Comparison of Moment Rates from GPS Observations and Late Quaternary Earthquakes on the Wasatch Fault, Utah

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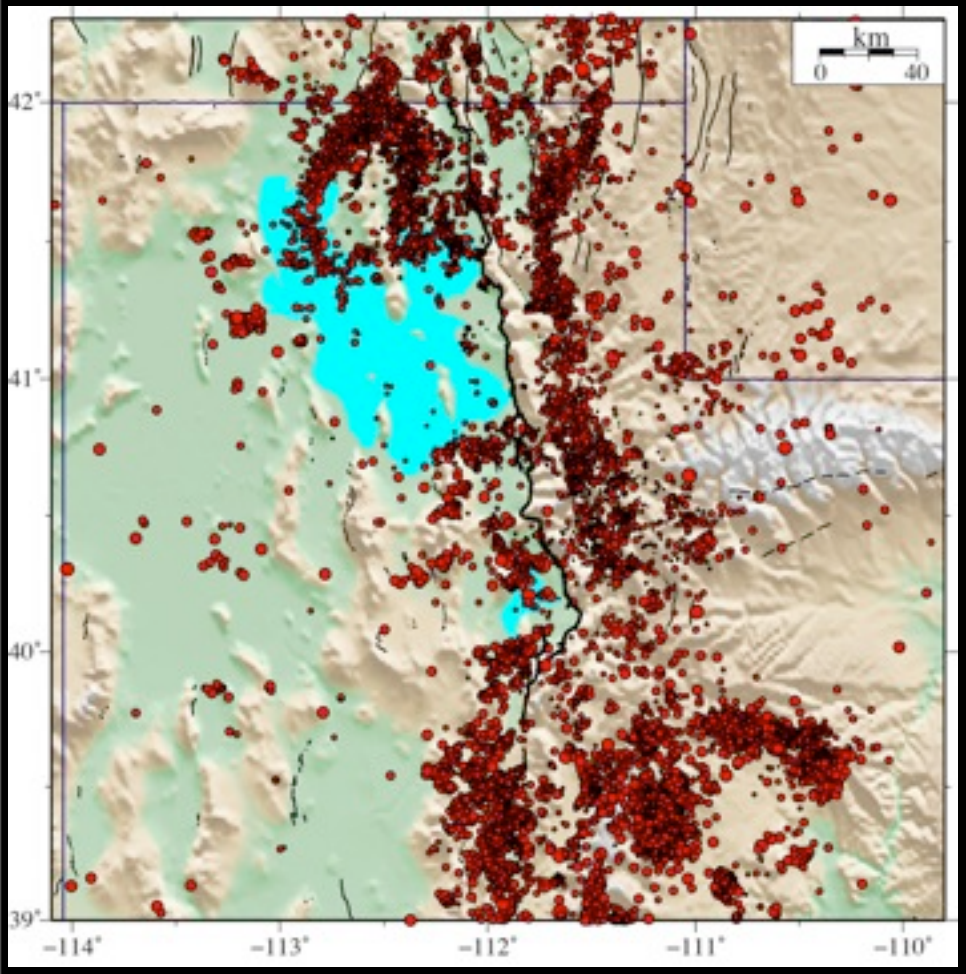
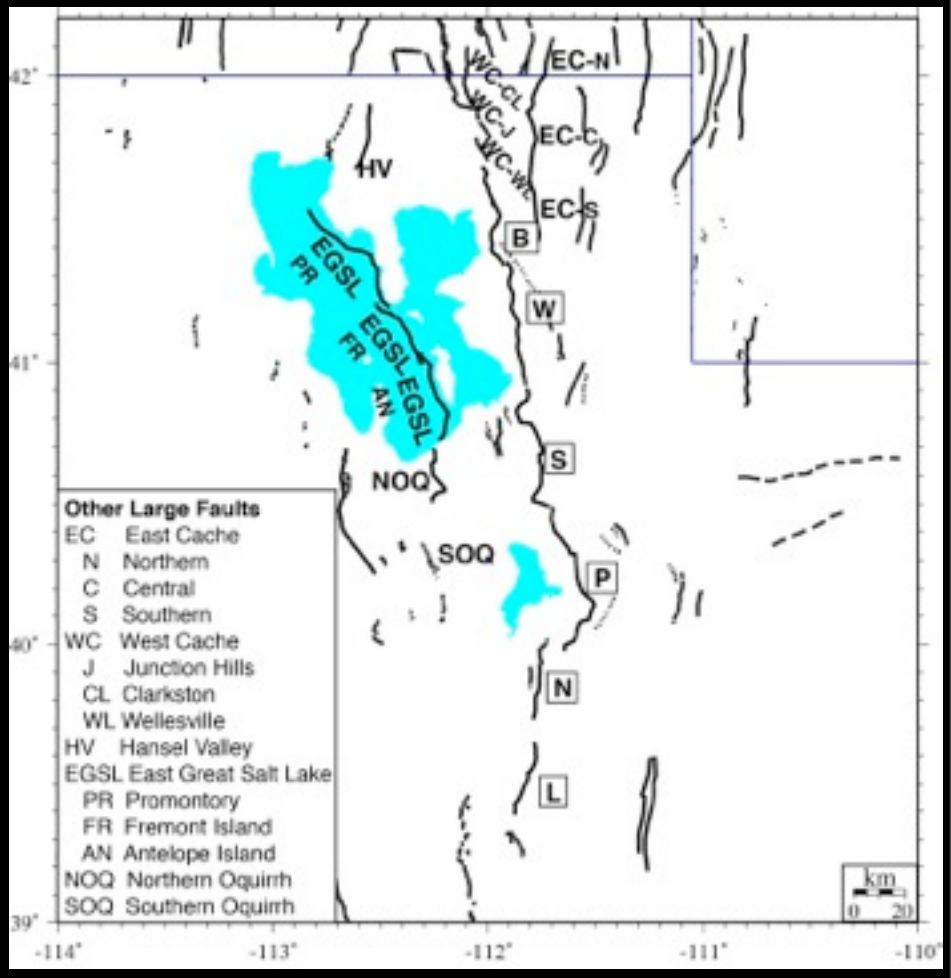
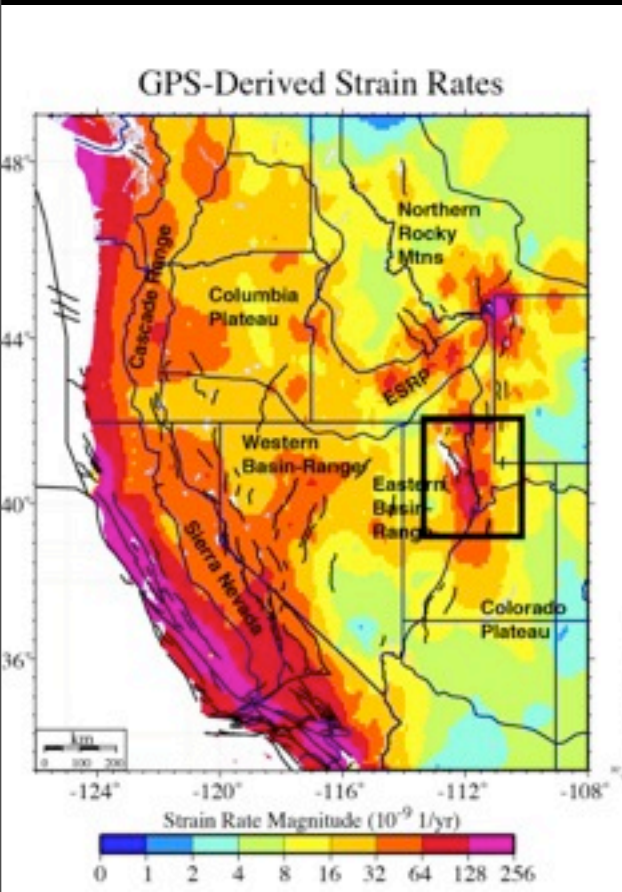
Wasatch Front Earthquakes 1962-2011

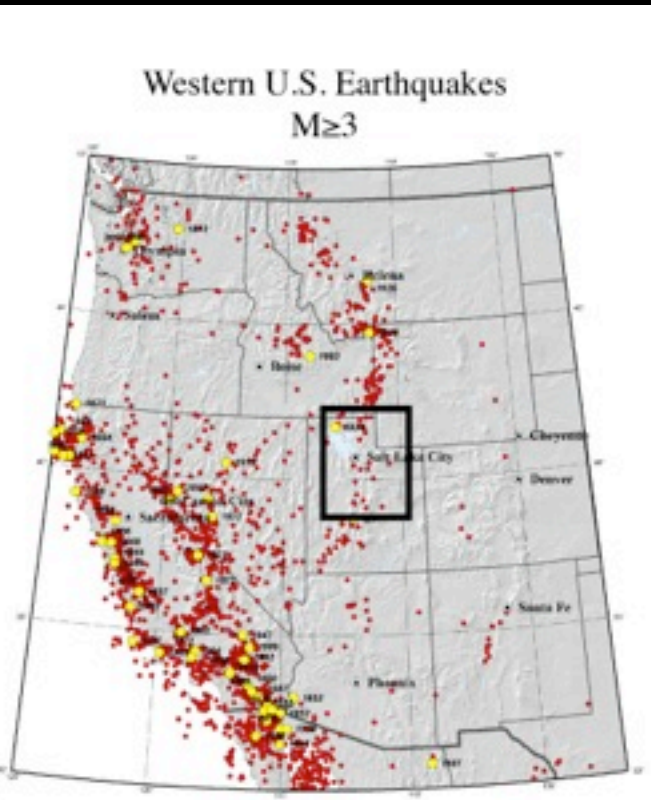


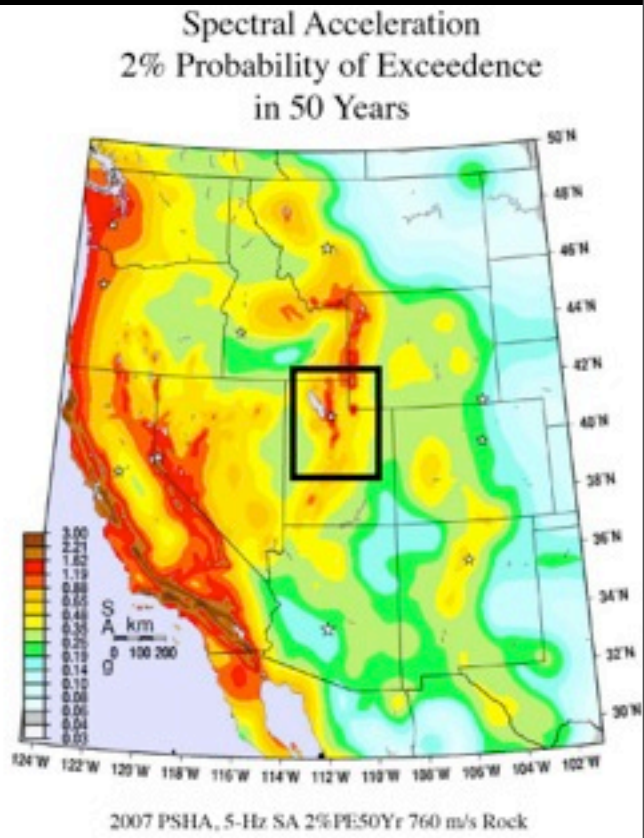
Major Faults in Northern Utah



- Seismic zone with frequent microearthquakes
- Largest historic quake was 1934 M6.6 Hansel Valley
- Trenching studies have dated prehistoric events on Wasatch, other faults

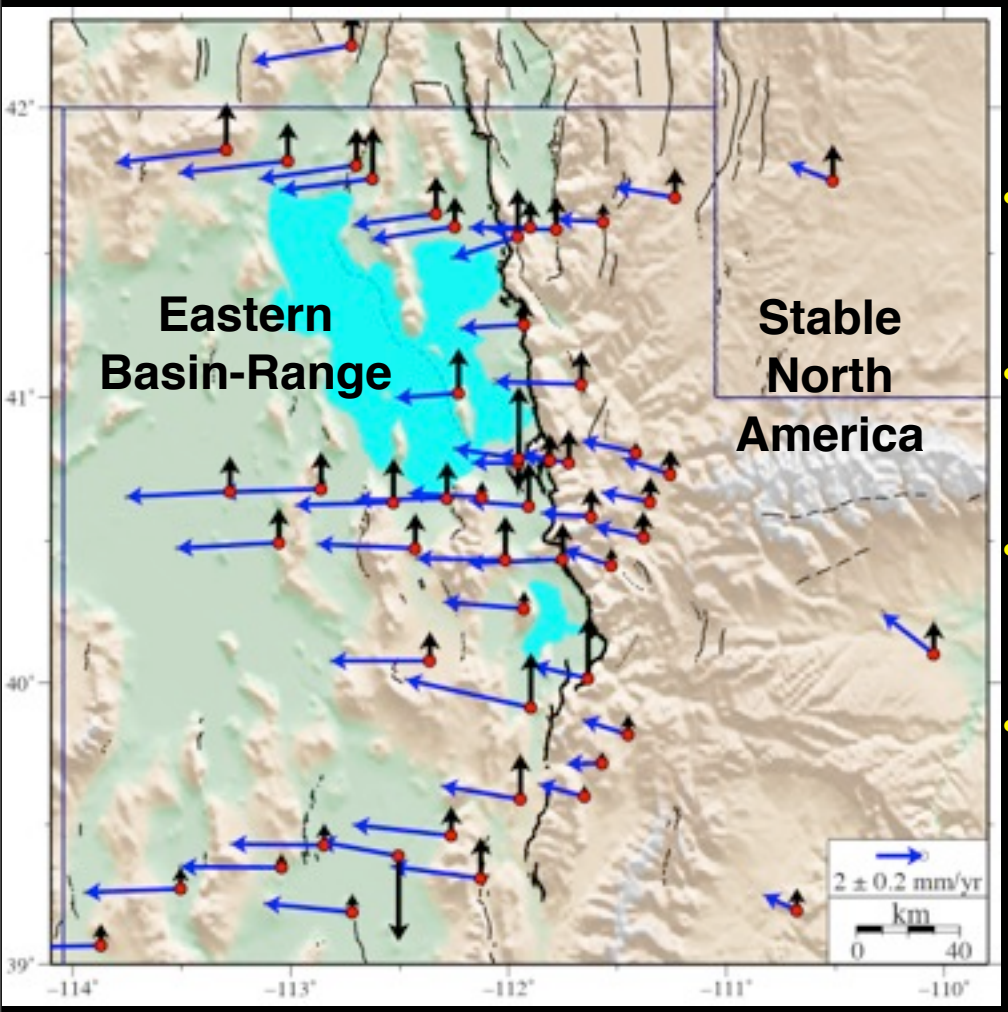






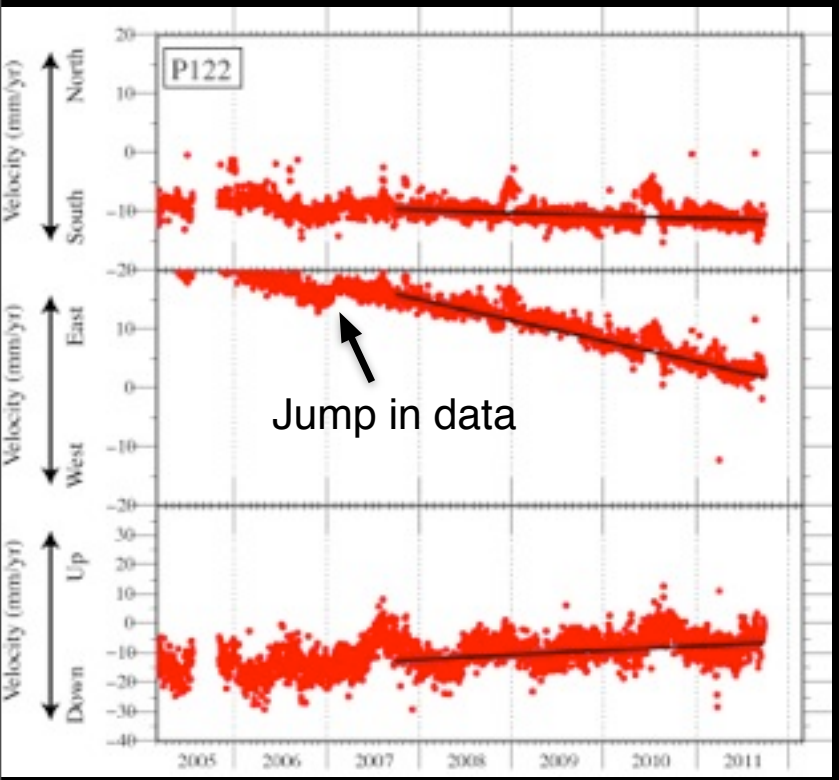
- Regional westward extension at Wasatch Front
- Boundary of eastern Basin and Range and Stable North America
- Earthquakes correlate with deformation
- Compare energy stored through deformation and released in earthquakes

Horizontal and Vertical Velocities



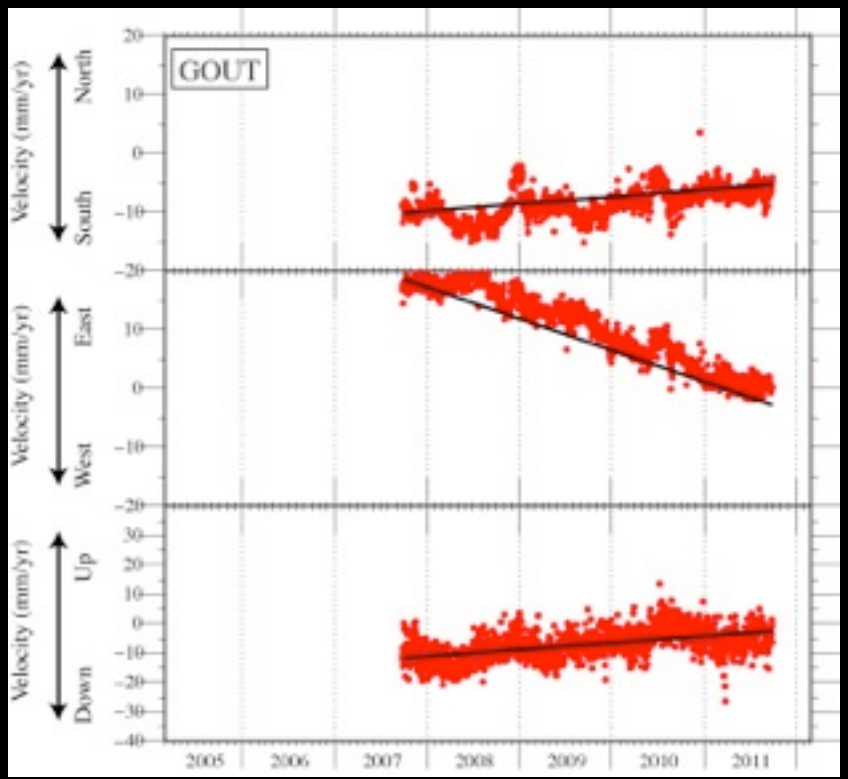
- Plate Boundary Observatory/University of Utah operate GPS stations
- University of Utah processes data and monitors regional deformation
- 55 stations in network across Utah and Wasatch Front
- Updated processing software in 2011
  - Bernese 5 replaced version 4.2
  - Improved station positions
  - Data available at university web site: www.uusatrg.utah.edu

Change in Position over Time



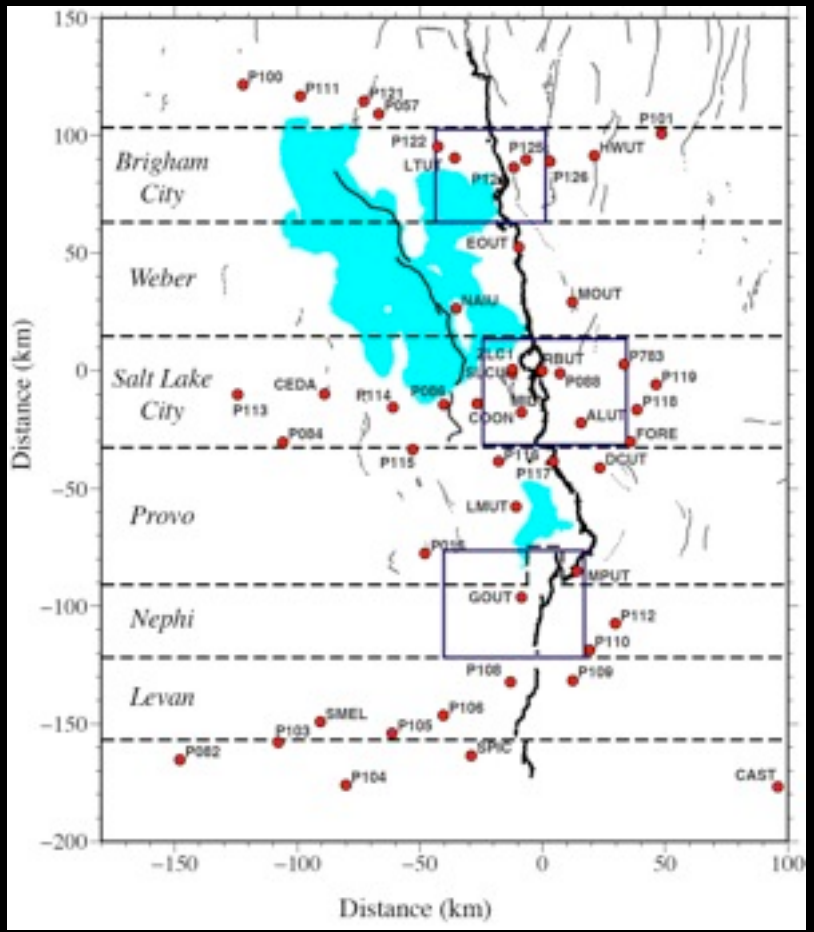
P122 north of Great Salt Lake

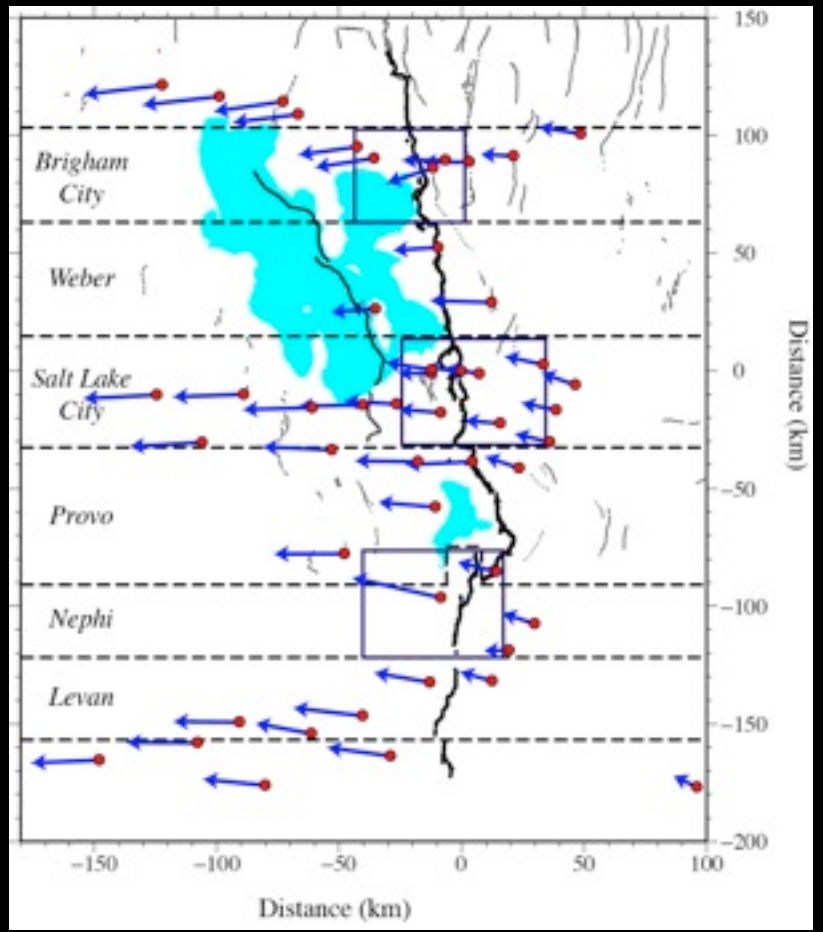
- Velocities calculated from time series
  - Linear least-squares fit
- Fit over periods of good quality data
  - Avoid offsets, jumps
  - Maximize time span
  - Requires inspection of time series



GOUT south of Utah Lake

GPS Station Distribution and Wasatch Fault Segments



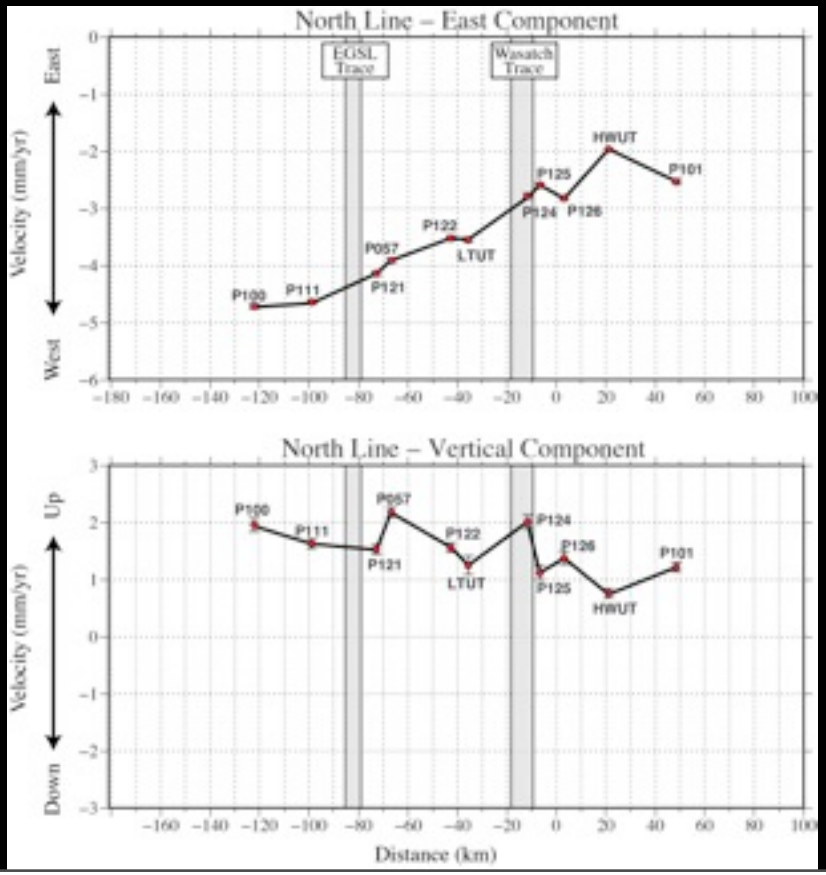


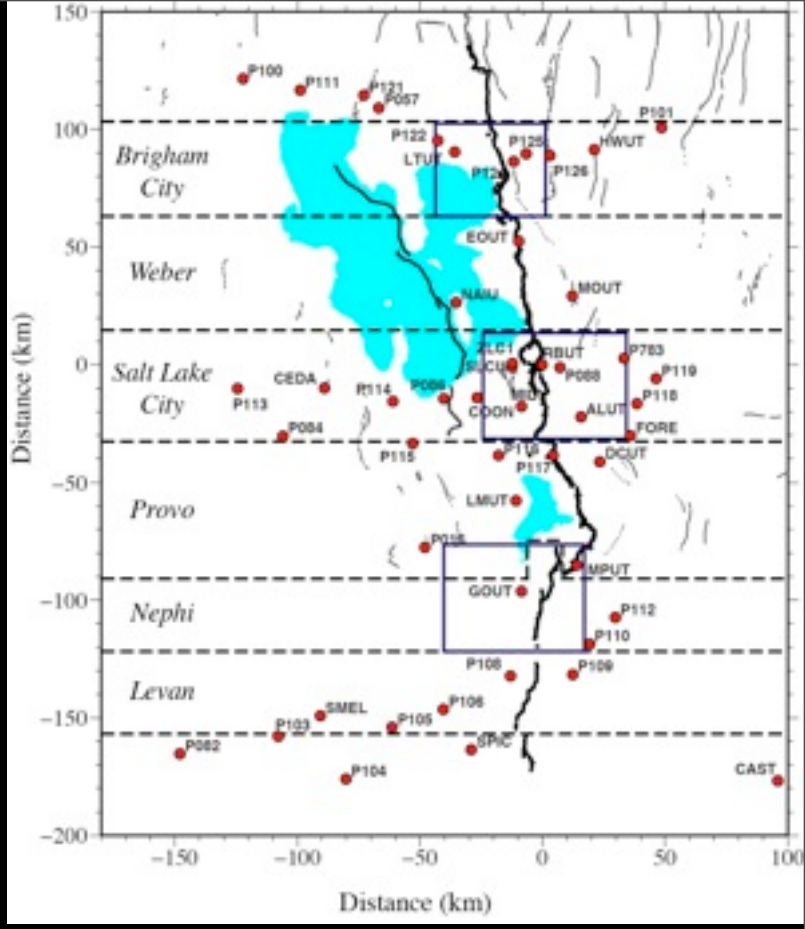
- GPS stations grouped into profiles across northern, central, southern fault zone
  - North = Brigham City segment
  - Center = Salt Lake City segment
  - South = Nephi segment + part of Provo segment

- Define boxes for each segment to use in loading calculations

Brigham City Profile

2.75 mm/yr



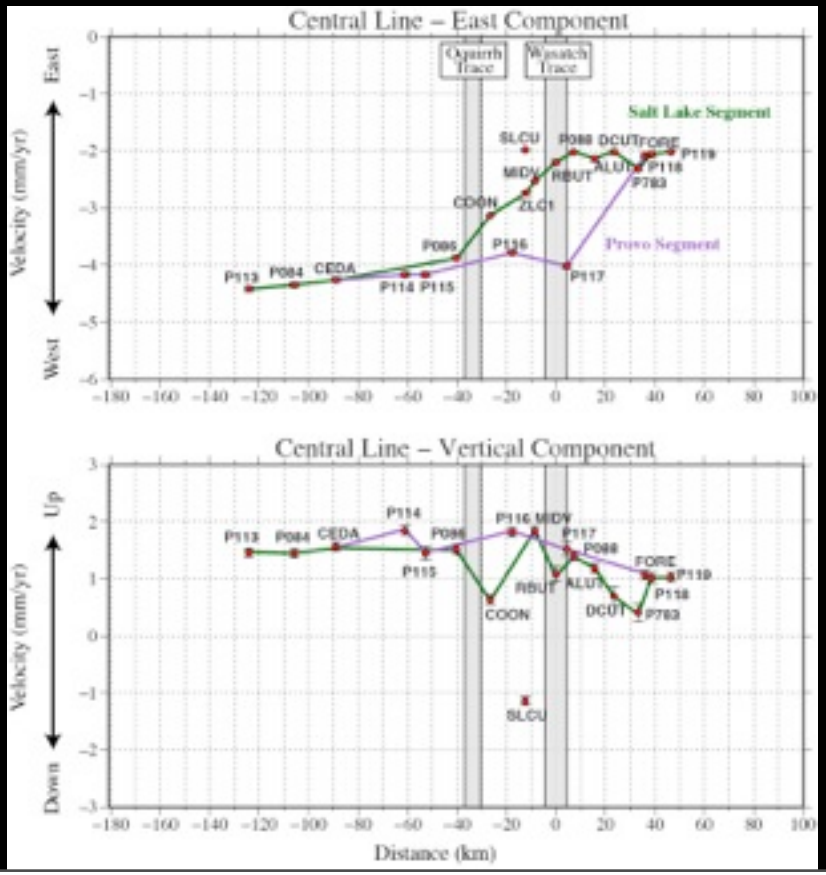


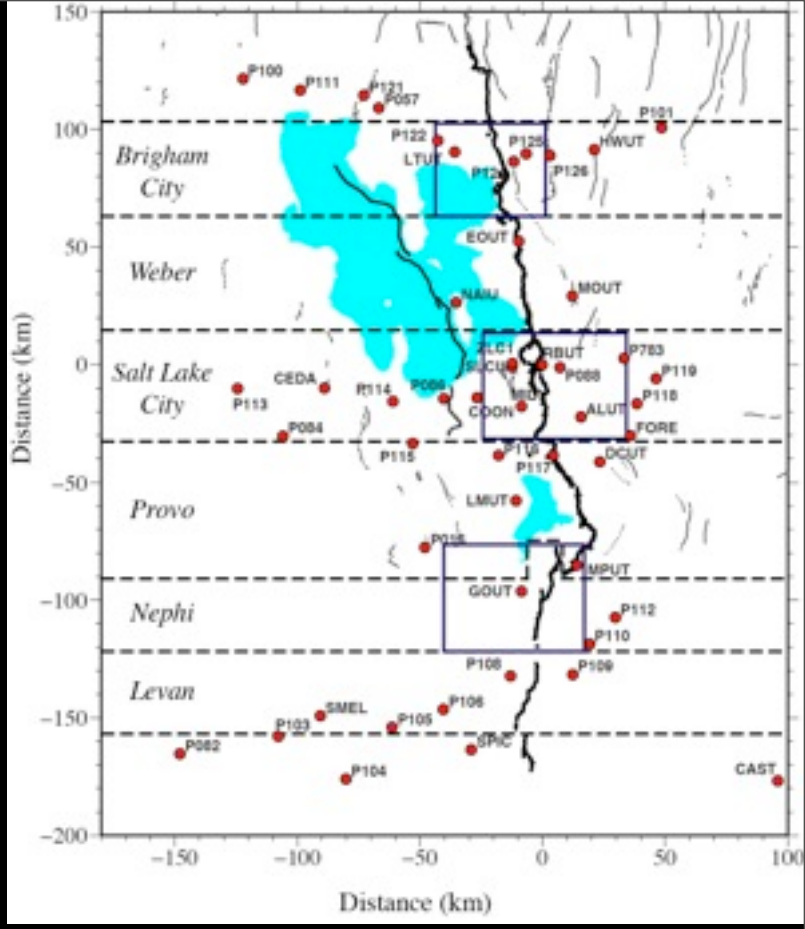
Faults sampled by profile:

- East Cache
- (West Cache)
- Wasatch – Brigham City
- East Great Salt Lake

Salt Lake City Profile

2.35 mm/yr





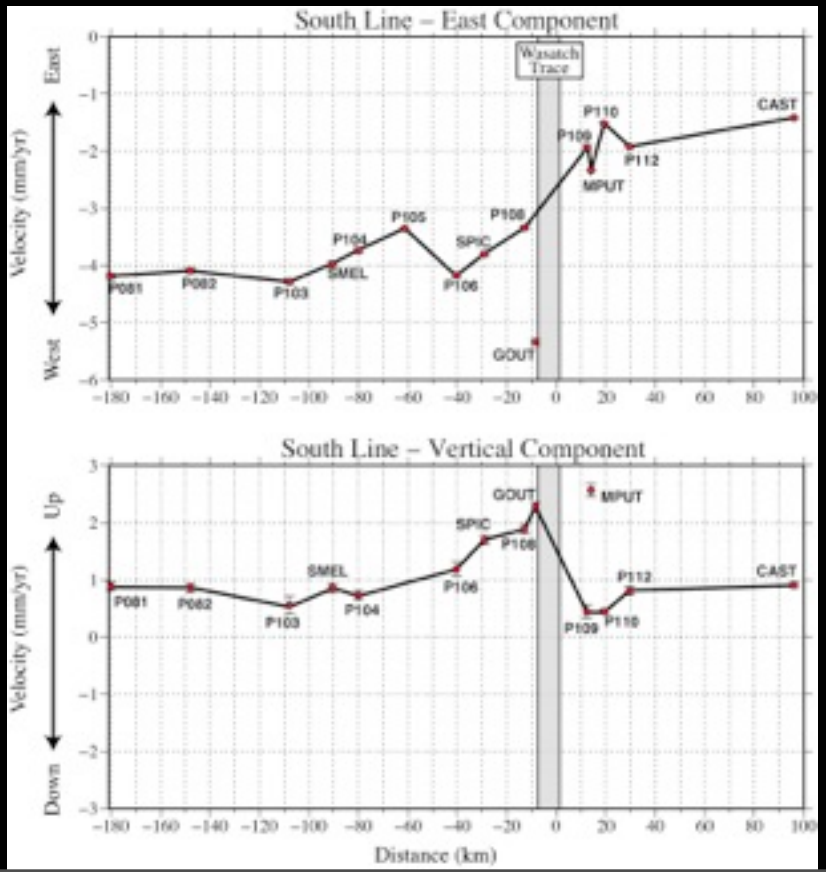
Faults sampled by profile:

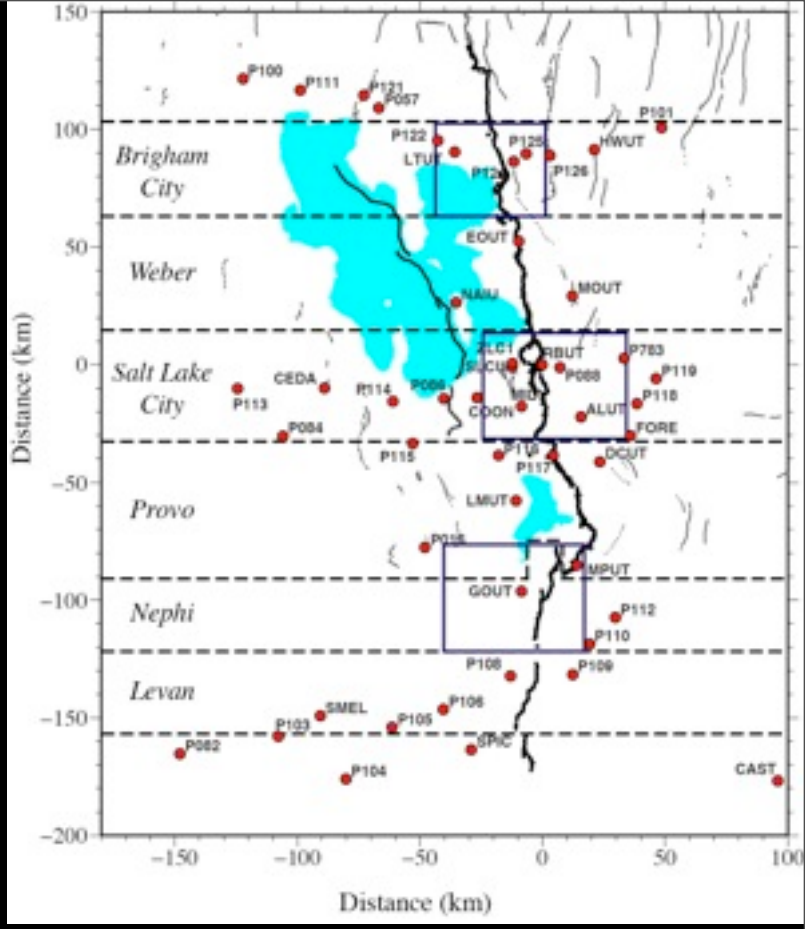
- Wasatch – Salt Lake City
- Wasatch – Provo (?)
- North Oquirrh

Outlier: SLCU

Nephi Profile

2.17 mm/yr



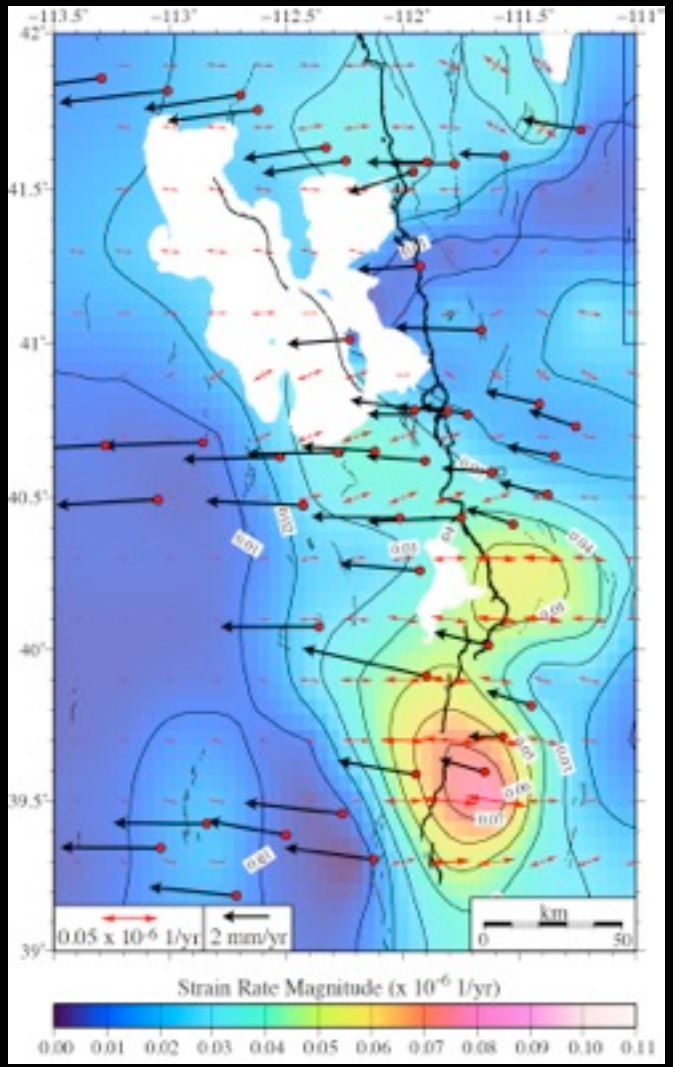


Faults sampled by profile:

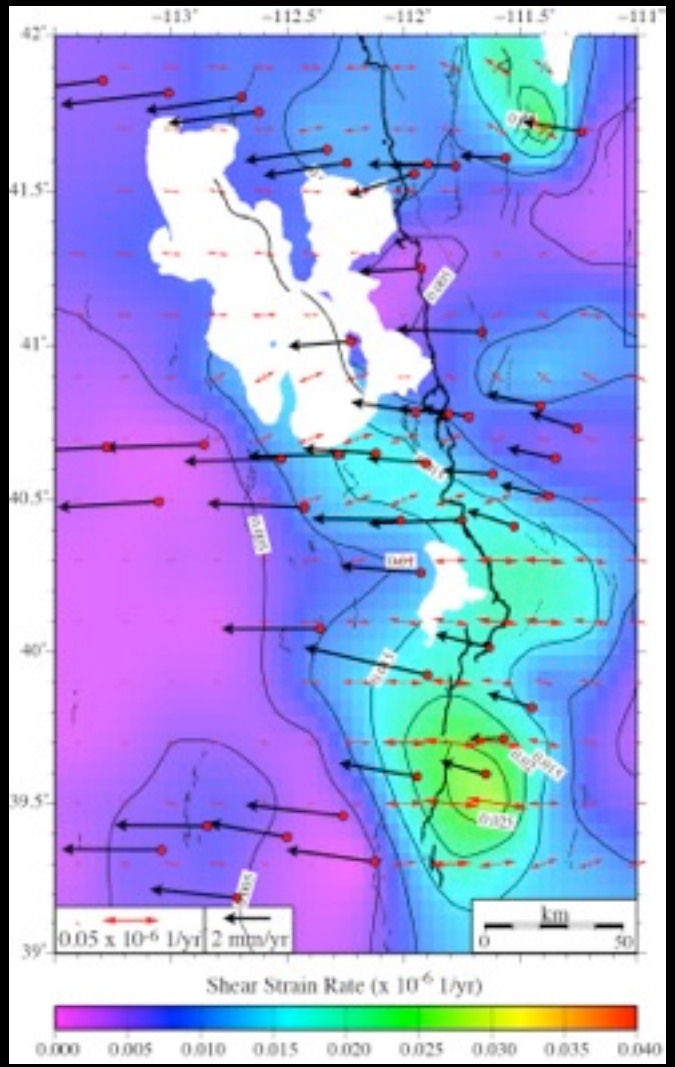
- Wasatch – Provo
- Wasatch – Nephi
- Wasatch - Levan

Outlier: GOUT

Strain Rate Magnitude



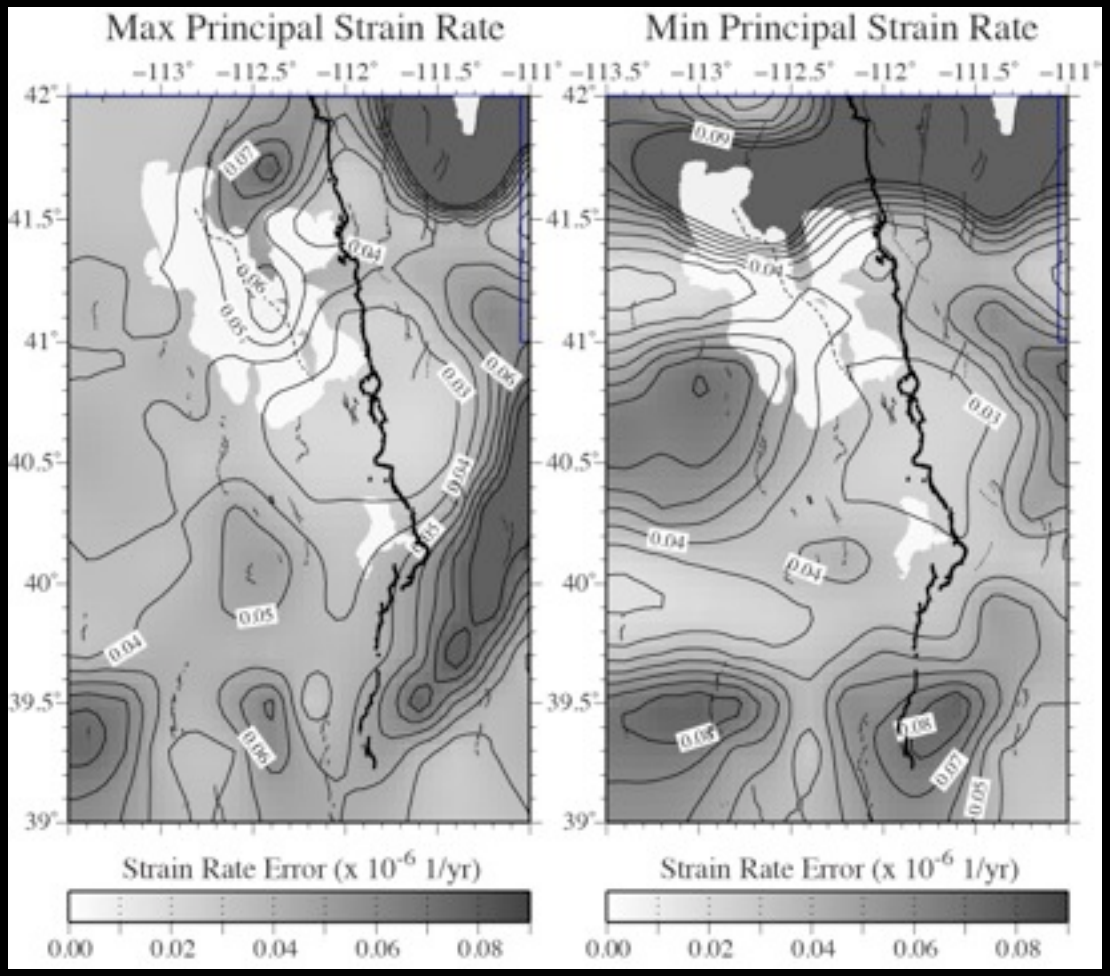
Shear Strain Rate



- Interpolate horizontal GPS velocities to strain rates
  - Eliminate outliers SLCU and GOUT

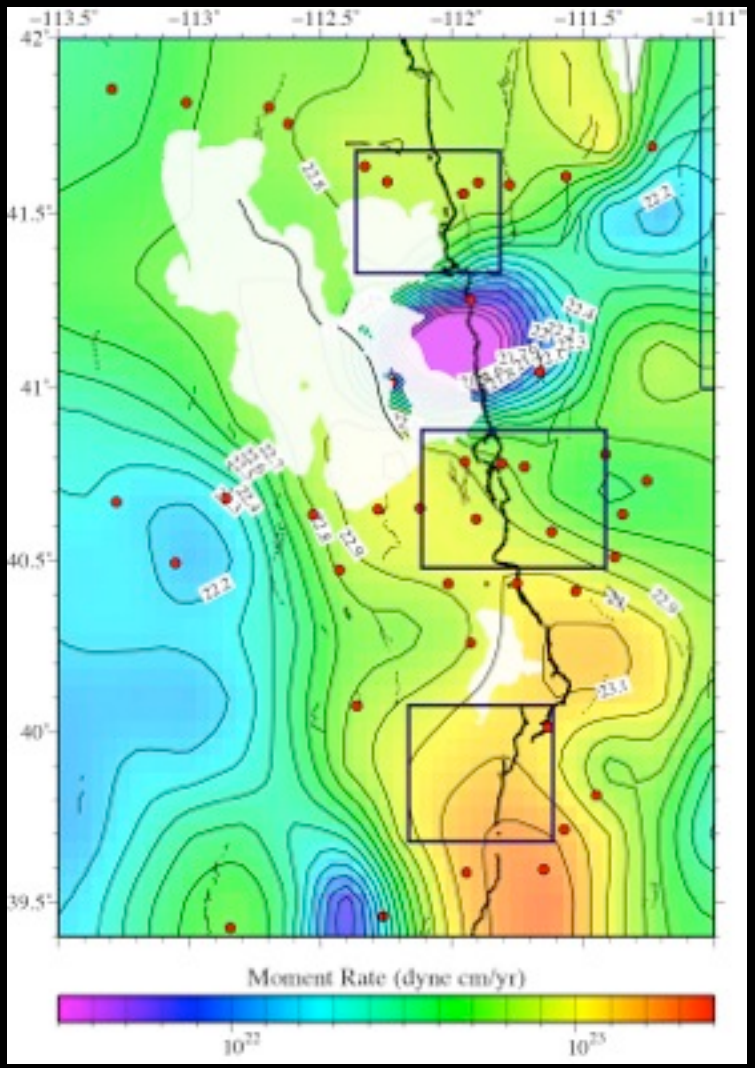
- Higher strain rates reflect larger changes of deformation over smaller areas

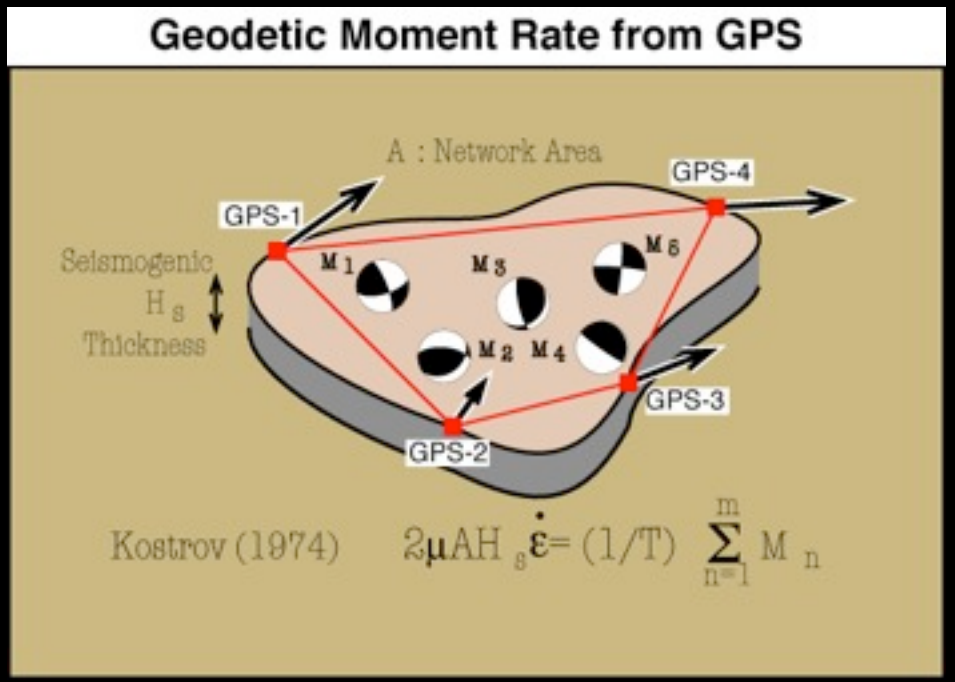
Strain Rate Errors



- Uncertainties depend on geographic distribution, strain component

Geodetic Moment Loading Rate



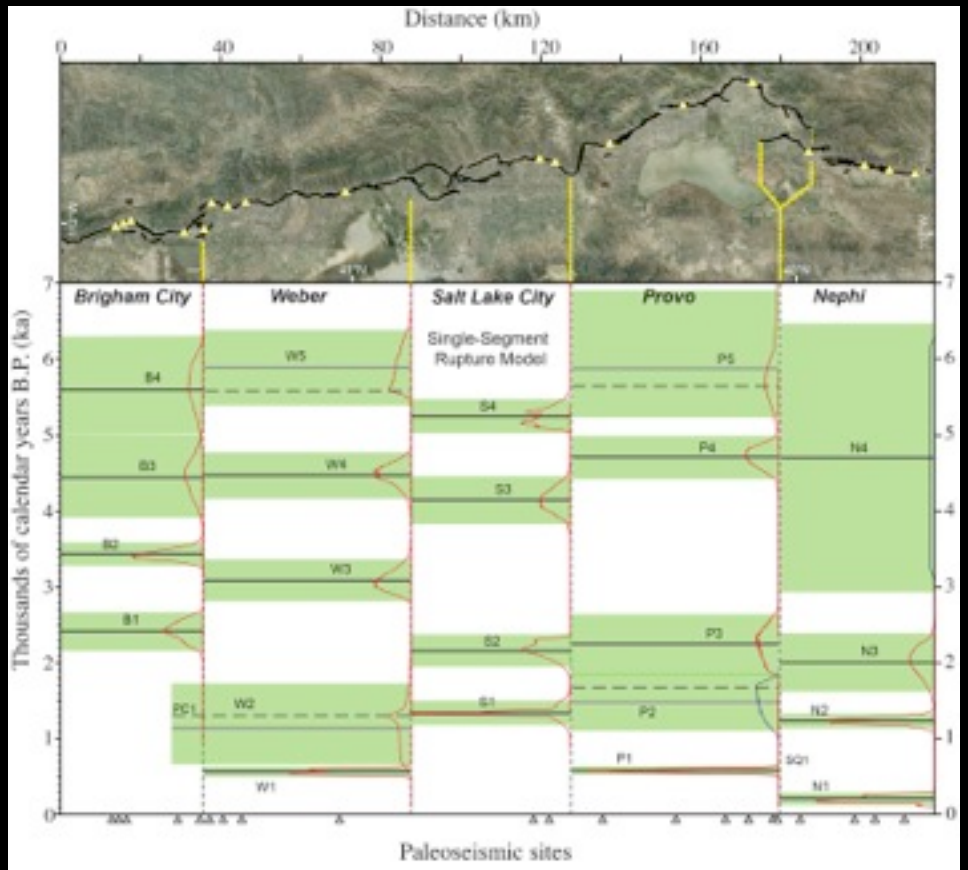


(Ward, 1998)

- Use Kostrov formula to convert deformation rate to geodetic moment rate
  - Moment is measure of energy required for deformation
- Moment available for earthquakes depends on:
  - Seismogenic volume
  - Strain rate for network area

Prehistoric Earthquakes Identified for Wasatch Fault

EQ Ref #	Segment Ref #	Age (yrs)	ΔAge (2-σ)	SRL (km)	ΔSRL (2-σ)
E1	N1	206	86	43	11.5
E2	P1	576	48	59	11.5
E3	W1	561	68	56	6.5
E4	W2	1137	641	65	8.5
E5	N2	1234	96	43	11.5
E6	S1	1343	162	40	6.5
E7	P2	1479	378	59	11.5
E8	N3	2004	388	43	11.5
E9	P3	2240	406	59	11.5
E10	S2	2160	215	40	6.5
E11	B1	2417	256	36	6
E12	W3	3087	275	56	6.5
E13	B2	3430	153	36	6
E14	B3	4452	543	36	6
E15	W4	4471	303	36	13
E16	S3	4147	315	40	6.5
E17	P4	4709	285	59	11.5
E18	N4	4699	1768	43	11.5
E19	S4	5250	221	40	6.5
E20	B4	5603	660	36	6
E21	P5	5888	1002	59	11.5
E22	W5	5891	502	56	6.5



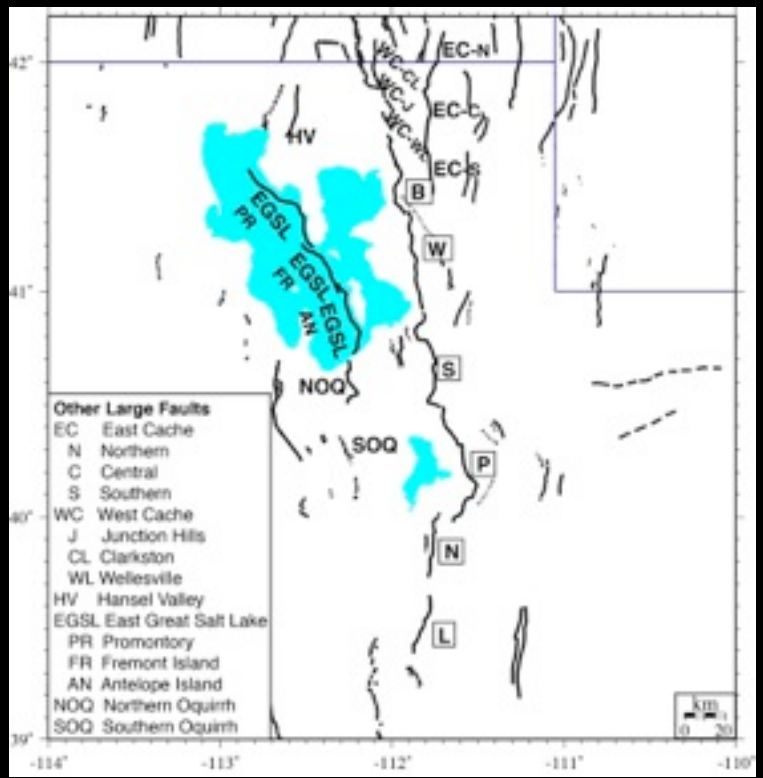
(DuRoss et al., 2011)

- 4-5 earthquake on each segment
- Events dated within last 6000 years

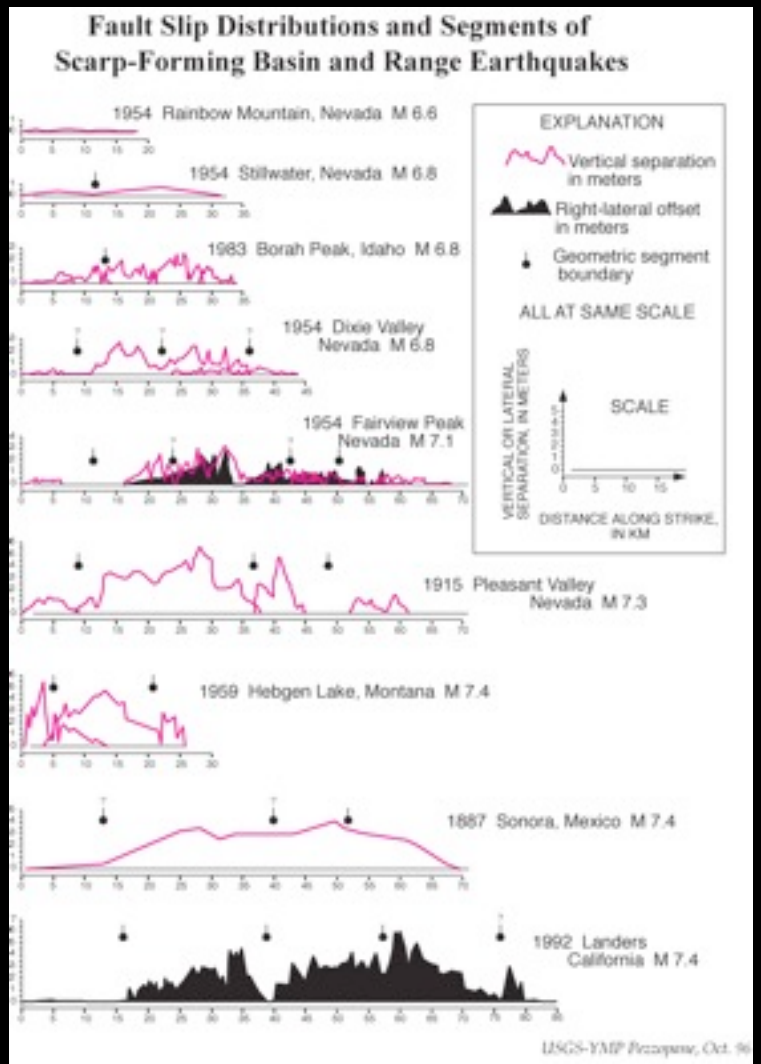
Other Prehistoric Earthquakes

Fault Name	Segment Name	Segment Length (km)	Age Range	Closest Wasatch
Hansel Valley		11	78 (1934 M6.6)	Collinston
EGSL	Promontory	49	355-797	Brigham City
EGSL	Antelope Island	35	5936-6406	Weber
EGSL	Fremont Island	30	2939-3385	Weber
N. Oquirrh		21	4800-7900	Salt Lake City
S. Oquirrh		24	1300-4830	Salt Lake City
West Cache	Clarkston	21	3600-4000	Clarkston
West Cache	Wellsville	20	4400-4800	Brigham City
East Cache	Central	17	4300-4600	Brigham City

(Hansel Valley: Doser, 1989; EGSL: Dinter and Pechmann, 2011; Oquirrh: Olig et al., 2011; West Cache, East Cache: Lund, 2005)



Historic Multi-Segment Earthquakes



(Pezzopane and Dawson, 2010)

- Earthquake magnitude scales with displacement, surface rupture length
- Choose rupture lengths corresponding to segment lengths on Wasatch fault
- Used average magnitudes from multiple magnitude-SRL relations for seismic moment calculation

Moment-Magnitude Relation:

Hanks and Kanamori (1979)	$\log(M_o) = 1.5\,M + 16.0$

Magnitude-Earthquake Parameter Relations:

Stirling et al. (2002)	$M = 5.88(0.17) + 0.80(0.10)\log(SRL)$
Wells and Coppersmith (1994)	$M = 5.08(0.10) + 1.16(0.07)\log(SRL)$
Wells and Coppersmith (1994)	$M = 4.07(0.06) + 0.98(0.03)\log(RA)$
Blaser et al. (2011)	$\log(SRL) = -1.91(0.29) + 0.64(0.02)\,M$

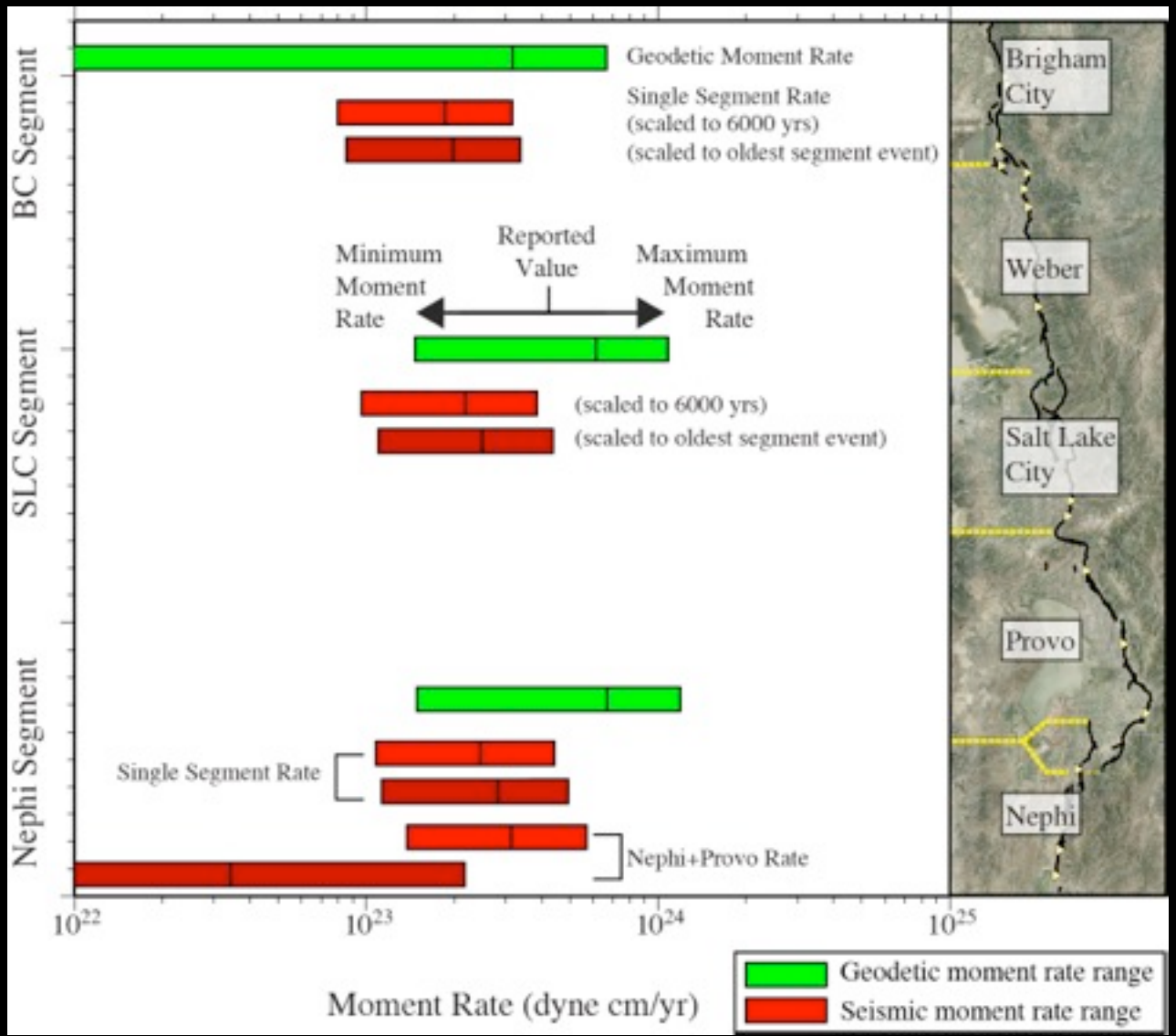
Fault Segment Moment Rates (dyne cm/yr)

GPS-Derived Moment Rates	BC	SLC	Nephi
Interpolated Strain Rates	3.18E23	6.13E23	6.71E23
Direct Calc from GPS Vels	5.61E23	4.46E23	1.10E23

Paleoseismic Moment Rates (scale to 6000 yrs)			
Single Segment Ruptures	1.86E23	2.19E23	2.46E23
Nephi + Provo			2.83E23
Wasatch + Other Known EQs	1.96E23	2.34E23	

Paleoseismic Moment Rates (scale to oldest event on segment)			
Single Segment Ruptures	1.99E23	2.50E23	3.14E23
Nephi + Provo			2.18E23
Wasatch + Other Known EQs	2.10E23	2.68E23	

Fault Segment Moment Rates (dyne cm/yr)

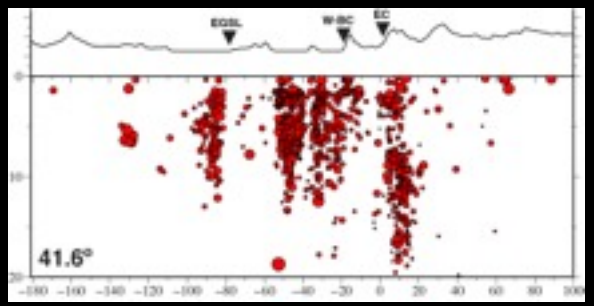


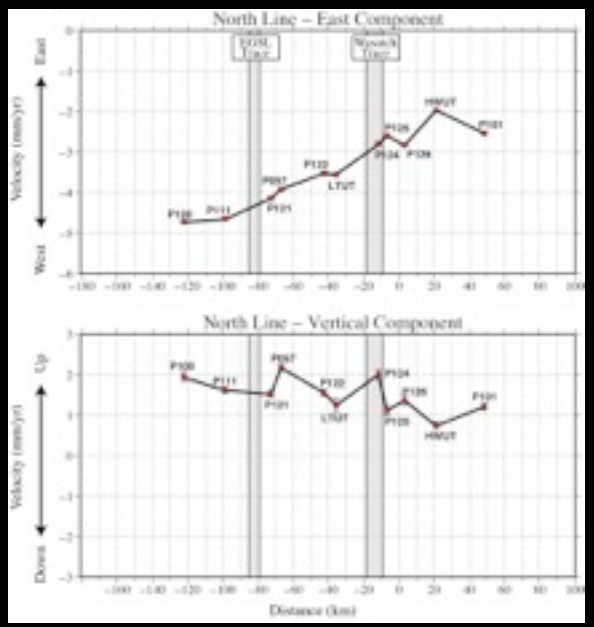
Brigham City Profile

3.18E23 dyne cm/yr geodetic loading (BC only)

2.75 mm/yr net extension rate

110-km wide seismic zone



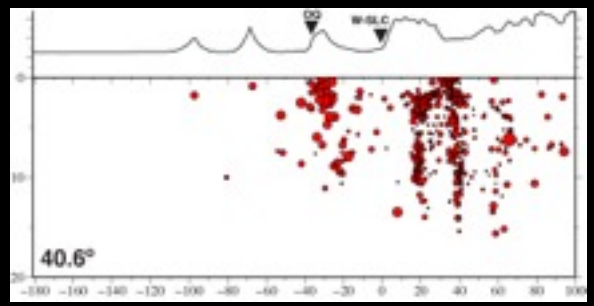


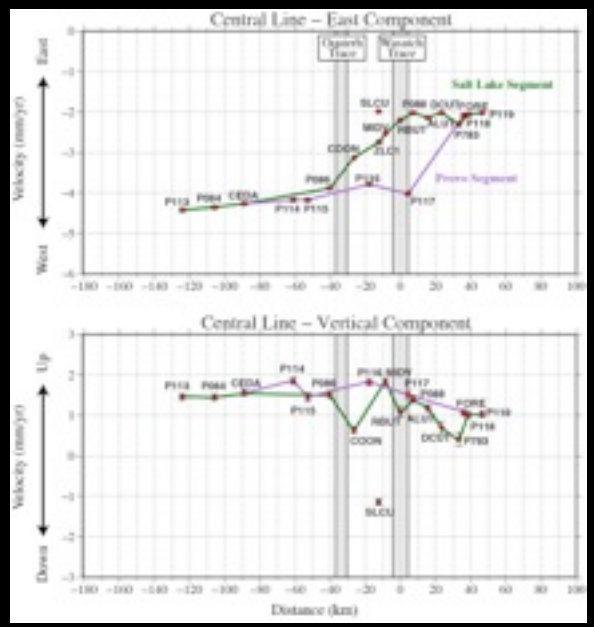
Salt Lake City Profile

6.13E23 dyne cm/yr geodetic loading (SLC only)

2.35 mm/yr net extension rate

80-km wide seismic zone



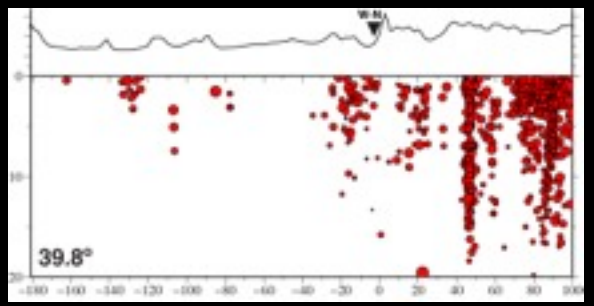


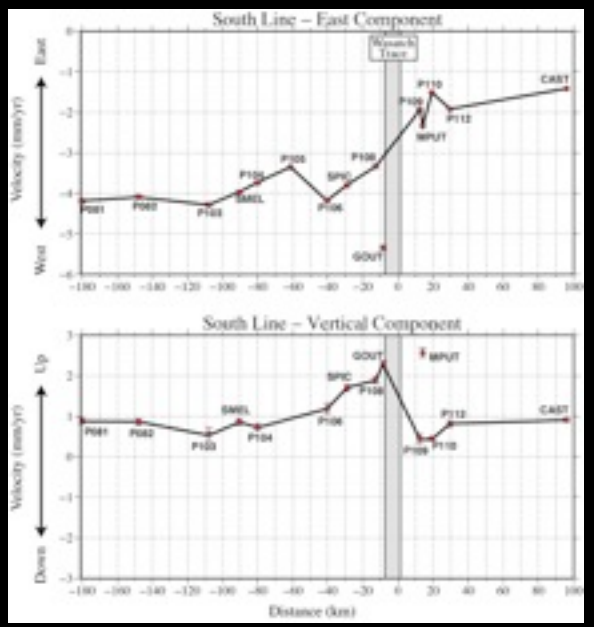
Nephi Profile

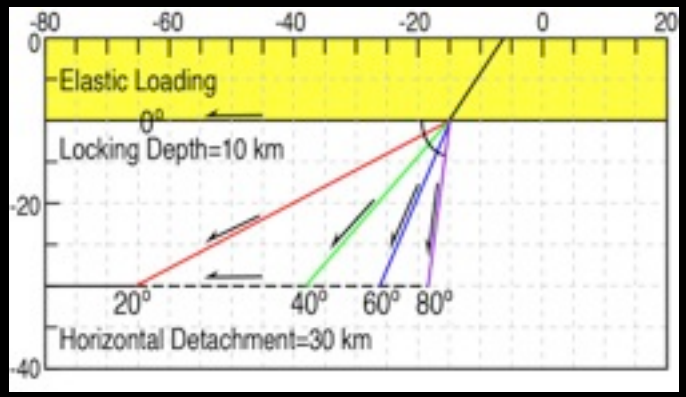
6.71E23 dyne cm/yr geodetic loading (SLC only)

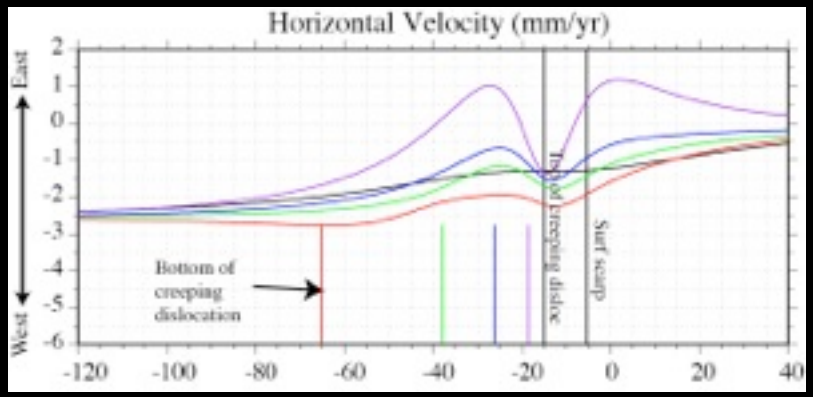
2.17 mm/yr net extension rate

50-km wide seismic zone





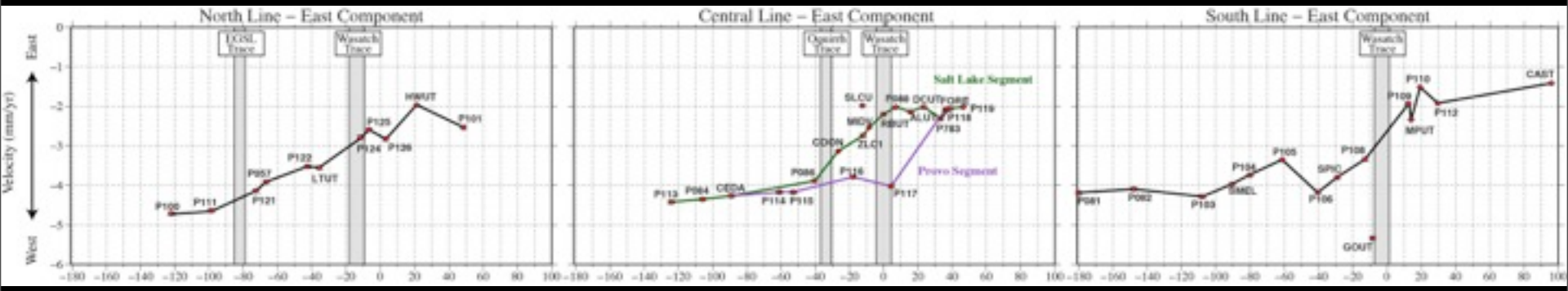




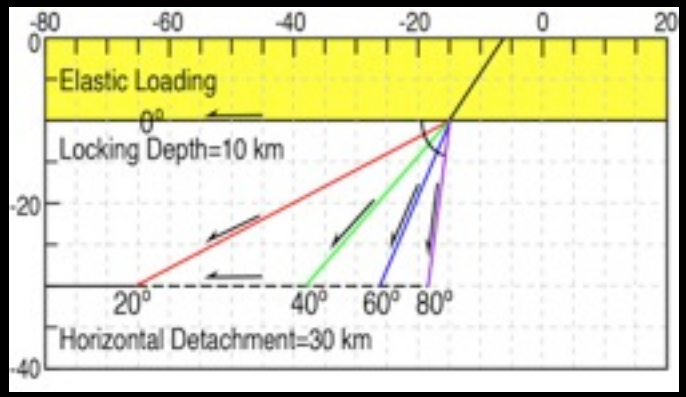
Brigham City Profile

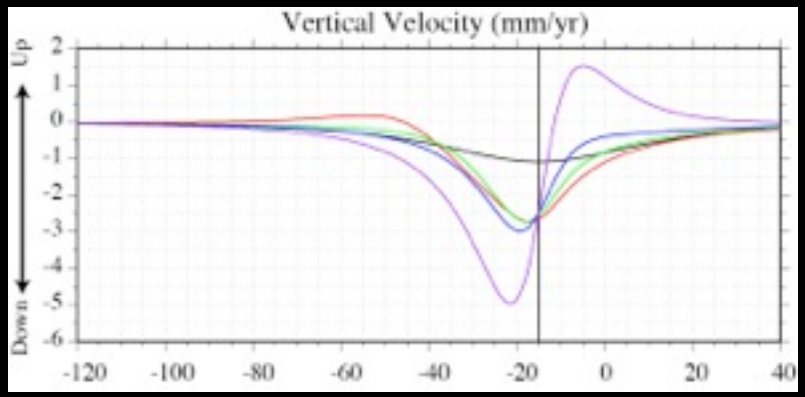
Salt Lake City Profile

Nephi Profile



- 1-D horizontal dislocations for fault creeping at depth
- Model predicts smoothly varying surface velocities
  - Width of deformation zone: ~65 km
  - Deformation amplitude depend on dip, slip rate
- Observed GPS velocity profiles
  - 2-D station distribution with more complex deformation
  - Have at least 100-km wide deformation zone

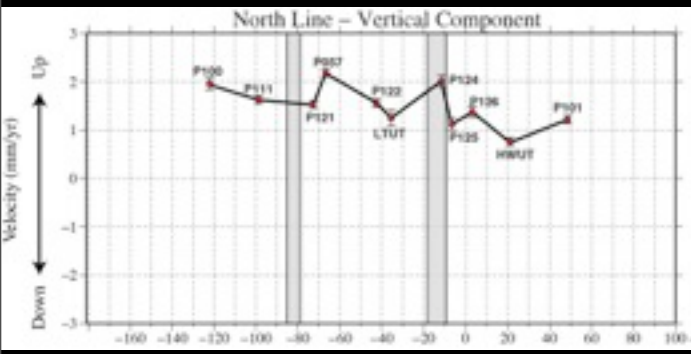


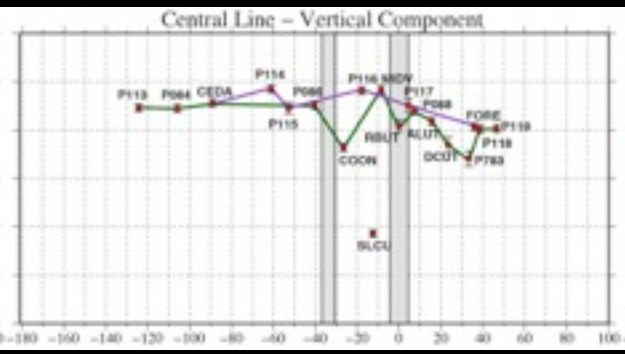


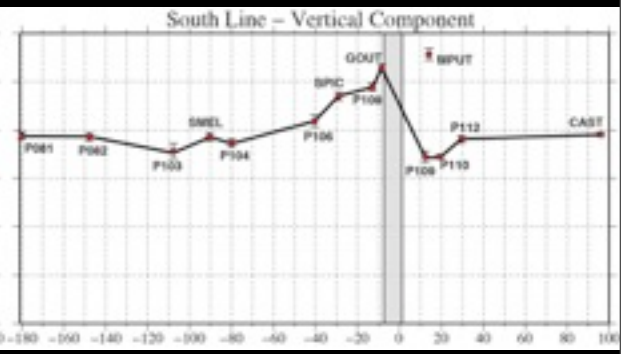
Brigham City Profile

Salt Lake City Profile

Nephi Profile

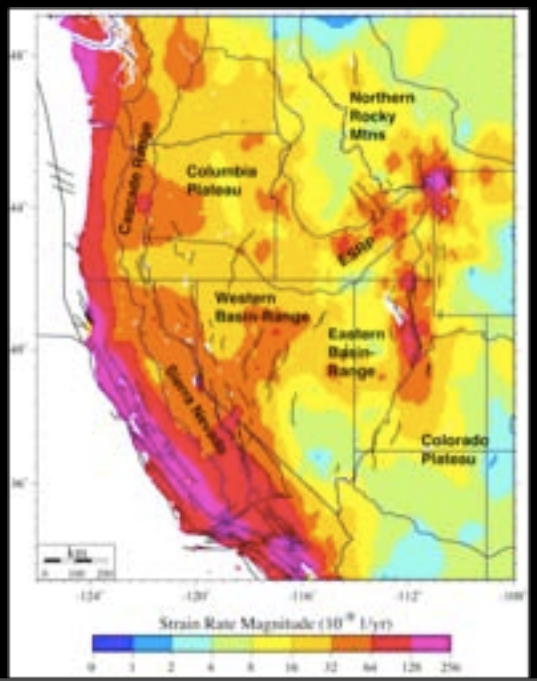






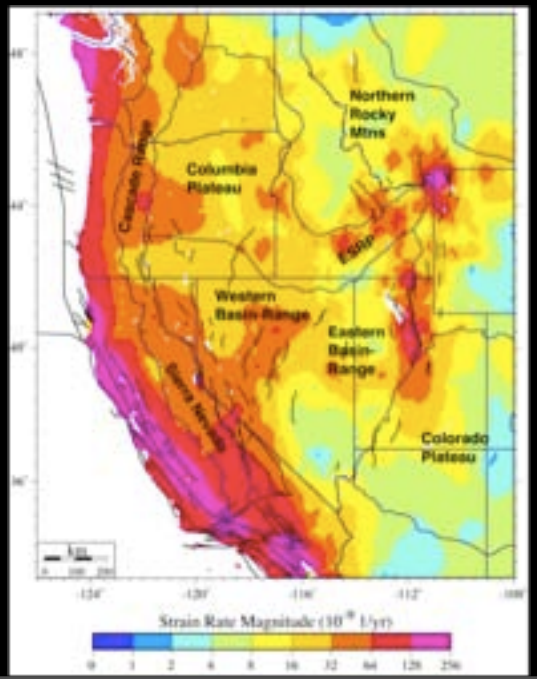
- 1-D vertical dislocations for fault creeping at depth
- Model predicts smoothly varying surface velocities
- Observed GPS velocity profiles
  - Do not resemble model profiles
  - More complex, noisy deformation pattern
- Possible multiple dislocations

Older Deformation Models

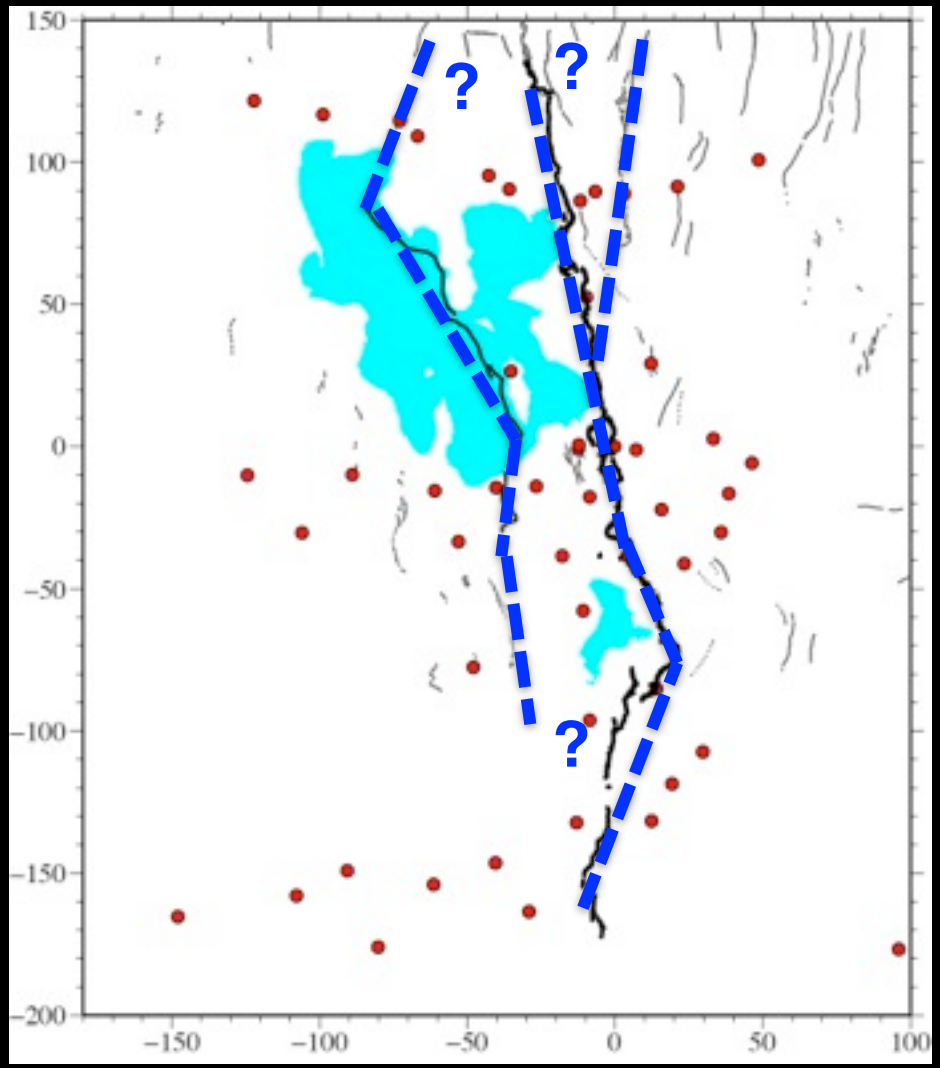


- Previous models treated Eastern Basin-Range as single block with Wasatch Fault as only major boundary fault
- Geodetic analysis suggests multiple faults contributing to extension across Wasatch Front
  - Similar extension rate from north to south
  - Geodetic moment rate decreases from south to north
  - Width of deformation zone decreases from north to south
  - Width of earthquake zone decreases from north to south
- Candidate faults
  - Brigham City profile: East Cache, EGSL faults
  - Salt Lake City profile: Oquirrh fault
  - Nephi profile: no other faults

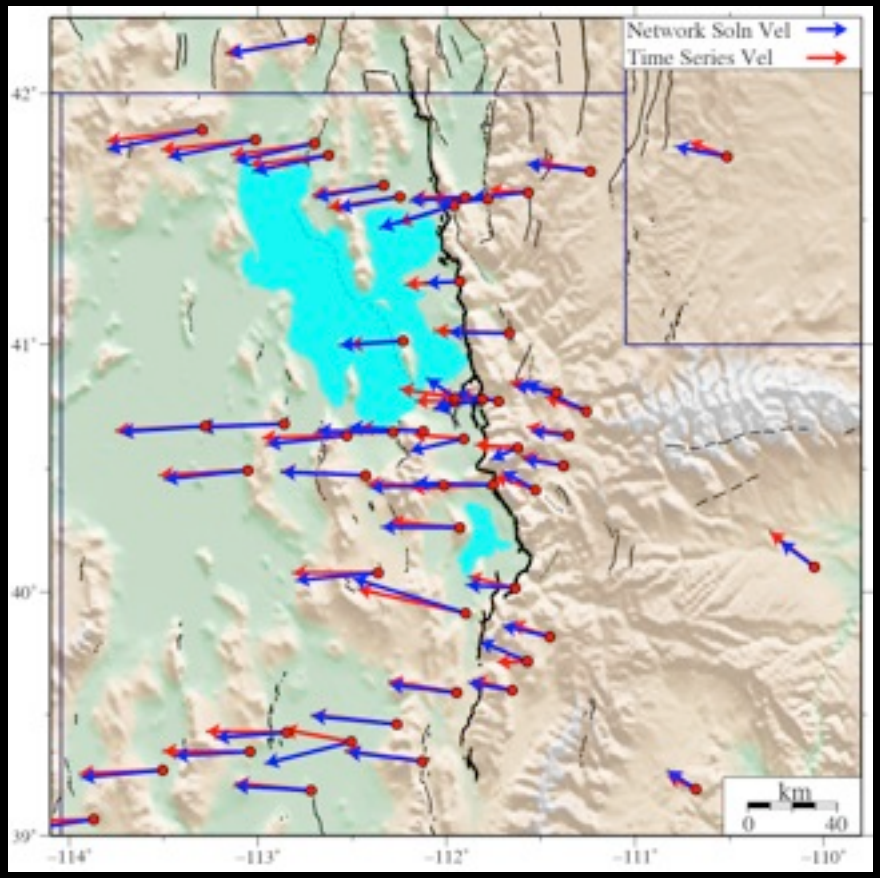
Older Deformation Models

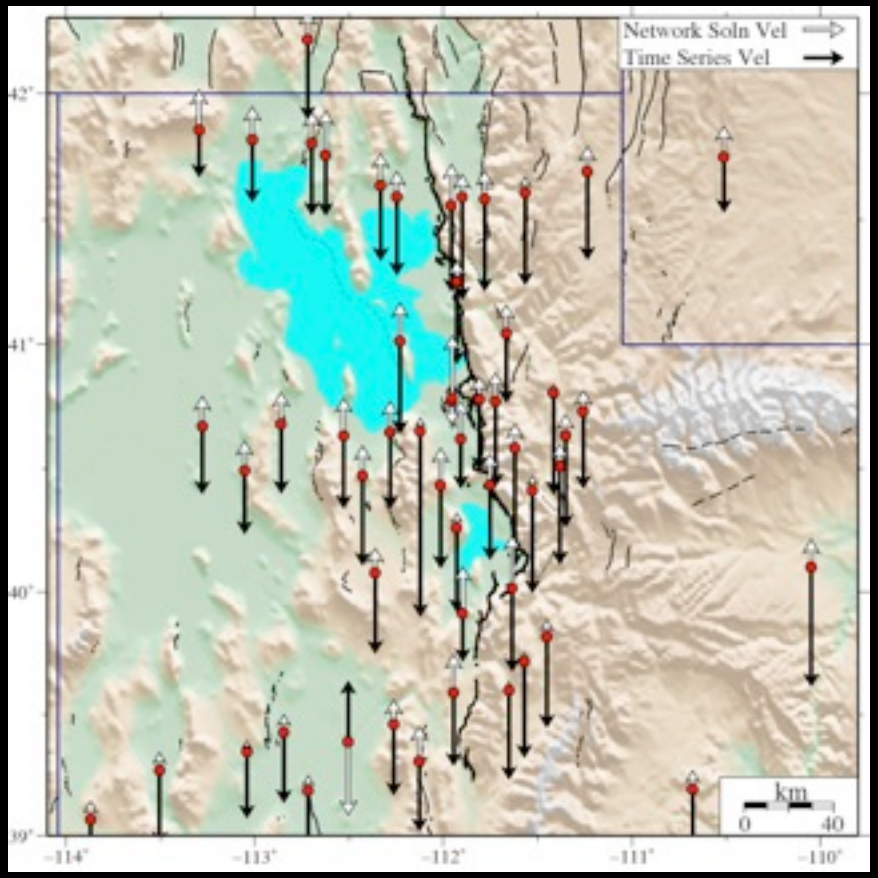


New 2012 Block Model

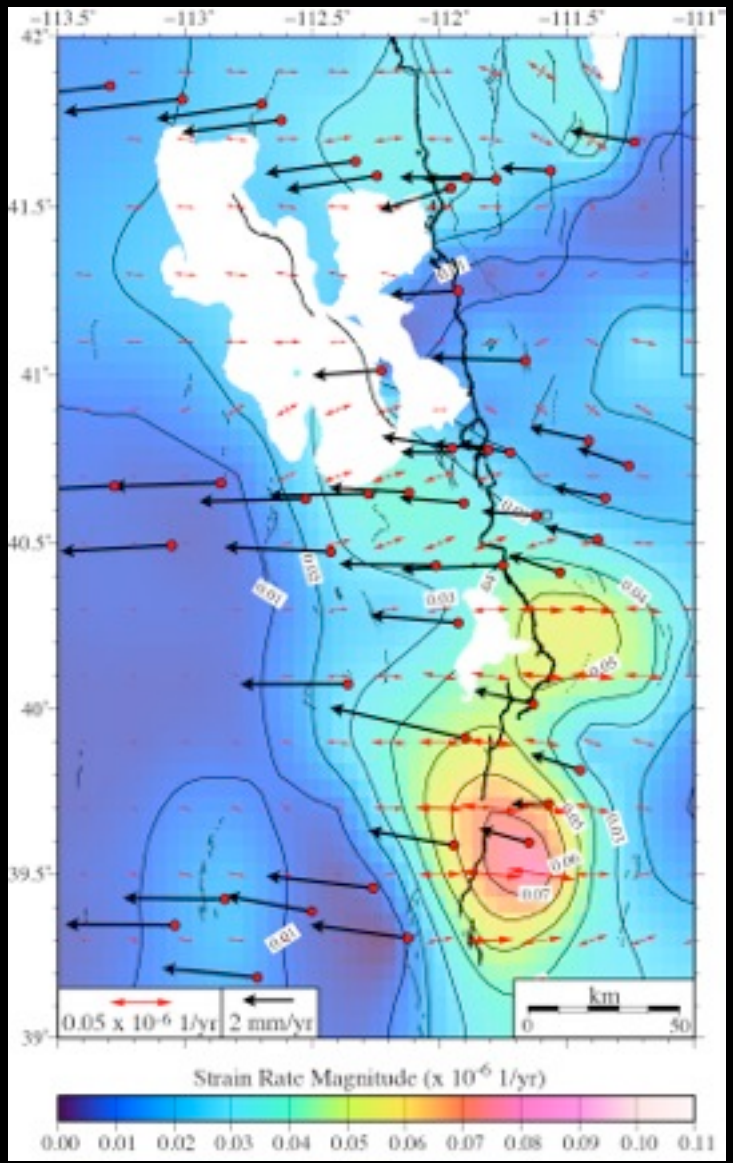


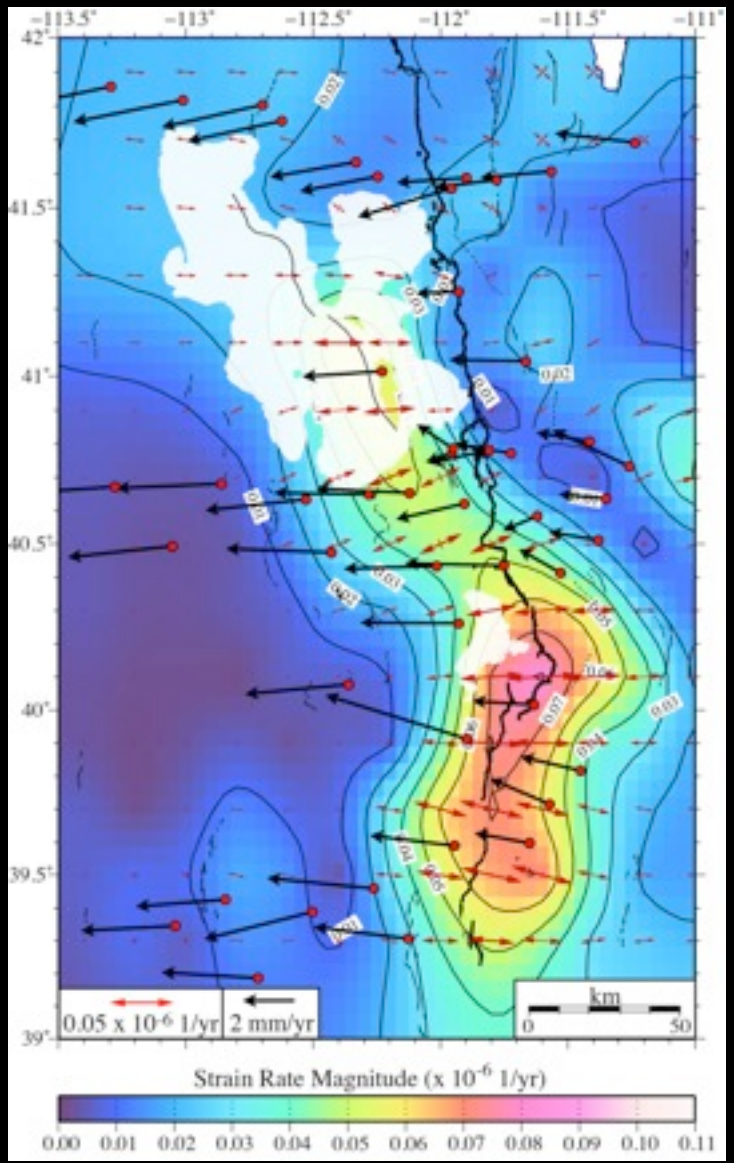
Horizontal and Vertical Velocities
Network Solution vs. Time Series



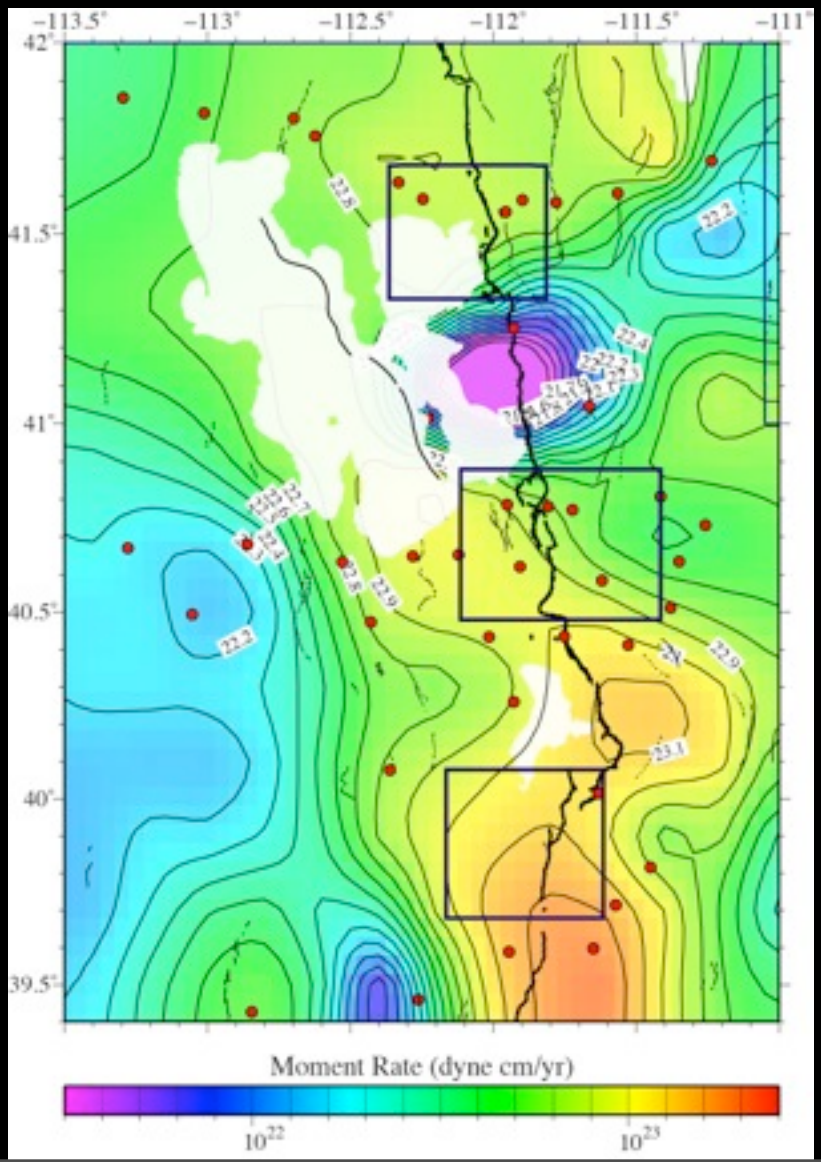


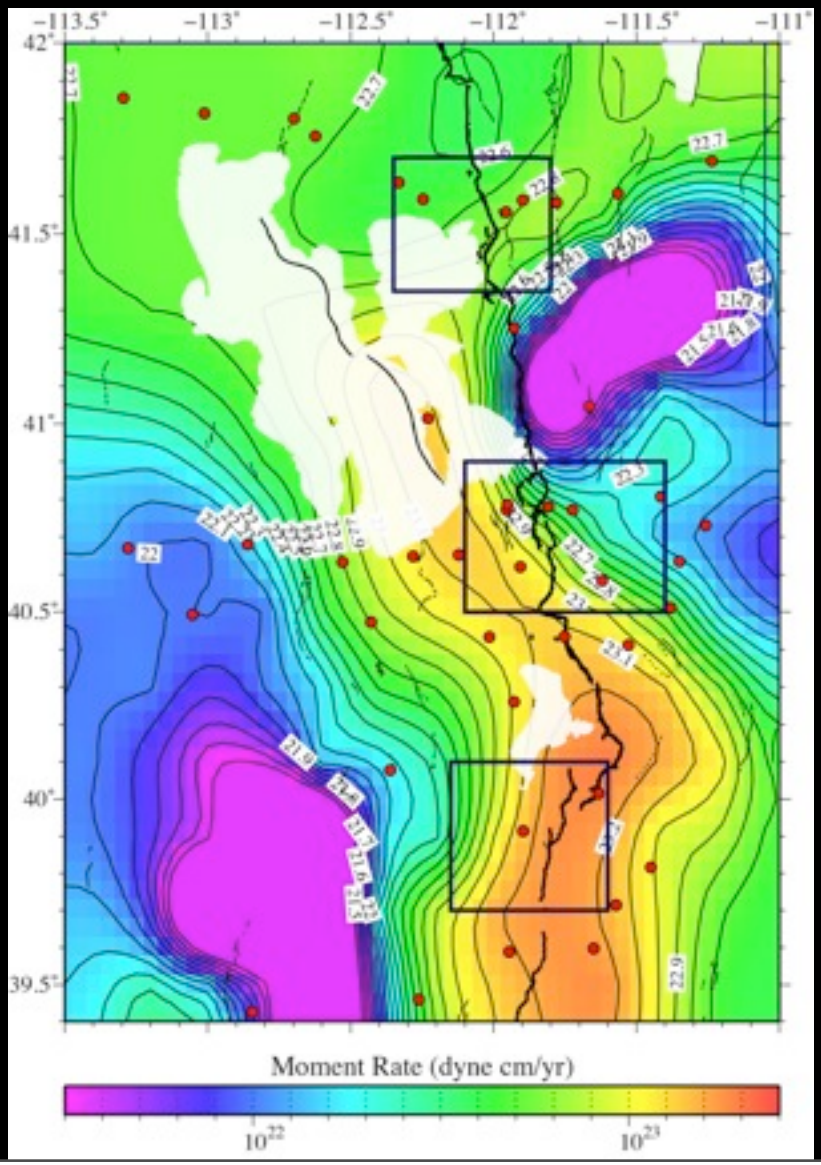
Strain Rates and Magnitudes
Time Series vs. Network Solution
(no GOUT in TS-derived strains



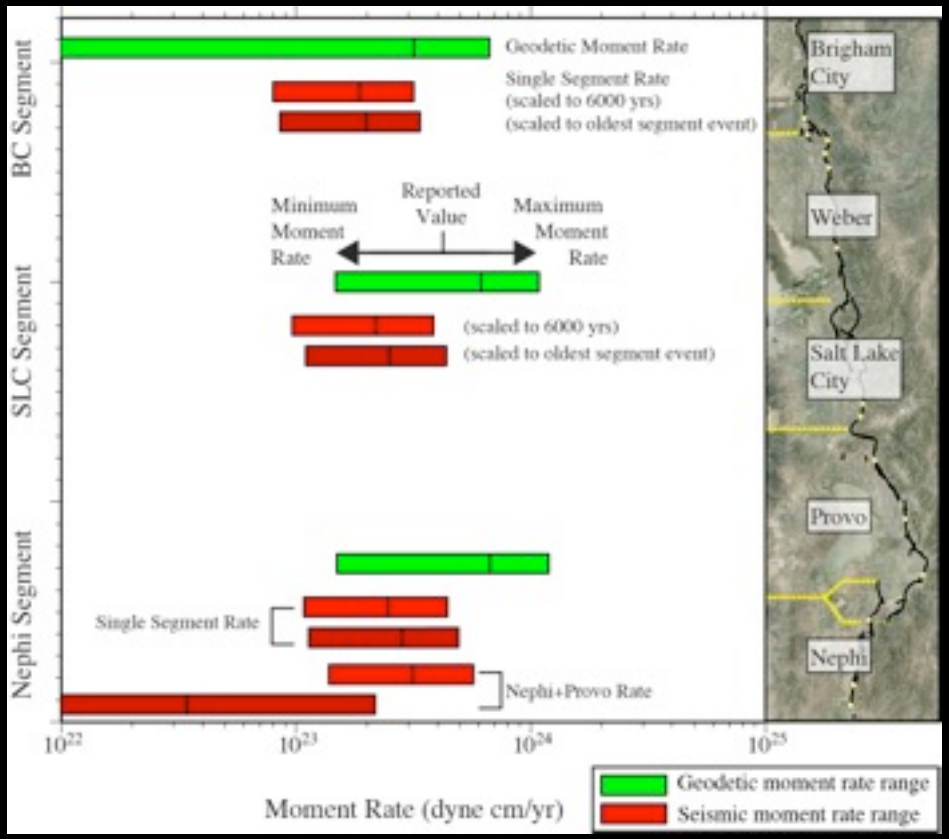


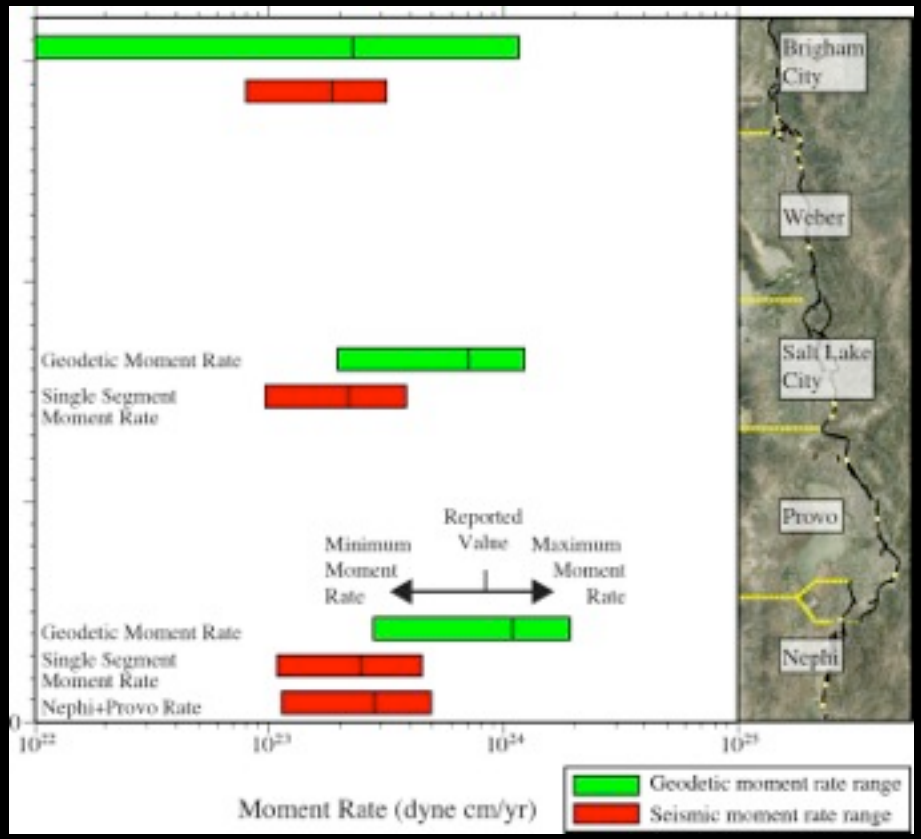
Geodetic Moment Rates
Time Series vs. Network Solution
(no GOUT in TS-derived strains





Seismic and Geodetic Moment Comparisons
Time Series vs. Network Solution
(no GOUT in TS-derived strains





Conclusions

- Improved analysis lead to better match between geodetic moment loading rate and seismic moment release rate
- Geodetic moment rate still exceeds seismic moment rate by up to 2.5X
- Wasatch fault is major source of deformation, seismic moment
- Other faults contribute to regional deformation
    - EGSL, East Cache, Oquirrh fault
- Geodetic data consistent with complex block model of Wasatch Front, where regional extension accommodated on multiple faults