CNWRA *A center of excellence in earth sciences and engineering*

A Division of Southwest Research Institute™
6220 Culebra Road • San Antonio, Texas, U.S.A. 78228-5166
(210) 522-5160 • Fax (210) 522-5155

September 27, 2002
Contract No. NRC–02–97–009
Account No. 20.01402.471

U.S. Nuclear Regulatory Commission
ATTN: Mrs. Deborah A. DeMarco
Office of Nuclear Material Safety and Safeguards
Mail Stop 8 A23
Washington, DC 20555-0001

Subject: Submittal of Slides for Three Presentations: (i) Tectonic Implications of Oligocene and Lower Miocene Strata in the Yucca Mountain, Nevada Region; (ii) Tectonic Setting of Yucca Mountain, Nevada, in Evaluations of Fault, Earthquake, and Volcanic Hazards; and (iii) Vertical and Inclined Axis Rotations in Extensional Settings

Dear Mrs. DeMarco:

The purpose of this letter is to transmit the subject material for programmatic review. These will be presented at the Geological Society of America Annual Meeting and Exposition to be held October 27–30, 2002, in Denver, Colorado.

This material documents work that has led to a better understanding of the tectonic setting of Yucca Mountain and provides fundamental components in the evaluation of the volcanic and seismic hazards at Yucca Mountain.

Should you have any questions regarding this please contact Dr. John Stamatakos at 210-522-5247 or Dr. Lawrence McKague at 210-522-5183.

Sincerely,

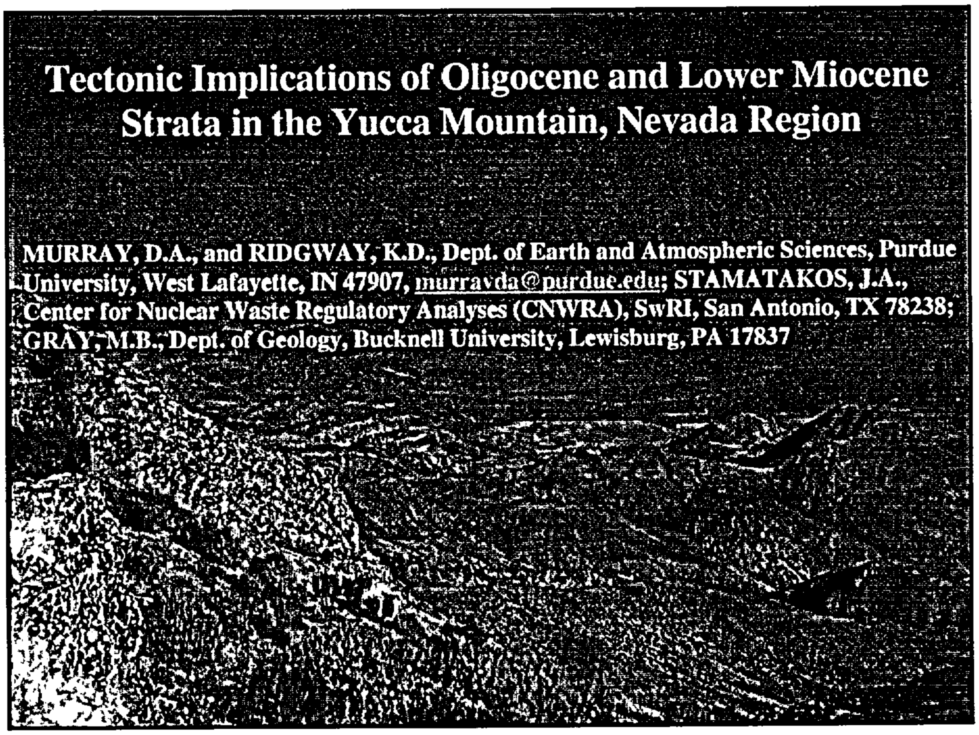
Budhi Sagar
Technical Director

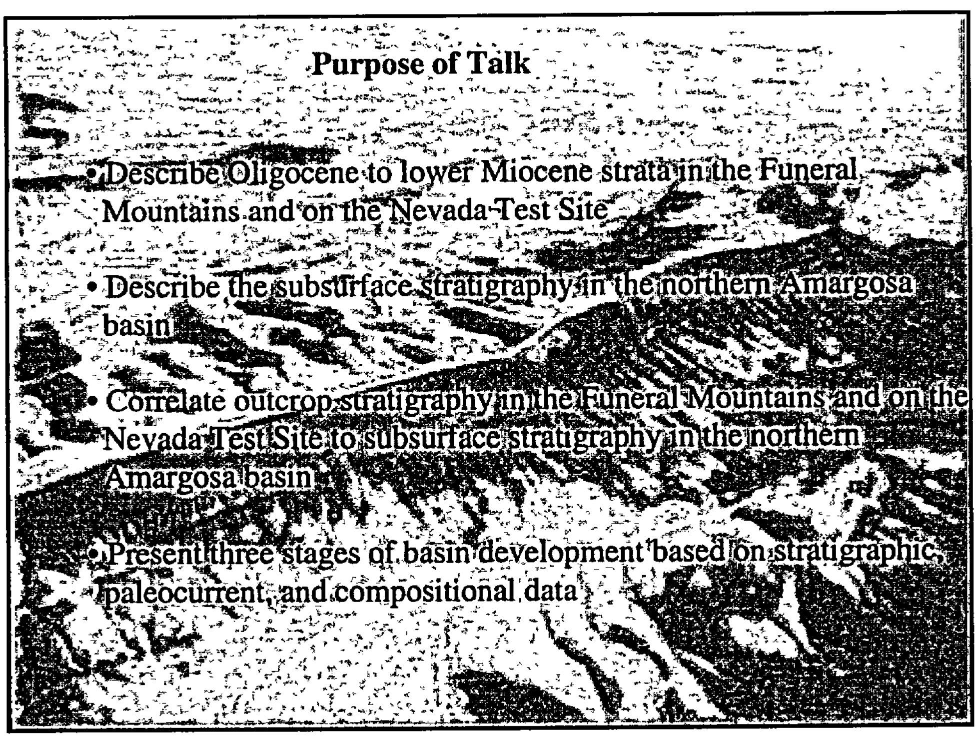
rae
Attachment

cc: J. Linehan, W. Reamer, J. Schlueter, D. Riffle, B. Meehan, J Greeves, K. Stablein, S Wastler, C. Trottier, L. Campbell, P. Justus, W. Patrick, CNWRA Dirs/EMs (ltr only), J. Stamatakos, D. Ferrill, D. Sims, T. Nagy (SwRI Contracts)

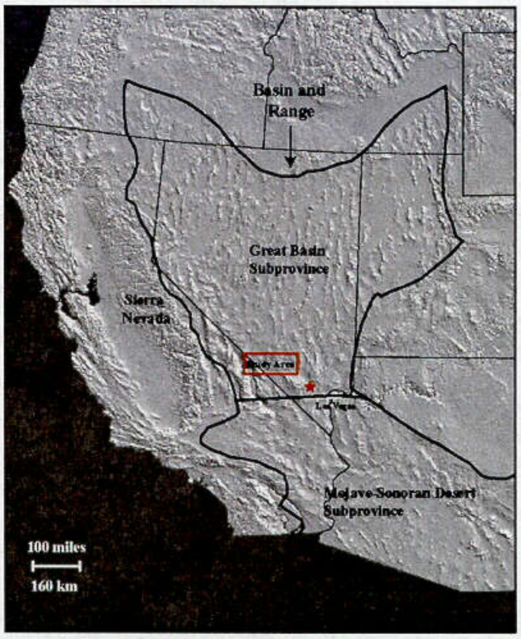
D:\GLGP Group\letters\sds\gsa-presentations-09-27-2002.wpd

Washington Office • Twinbrook Metro Plaza #210
12300 Twinbrook Parkway • Rockville, Maryland 20852-1606

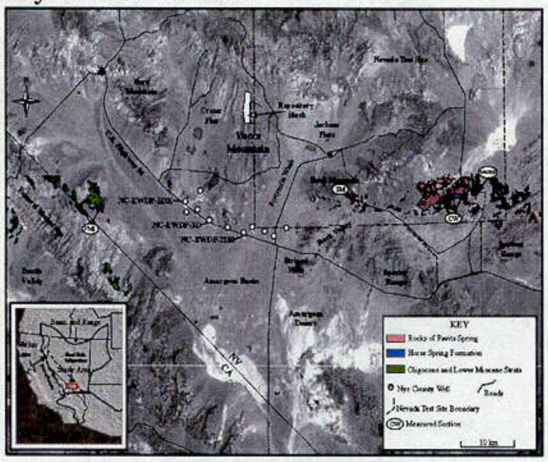

Tectonic Implications of Oligocene and Lower Miocene Strata in the Yucca Mountain, Nevada Region
MURRAY, D.A., and RIDGWAY, K.D., Dept. of Earth and Atmospheric Sciences, Purdue University, West Lafayette, IN 47907, murravda@purdue.edu; STAMATAKOS, J.A., Center for Nuclear Waste Regulatory Analyses (CNWRA), SwRI, San Antonio, TX 78238; GRAY, M.B., Dept. of Geology, Bucknell University, Lewisburg, PA 17837

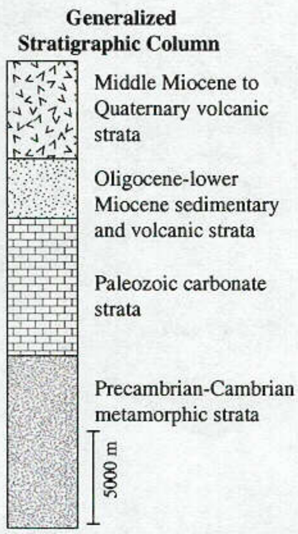

Purpose of Talk
• Describe Oligocene to lower Miocene strata in the Funeral Mountains and on the Nevada Test Site
• Describe the subsurface stratigraphy in the northern Amargosa basin
• Correlate outcrop stratigraphy in the Funeral Mountains and on the Nevada Test Site to subsurface stratigraphy in the northern Amargosa basin
• Present three stages of basin development based on stratigraphic, paleocurrent, and compositional data

Study area is located in the Great Basin of the Basin and Range Province



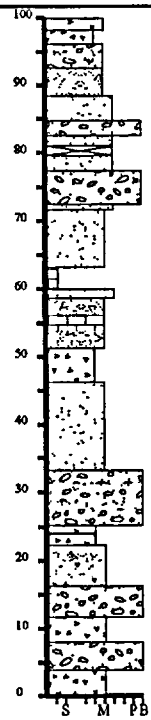
Satellite Image of Study Area Showing Outcrops of Oligocene and Early Miocene Strata



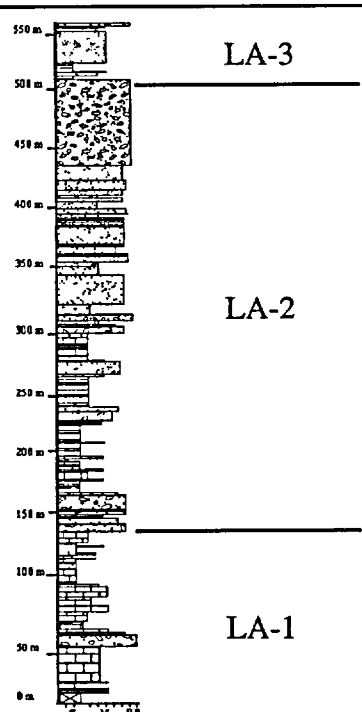


- Stratigraphic position suggests that they are correlative to Oligocene-lower Miocene strata
- Outcrops were studied to see if a correlation could be drawn between outcrop and subsurface strata

C01



- Outcrop data were collected through measuring stratigraphic section
- Data consists of thickness of section, description of lithologies, sedimentary structures, and paleocurrent data
- In the Funeral Mountains, 800 m of section was measured
- On the Nevada Test Site 1100 m of section was measured



Outcrop Data Indicate Three Lithofacies Associations

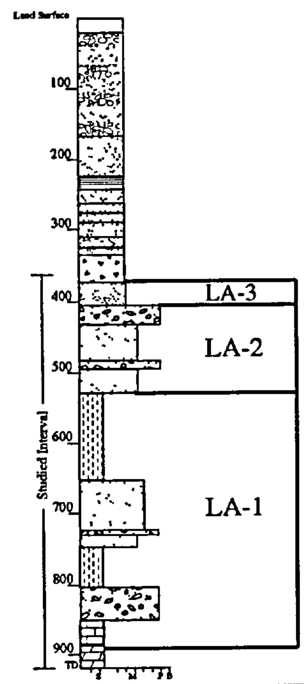
LA-3. Upper part of the section dominated by Tuff and volcaniclastic sandstone

LA-2. Middle part of the section dominated by red clast-supported conglomerate and red fine-to-coarse-grained sandstone

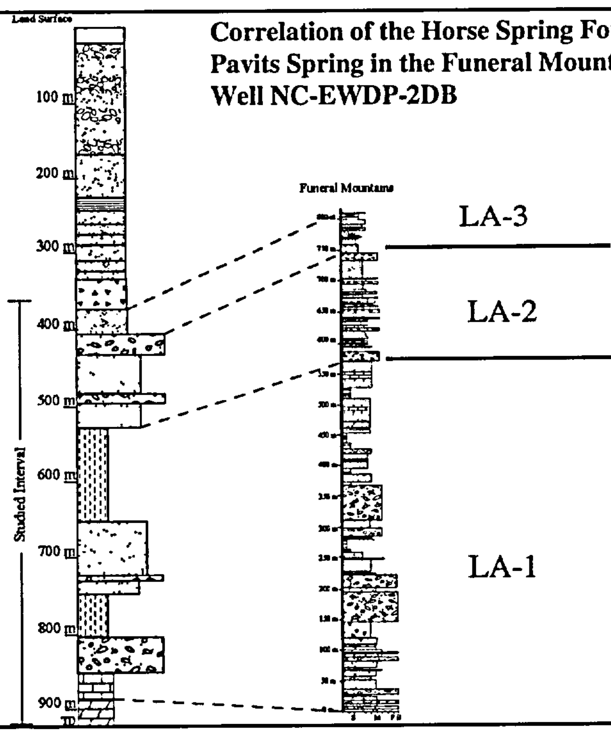
LA-1. Lower part of the section dominated by white to brown fossiliferous limestone and matrix supported conglomerate

Stratigraphic column of well cuttings from Well NC-EWDP-2DB

- Well NC-EWDP-2DB was the only well drilled into Paleozoic strata
- Three lithostratigraphic units were recognized in the subsurface stratigraphy.
- Lithologic similarities in the subsurface and outcrop strata indicate that they can be correlated.



Correlation of the Horse Spring Formation and the Rocks of Pavits Spring in the Funeral Mountains to the stratigraphy in Well NC-EWDP-2DB

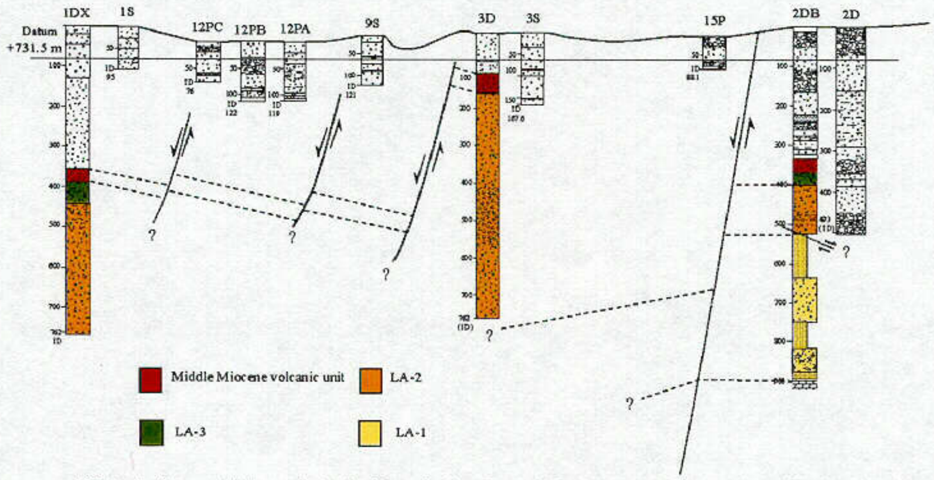


Tuff and volcaniclastic sandstone

Red sandstone and red conglomerate with quartzite and carbonate clasts

White to brown fossiliferous limestone and matrix-supported conglomerate

Structural Cross Section Through Nye County Wells



Lithologies for unstudied intervals obtained from the Nye County Nuclear Waste Repository Project Office (2000)

Main points of cross section:
- Complexity of subsurface in Yucca Mountain area
- Changes in thickness of units and discontinuous units imply that faults exist in the subsurface

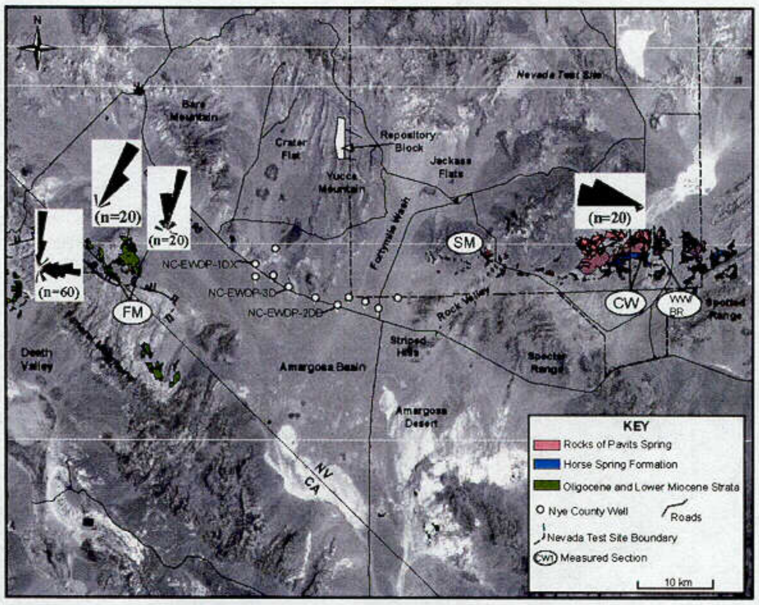
Conclusions from Correlation

- The Oligocene to lower Miocene strata can be divided into three lithostratigraphic units
- These three lithostratigraphic units can be correlated at least 120 km
- The Oligocene to lower Miocene strata are an important component of the subsurface stratigraphy in basins adjacent to Yucca Mountain
- Recognition of the thickness, lateral extent and heterogeneity of these strata is important to the development of an accurate depiction of the subsurface geology and more reliable models of groundwater flow and transport

Oligocene-early Miocene Basin Development in southwestern Nevada and Southeastern California

By studying trends in stratigraphic and sedimentological data we were able to:

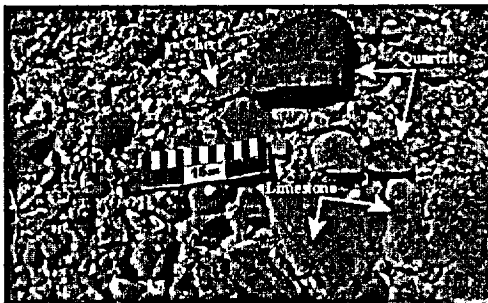
1. Identify provenance for sandstone and conglomerate in the basinal strata
2. Define a three-part model of Oligocene-early Miocene basin development for southwestern Nevada and southeastern California



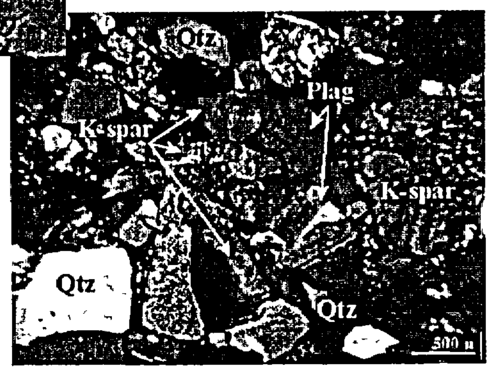
Eastward and westward paleocurrent directions indicate that the Funeral Mountains and the Nevada Test Site may represent the western and eastern margins of the paleobasin.

C03

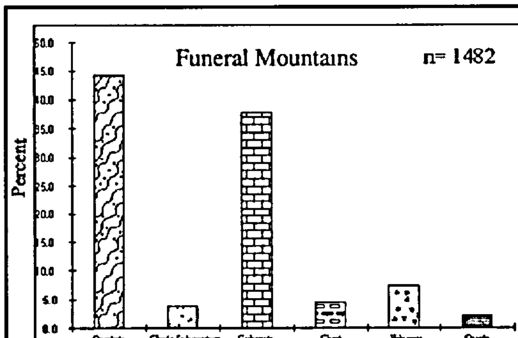
Provenance Data From:

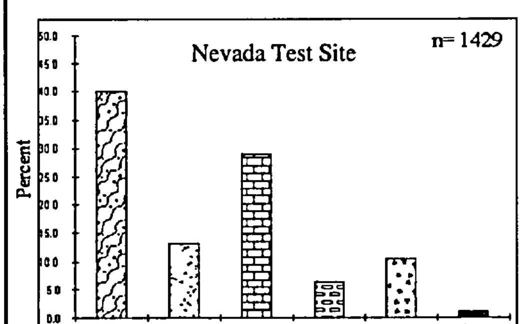


Conglomerate clast count data

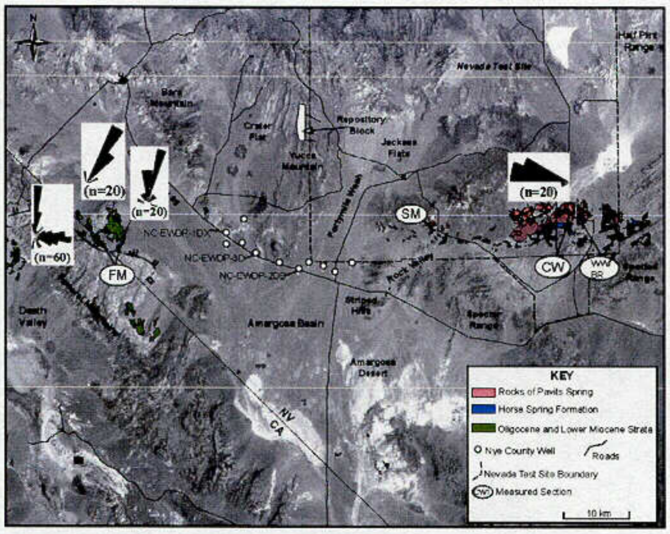


Sandstone point count data



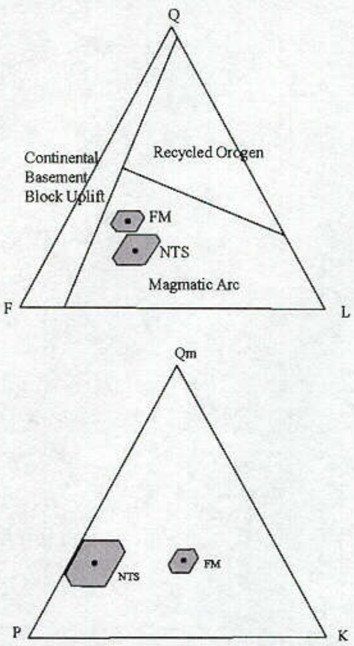


The conglomerate clast composition in the Funeral Mountains and on the Nevada Test Site is dominated by quartzite and carbonate.



- The source of the conglomerate clasts is interpreted to be Precambrian and Paleozoic quartzite and carbonate units
- These units are exposed in the Funeral Mts., Bare Mt., and the Spotted Range

Sandstone Point Count Data

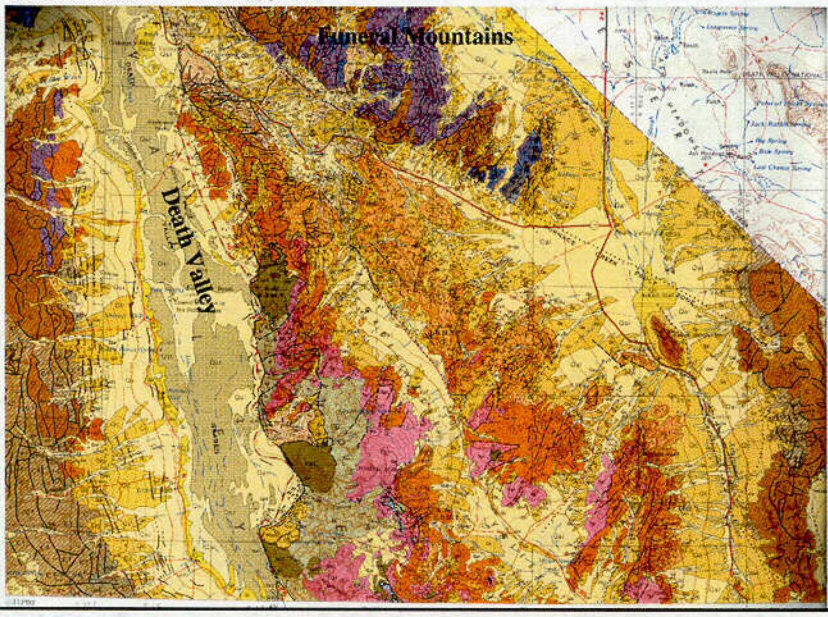


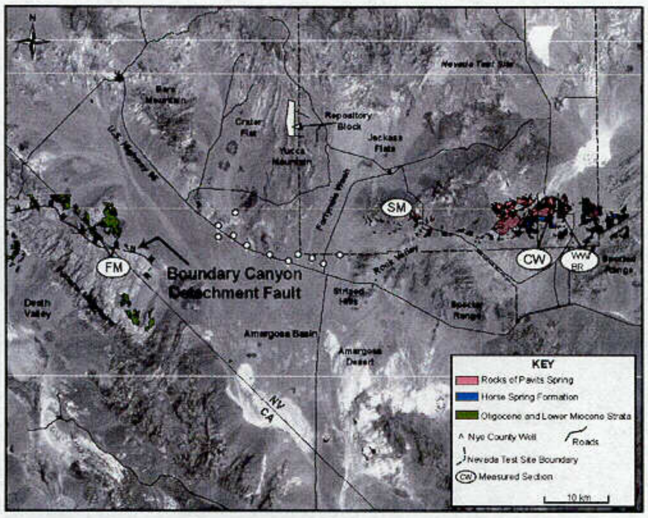
- The framework grain composition in the sandstone samples is dominated by feldspar
- In the Funeral Mountains samples plagioclase and K-spar are present in approximately equal proportions
- In the Nevada Test Site samples, plagioclase feldspar is more common
- The sandstone is interpreted to have a volcanic and a plutonic source terrane

C04

Potential Plutonic Source Terrane for Sandstone Samples

Modified from Streitz and Stinson, 1974

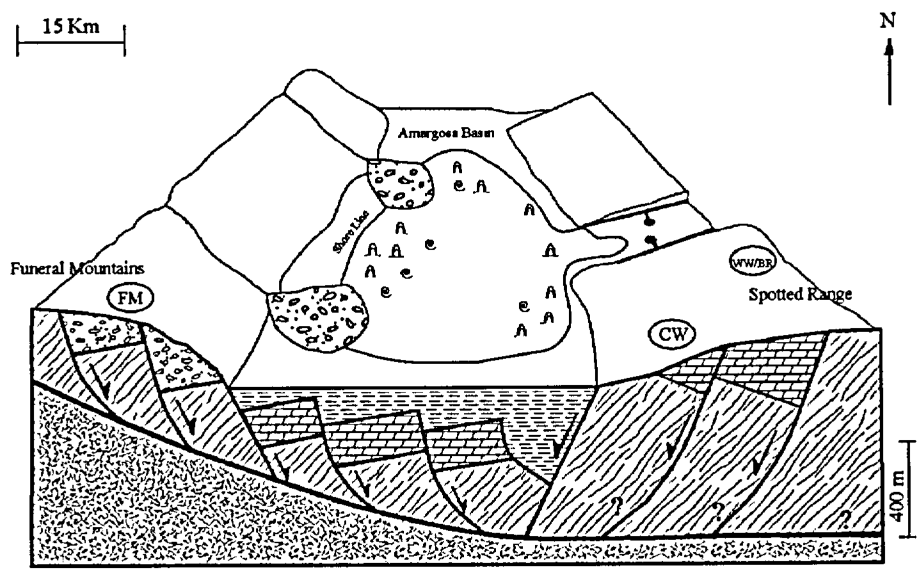




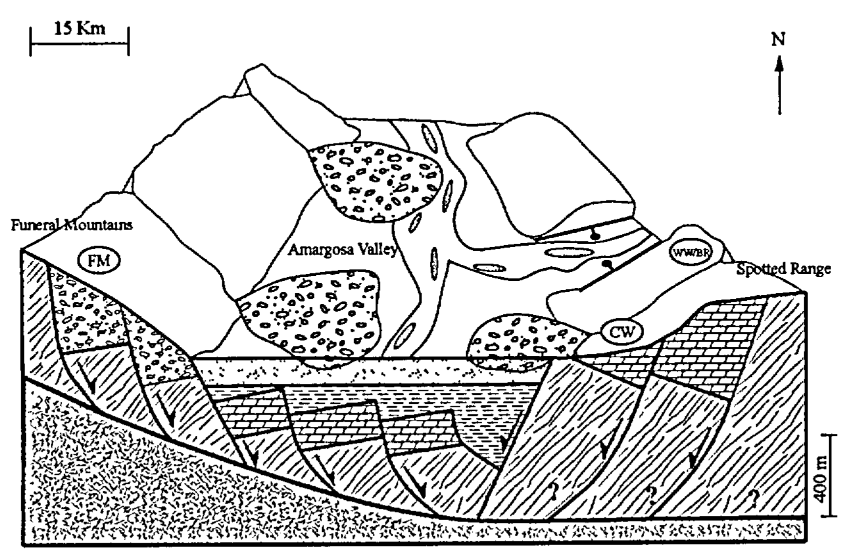
- Model of basin development based on stratigraphic, provenance, and compositional data
- The stratigraphic data indicate that basin development is related to detachment faulting
- Possibly an early detachment fault in the region of the Boundary Canyon detachment

C05

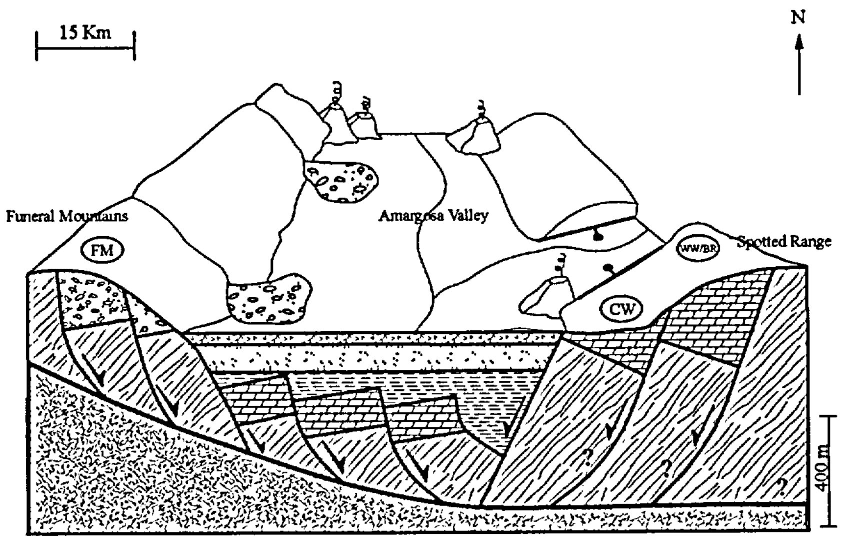
Paleogeographic Reconstruction: Oligocene-early Miocene



Paleogeographic Reconstruction: Early Miocene



Paleogeographic Reconstruction: Late-early Miocene

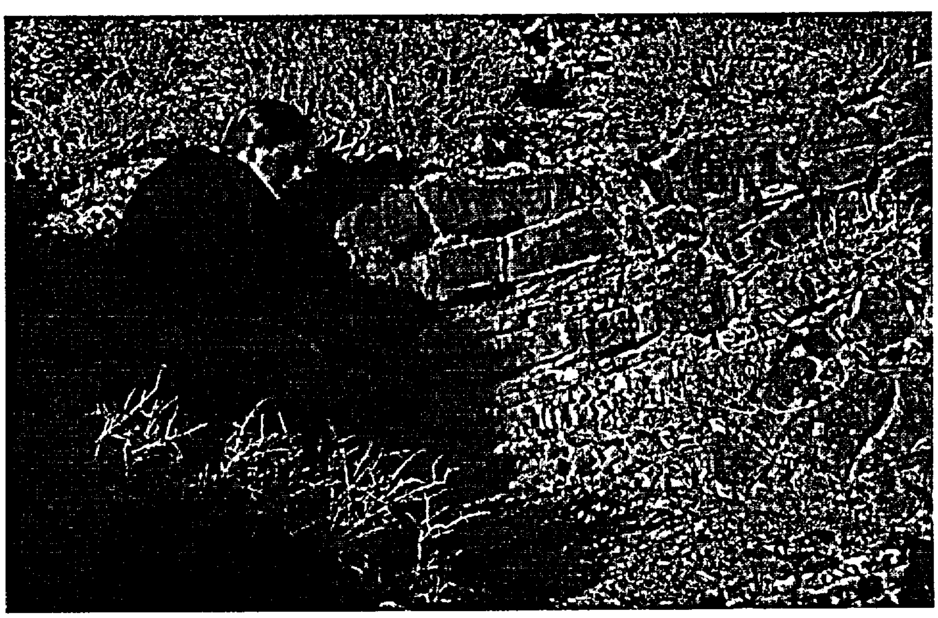


Conclusions

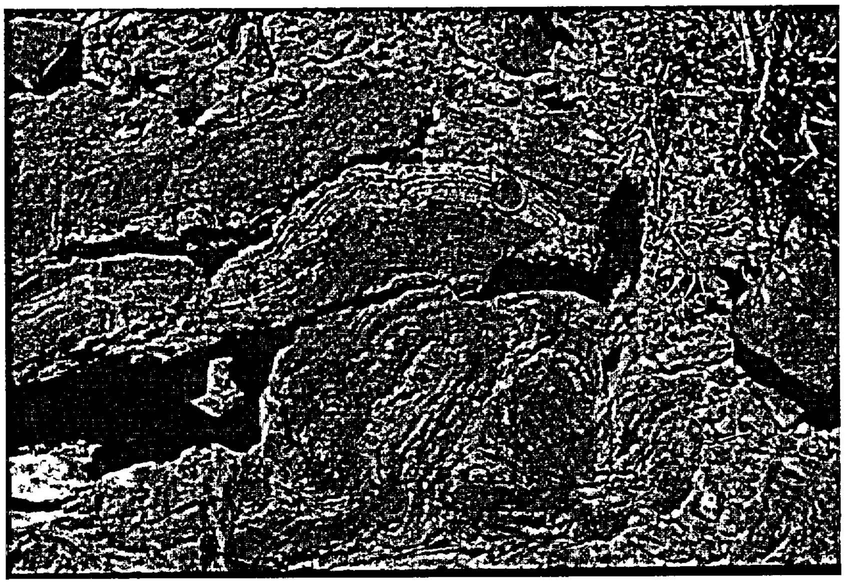
- The Oligocene-lower Miocene strata can be divided into three lithostratigraphic units and correlated at least 120 km in southwestern Nevada and southeastern California
- These three lithostratigraphic units correspond to three stages of extensional basin development and were deposited by a combination of lacustrine, alluvial fan, fluvial, and volcanic systems
- Compositional data indicate two distinct source terranes for basinal strata, and paleocurrent data indicate that the Funeral Mountains and the Nevada Test Site represent the western and eastern margins of the paleobasin
- Recognition of the lateral extent and thickness of these units is important for the development of reliable models of groundwater flow away from a potential repository at Yucca Mountain

Back Up Slides

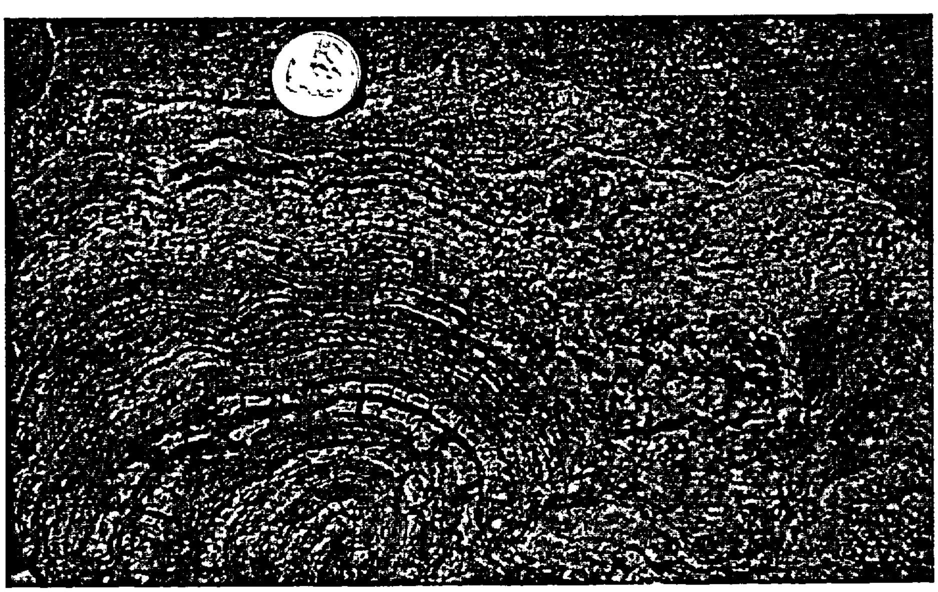
Lithofacies Association 1



Lithofacies Association 1

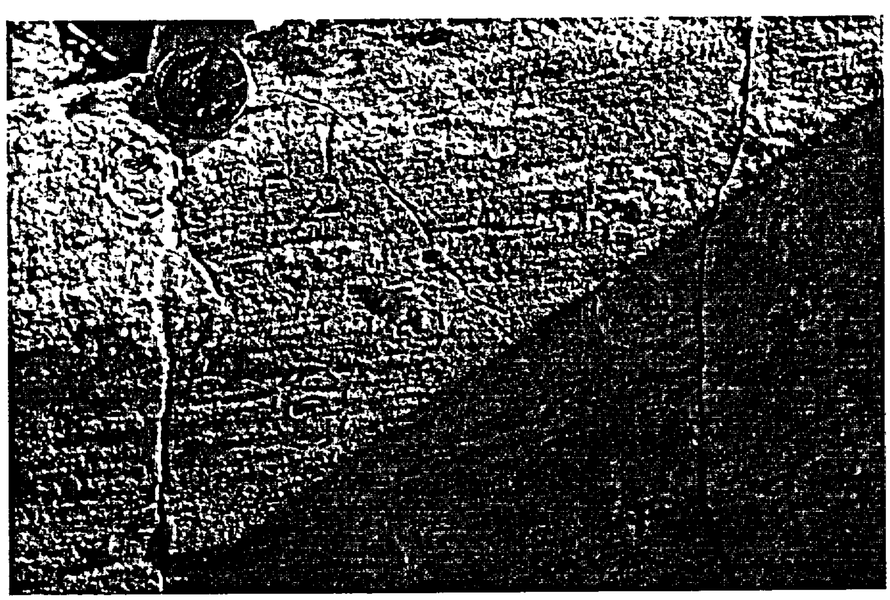


Lithofacies Association 1

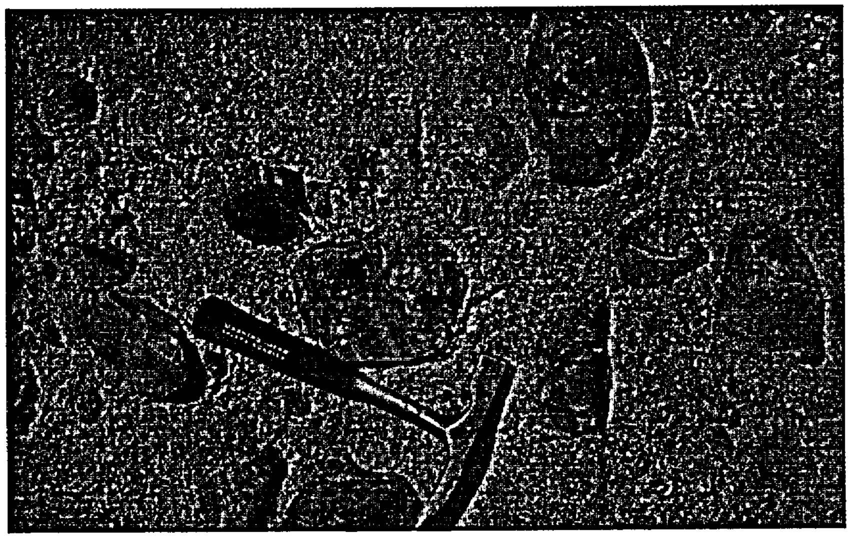


Lithofacies Association 1

Lithofacies Association 1

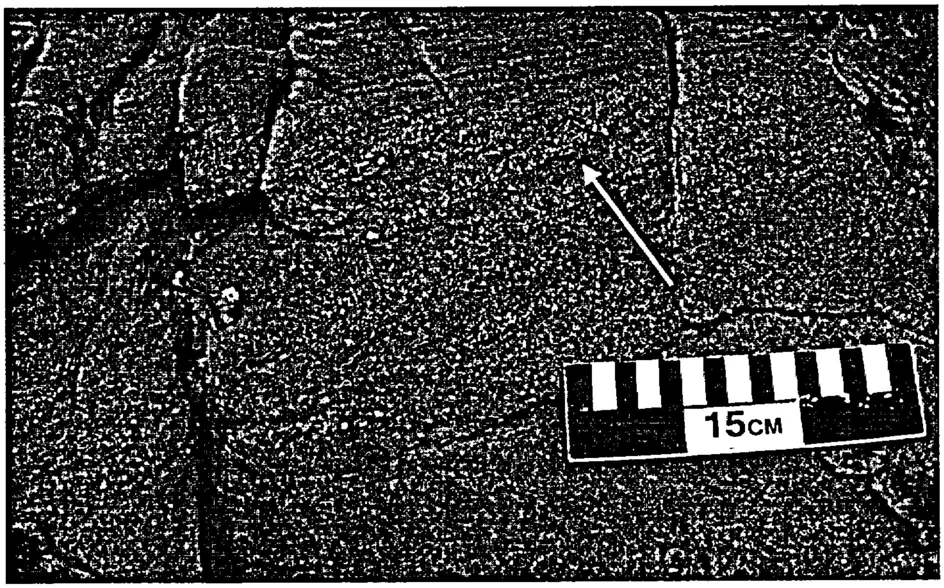


Lithofacies Association 1

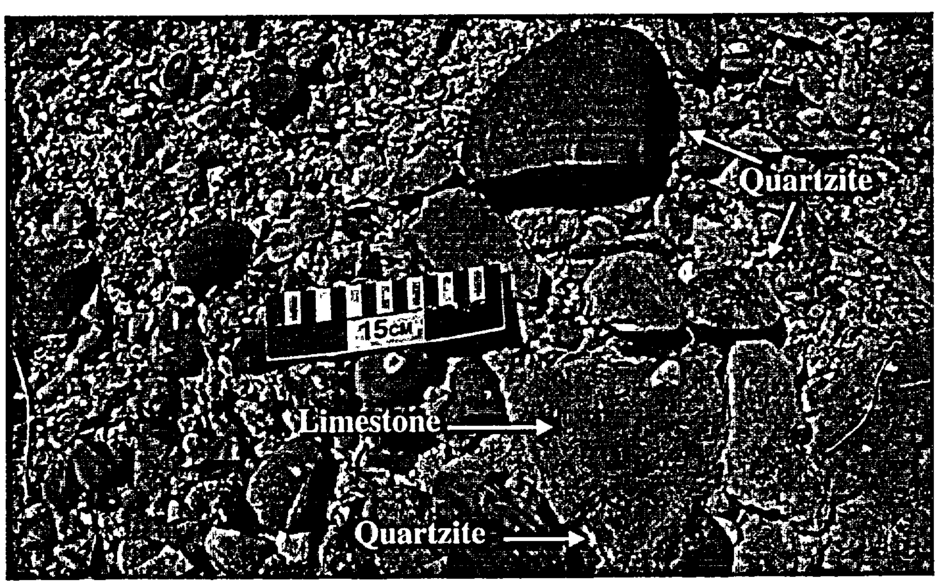


Lithofacies Association 2

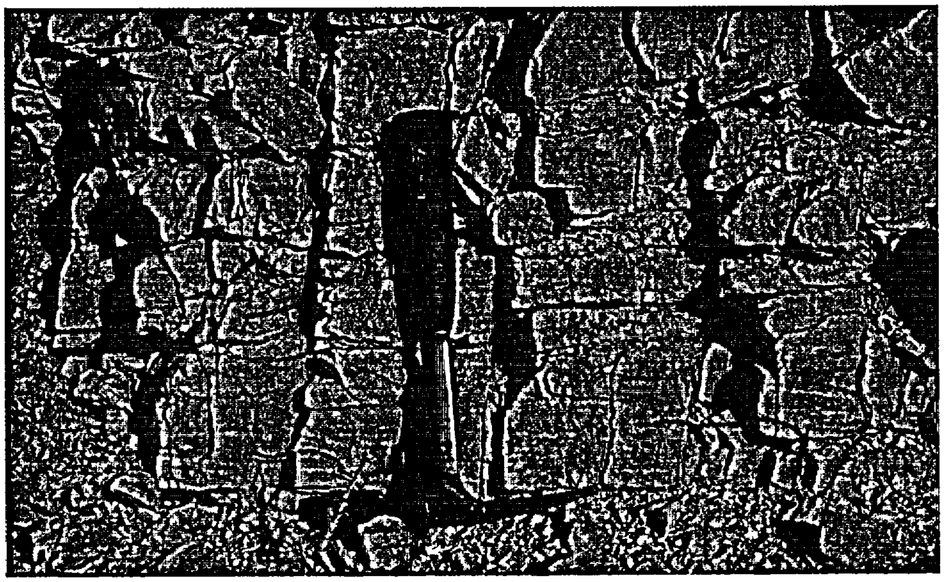
Lithofacies Association 2



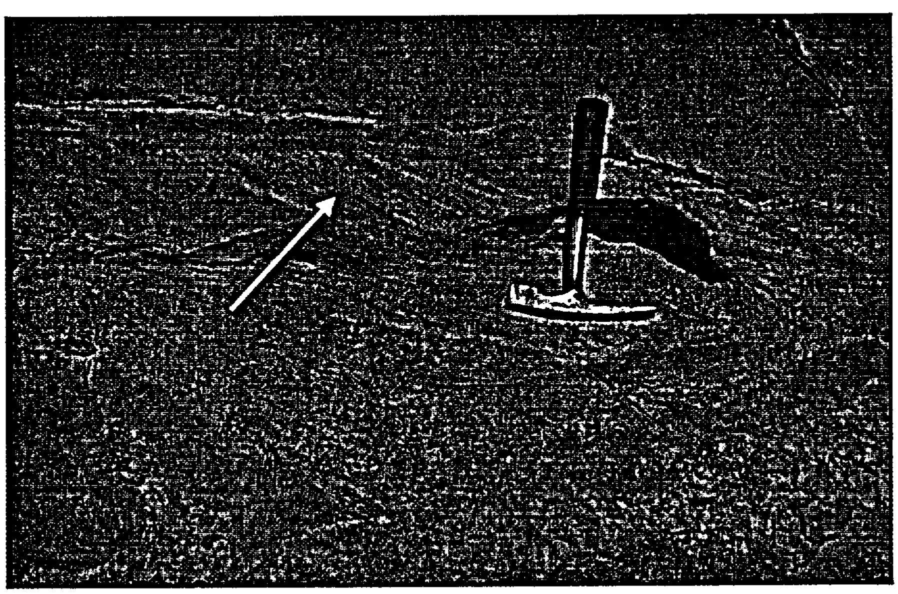
Lithofacies Association 2



Lithofacies Association 3

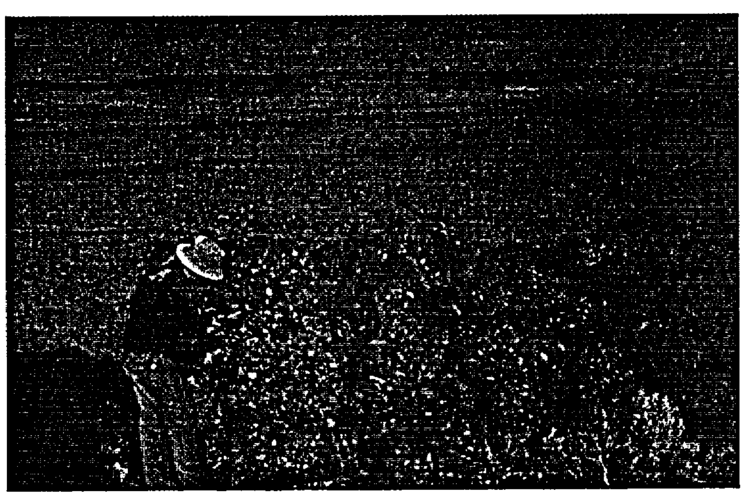


Lithofacies Association 3

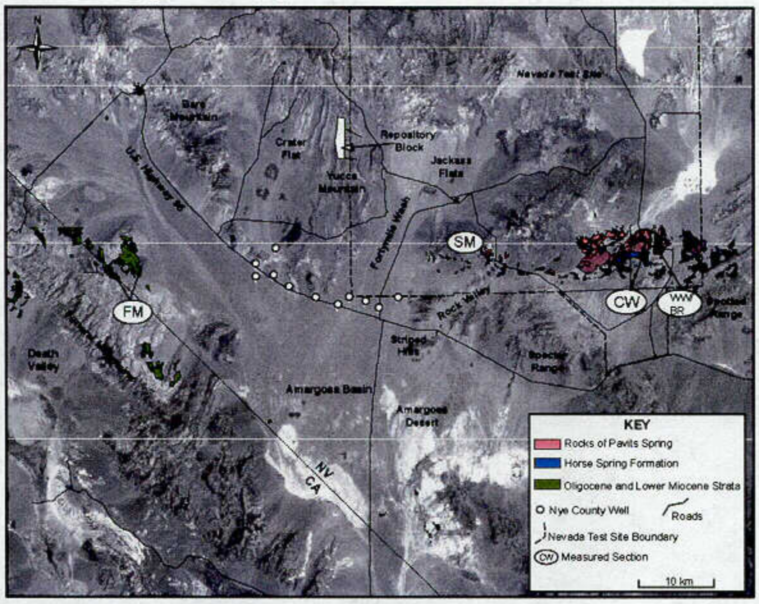


Paleocurrent Data

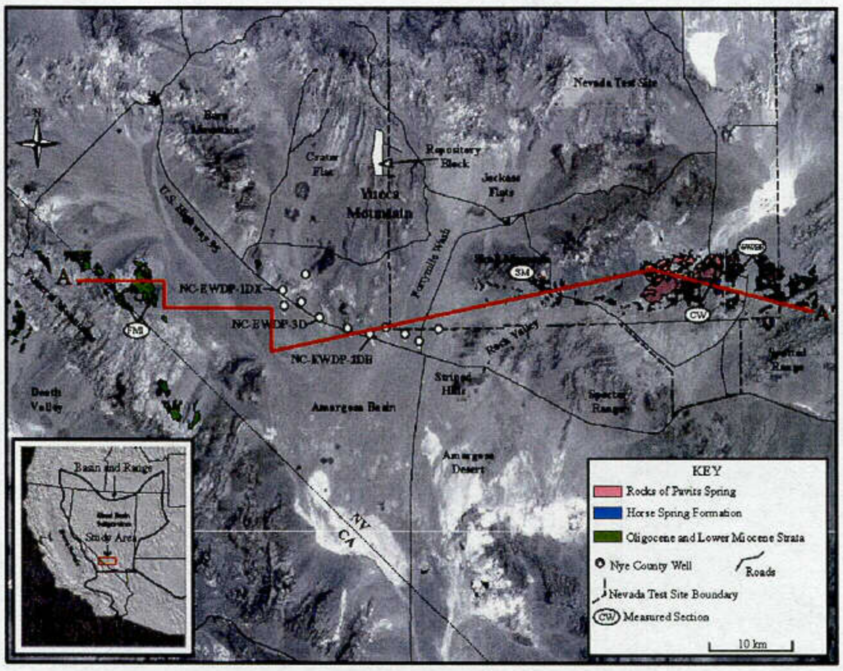
Three locations in the Funeral Mountains and one location on the Nevada Test Site



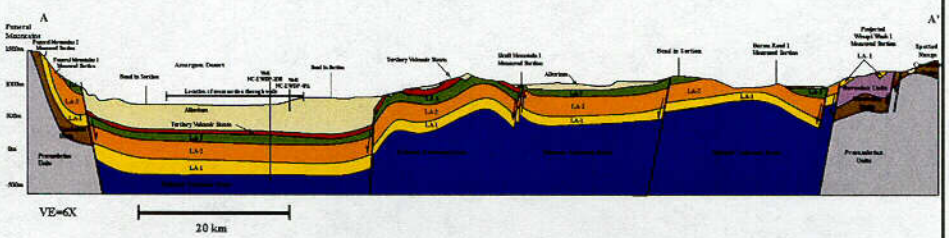
Satellite Image of Study Area



C06



Interpretive Regional Cross Section from A-A'



- Focus of cross section is Oligocene-lower Miocene strata
- Lithofacies associations are a major component of subsurface strata
- Lithofacies associations are regionally extensive

C07

Tectonic Setting of Yucca Mountain, Nevada, in Evaluations of Fault, Earthquake, and Volcanic Hazards

John A. Stamatakos

Center for Nuclear Waste Regulatory Analyses,
Southwest Research Institute®, San Antonio, Texas

CNWRA

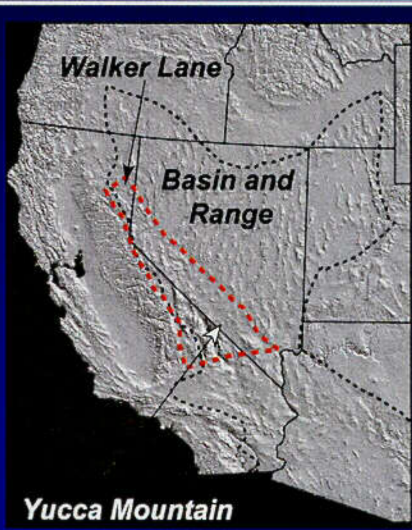
GSA 2002

Outline

- Review of Yucca Mountain models
- Incorporation into PSHA
- Review of some existing models
- New data and model for Crater Flat
- What's next

Classes of Tectonic Models Proposed for Yucca Mountain

- Volcano-genic
  - Miocene silicic volcanism or continental rifting
- Extension
  - normal and low-angle detachment faulting
- Dextral Shear
  - pull-aparts



Volcano-Genic

- Collapsed Caldera in Crater Flat
- Kawich-Greenwater Rift

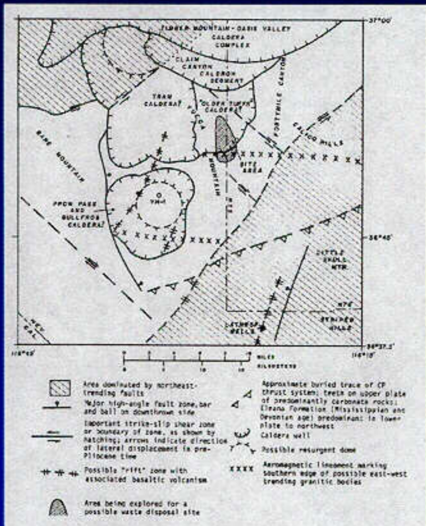
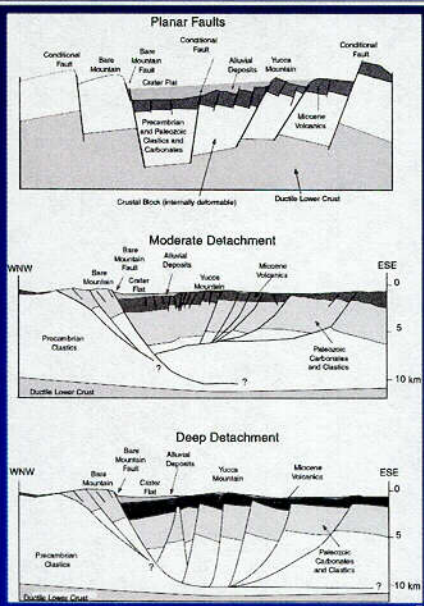


Figure 4.--Tectonic diagram of Crater Flat region, showing structural setting of proposed calderas, major-thrust and strike-slip fault zones, and basalt "rift" zones.

C08

Extensional

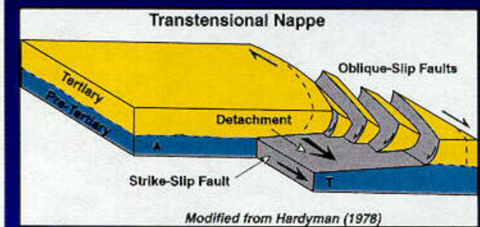
- **Listic Normal Faults**
- **Planar Block Faults**
- **Regional Detachments**



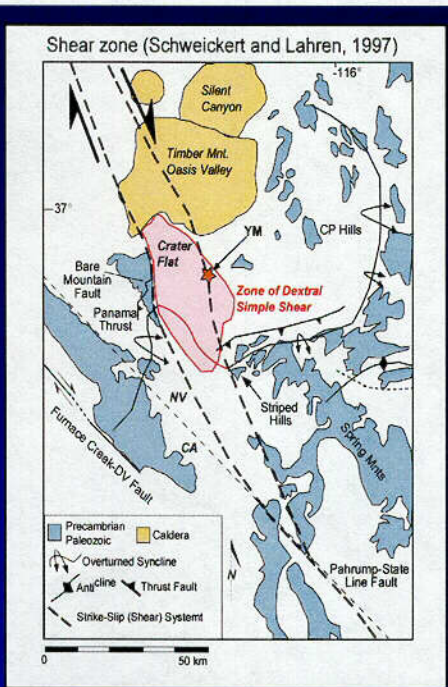
5

Dextral Shear

- **Amargosa Desert Fault System**



- **Pull-Apart Basins, Rhombocasm, Sphenocam**



6

C09

Tectonic Models Based on Voluminous Data

- structural
- stratigraphic
- geochemical
- paleomagnetic
- radiometric
- seismic
- gravity
- magnetic
- borehole
- geomorphic
- paleoseismic
- earthquake
- geodetic
- chronological
- electromagnetic
- hydrologic
- petrologic
- petrophysical

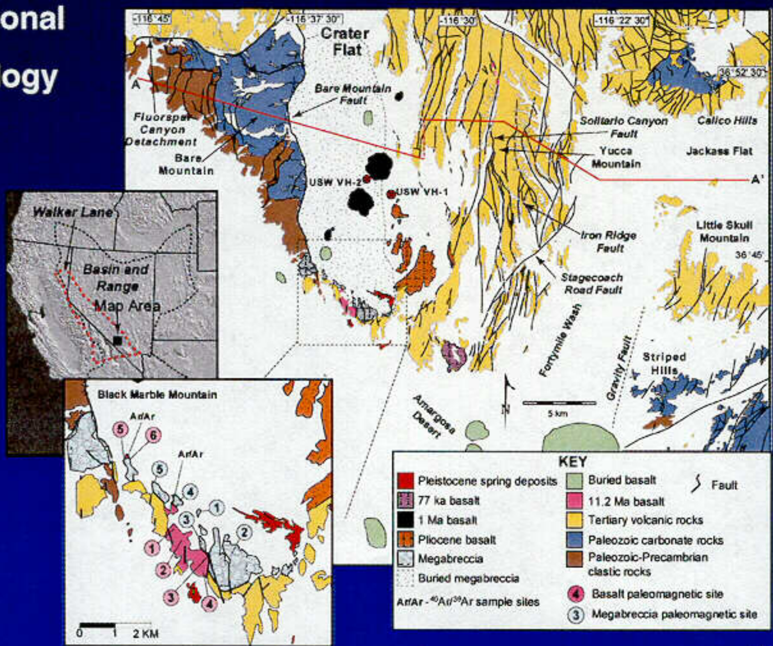
Incorporation of Models into PSHA

- "*Murphy's Razor*"
  - Additional research often increases uncertainty.
  - No single tectonic model adequately incorporates all the data and information.
- **PSHA (and especially an expert elicitation) well suited for incorporation of this kind of uncertainty.**
  - DOE PSHA incorporated large variety of models.
  - Albeit some models given higher weight than others.

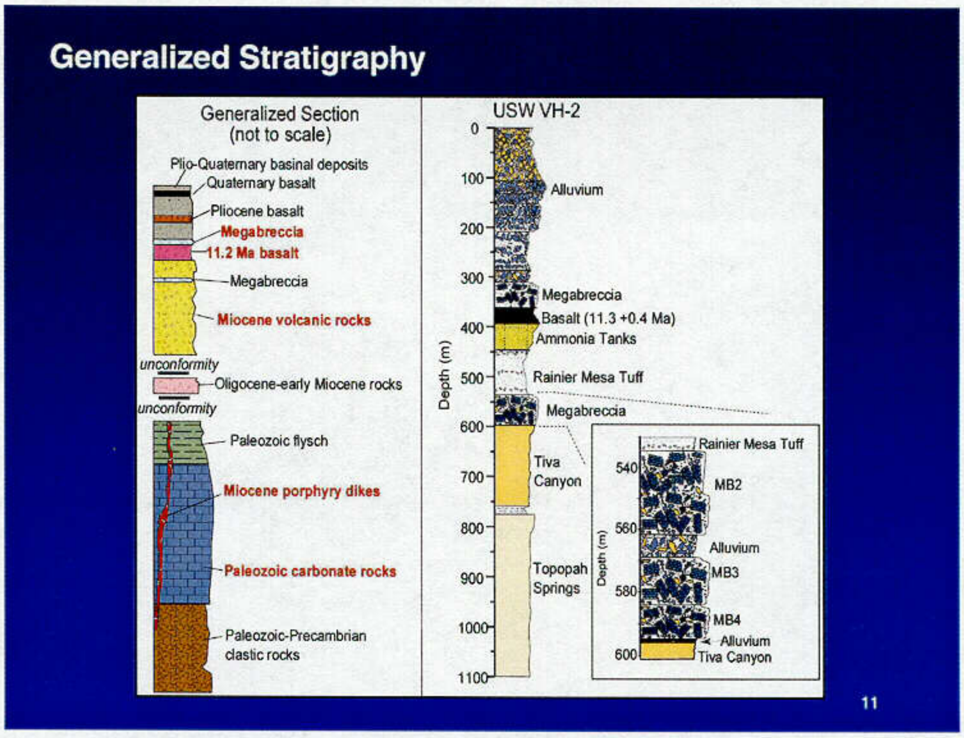
New Data and Model for Crater Flat

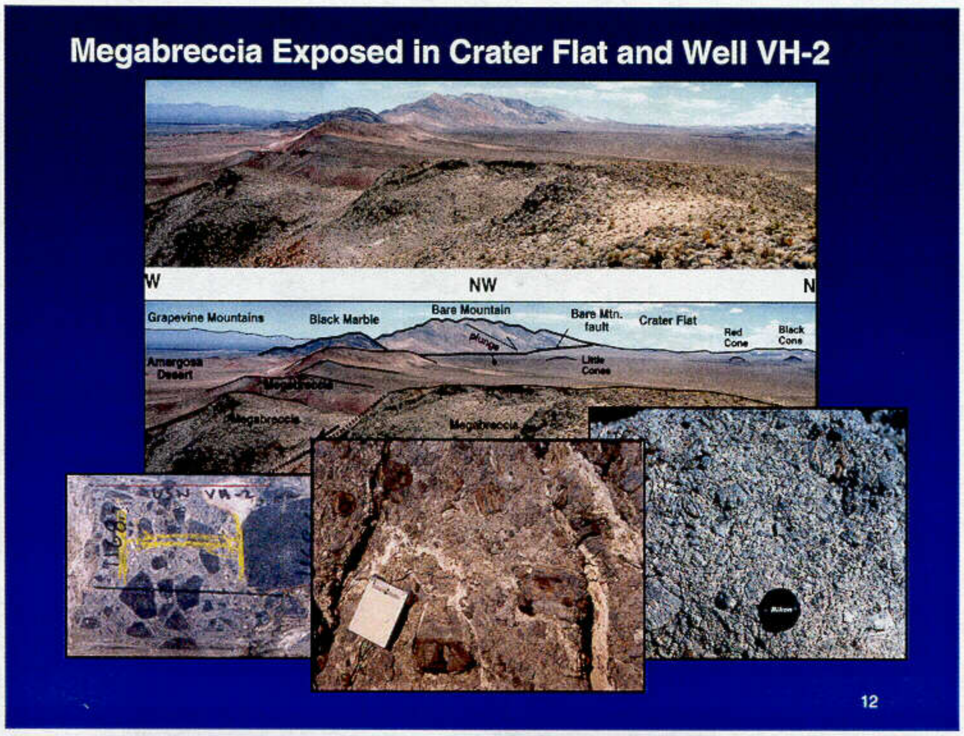
- Paleomagnetic and radiometric age data from Miocene basalt and megabreccia in southern Crater Flat.
- Revised 2D magnetic and gravity models across Crater Flat.
- Structural interpretation of Crater Flat Basin as the hanging wall of Bare Mountain Fault.

Regional Geology



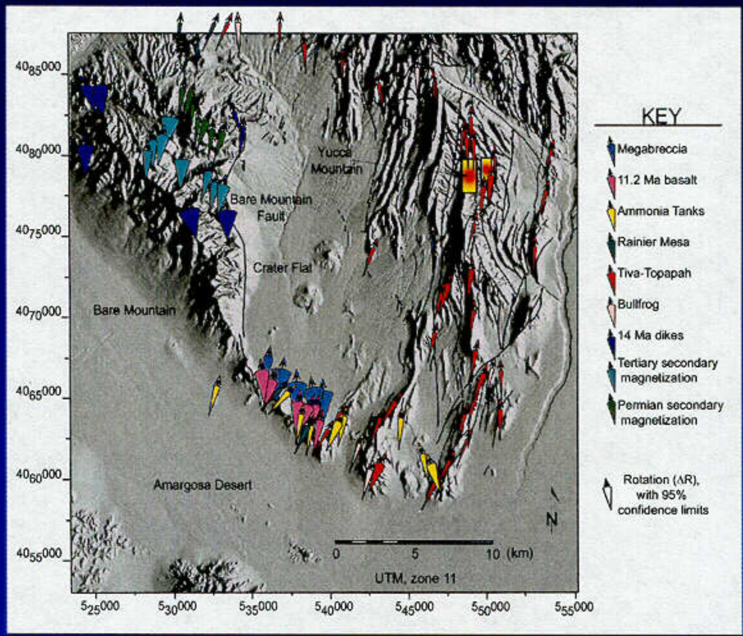
CID


Generalized Stratigraphy
Generalized Section
(not to scale)
Plio-Quaternary basinal deposits
Quaternary basalt
Pliocene basalt
Megabreccia
11.2 Ma basalt
Megabreccia
Miocene volcanic rocks
unconformity
Oligocene-early Miocene rocks
unconformity
Paleozoic flysch
Miocene porphyry dikes
Paleozoic carbonate rocks
Paleozoic-Precambrian
clastic rocks
USW VH-2
Depth (m)
0
100
200
300
400
500
600
700
800
900
1000
1100
Alluvium
Megabreccia
Basalt (11.3 +0.4 Ma)
Ammonia Tanks
Rainier Mesa Tuff
Megabreccia
Tiva
Canyon
Topopah
Springs
Rainier Mesa Tuff
540
MB2
560
Alluvium
MB3
580
MB4
Alluvium
600
Tiva Canyon
11


Megabreccia Exposed in Crater Flat and Well VH-2
W
NW
N
Grapevine Mountains
Black Marble
Bare Mountain
Bare Mtn. fault
Crater Flat
Red Cone
Black Cone
Amargosa Desert
Little Cones
Megabreccia
Megabreccia
Megabreccia
12

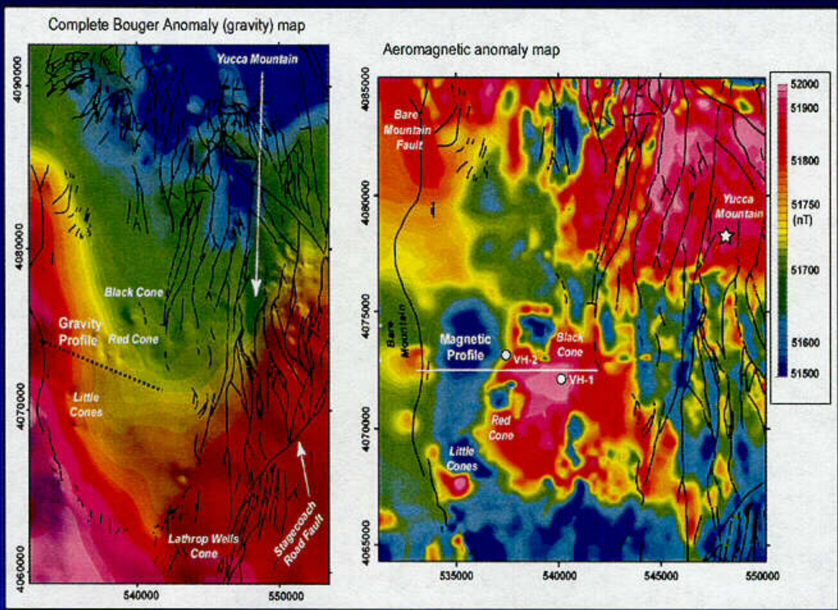
C11

Summary of Paleomagnetic Vertical-Axis Rotation Data



13

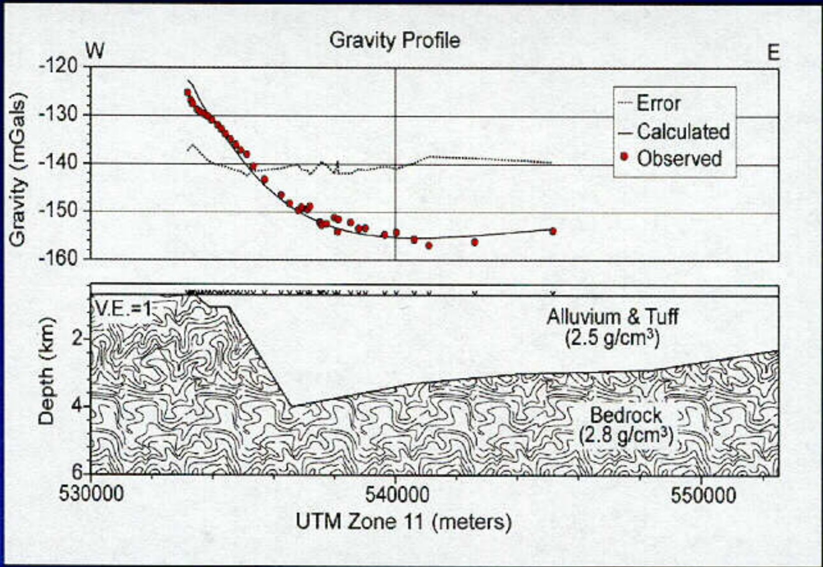
Gravity and Magnetic Data



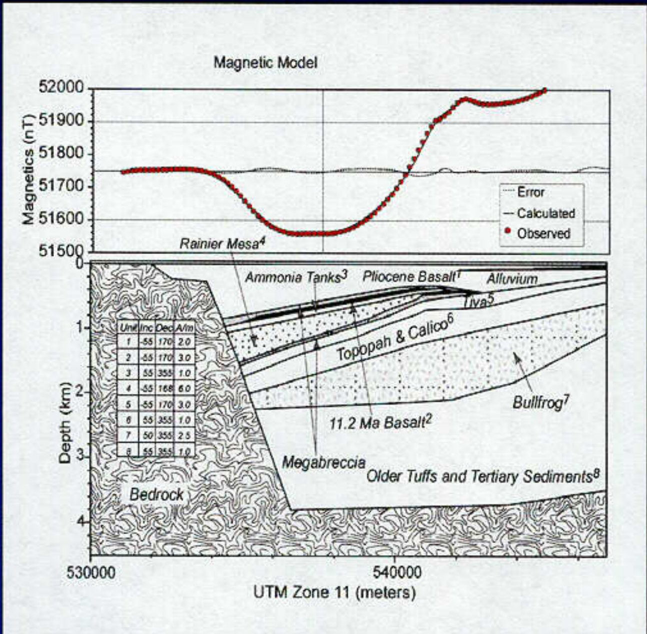
14

C12

Gravity Model for Crater Flat



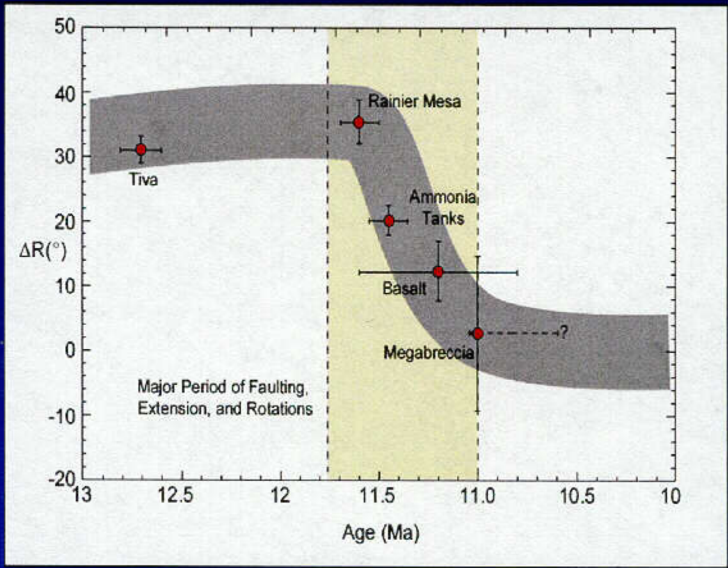
Magnetic Model for Crater Flat



Unit	Inc	Dec	A/m
1	-55	170	2.0
2	-55	170	3.0
3	55	355	1.0
4	-55	168	6.0
5	-55	170	3.0
6	55	355	1.0
7	50	355	2.5
8	55	355	1.0

C13

Paleomagnetic Rotations Constrain Age of Faulting



Conclusions

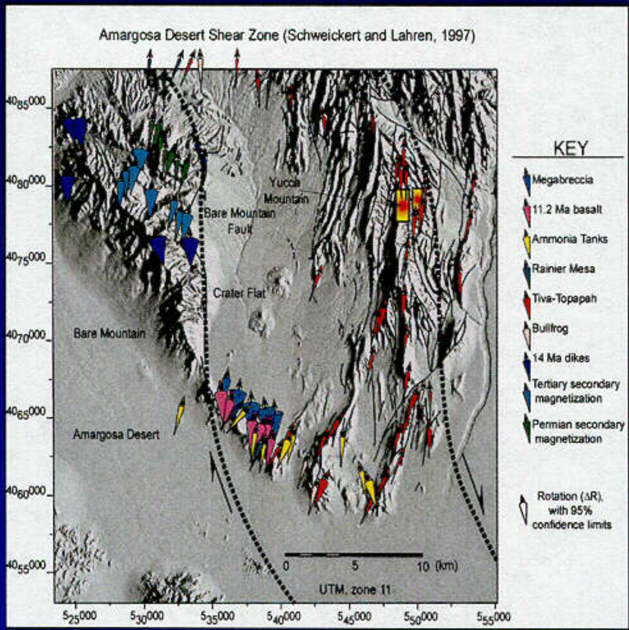
- **Basin architecture controlled by 3D geometry of Bare Mountain fault**
- **Vertical-axis rotations from horizontal shear in hanging wall**
  - age and timing of extension constrained by age of vertical-axis rotations
  - main stage of basin growth between ~12 and 11 Ma., slip rates 1-3 mm/yr
  - since 11 Ma basin growth slow, slip rate 0.06 mm/yr or less
- **Geology also indicates rapid basin growth ~12-11 Ma**
  - wedge of Rainier Mesa adjacent to Bare Mountain
  - megabreccia younger than 11.2 Ma from over-steep Bare Mountain

Conclusions

- **Implications for Seismic Hazard Assessment**
  - many faults at Yucca Mountain may not extend through entire sesimogenic crust.
  - Bare Mountain fault is the master fault in Crater Flat Basin
  - most of the fault slip occurred in Miocene (12-11 Ma)
- **Implications for Volcanic Hazard Assessment**
  - Many volcanic features localized along pre-existing structures.
  - No tectonic evidence to subdivide Crater Flat Basin into discrete source zones.

Back Up Slides

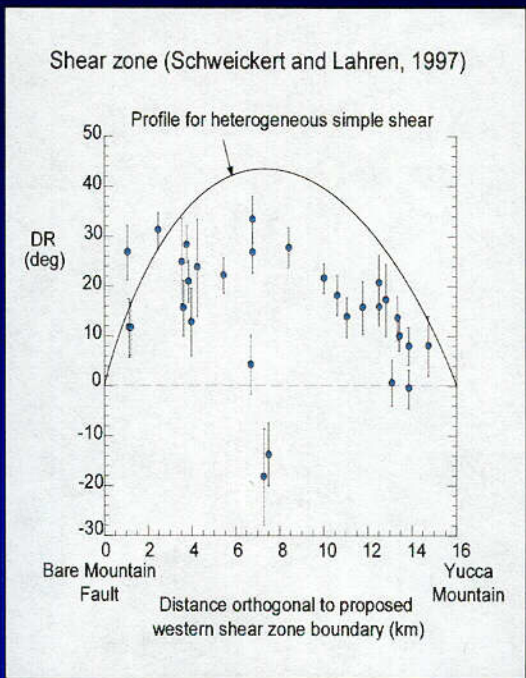
Amargosa Desert Fault System



21

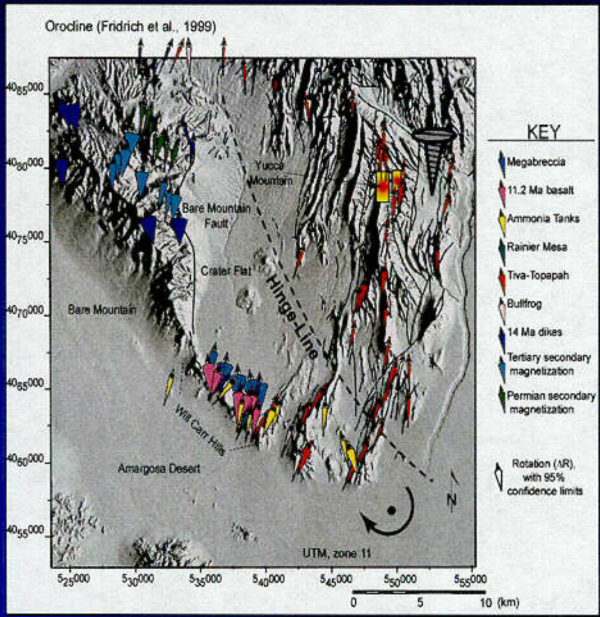
Paleomagnetic rotation data do not fit expected shear profile

(Stamatakos and Ferrill, 1998)



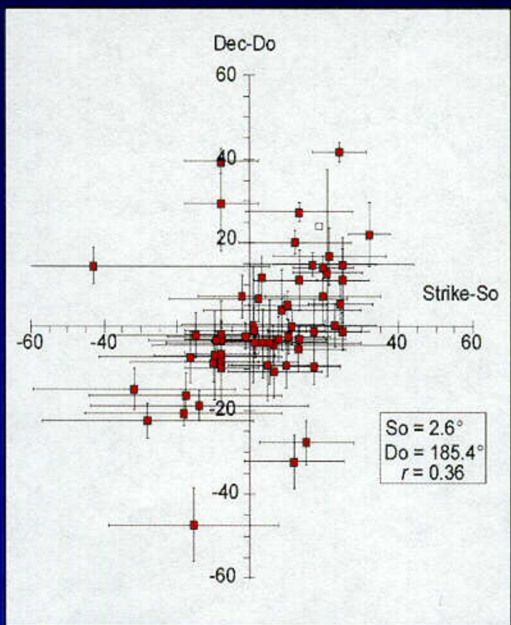
C15

Yucca Mountain Orocline



Paleomagnetic rotation data do correlate with orientation of faults

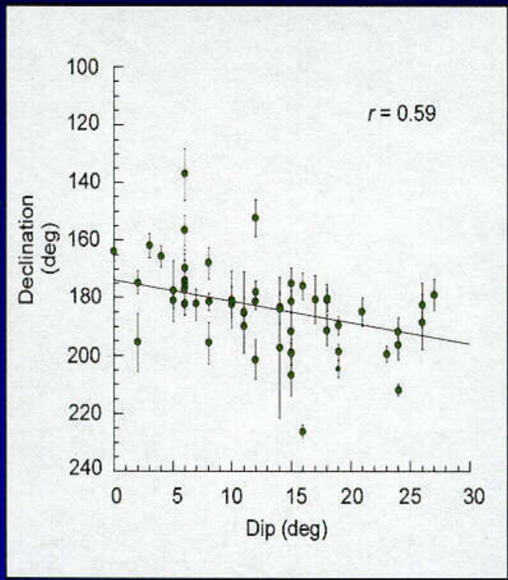
(Stamatakos and Ferrill, 1998)



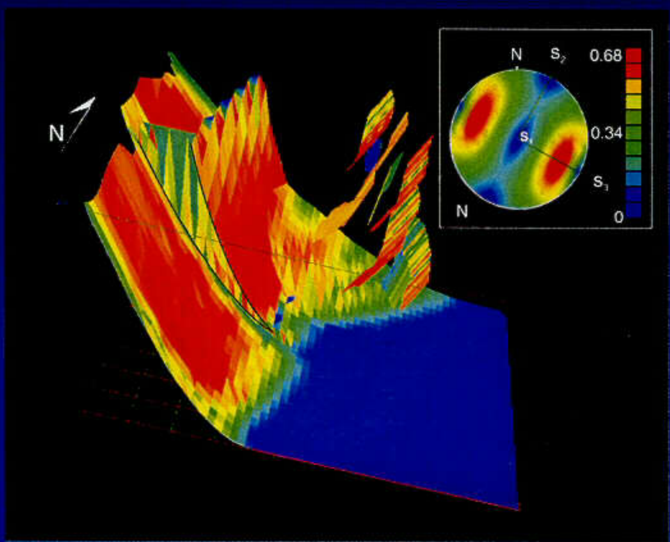
C16

Paleomagnetic rotation data correlate with stratal tilt

(Stamatakos and Ferrill, 1998)



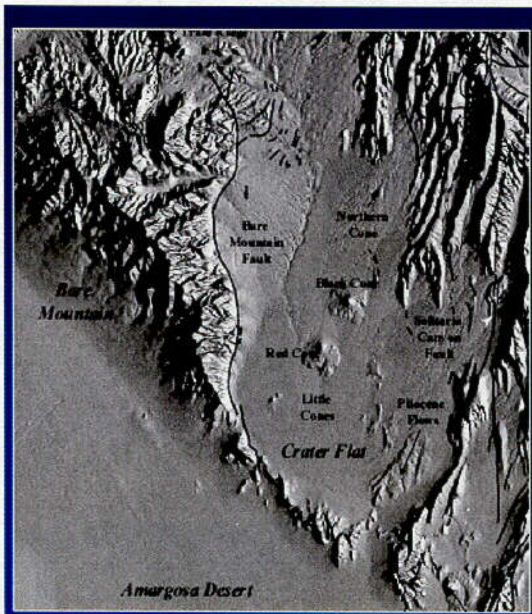
3D Stress™ OF Yucca Mountain, Nevada

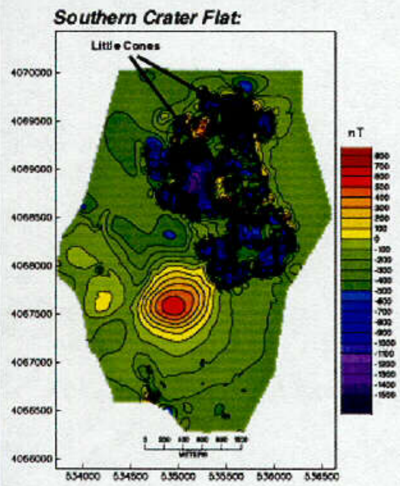


C17

Little Cones Buried Basalt

(Slip Rate = 0.1 mm/yr)





Vertical and Inclined Axis Rotations in Extensional Settings

John A. Stamatakos

David A. Ferrill, Darrell W. Sims,

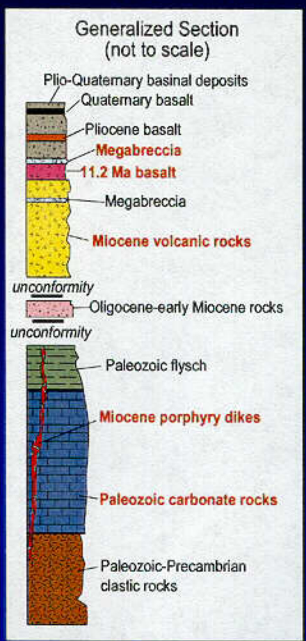
Center for Nuclear Waste Regulatory Analyses, Southwest Research Institute™, San Antonio, Texas

Alan P. Morris

University of Texas at San Antonio, San Antonio, TX

GSA 2002

1



Generalized Stratigraphy of Yucca Mountain Region

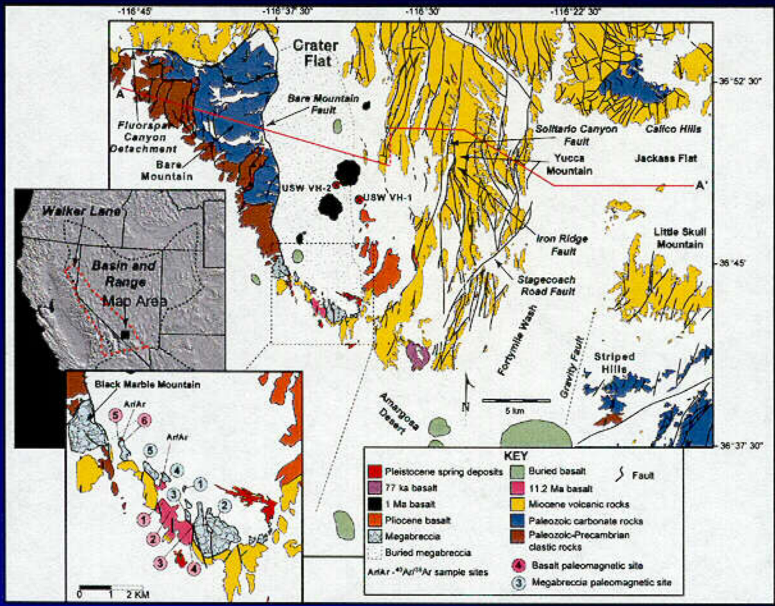
Vertical Axis Rotation Data From Paleomagnetic Studies of:

- Paleozoic Carbonate Strata
- Miocene (~14 Ma) quartz-latite dikes
- Miocene (~13-11 Ma) rhyolite tuff strata
- Miocene Basalt (11.2 Ma)
- Miocene carbonate megabreccia

2

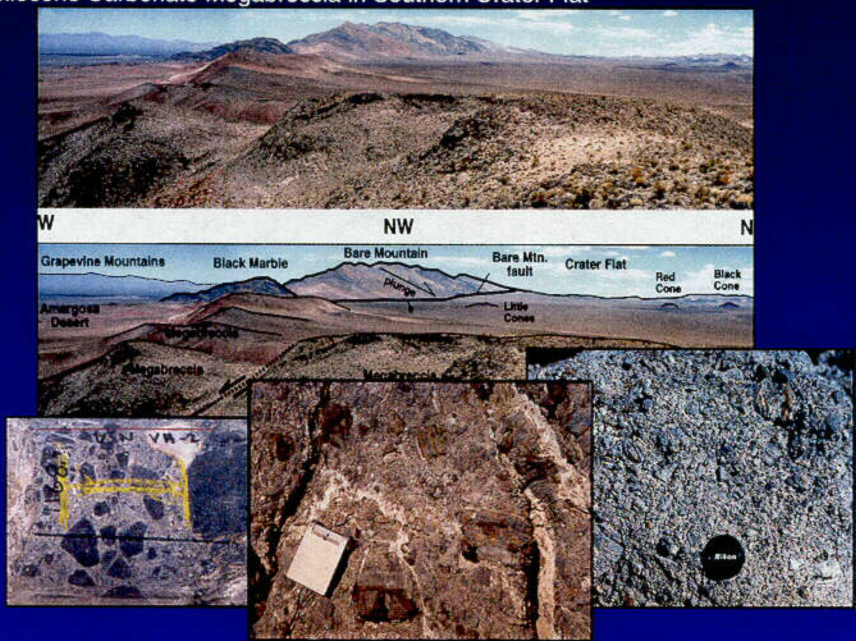
c19

Geologic Setting of Yucca Mountain Region



3

Miocene Carbonate Megabreccia in Southern Crater Flat

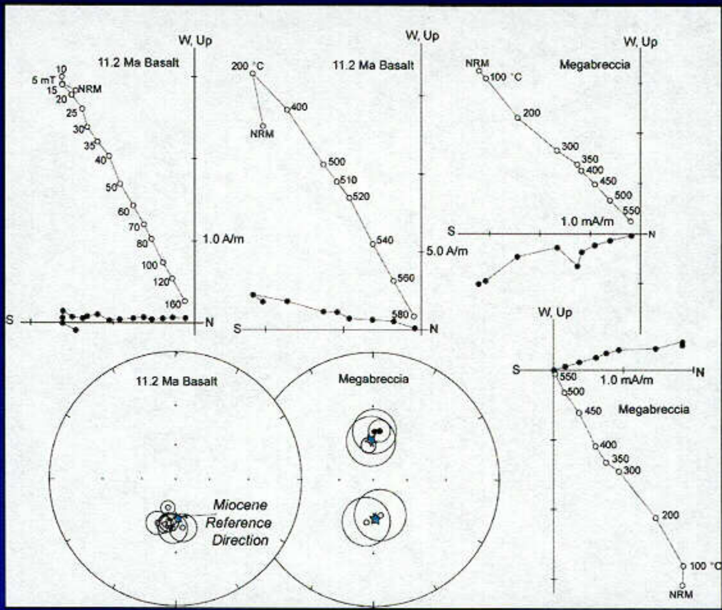


4

2

C20

Paleomagnetic Results from Miocene Megabreccia and 11.2 Ma Basalt



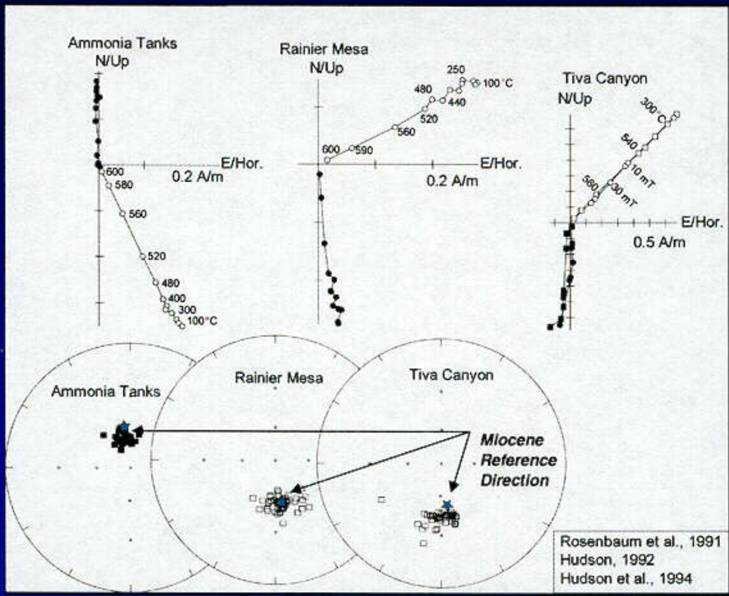
5

Aerial View of Miocene Tuff Strata at Yucca Mountain

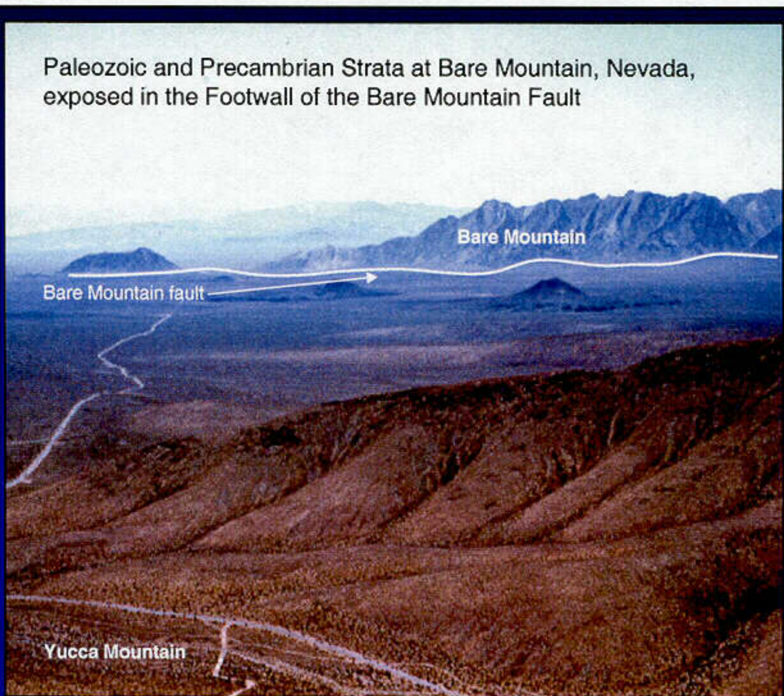
6

C21

Paleomagnetic Results from Miocene Tuff Strata at Yucca Mountain



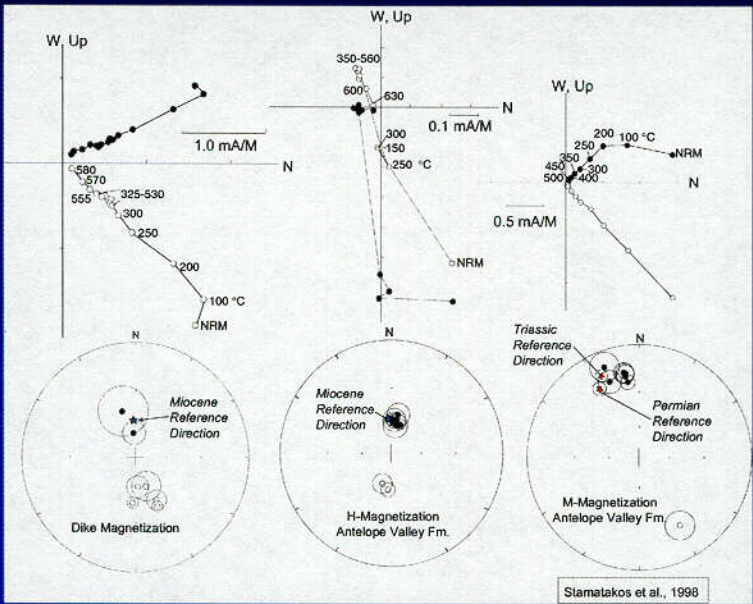
7



8

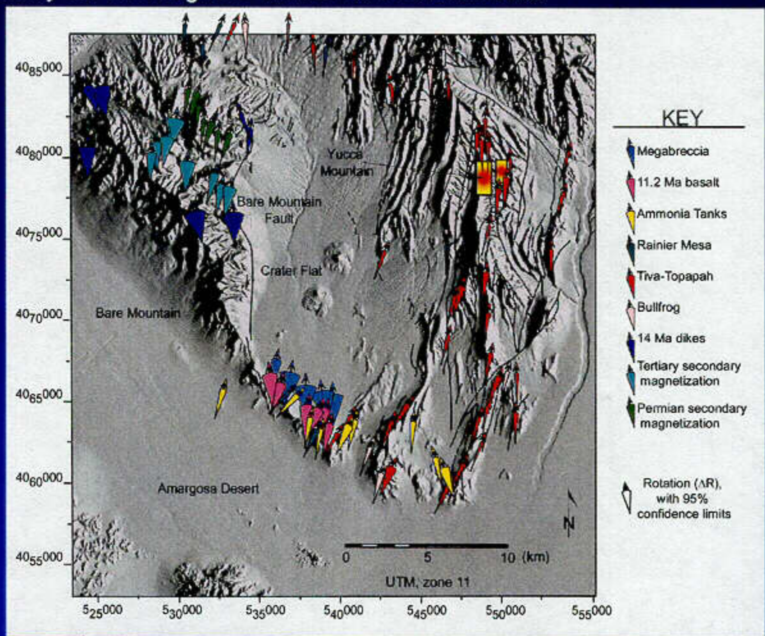
C22

Paleomagnetic Results from Paleozoic Carbonate Strata and Miocene Dikes at Bare Mountain, Nevada



9

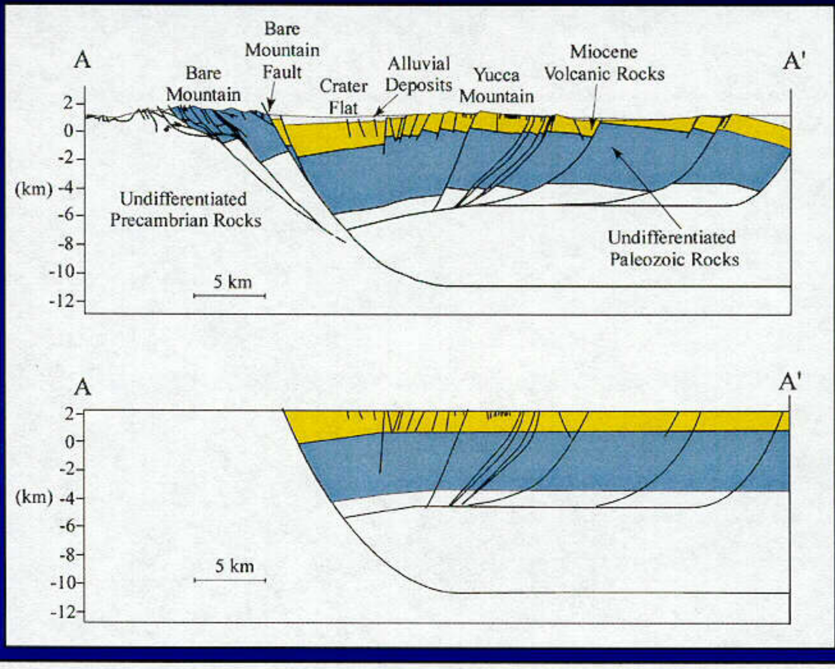
Summary of Paleomagnetic Vertical-Axis Rotation Data



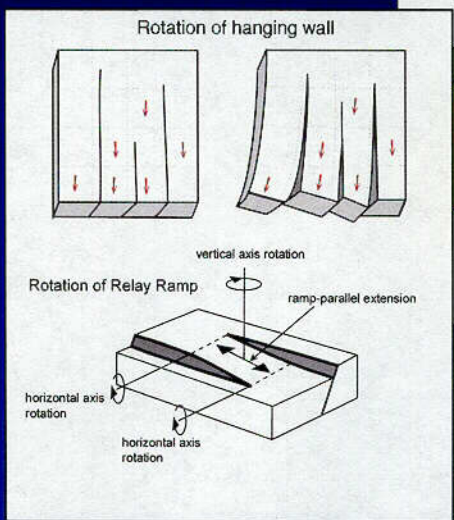
10

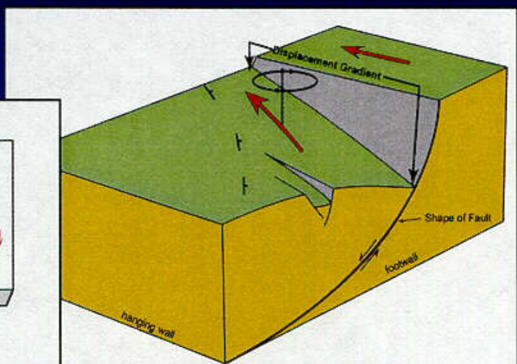
C23

Cross-Section Across Crater Flat and Yucca Mountain



Models for how vertical-axis rotations are manifest in normal fault systems



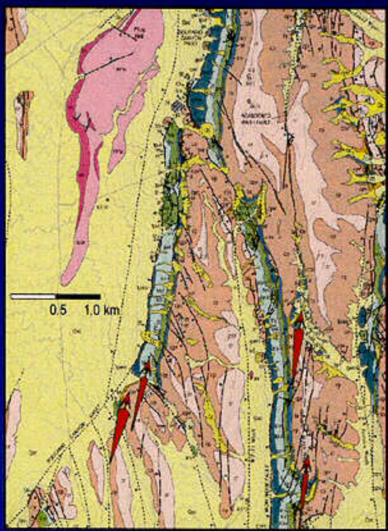


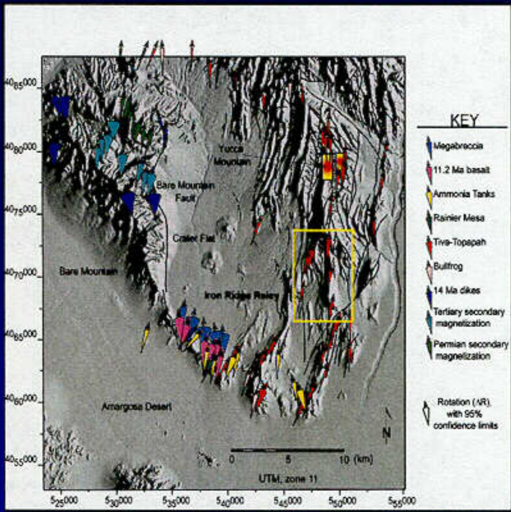
Two factors control apparent vertical-axis rotation, displacement gradient and shape of the fault

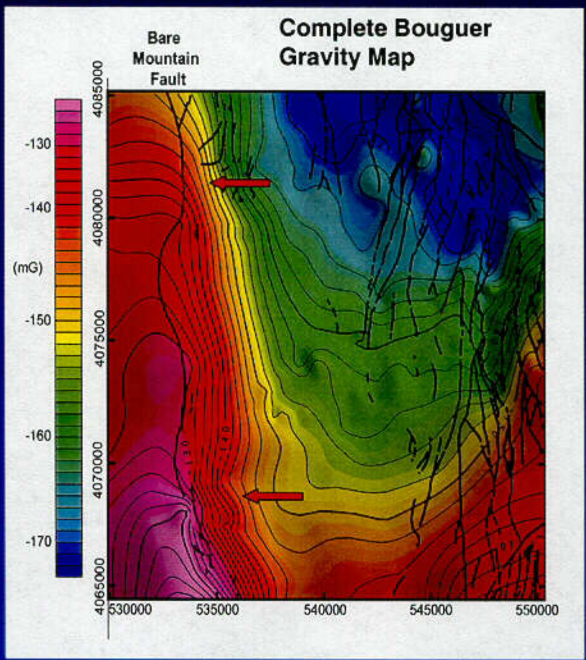
12

C24

Example: rotations in the Iron Ridge relay ramp







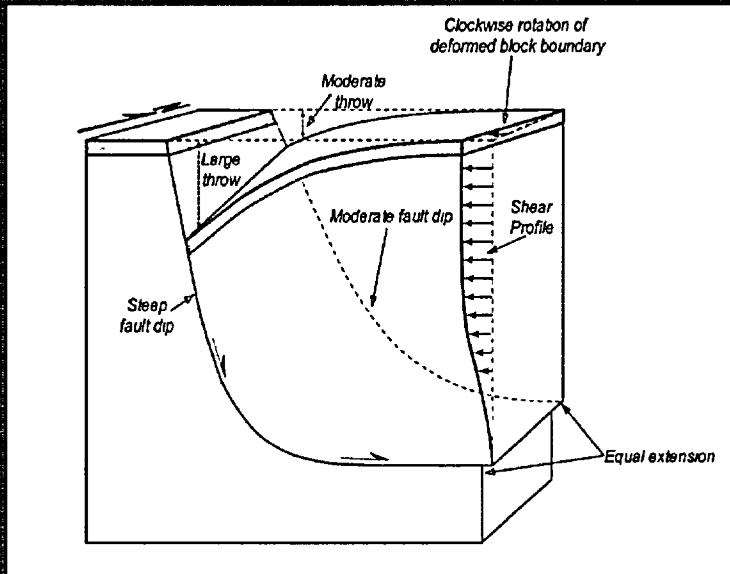
Dip of the Bare Mountain Fault:

Shallower in Northern Crater Flat (~45°)

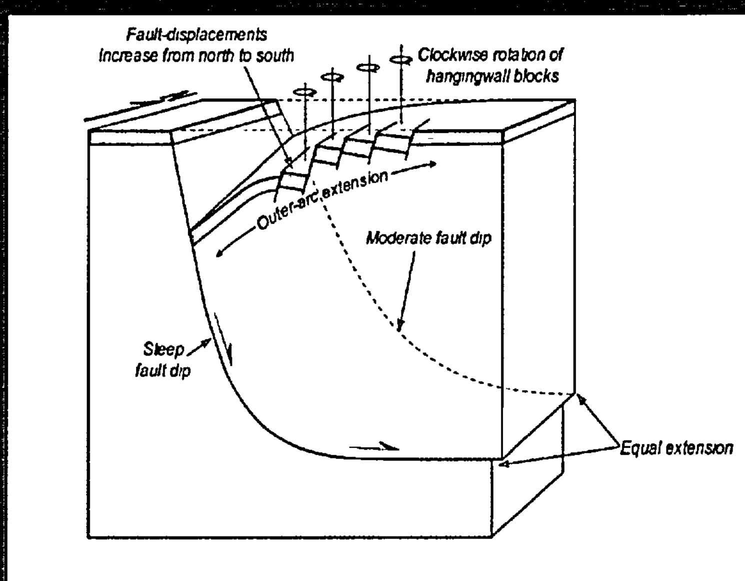
Steeper in southern Crater Flat (~70°)

C25

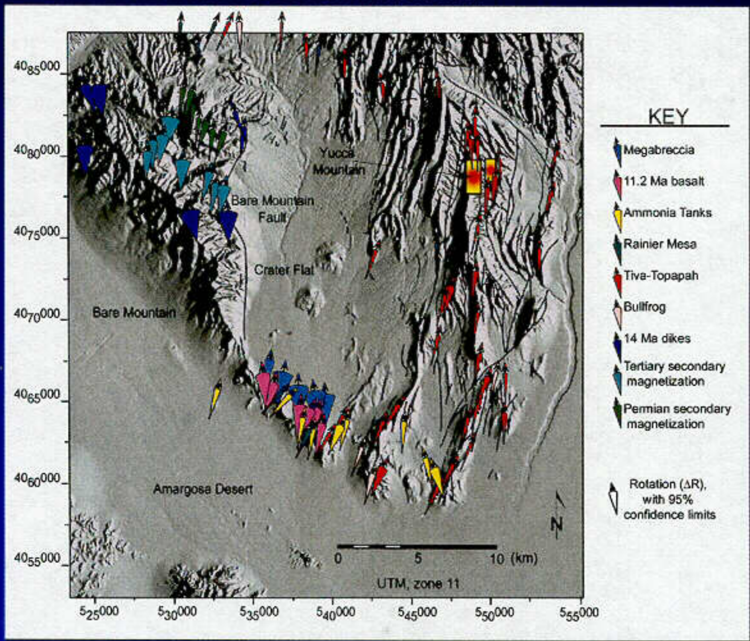
Model of hanging wall deformation above listric Bare Mountain Fault



Model of hanging wall deformation above listric Bare Mountain Fault

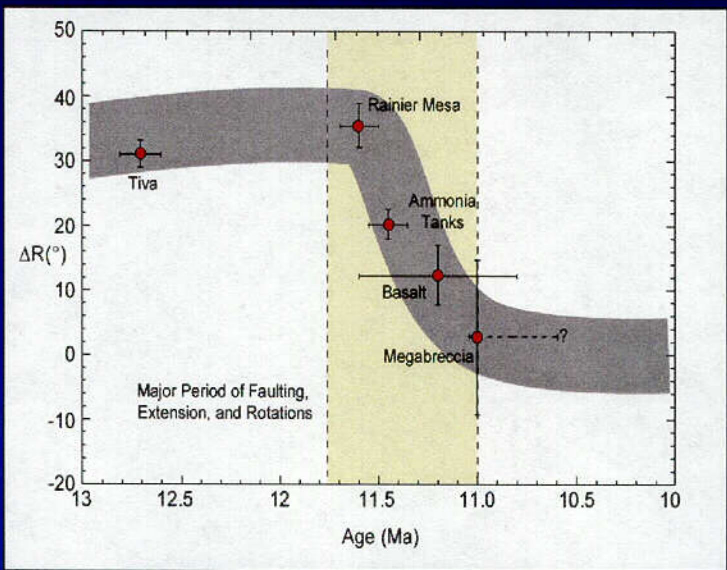


Vertical-axis rotation data consistent with this model



17

Paleomagnetic Rotations (ΔR) Constrain Age of Faulting



18

C26

Conclusions

- **Basin architecture controlled by 3D geometry of Bare Mountain fault**
  - fault steepens from north to south
  - steeper fault segments less efficient at accommodating extension
- **Vertical-Axis Rotations from horizontal shear in hanging wall**
  - age and timing of extension constrained by age of vertical-axis rotations
  - main stage of basin growth between ~12 and 11 Ma., slip rates 1-3 mm/yr
  - since 11 Ma basin growth slow, slip rate 0.06 mm/yr
- **Geology also indicates rapid basin growth ~12-11 Ma**

19