



**Mitigation Strategies for Earthquake Surface Rupture Hazard  
in the Basin and Range Province**



**1992 Landers, California Earthquake**

**The Mitigation of  
Earthquake Surface Faulting  
in the Basin and Range Province:**

**Perspectives Gained from Historical  
Earthquakes**

**Craig M. dePolo**

**Nevada Bureau of Mines and Geology**

- **Introduction to Symposium**
- **Reducing the Cost of Earthquakes**
- **Basin and Range Province Communities, Faults, and Earthquakes**
- **Hazardous Faults in the BRP**
- **Widths of BRP Surface Ruptures**
- **Avoidance of Earthquake Surface Faulting**
- **The Weak Link in Mitigation: Local Communities**
- **A Generalized Mitigation Framework**

# Symposium Speakers

- **Jim McCalpin** – normal fault widths
- **Ivan Wong** – addressing surface faulting hazard
- **Gary Christenson** – Utah approaches
- **Eric Hubbard** – Nevada approaches
- **Roy Shlemon** – California approaches
- **Don Wells** – Mitigation: the good, the bad, and the uncertain
- **Group Discussion**



**Carson City fault, Nevada**



**Fault Set-Back Zone, Las Vegas, Nevada**

# Reduce the Cost of Earthquakes!

- Reduce owner's and societal exposure to surface faulting losses
- The most important earthquakes to cover with seismic hazard studies are the *next* disastrous earthquakes
- Reduce the number of unanticipated events

# Christchurch from Port Hills Feb. 22, 2012

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From Ian Buckle, UNR Eq. Engineering

# Risk and Economic Balance

- Reasonable mitigation costs
- Reasonable handling of demonstrably low hazard or risk
- Flexibility strategies for difficult situations

## **Which Faults Are Hazardous?**

- Active Faults
- Conditionally Active Faults
- Type of Fault (Main vs. Secondary)
- Fault with Significant Offset per Event

## **Mitigation Technique?**

- Fault Avoidance (set back, reorient, plan around, economic opportunity)
- Engineering Solution
  - Foundation design
  - Structural design solutions

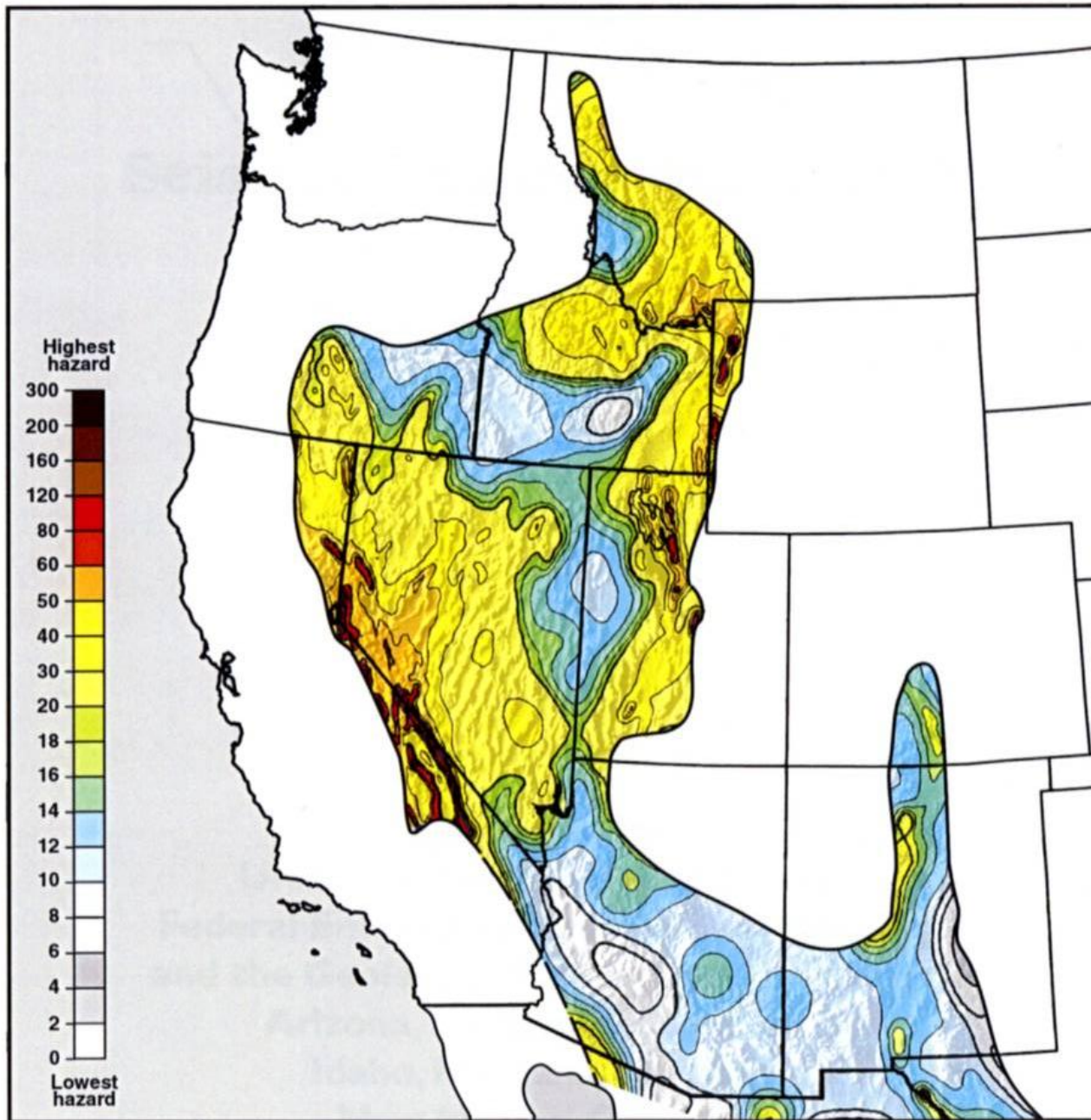
## **Regulation versus Advice?**

- Community Ordinances
- Establish as Professional Practice
- Builder/Owner Disclosure Information

## **Other Considerations -**

- Risk of Structure
- Defining Area of Concern (area of investigation)
- Faults of Interest (candidate faults)
- Exploration Techniques
  - Cost?
  - Quality?

# BRPSHS II



Peak accelerations (%g) with 2% probability of exceedence in 50 years

# Basin and Range Province

- Wild west of seismic hazard analysis
- Surprisingly urban society
- Pioneering nature/spirit
- Independently minded:
  - don't like limitations (regulations)
  - commonly can be reasoned with, especially if the hazard/losses can be illustrated
- Low-regulation environment
- Growing communities with defined expansion areas
- Opportunity for planned urban growth

# Quaternary Fault Setting

- Normal, strike-slip, oblique-slip faults
- Fault slip rates, 1 to 0.001 m/ky
- 1000s of Quaternary faults
- Complex faults and distributed fault strands are common
- Several fault strands failing during large earthquakes is common (in-line & parallel)

# Basin and Range Province Earthquakes

14ish surface-faulting events

Important anecdotal information

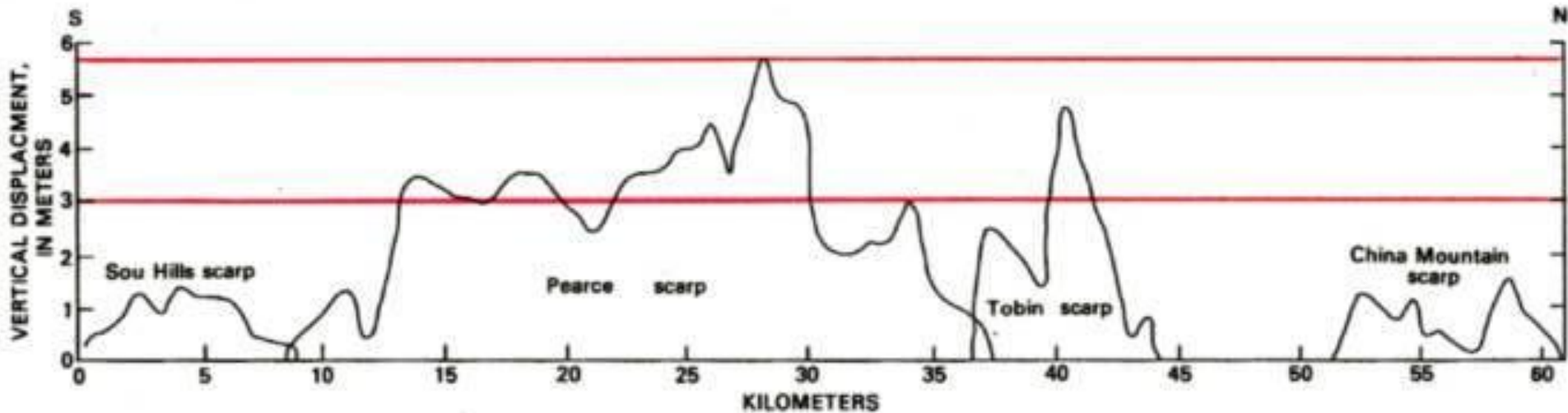
<b>Date</b>	<b>L(km)</b>	<b>M<sub>w</sub></b>	<b>M<sub>length</sub></b>	<b>M<sub>Dmax</sub></b>	<b>D<sub>max</sub>(m)</b>
1872	110	7.6	7.45*	7.32	7
1887	102	7.5	7.41*	7.21	5.1
1915	62	7.3	7.16	7.25*	5.8
1959	28	7.3	6.76	7.24*	5.5
1954d	67	7.1	7.19*	7.23	5.3
1932	75	7.1	7.26*X	6.91* (7.01)	2 (2.7)
1954e	42	6.9	6.96*	7.11	3.7
1954c	53	6.9	7.08*	6.69	1
1983	36	6.8	6.89*	7.01	2.7
1934-H	10	6.6	6.24	6.47*	0.5
1954a	18	6.3	6.54	6.40*	0.4(?)
1934-E	1.7	6.1	5.35	6.47*	0.5(?)
1954b	6.5	6.0	6.02*	6.40	0.4
1950	9.5	5.6	6.21*	6.53	0.6

Calcs. using Wells and Coppersmith (1994) relations for all eqs.

\* closer to eq. value.

X doubtful could be measured w/o event

# 1915 Pleasant Valley, Nevada Earthquake, M7.3



Wallace, 1984



Jones, 1915

**1915 Pleasant Valley, Nevada Earthquake**

# Hazardous Faults in the BRP

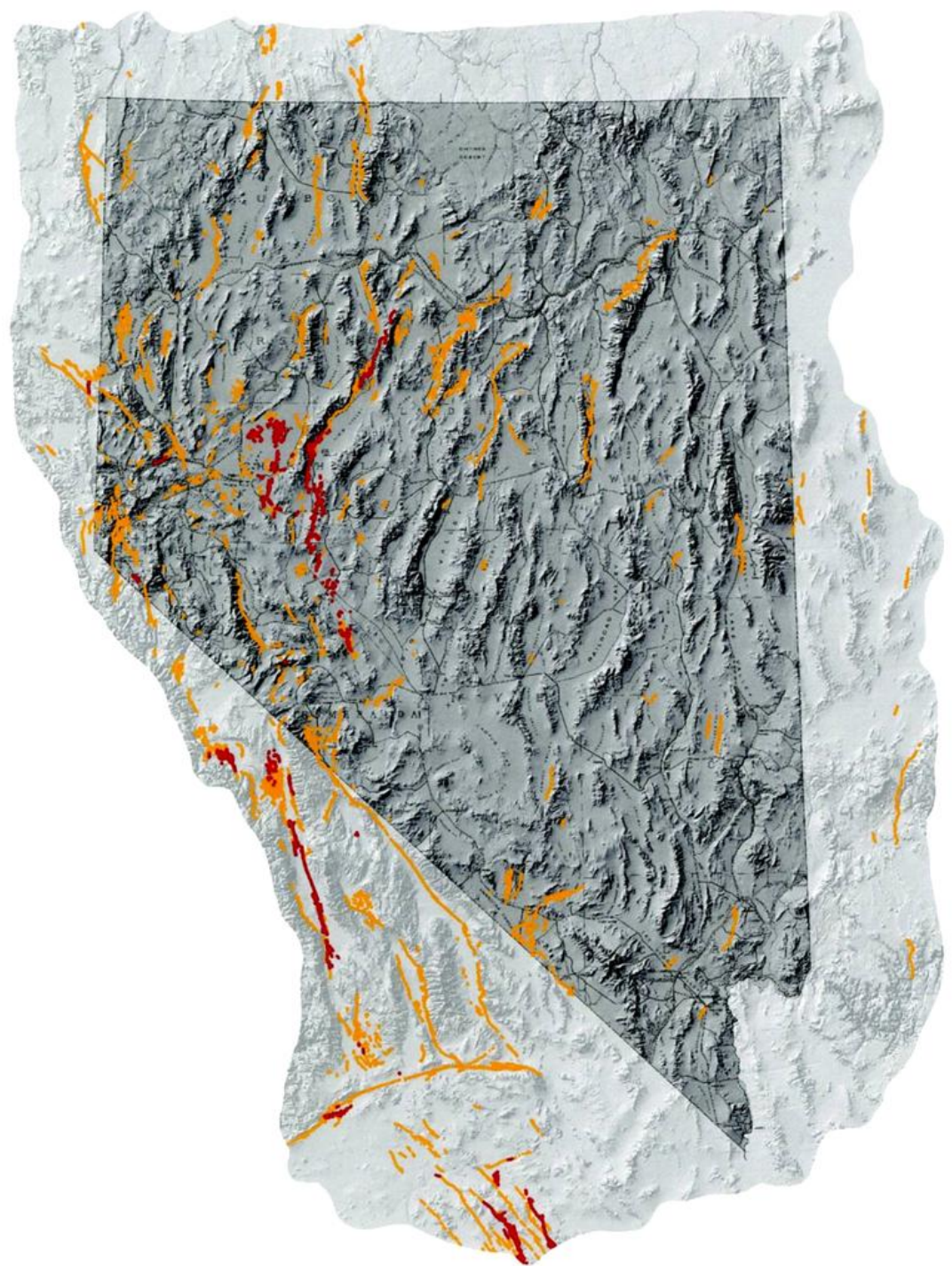
- dePolo and Slemmons (1998) advocated a late Quaternary hazardous active fault criterion for the BRP.

# Active Fault Criterion for the BRP

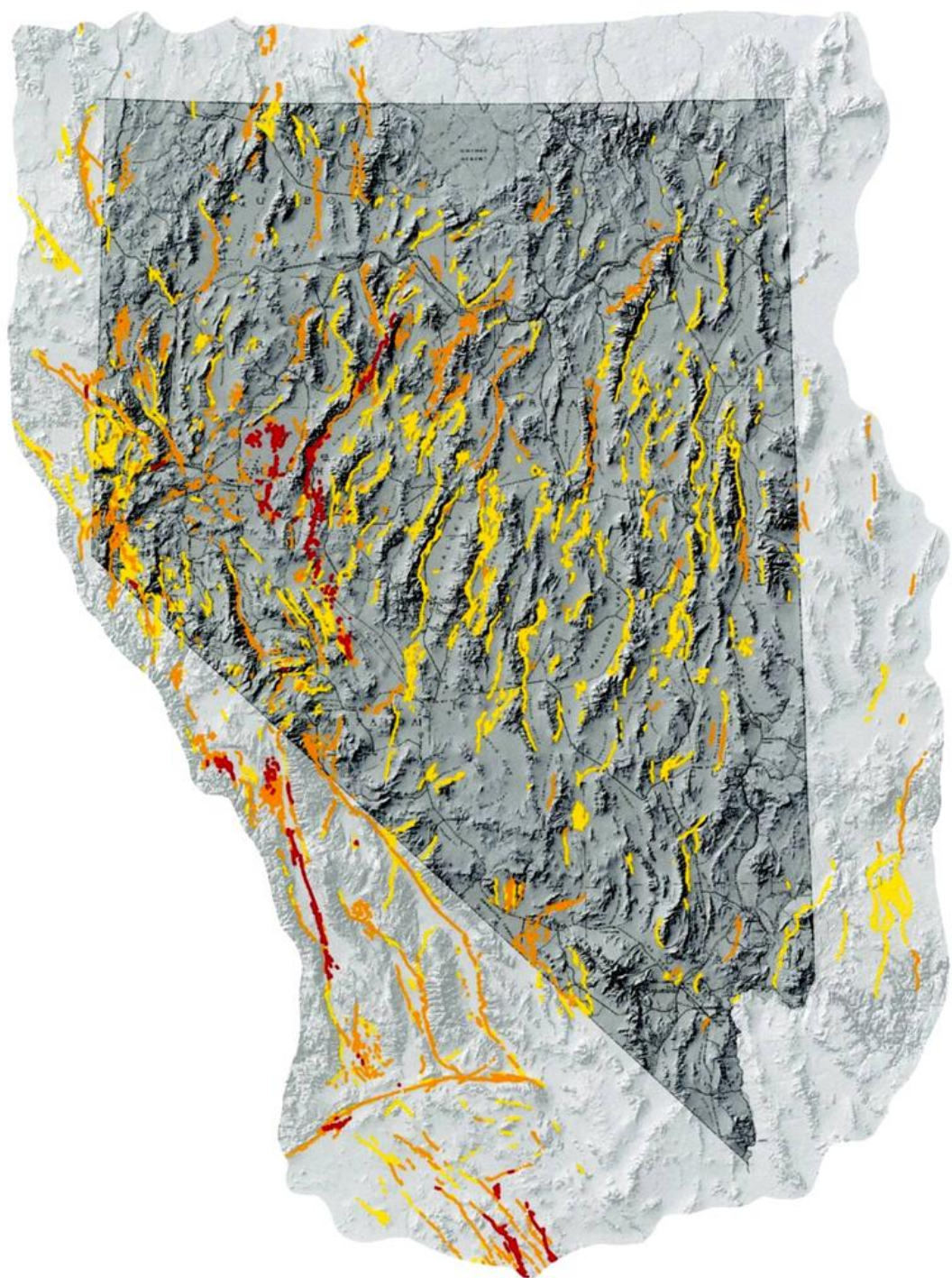
**130,000 ybp** (Sangamonian interglacial) fault activity criterion  
(dePolo and Slemmons, 1998)

- Encompasses common earthquake recurrence intervals in the BRP
- Clear cases of pre-Holocene faults having large earthquakes in the BRP
- Over half BRP surface ruptures include pre-Holocene faults
- Encompasses all faults with historical surface ruptures
- Better representation of the current seismotectonic fault pattern

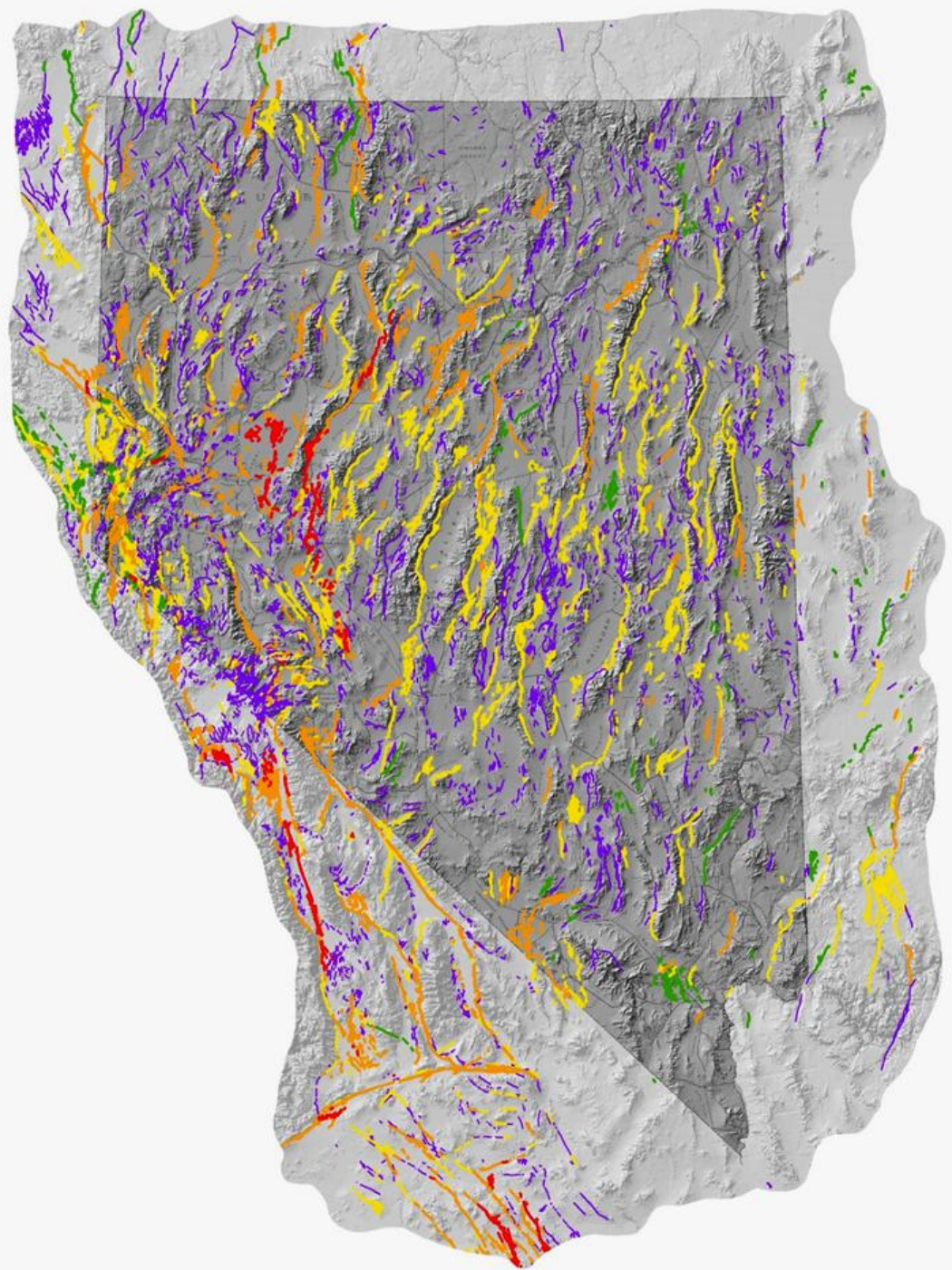
**Faults with  
Activity  
<15,000 yrs**



**Faults with  
Activity  
<130,000 yrs**



**All  
Quaternary  
Faults**



# 130,000 ybp Age Criterion

- Practical because Sangamonian soil (strong argillic) and alluvial surfaces (fan-forming period) are widely recognizable
- Also practical because a longer time allows a better fault expression to be built up for the most active faults

# 130,000 ybp Age Criterion

- Widely applicable in the BRP although not in some important places, such as western Utah
- Does not imply a 1 in 130,000 year chance of occurrence of earthquakes for these faults. Lowest chance possible, but many faults are much younger (most are not studied)

# Faults with Significant Offsets

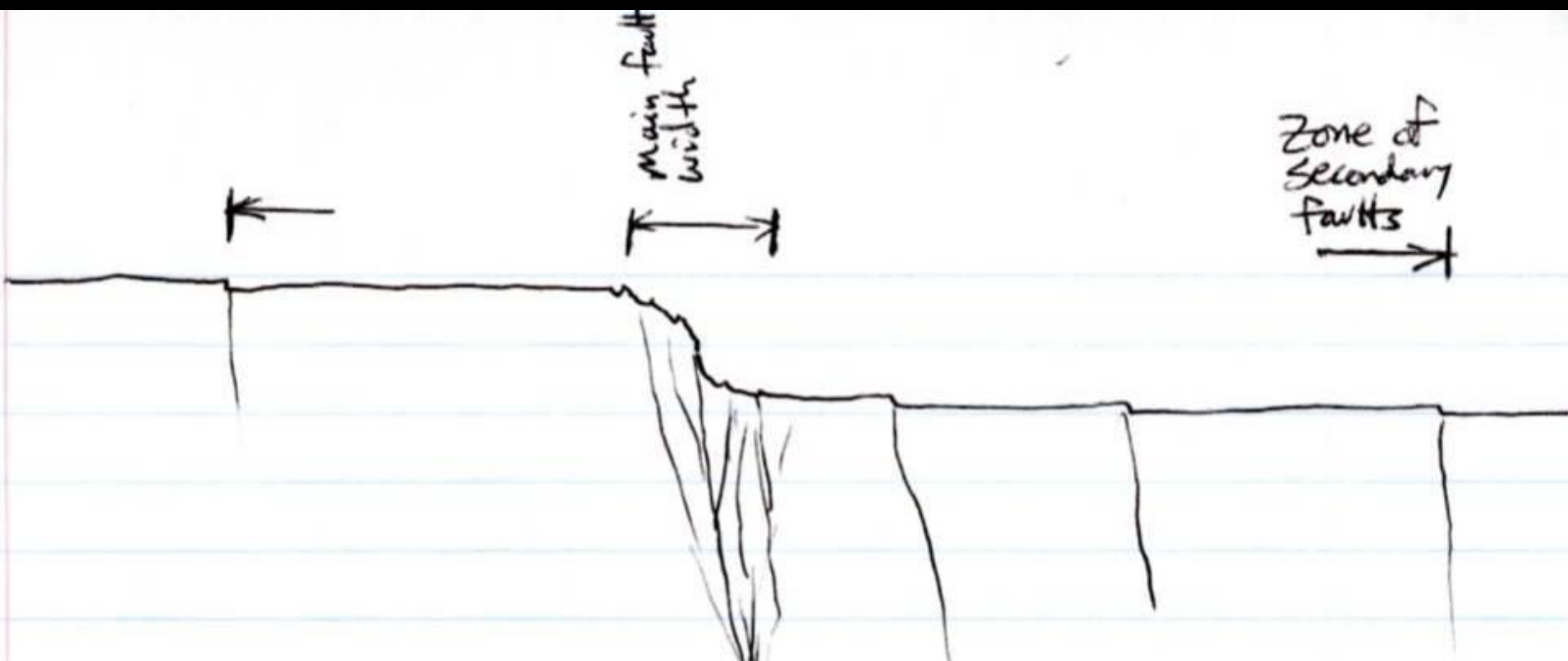
- **Main** fault versus **Secondary** faults
- Fault with less than or equal to 4" per event
- Main faults and faults with 4" (or maybe 8") or more of offset potential would be avoided in general. Secondary faults and faults with less than 4" (or maybe 8") of offset would be engineered for

# Faults with Significant Offsets

- Main fault versus Secondary fault
- Fault with less than or equal to 4" per event (Bray, 2012, EERI Annual Meeting Lecture)
- Main faults and faults with >4" (or maybe 8") of offset potential would be *avoided in general*. Secondary faults and faults with <4" (or maybe 8") of offset would be engineered for
- **GEOLOGISTS WILL MAKE THIS CALL AND CAN BE SUED IF DISPLACEMENTS EXCEED THEIR ESTIMATE**

# Historical BRP Surface Faulting Widths

- Main fault damage zones
- Graben
- Disturbed ground/Shattered ground
  
- **Main fault damage zones**
- **Secondary fault areas (set-back zones)**
- **Small fault regions**



Main fault

width

Zone of  
Secondary  
faults

# Variables That Affect The Width of Main Fault Damage Zones

- Amount of Displacement
- Sense of Displacement (near-fault graben vs. flower structures)
- Fault Dip
- Material Properties
  - type of rock/sediment
  - depth of alluvium

# Main Fault Damage Zones

<u>Year</u>	<u>Width</u>	<u>Report/Trench</u>	<u>Notes</u>
1915	5'	T	hanging wall
1954	3'	R	moletrack
"	13'	T	flower struc.
"	8.2'	T	" "
"	10'	R	parallel cracks
1959	6-10'	R	hanging wall

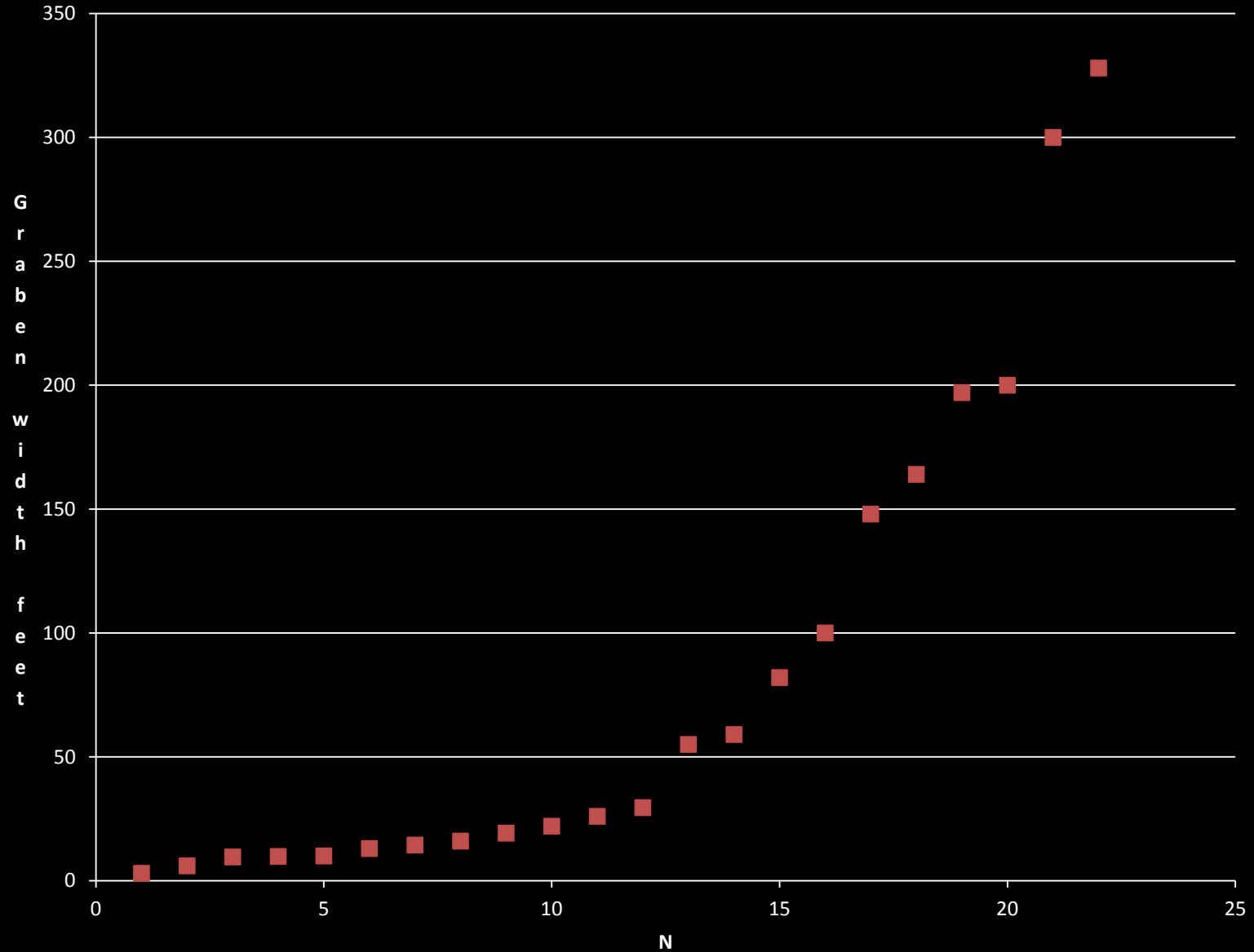
# Main Fault Damage Zones

- Limited information
- Flower structures up to  $\pm 6.5'$
- All but one measurement below  $\pm 5'$ 
  - Clark County, Nevada guidance
- Normal fault hanging wall damage zone out to **10'** (1959 eq.)
- Fault-damage-zone width is likely a function of displacement.

# Variables that Affect the Width of Secondary Faults

- Amount of Displacement
- Sense of Displacement (graben vs. flower structures)
- Fault Dip, Changes in Dip
- Fault Maturity
- Material Properties
  - Type of rock/sediment
  - Depth of alluvium
  - Sedimentary character

# BRP Graben Widths



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- 23 literature observations, but this is not a rigorous treatment of surface faulting
- Over half of the data were 59' or less. Larger widths are more widely distributed

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- 23 literature observations, but not a rigorous treatment of surface faulting,
- Over half of the data were 59' or less. Larger widths are more widely distributed.
- **Your Fundamental Graben Question:**

# Dixie Valley Earthquake Shack



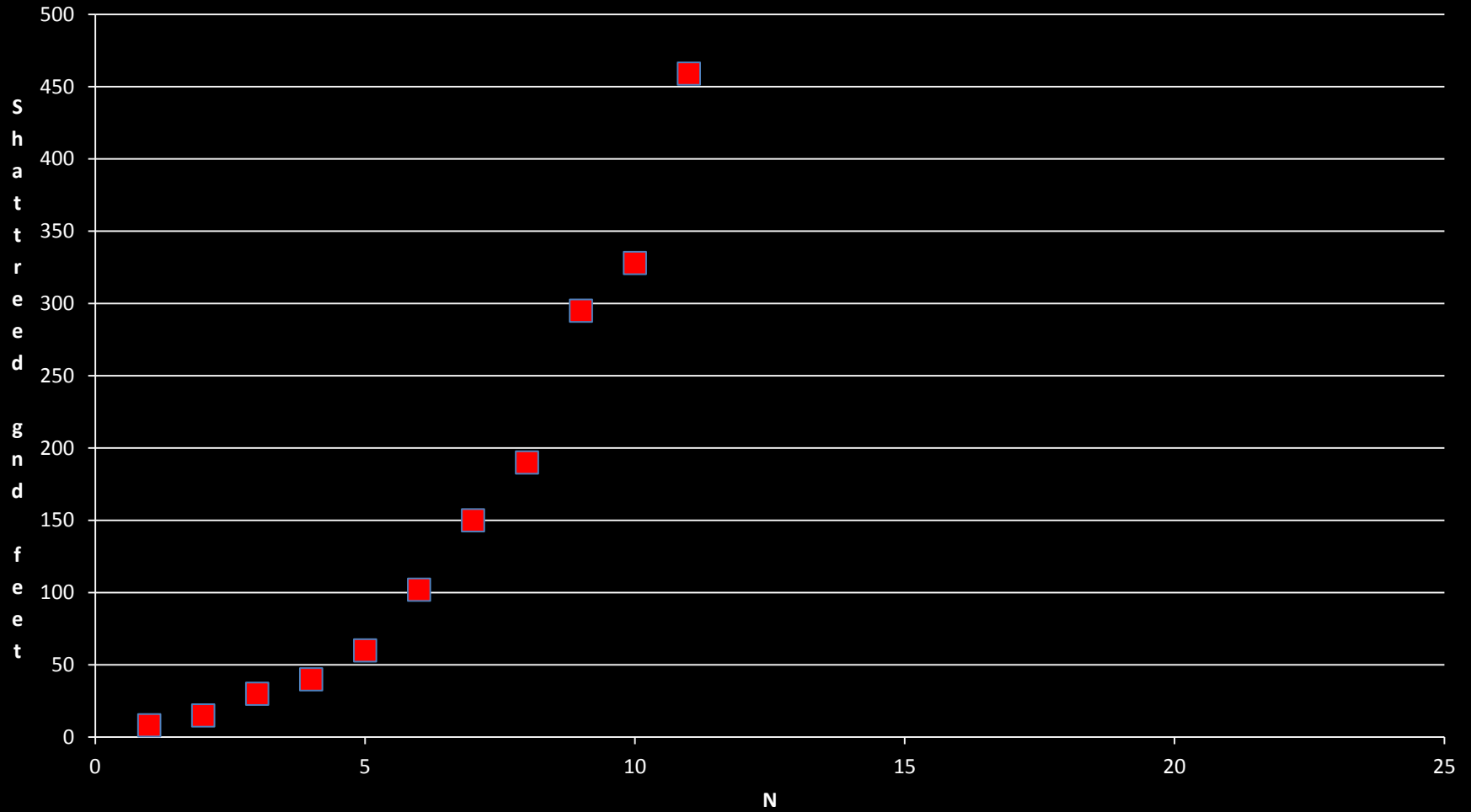
Steinbrugge, 1954

# Dixie Valley Earthquake Shack



**55-foot-wide graben**

# BRP Shattered Ground



# BRP Shattered Ground

- 16 observations in literature; barely a sampling but this is hard to measure today
- A 50' zone for secondary faults is consistent with the lower part of the graph; can't be ruled out
- More observations  $> 50'$  – these tend to be structural complexities

# Small Fault Regions

- Structural complications in fault zones
- The graben and shattered ground widths include many values over 50' wide, with the largest values being 1320' and 3200' wide
- Many of these are areas of stepping and subparallel fault traces



Region of possible  
small faults

# Mitigation of Surface Faulting Hazard

- **Avoidance** – easy to do in low population areas like much of the BRP *if faults are mapped*
- **Engineering Solutions** – detachable building elements, foundation mats that absorb ruptures, and others
- **REGULATED BY LOCAL COMMUNITIES OR COUNTY GOVERNMENTS**
- Need to have hazardous **fault locations** available at a scale of 1:24,000 or larger
- Need to do a good job **locating fault traces** on site

# Fault Set-Back Special Study Zones are Good !

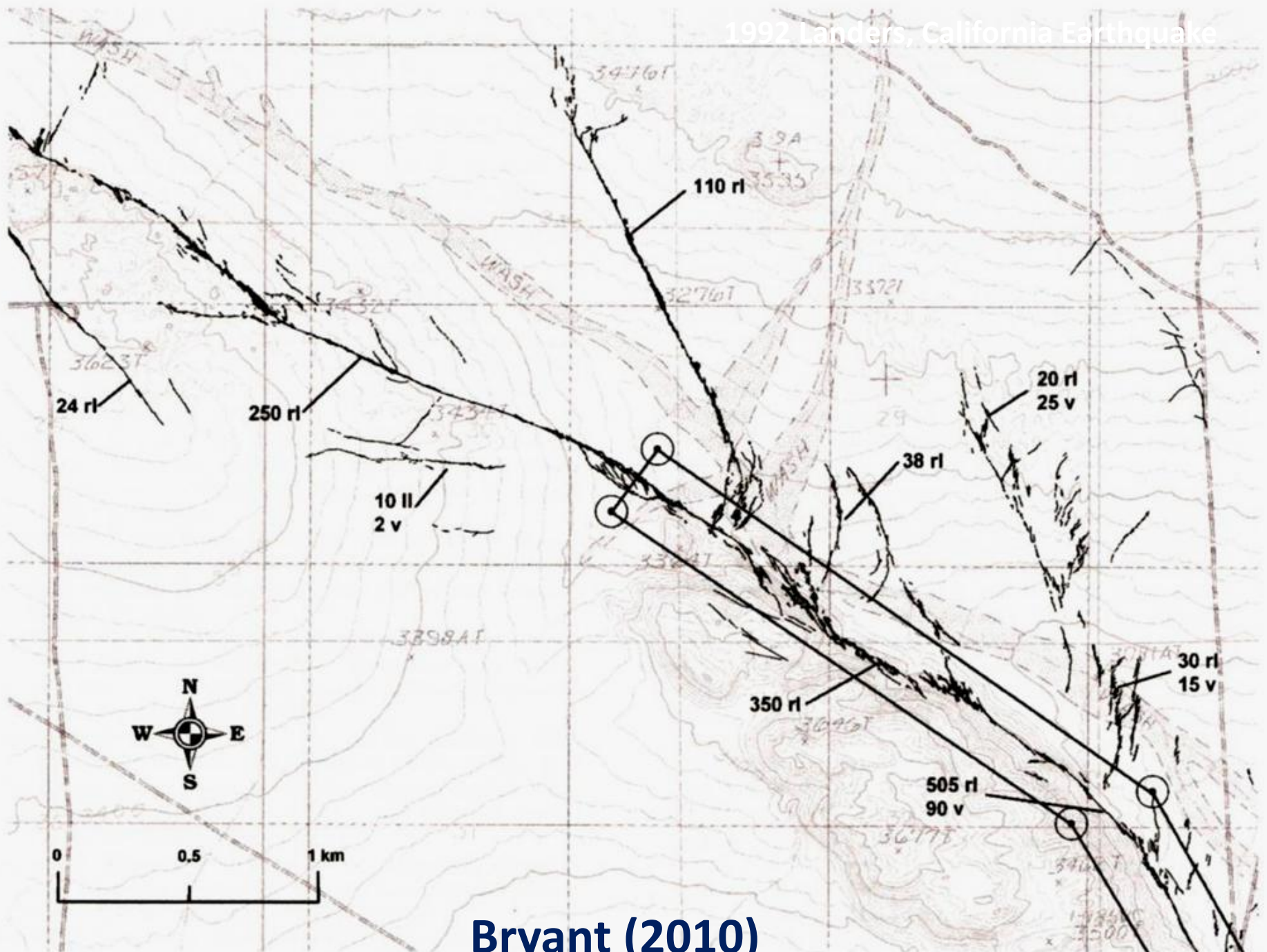
- Avoidance is effective
- Generally predictable; easy to use and administer
- With normal faults, relatively easy to explore
- But can lead to inflexibility with complicated situations

# Fault Set-Back Special Study Zones are Good !

**Make MONEY \$\$\$ with Set-Back Zones:**

golf courses, required green belts, open-space requirements, wildlife corridors, larger backyards

1992 Landers, California Earthquake



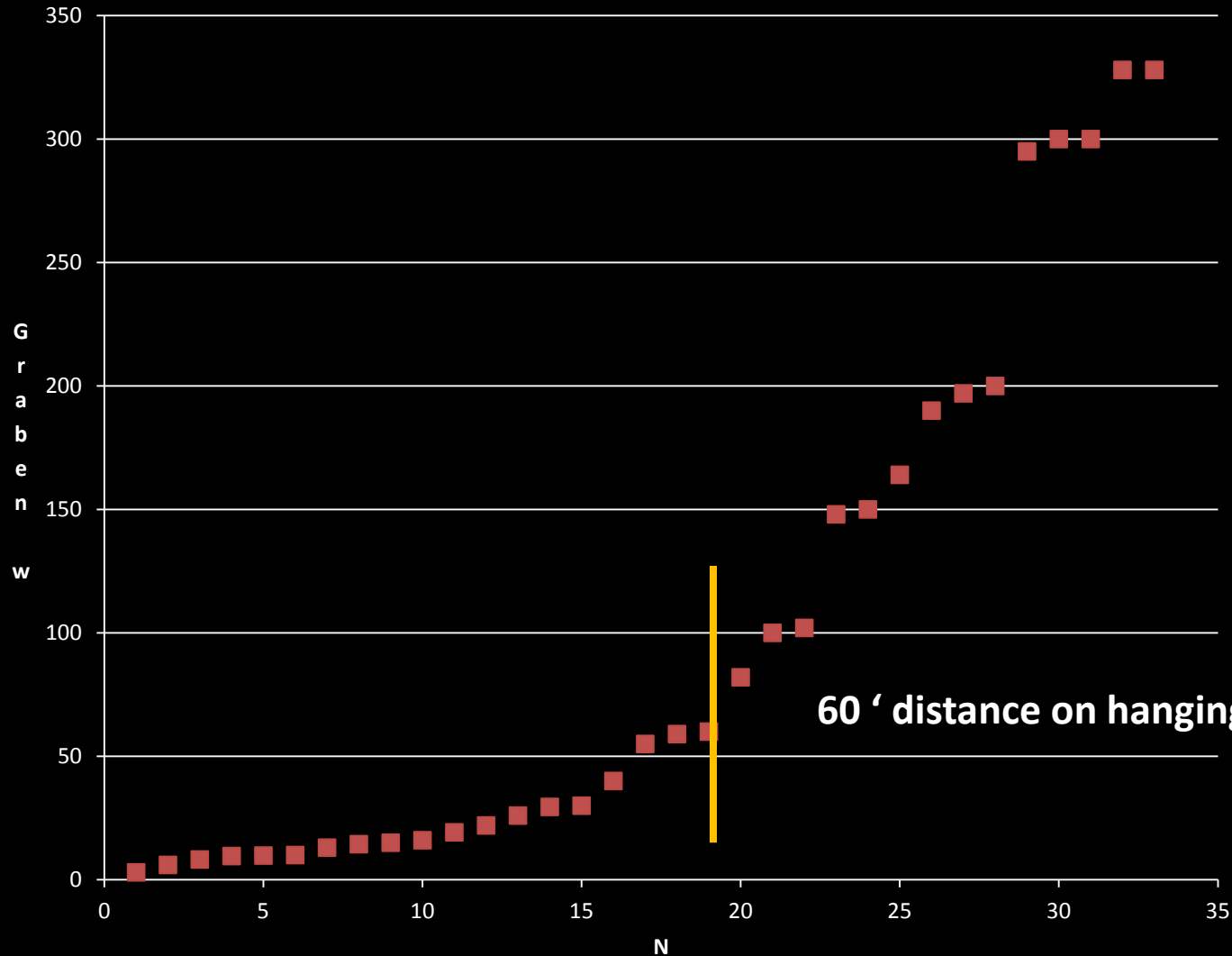
**Bryant (2010)**

# 50-Foot Set-Back Avoidance

- Lawson (1906 San Francisco eq.)  
“The width of the zone of surface rupturing varied usually from a few feet up to 50 feet or more.”
- 1969 Bonilla Surface Faulting Paper
- 1972 California Alquist-Priolo Act
- Society has accepted 50' set-backs in many cases for three decades now
- Consistent with historical BRP data

# Graben and Shattered Ground Widths

## BRP Historical Earthquakes



# Execution of Mitigation Strategies (who has to do it)

- Community Decision Makers – Leaders
- Original Owners – Developers
- Geologists and Engineering Geologists
- Geotechnical or Structural Engineers
- Inspectors
- Current Owners (future modifications)

# The Weak Link in Mitigation

- Engagement of the hazard by communities and counties; the mitigation of surface faulting is a local responsibility.
- Need:
  - Community guidelines/suggestions
  - Good fault hazard maps
  - Encouragement to take action
  - Give people a better understanding of surface-fault hazards

# Three-Tiered Mitigation Framework for Local Communities

- Simple secondary-fault set-back mitigation for hazardous faults (cookbook); fault damage zone avoidance
- Engineering solutions for low hazard and low to moderate risk
- Engineering mitigation for crossing faults or for existing structures that are built across faults

# Conclusions

- BRP active fault criteria –  
130,000 ybp
- BRP earthquakes include several width measurements that are consistent with 50' to 60' widths on the hanging walls of faults
- Use fault avoidance when possible



# Conclusions

- True, we inevitably have to cross faults at times, but lets always be pushing **Avoidance as the primary mitigation strategy.**
- Lowering the cost of repair and clean up helps lower the cost of earthquakes.

# Cut Slides

# Freeboard Surface (Glen Borchardt, in review)

- Tectonically undisturbed materials,
- Factor-of-safety that the freeboard surface will not be faulted,
- Dependent on recurrence interval and the number of paleoearthquakes that occurred.

# Important Link in Mitigation

- High-quality fault studies for society,
- Effective mitigation techniques,
- People are going to demand performance-based engineering and mitigation in the future; why not give it to them now!

# Reminder

- As professionals, we need to do our part to lower the cost of earthquakes. For surface faulting this means do a good job identifying hazardous faults, recommending effective mitigation strategies, and giving a proper treatment of uncertainties.
- The next earthquakes are some of the most important events we can characterize for society.

# Which Faults Are Hazardous?

- **Active Faults,**
- **Conditionally Active Faults,**
- **Kind of Fault (Main vs. Secondary),**
- **Active Fault with Significant Offset Per Event  
(a Threshold of Displacement).**

# Active Faults

- Designated age criterion,
- Other evidence of activity (e.g., geomorphology; seismic cycle),
- Contemporary seismotectonic regime age,
- Fault with seismic activity,
- Fault with geodetic activity,
- Fault influenced by non-tectonic process.