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February 13, 2002
Contract No. NRC–02–97–009
Account No. 20.01402.471

U.S. Nuclear Regulatory Commission
ATTN: Dr. Philip S. Justus
Office of Nuclear Material Safety and Safeguards
Two White Flint North, Mail Stop 7 C6
Washington, DC 20555

Subject: Fault Displacement Gradients, Cutoff-Parallel Strains, and Fractures: Significance for Characterization of Proposed Expanded Repository at Yucca Mountain, Nevada (AI 01402.471.180)

Dear Dr. Justus:

The purpose of this letter is to transmit Administrative Milestone 01402.471.180 titled Fault Displacement Gradients, Cutoff-Parallel Strains, and Fractures: Significance for Characterization of Proposed Expanded Repository at Yucca Mountain, Nevada. The manuscript discusses the potential for a differing strain regime in blocks of the proposed expanded repository relative to the block currently under consideration. The assessment concludes that the other blocks may have been subjected to higher strain that could require fracture characterization in the blocks of the expanded repository, if DOE elects to use additional blocks other than the one currently under consideration. This deliverable has been carried on the CNWRA's Configuration Control Log with the title Briefing Material on Geologic Evaluation of DOE's Proposed Cold Repository. Because of the original purpose of using this material for a briefing, the material is sent in PowerPoint format.

This work was initiated to evaluate the potential for new or unidentified risks if the DOE uses an expanded repository.

If you have any questions please contact Dr. David Ferrill at (210) 522-6082 or me at (210) 522-5183.

Sincerely,

H. Lawrence McKague
GLGP Element Manager

HLM:rae
Attachment

cc:					
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FAULT DISPLACEMENT GRADIENTS, CUTOFF-PARALLEL STRAINS, AND FRACTURES: SIGNIFICANCE FOR CHARACTERIZATION OF PROPOSED EXPANDED REPOSITORY AT YUCCA MOUNTAIN, NEVADA

Prepared for

U.S. Nuclear Regulatory Commission

Prepared by

David A. Ferrill, Alan Morris, Nathan Franklin

CNWRA, Southwest Research Institute™

February 2002

INTRODUCTION 1

- Fracture characterization at Yucca Mountain has focused on area between Solitario Canyon Fault and Bow Ridge fault
- Modeling of various processes (e.g., rockfall, unsaturated zone flow and transport) has relied on characterization in area between Solitario Canyon Fault and Bow Ridge fault

INTRODUCTION 2

- DOE (2001) is considering expanding the repository to areas beyond the Solitario Canyon and Bow Ridge faults to reduce thermal load
- Potential expanded waste emplacement areas are in structural positions in which fractures may not match those in the characterized block:
  - Displacement gradients are different from those on the Solitario Canyon and Bow Ridge faults
  - Displacement gradients show areas of potentially high strain
  - Increased fracturing is a possible outcome in the areas of potentially high strain

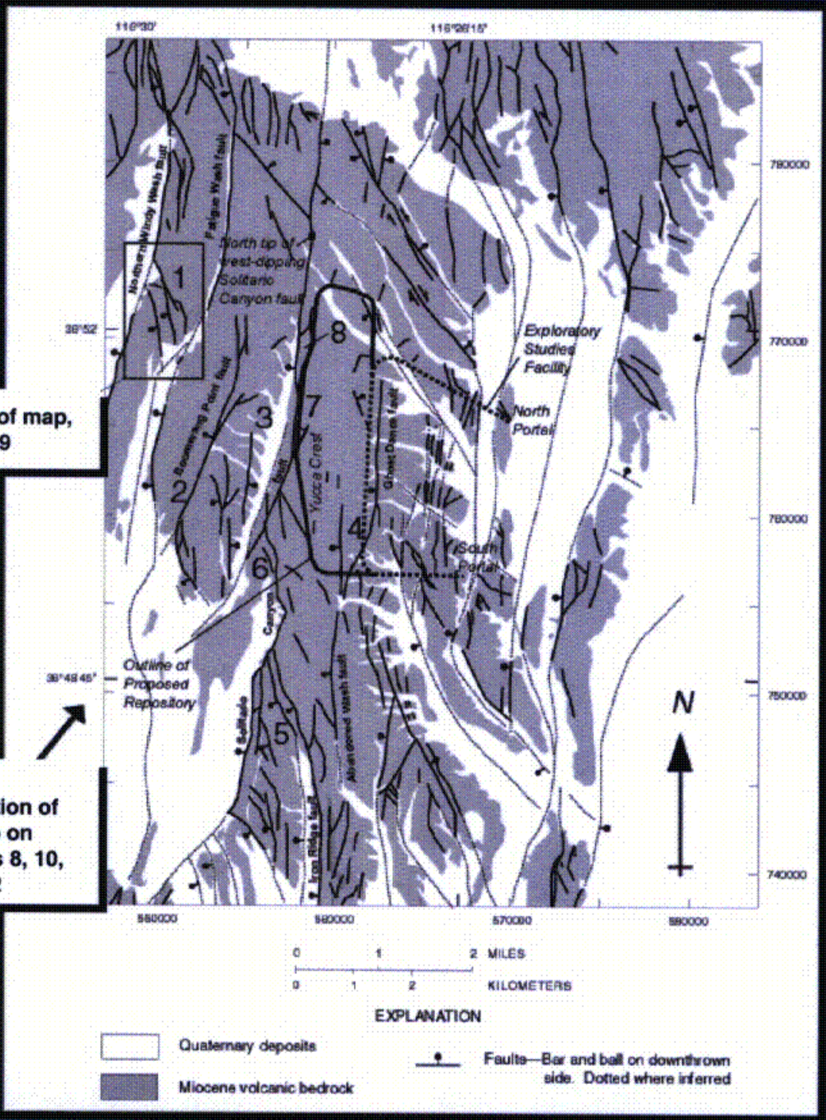
INTRODUCTION 3

- Therefore, fractures in the potential repository expansion areas will need to be characterized

- This presentation summarizes the method of identification of variably strained areas by analysis of the fault cutoff lines (lines of intersection between faults and beds) calculated from fault:

  - geometry
  - bed geometry
  - fault slip direction.

FAULT MAP OF YUCCA MOUNTAIN AND POTENTIAL REPOSITORY AREAS



Area of map, page 9

View direction of photo on pages 8, 10, 11, 12

Yucca Mountain Science and Engineering Report
DOE/RW-0539

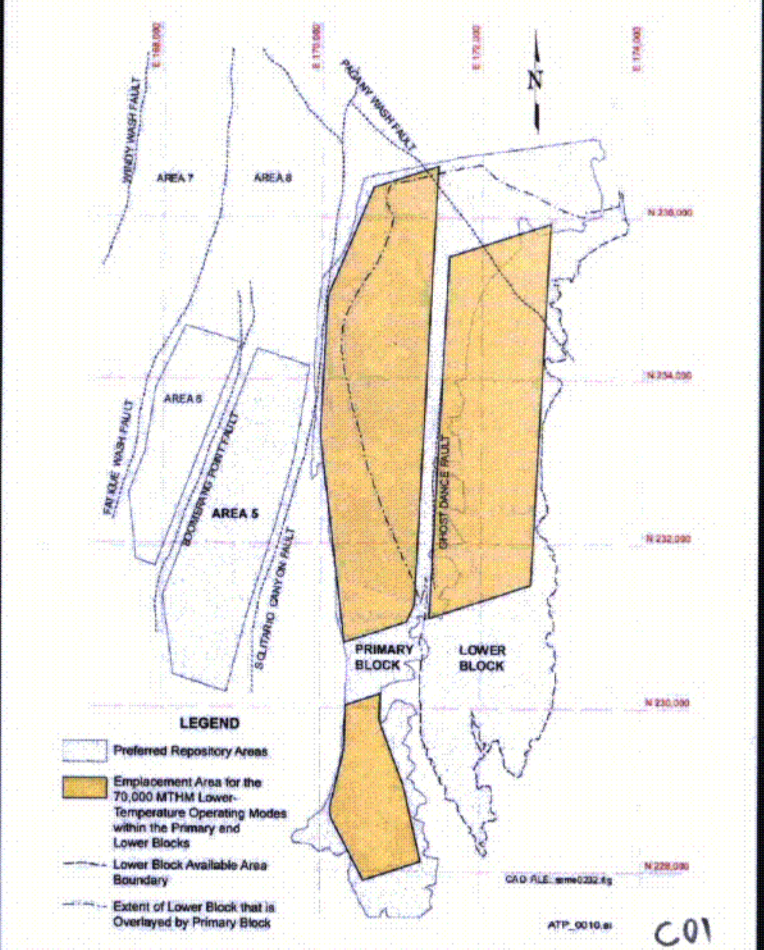
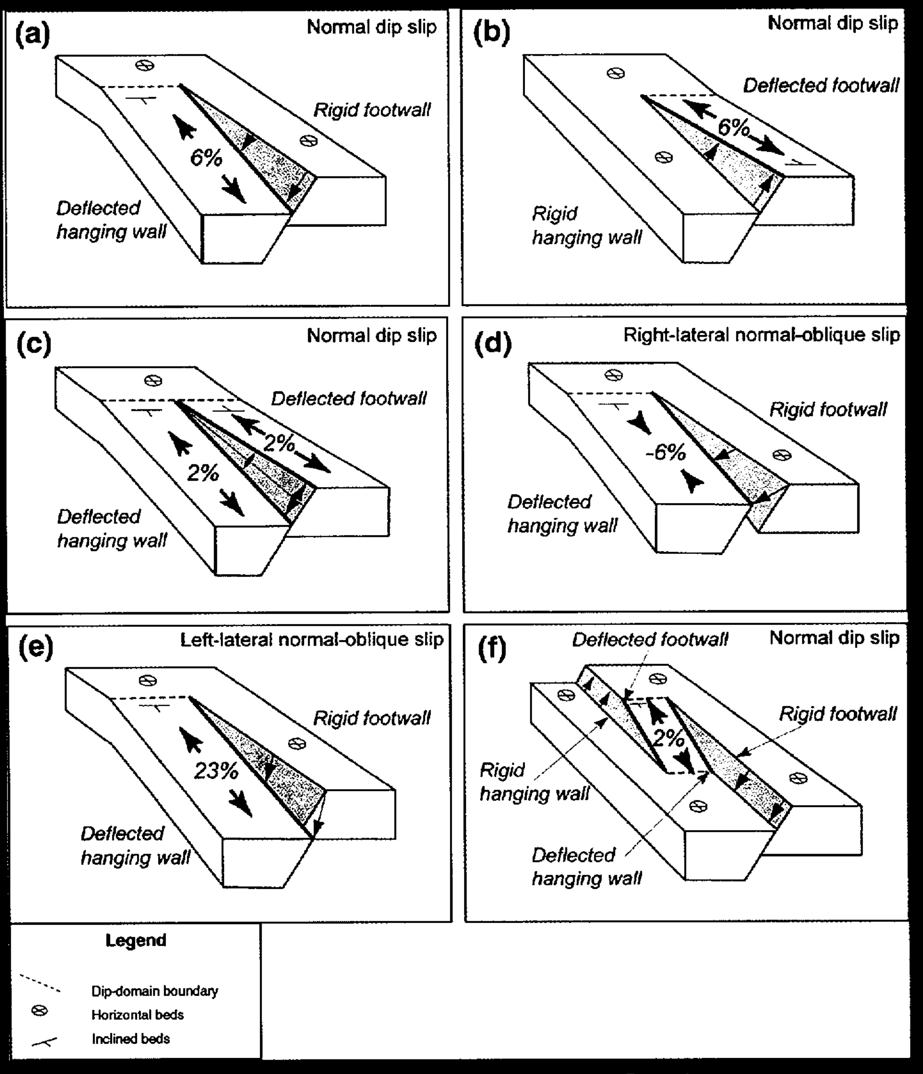


Figure 2-6. Preferred Repository Areas and Emplacement Area for the Lower-Temperature Operating Modes
The emplacement areas shown within the primary and lower blocks would accommodate 70,000 MTHM in lower-temperature operating modes. Source: Modified from BSC 2001b; CRWMS M&O 2000f; and CRWMS M&O 2000m.

Figure 2-6 from U.S. DOE, 2001

DISPLACEMENT GRADIENT CONTROLS ON FAULT BLOCK DEFORMATION

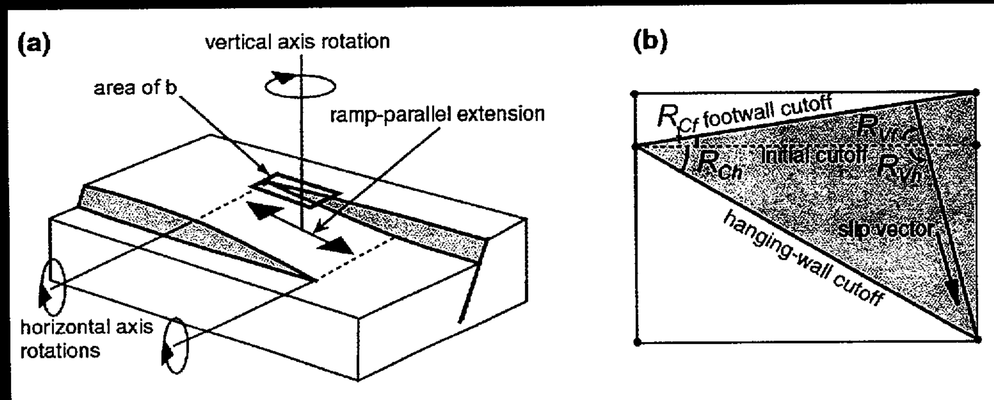
- Fault cutoff elongation depends on displacement gradient and displacement direction
- Fault block deformation likely to be concentrated in most-deflected fault blocks
- Strain can be either extensional or contractional
- Increased strain in the brittle crust is usually manifest by increased fracture density



GEOMETRICAL ANALYSIS

Calculation of cutoff line elongation requires knowledge of these orientations:

- Fault
- Slip vector
- Initial bedding (pre-faulting)

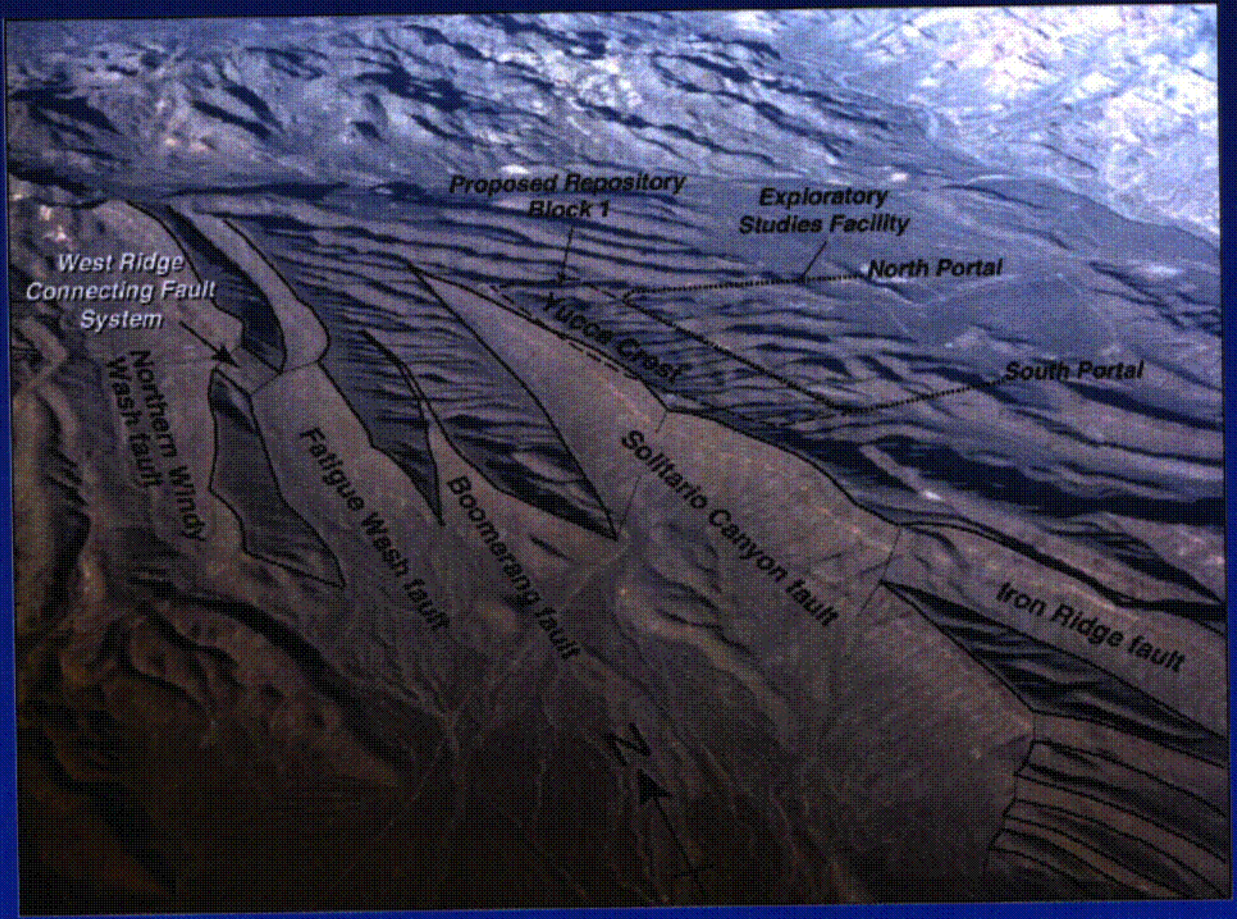


Two overlapping normal faults.
(a) Block diagram illustrating the principal geometrical elements of two overlapping normal faults.
(b) Fault-plane-perpendicular view of fault tip illustrating the relationship between initial, footwall, and hanging wall cutoff lines and the slip vector. The fault plane is shaded.

Elongation parallel to the cutoff line (e_c) may be either positive (extensional) or negative (contractional), and depends only on angular relationships:

$$e_C = \frac{\sin(R_V)}{\sin(180 - R_V - R_C)} - 1$$

FAULTS AT YUCCA MOUNTAIN



Cutoff line elongation is greatest where displacement gradients are high.

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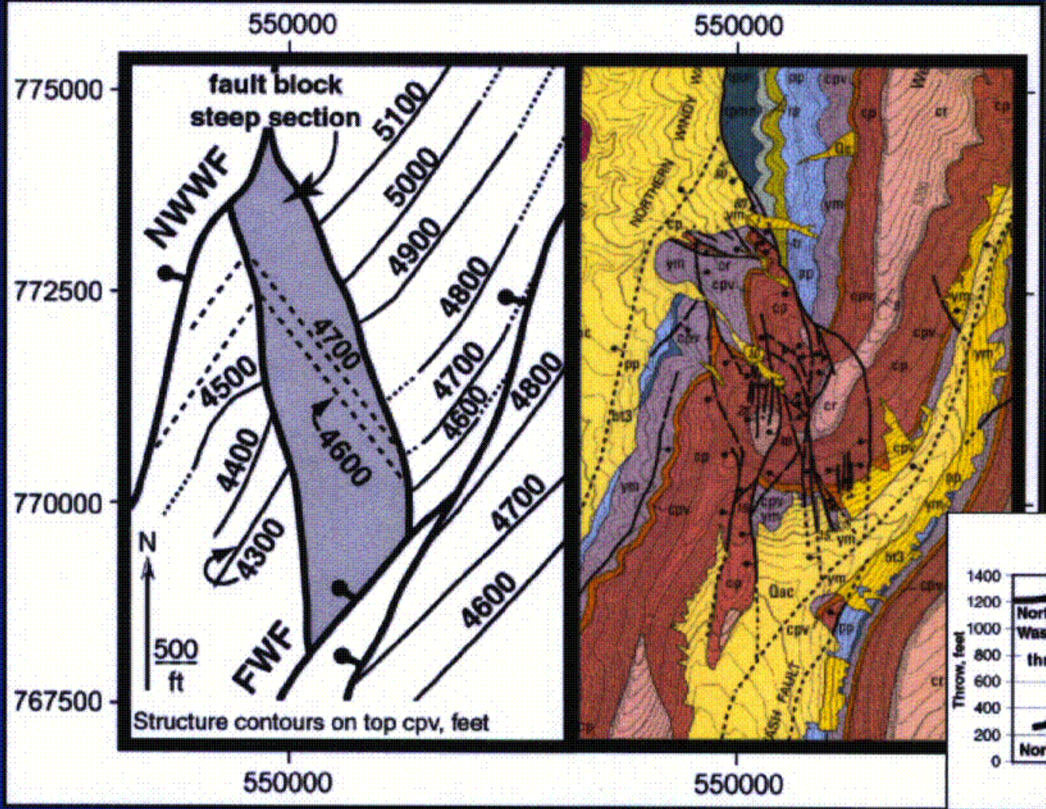
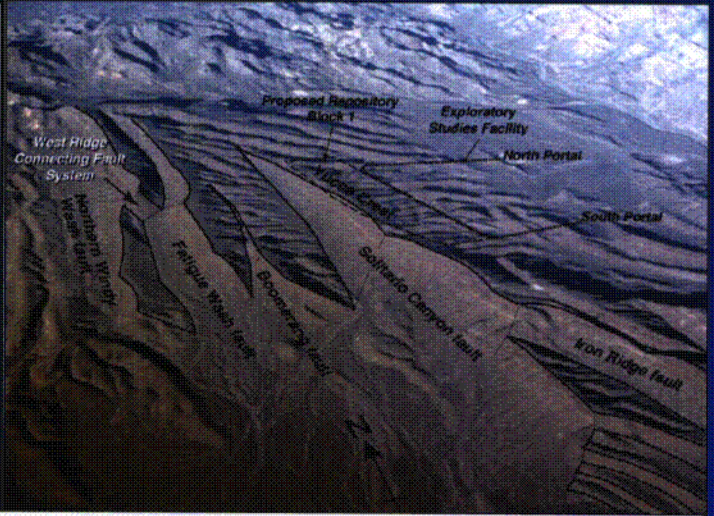
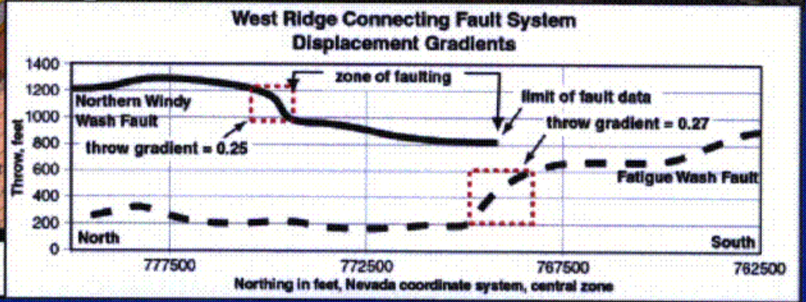
FAULTS AT YUCCA MOUNTAIN







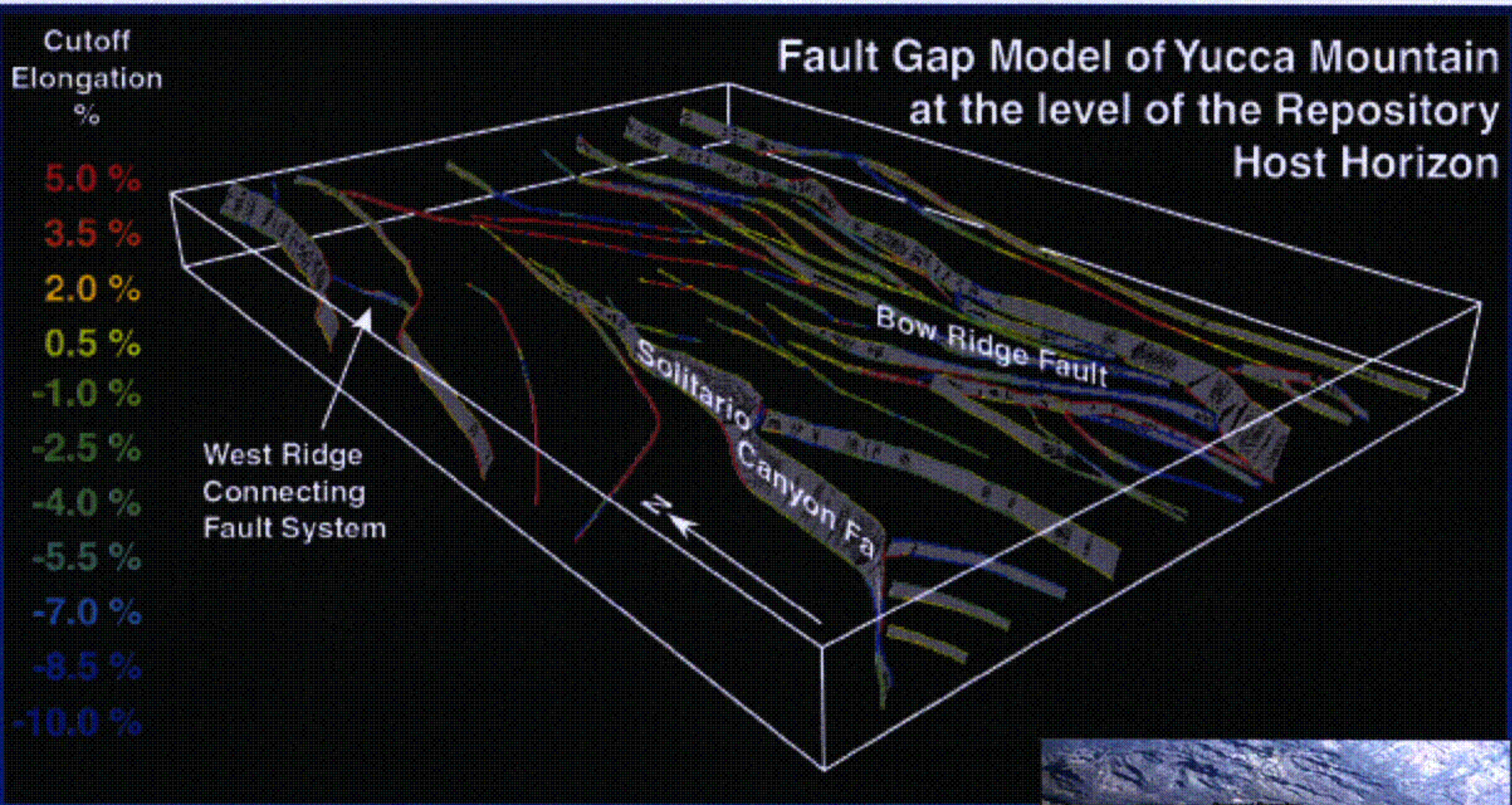
The West Ridge Connecting Fault System:

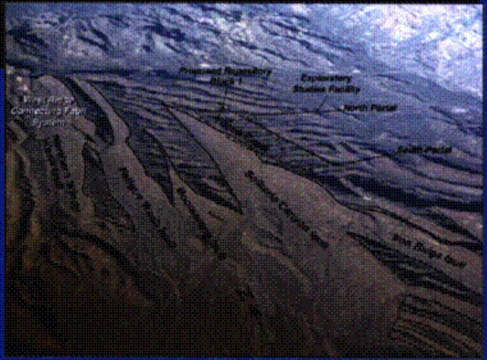
- steep displacement gradients on bounding faults
- numerous faults accommodate resulting 10% extension

Geologic map from Day et al., 1998

C03

FAULTS AT YUCCA MOUNTAIN





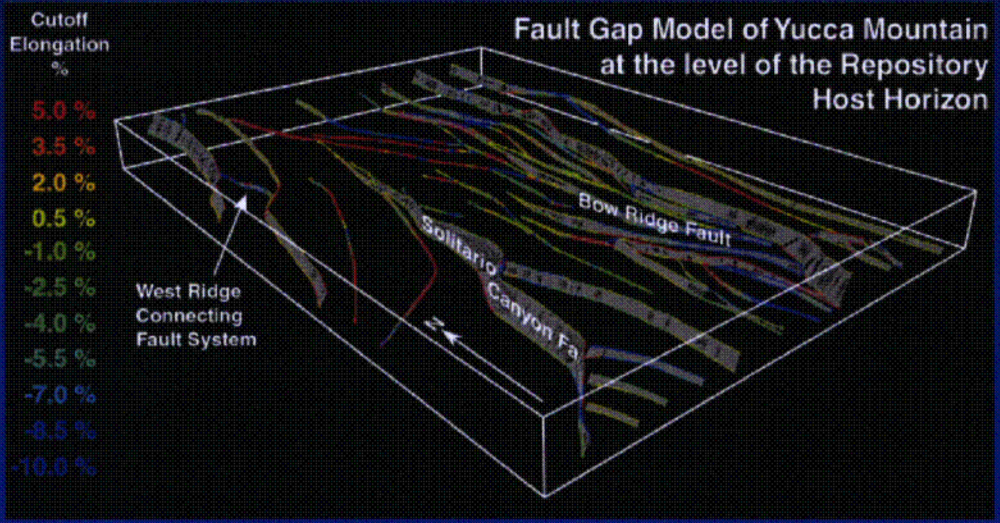
A model of fault cutoff lines for a given bed is a fault gap model. With high quality data, all fault segments can be analyzed for the strain resulting from displacement gradients.

C04

CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

- **Fault orientations** ✓
  - The Geological Framework Model provides excellent fault shape and orientation data



- Slip vector orientations
- Initial bedding orientation

Geologic Framework Model from CRWMS M&O, 2000

C05

CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

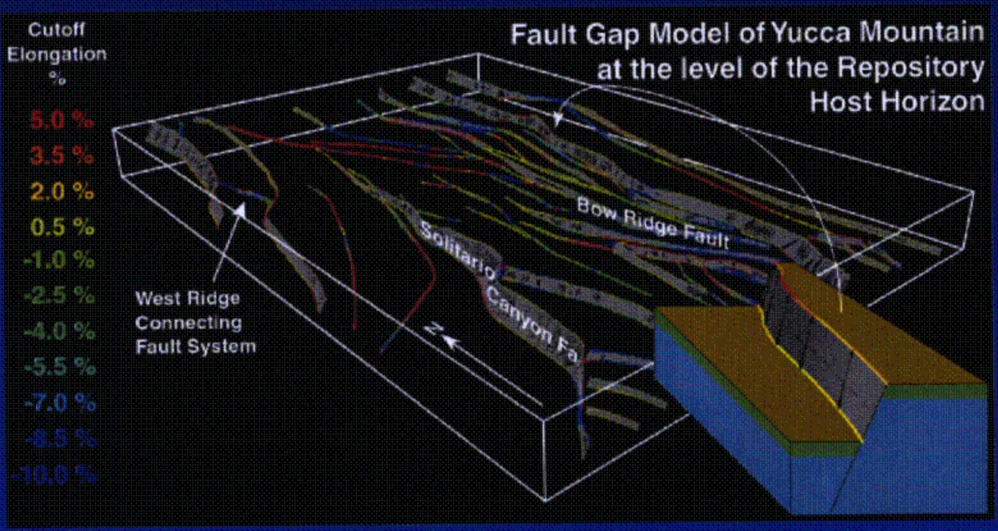
- Fault orientations
- Slip vector orientations
  - Choose an appropriate stress system for the time of faulting, for example:

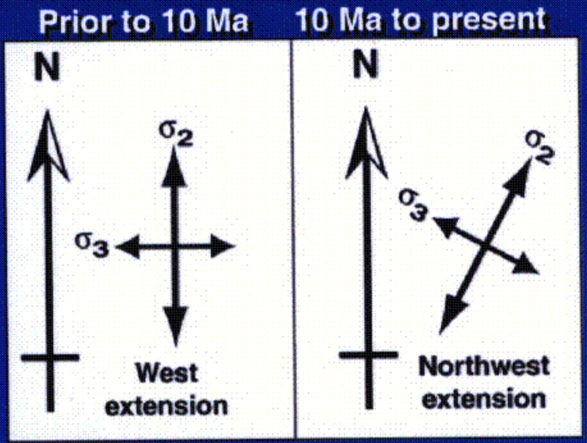
    σ_1 = vertical, 21 MPa

    σ_2 = NS, 17 MPa

    σ_3 = EW, 11 Mpa

  - 3DStress™ computes slip vectors for all parts of a fault's surface
- Initial bedding orientation





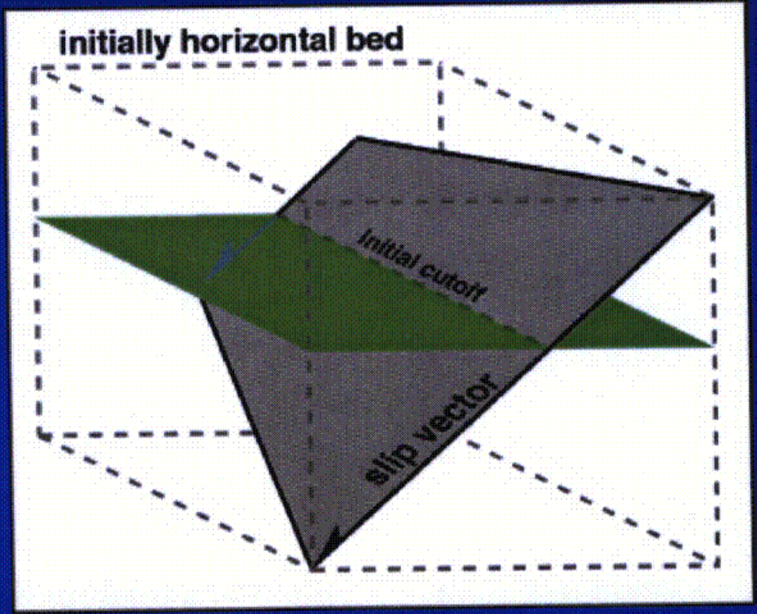
Stress magnitudes from Ferrill et al., 1999
Stress orientations from Morris et al., 1996

c06

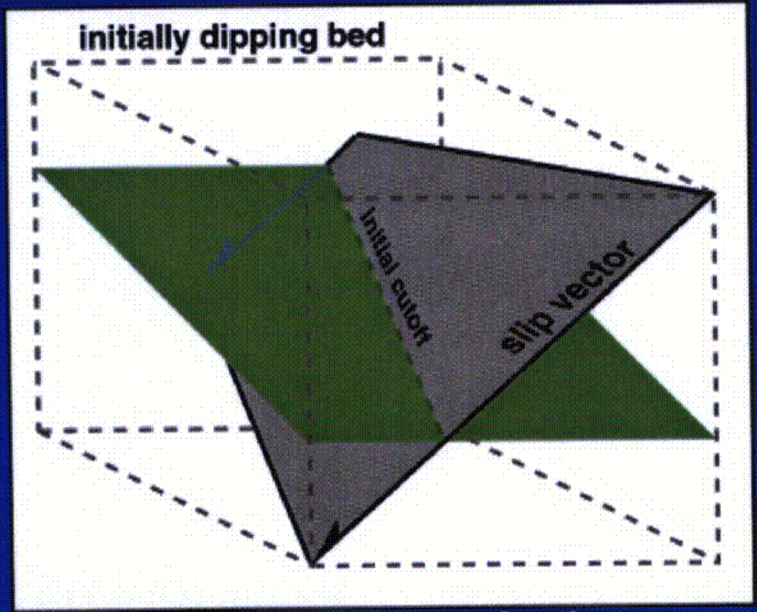
CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

- Fault orientations ✓
- Slip vector orientations ✓
- Initial bedding orientation
  - Test various initial bedding orientations



Step 1

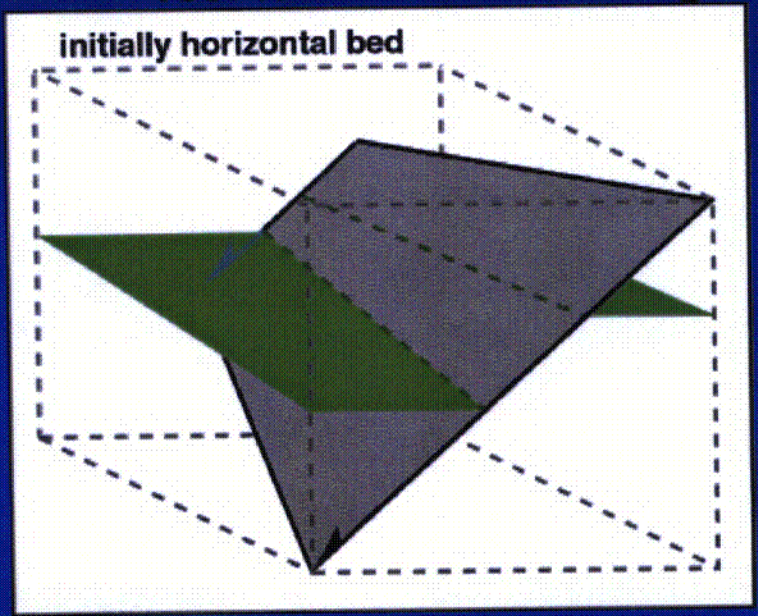


C07

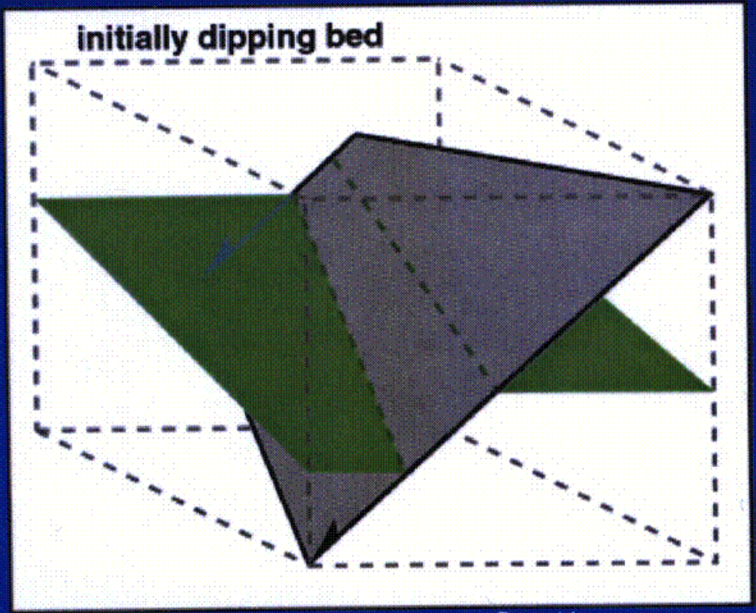
CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

- Fault orientations ✓
- Slip vector orientations ✓
- Initial bedding orientation
  - Test various initial bedding orientations



Step 2

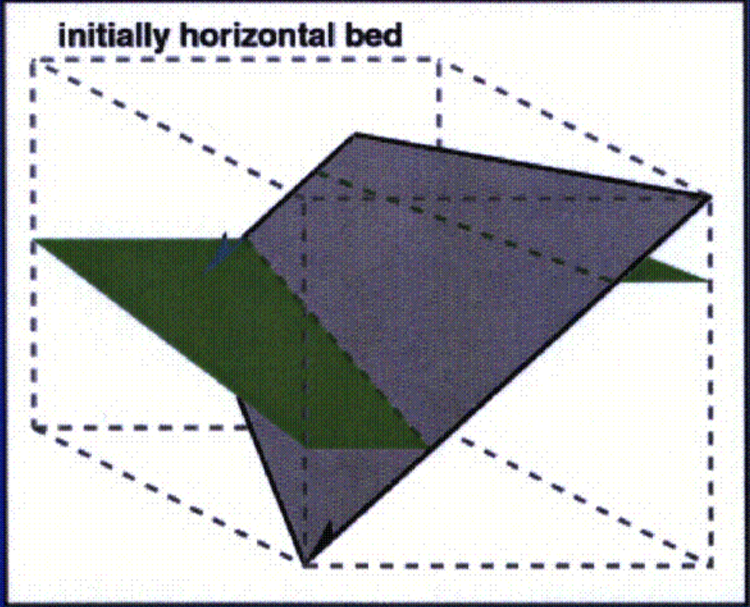


C08

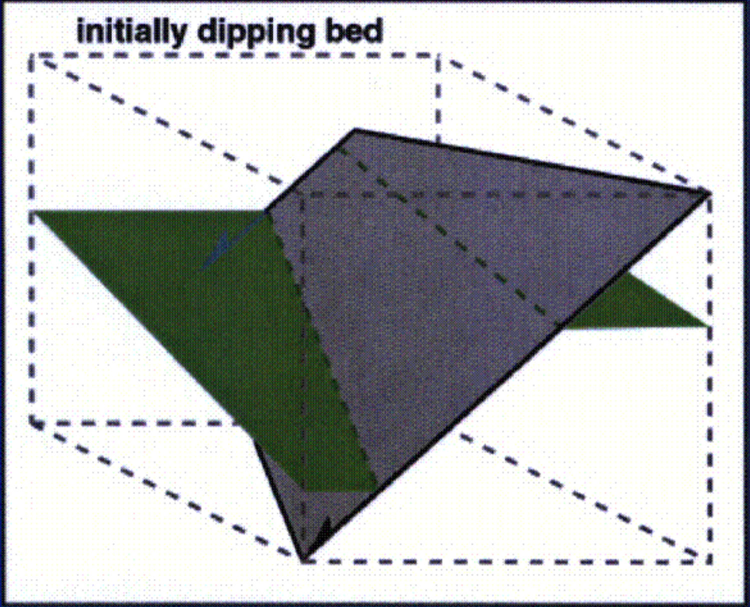
CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

- Fault orientations ✓
- Slip vector orientations ✓
- Initial bedding orientation
  - Test various initial bedding orientations



Step 3

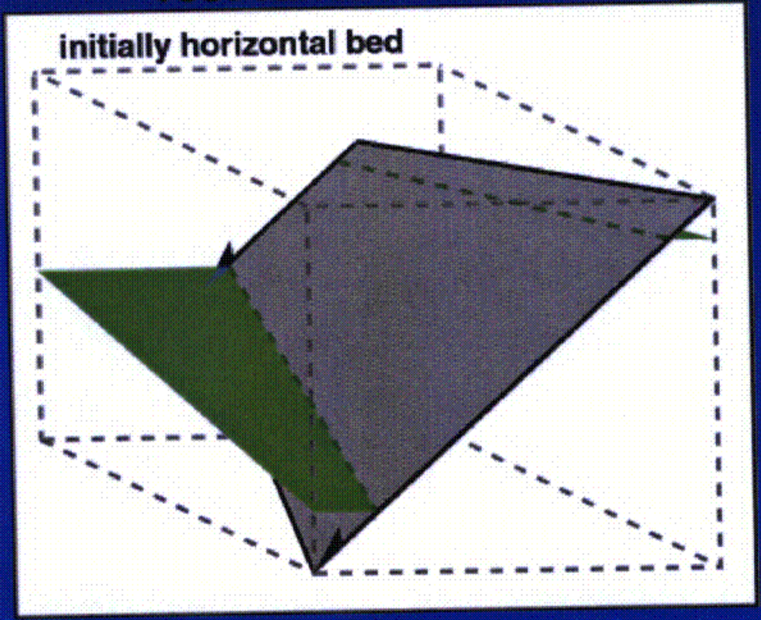


C09

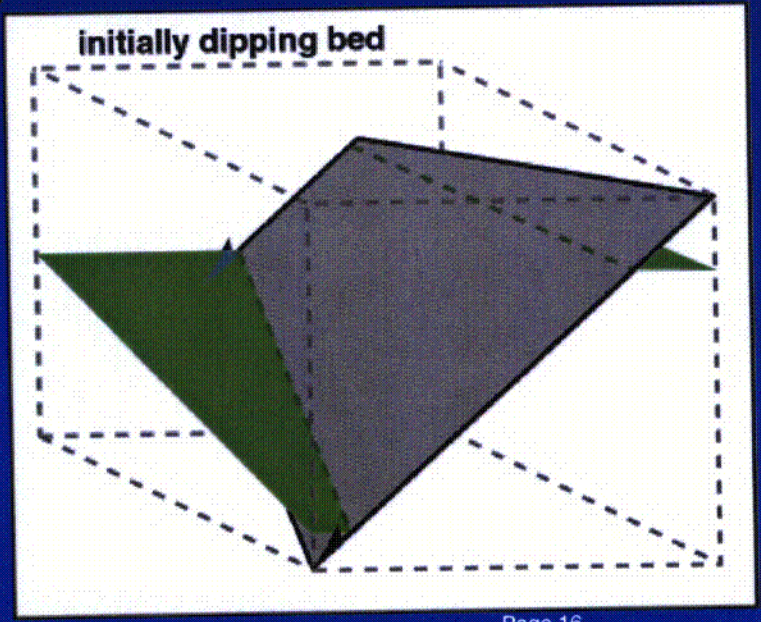
CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

- Fault orientations ✓
- Slip vector orientations ✓
- Initial bedding orientation
  - Test various initial bedding orientations



Step 4

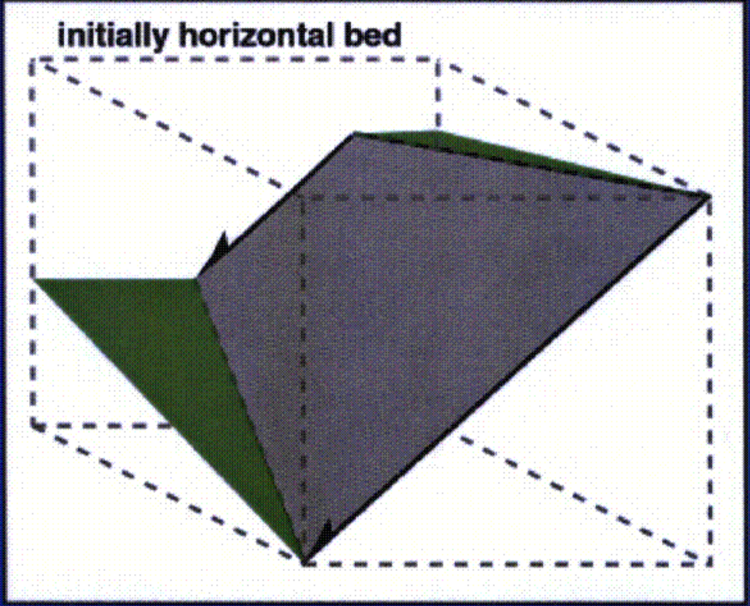


C10

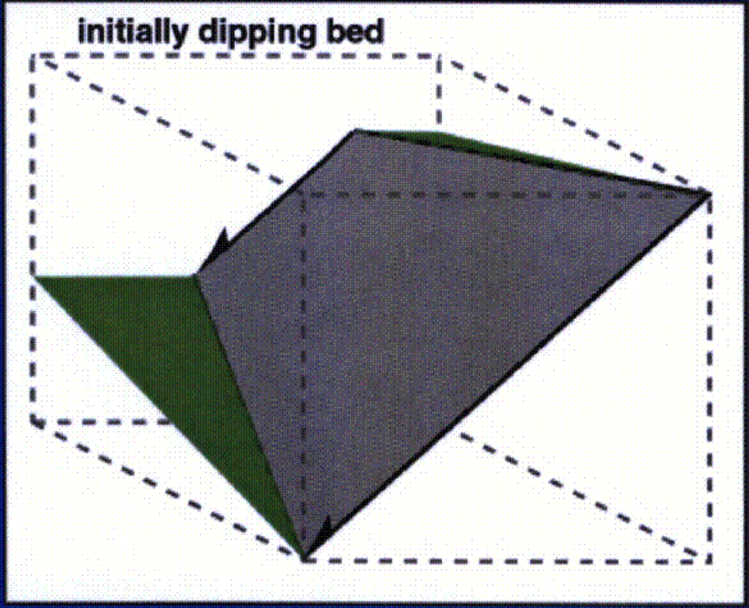
CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

- Fault orientations ✓
- Slip vector orientations ✓
- Initial bedding orientation
  - Test various initial bedding orientations



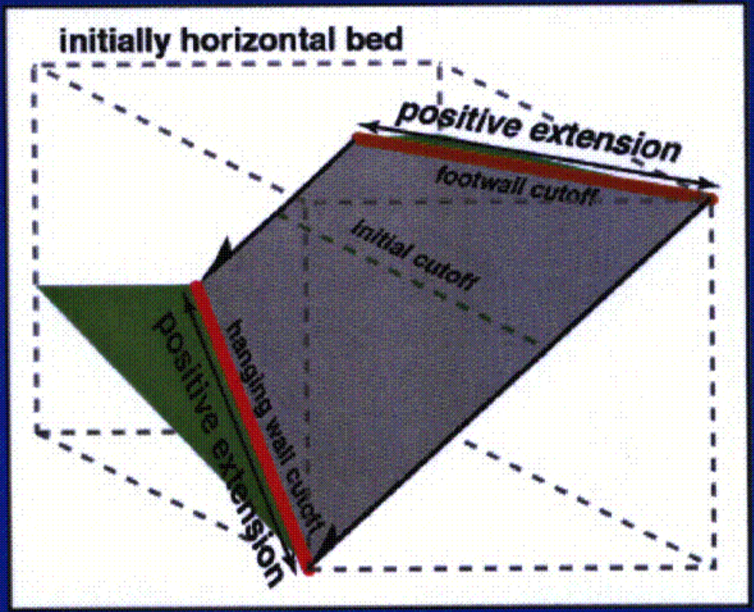
Step 5



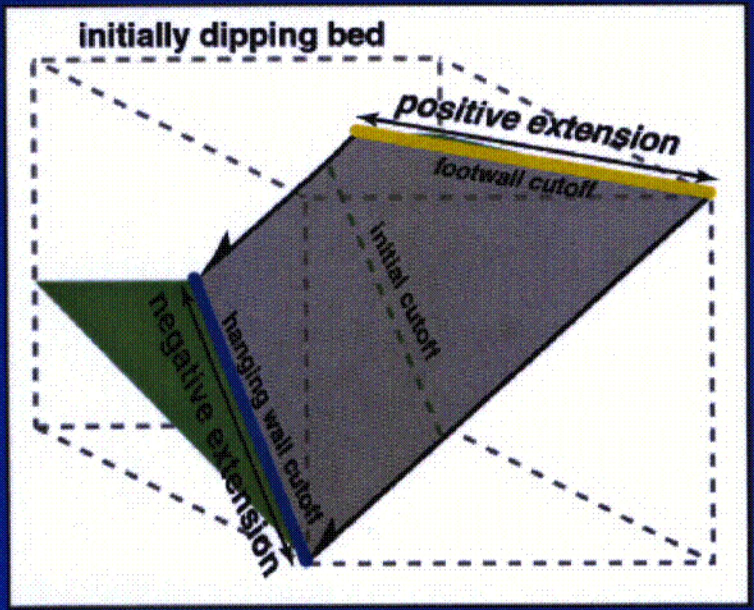
CRITICAL INPUT FOR ANALYZING FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:

- Fault orientations ✓
- Slip vector orientations ✓
- Initial bedding orientation
  - Test various initial bedding orientations



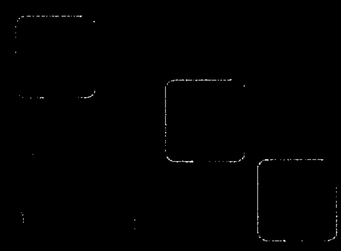
Step 6



C12

ANALYSIS OF FAULTS AT YUCCA MOUNTAIN

Calculation of cutoff line elongation requires:



Cutoff elongation maps of Yucca Mountain developed using:

- faults from the GFM
- deformed cutoff geometries from GFM
- alternative original layering orientations
- fault slip directions calculated using 3DStress™ v. 1.3.3
- effective stress magnitudes from Ferrill et al. (1999)
- alternative extension directions (E-W, WNW-ESE)

ANALYSIS OF FAULTS AT YUCCA MOUNTAIN

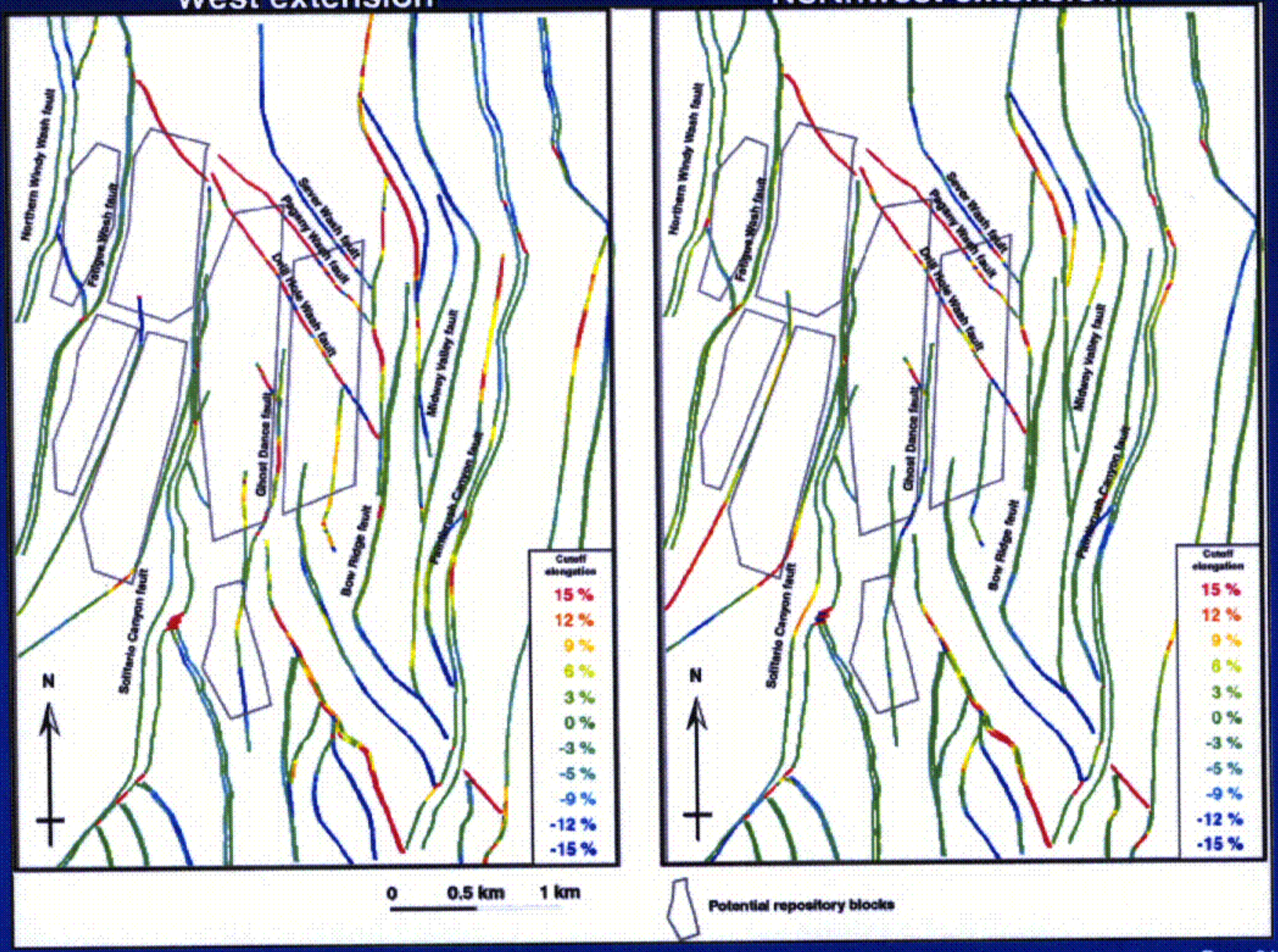
The following four slides show the sensitivity of cutoff parallel elongation at Yucca Mountain to initial layer dip.

SENSITIVITY ANALYSIS

Initial dip = 0°

West extension

Northwest extension



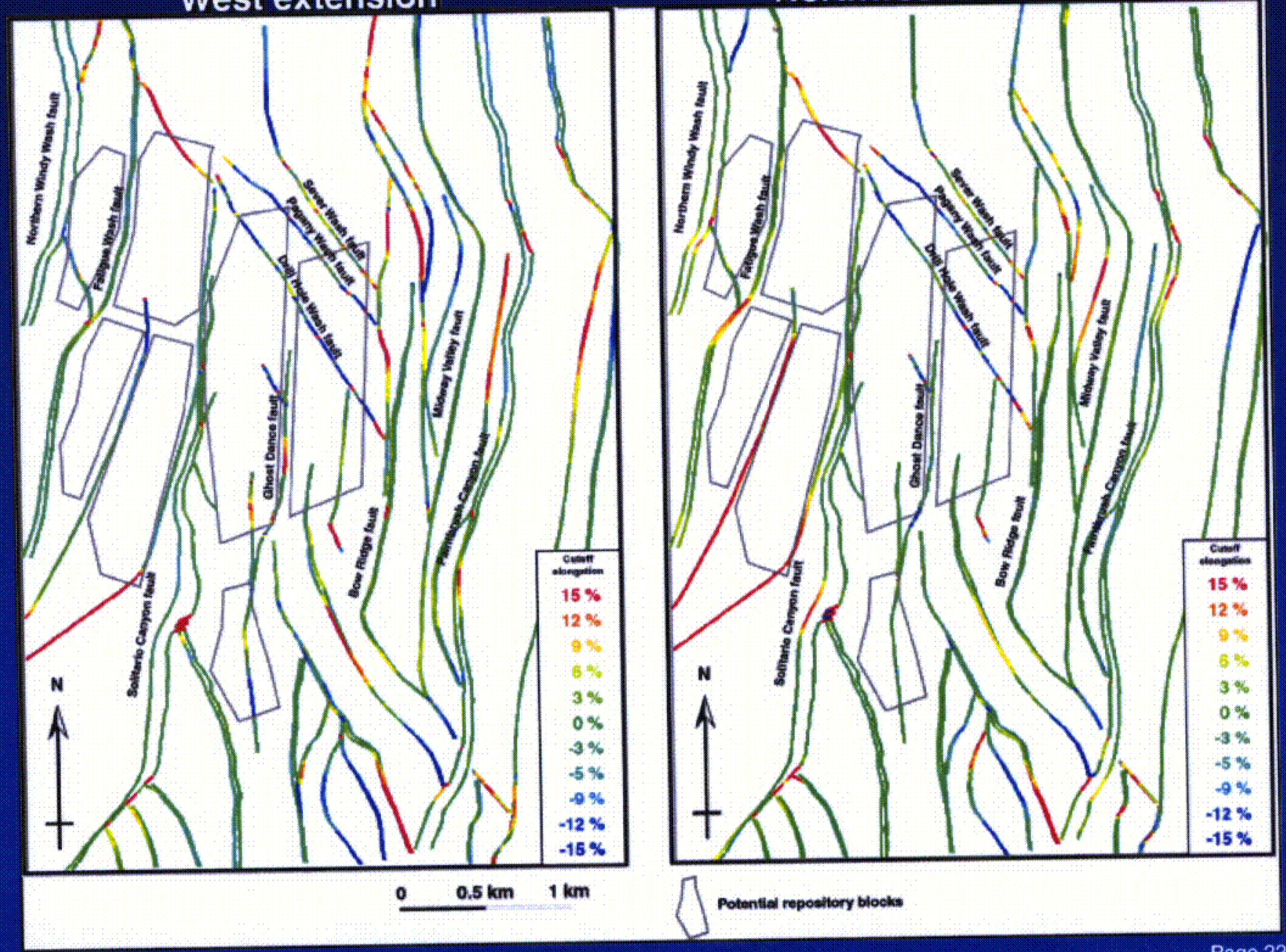
C13

SENSITIVITY ANALYSIS

Initial dip = 8^{o} E

West extension

Northwest extension

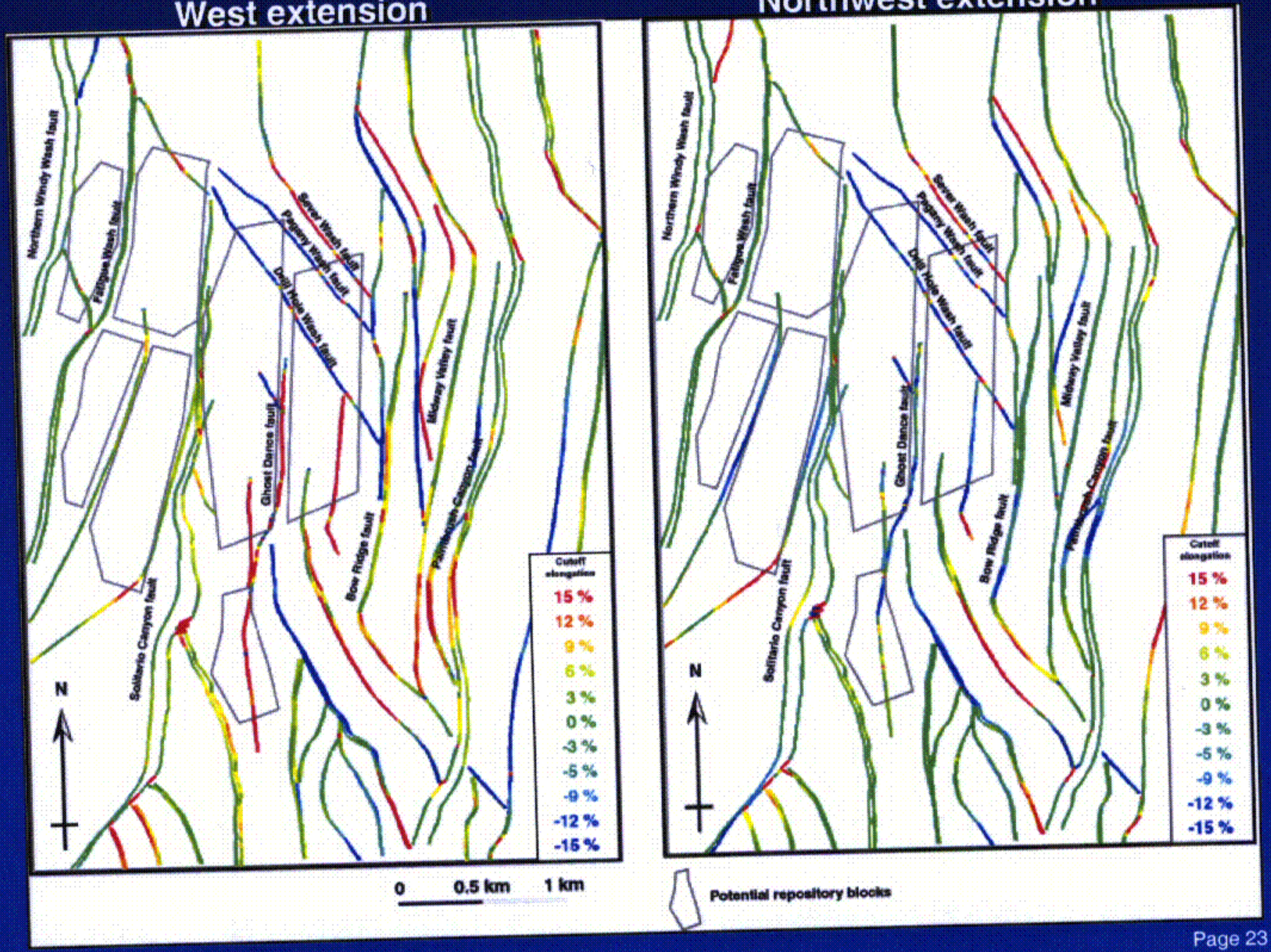


C14

SENSITIVITY ANALYSIS

Initial dip = 8° SE

West extension | Northwest extension



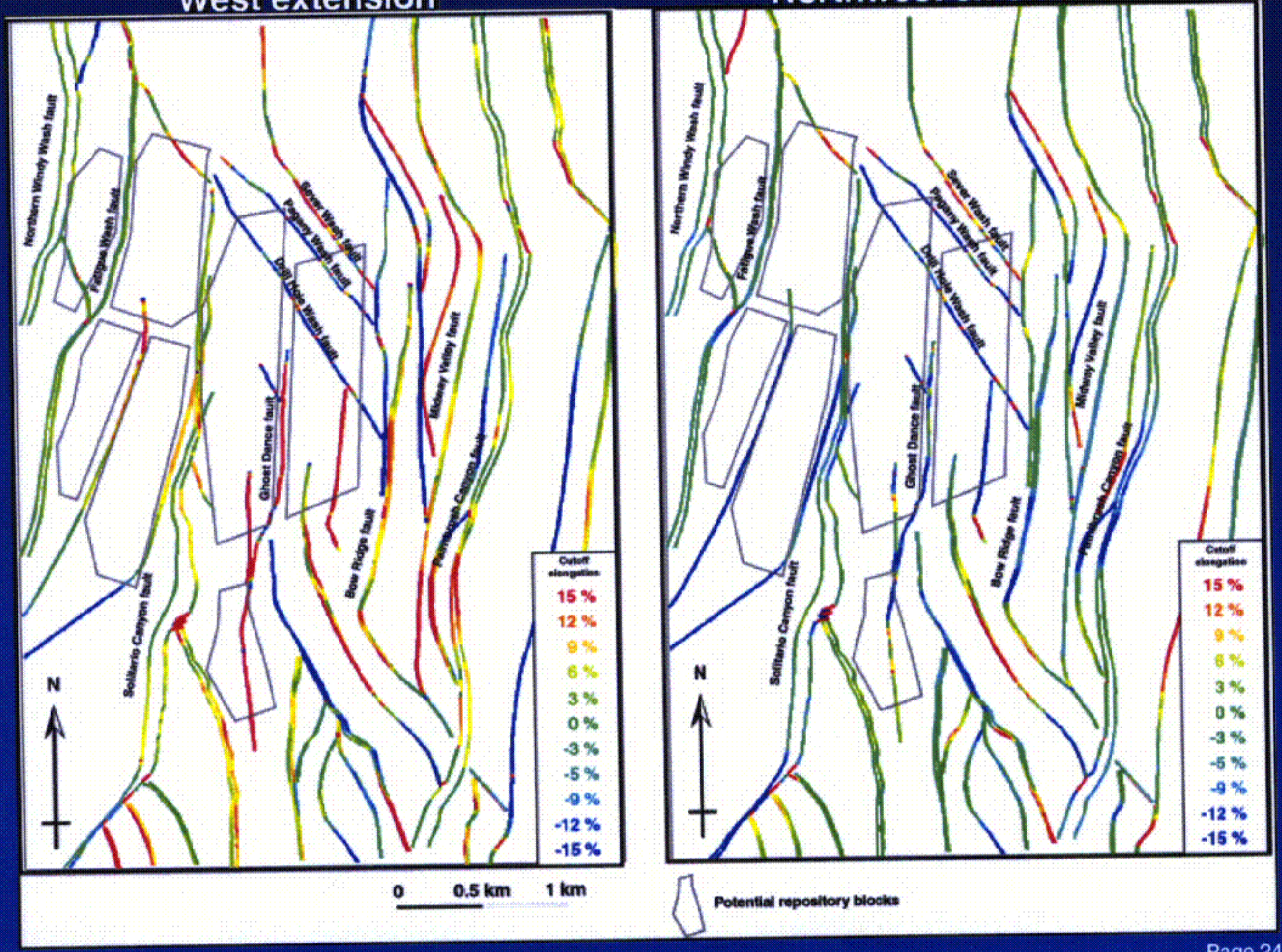
C15

SENSITIVITY ANALYSIS

Initial dip = 8° S

West extension

Northwest extension



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SUMMARY 1

- Cutoff elongation, and consequently the distribution and orientation of fractures within fault blocks are sensitive to:
  - stress system and resulting slip directions at time of faulting
  - initial bed orientation

SUMMARY 2

- Preliminary analyses of strains generated by fault displacement gradients indicate that many parts of Yucca Mountain may have experienced significant strains.

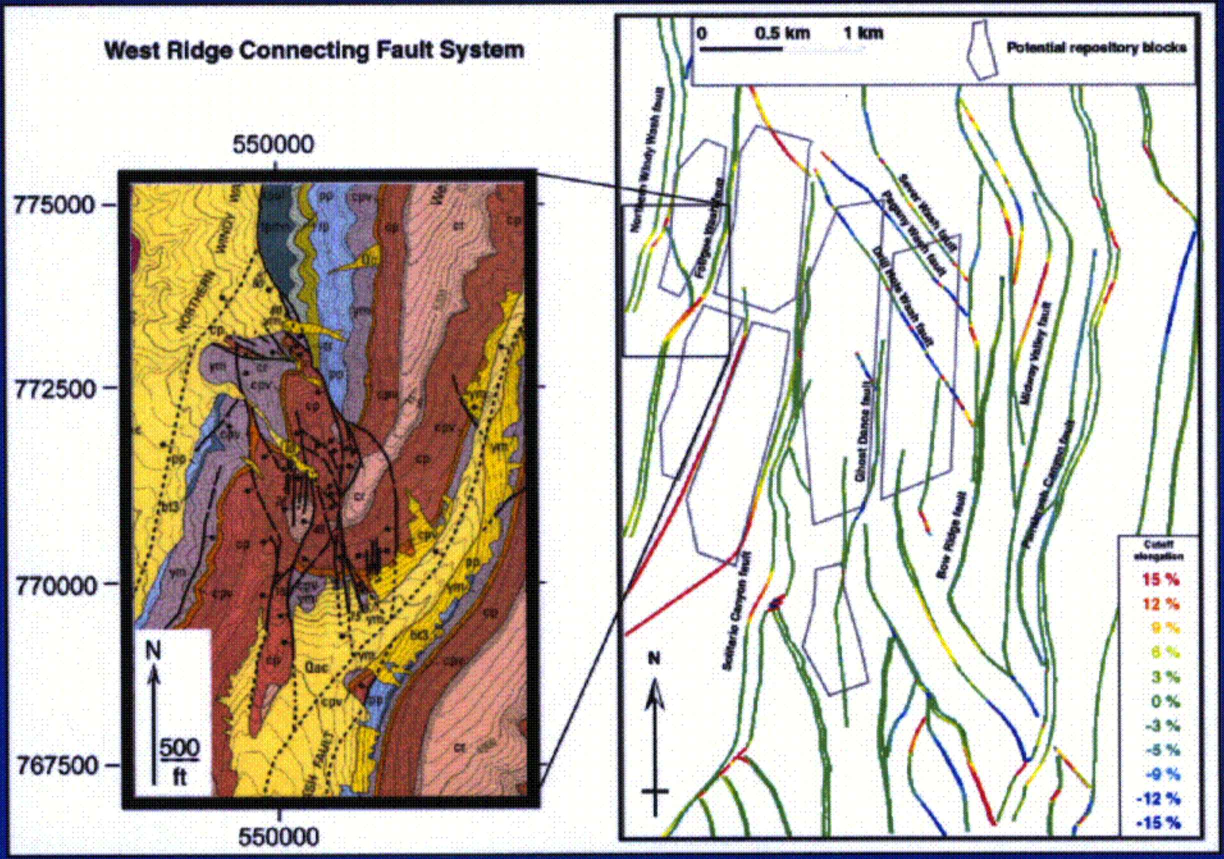
- The variable extension direction at Yucca Mountain since the inception of faulting (prior to 10 Ma) suggests:

  - cumulative strain patterns are likely complex

  - strains generated by fault displacement are more pervasive than a single stress state "snapshot" would suggest

SUMMARY 3

- At Yucca Mountain, one area of documented high fault and fracture density is the West Ridge Connecting fault system. This is consistent with predictions from cutoff elongation analysis.



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CONCLUSION

- Cutoff line elongation analysis in the Yucca Mountain region leads to the conclusion that additional fracture characterization may be needed if the repository is expanded to include additional fault bounded blocks.

- In order to fully characterize other fault blocks, it is necessary to investigate the possibility that fault displacement gradients have influenced strain intensity and orientation in the fault blocks under consideration for repository expansion.

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CRWMS M&O. "Geologic Framework Model (GFM 3.1) Analysis Model Report." MDL–NBS–GS–000002. Revision 00 ICN 01. Las Vegas, Nevada: CRWMS M&O. 2000.

Day, W.C., R.P. Dickerson, C.J. Potter, D.S. Sweetkind, C.A. San Juan, R.M. Drake, II, and C.J. Fridrich. "Bedrock Geologic Map of the Yucca Mountain Area, Nye County, Nevada." U.S. Geological Survey Miscellaneous Investigations Series Map I-2627. Scale 1:24,000. 1998.

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Morris, A.P., D.A. Ferrill, D.B. Henderson. "Slip Tendency Analysis and Fault Reactivation." Geology. Vol. 24. pp. 275–278. 1996.