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Interpretation of Stress Orientation in the Peninsular Ranges and Coachella Valley Region of Southern California

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Presentation at 5th UJNR, October 14, 2004

Motivation

- How to confirm basic assumptions underlying probabilistic rupture forecasts in probabilistic seismic hazard analysis (PSHA)?
- Current time-dependent, physics-based, PSHA models are largely based on estimates of accumulated slip deficit, i.e. the amount of slip accumulated since the last significant earthquake.
- Are there any geophysical observables that can be used to confirm or refine estimates of slip deficit?

Candidate

- Stress Orientation

Outline of Talk

- Observations of Stress Orientation
- Simple Dislocation Models
- Observations of Changes in Stress Orientation
- Preliminary Testing of Slip Deficit Models for Stress Orientation in Southern California

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Candidate: Stress Orientation

- Stress Orientation
  - Orientation of the principal horizontal stresses (S_{Hmax}) relative to fault plane
- Observations of stress orientation inferred from earthquake focal mechanisms are increasingly available and reliable
- Issues about spatial sampling largely resolved

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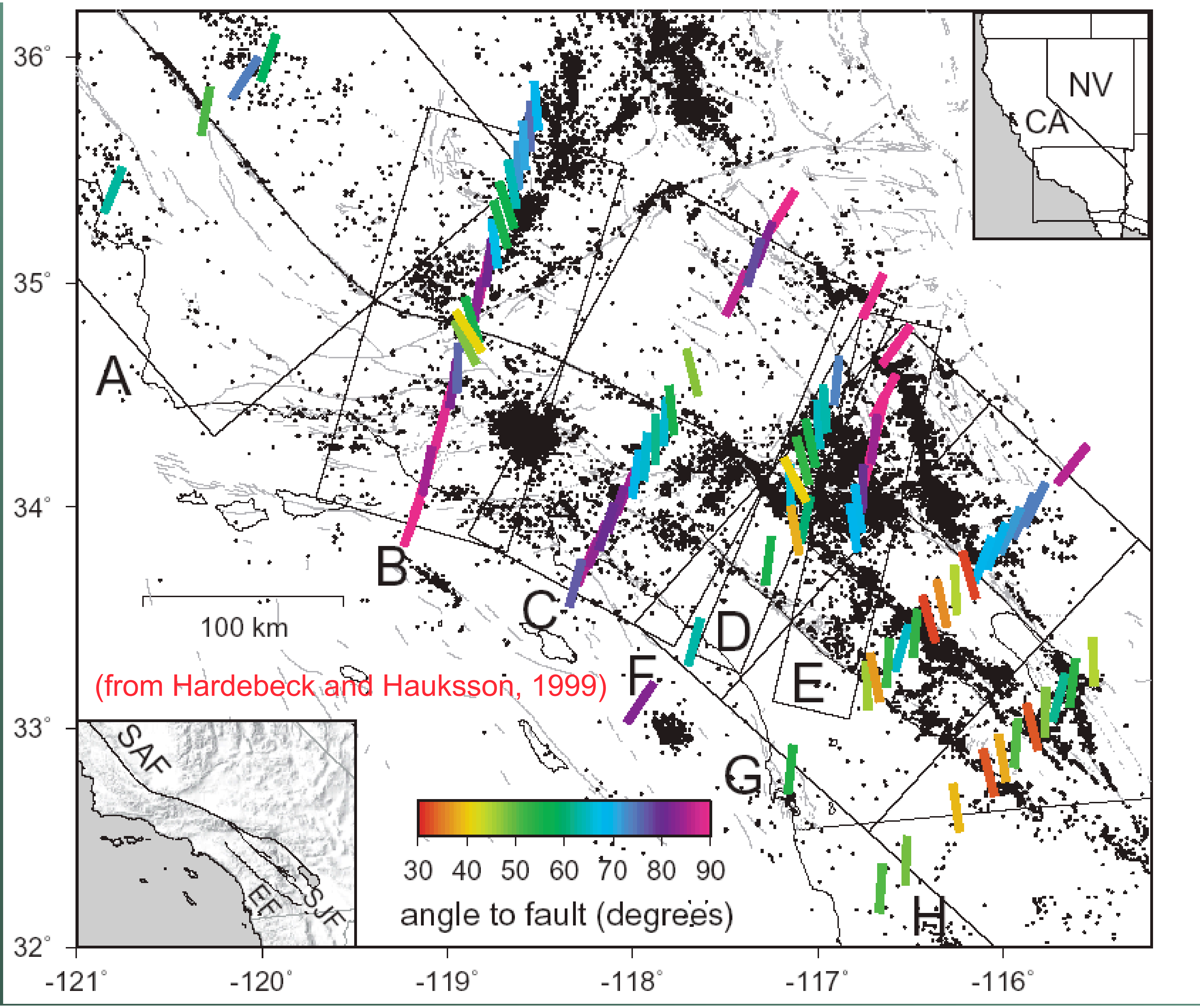

36°
35°
34°
33°
32°
-121°
-120°
-119°
-118°
-117°
-116°
A
B
C
D
E
F
G
H
100 km
(from Hardebeck and Hauksson, 1999)
NV
CA
SAF
EF
SJF
30 40 50 60 70 80 90
angle to fault (degrees)

Stress Orientation: Challenges

- Requires occurrence of small earthquakes
- Continue to improve reliability, spatial sampling
- Requires model for interpretation in terms of slip deficit

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Dislocation Model

- Dislocation model of constant slip rate at depth below seismogenic zone extremely well supported by geodetic observations
- Implicit basis for both empirical and physics-based probabilistic seismic hazard analysis (PSHA)

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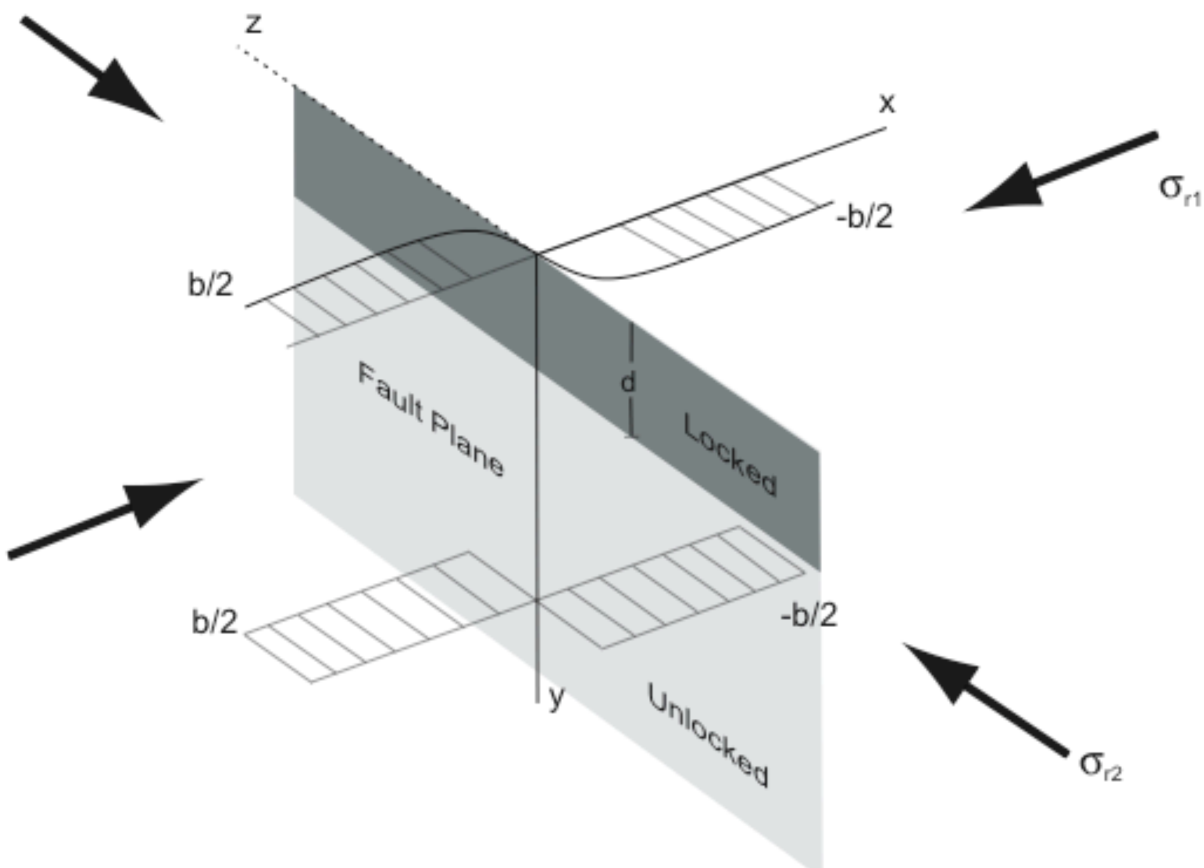
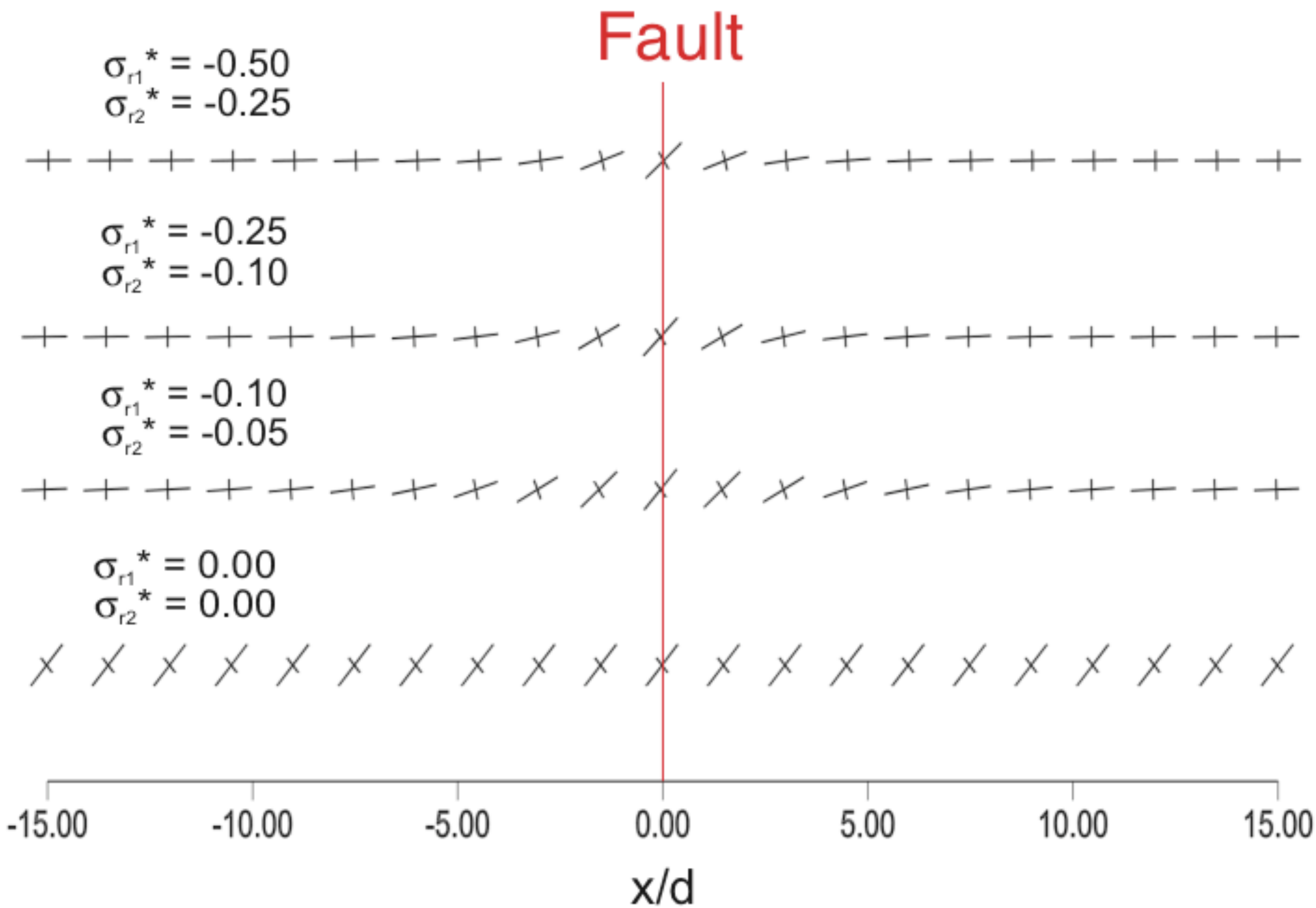

z
x
σr1
-b/2
b/2
d
Fault Plane
Locked
b/2
-b/2
y
Unlocked
σr2

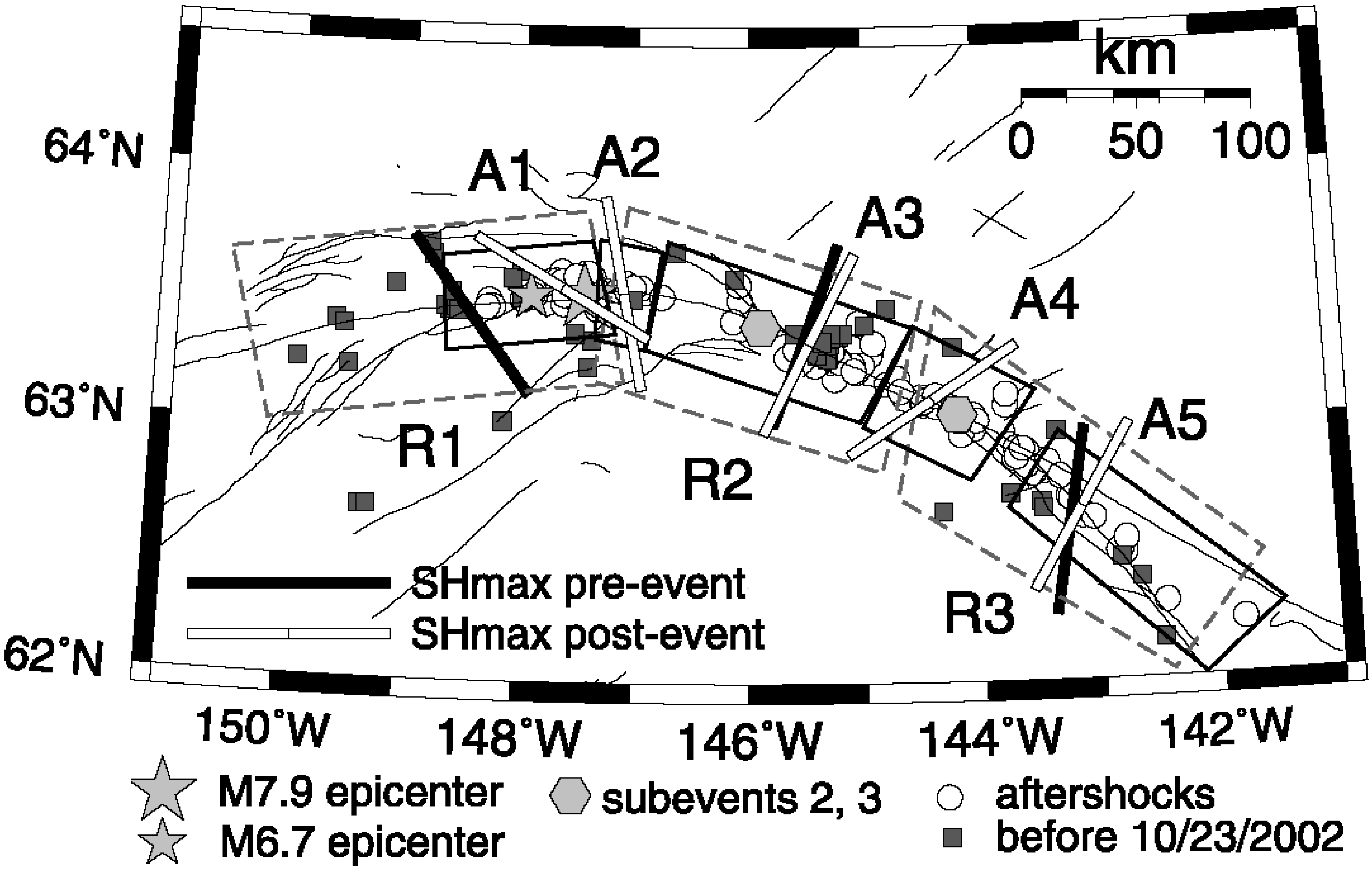


Fault
σr1* = -0.50
σr2* = -0.25
σr1* = -0.25
σr2* = -0.10
σr1* = -0.10
σr2* = -0.05
σr1* = 0.00
σr2* = 0.00
-15.00
-10.00
-5.00
0.00
5.00
10.00
15.00
x/d

Observations of Change in Stress Orientation

- Loma Prieta (Beroza and Zoback, 1993)
- Landers (Hauksson, 1994)
- Denali (Ratchkovski, 2003)

➢ Reasonable assumption that stress is fault-normal immediately after significant event



(from Ratchkovski, 2003)

Slip Deficit Model for Southern California

- Simplified faults for Peninsular Ranges and Coachella Valley
- Slip rates from geodetic data (Bennett et al, 1996)
- Dates of last earthquakes from time-dependent PSHA model of Cramer et al (2000)

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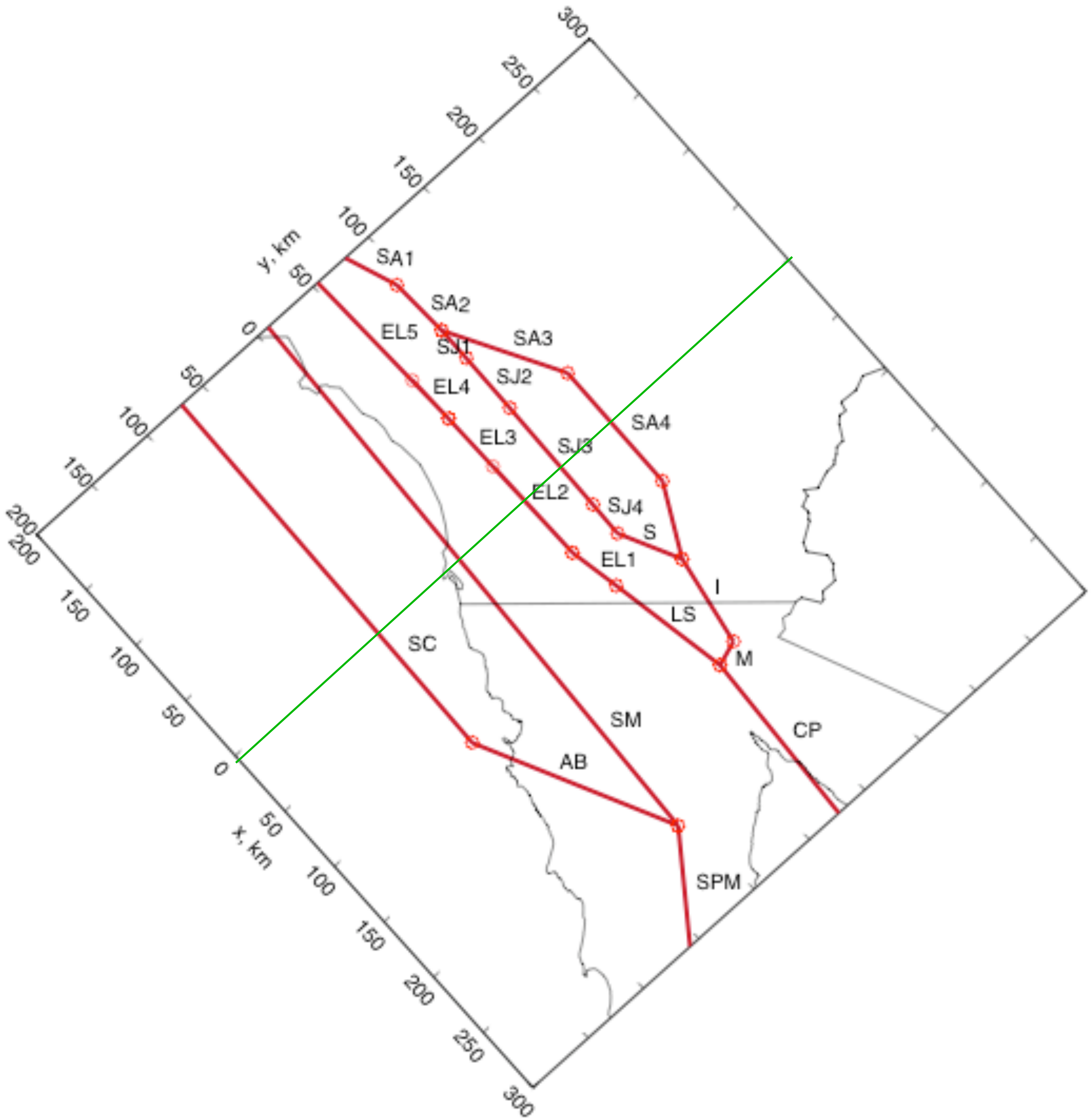
y, km
x, km
SA1
SA2
SA3
SA4
EL1
EL2
EL3
EL4
EL5
SJ1
SJ2
SJ3
SJ4
S
I
LS
M
CP
SC
SM
AB
SPM
0
50
100
150
200
250
300

Fault or Fault Segment	Symbol	Year of Last Event	Time Interval Since Last Event	Source (Last event)	Slip Rate Parallel (mm/yr)	Slip Rate Perpendicular (mm/yr, convergence negative)	Locking Depth (km)	Source (Slip rates, locking depth)	Slip Deficit Parallel (m)	Slip Deficit Perpendicular (m, convergence negative)
San Andreas-Mojave	SA1	1857	147	Cramer et al, 2000	33	-12	12	Bennett et al, 1996	4.9	-1.8
San Andreas-San Bernardino NW	SA2	1812	192	"	35	0	12	"	6.7	0.0
San Andreas-San Bernardino SE	SA3	1812	192	"	22	-13	12	"	4.2	-2.5
San Andreas-Coachella	SA4	1690	314	"	26	0	12	"	8.2	0.0
San Jacinto-San Bernardino	SJ1	1890	114	"	9	0	7.5	"	1.0	0.0
San Jacinto-San Jacinto Valley	SJ2	1918	86	"	9	0	7.5	"	0.8	0.0
San Jacinto-Anza	SJ3	1750	254	"	9	0	7.5	"	2.3	0.0
San Jacinto-Borrego Mountain	SJ4	1968	36	"	9	0	7.5	"	0.3	0.0
Superstition Mountains	S	1430	574	"	8	-5	7.5	"	4.6	-2.9
Imperial	I	1979	25	"	35	0	7.5	"	0.9	0.0
Brawley	B	1981	23	NEIC	23	12	7.5	"	0.5	0.3
Laguna Salada	LS	1892	112	Cramer et al, 2000	6	-1	7.5	"	0.7	-0.1
Elsinore-Coyote Mountain	EL1	1892	112	"	6	0	7.5	"	0.7	0.0
Elsinore-Julian	EL2	1892	112	"	6	0	7.5	"	0.7	0.0
Elsinore-Termecula	EL3	1818	186	"	6	0	7.5	"	1.1	0.0
Elsinore-Glen Ivy	EL4	1910	94	"	6	0	7.5	"	0.6	0.0
Elsinore-NW extension	EL5	???	200	Unknown, assumed	6	0	7.5	"	1.2	0.0
Mexicali	M	???	200	"	16	31	6	"	3.2	6.2
San Miguel	SM	???	200	"	3	0	12	"	0.6	0.0
San Clemente	SC	???	200	"	4	0	12	"	0.8	0.0
Agua Blanca	AB	???	200	"	4	-2	12	"	0.8	-0.4
San Pedro Martir	SPM	???	200	"	5	5	12	"	1.0	1.0
Cerro Prieto	CP	???	200	"	42	0	6	"	8.4	0.0

Examples of Estimated Slip Deficits

Fault Segment	Last Event	Time Interval (yr)	Slip Rate (mm/yr)	Slip Deficit (m)
San Andreas-Coachella	1690	314	26	8.2
San Jacinto-Anza	1750	254	9	2.3
Elsinore-Julian	1892	112	6	0.7
San Miguel	???	200???	3	0.6
San Clemente	???	200???	4	0.8

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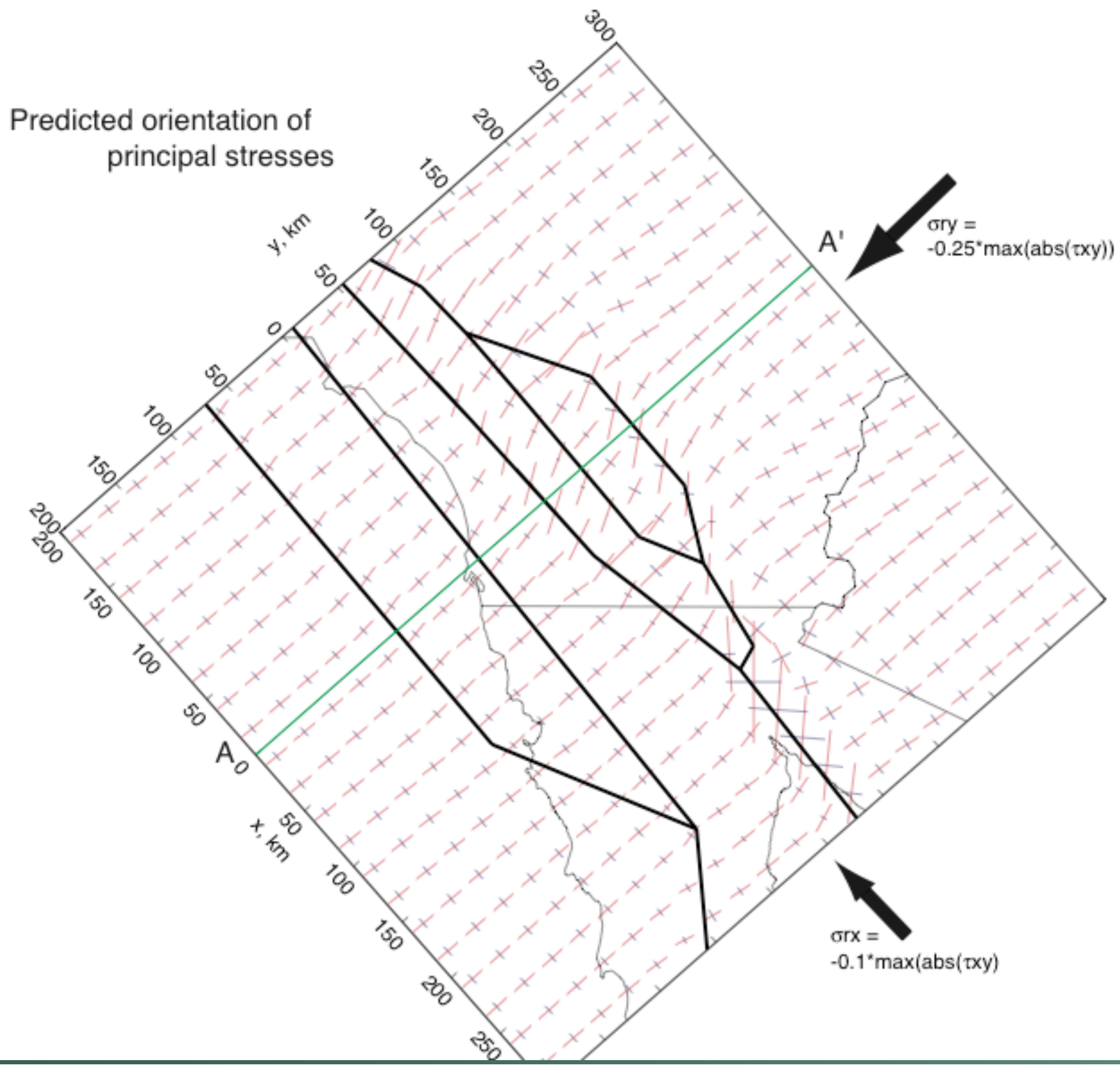
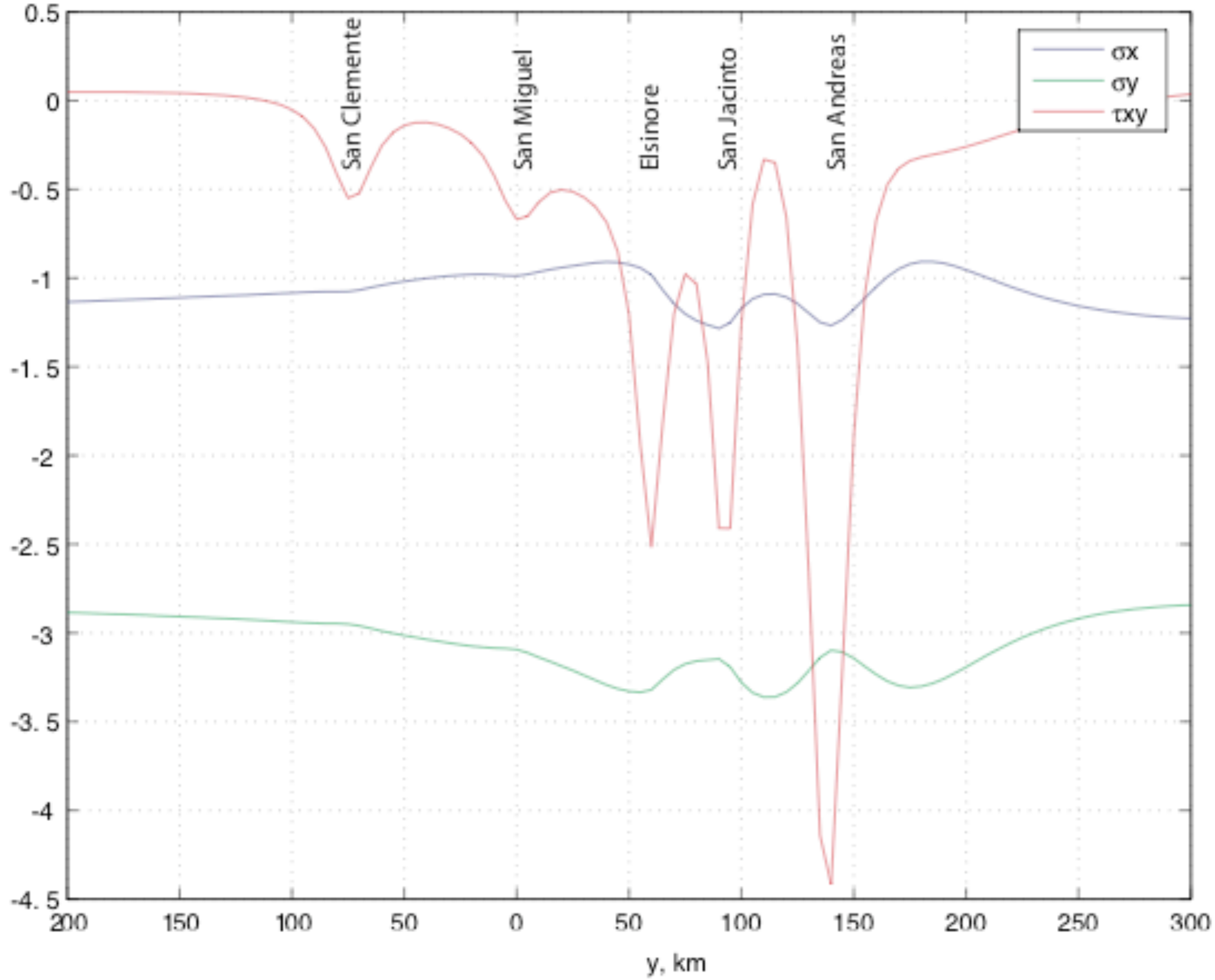
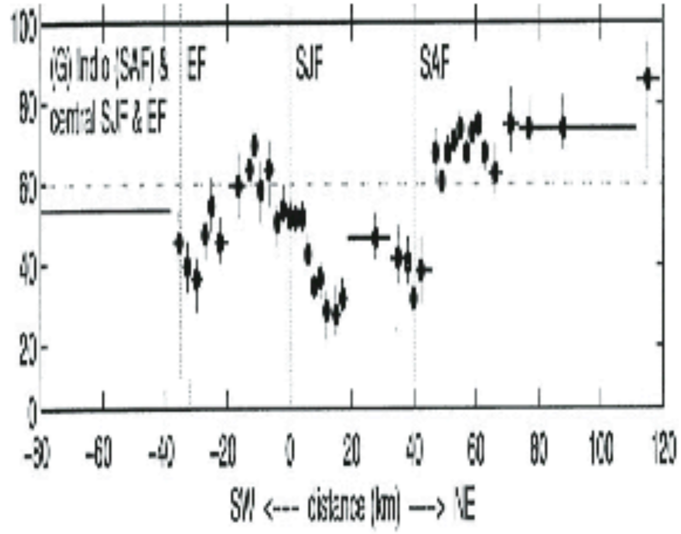


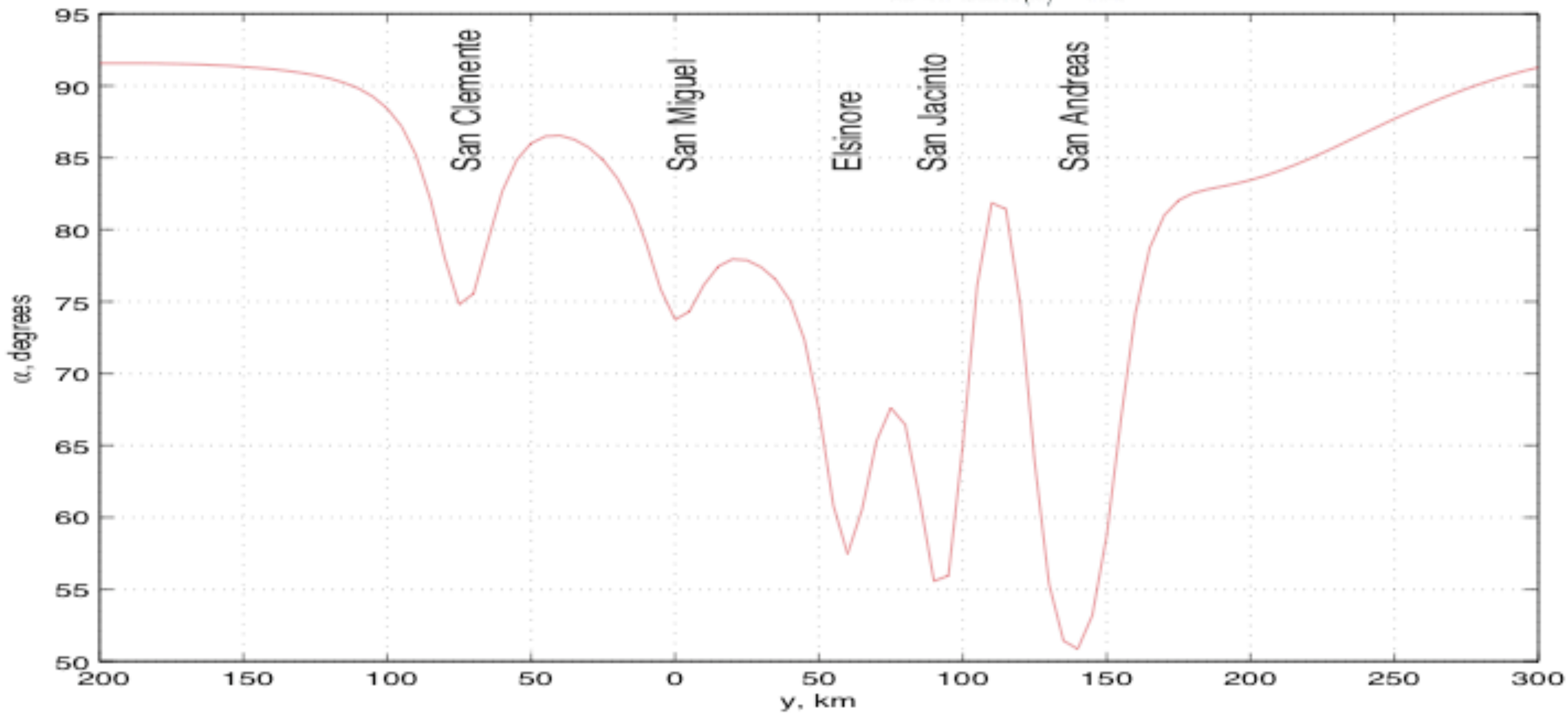
Predicted orientation of principal stresses
σry =
-0.25*max(abs(τxy))
σrx =
-0.1*max(abs(τxy)
A'
A
y, km
x, km



San Clemente
San Miguel
Elsinore
San Jacinto
San Andreas
σx
σy
τxy
0.5
0
-0. 5
-1
-1. 5
-2
-2. 5
-3
-3. 5
-4
-4. 5
200
150
100
50
0
50
100
150
200
250
300
y, km

(Data from Hardebeck and Hauksson, 1999)





Conclusion

- Stress orientation offers promise for use in estimating or confirming estimates of slip deficit

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