NRC/PG&E Open Meeting, San Francisco, CA Diablo Canyon Power Plant Independent Spent Fuel Storage Installation

■ 8:00	Introduction	1
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■ 8:10	Overview	Ć
■ 8:40	Seismicity	N
9:10	Ground Motions	A
11:15	Break	
11:30	Public Comments	ľ
■ 11:45	Lunch	

NRC Strickland/Grebel Cluff McLaren Abrahamson

NRC

PG/aE

April 11, 2002

NRC/PG&E Open Meeting, San Francisco, CA **Diablo Canyon Power Plant Independent Spent Fuel Storage Installation**

- 12:30 **Slope-Material Properties**
- Slope Stability 1:15
- Transport Slope stability 2:15
- Break 2:45
- 3:00 Cutslope Stability
- **3:45** Slope Stability Summary
 - 4:45 **Public Comment**
- **5:00** Adjourn

White Sun White

Bachhuber Team NRC

April 11, 2002

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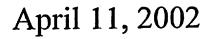
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NRC/PG&E Open Meeting, San Francisco, CA Diablo Canyon Independent Spent Fuel Storage Installation

Geology, Ground Motions, and Geotechnical Studies

Lloyd Cluff Director PG&E Geosciences Department





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Project Team

■ PG&E

Lloyd S. Cluff, Project Management William D. Page, Engineering Geology Marcia McLaren, Seismology Norman A. Abrahamson, Ground Motions Robert K. White, Geotechnical Engineering Joseph I. Sun, Geotechnical Engineering William U. Savage, Seismology

Consultants

William R. Lettis, Consultant, Geology Jeff Bachhuber, Consultant, Geology Faiz Makdisi, Consultant, Geotechnical Engineering

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Technical Review Board

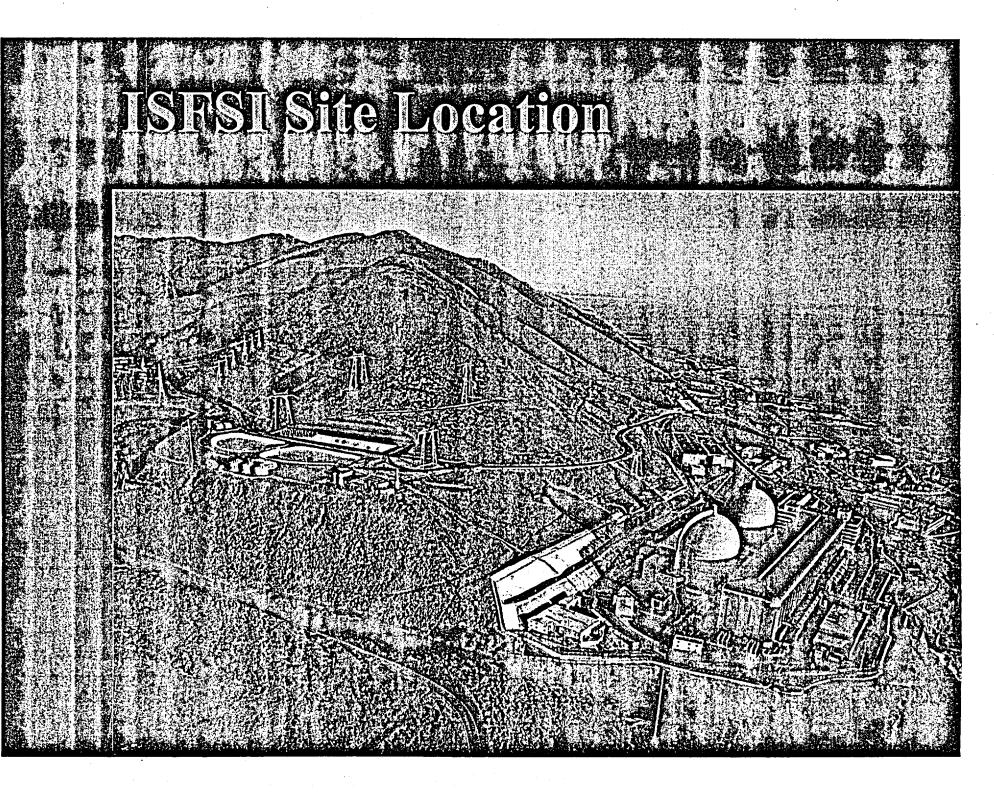
 Clarence Allen - Geology/Tectonics
 Robert Kennedy - Structural Engineering
 Bruce Bolt - Seismology/Ground Motions
 I. M. Idriss - Geotechnical Engineering/ Ground Motions

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Peer Reviewers and Technical Specialists

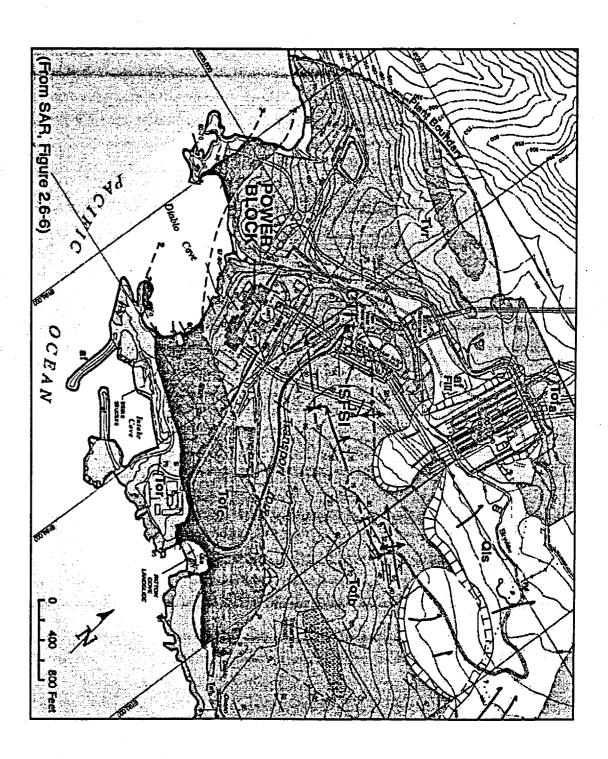
- Skip Hendron Geotechnical Engineering
- Paul Somerville Seismology
- Dale Marcum Geotechnical Engineering

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Bedrock in ISFSI Area

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Investigations

Site geology

Seismicity and seismic geology

Earthquake ground motions

Geotechnical engineering

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Previous Seismicity and Seismic Geology Studies (LTSP)

- Detailed geologic mapping, trenching, surveying of coastal terraces, and offshore geophysics to locate active faults in region
- Detailed analysis of regional seismicity
- PG&E seismic network established in 1987 to supplement existing USGS regional network
- Hosgri fault confirmed to be the controlling earthquake source for the DCPP

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Ground Motions

- Compare earthquake source and distance and ISFSI site conditions with those at DCPP to confirm applicability of DCPP ground motions
- Use DCPP ground motions as basis for developing ISFSI design ground motions, in accordance with 10 CFR 72.102(f)

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Ground Motions

- For ISFSI components sensitive to longer-period motions need to develop appropriate response spectra and time histories
- ISFSI long-period (ILP) spectra, taking into account the influence of near-fault effects recorded in recent large earthquakes, such as fault rupture directivity and fling

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NRC/PG&E Open Meeting, San Francisco, CA Diablo Canyon Independent Spent Fuel Storage Installation

Seismicity

Marcia McLaren Seismologist PG&E Geosciences Department



April 11, 2002

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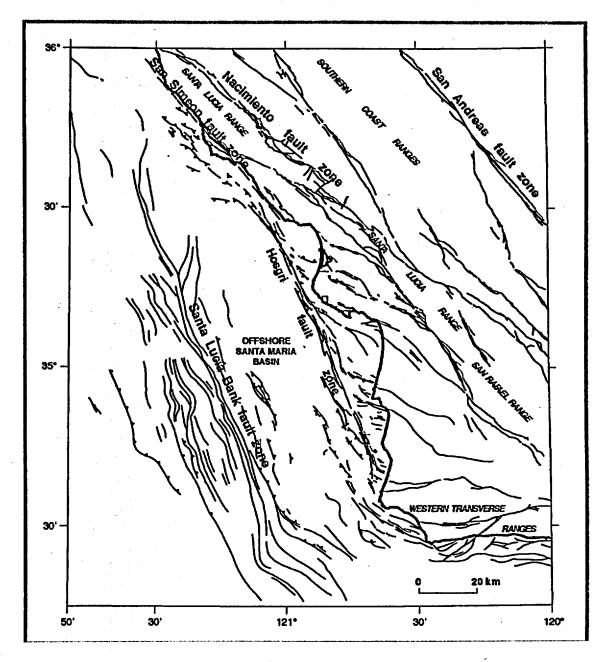
Outline

- Tectonic setting
- Seismographic station coverage
- Seismicity patterns and focal mechanisms
- Conclusions

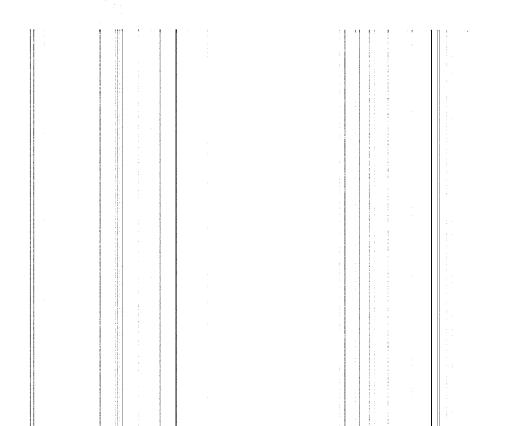
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Tectonic setting

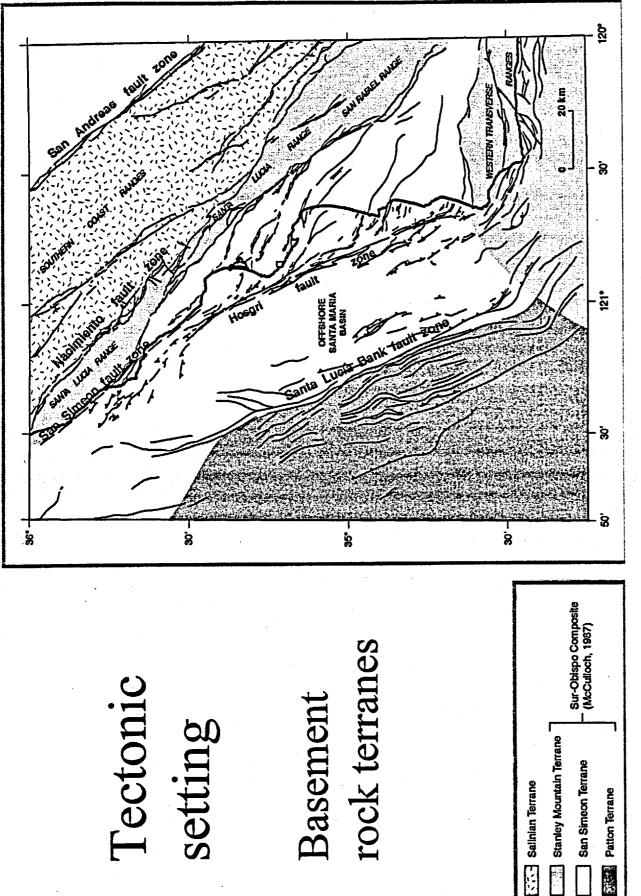
Quaternary faults



From LTSP (PG&E, 1988)



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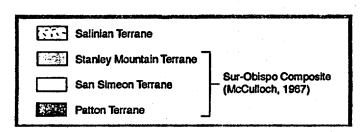
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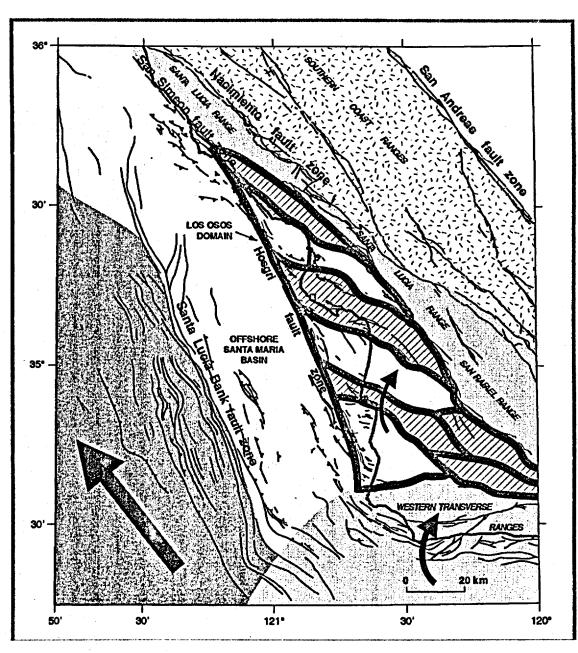
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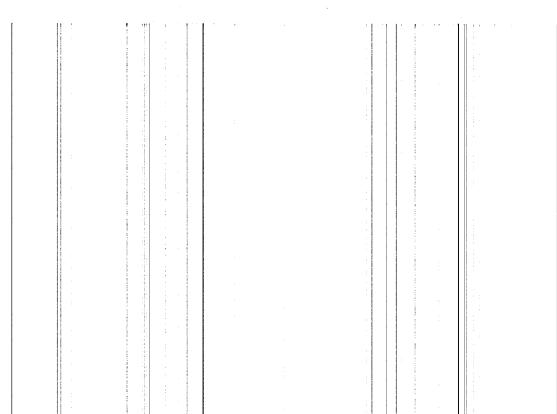
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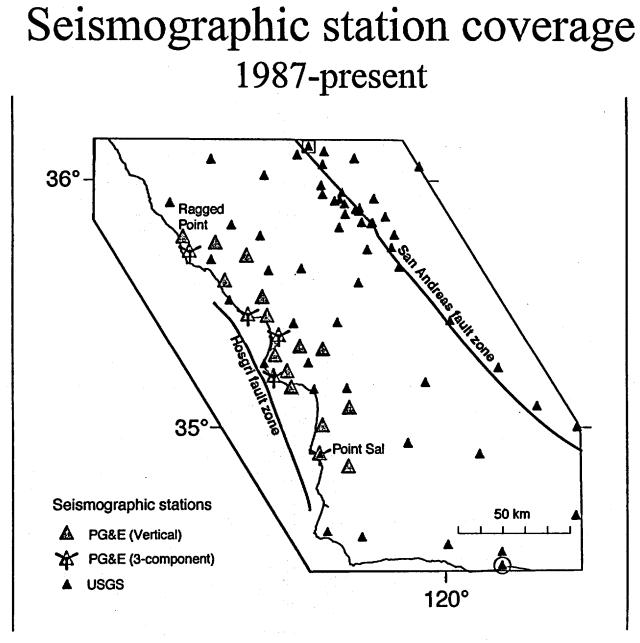




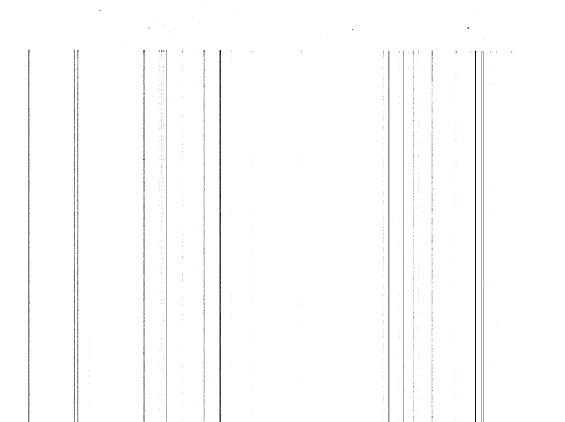
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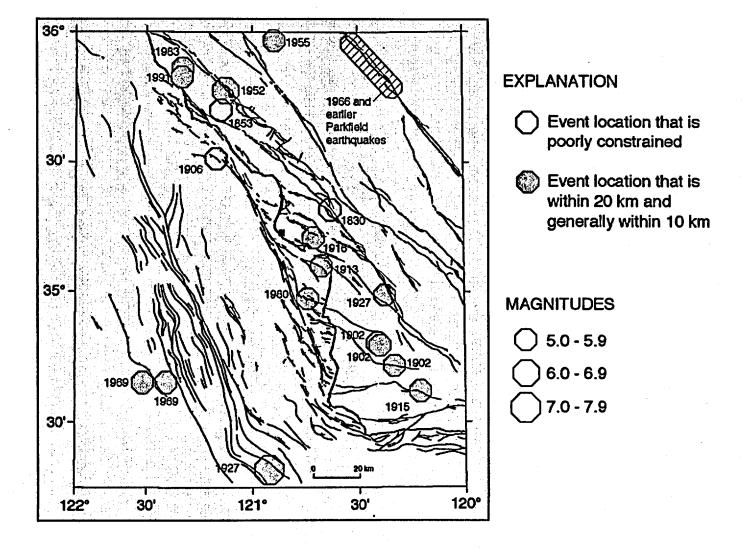
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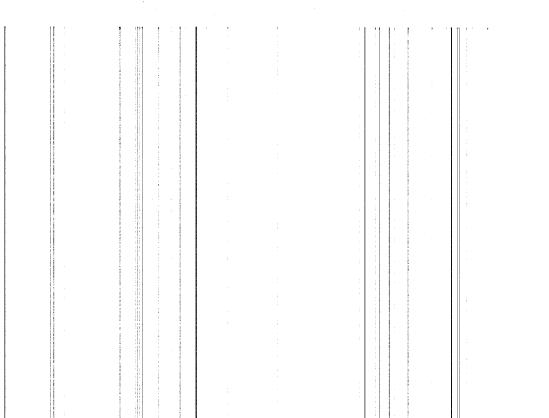
From LTSP (PG&E, 1988)



Magnitude 5 and greater earthquakes since 1830



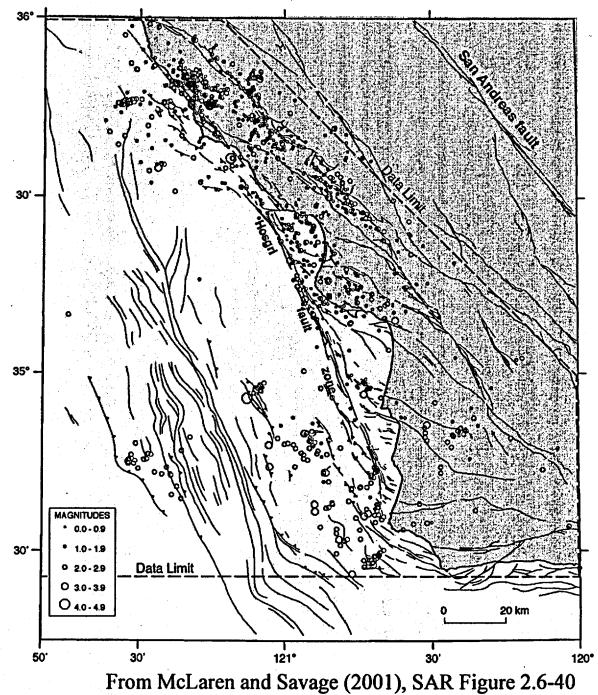
From McLaren and Savage (2001), SAR Figure 2.6-39

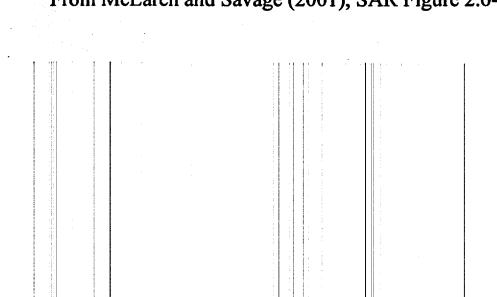


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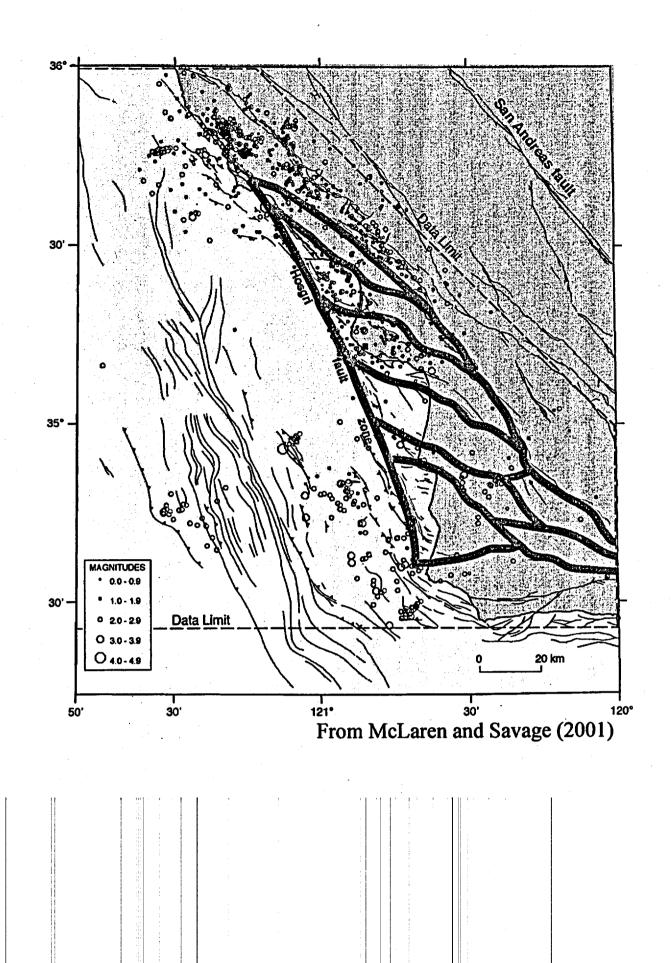




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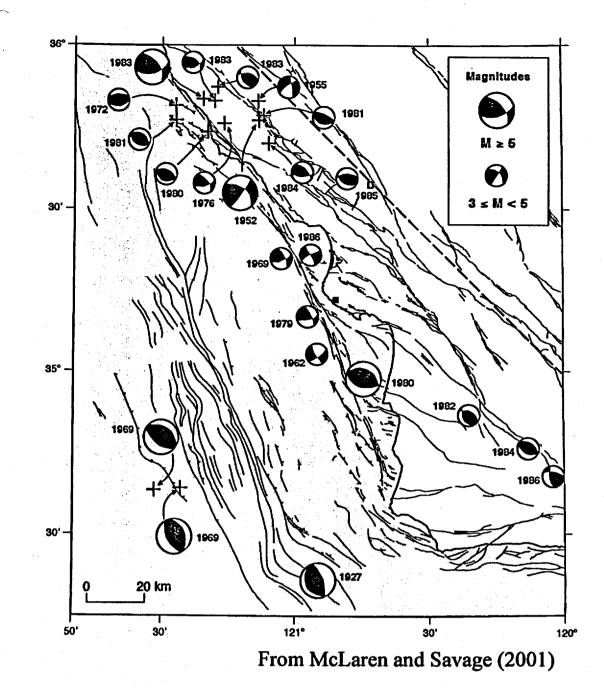
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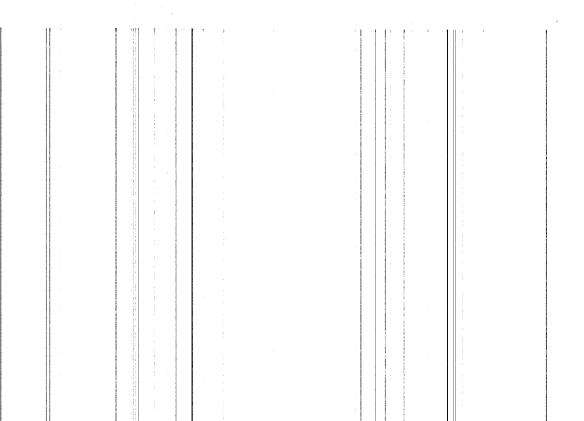


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Focal mechanisms

Magnitude 3 and greater earthquakes, 1927-1986

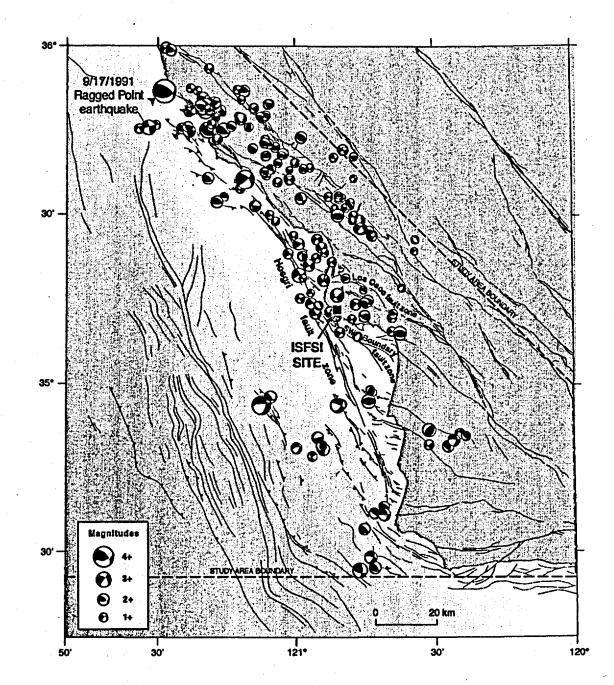




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Focal mechanisms

Oct. 1987 through Jan. 1997



From McLaren and Savage (2001), SAR Figure 2.6-42

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Conclusions

- Seismicity patterns and focal mechanisms of the 1987-1997 earthquakes recorded by the PG&E and USGS networks are consistent with the data presented in the Final Report of the Long Term Seismic Program (PG&E, 1988).
- Focal mechanisms along the Hosgri fault zone show consistent strike-slip motion along northwest trending, nearly vertical fault planes.

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NRC/PG&E Open Meeting, San Francisco CA Diablo Canyon Independent Spent Fuel Storage Installation

Ground Motions: Lessons from Recent Earthquakes

Norm Abrahamson Engineering Seismologist PG&E Geosciences Department



April 11, 2002

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Outline

Lessons from recent earthquakes
 Three large earthquakes in 1999
 Application of those lessons to the ground motions for the ISFSI

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Importance of Recent Earthquakes

- LTSP Evaluation Earthquake
 - ◆ M=7.2, Dist = 4.5 km
 - Prior to 1999, few empirical recordings were available for this magnitude and distance range
- Recent Earthquakes Have Greatly Increased the Empirical Data Base of Strong Motion Recordings Close to Large Crustal Earthquakes
 - ♦ 1999 Kocaeli, Turkey (M=7.4)
 - ♦ 1999 Chi-Chi, Taiwan (M=7.6)
 - ♦ 1999 Duzce, Turkey (M=7.1)
- Resulting in new models for long period ground motion

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Strong Motion Recordings Close to Large Crustal Earthquakes

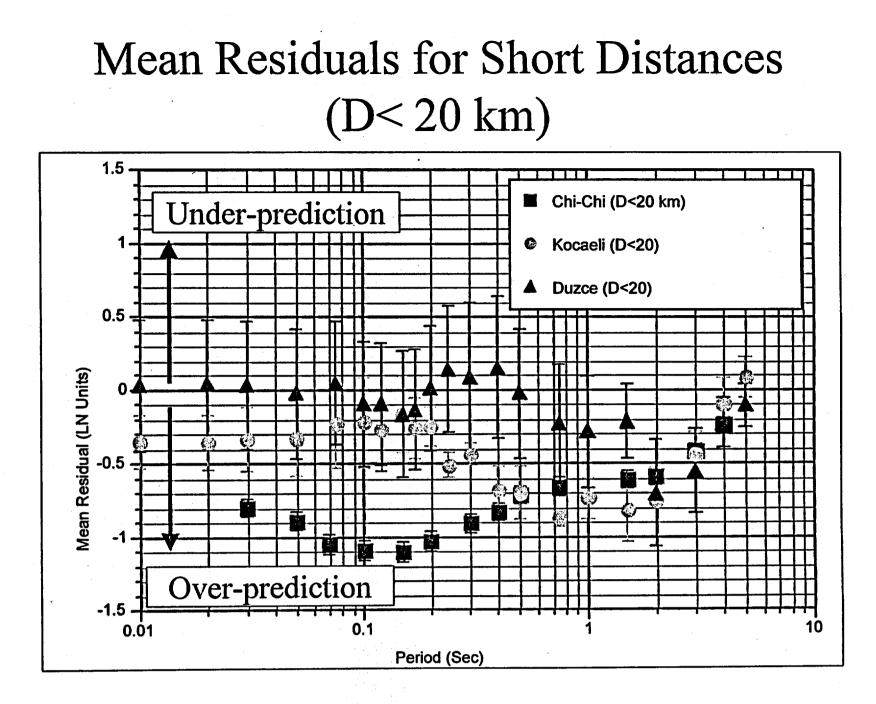
	M≥7.0	M≥7.0	M_≥7.0
	$D \le 20 \text{ km}$	$D \le 10 \text{ km}$	$D \le 5 \text{ km}$
Prior to 1999	9	5	2
1999	6	3.	2
Kocaeli			
1999 Chi-	63	32	14
Chi			
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Duzce			

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Evaluation of Ground Motions from Recent Earthquakes

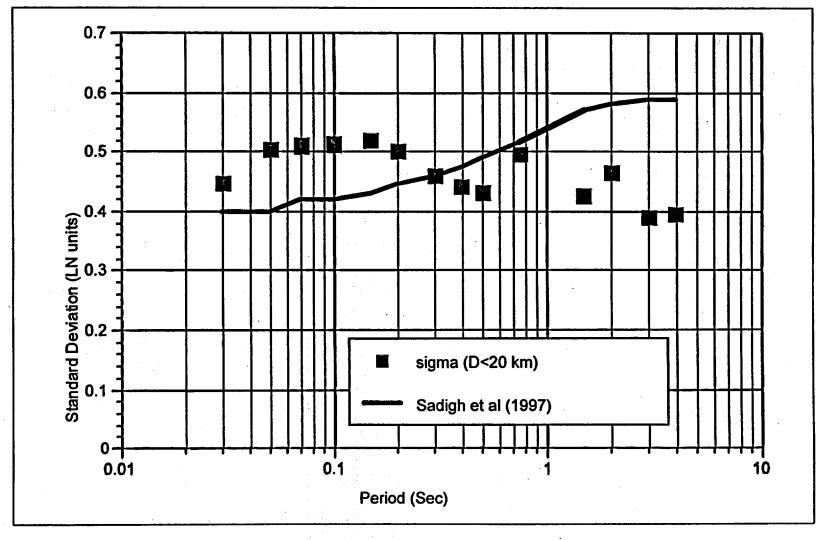
- Compare response spectra to predicted values from recent attenuation relations
- Compute residuals (observed calculated) from Sadigh et al (1997) attenuation relation
 - Mean residual
 - Standard deviation of the residuals

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Ground Motion Variability (D<20 km)



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Lessons for Low and Moderate Periods

- Compared to current attenuation relations used in for California earthquakes:
 - Median ground motion lower than expected (T<2 sec)
 - Variability (standard deviation) of the ground motion is larger than expected at short periods (T<0.2 sec)

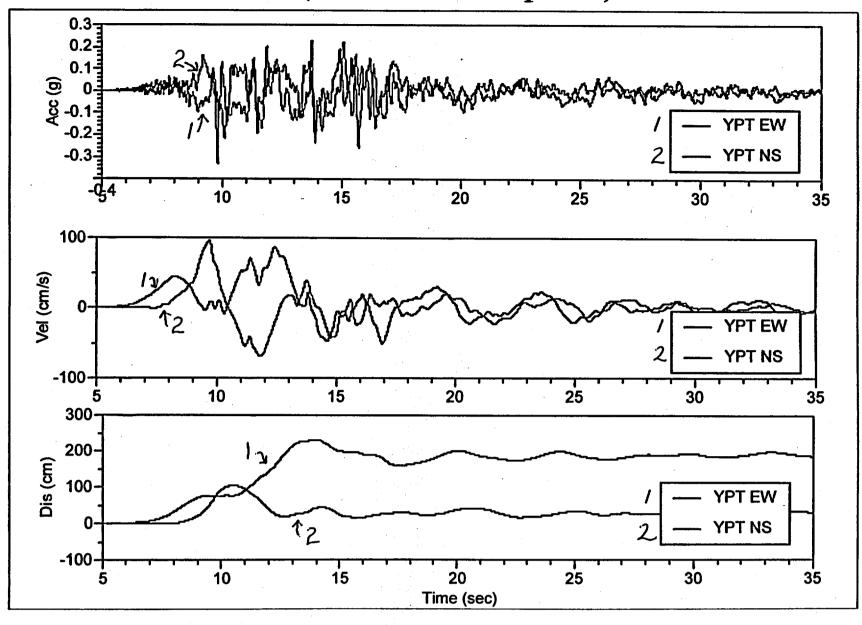
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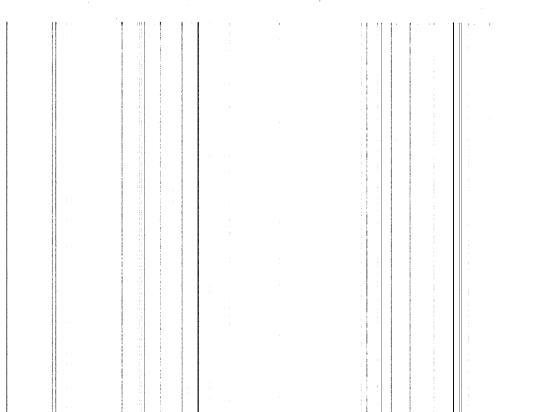
Lessons for Long Periods (T>2 seconds)

- Recordings close to the fault showed strong nearfault effects
 - ♦ Large velocity pulse
 - ◆ Increased long period spectral values
- Two Causes of large velocity pulses
 - Directivity
 - ♦ Fling

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Example of Near-Fault Effects (Kocaeli Earthquake)





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Causes of Velocity Pulses

Directivity

- Related to the direction of the rupture front
 - Forward directivity: rupture toward the site (site away from the epicenter)
 - Backward directivity: rupture away from the site (site near the epicenter)
- Fling

 Related to the permanent tectonic deformation at the site

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Velocity Pulses

- Forward Directivity
 - Two-sided velocity pulse due to constructive interference of SH waves from generated from parts of the rupture located between the site and epicenter
 - Constructive interference occurs if slip direction is aligned with the rupture direction
 - Occurs at sites located close to the fault but away from the epicenter for strike-slip
- Fling
 - One-sided velocity pulse due to tectonic deformation
 - Occurs at sites located near the fault rupture independent of the epicenter location

Observations of Directivity and Fling

<u>Sense of Slip</u>	<u>Directivity</u>	Fling
Strike-Slip	Fault Normal	Fault Parallel
Dip-Slip	Fault Normal	Fault Normal

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Directivity Effects (Somerville et al, 1997)

Two Effects on Ground Motion Amplitudes

- Changes in the average horizontal component as compared to standard attenuation relations
 - Increase in the amplitude of long period ground motion for rupture toward the site
 - Decrease in the amplitude of long period ground motion for rupture away from the site
- Systematic differences in the ground motions on the two horizontal components
 - Fault normal component is larger than the fault parallel component at long periods

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Landers Earthquake (1992)

Directivity

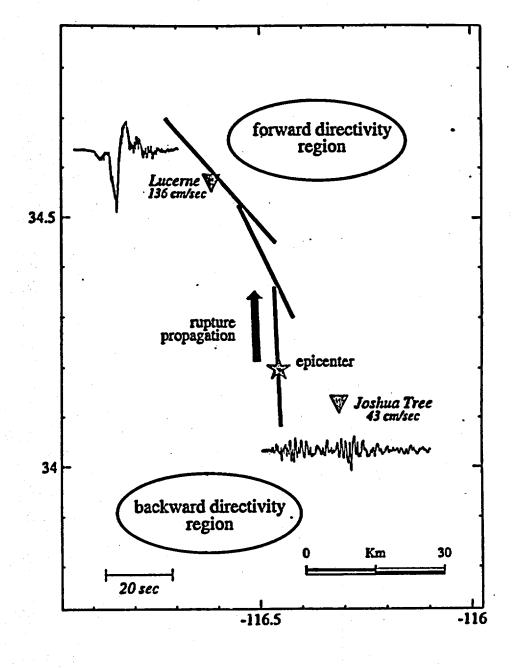
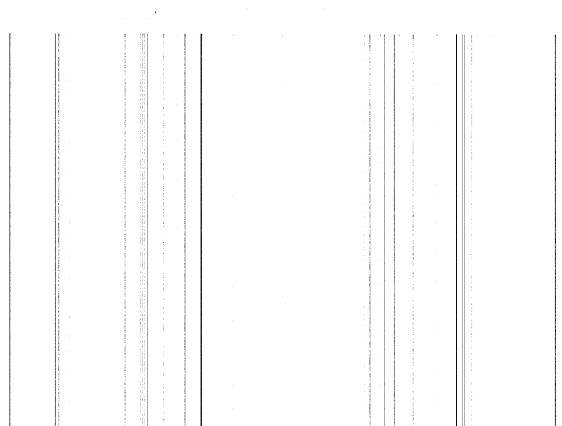
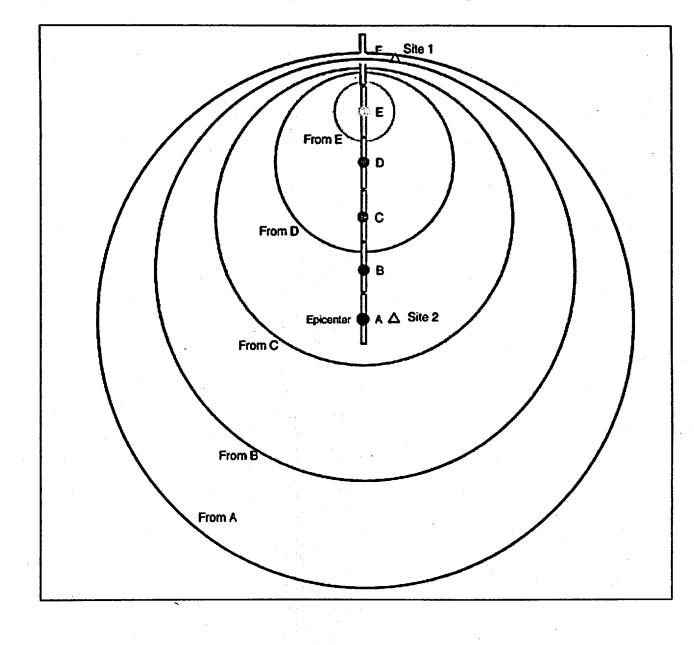


Figure 1. Map of the 1992 Landers earthquake showing the velocity time histories at Lucerene (forward directivity) and Joshua Tree (backward directivity).



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Directivity



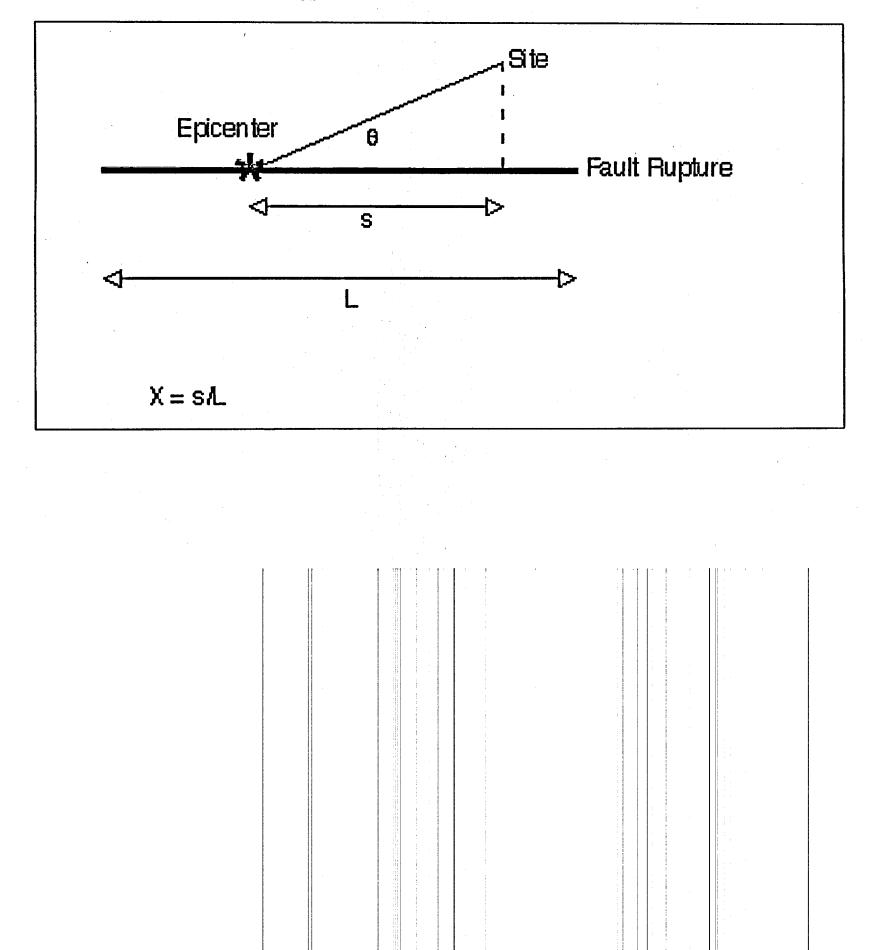
Model for Directivity Effects

Additional Parameters Required

- Strike-Slip Fault
 - X = fraction of fault rupture between the epicenter and the site
 - θ = angle between the fault strike and the epicentral direction from the site

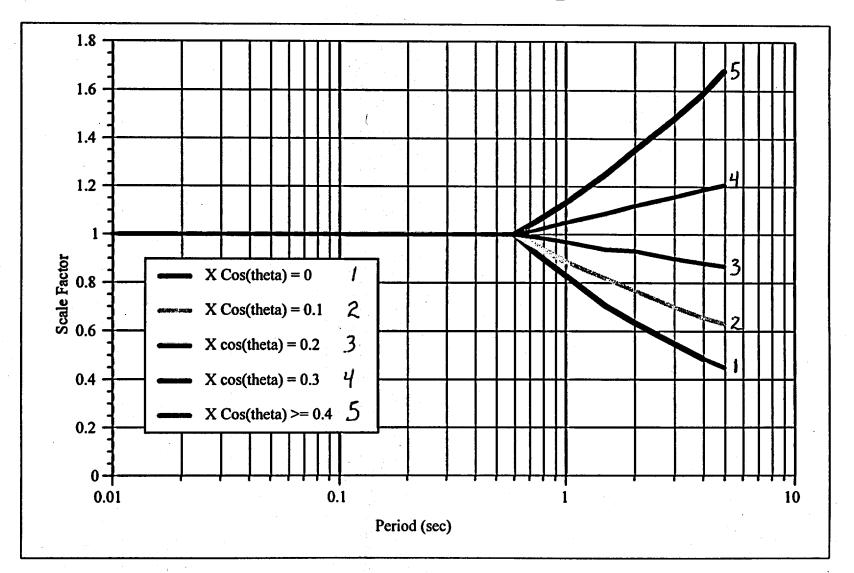
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Directivity Parameters for Strike-Slip Faults



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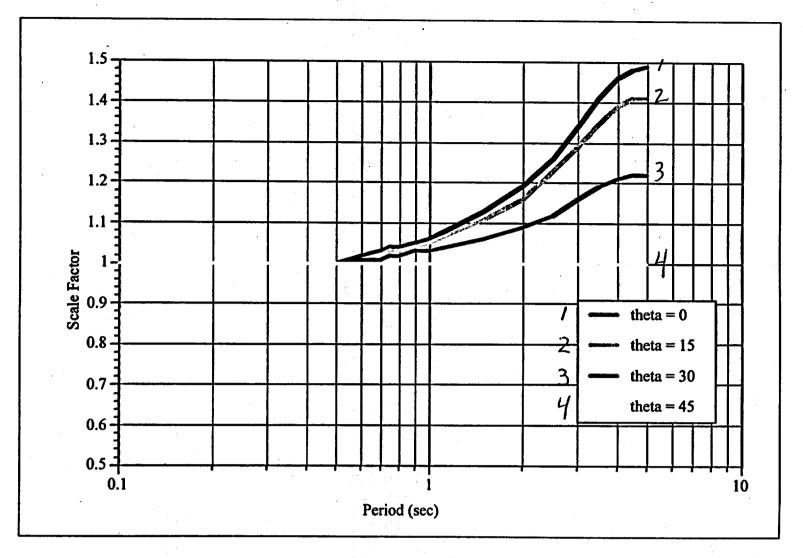
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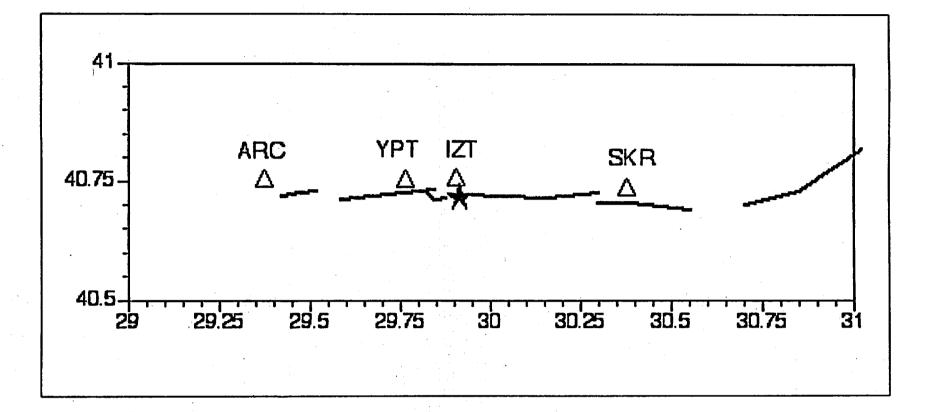
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Somerville et al (1997) Scale Factors for FN/Ave Horiz

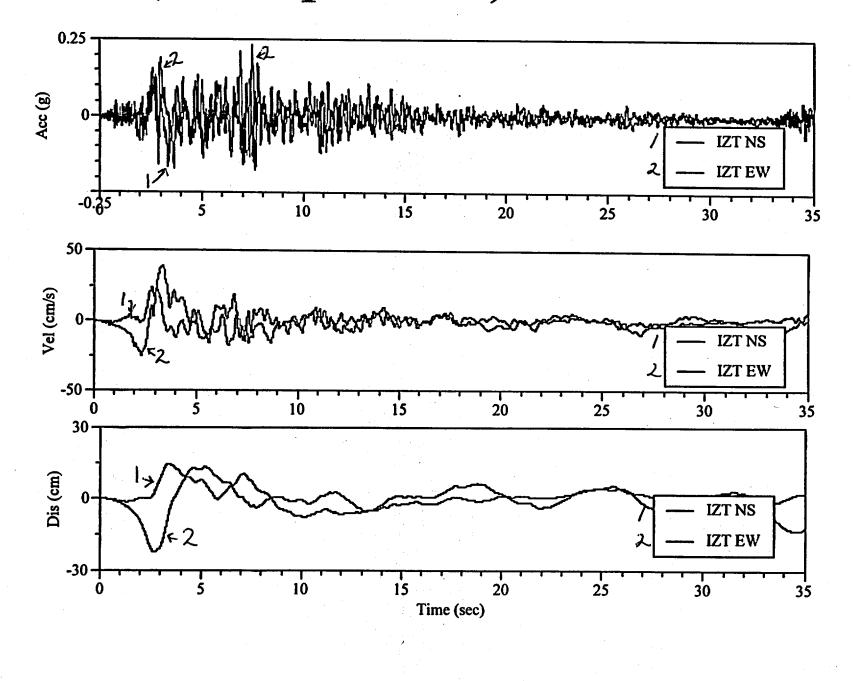


Kocaeli Rupture and Strong Motion Stations

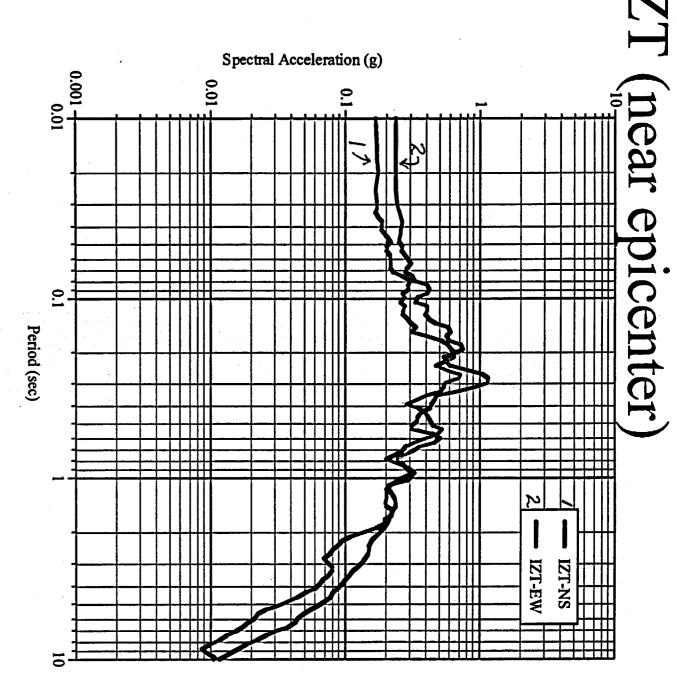


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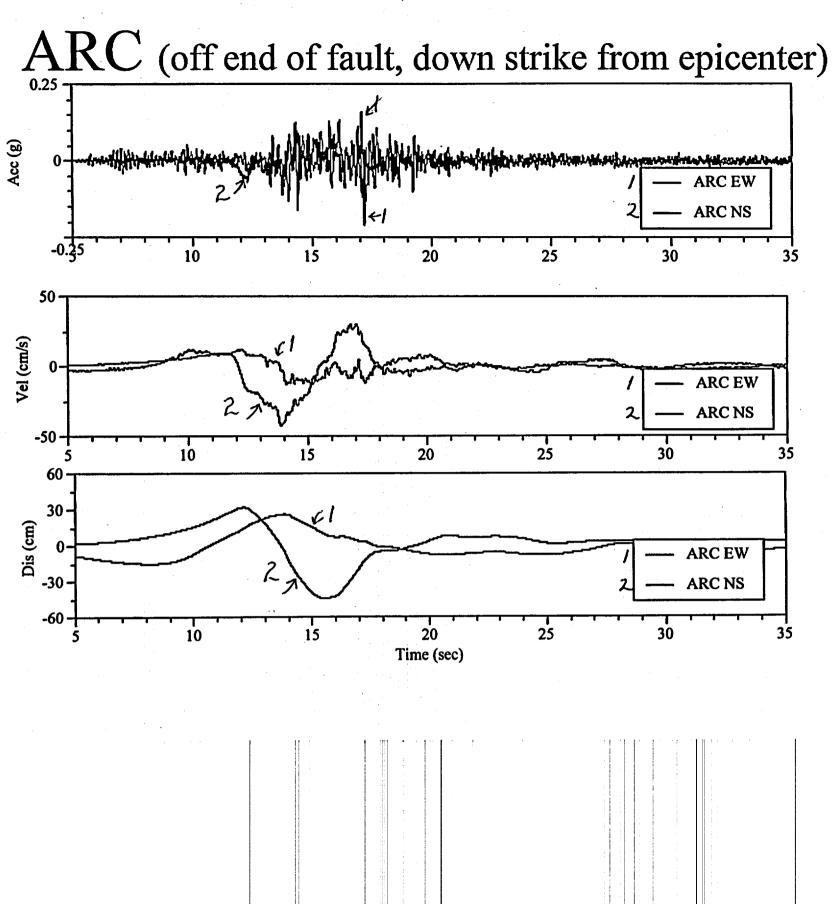
IZT (near epicenter)

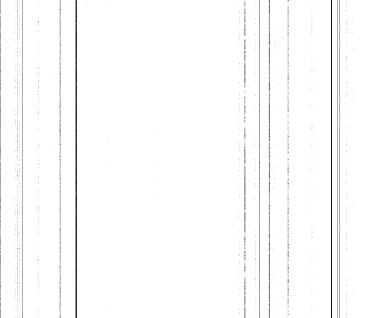


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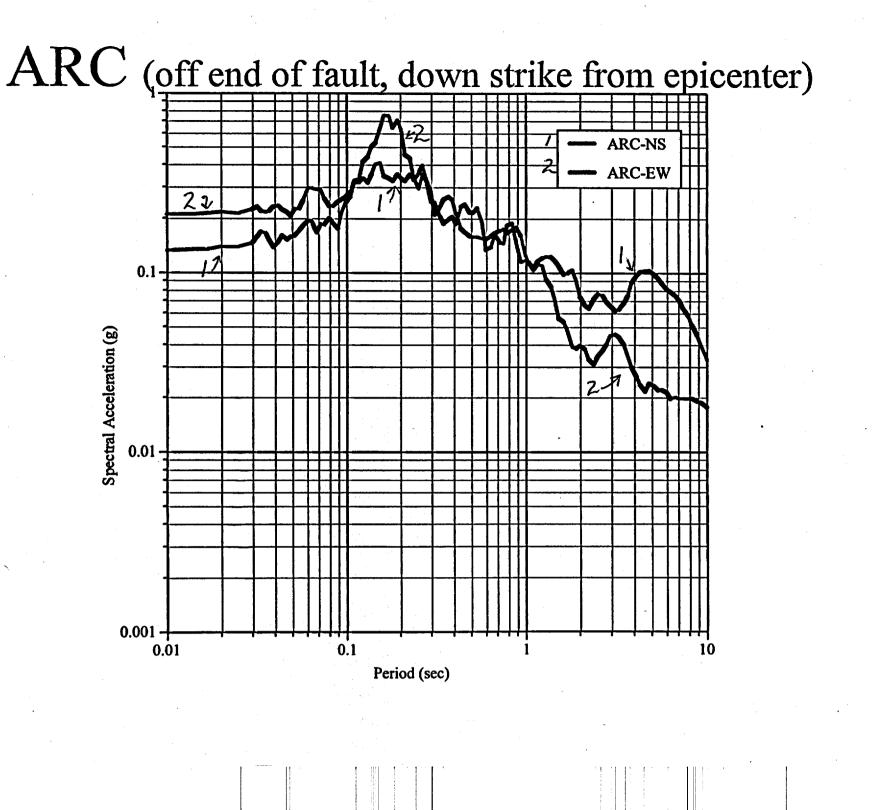


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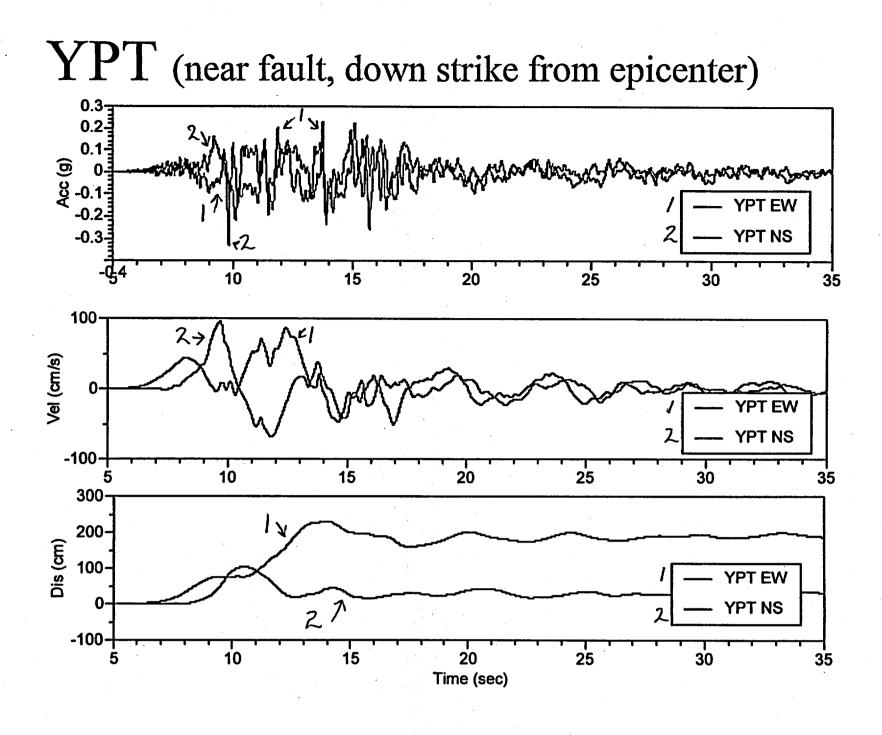


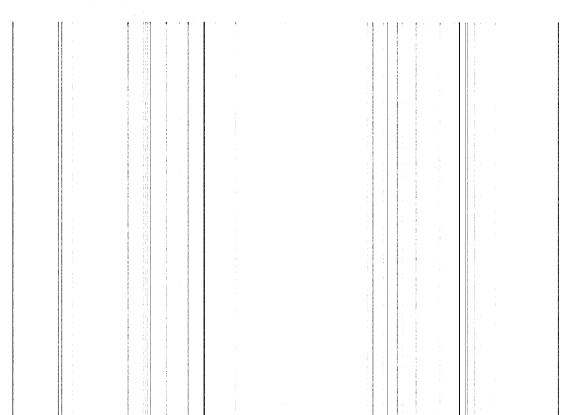


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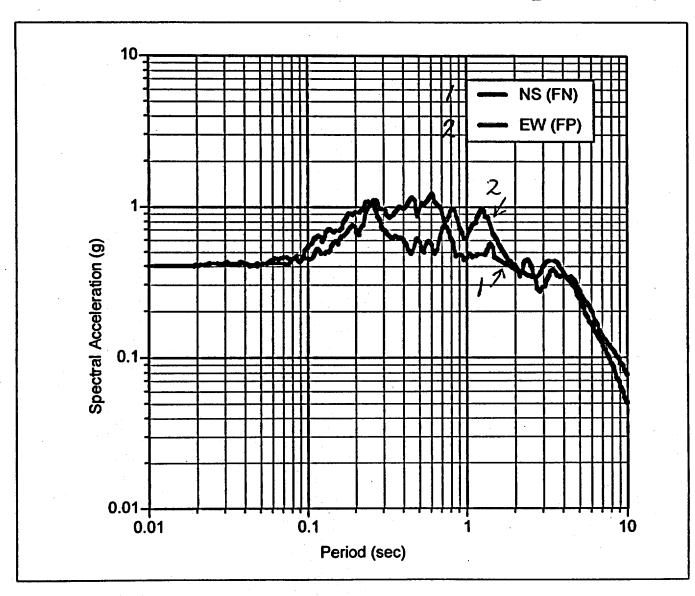
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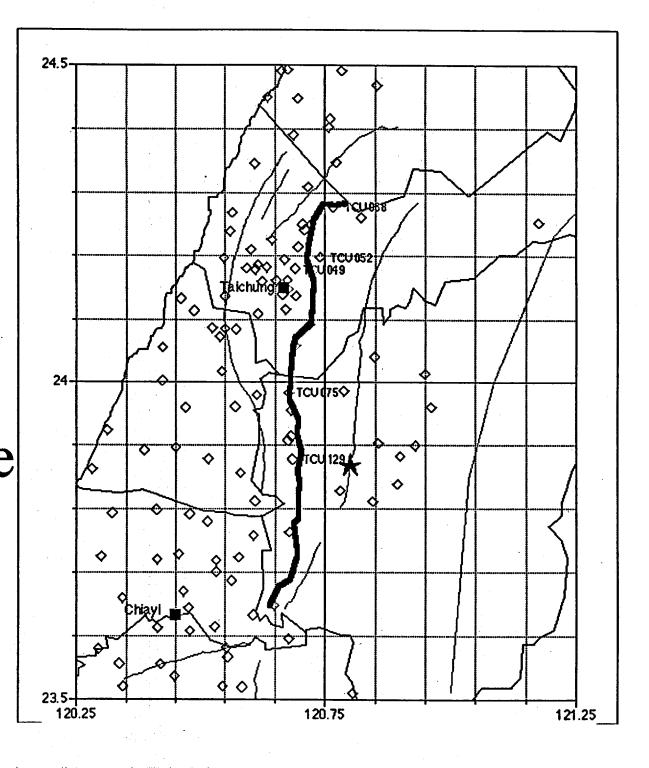
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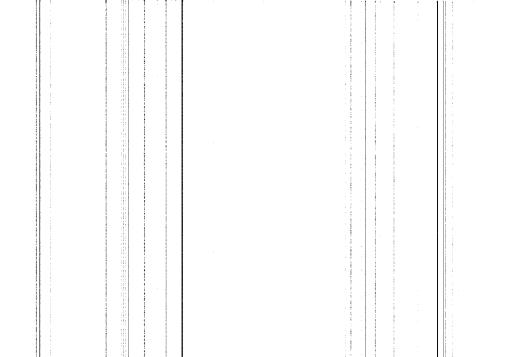
YPT (near fault, down strike from epicenter)



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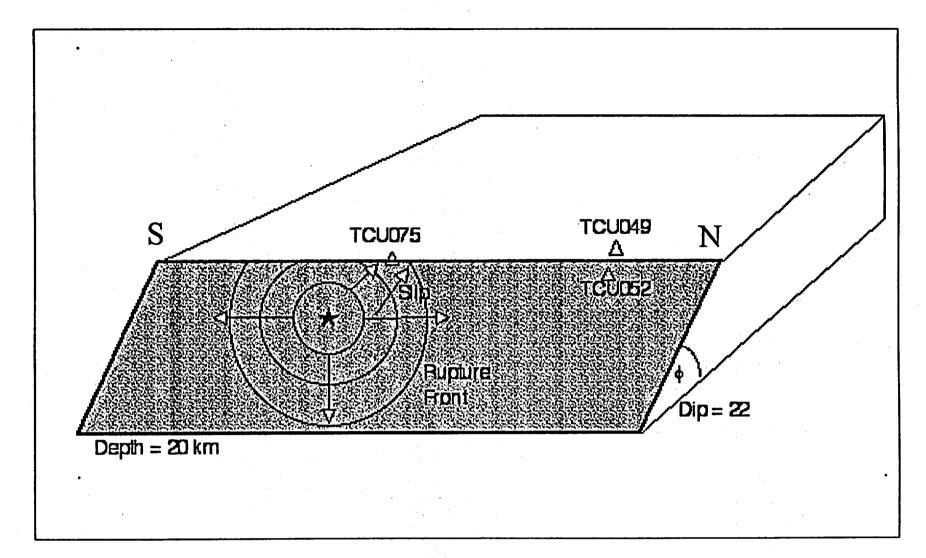
Strong Motion Stations from the Chi-Chi Earthquake

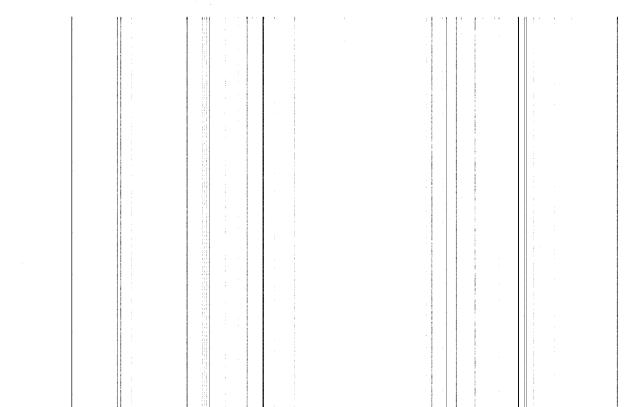




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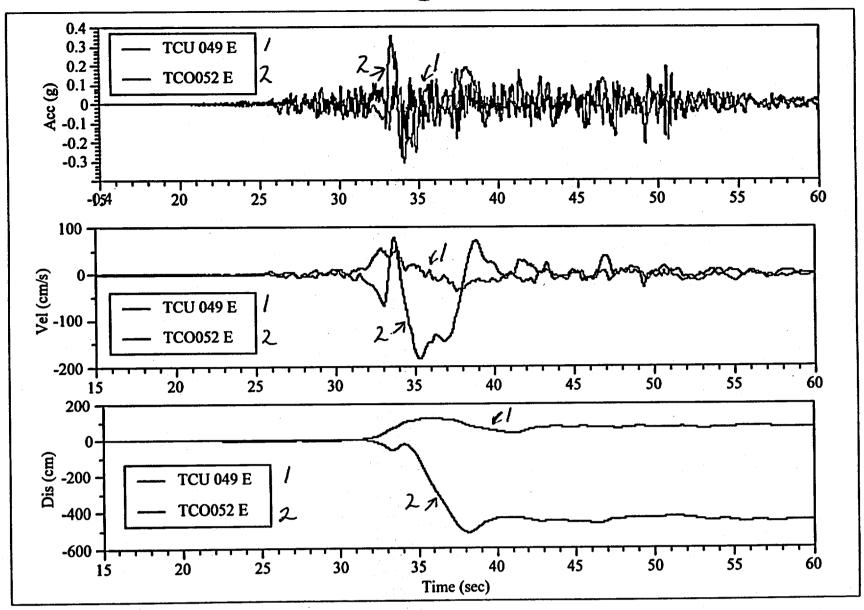
Chi-Chi Earthquake

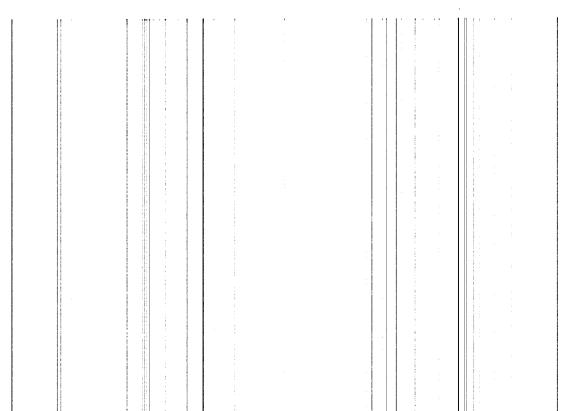




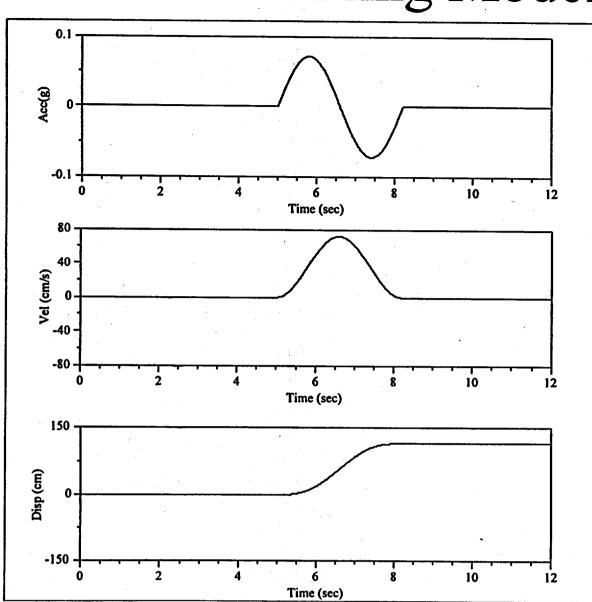
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Fling Effects

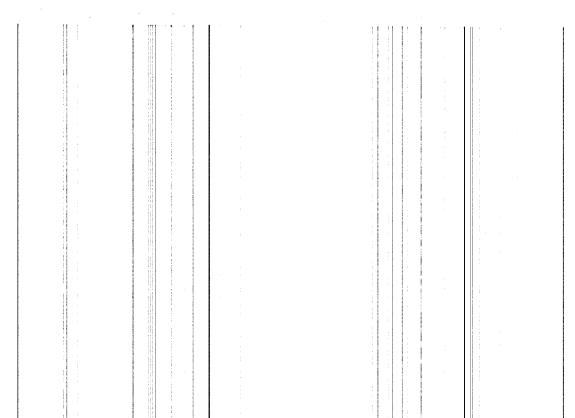




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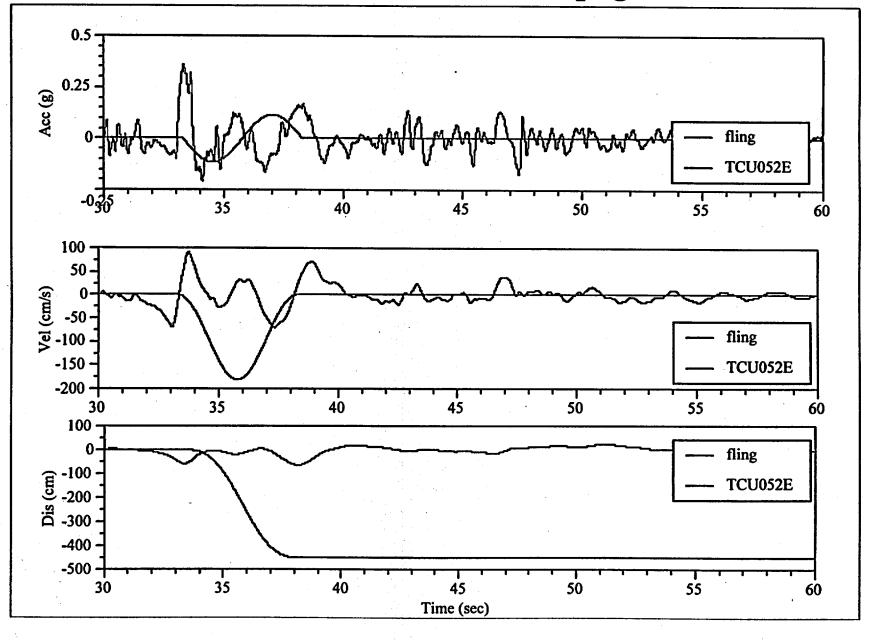


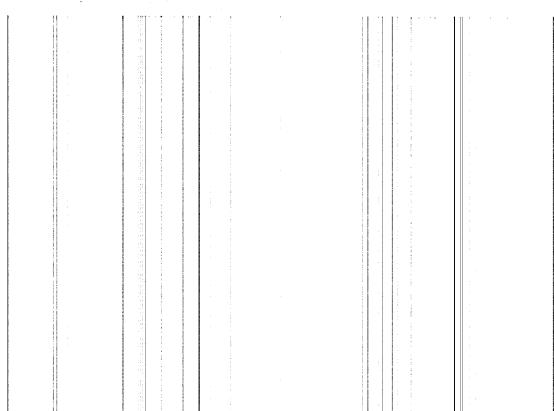
Time Domain Fling Model



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Separation of Fling and Wave Propagation Effects





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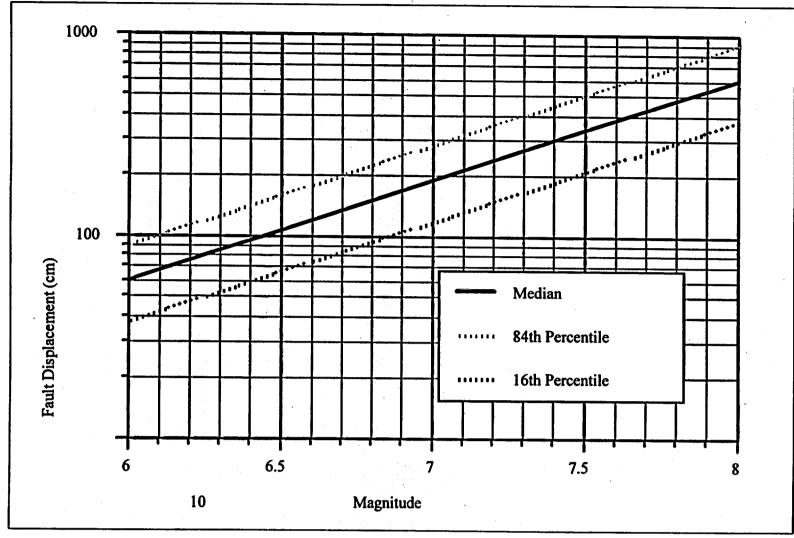
Parameters Required for Fling

Amplitude of Fling

- From fault slip and geodetic data
- Duration (period) of Fling
 - From strong motion data
- Arrival Time of Fling
 - From numerical modeling
 - Relative timing of fling and S-waves

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Fault Displacement

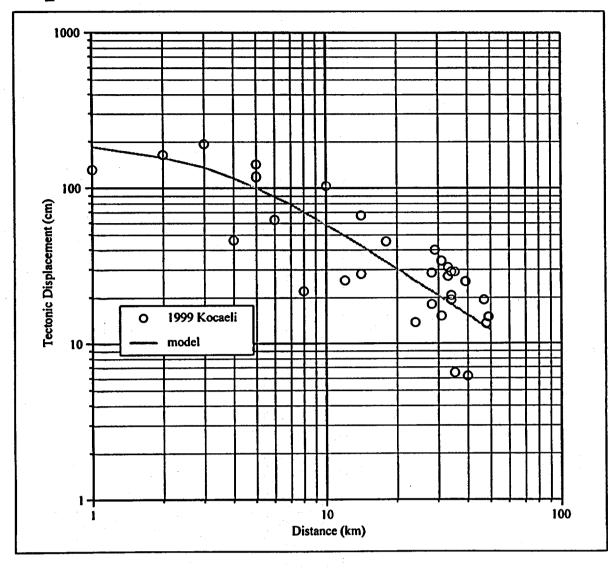


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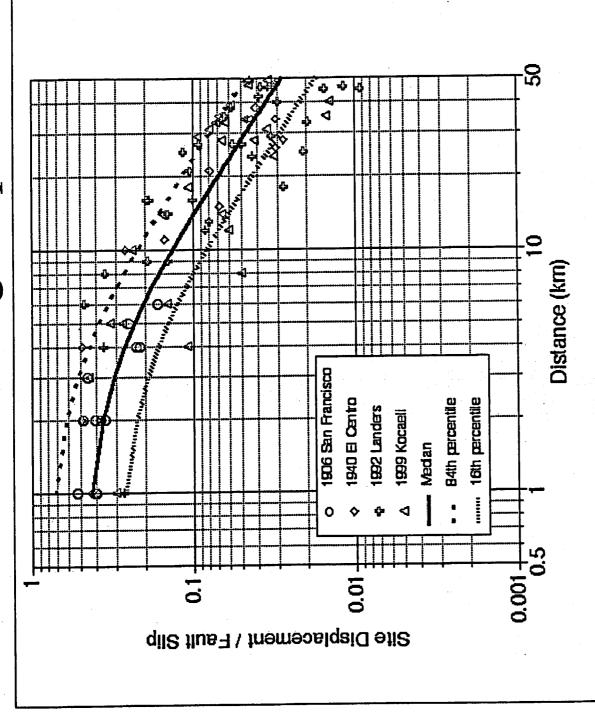
Attenuation of Fling Amplitude

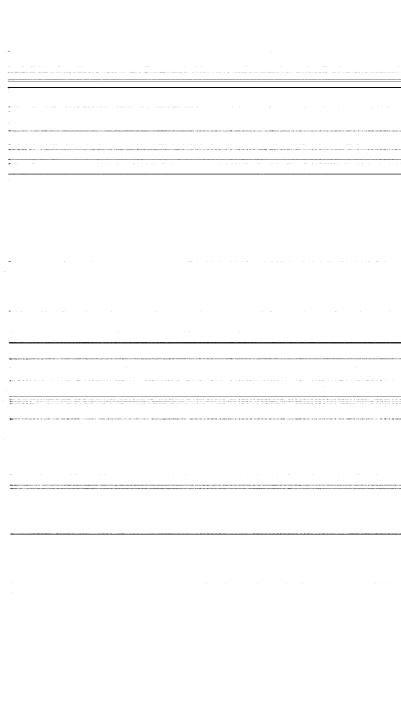
Example from Kocaeli Geodetic Data



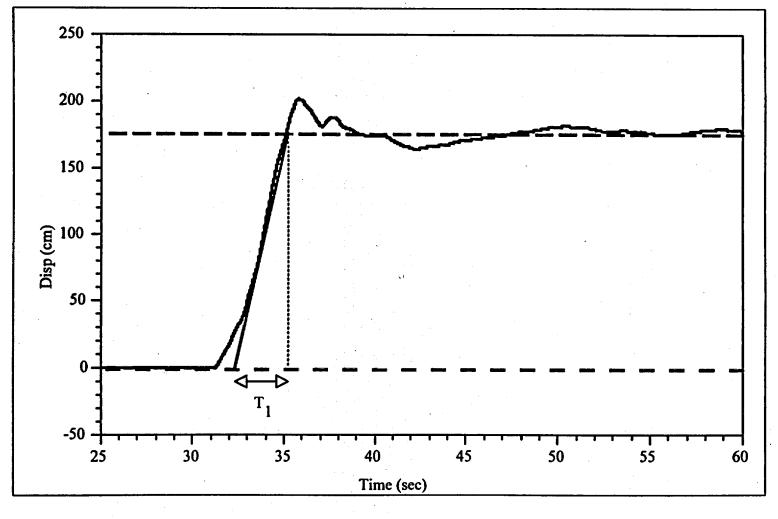
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Attenuation of Fling Amplitude





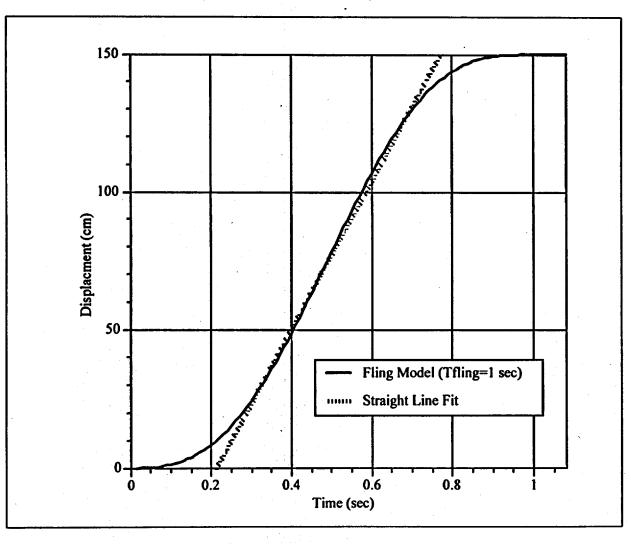
Duration of Fling Measured from Strong Motion Recordings (SKR from Kocaeli)



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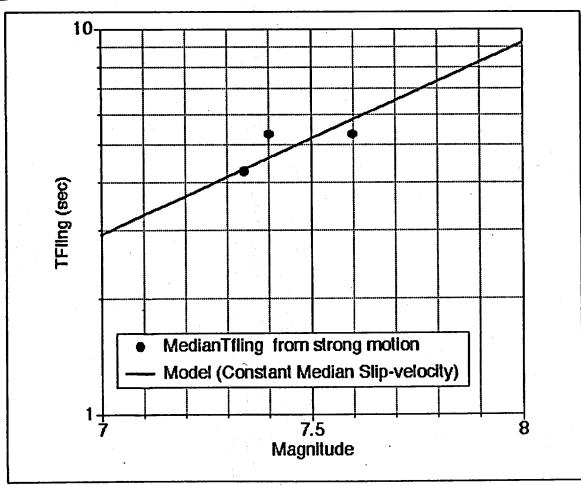
Fling Period



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Model for Duration of Fling

(slope fixed by assuming median slip-velocity is independent of magnitude)



Lessons for Long Period Ground Motions

- Near fault ground motions can have large velocity pulses caused by directivity and/or fling
- Forward Directivity Effects
 - ♦ Observed in Kocaeli earthquake
 - Consistent with previously derived models
 - Not observed in Chi-Chi earthquake due to shallow depth of hypocenter
- Fling
 - ♦ Observed in both Kocaeli and Chi-Chi

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Lessons for Long Period Ground Motions

Directivity

- Current scaling relations for directivity effects are generally consistent with data from new earthquakes
- Directivity effects result in narrow band peak in the long period spectrum

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Lessons for Long Period Ground Motions

- Fling
 - Commonly used attenuation relations do not include fling
 - Fling effects are not represented in the empirical data prior to 1999
- A separate ground motion model is needed for the fling,
 - Fling effects scale differently with magnitude and distance than ground motion due to wave propagation
- Ground motion from fling effects needs to be combined with the ground motion due to wave propagation

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NRC/PG&E Open Meeting, San Francisco CA Diablo Canyon Independent Spent Fuel Storage Installation

Ground Motions

Norm Abrahamson Engineering Seismologist PG&E Geosciences Department



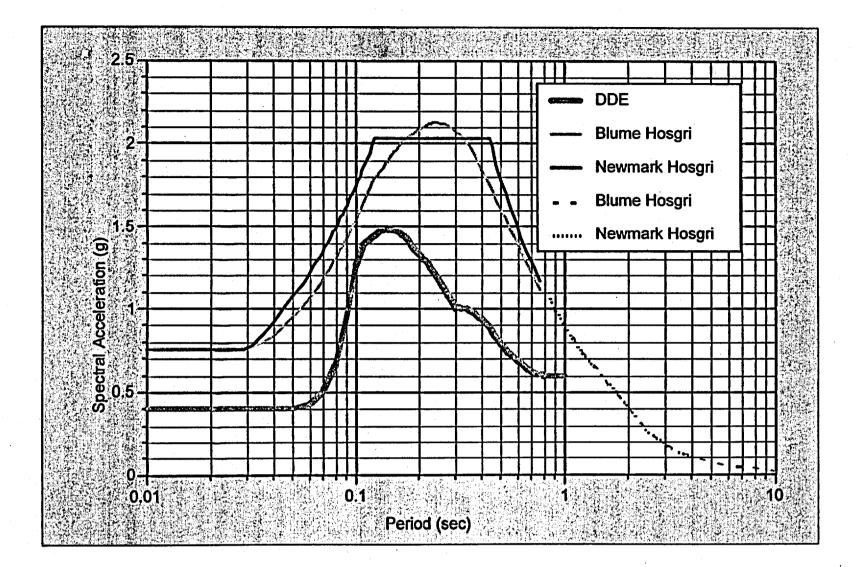
April 11, 2002

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DCPP Ground Motions

- Design Basis Ground Motions
 - Design Earthquake (DE)
 - Double Design Earthquake (DDE)
 - Hosgri Earthquake (HE)
 - Newmark Hosgri
 - Blume Hosgri
- Margin Evaluations
 - ♦ Long Term Seismic Program (LTSP)

Response Spectra (5% damping)



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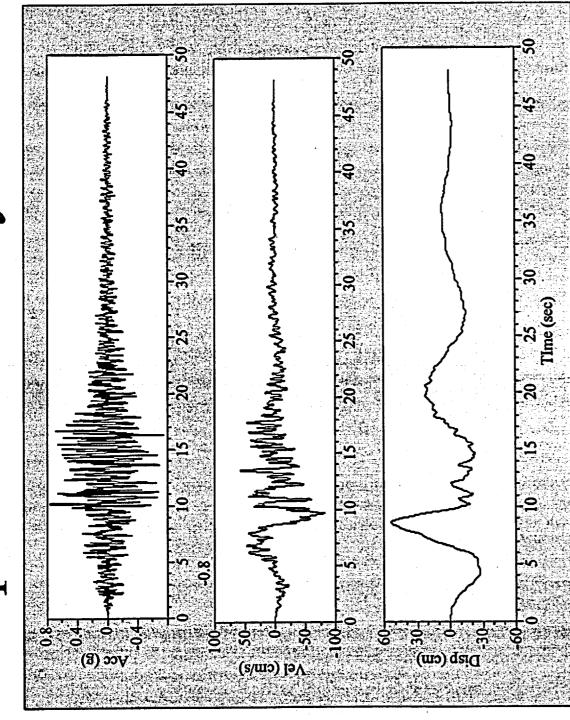
Time Histories for Hosgri Eqk

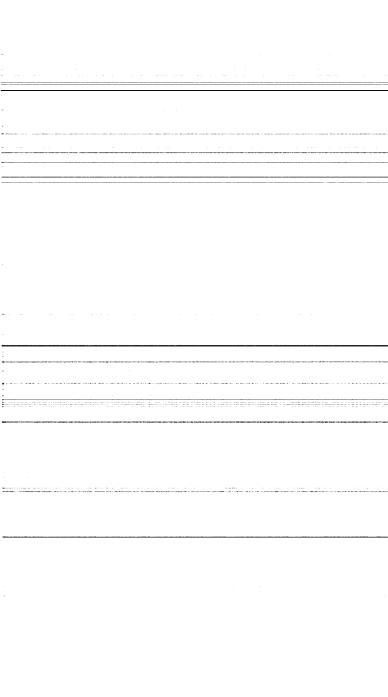
Approach

- Develop spectrum compatible time histories
- Use recorded ground motions as the reference
 - Lucerne recording from the 1992 Landers earthquake
 - M = 7.3, Strike-slip, Dist = 1 km
- Satisfy SRP 3.7.1 requirements for time histories

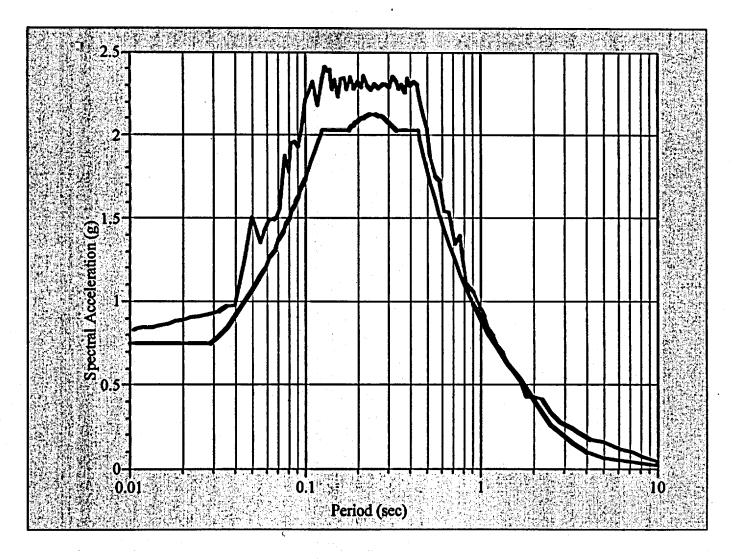
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rt) Example Time History for





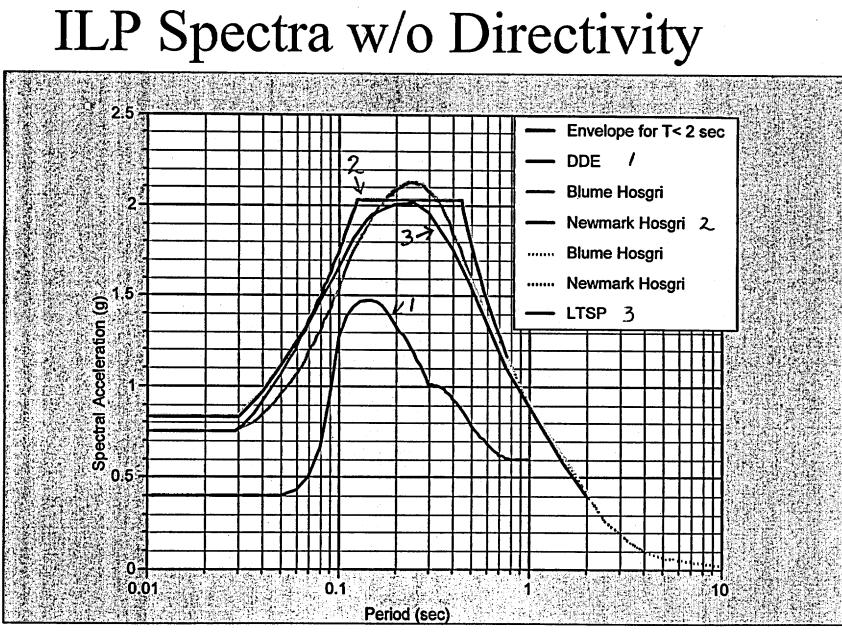
Example Spectrum for HE Time History



Accounting for Lessons from Recent Earthquakes

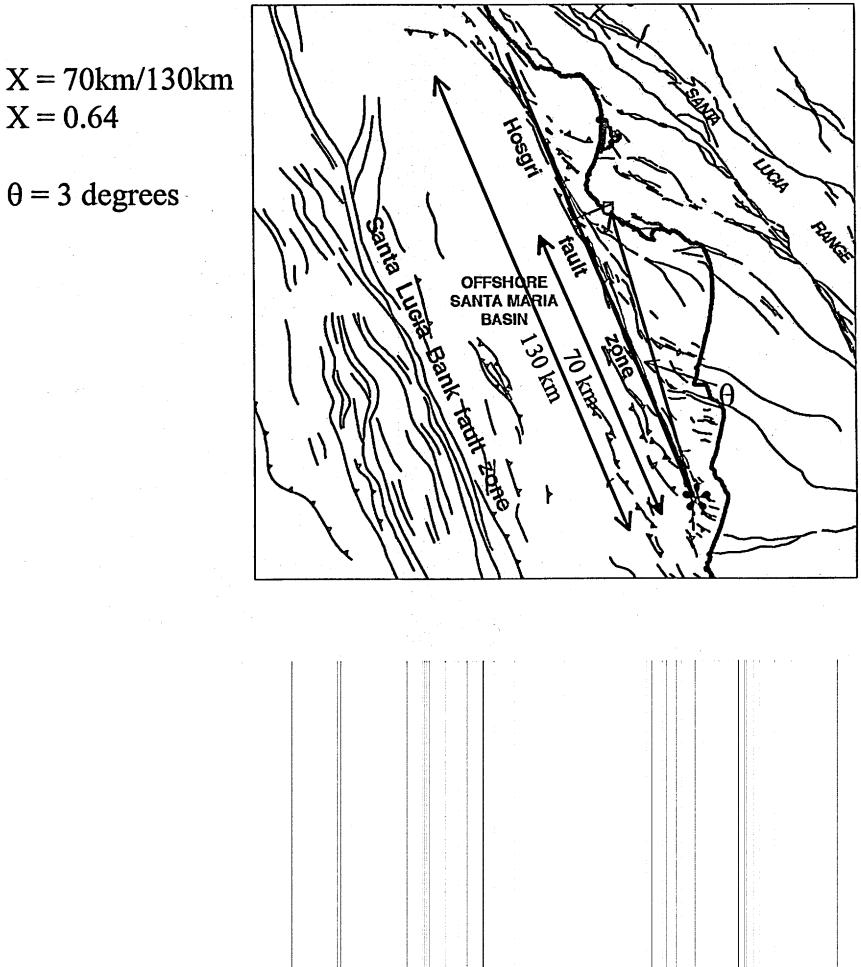
- No change was made to account for smaller ground motions at short-periods from recent earthquakes
- An ISFSI Long-Period (ILP) spectrum was developed to account for the new information on long period ground motions
 - ◆ Envelope of HE and LTSP for T<2 sec
 - Extended to T=10 seconds using attenuation relations developed by PG&E
 - Increased at T> 0.5 sec for directivity effects
- Fling effects were added to the time history
- ILP ground motions were used for ISFSI Part 72 analyses

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Directivity Parameters

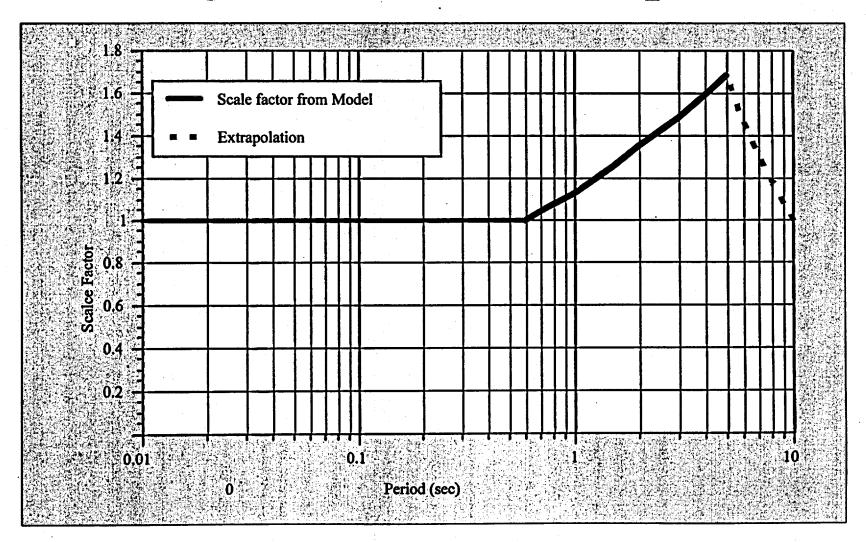


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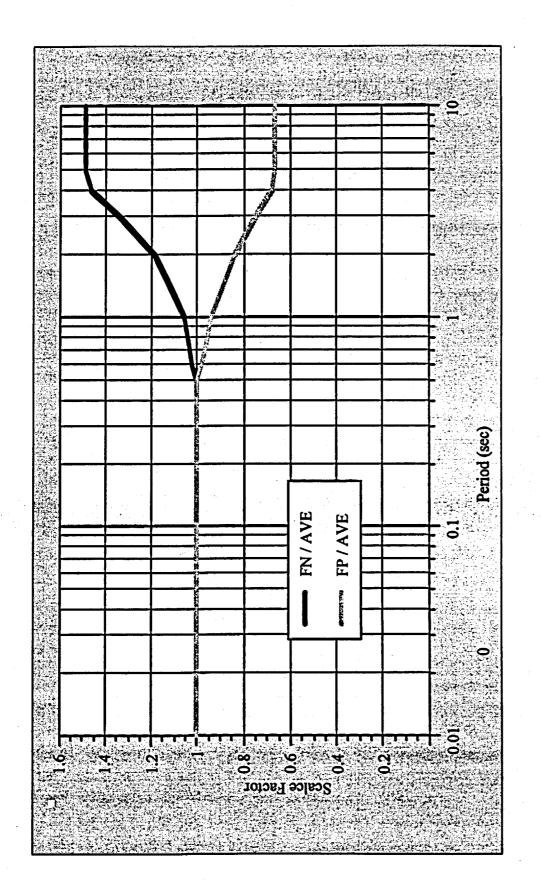
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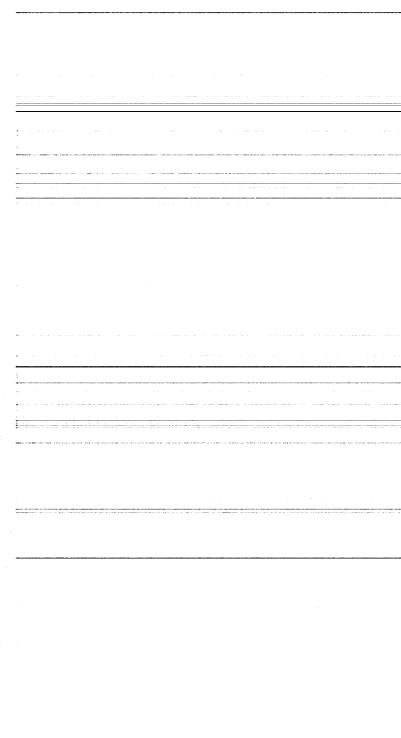
Directivity Effects on the Average Horizontal Component



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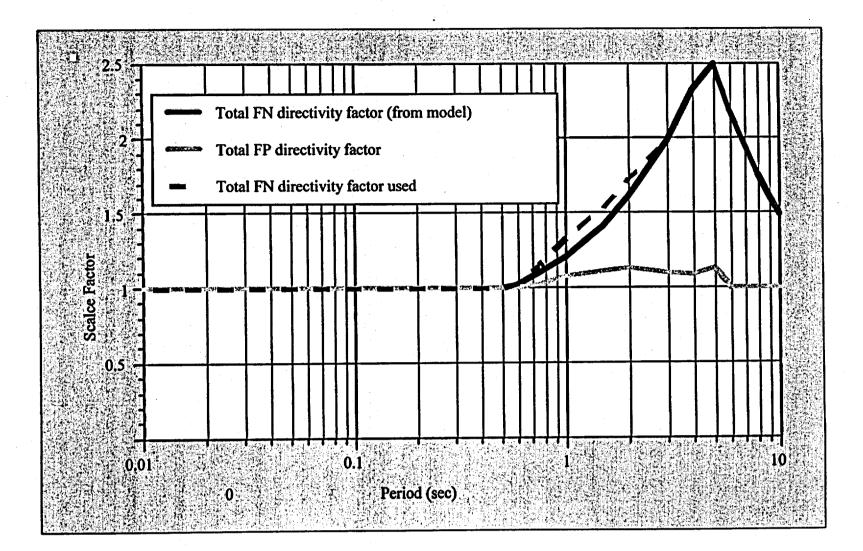
Directivity Effects on FN/Ave and FP/Ave





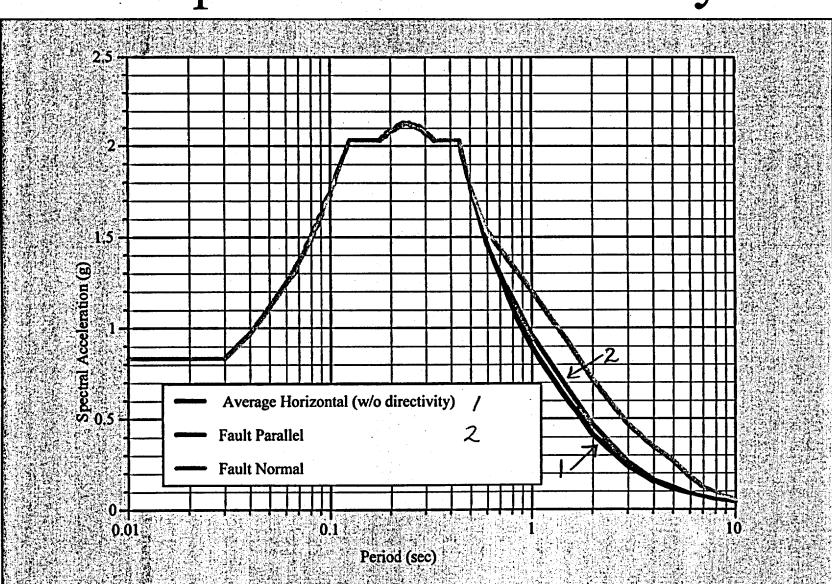
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Combined Directivity Effects

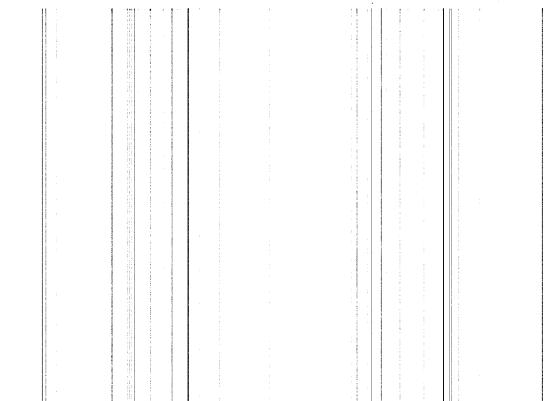


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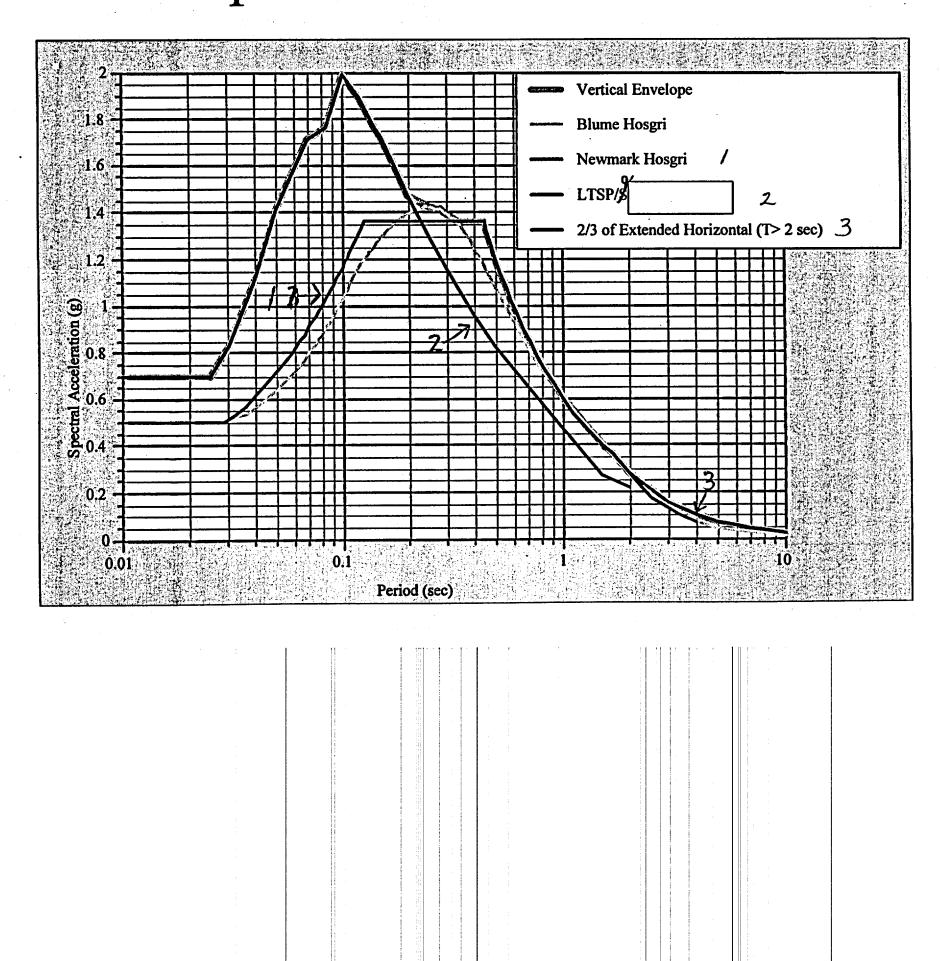
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ILP Spectra with Directivity



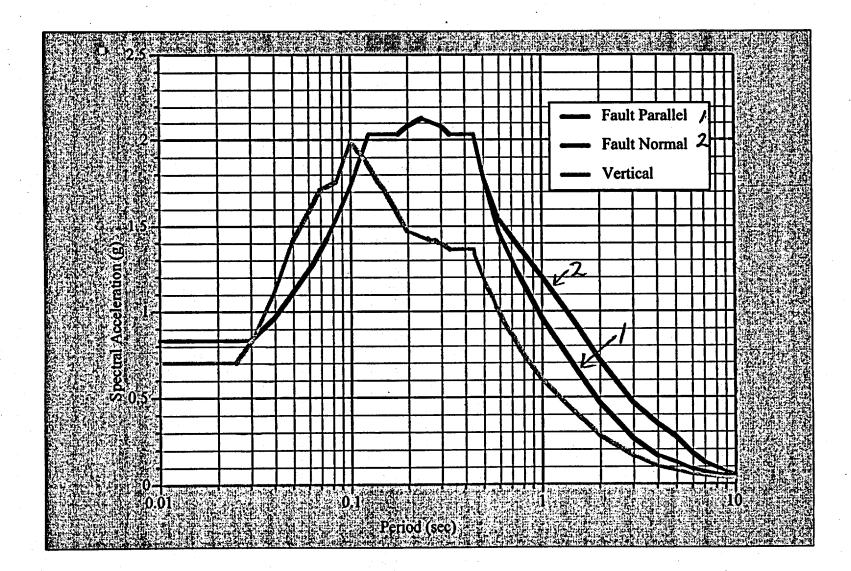
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ILP Spectra (5% damping)



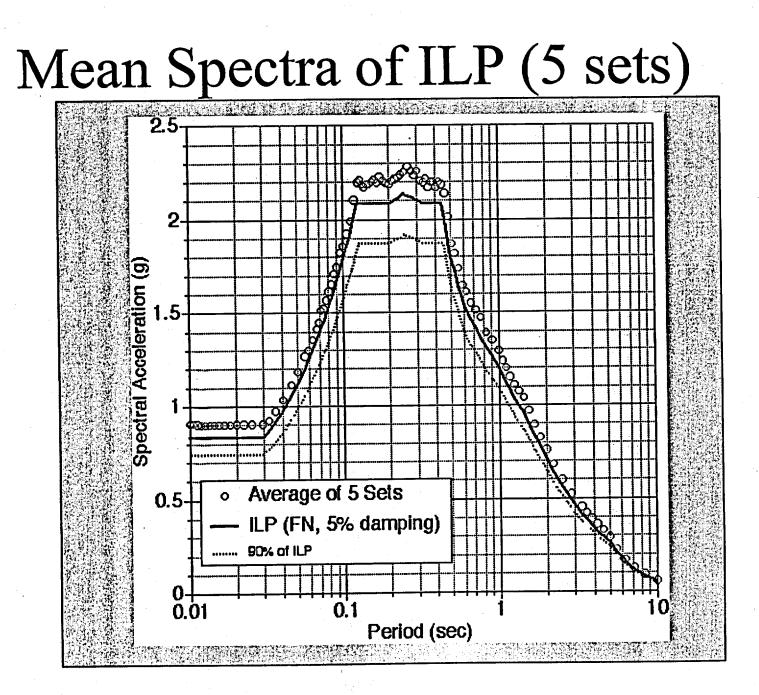
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ILP Time Histories

- 5 Sets of 3-component spectrum-compatible time histories were developed (SRP 3.7.1 criteria)
- Time histories are matched to the ILP spectra

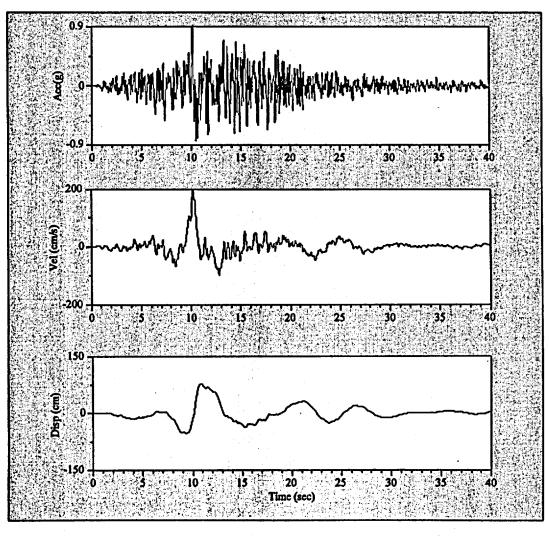
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3	1989 Loma Prieta	LGPC
5	1940 Imperial Valley	El Centro
6	1989 Loma Prieta	Saratoga

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Example of Time Histories for ILP (Set 1 FN)



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Fling

Use 84th Percentile

• Two parameters: Displacement at site and Fling period

• Use 84th percentile displacement

• Use fling period to give 84th percentile acceleration Fling Displacement

Median slip on fault = 233 cm

Median disp at site = 59 cm

84th percentile disp at site = 115 cm

Fling Period

3.2 sec

(84th percentile acc = 0.072g)

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Issues for Combining Fling and Vibratory Ground Motion

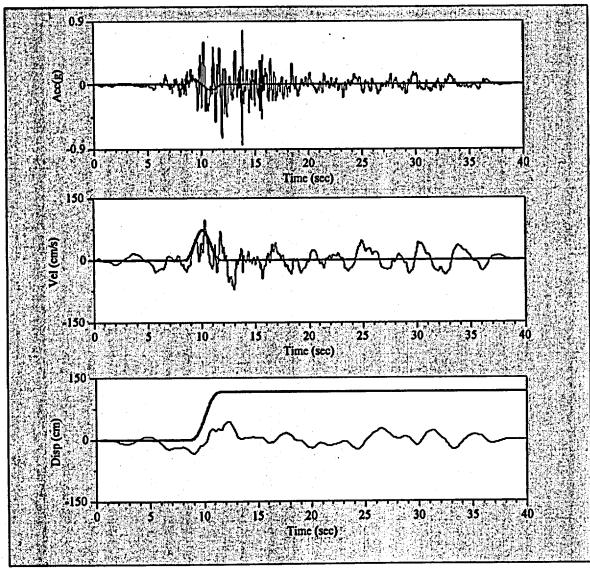
- What is the timing between fling and S-waves?
 - For sites close to the fault, fling arrives near the S-wave

Polarity of fling and S-waves?

 For design ground motions, require constructive interference of velocity

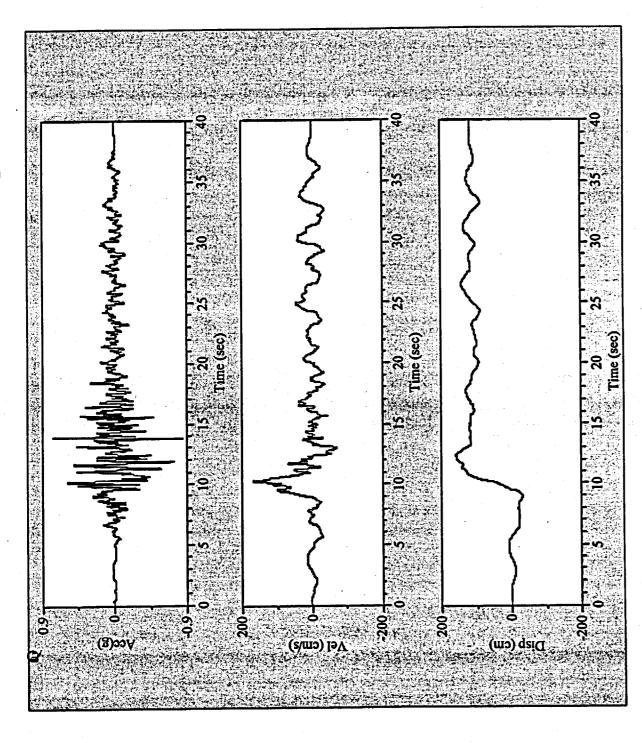
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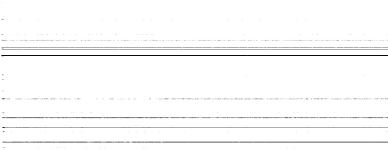
Example Timing of Fling

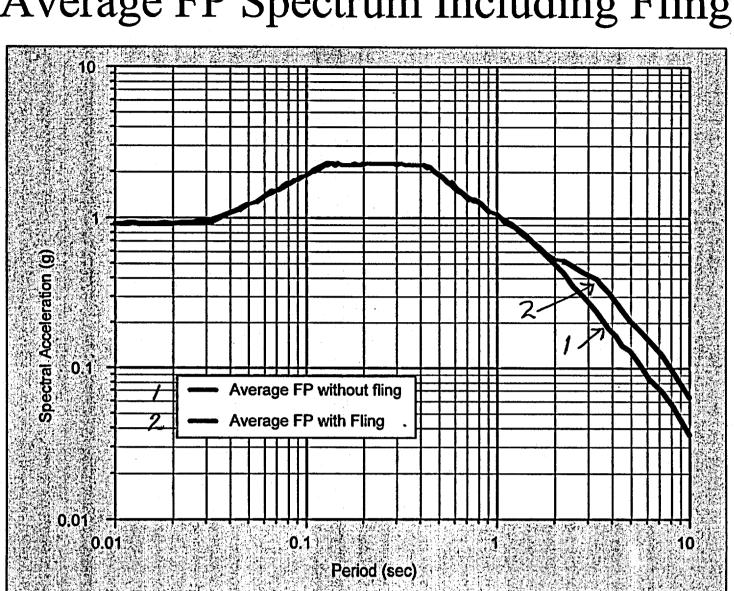


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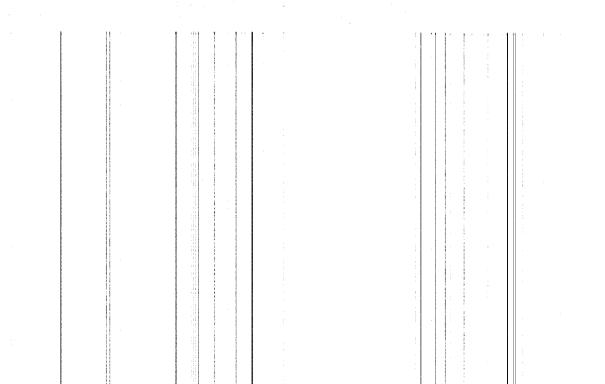
Ground Motion with Fling





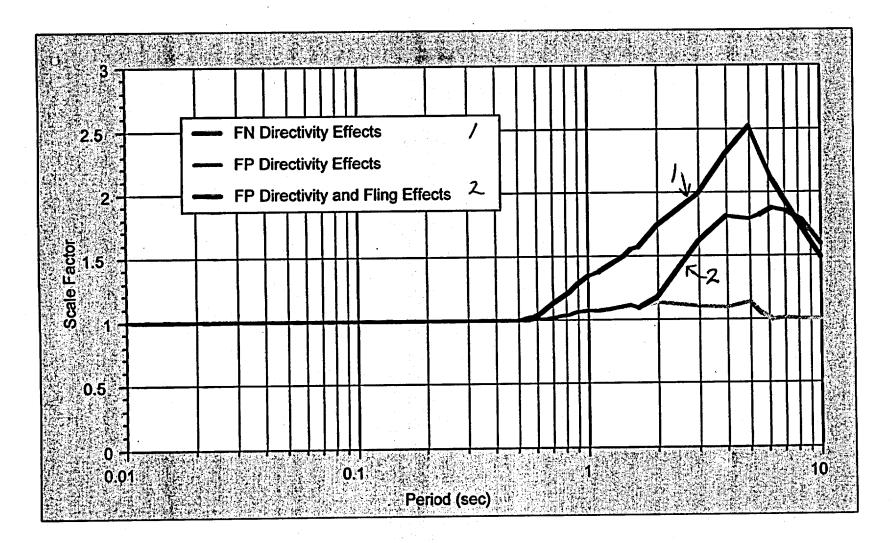


Average FP Spectrum Including Fling



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Effects of Directivity and Fling



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Ground Motion Summary

- Used DCPP design basis ground motions
 - ◆ HE, DDE spectra
 - ◆ HE time histories
- Applied new research results for directivity and fling
 - ◆ ILP spectra and time histories
 - Increase in the long period ground motions
 - Approaches are new and are not standard in earthquake engineering practice

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NRC/PG&E Open Meeting, San Francisco, CA Diablo Canyon Independent Spent Fuel Storage Installation

Geology

William Page Engineering Geologist PG&E Geosciences Department



April 11, 2002

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Geology Team

- Bill Page, PG&E Geosciences Dept.
- Jeff Bachhuber, William Lettis & Assoc.
- Charlie Brankman, William Lettis & Assoc.
- Bill Lettis, William Lettis & Assoc.

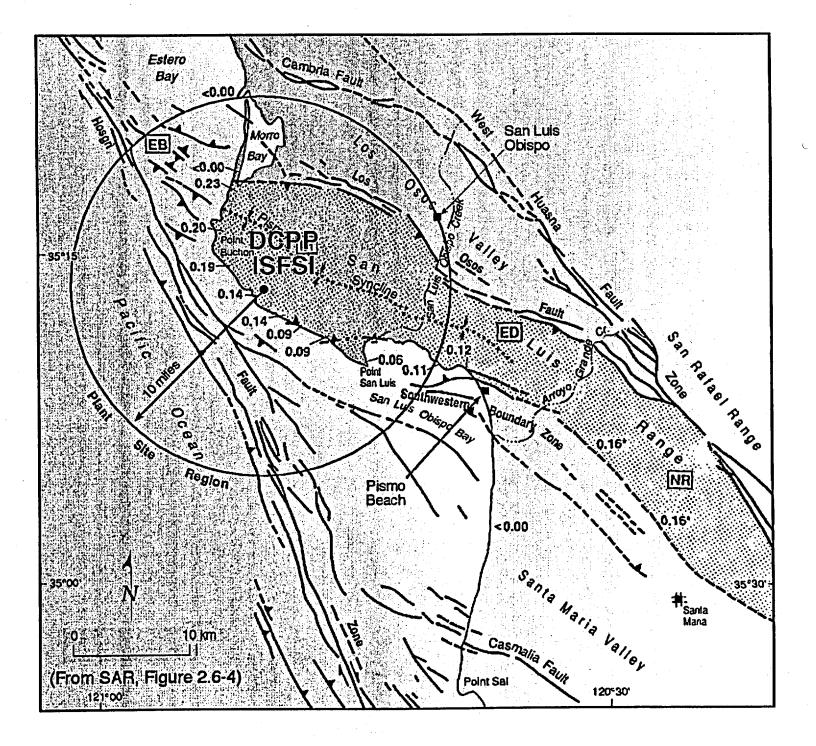
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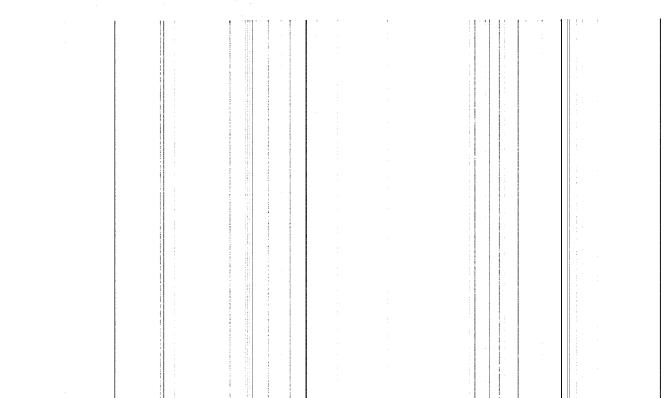
Purpose of Geologic Investigations

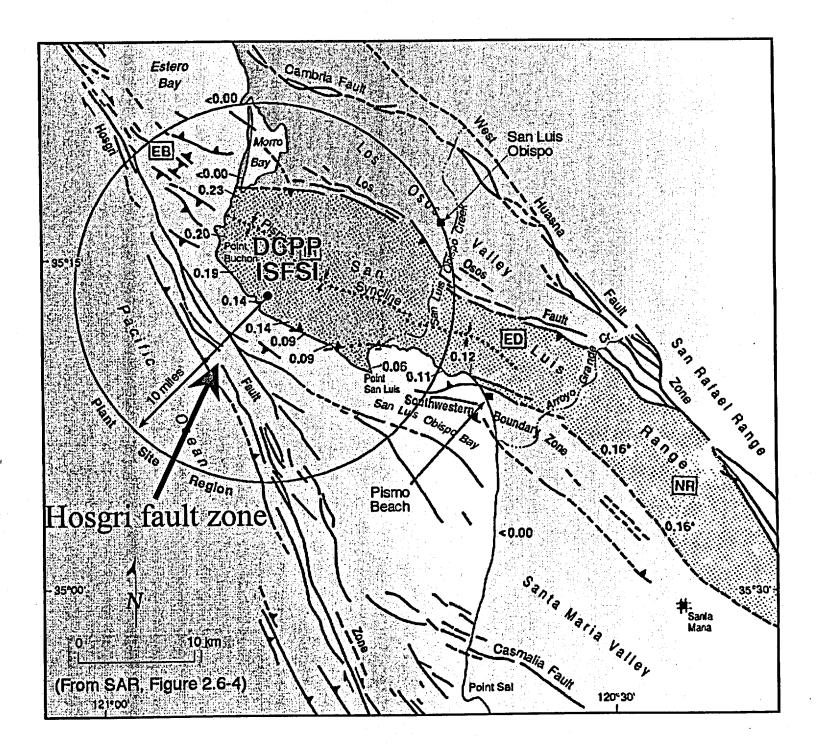
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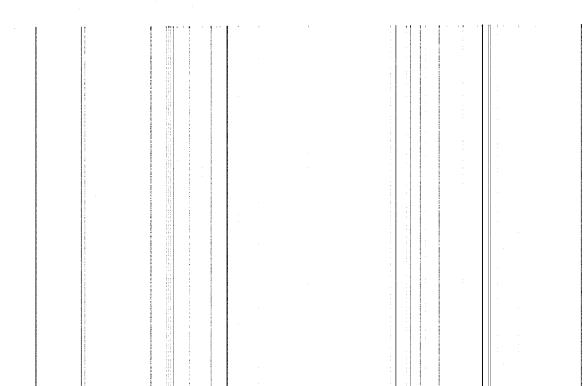
- Rock characteristics
- Surficial deposits
- Slope stability
 - Landslides, debris flows
 - Rock characteristics
 - Bedding, joints, faults
 - Clay beds

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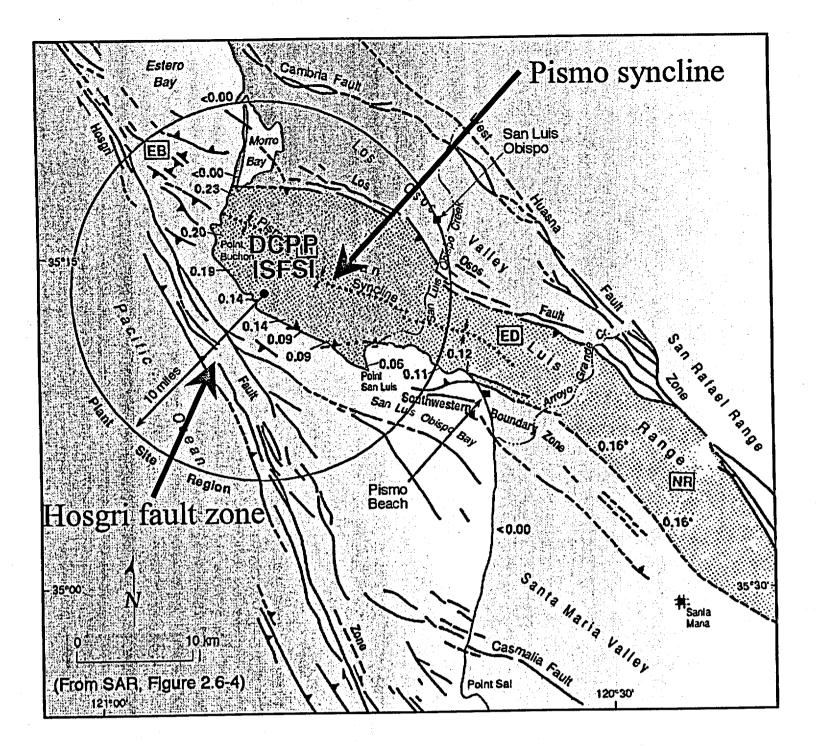


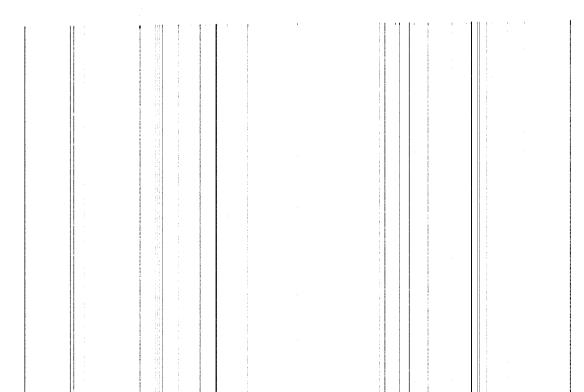






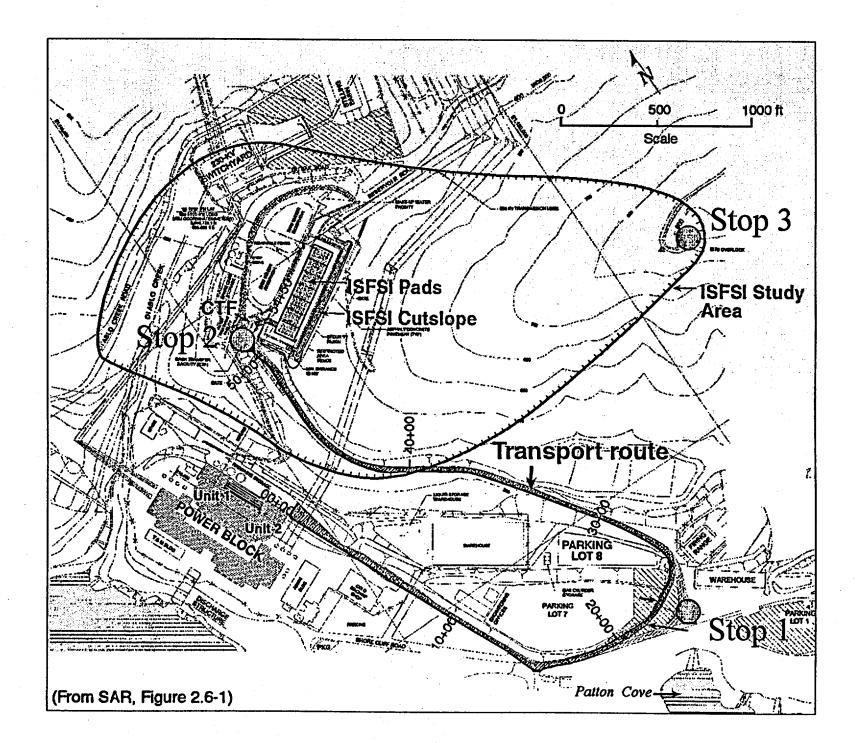
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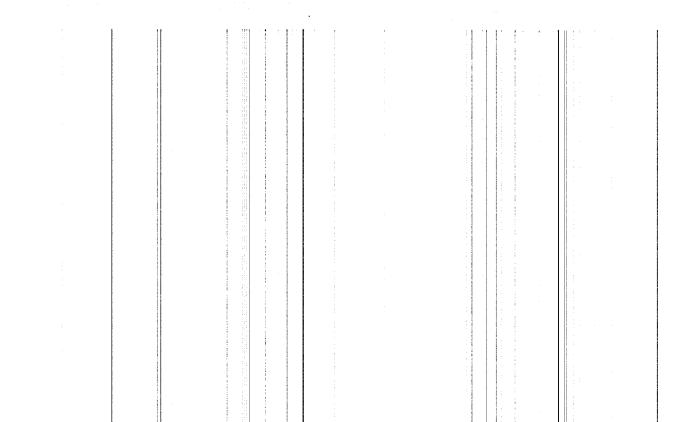




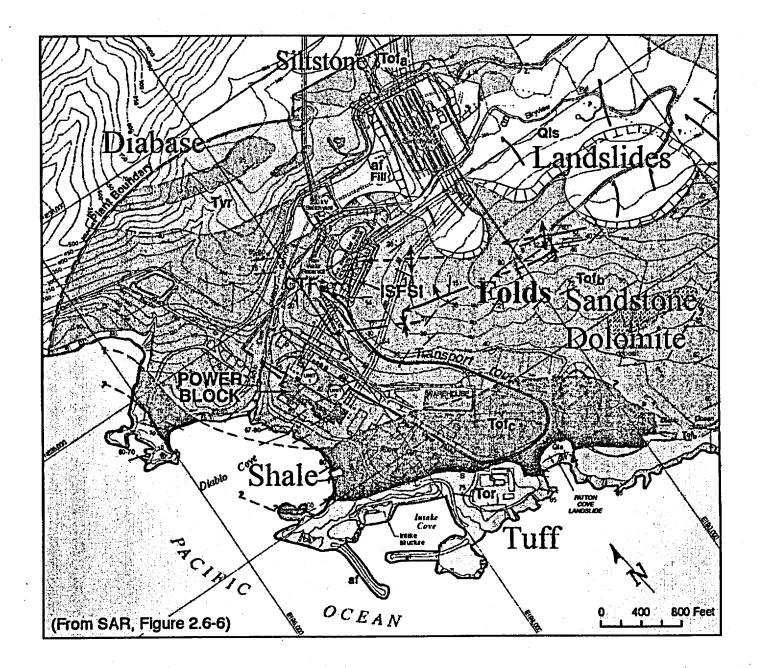
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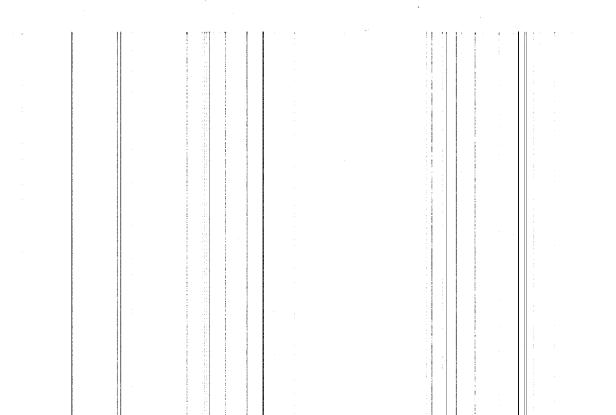




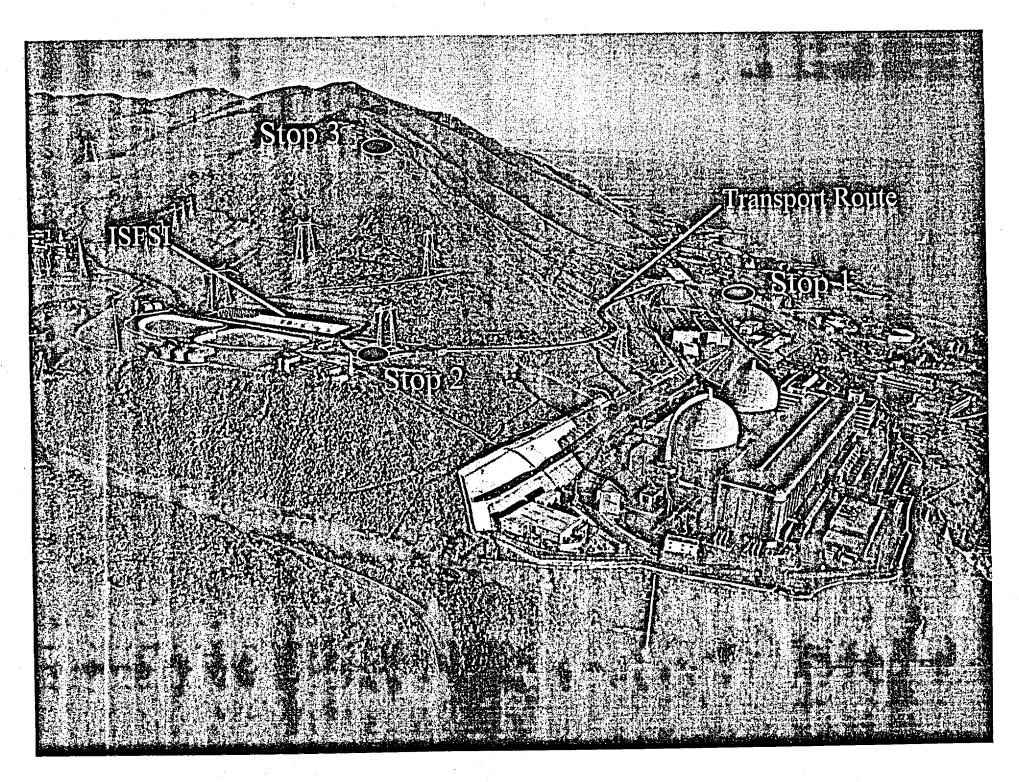
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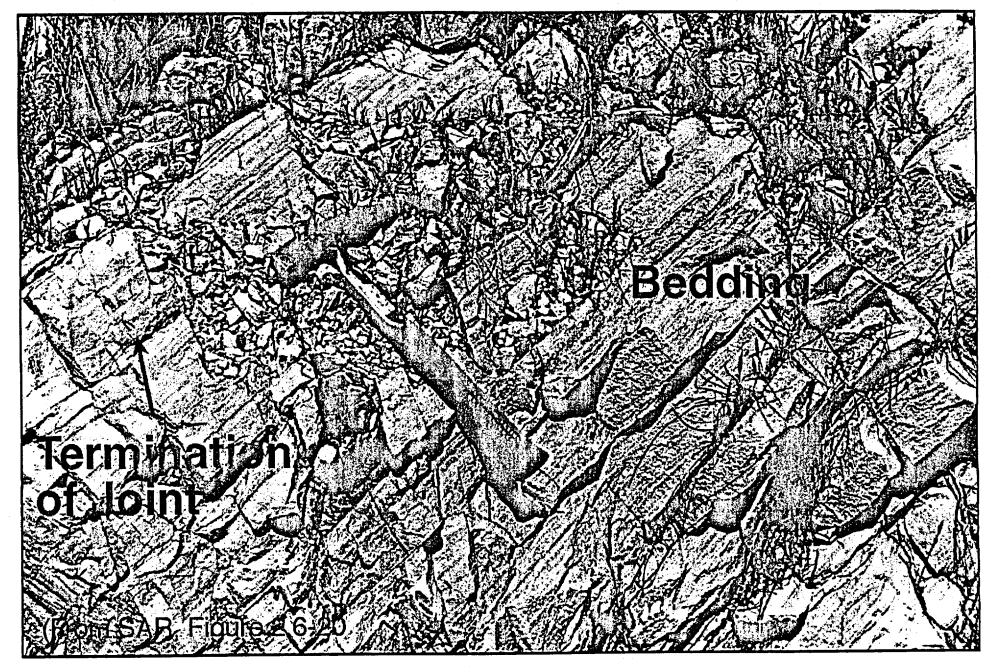


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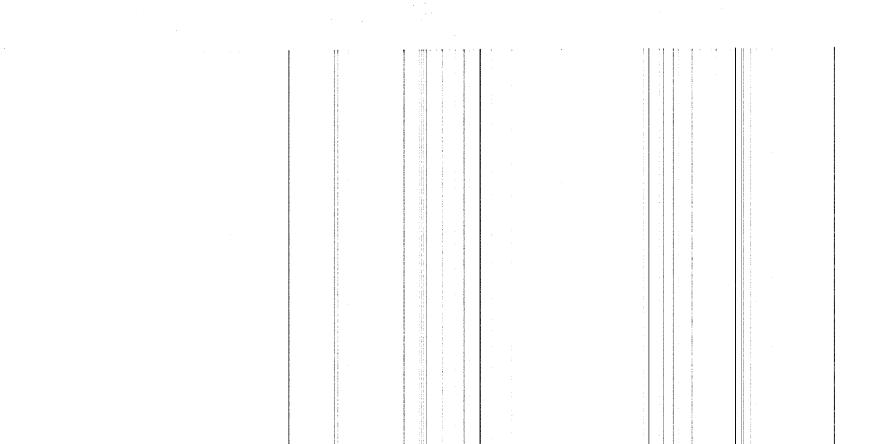


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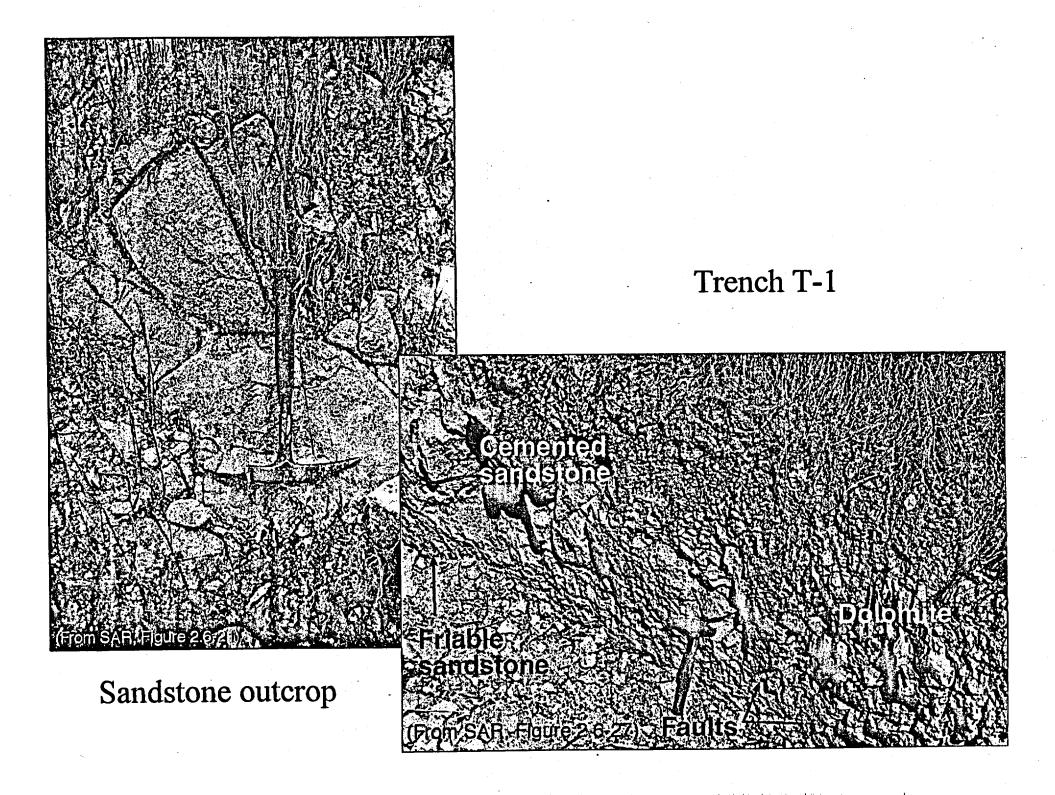
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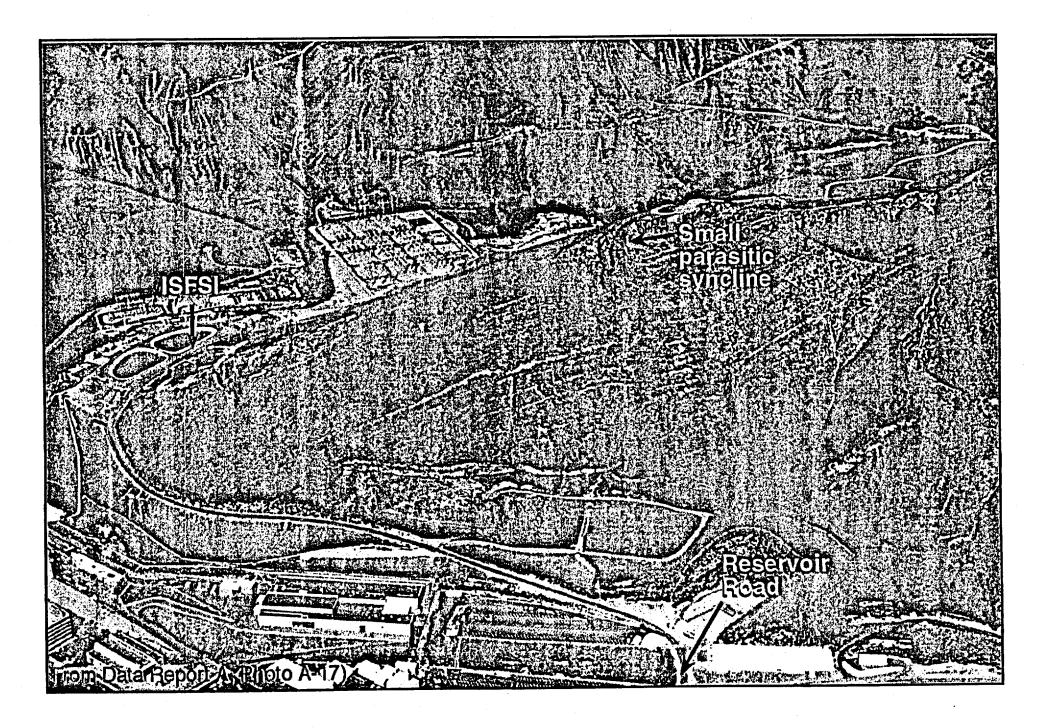
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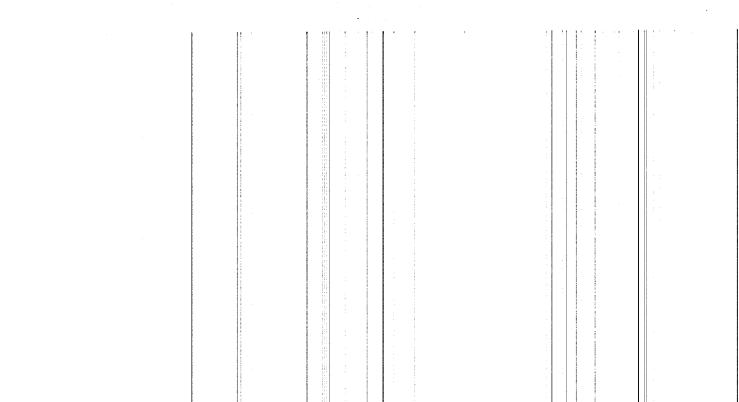
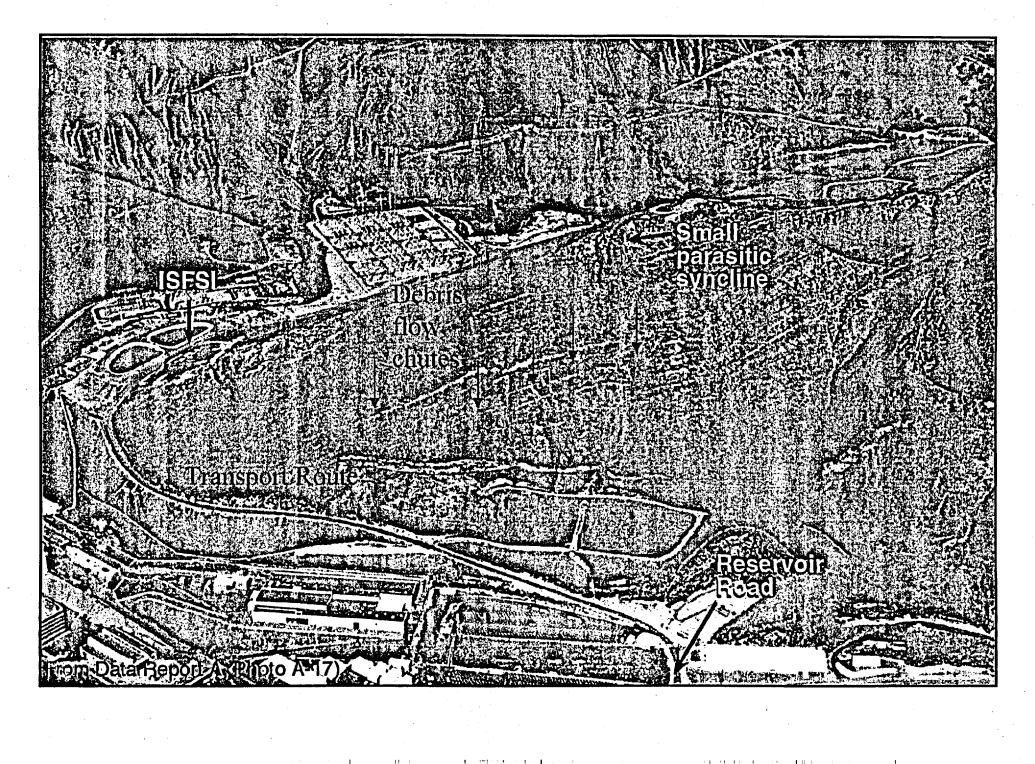
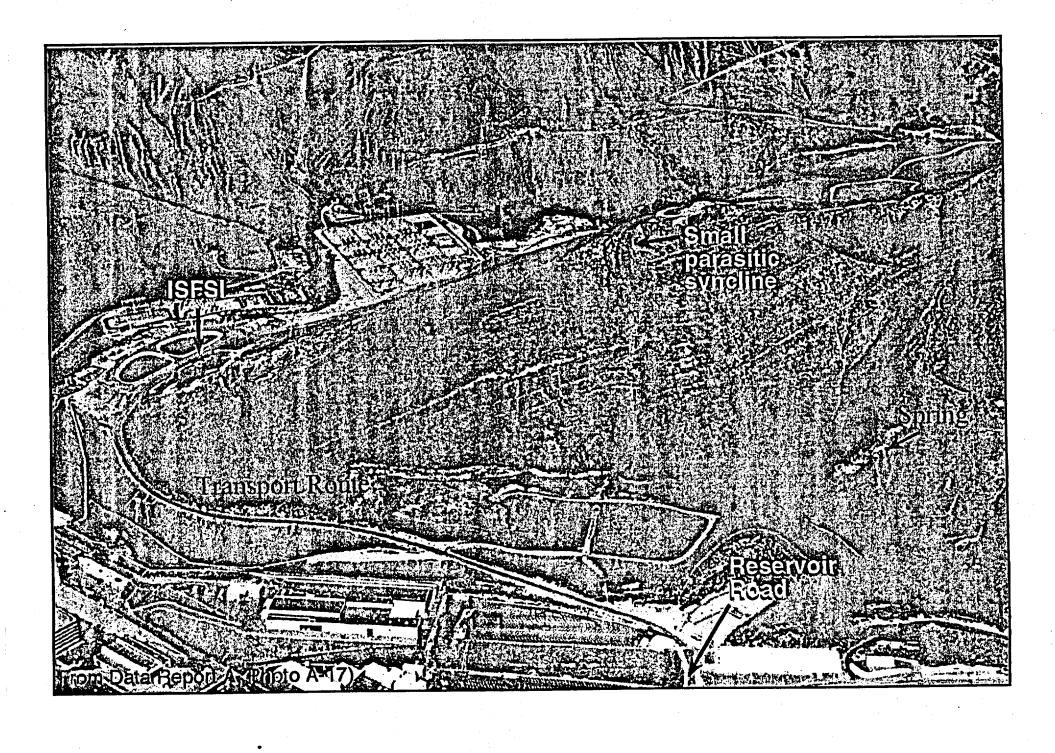


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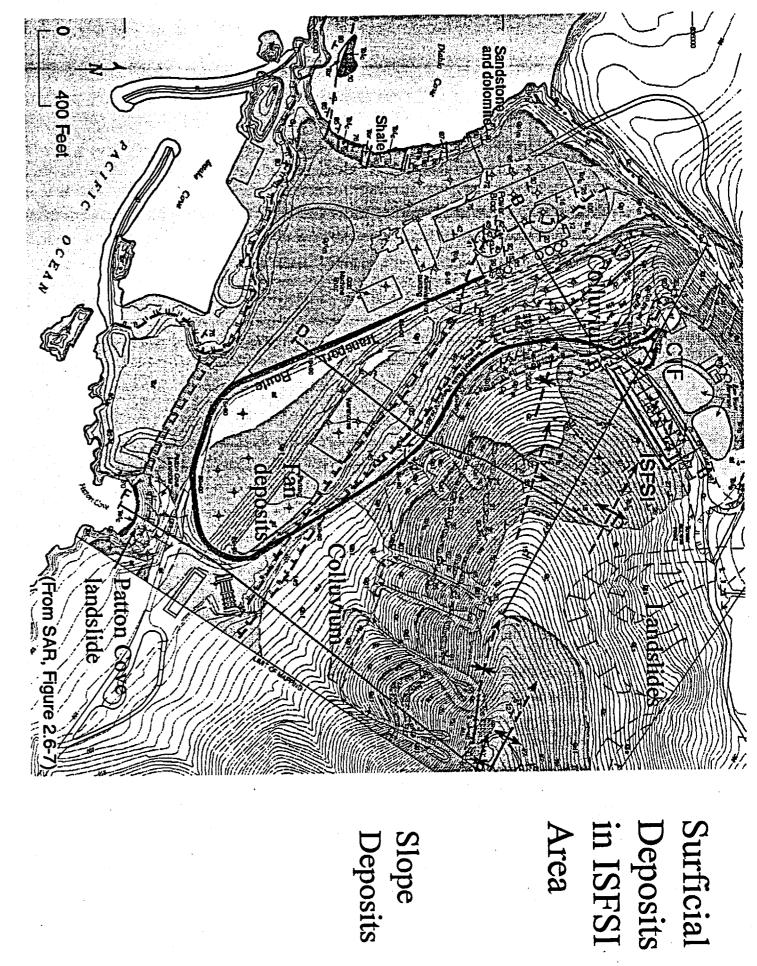


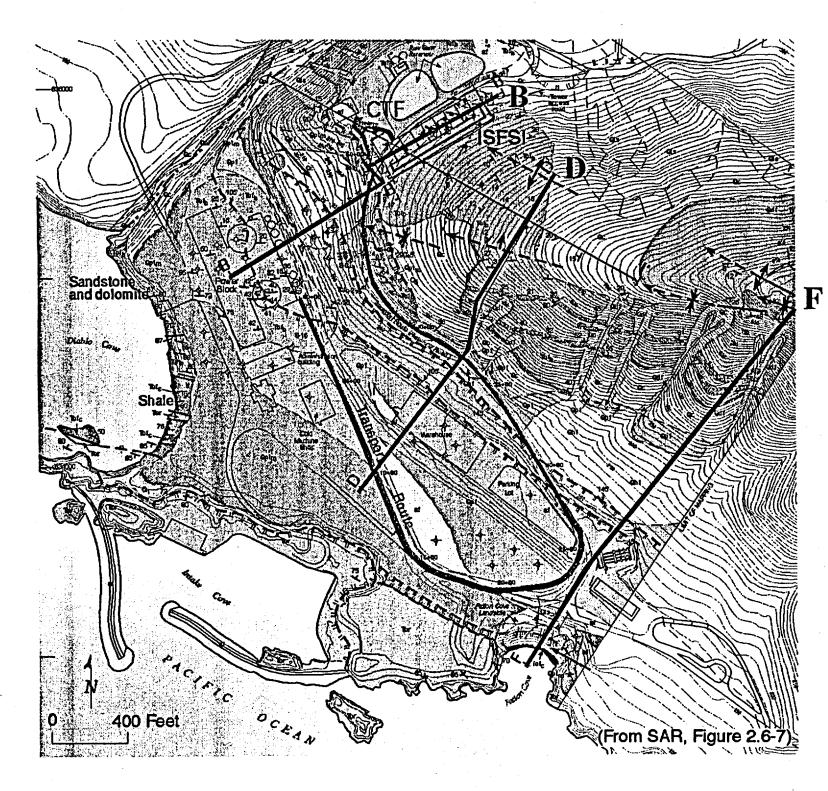
Surficial Deposits in ISFSI Area

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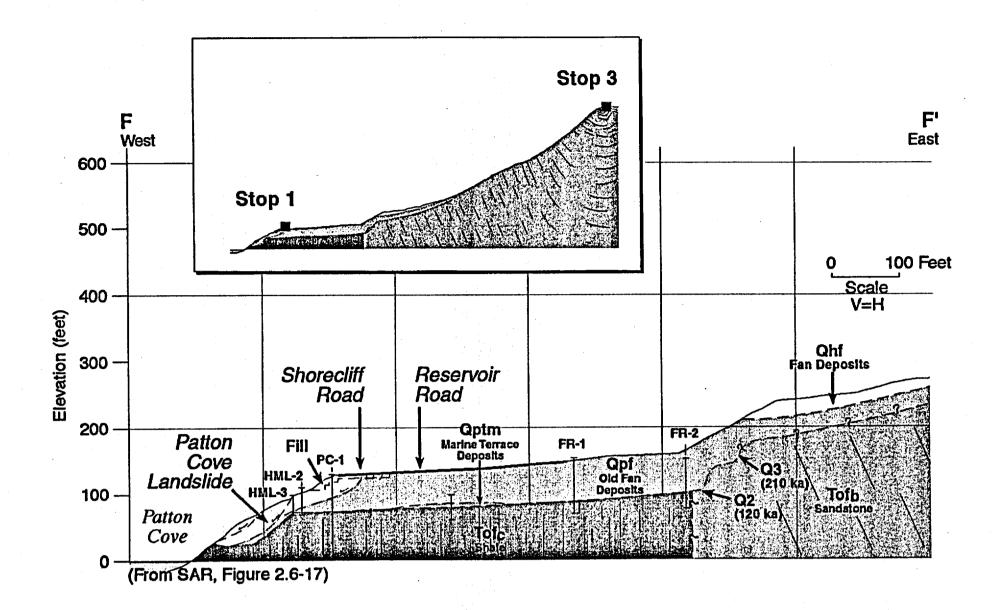


Surficial Deposits in ISFSI Area

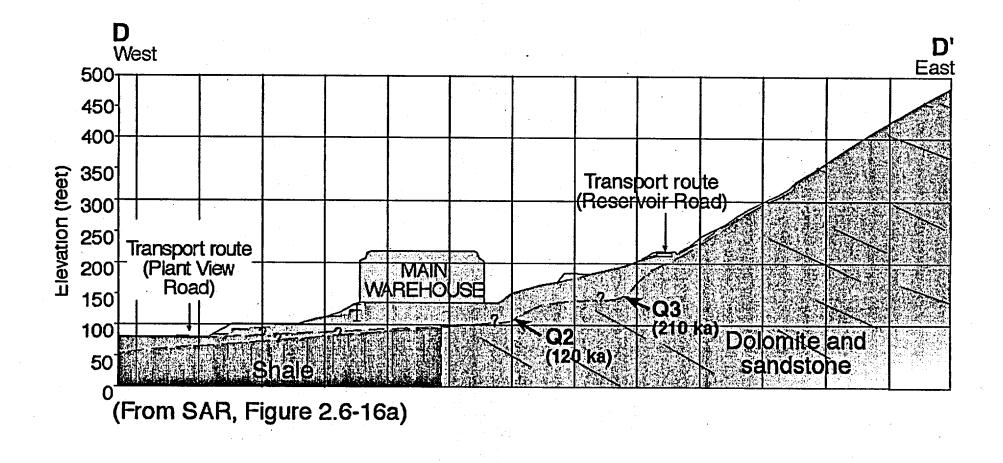
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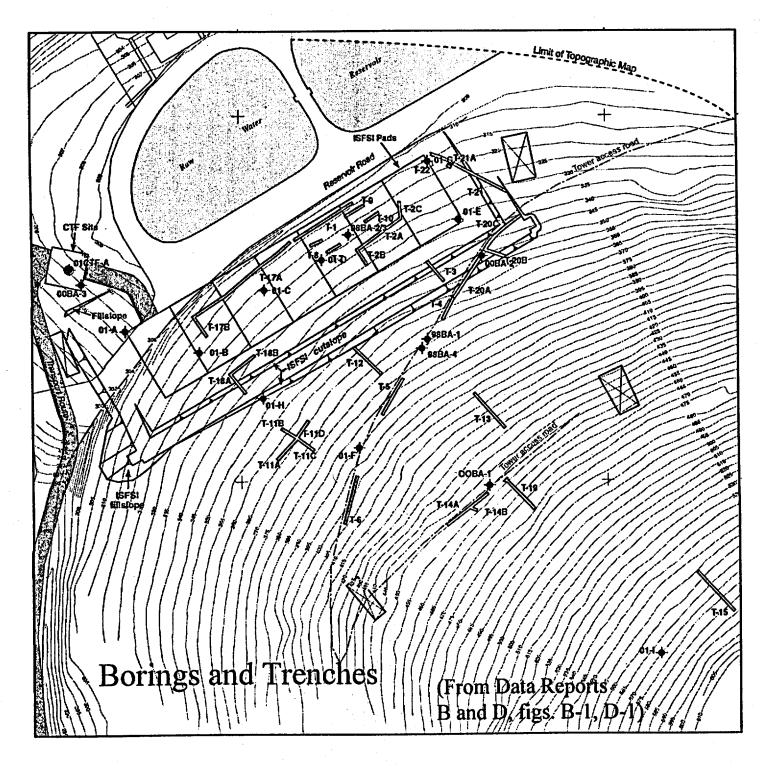
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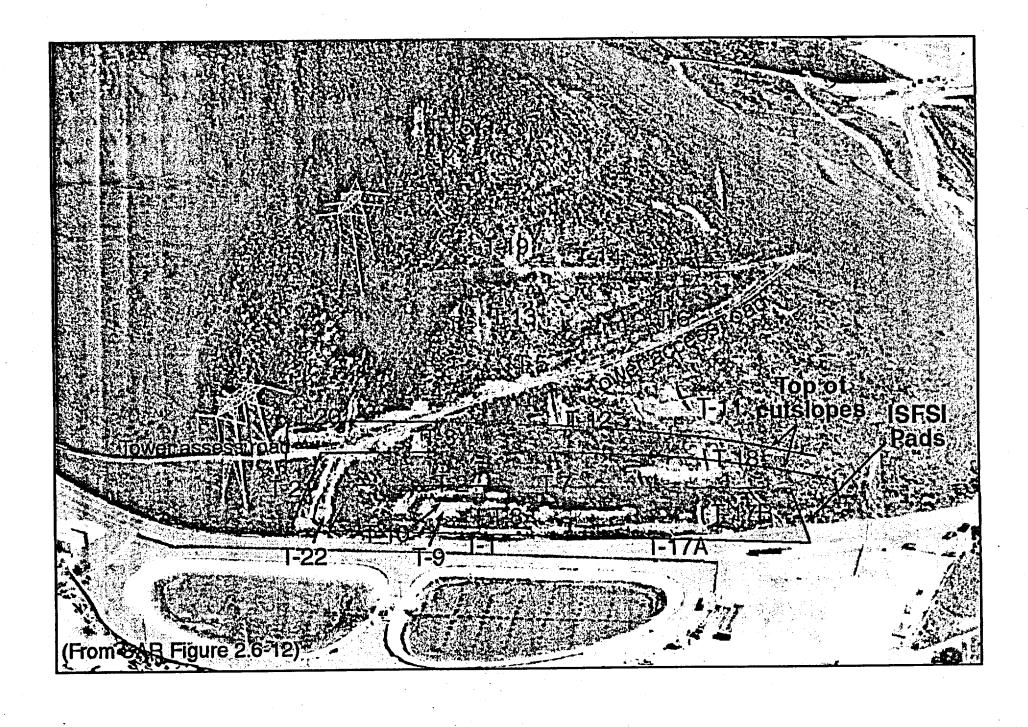
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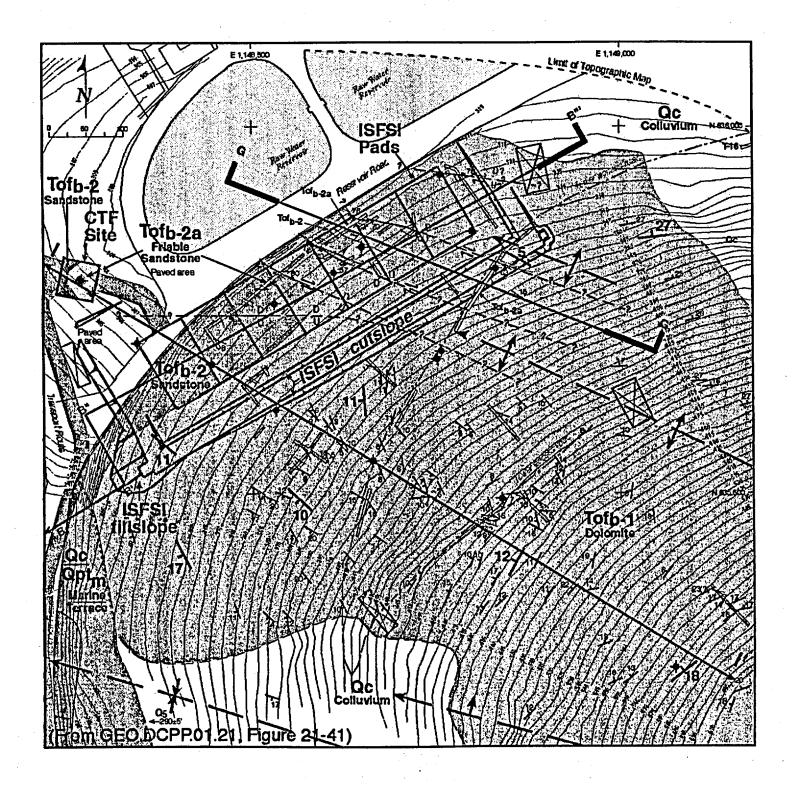
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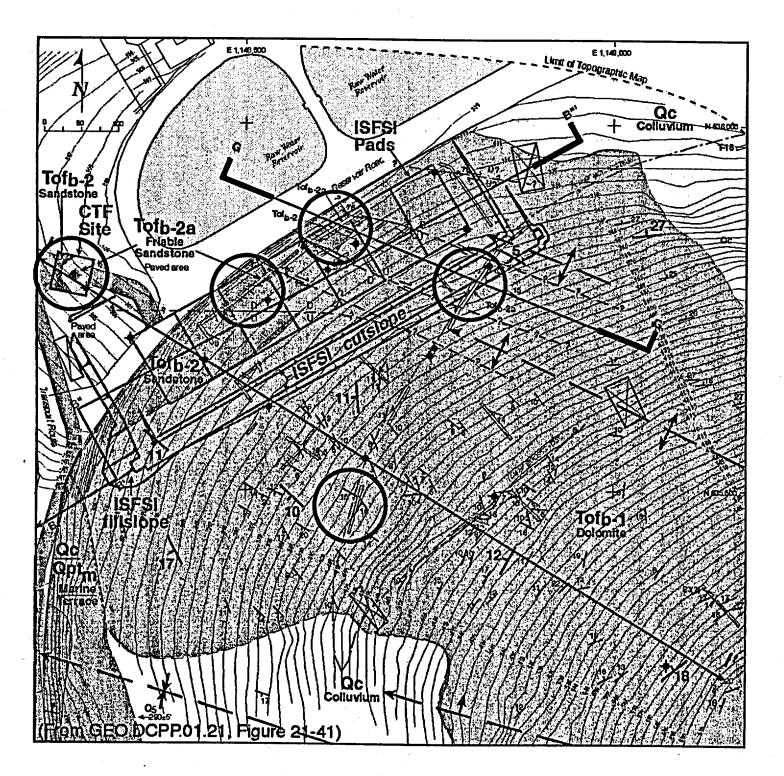
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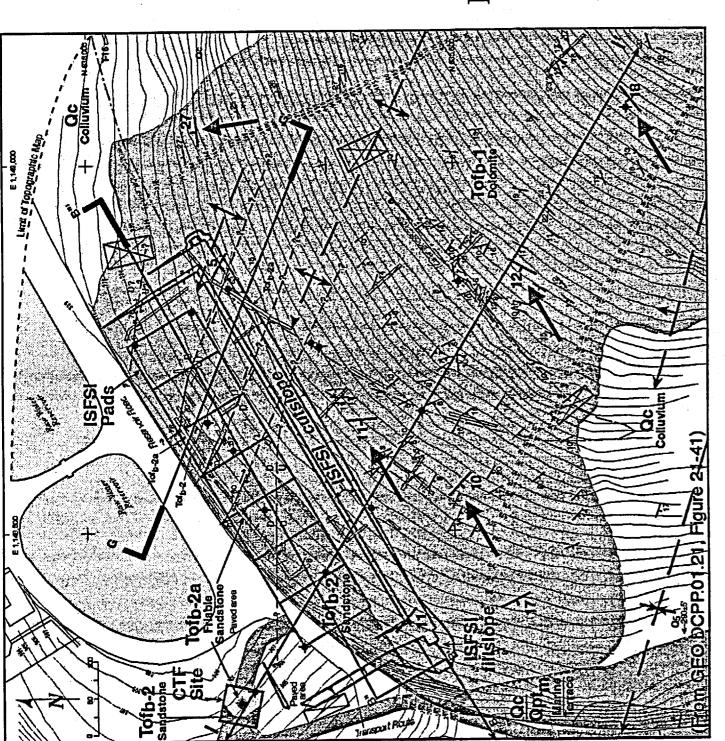




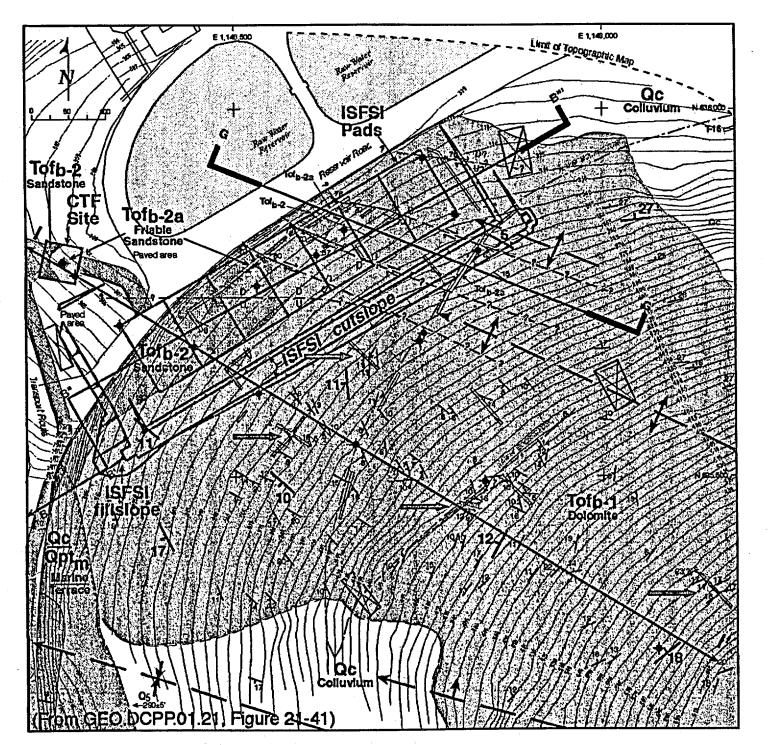


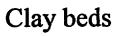
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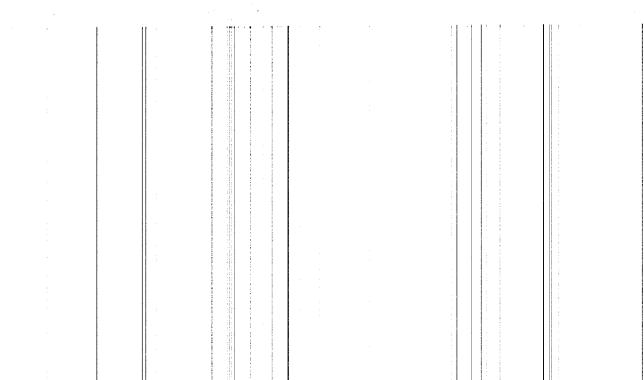
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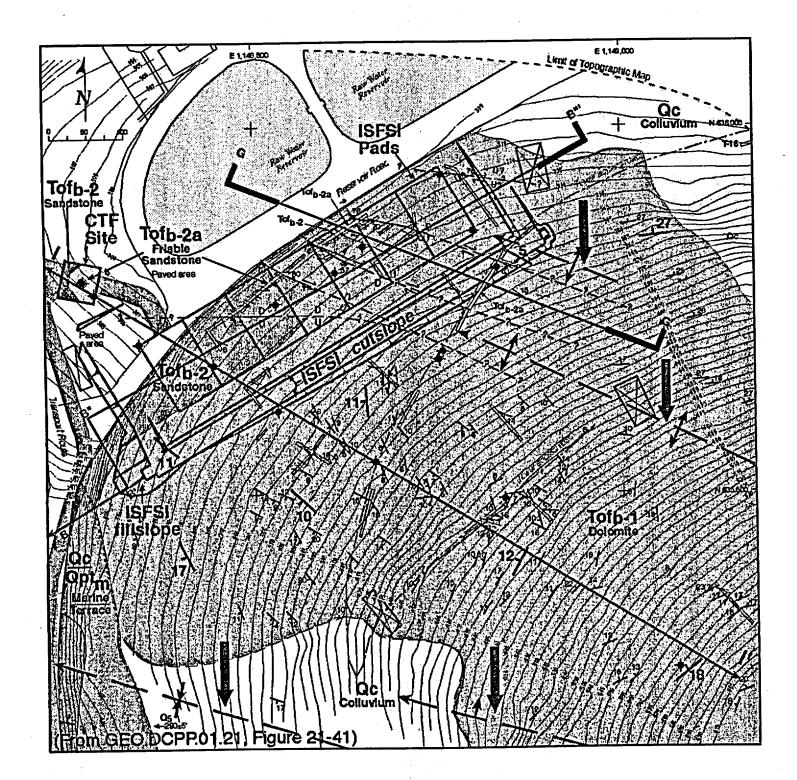
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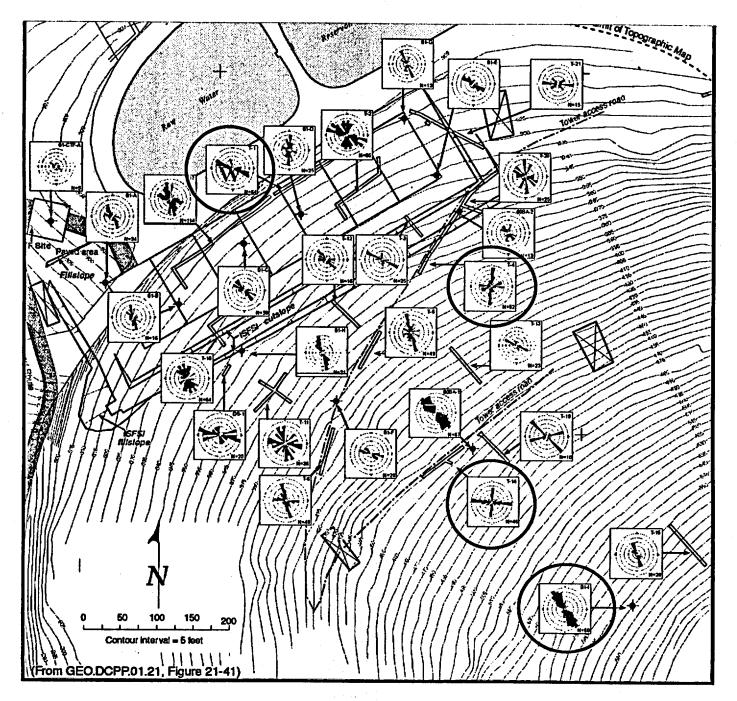




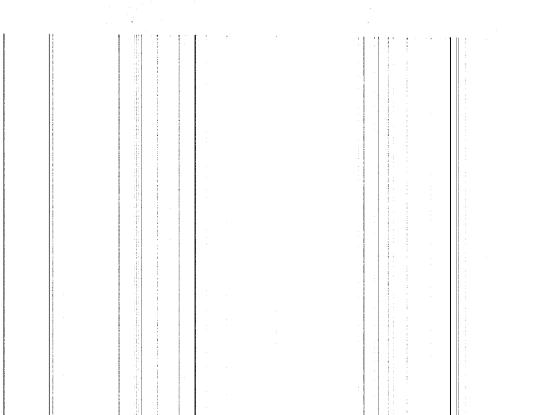
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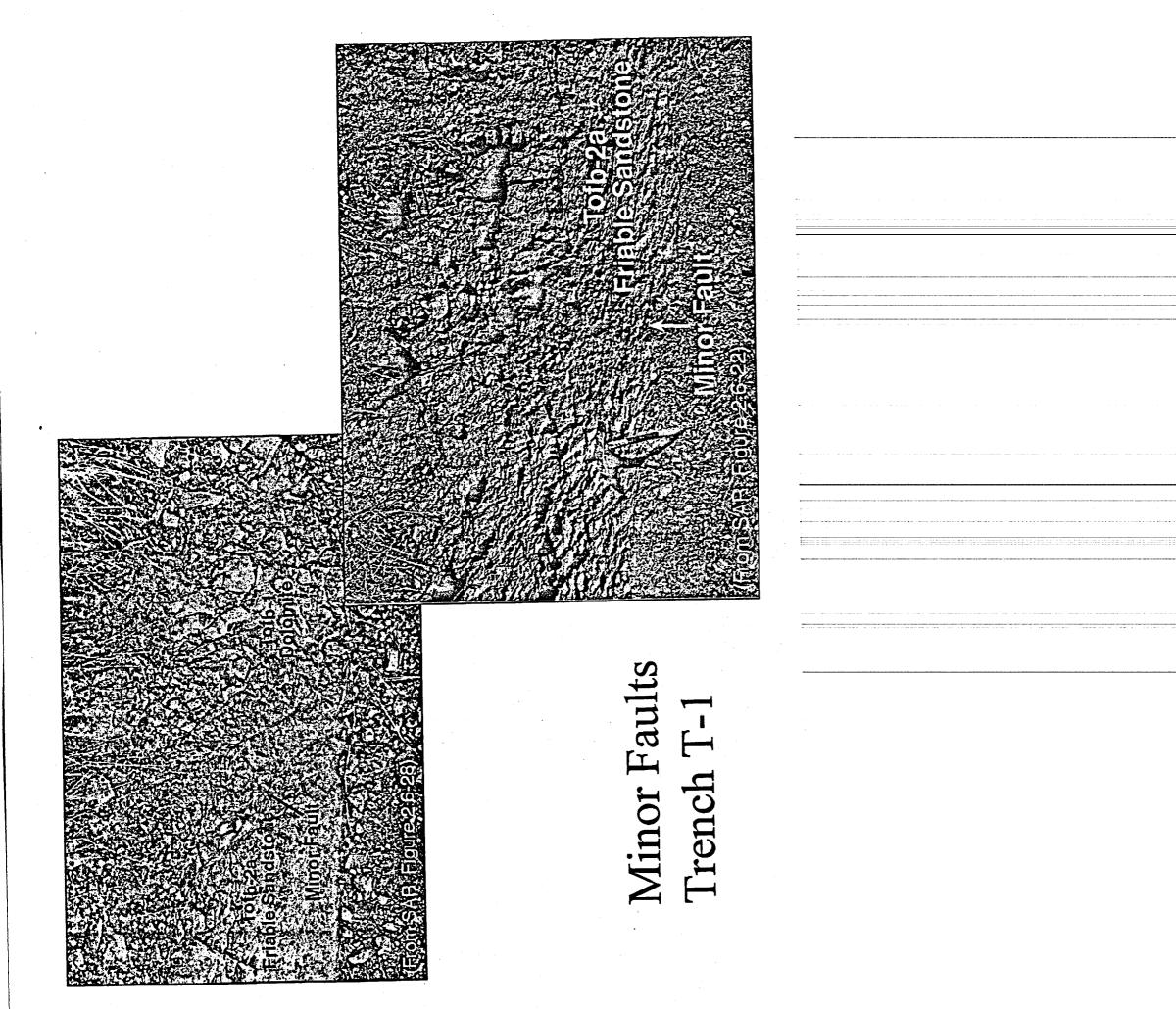
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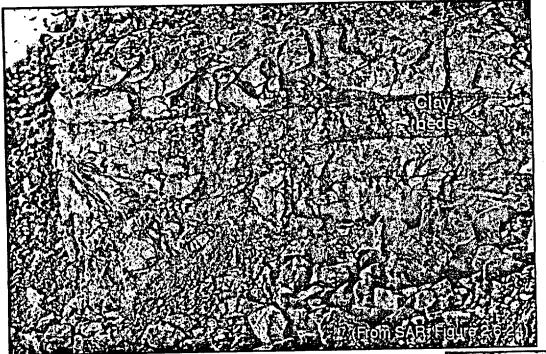


Rose Diagrams for Joints and Faults



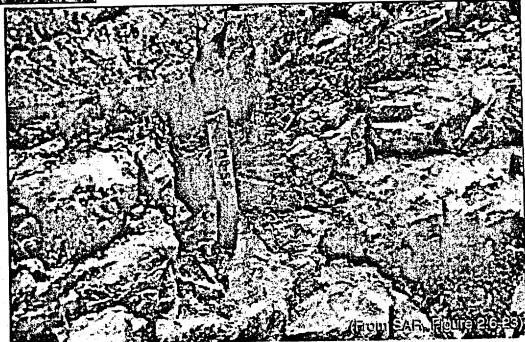
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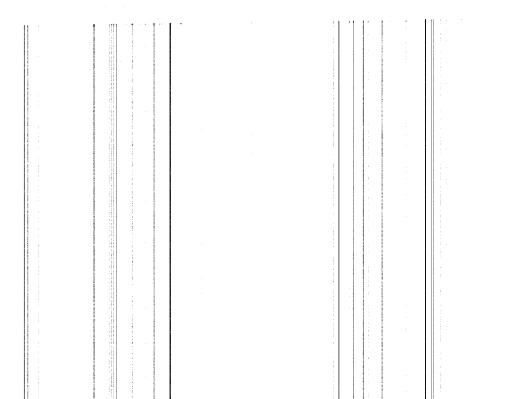


1/16- to 3/4-inch thick clay beds

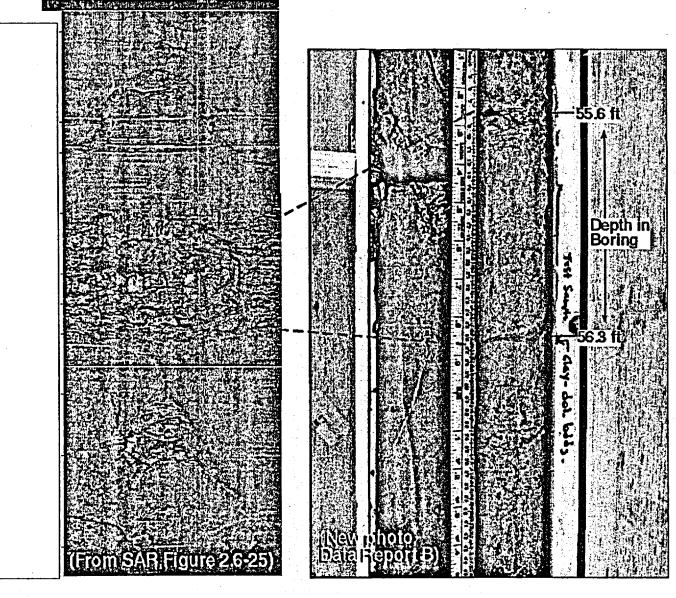
Clay Beds in Trench T-14



1- to 4-inch thick clay beds



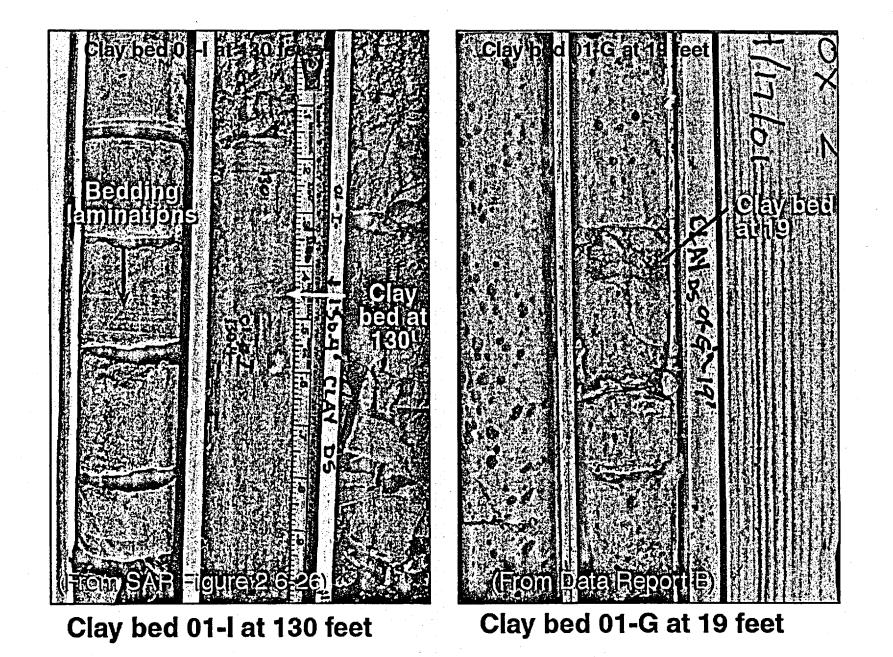
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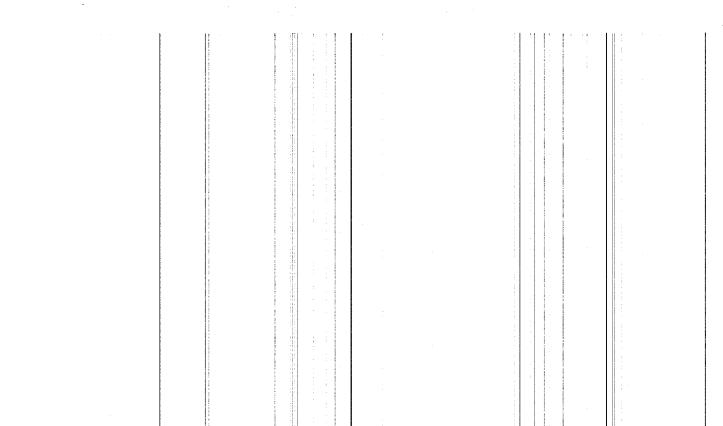
Optical televiewer image Core Thick Clay Bed in Boring 00BA-1 at 55 Feet

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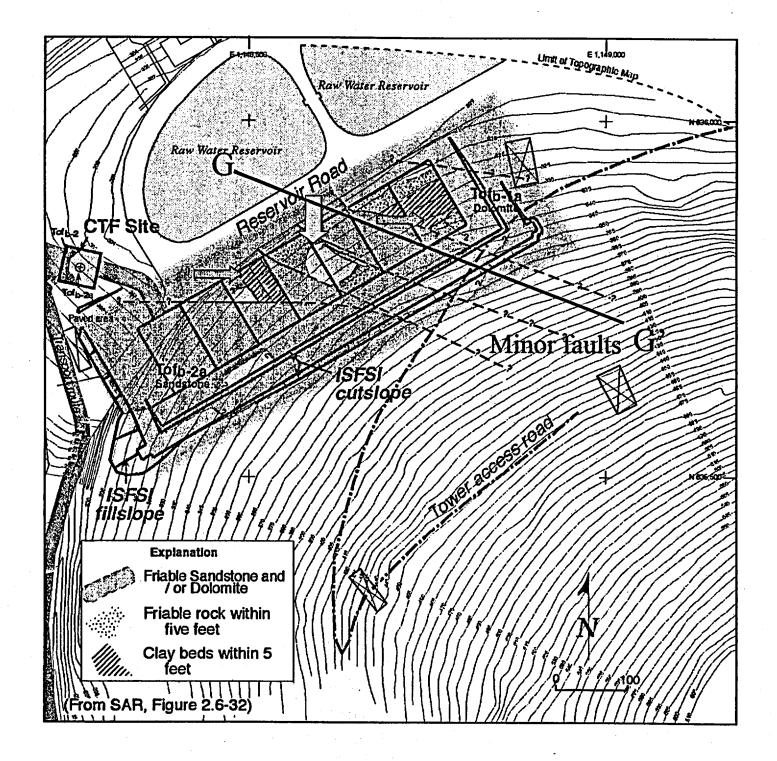
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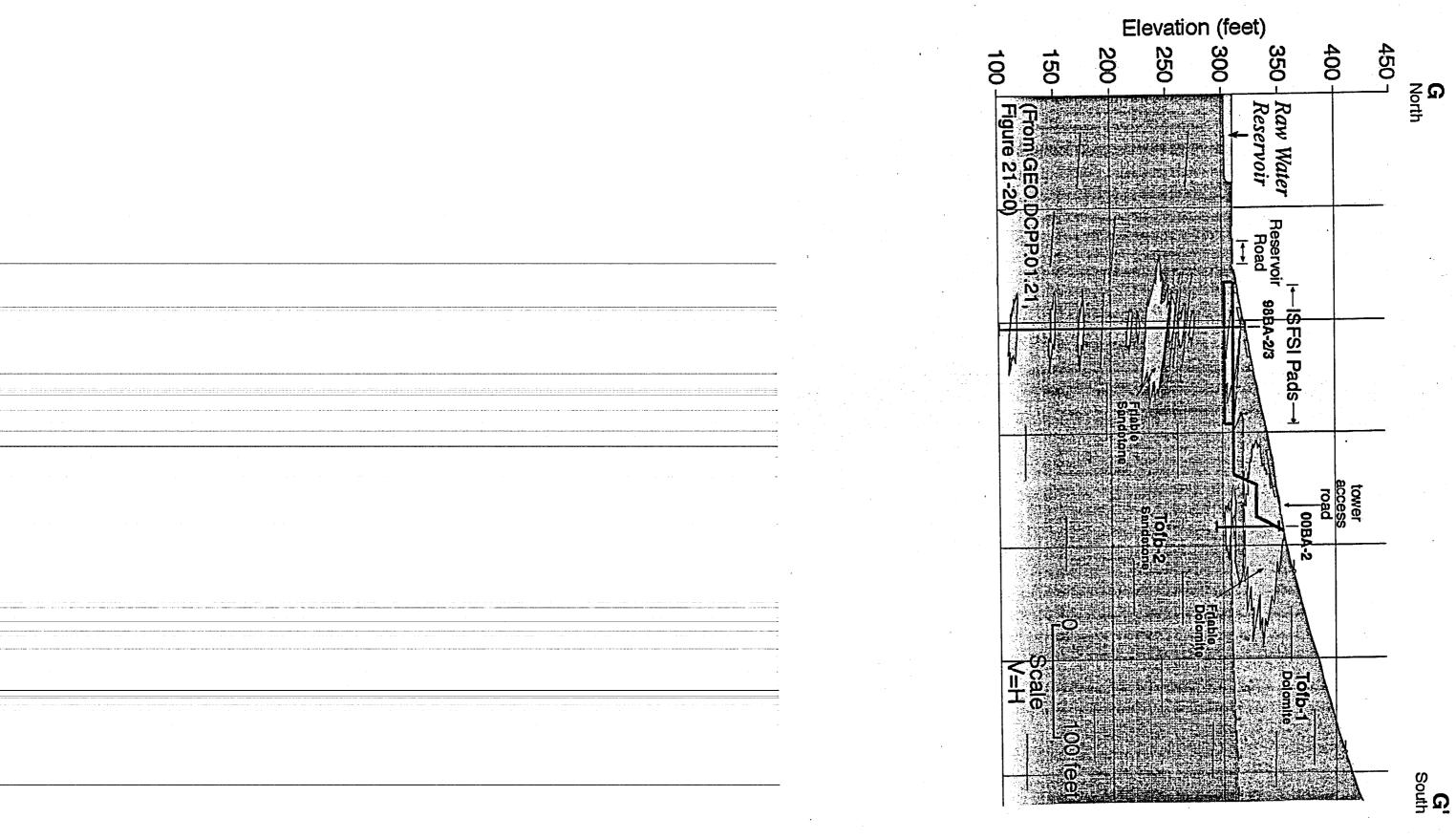
Thin Clay Beds in Boring 01-I and 01-G

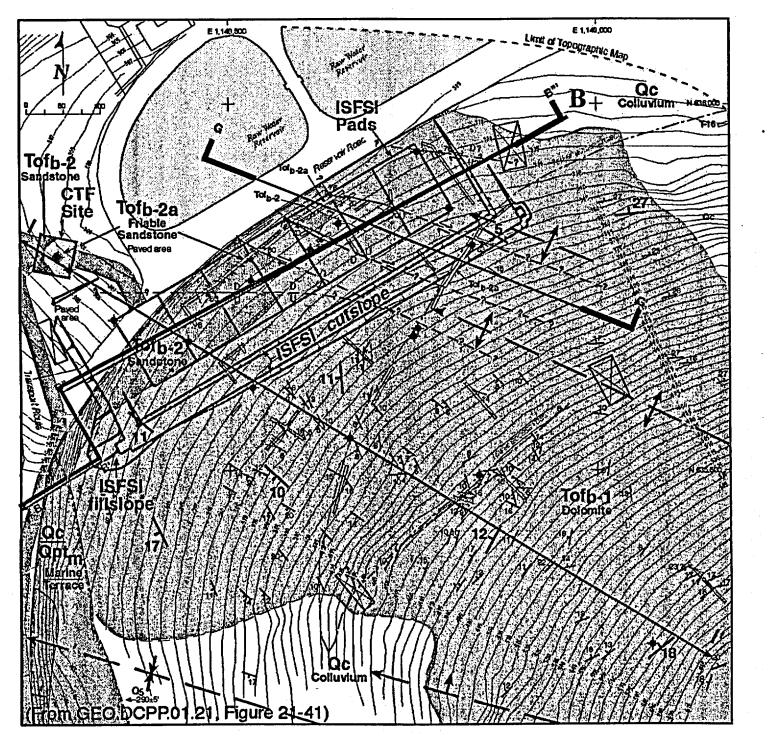


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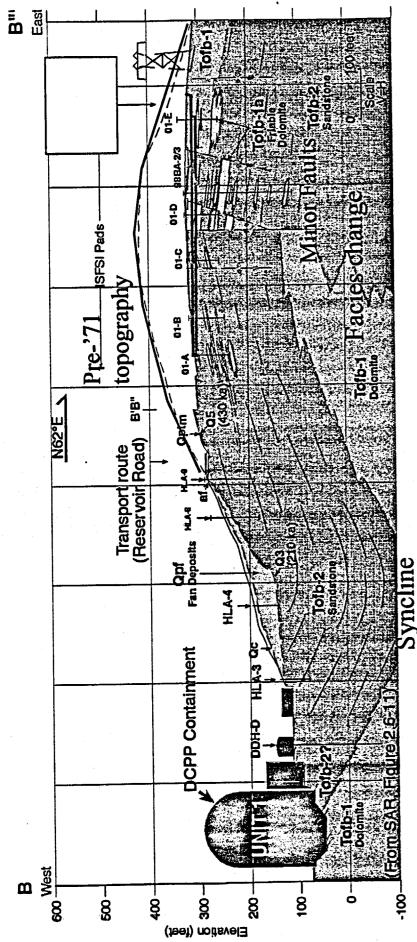


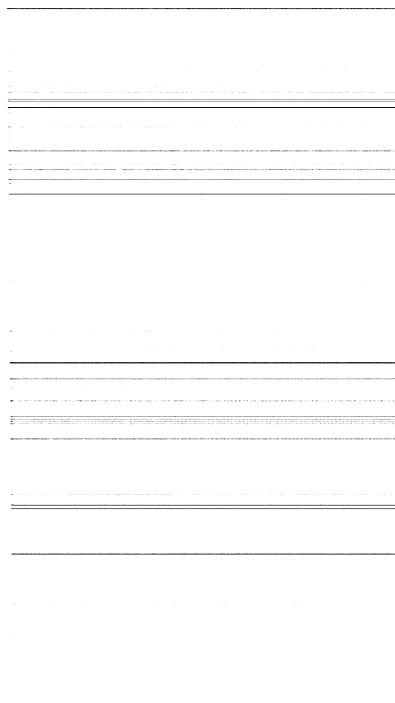


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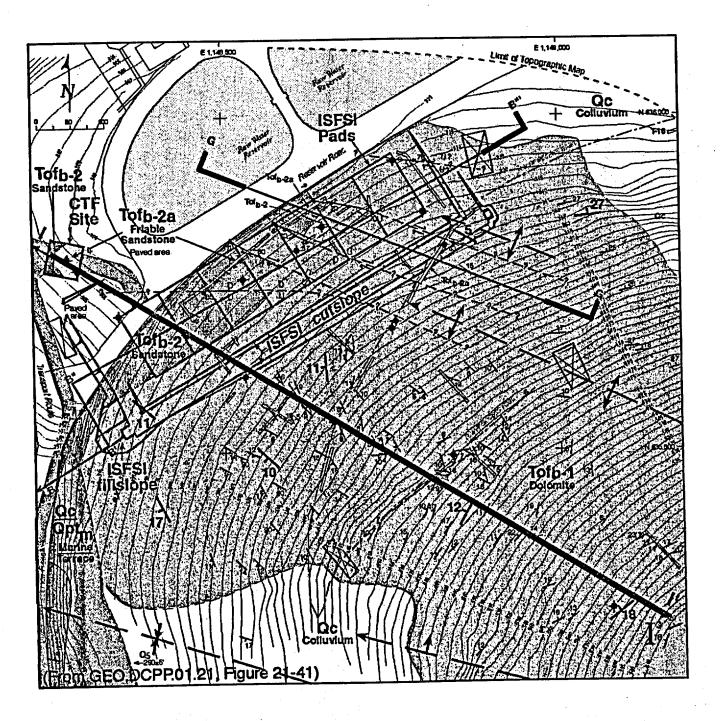
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Comparison of Bedrock at ISFSI and Power Block

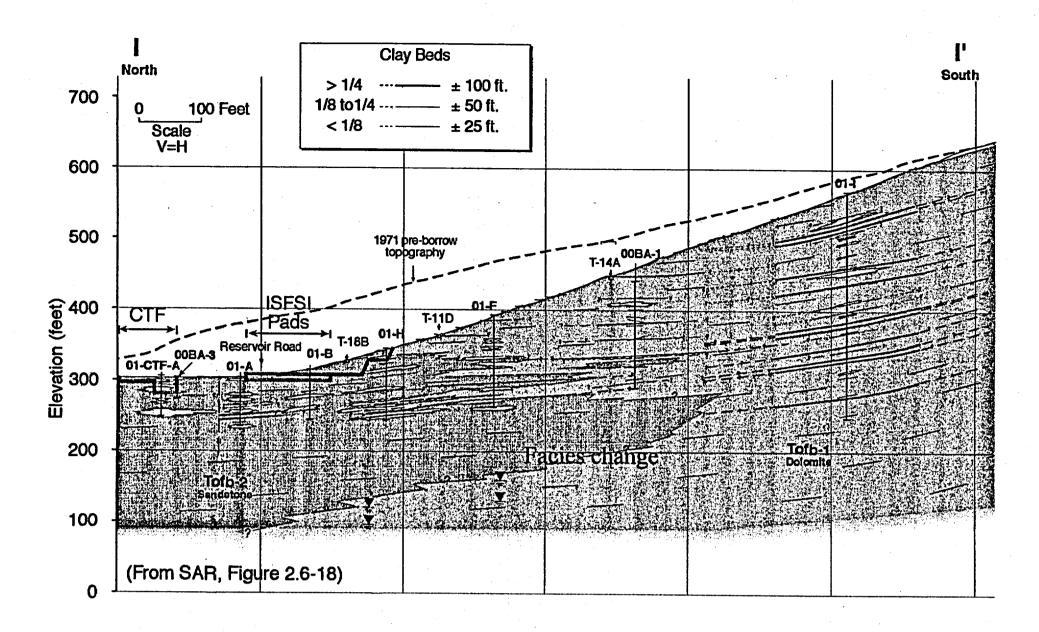
Same stratigraphic unit
 Obispo Formation Tof_b
 Same lithology and density
 Dolomite and sandstone
 Similar shear wave velocity



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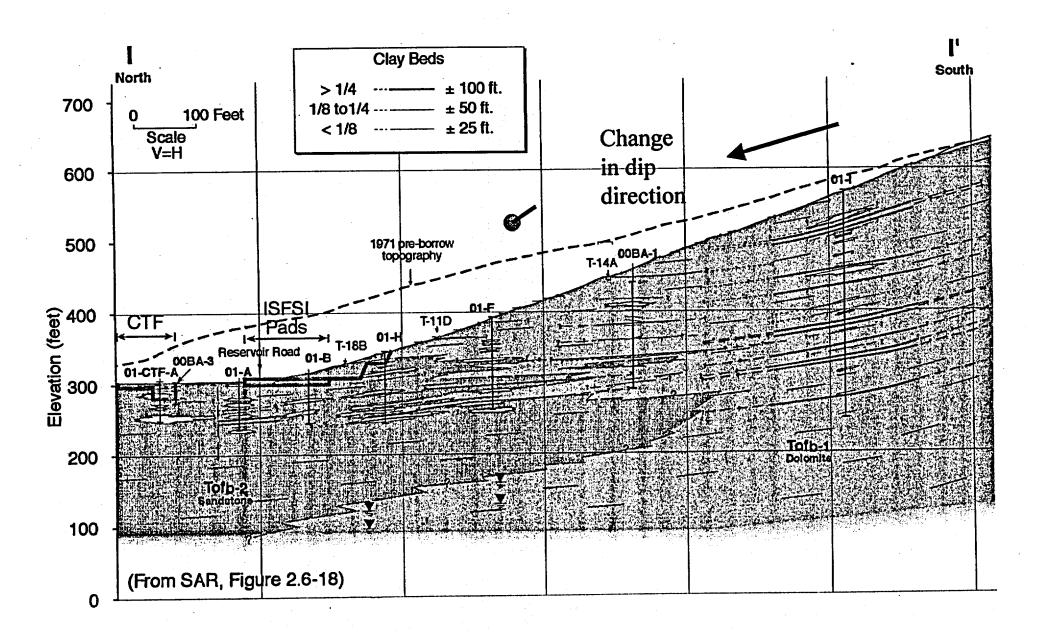


Facies Change

Geologic Constraints for Modeling Potential Large-scale Rock Mass Movements

Geometry of clay beds
Clay strength
Discontinuity of clay beds
Rock mass discontinuities
Groundwater

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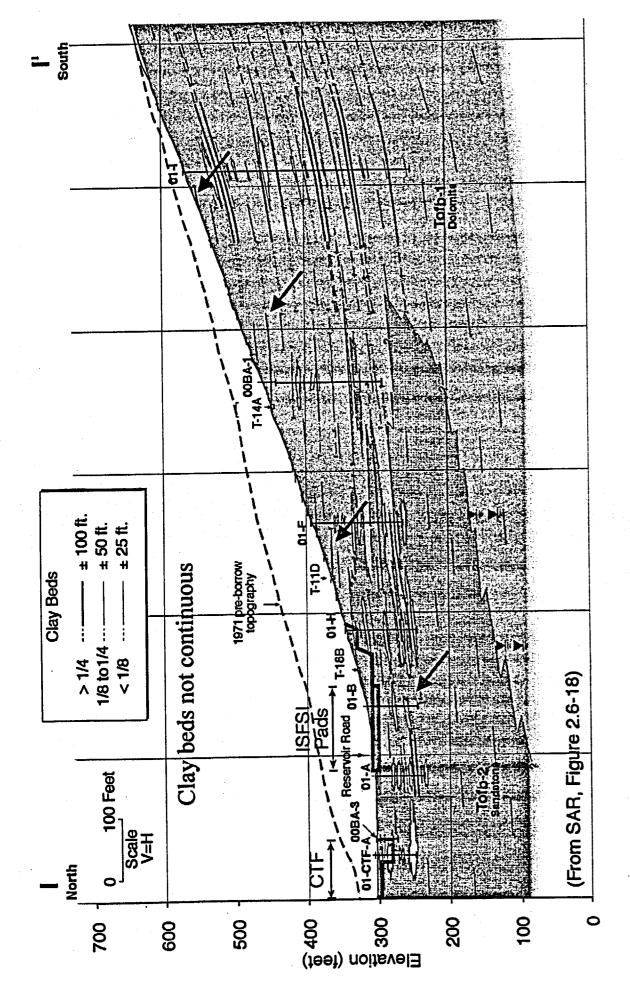
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Geometry of Clay Beds

- Change in dip directions across the structural transitions from monocline to syncline
 - Upper part of slope bedding dips out of slope
 - ♦ 10 to 20 degrees
 - Lower part of slope bedding dips to the west; apparent dip is subhorizontal

These structural changes limit size of potential rock mass movements

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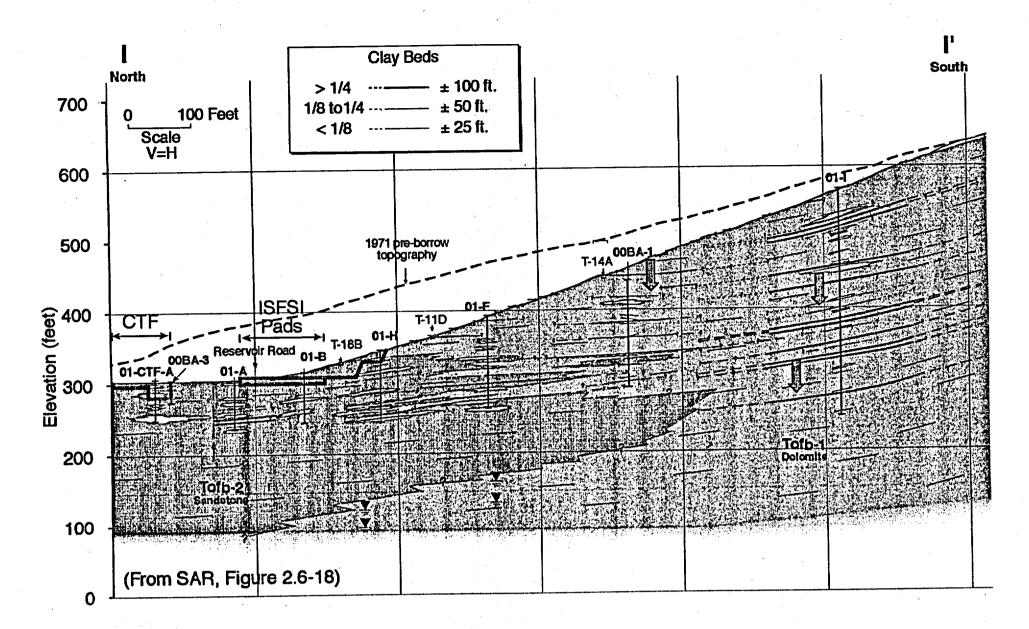


Clay Beds

Discontinuity of Clay Beds

- Clay beds have limited lateral extent
 - Limited correlation between borings and outcrops
 - Clay beds more common in dolomite, do not extend across facies contacts
 - Analysis indicates beds extend a few tens to a few hundreds of feet
- Potential large rock mass movements would step between clay beds along joints and through rock in a "staircase" profile.

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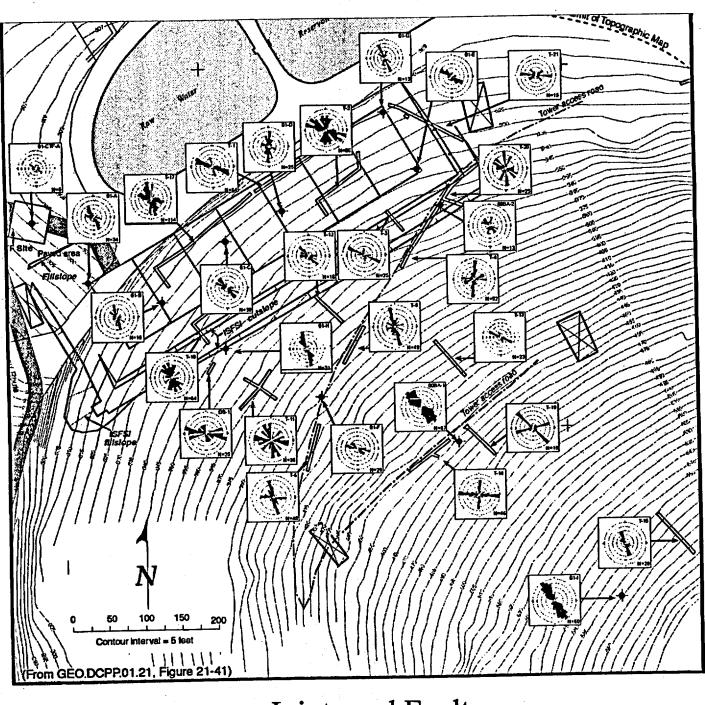
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Clay Strength

- Clay bed thickness varies laterally from a few inches to less than 1/8-inch thick
- Rock to rock contact through the clay bed is typical, increasing effective shear strength
- Clay strength measured in laboratory used in the modeling analysis (presented later)

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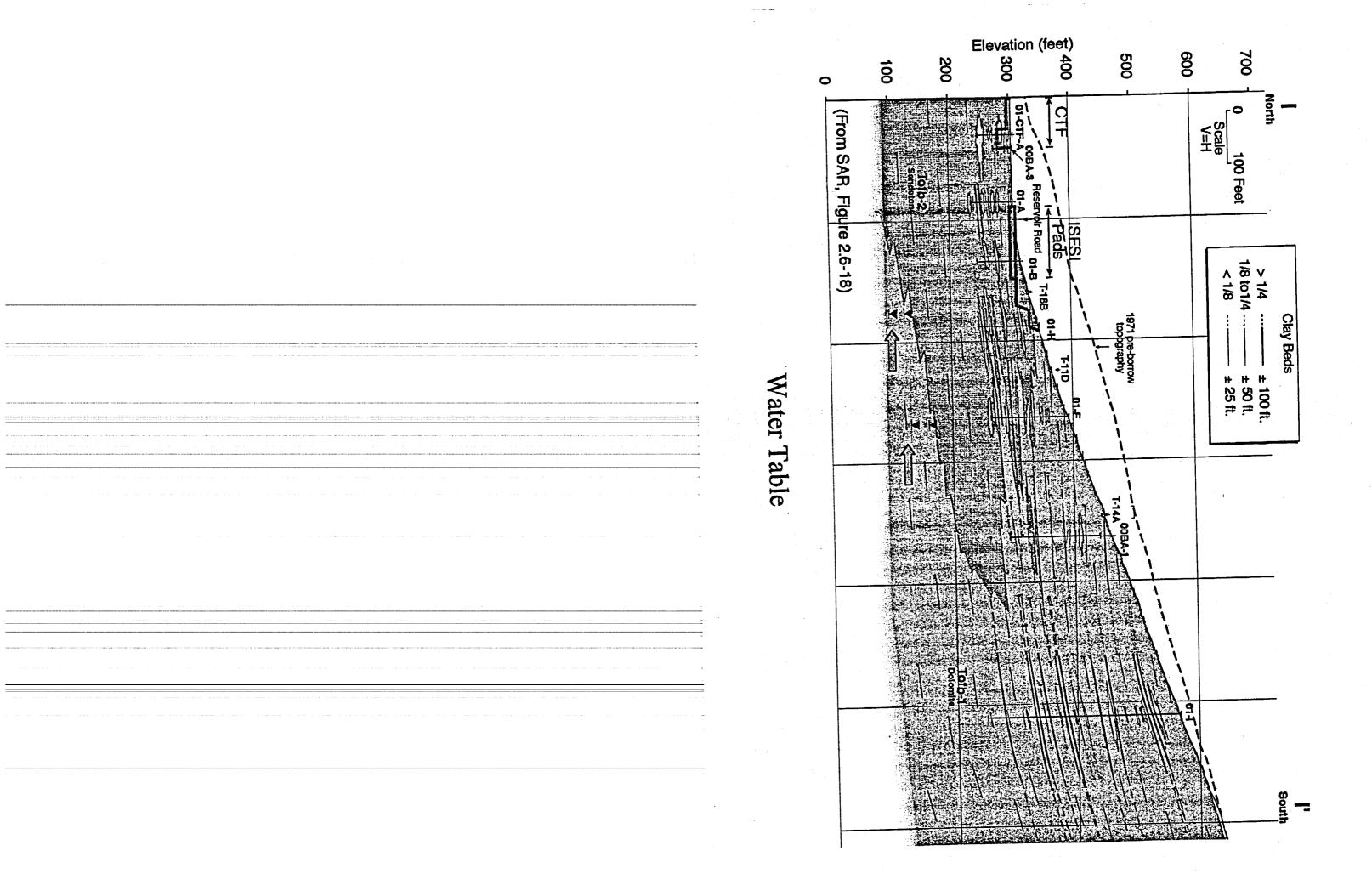
Joints and Faults

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Rock Mass Discontinuities

- Joints and minor faults disrupt the continuity of the clay beds causing large-scale rock mass movement to break through rock.
- Faults and joint sets that are subparallel to the potential down slope motion would form the lateral margins of potential rock slides

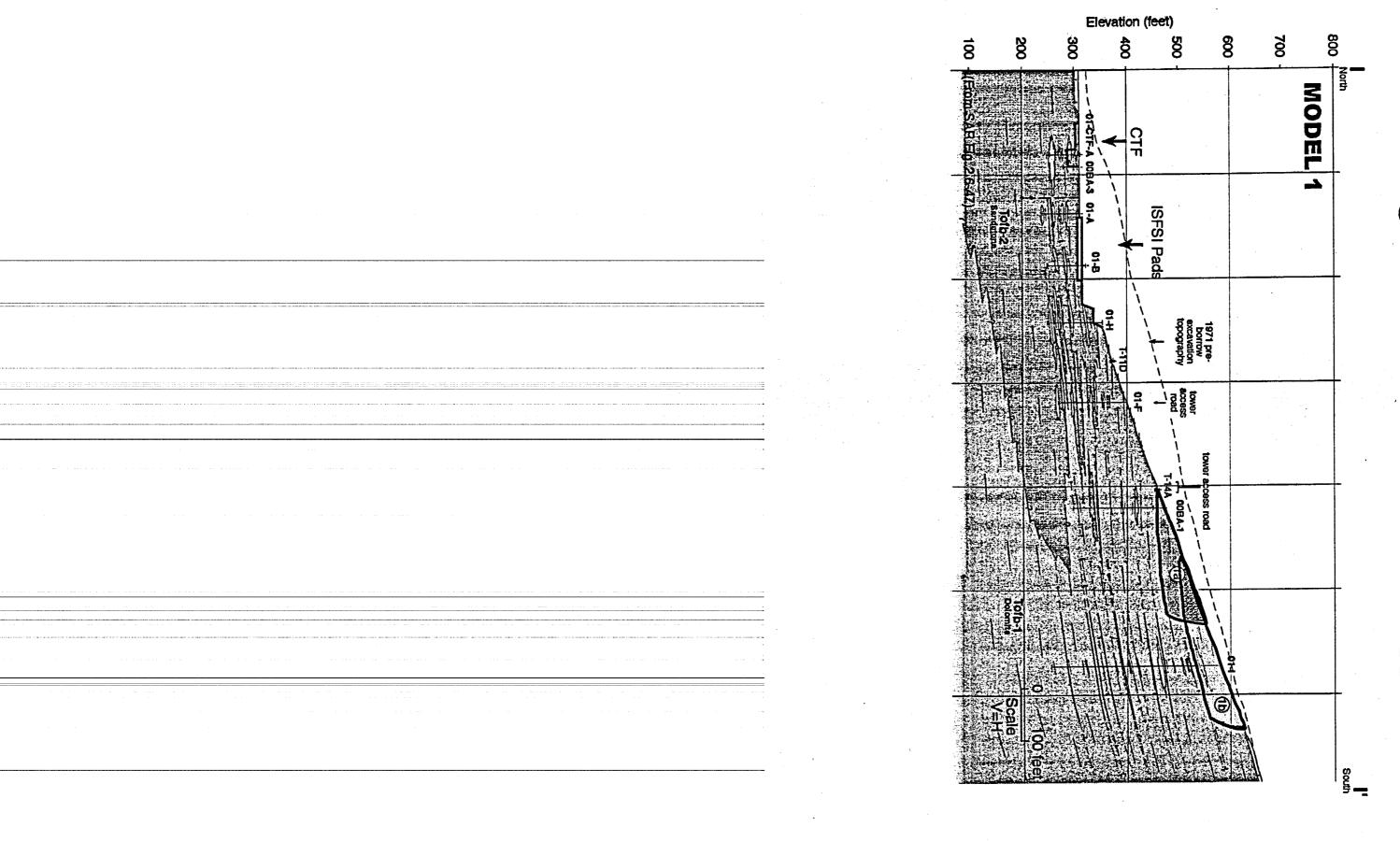
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Groundwater in ISFSI Area

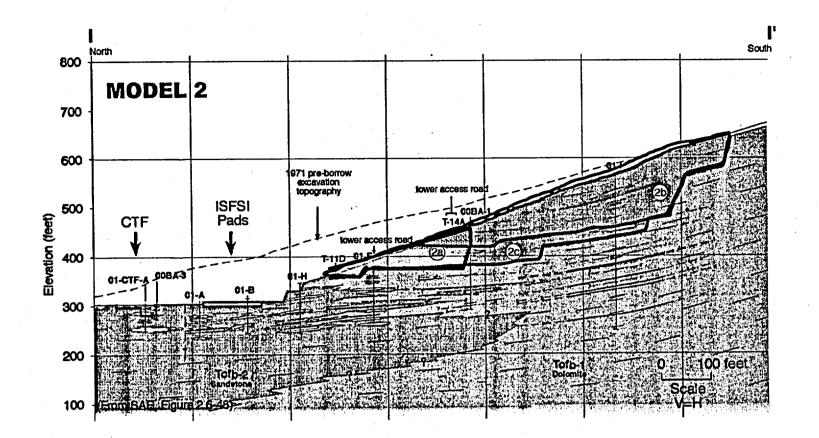
- Main water table 200 feet below ISFSI
 - ♦ (100 ft elevation)
 - Hence, not an issue for slope stability
 - **Temporary perched ground water**
 - Top of clay beds in slope above ISFSI
 - Assume clay beds are saturated in large rock mass models
 - Assume perched water in cutslope rock wedge models

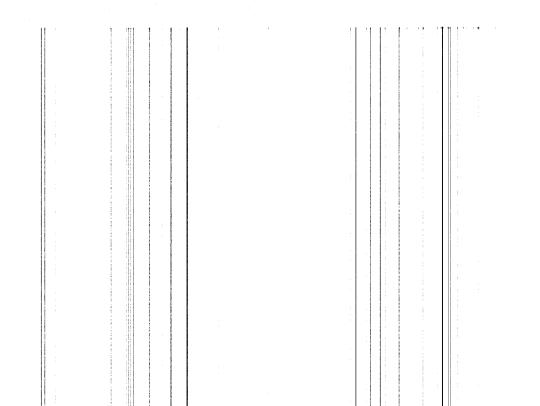
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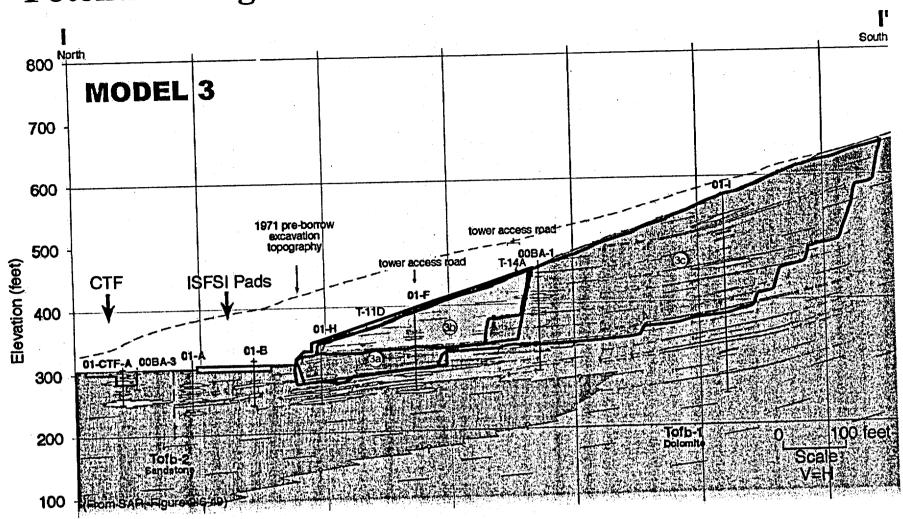
Potential Large-scale Rock Mass Model – Upper Slope

Potential Large-scale Rock Mass Model –Intermediate Slope



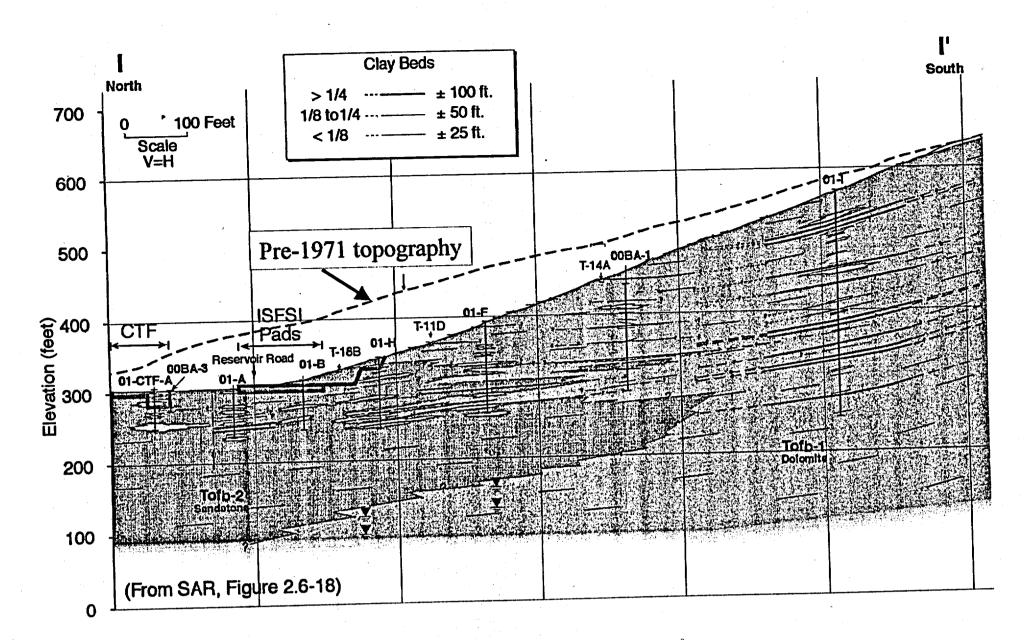


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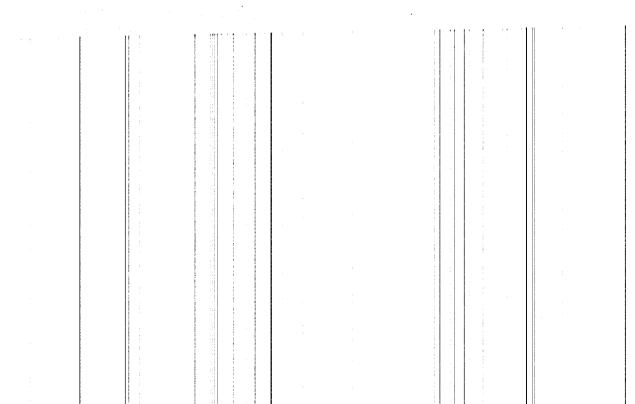


Potential Large-scale Rock Mass Model –Lower Slope

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Evidence of No Landslides at ISFSI



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Evidence of No Landslides at ISFSI

- No evidence on pre-1970 air photos
- No evidence at the borrow site in studies thereof or during excavation
- No evidence of any fissures or fissure fills in trenches for ISFSI
- Topography of ridge 430,000 years old
- Slope has been subjected to numerous large earthquakes in this time period

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"Back Calculation"

- Never the less, assume 3 to 4 inches of movement for a "back calculation".
- Results indicate that undrained clay strengths are substantially greater than those from the laboratory tests.

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Conclusions

- The ISFSI and CTF sites will be founded on bedrock
 - Sandstone and dolomite
 - Contain zones of friable rock

The ISFSI will be founded on bedrock that is the same as the DCPP power block.

Conclusions (cont'd)

- The slope above the ISFSI site has stratigraphy and geometry that allows for potential large rock mass movements.
- This is extremely unlikely because
 - no rock slides have occurred in the past 430,000 years
 - modeling ignores several geologic factors that tend to resist down slope movements

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Conclusions (cont'd)

- The transport route has variable foundation conditions – rock, dense surficial deposits, and engineered fill.
- Small debris flows could potentially close portions of the transport route during or immediately following intense rainstorms.

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Conclusions (cont'd)

The several minor bedrock faults at the ISFSI site are not capable. Therefore, there is no potential for surface faulting at the ISFSI or CTF sites.