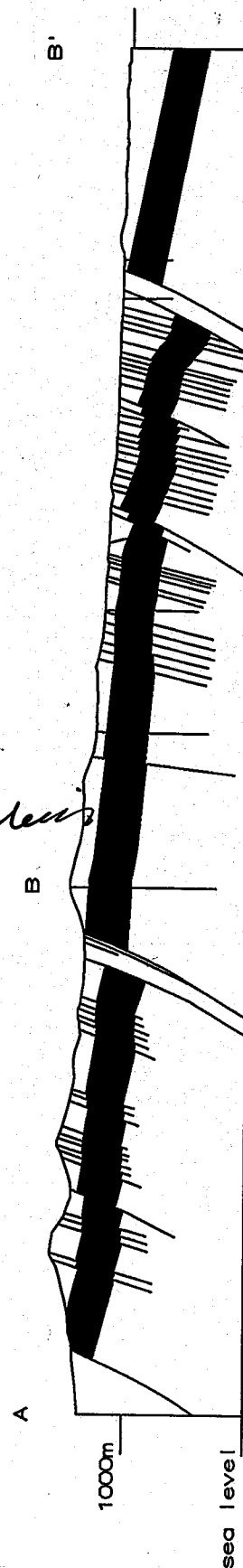
17th July 1992

Re-Digitised ABB'

plotting for alternative models work in Santa Fe

Alan
 Messing

Alan Messing



5 kilometers

Note:
Miscellaneous
Rebelling approx 15 hours
17 July - 6 Aug.

6th August - Santa Fe

Alternatives:

Vertical/oblique shear

Flat slip

Domino

"Soft domino"

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

Multiple detachments (synchr. in space)

Multiple detachments (time + space transgressive)

Rotating regional stress fields.

Far-travelled terranes (Zeeke Snow / Brian Wernicke)

Slip-tine

Alu

musi

Shrs7th August - Santa Fe.

Alan Hersh

Domino

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

Prerequisites

- 1) Simplify all fault blocks to a uniform (and consistent)

dip

Assumptions

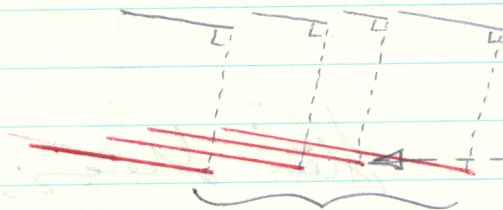
- 1) Simplest case - horizontal detachment
- 2) No antithetic faults
- 3) Max. initial fault dip = 90°

Procedure

- 1) Choose an initial depth to detachment.
- 2) Construct this thickness for each deformed state

fault block:

This gives ---

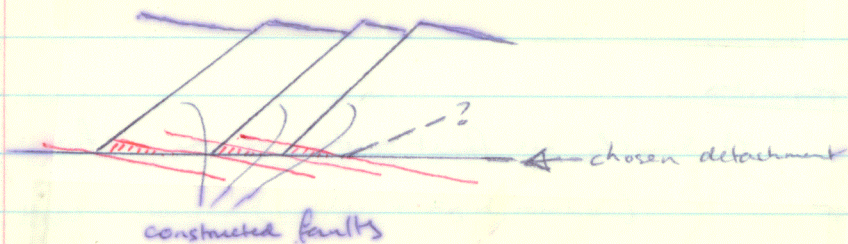


- 3) Max. depth of deformed state detachment for this example.

constructed thicknesses of fault blocks

- 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. 160)

The size of the low-cutoff "collapse" region and the dip of the rigidly rotated portion of the ho. uniquely determine the depth to detachment.

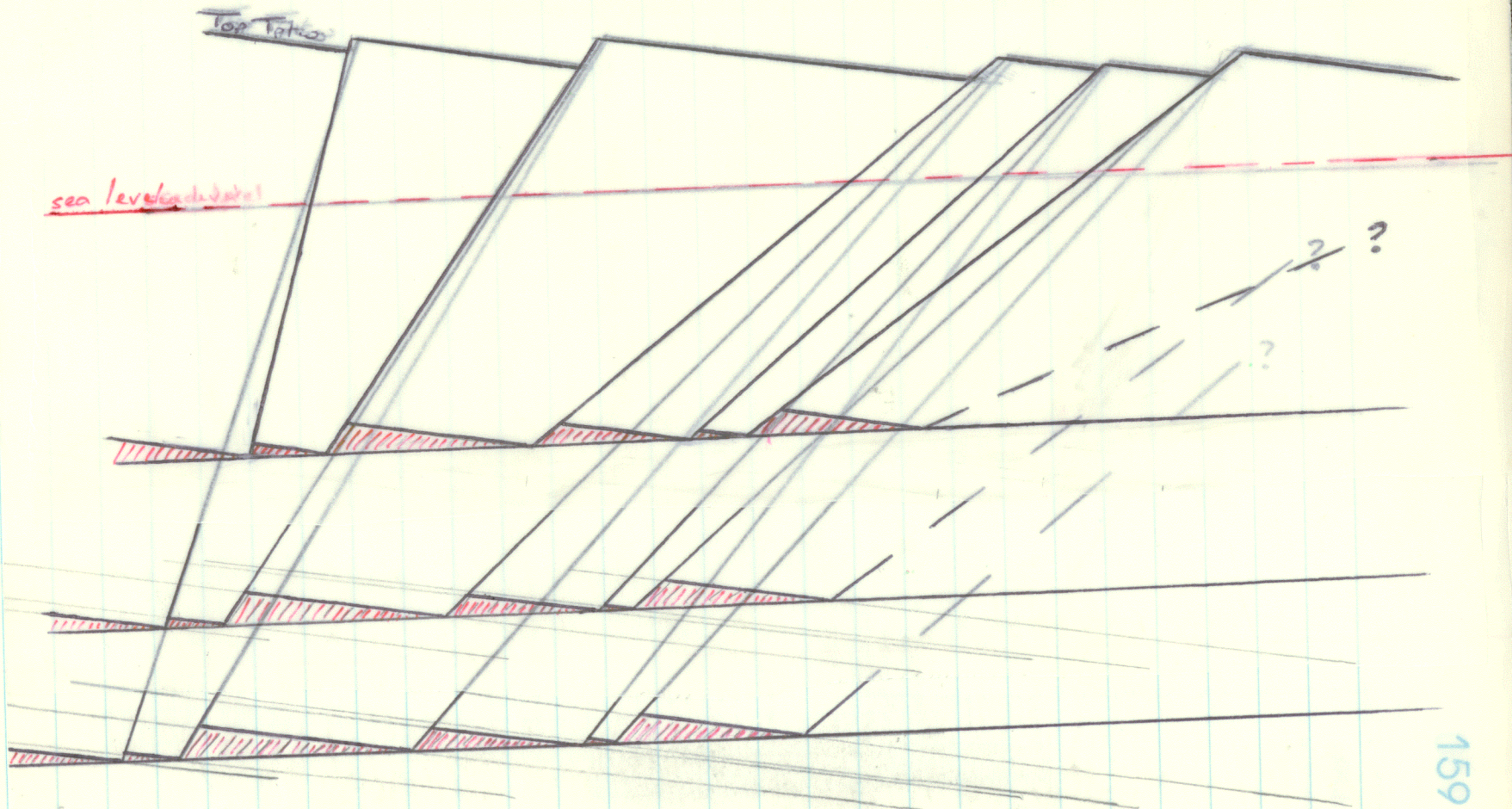
One catch - part of the fault must be a circular arc

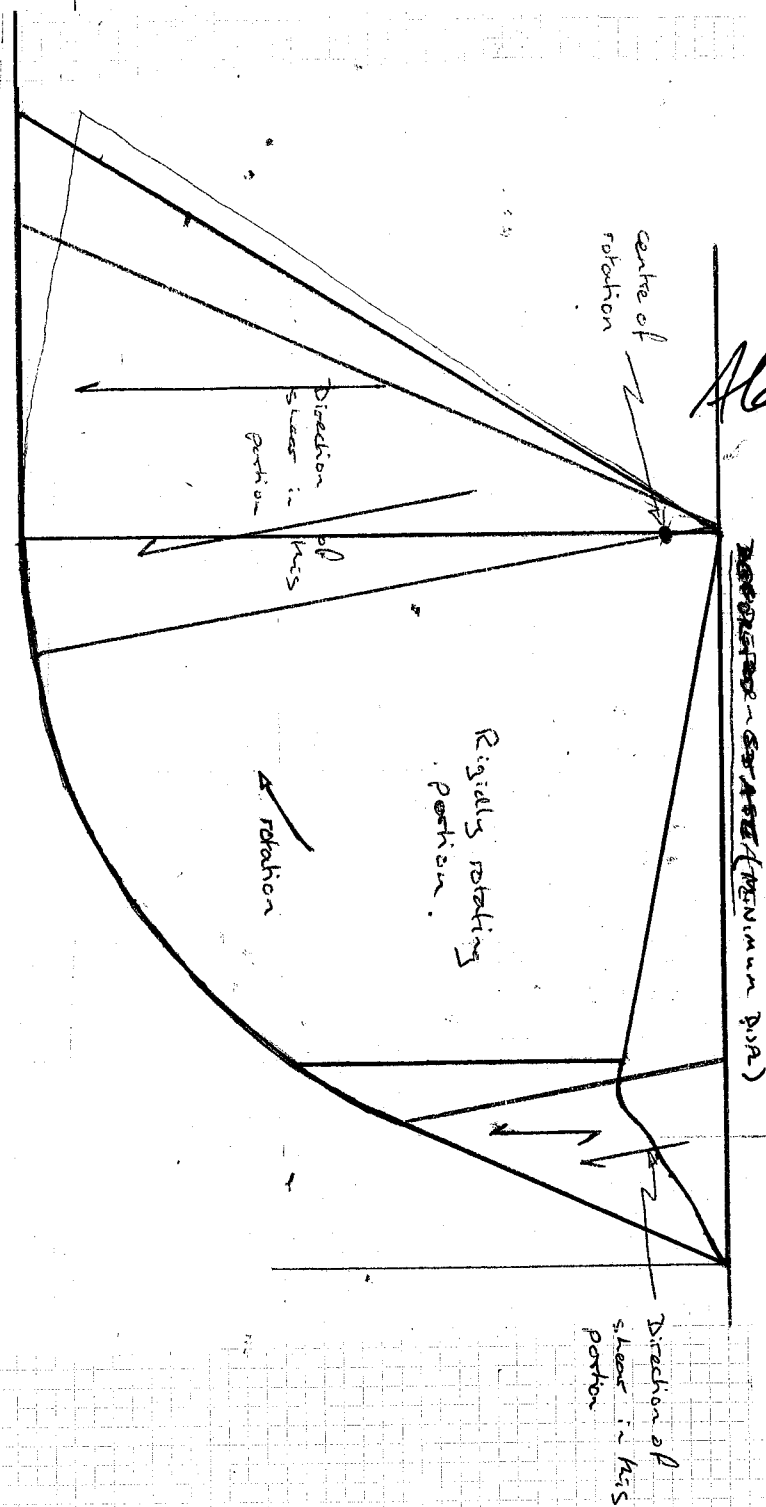
Alan Meigs

How
much

Top Tecton

sea level





Alan Morris

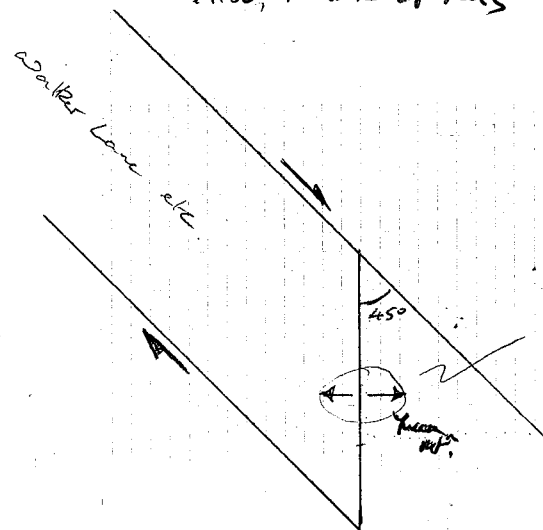
2 hrs

10th August

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

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

Also, think of this



At Yucca Mt. EW ext. is only seen, $\therefore$ faults won't be oblique slip esp. at ext. values of only 10%

Alan Morris

Howe *ill*

12-13 Aug 1992 2 hrs

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

More details on Little Skull Mt. E quake:

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?

Monday 24 Aug 1992 5 hrs

Start 9:00am
Finish 2:00pm

Alternatives
report.

508 977 3000 x 2083.
INTERVIEW

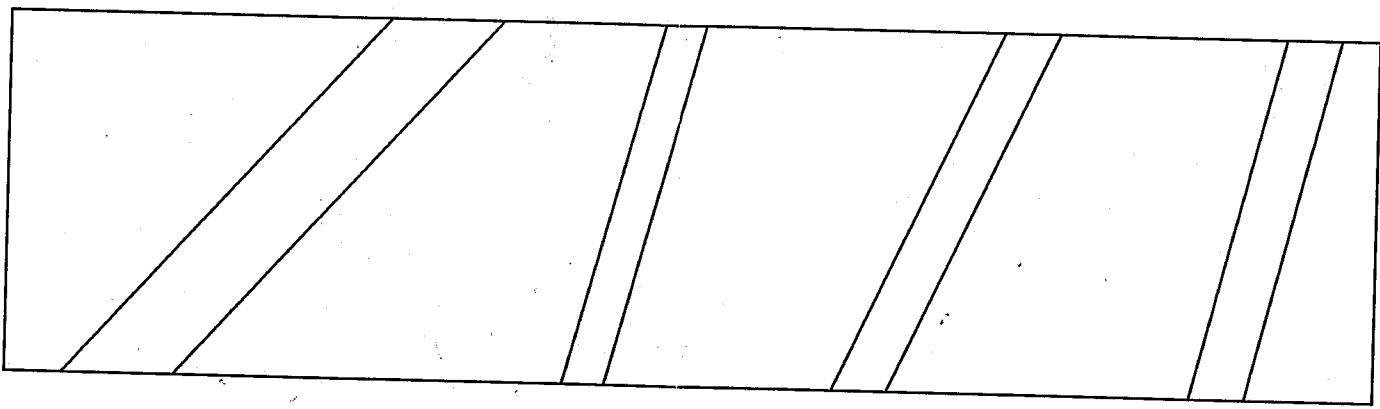
Howe *ill*

21st Aug 1992 SORI

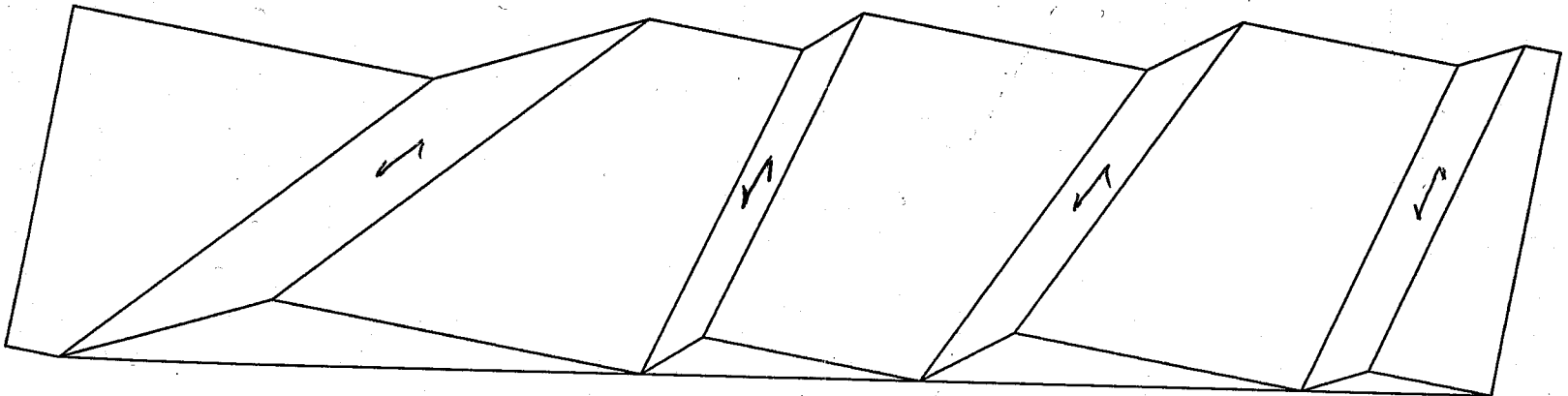
Start: 9:00am
Finish: 5:00pm

APM

Her Majesty



Hybrid-domino
(The real thing)



21st Aug 1992 SioRI

Start: 9:00am
Finish: 5:00pm

SPM

Top Tptw

Domino model, thickness = 2.5km
section ABB'

USW-H-5

USW-G-4

UE-25a-1

UE25-WT-5

UE25-WT-14

5 kilometers

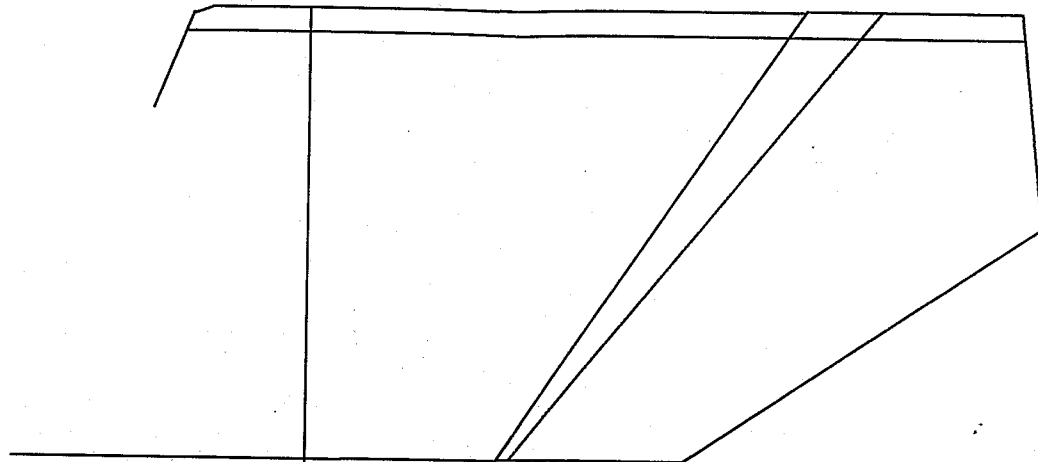


21st Aug 1992 SWRI

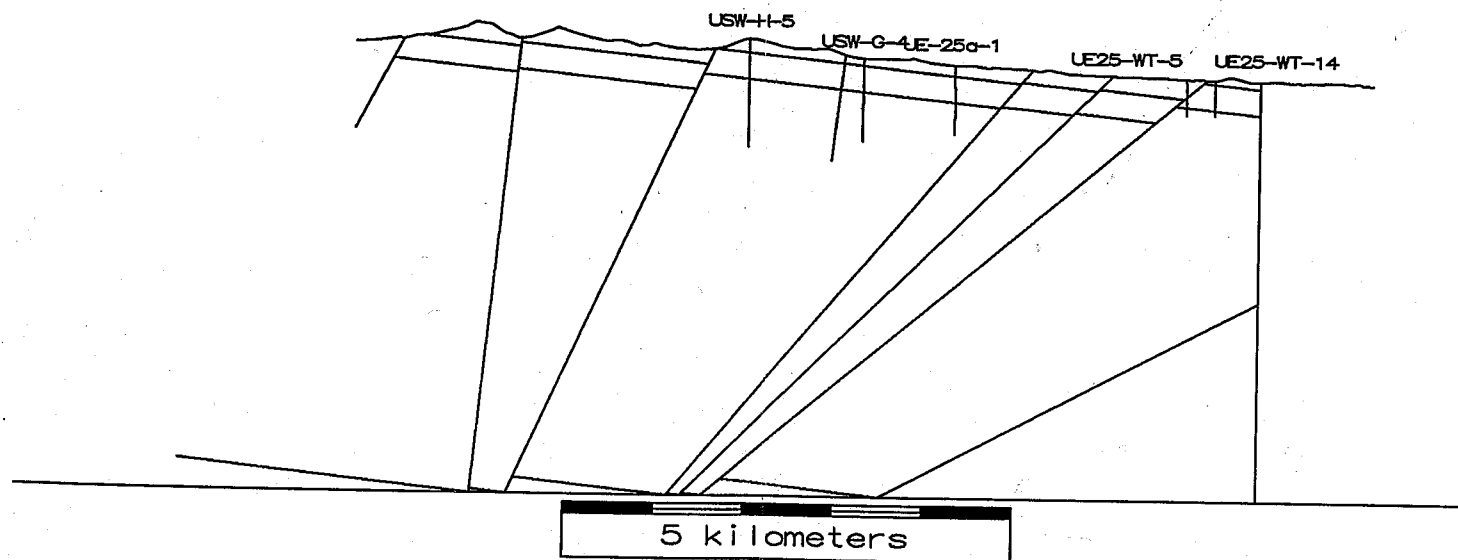
Start: 9:00am
Finish: 8:00pm

APM

Top Tptw



Domino model, thickness = 5km
section ABB'



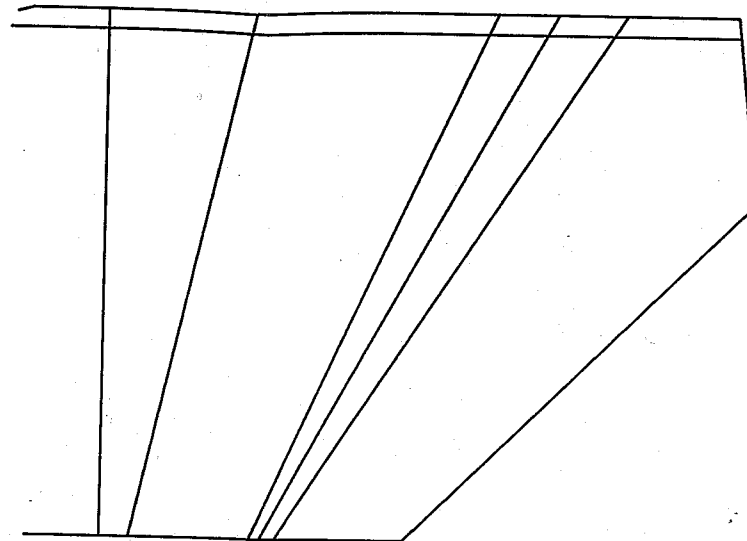
21st Aug 1992

SuRI

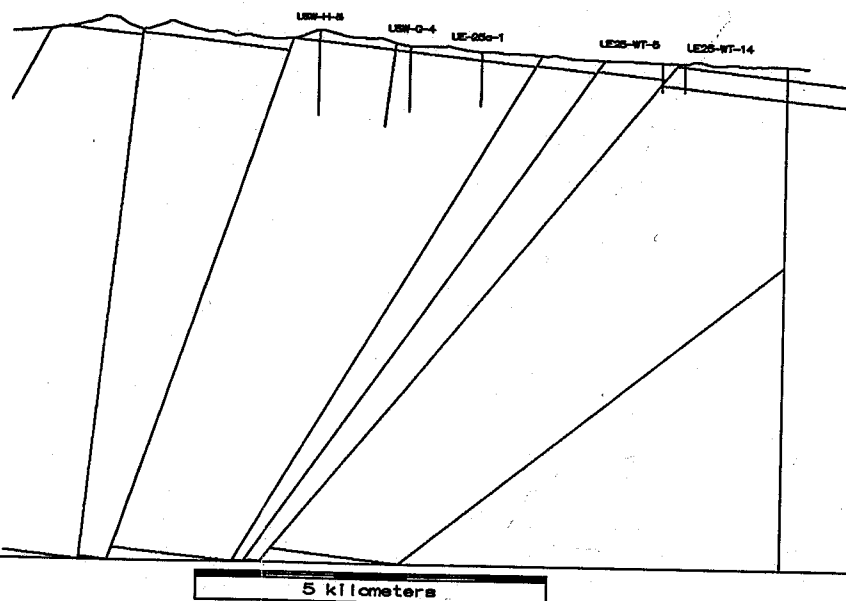
Start: 9:00am
Finish: 5:00pm

SPM

Top Tptw



Domino model, thickness = 7.5 km
section ABB'

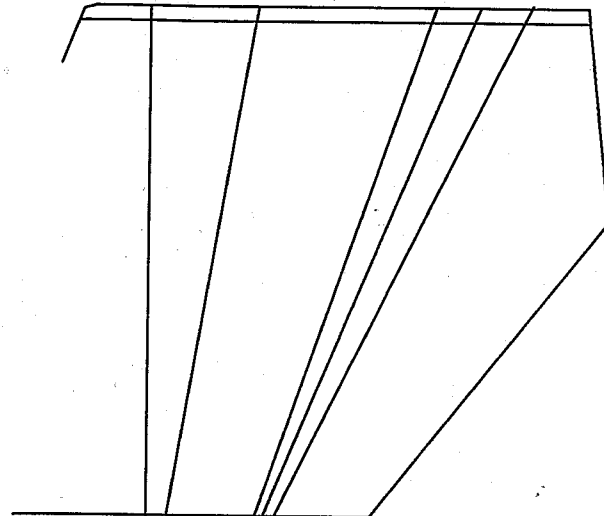


21st Aug 1992 SioRI

Start: 9:00am
Finish: 5:00pm

SPM

Top Tptw



Domino model, thickness = 10km
section ABB'

