ASSESSING THE POTENTIAL FOR FAULT DISPLACEMENT FOR HIGH-LEVEL NUCLEAR WASTE REPOSITORIES

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ASCE WORKING GROUP RECOMMENDATIONS WITH RESPECT TO FAULT DISPLACEMENT HAZARDS

- Characterize Quaternary History of Fault Displacement
  - Location and geometry
  - Sense and amount of displacement
  - Likelihood of occurrence

There are accepted direct and indirect methods for quantifying these parameters and their associated uncertainty

ASCE WORKING GROUP RECOMMENDATIONS WITH RESPECT TO FAULT DISPLACEMENT HAZARDS

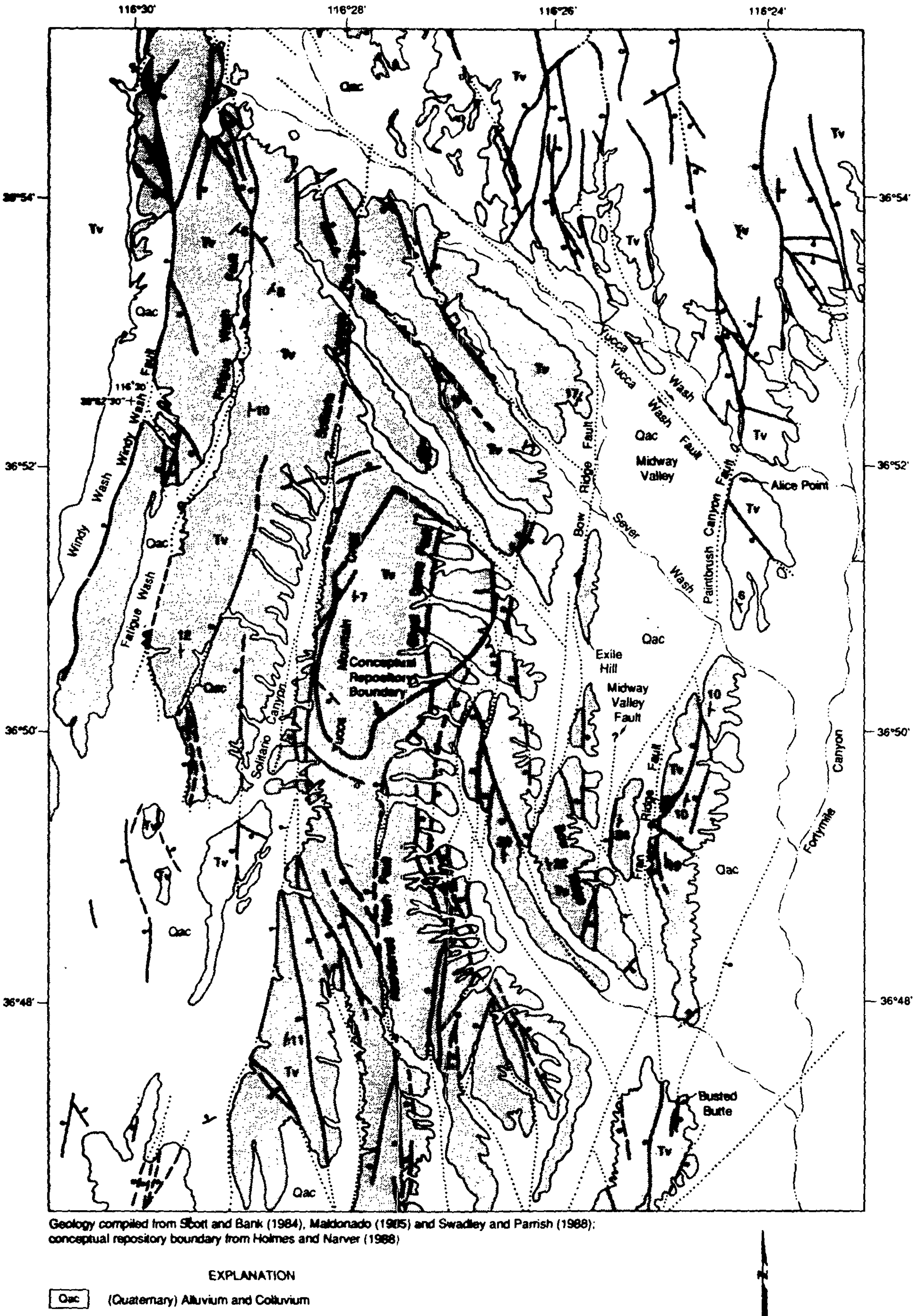
- Combined Probabilistic and Deterministic Approach to Quantify Faulting Hazard
  - Quantifies uncertainty in the input parameters and analytical methods
  - Test sensitivity of results
  - Prioritize issues and focus investigation/analyses on the significant factors

ASCE WORKING GROUP RECOMMENDATIONS WITH RESPECT TO FAULT DISPLACEMENT HAZARDS

- Need to Clearly Define the Relation Between Hazard and Risk to Assess:

  1. Level of acceptable hazard

  2. Appropriate design measures to mitigate unacceptable effects of fault hazards



Geology compiled from Scott and Bank (1984), Maldonado (1985) and Swadley and Parrish (1988); conceptual repository boundary from Holmes and Narver (1988)

EXPLANATION

Qac (Quaternary) Alluvium and Colluvium

Tv (Tertiary) Silicic Volcanic Rocks

Fault - dotted where concealed; ball and bar on downthrown side; arrows indicate relative movement

17 Strike and dip of bedding or foliation

0 2 km

POTENTIAL FOR FAULT RUPTURE

"Fault Rupture" includes the displacement that may occur on primary faults as well as any associated deformation (folding and secondary faulting).

- Location and three-dimensional geometry of faults relative to the location of the repository
- Sense of slip
- Amount of net slip per event and/or the cumulative net slip during the "design life" of the facility of concern
- Likelihood of occurrence
  - activity
  - earthquake recurrence characteristics
  - slip rate

BASIC PREMISE

- Future fault slip will re-occur at the same locations and in the same manner as geologically recent (Quaternary) past displacements
  - future fault displacements will only occur on pre-existing faults
  - the likelihood of future displacements is related to the frequency of the most recent past displacements
  - the tectonic forces that cause faulting are assumed to be constant over the geologically short period of concern (next 10,000 years)
- Unfaulted bedrock will remain unfaulted

THE PAST IS THE KEY TO THE FUTURE

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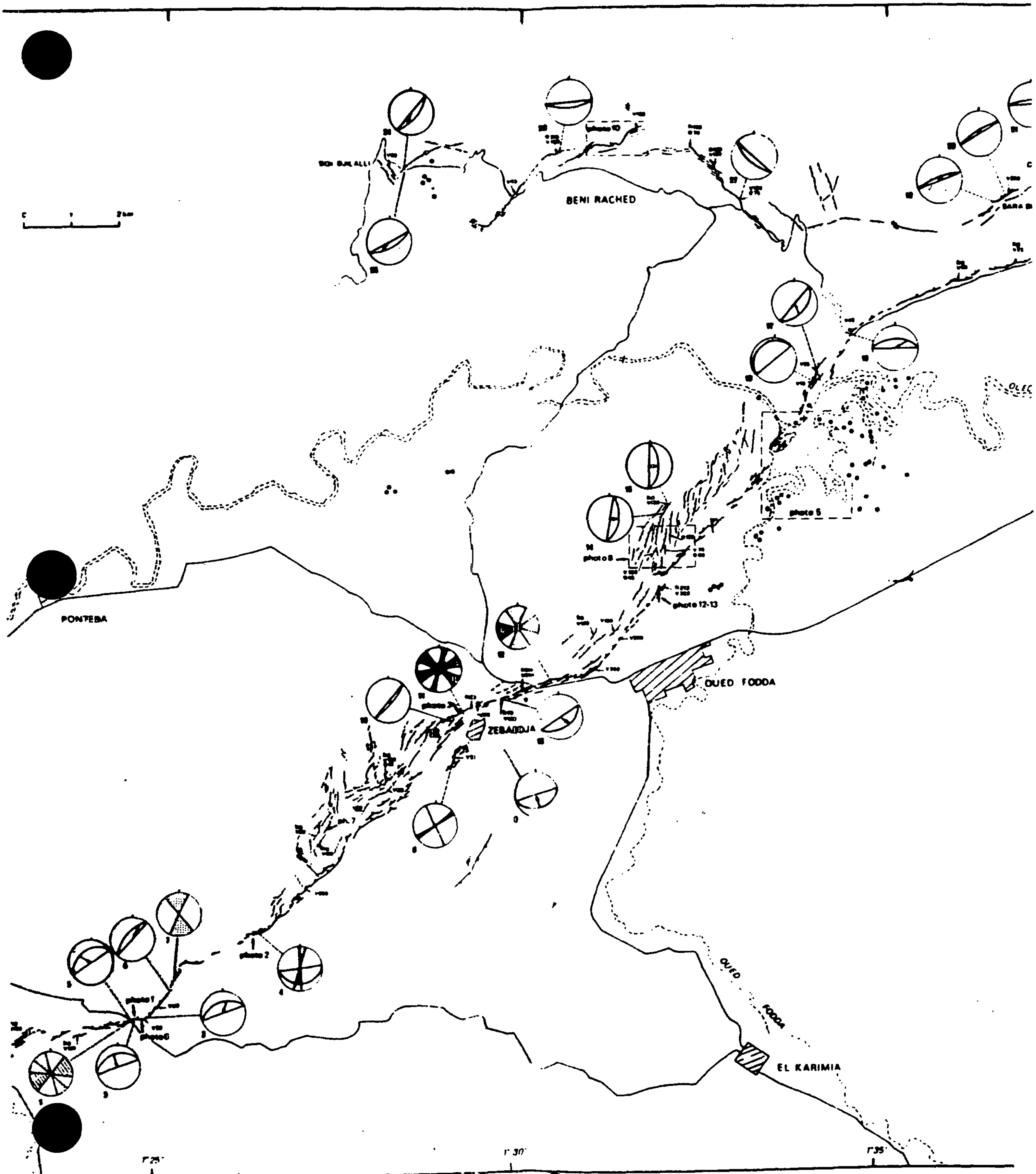
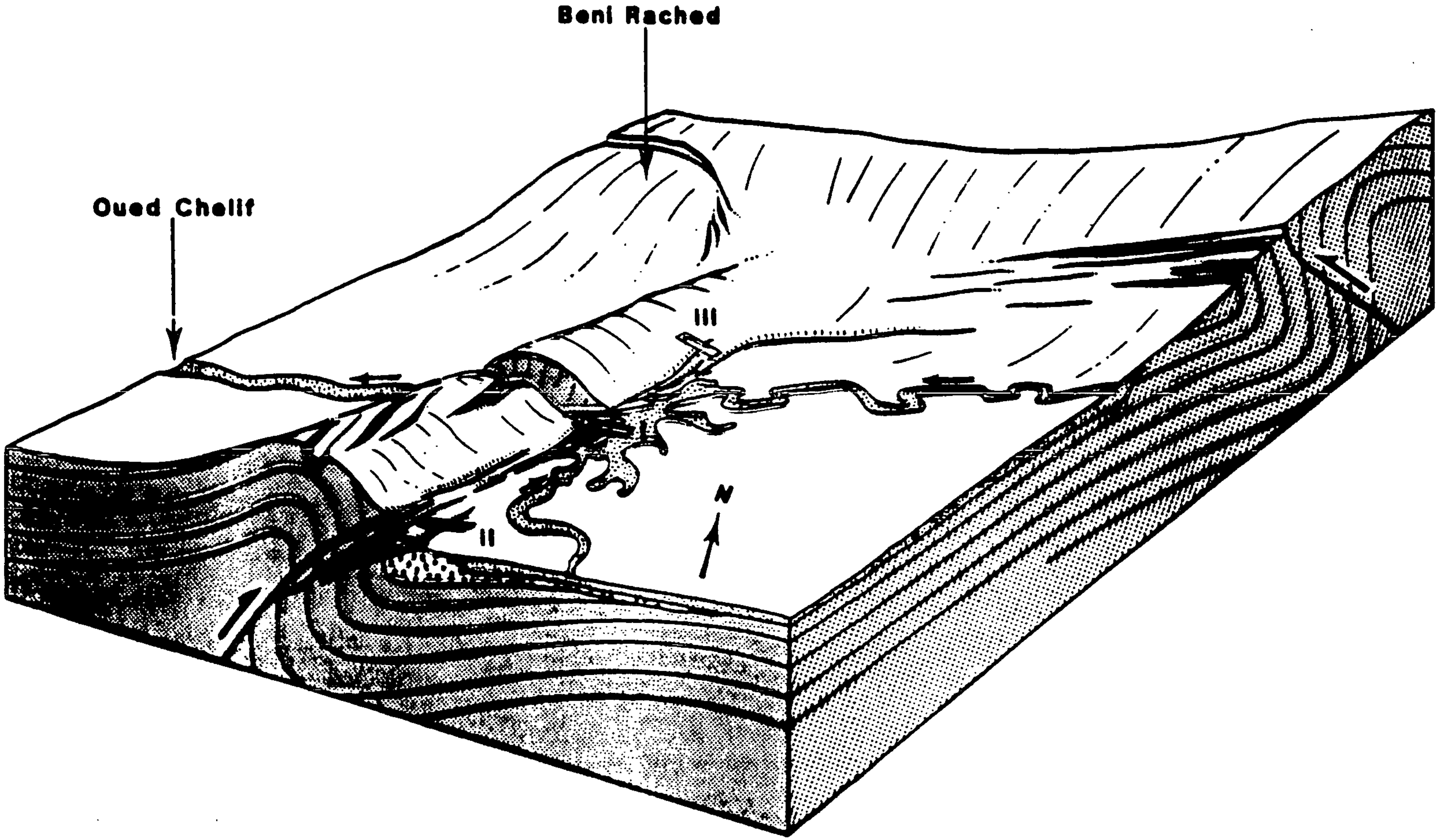


1980 El Asnam EQ, Algeria



Trench locations and geomorphologic environment near central segment of the El Asnam thrust fault. Damming of rivers was caused by the thrust fault, and it took place at the entrance of the canyon where tilted and uplifted terraces can be observed in the field. Trench sizes are shown schematically and are not drawn to scale.

THE MOST DIRECT APPROACH FOR ASSESSING THE POTENTIAL FOR FAULT RUPTURE IN THE REPOSITORY IS TO:

1) Determine the locations and three-dimensional geometry of the faults in the vicinity that could affect the performance of the repository if they were to experience displacement(s) during the next 100 years (pre-closure) or 10,000 years (post-closure).

2) Reconstruct the history of Quaternary displacement on the faults that could impact the site.

CRITERIA MUST BE FLEXIBLE ENOUGH TO ALLOW FOR

1) Different functions (and risk factor) associated with the various elements of a HLNWR

2) Pre-closure (~100 yr) versus post-closure (10,000 yr) considerations

3) Different approaches to mitigate risk are appropriate for different parts of the repository. Approaches may include:
   - Determine that risk is acceptably low
   - Locate facilities to avoid "active" faults
   - Design for fault displacement

AREAS OF INVESTIGATION

- Major Tectonic Features Only (~100 km)
- Earthquake Sources (~50 km)
- Potential for Fault Displacement
  (Focus on Site to 10-20 km)

DETERMINISTIC VERSUS PROBABILISTIC APPROACHES

DETERMINISTIC

- Faults are classified as either "active" or "not active"
- If active, determine the "maximum credible" **event/scenario**

PROBABILISTIC

- Explicitly incorporates uncertainty in the analysis
  - analytical models
  - input parameters

DETERMINISTIC VERSUS PROBABILISTIC APPROACHES Cont.

- Considers full range of possibilities ("maximum" & "minimum") to assess the "most likely" event/scenarios

- Test sensitivity of results to various input parameters
  - prioritize issues in terms of their potential impacts
  - focus investigations on the issues important to design and performance

LIMITATIONS TO DIRECT APPROACH:

- Incomplete structural information on the location and geometry of faults

- Limited distribution of Quaternary deposits, soils and geomorphic surfaces that can be used to reconstruct the history of faulting

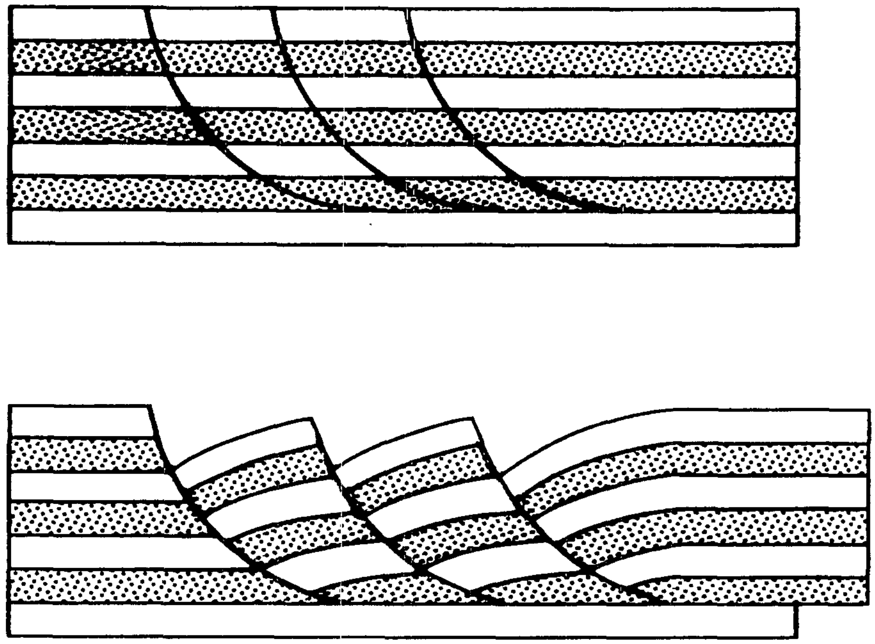
  - incomplete cover resulting from non-deposition and or erosion

  - uncertainties in the ages of the deposits

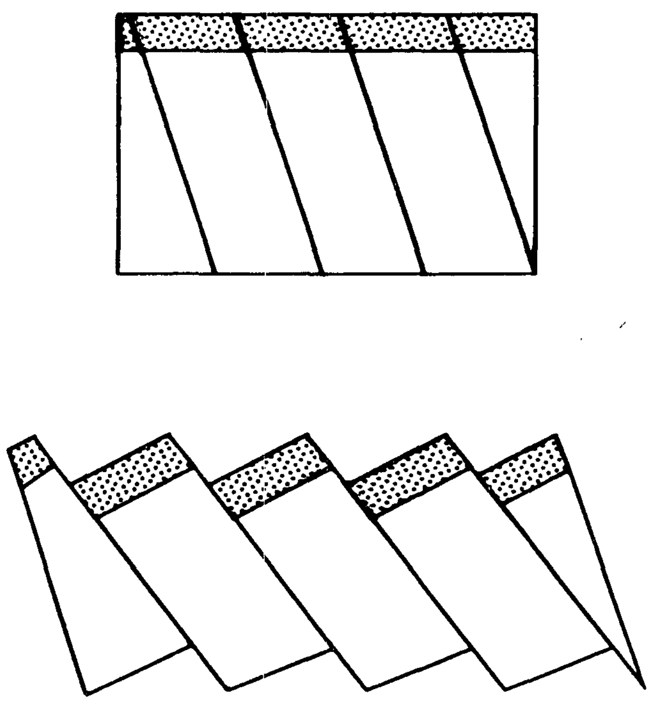
INDIRECT APPROACHES:

- Regional Tectonic Models and Local Structural Models
- Comparisons to historical fault ruptures
- Analogies based on paleoseismic investigations of similar faults in the vicinity of the proposed repository

USE OF TECTONIC/STRUCTURAL MODELS AS PREDICTIVE TOOLS

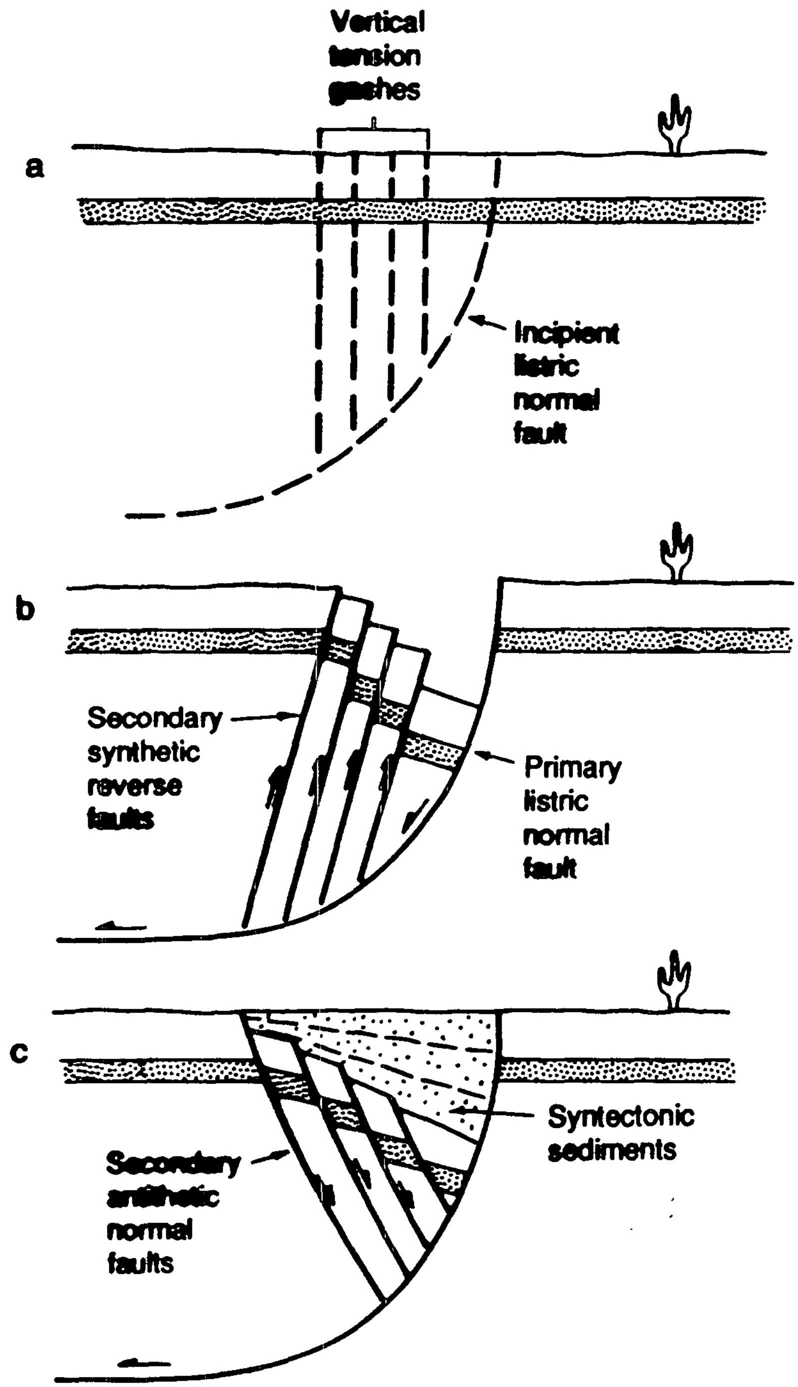


A

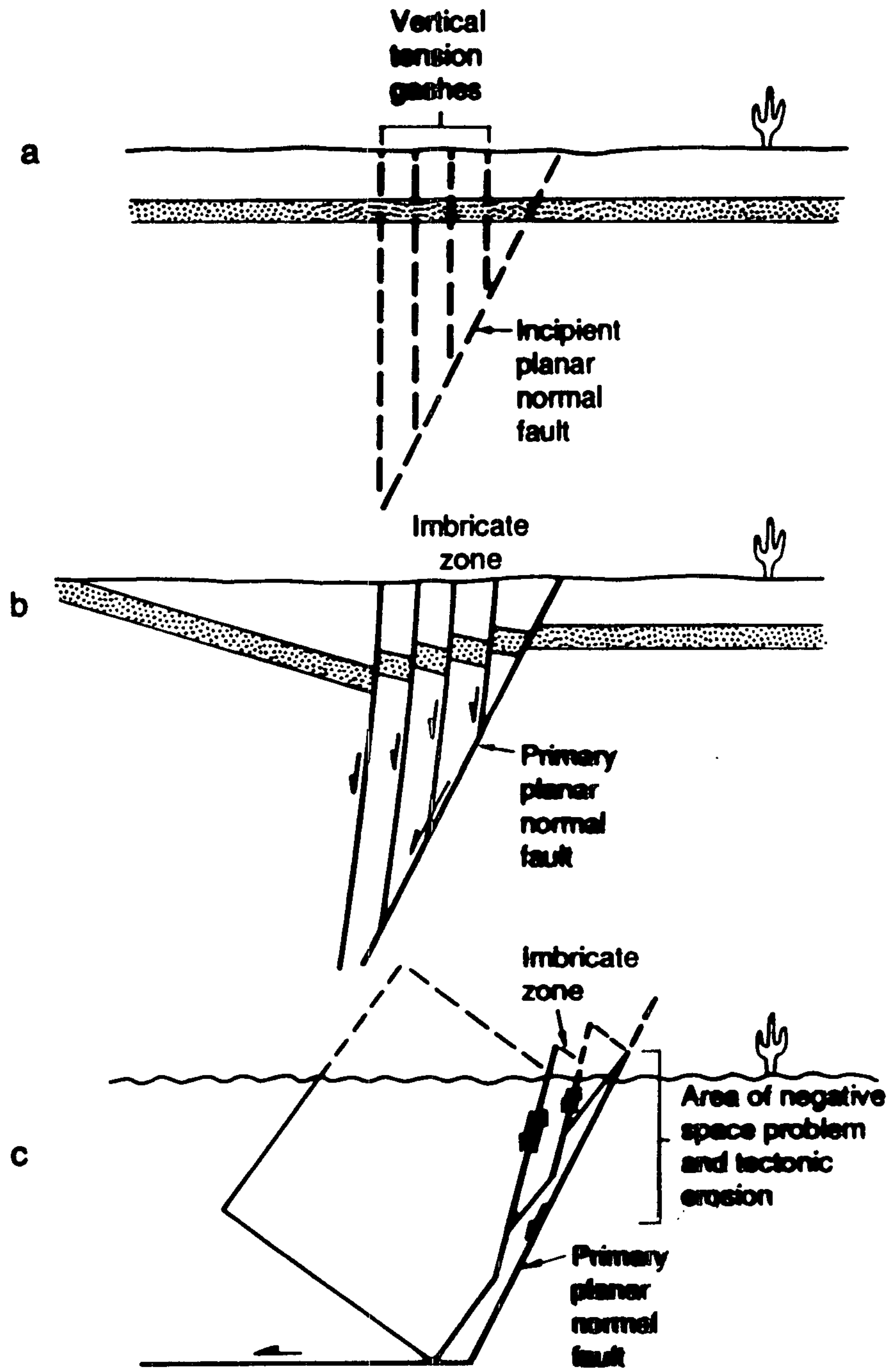


B

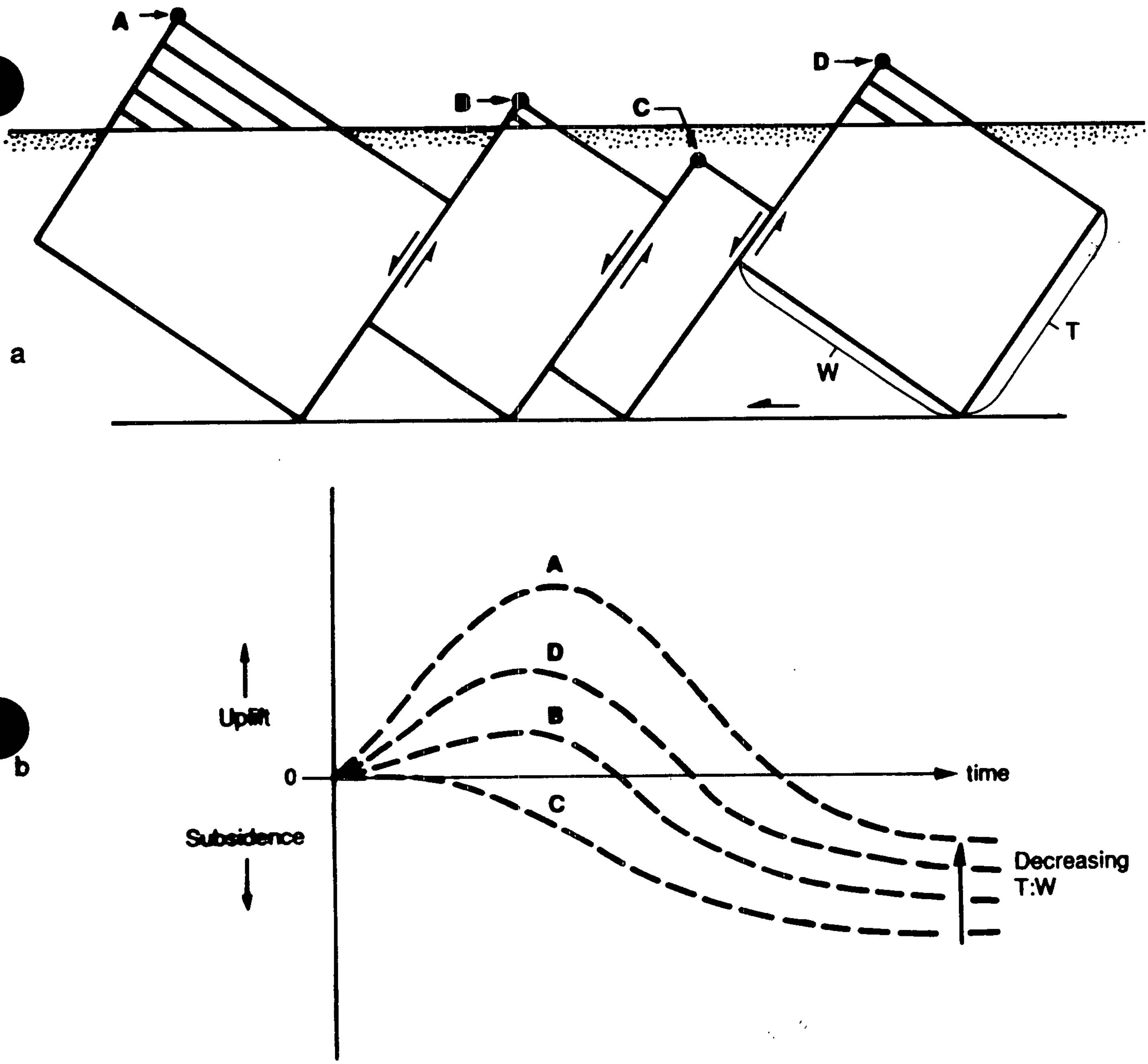
Schematic models of extensional fault systems.
A) Listric normal fault system; B) Planer rotational (domino-style) normal fault system.



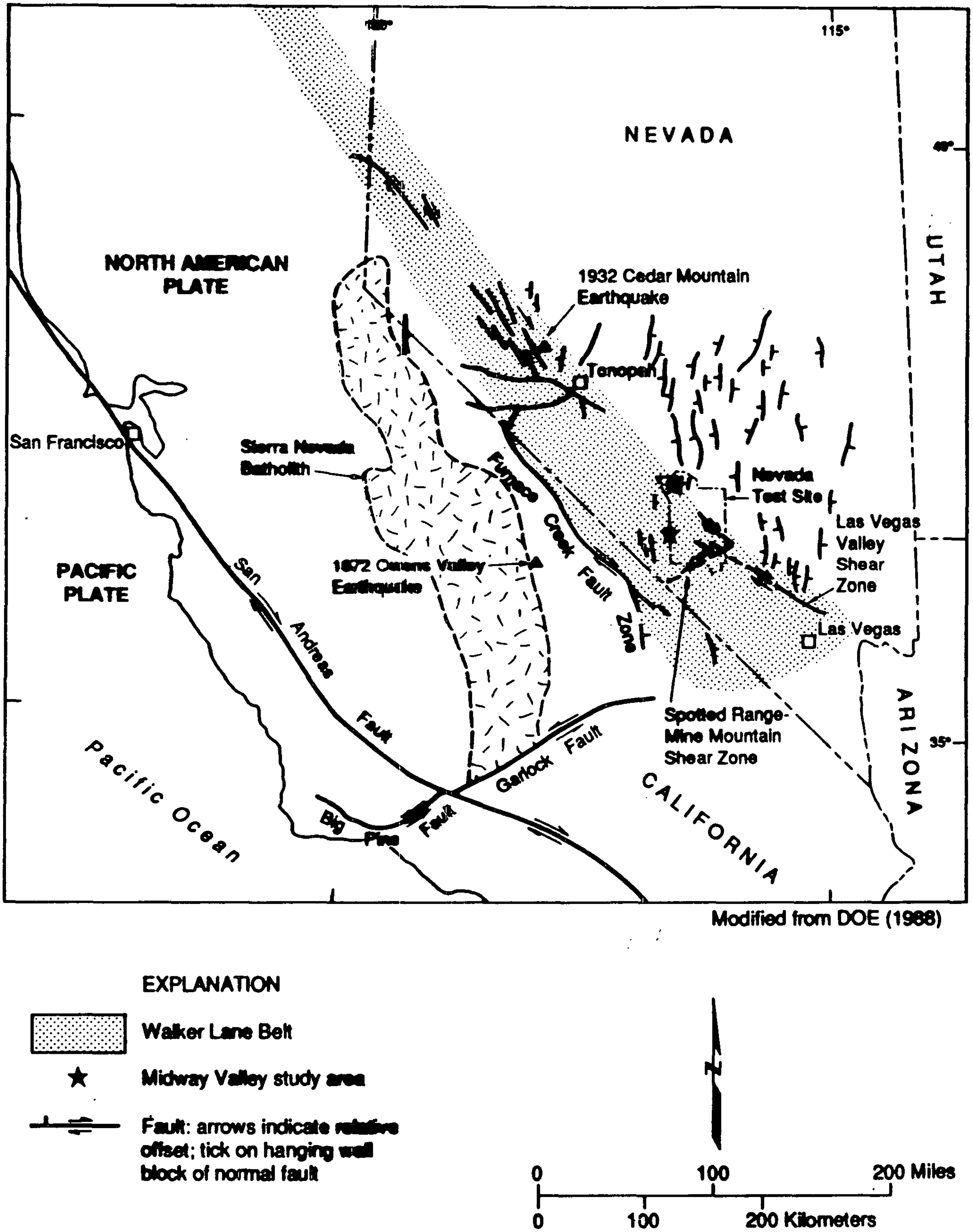
Kinematic development of secondary synthetic and antithetic minor faults in the hanging wall of a listric normal fault. Synthetic faults (4-8b) will have reverse displacement; antithetic faults (4-8c) will have normal displacement. Figures not drawn to scale; all displacements greatly exaggerated.



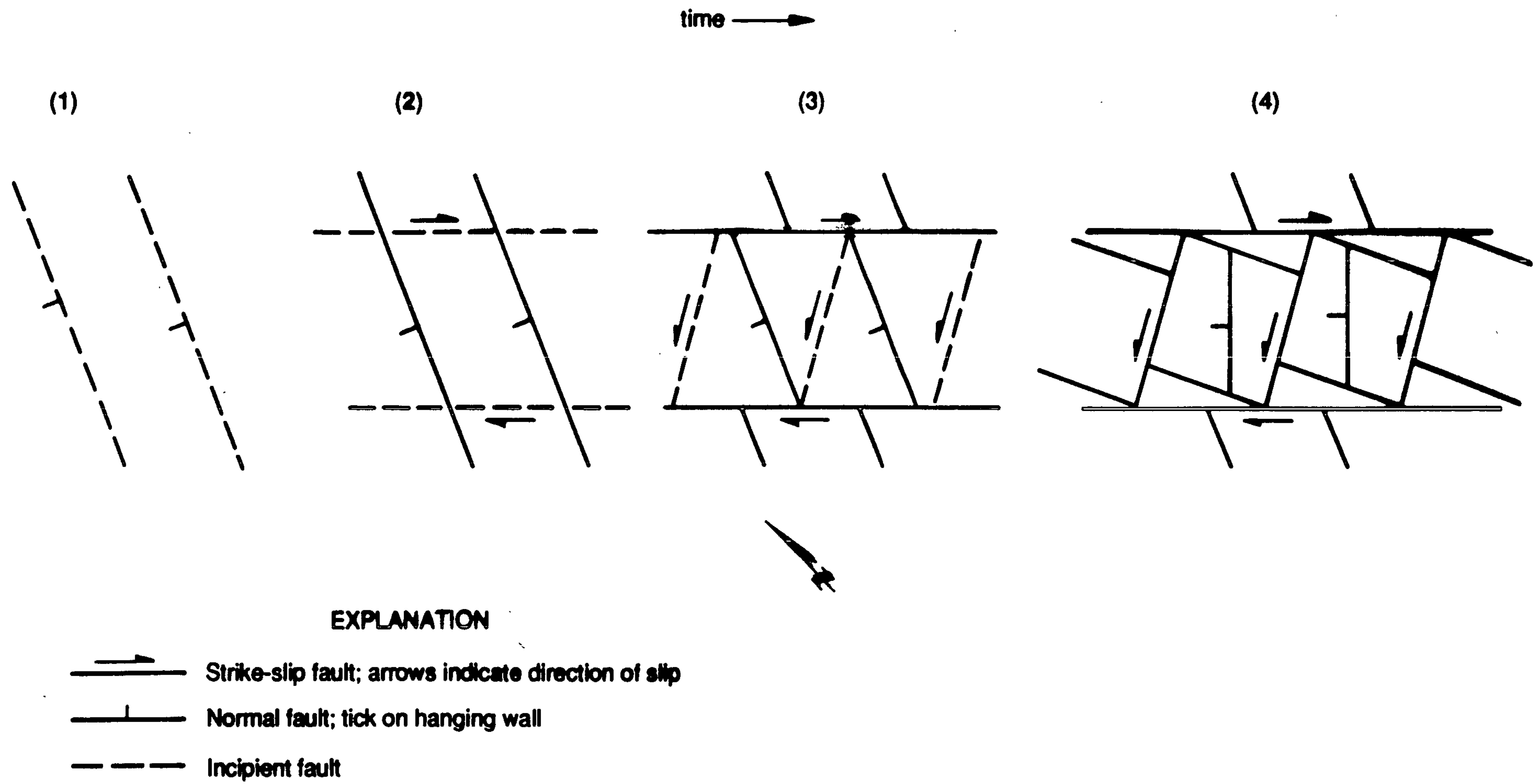
Kinematic development of secondary synthetic normal faults in the hanging wall of a planar normal fault. Secondary normal faults result from tectonic erosion of the hanging wall. Figures not drawn to scale; all displacements greatly exaggerated.



Relationship between thickness: width ratios and uplift/subsidence of fault blocks during dominoe-style faulting on planar normal faults. Figures not drawn to scale; all displacements greatly exaggerated.

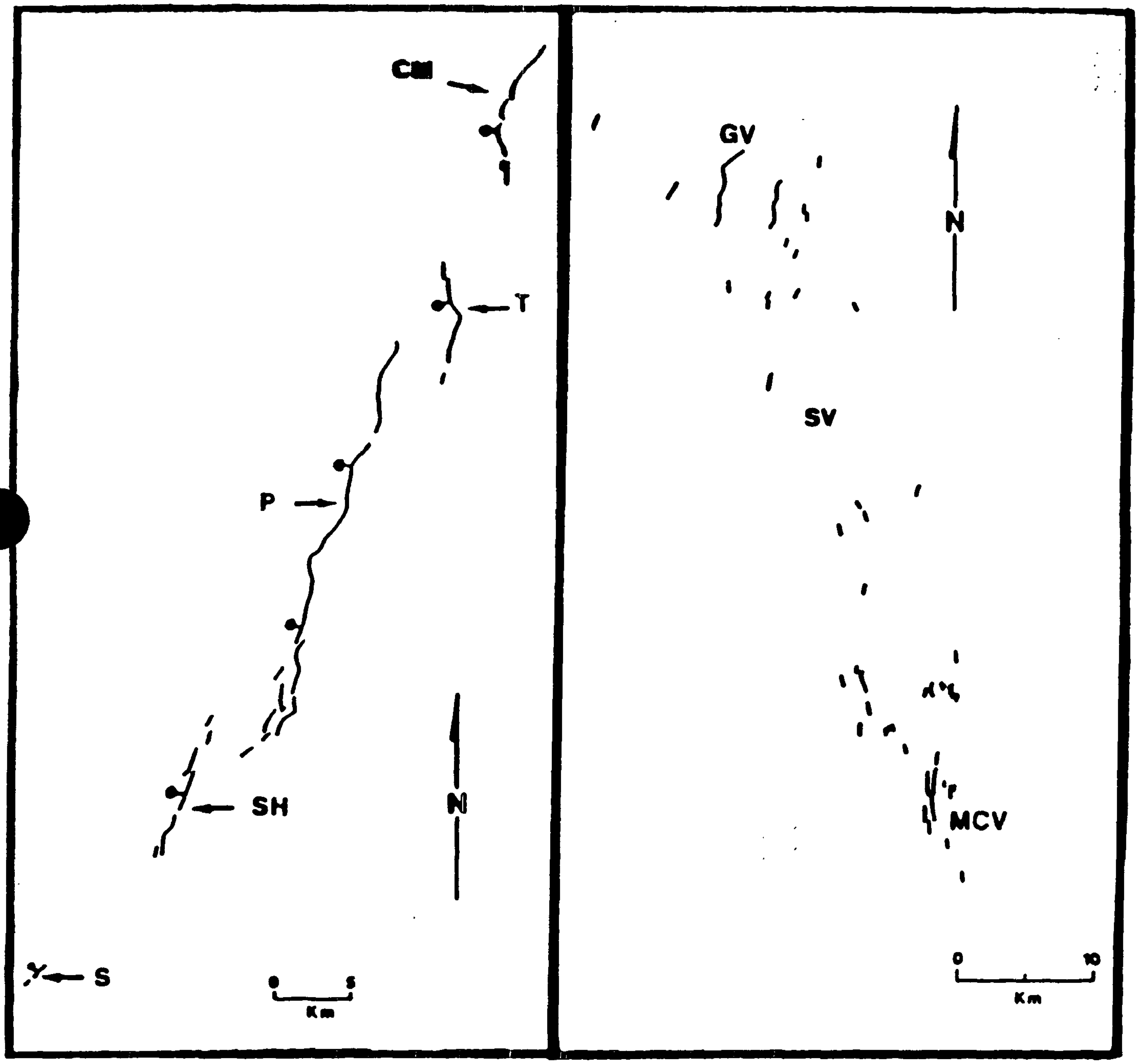


From Gibson and others (1991)



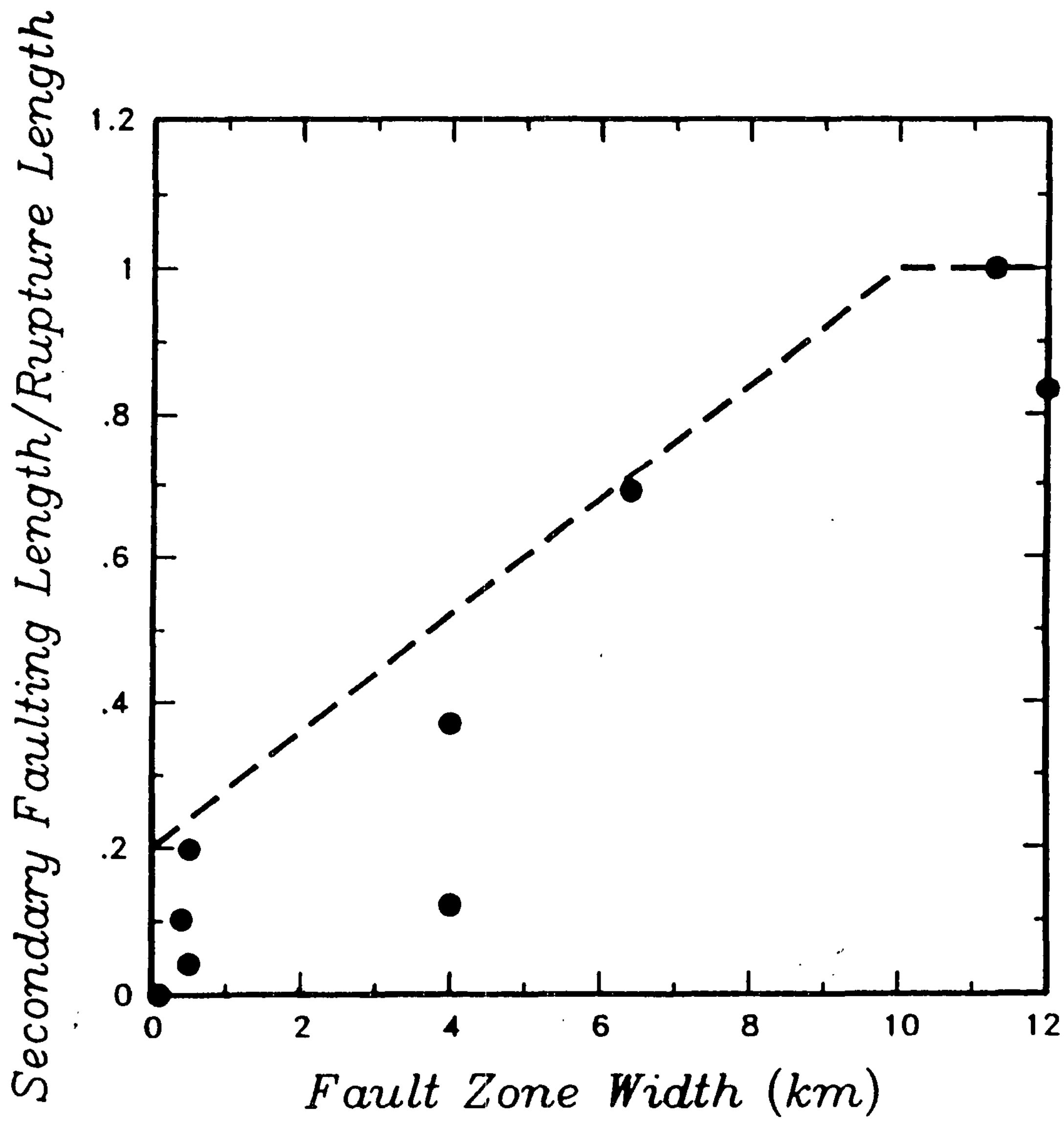
Map view kinematic model relating the major fault systems of the southern Walker Lane Belt to a right-lateral simple shear couple.

COMPARISONS TO FAULT RUPTURES ASSOCIATED WITH HISTORICAL EARTHQUAKES



Examples of pattern of surface faulting in Basin and Range normal faulting earthquakes. On left is 1915 Pleasant Valley earthquake and on right is the 1932 Cedar Mountain earthquake. From (8)

From EPRI NP - 7057



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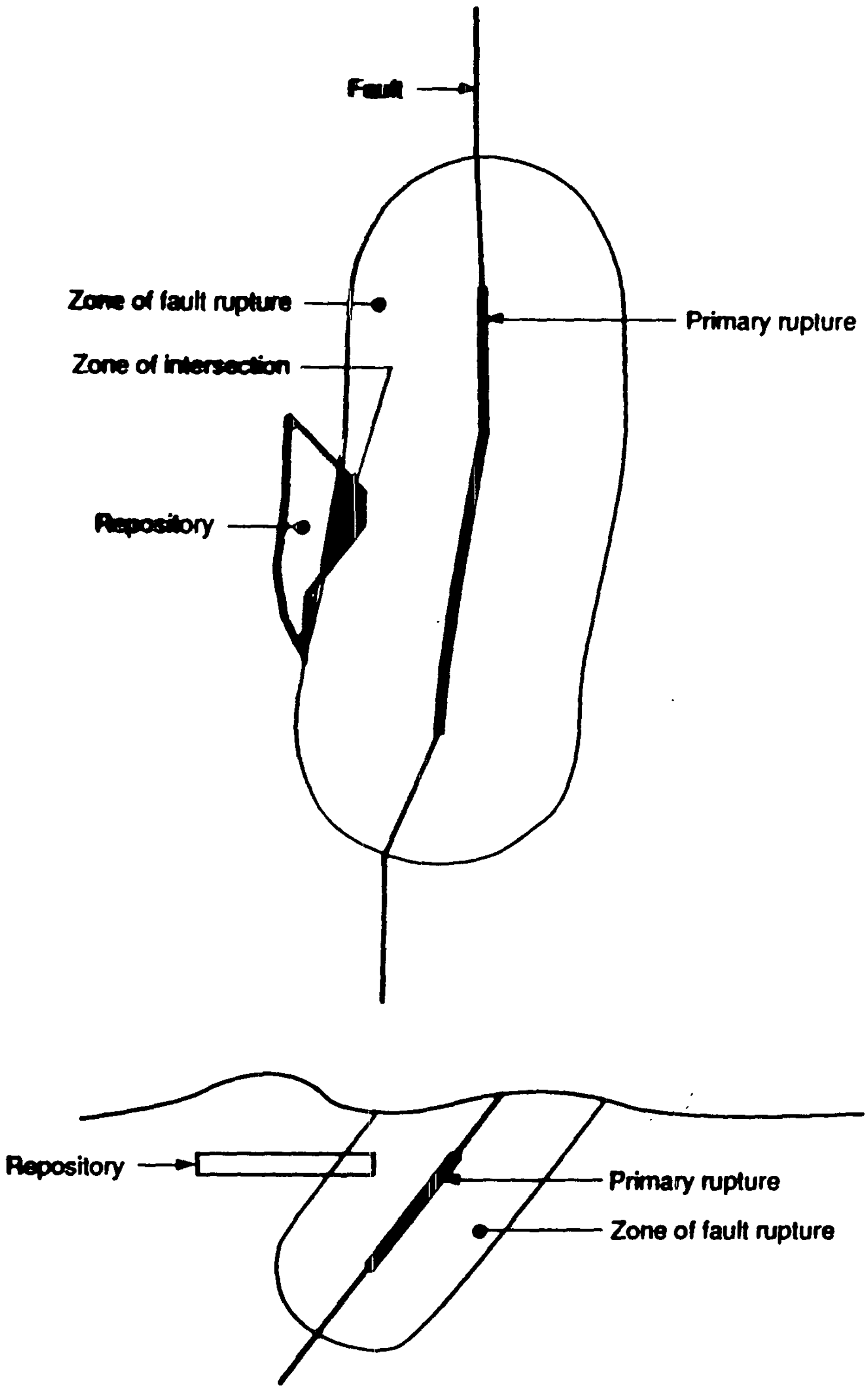
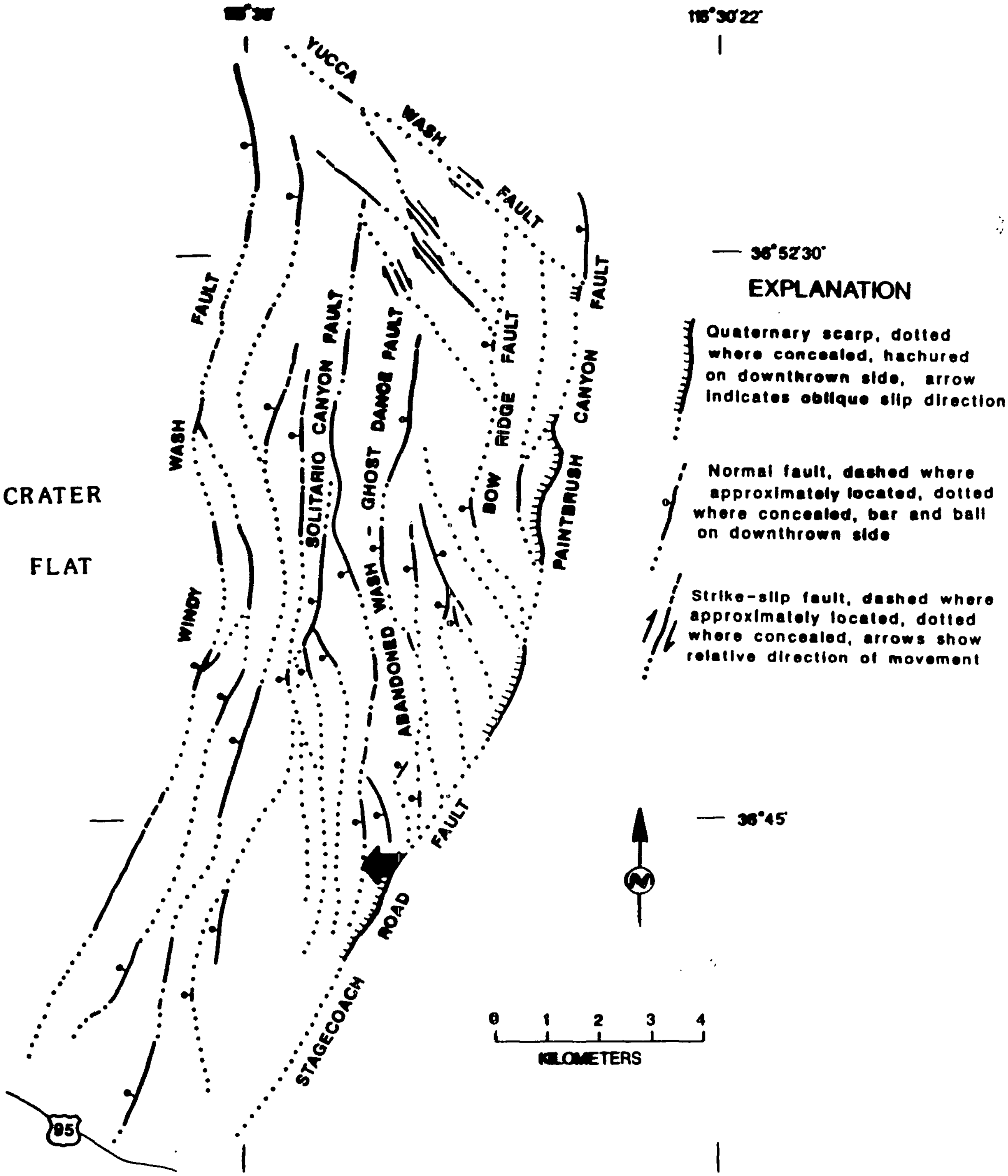


Illustration of simulation of a zone of faulting for a single event occurring on a fault near the repository. Shaded area represents the area of interSection of the rupture zone with the repository footprint.

COMPARISONS BASED ON PALEOSEISMIC INVESTIGATIONS OF SIMILAR FAULTS IN THE VICINITY OF THE REPOSITORY



From R. B. Scott (1990)

ESTIMATING SLIP PER EVENT & CUMULATIVE DISPLACEMENT ON FAULTS IN THE REPOSITORY BLOCK DURING POST-CLOSURE PERIOD

1) Direct Observational Data.

Data are generally limited to geometry and cumulative displacement on faults in Tertiary bedrock.

2) Indirect Approach:

a) Primary Faults

- (inferred slip rate) x (fault geometry) = moment rate

- Utilize moment rate and earthquake recurrence model(s) to derive magnitude frequency distribution of earthquakes.

ESTIMATING SLIP PER EVENT & CUMULATIVE DISPLACEMENT ON FAULTS IN THE REPOSITORY BLOCK DURING POST-CLOSURE PERIOD-Cont.

- Recurrence Model (e.g., log normal versus "characteristic earthquake")

  - M_{max}

  - M_{min}

- Relate resulting magnitudes to displacement

  e.g., Bonilla and others (1980)

  Wells and others (1992)

ESTIMATING SLIP PER EVENT & CUMULATIVE DISPLACEMENT ON FAULTS IN THE REPOSITORY BLOCK DURING POST-CLOSURE PERIOD-Cont.

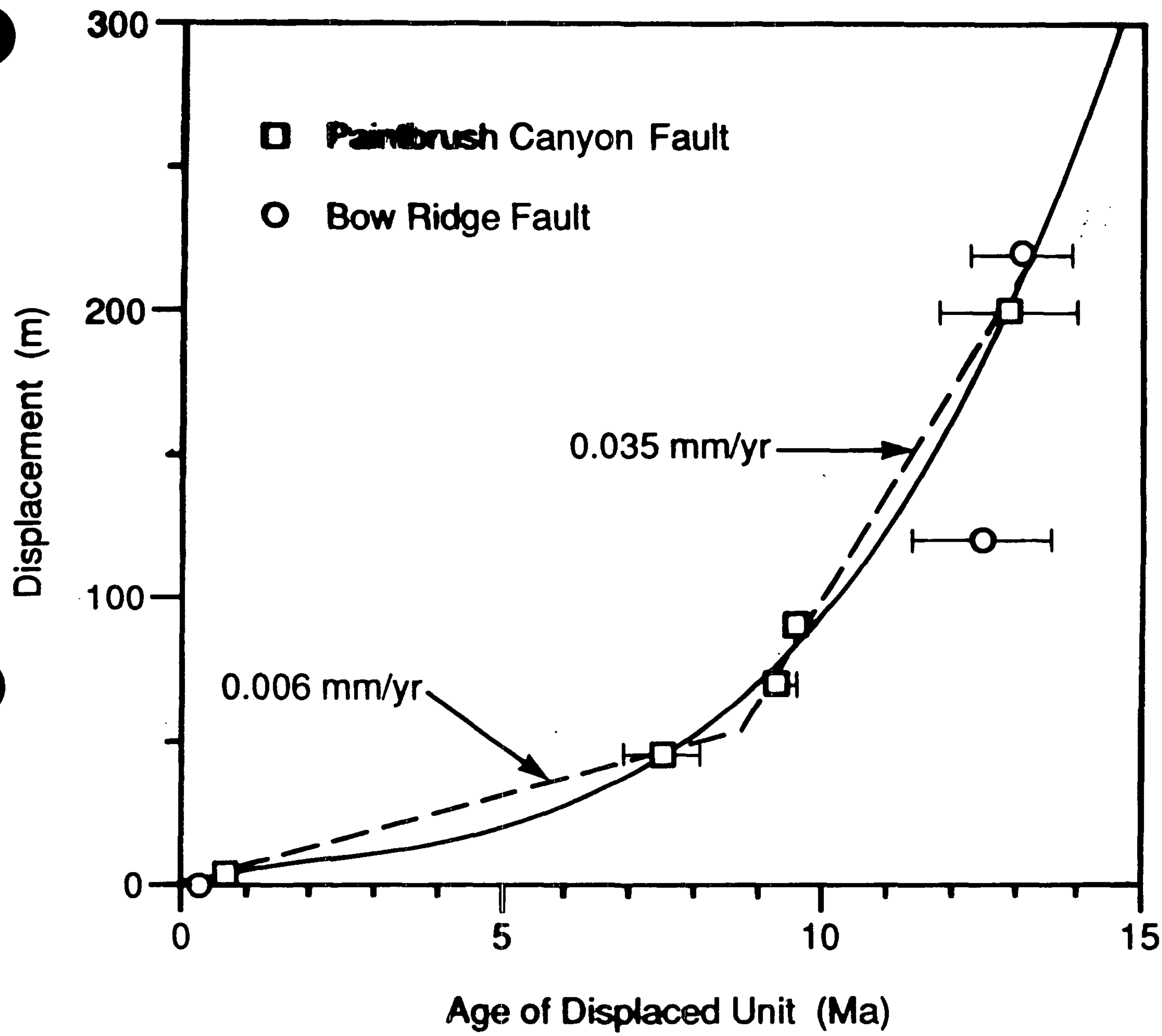
b) Secondary faults

Same as a) plus scaling factor relating slip on primary fault to amount of displacement on secondary fault

Scaling Factors

- fault specific structural models

- empirical observations



Graph showing displacement versus age of displaced unit for the Paintbrush Canyon and Bow Ridge faults. Lines are drawn through Paintbrush Canyon fault data points.

UNCERTAINTIES:

FAULT SLIP RATES

Cumulative Vertical Displacement

Sense of Slip and Amount of Net Slip

Ages of the Displaced Quaternary Horizons

SLIP PER EVENT

- Average
- Maximum

UNCERTAINTIES:
Cont.

EARTHQUAKE RECURRENCE MODELS

- Magnitude frequency distribution
- Temporal and spacial clustering

RELATION BETWEEN FAULTING AT SURFACE AND DISPLACEMENTS AT DEPTH (i.e. REPOSITORY LEVEL)

- Historical examples
- Data from underground excavations (primarily from mining)

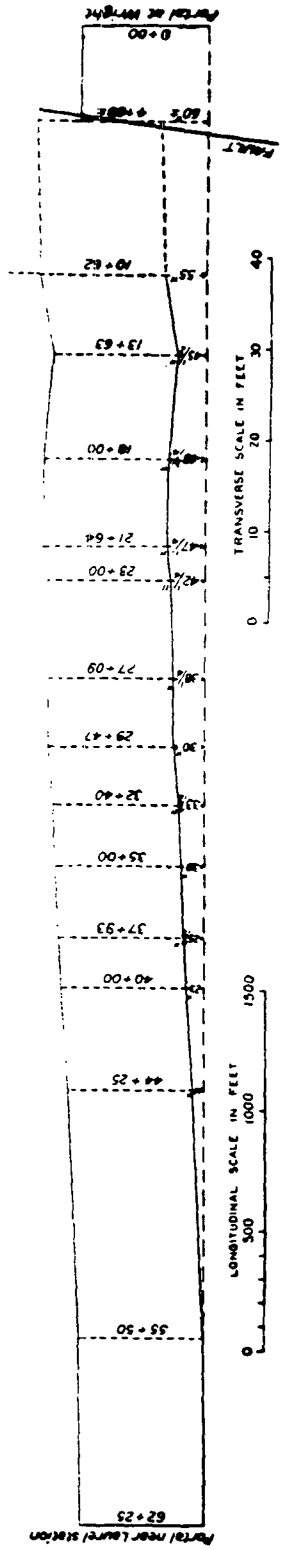


FIG. 42.—Tunnel at Wright Station, showing distribution of deformation.

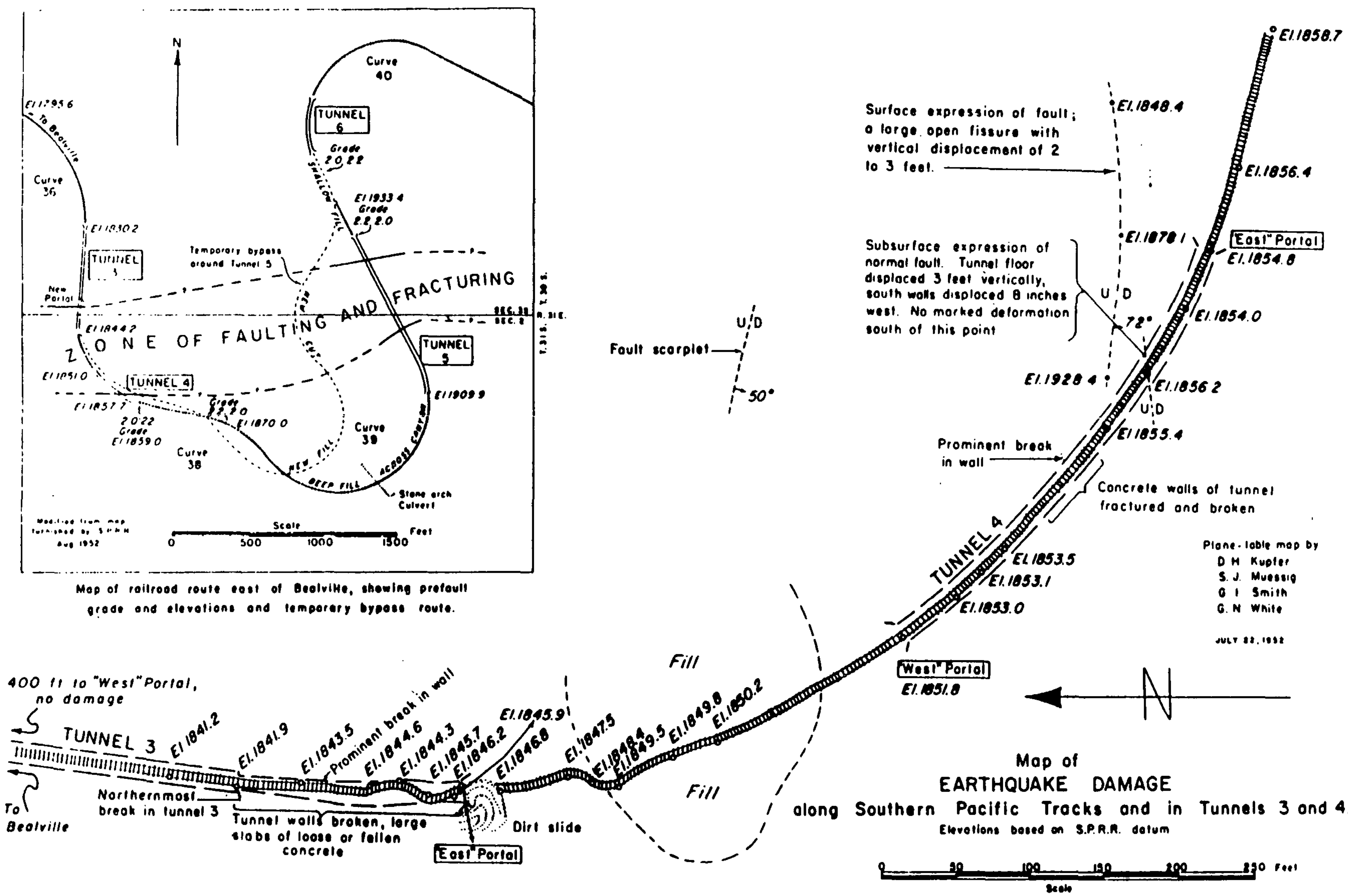

Map of railroad route east of Bealville, showing prefault grade and elevations and temporary bypass route.
ZONE OF FAULTING AND FRACTURING
TUNNEL 6
TUNNEL 5
TUNNEL 4
Curve 40
Curve 36
Curve 39
Curve 38
Temporary bypass around Tunnel 5
Stone arch Culvert
Scale
0 500 1000 1500 Feet
Surface expression of fault; a large open fissure with vertical displacement of 2 to 3 feet.
Subsurface expression of normal fault. Tunnel floor displaced 3 feet vertically, south walls displaced 8 inches west. No marked deformation south of this point
Fault scarplet
Prominent break in wall
Concrete walls of tunnel fractured and broken
Plane-table map by
D. H. Kupfer
S. J. Muessig
G. I. Smith
G. N. White
TUNNEL 4
"East" Portal
"West" Portal
El. 1851.8
Fill
Fill
400 ft to "West" Portal, no damage
TUNNEL 3
To Bealville
Northernmost break in tunnel 3
Tunnel walls broken, large slabs of loose or fallen concrete
"East" Portal
Dirt slide
Prominent break in wall
Map of
EARTHQUAKE DAMAGE
along Southern Pacific Tracks and in Tunnels 3 and 4.
Elevations based on S.P.R.R. datum
0 50 100 150 200 250 Feet
Scale

FIGURE 2.