APPLYING GEODESY TO GEOSCIENCE 2

Donald Argus
Jet Propulsion Laboratory
California Institute of Technology

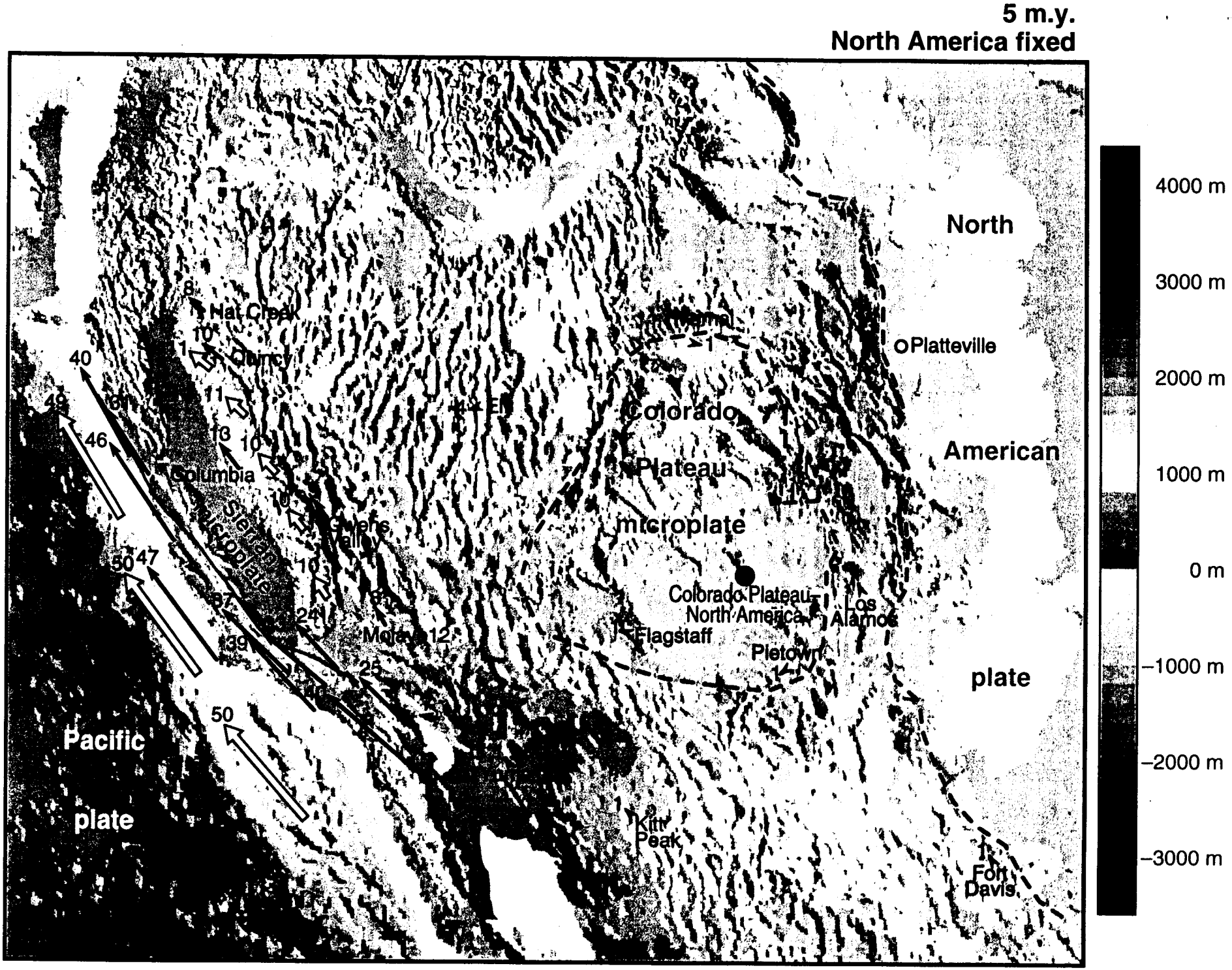
PART 1
Mountain Building
Along San Andreas Fault

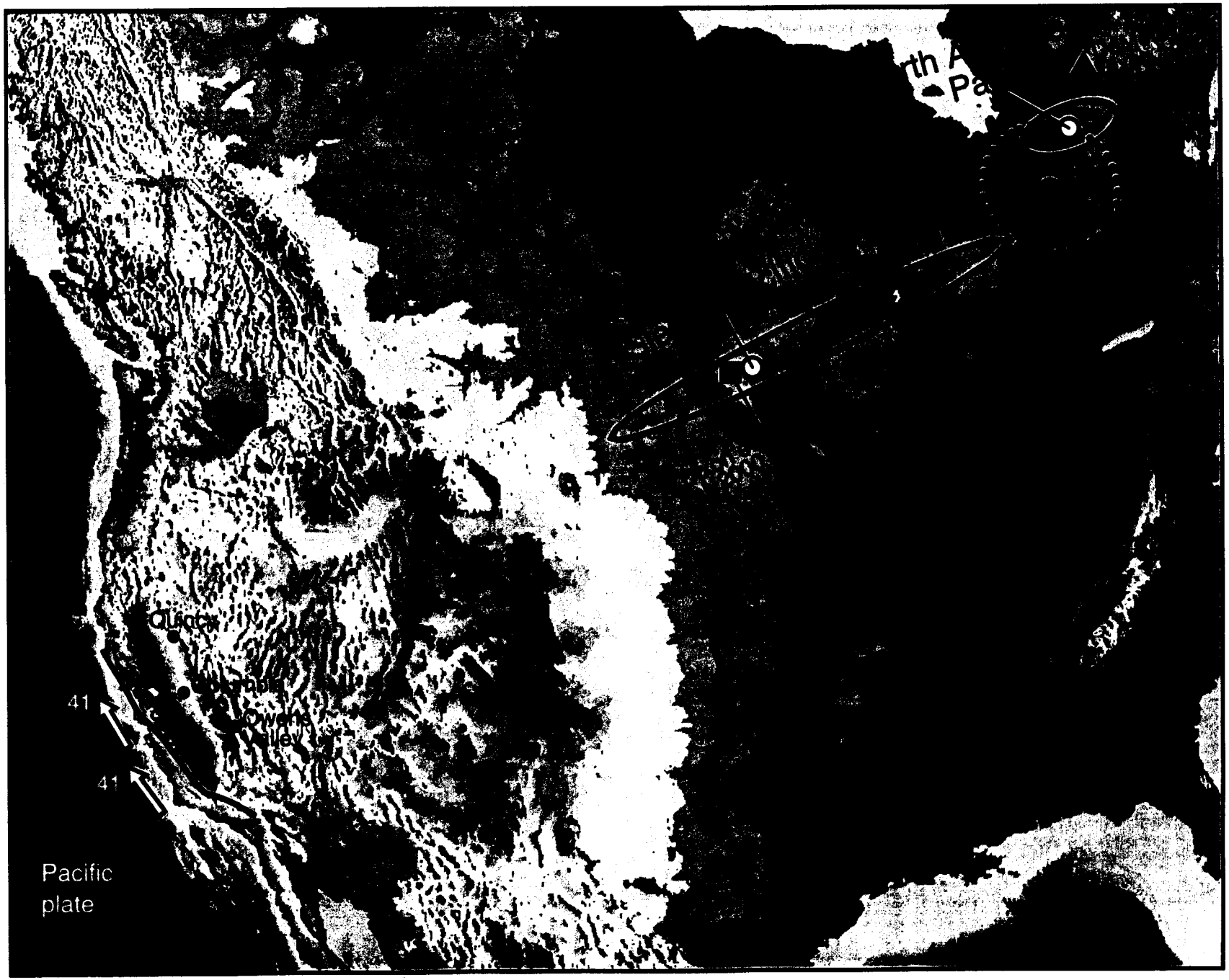
PART 2
Elastic Microplate Model
of Southern California
San Andreas Fault
Strain Accumulation

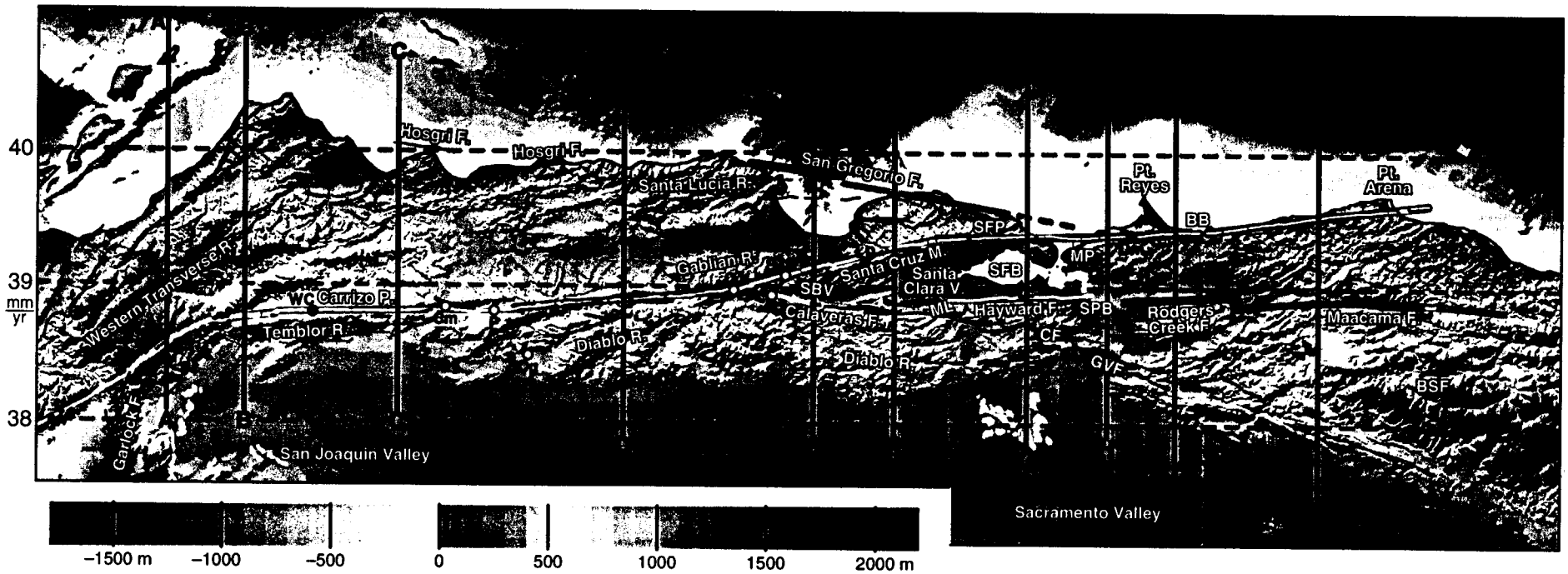
PART 3
Los Angeles Metropolis
Shortening and Thickening
Thrust Fault Strain Accumulation
Aquifers and Oil Fields

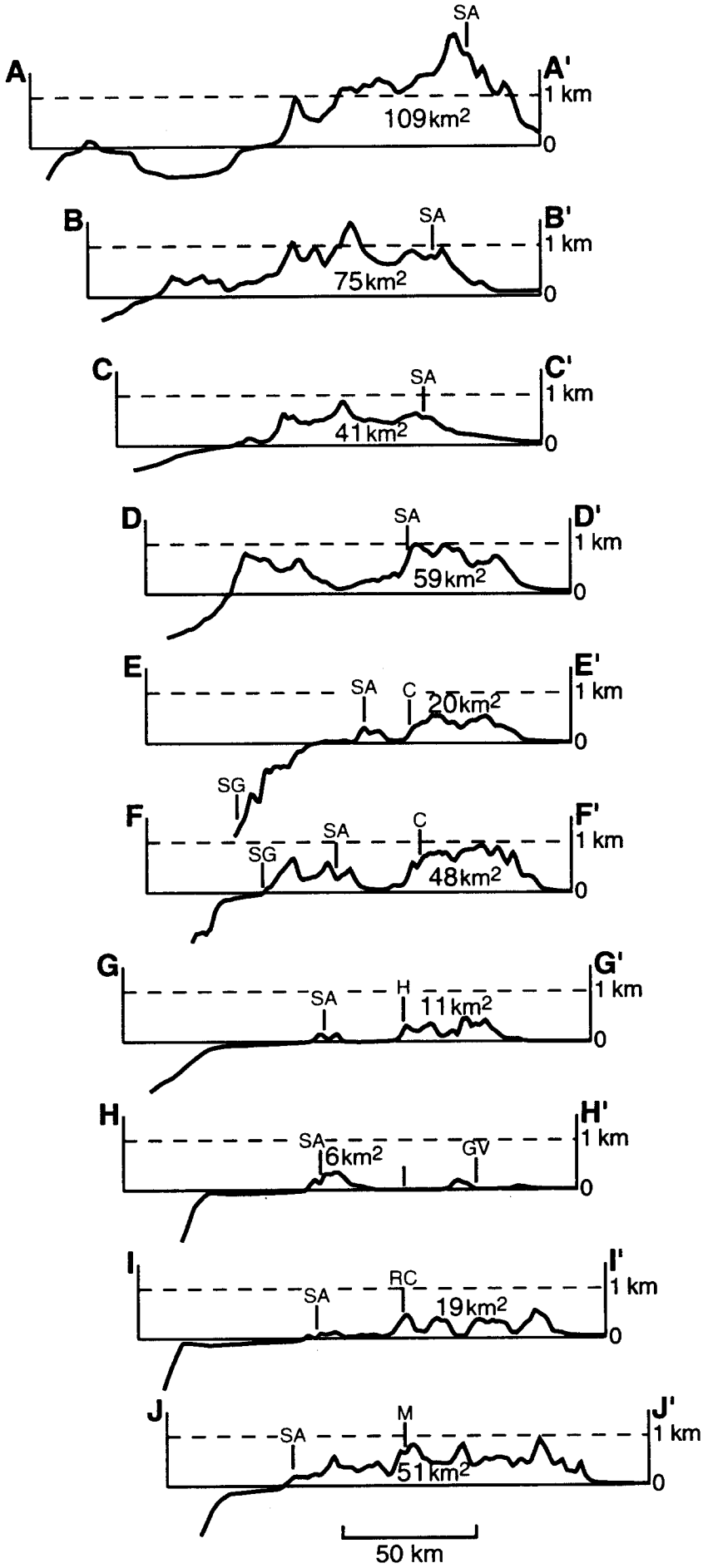
Earthquake Research Institute 27 August 2002

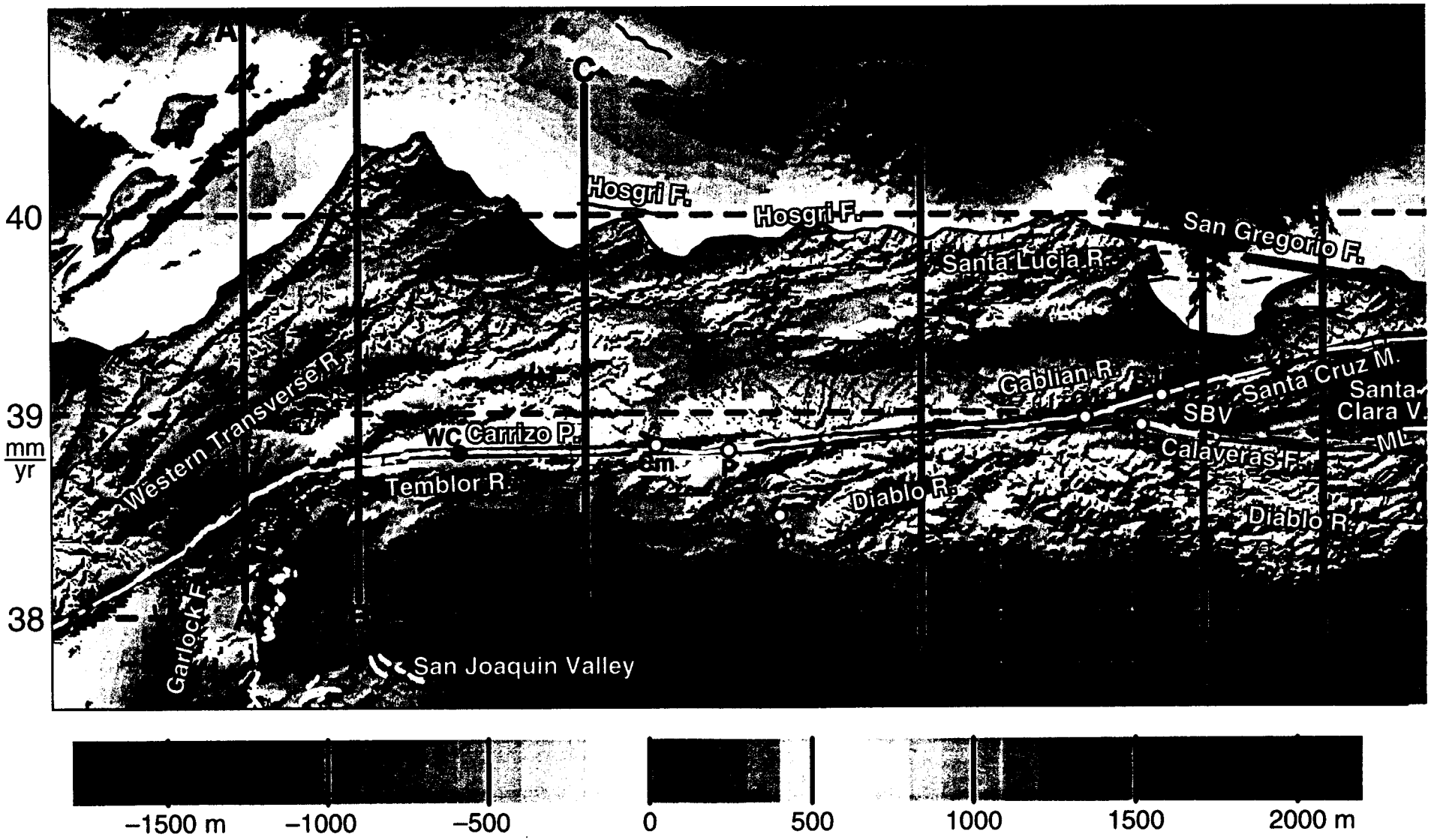
PART 1
Mountain Building Along San Andreas Fault

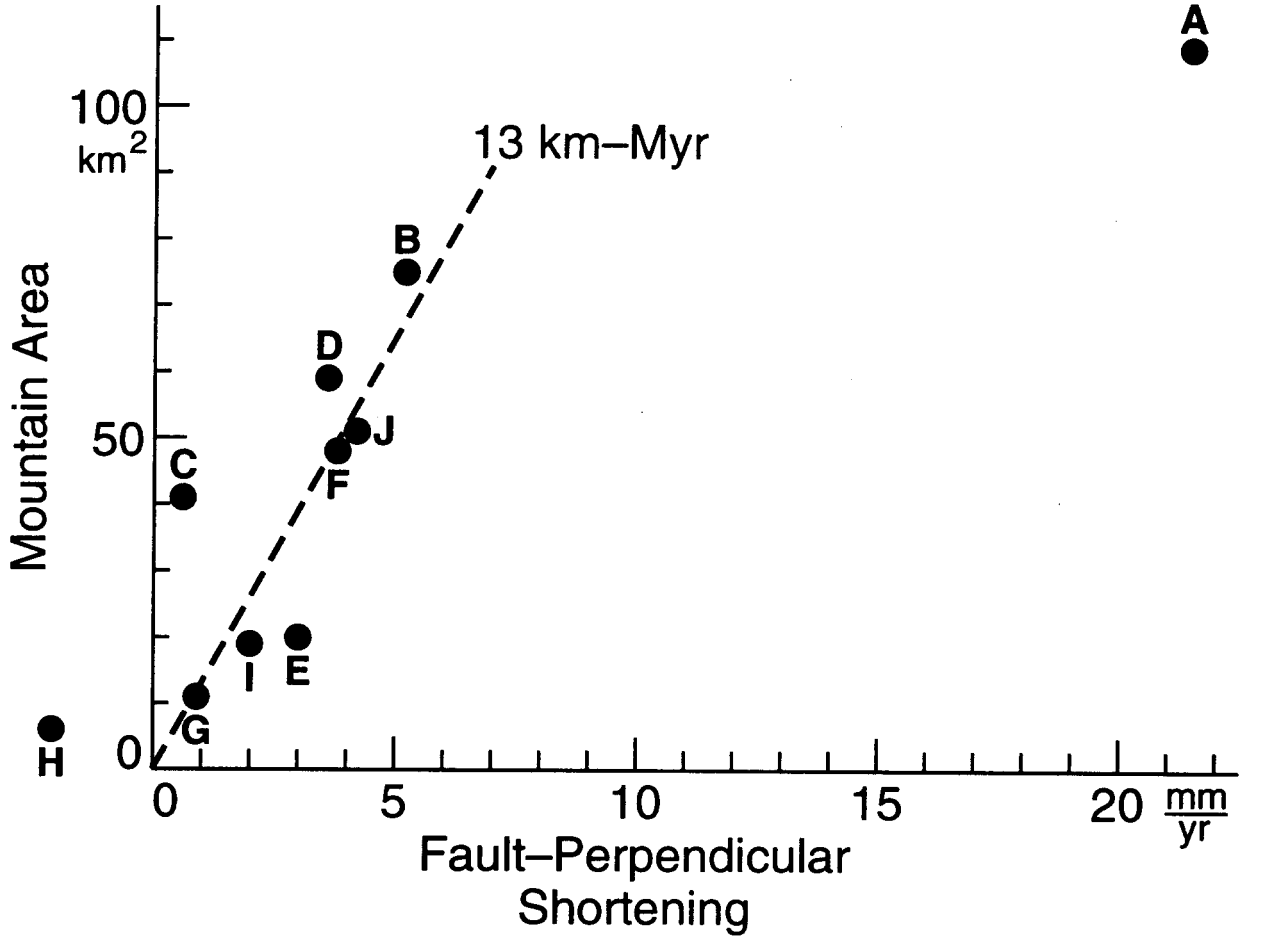

5 m.y.
North America fixed
North
American
plate
Platteville
Colorado
Plateau
microplate
Colorado Plateau
North America
Los
Alamos
Flagstaff
Pietown
Kitt
Peak
Fort
Davis
Hat Creek
Quincy
Columbia
Sierran
microplate
Gwens
Valley
Mojave
Pacific
plate
40
49
46
50
47
50
8
10
11
13
10
10
10
24
25
39
37
4000 m
3000 m
2000 m
1000 m
0 m
−1000 m
−2000 m
−3000 m

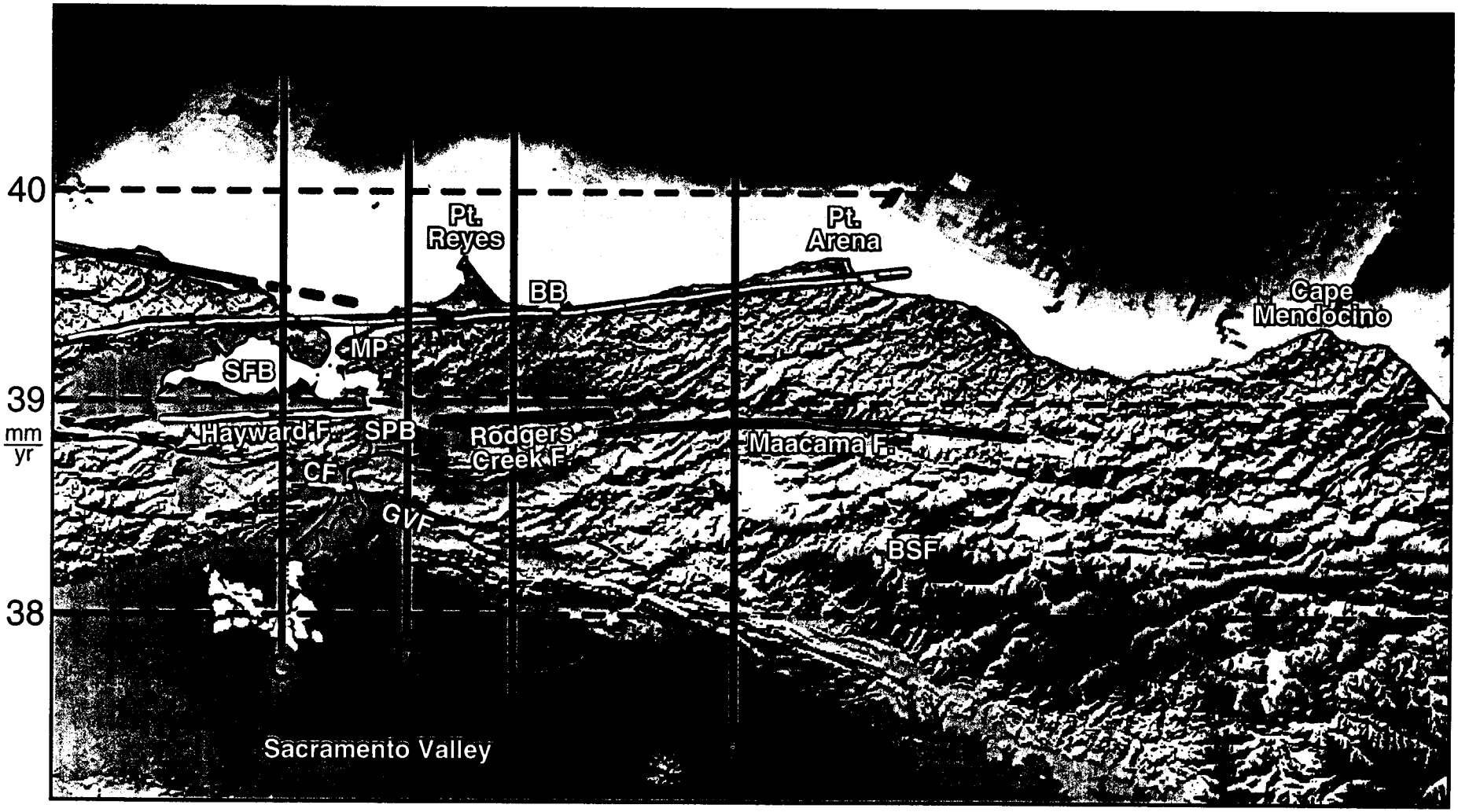

41
41
Pacific
plate

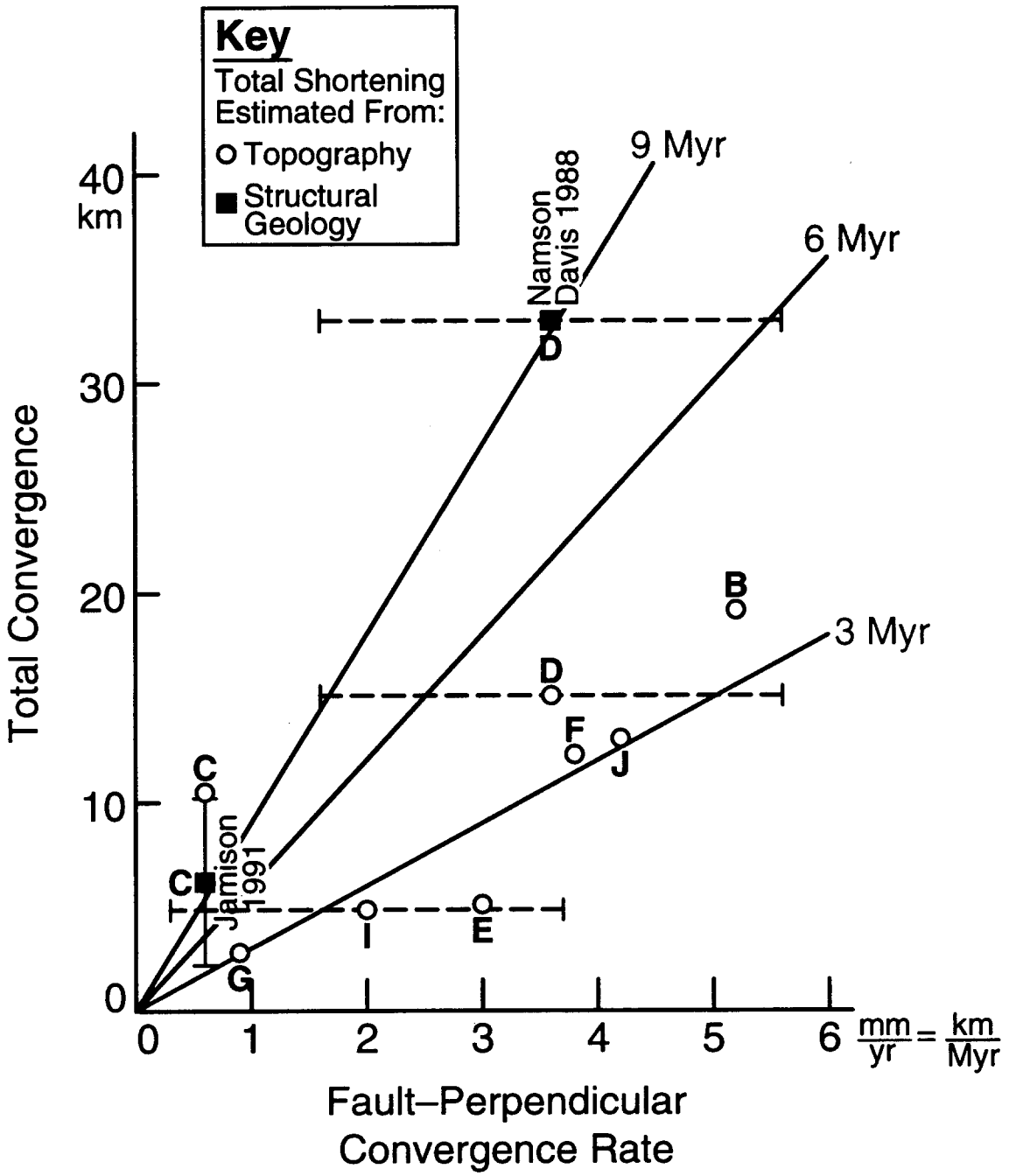

40
39
mm/yr
38
Hosgri F.
Hosgri F.
San Gregorio F.
Santa Lucia R.
Pt. Reyes
Pt. Arena
BB
SFP
MP
SFB
Santa Cruz M.
Santa Clara V.
Gablian R.
SBV
Calaveras F.
ML
Hayward F.
SPB
CF
GVF
Rodgers Creek F.
Maacama F.
BSF
Western Transverse R.
WC
Carrizo P.
Temblor R.
Diablo R.
Diablo R.
Garlock F.
San Joaquin Valley
Sacramento Valley
−1500 m
−1000
−500
0
500
1000
1500
2000 m


A
A'
SA
1 km
109km2
0
B
B'
SA
1 km
75km2
0
C
C'
SA
1 km
41km2
0
D
D'
SA
1 km
59km2
0
E
E'
SA
C
1 km
20km2
0
SG
F
F'
SA
C
SG
1 km
48km2
0
G
G'
SA
H
1 km
11km2
0
H
H'
SA
1 km
6km2
GV
0
I
I'
RC
SA
1 km
19km2
0
J
J'
M
SA
1 km
51km2
0
50 km

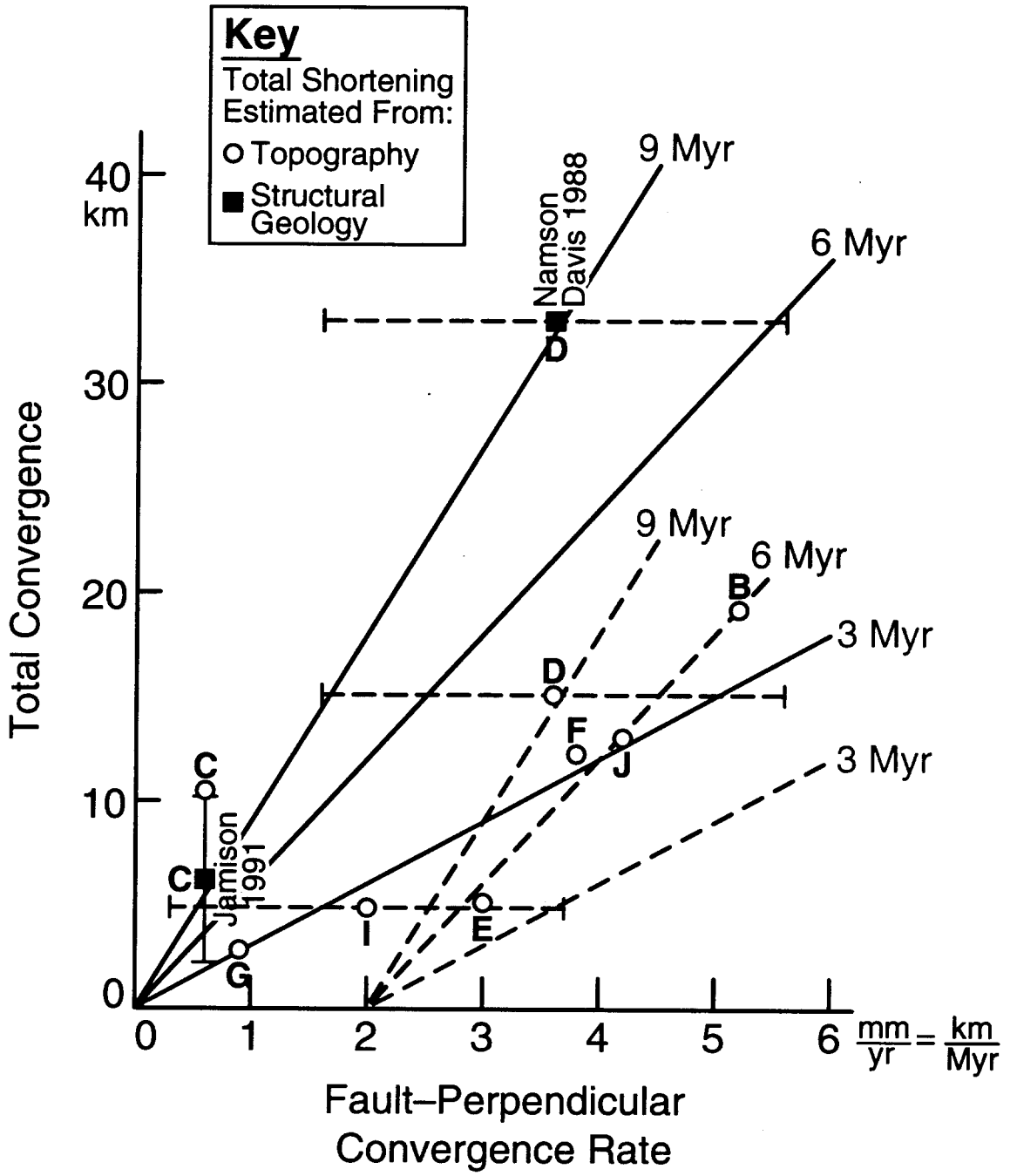

A
B
C
40
39
38
mm
yr
Hosgri F.
Hosgri F.
San Gregorio F.
Santa Lucia R.
Western Transverse R.
Gablian R.
Santa Cruz M.
Santa
Clara V.
SBV
ML
Wc Carrizo P.
Calaveras F.
Temblor R.
Diablo R.
Diablo R.
Garlock F.
San Joaquin Valley
−1500 m
−1000
−500
0
500
1000
1500
2000 m


A
100
km²
13 km–Myr
B
D
J
50
C
F
I
E
G
H
0
Mountain Area
0
5
10
15
20
mm/yr
Fault–Perpendicular
Shortening

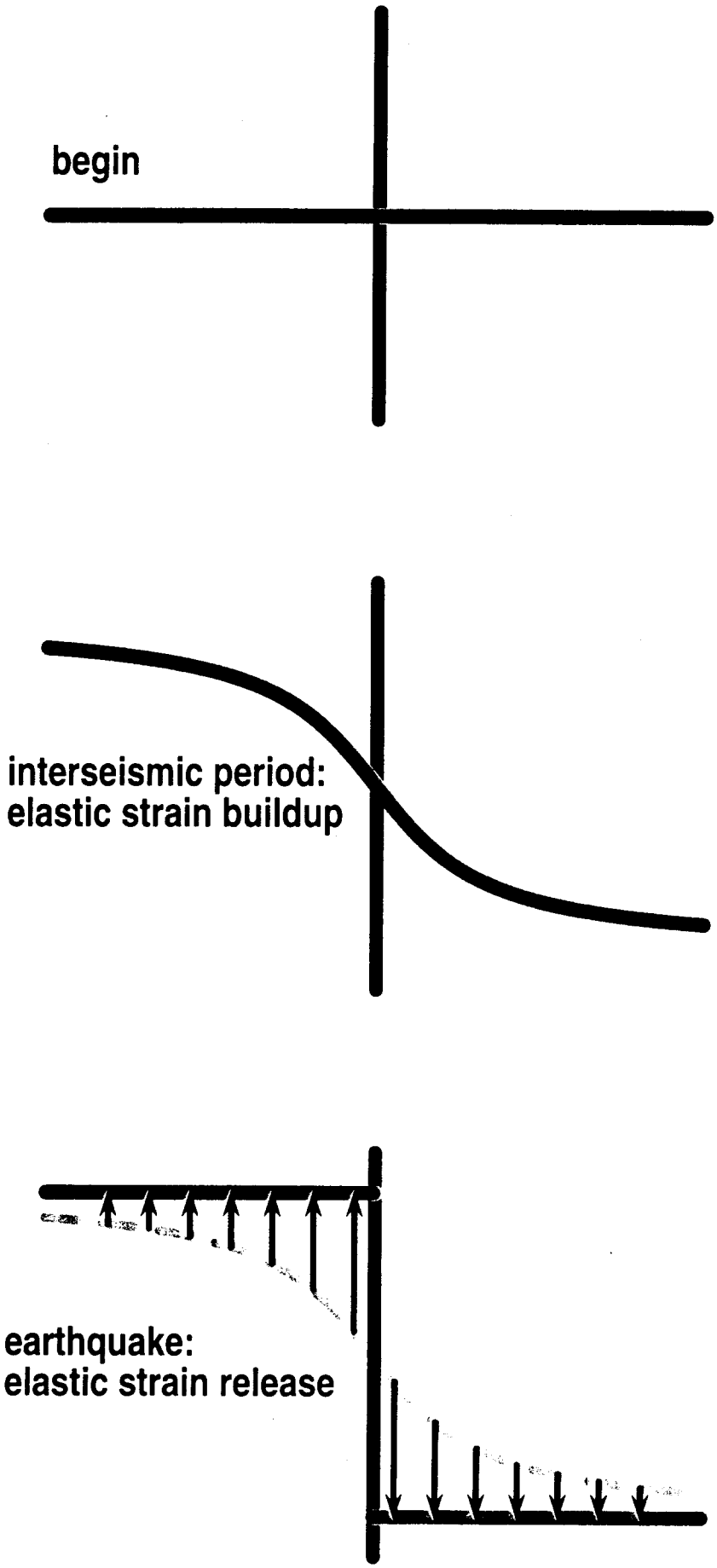

40
39
mm/yr
38
Pt. Reyes
Pt. Arena
BB
Cape Mendocino
MP
SFB
Hayward F.
SPB
Rodgers Creek F.
Maacama F.
CF
GVF
BSF
Sacramento Valley



Key
Total Shortening Estimated From:
Topography
Structural Geology
9 Myr
6 Myr
3 Myr
Namson Davis 1988
Jamison 1991
Total Convergence
40 km
30
20
10
0
0
1
2
3
4
5
6
mm/yr = km/Myr
Fault–Perpendicular Convergence Rate
B
C
D
E
F
G
I
J

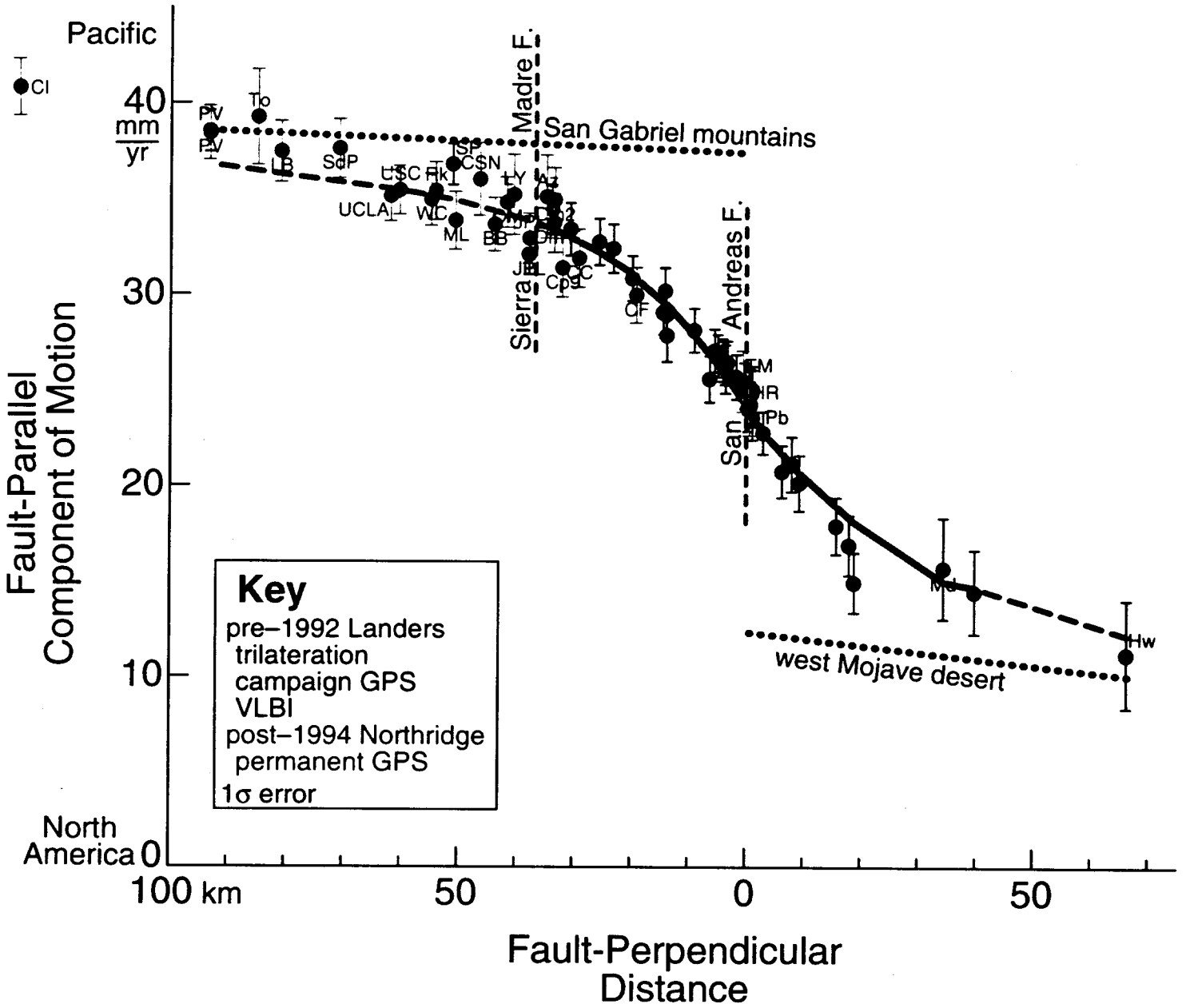

Key
Total Shortening Estimated From:
Topography
Structural Geology
Total Convergence
40 km
30
20
10
0
0
1
2
3
4
5
6
mm/yr = km/Myr
Fault–Perpendicular Convergence Rate
9 Myr
6 Myr
3 Myr
9 Myr
6 Myr
3 Myr
Namson Davis 1988
Jamison 1991
D
B
D
F
J
C
C
I
E
G

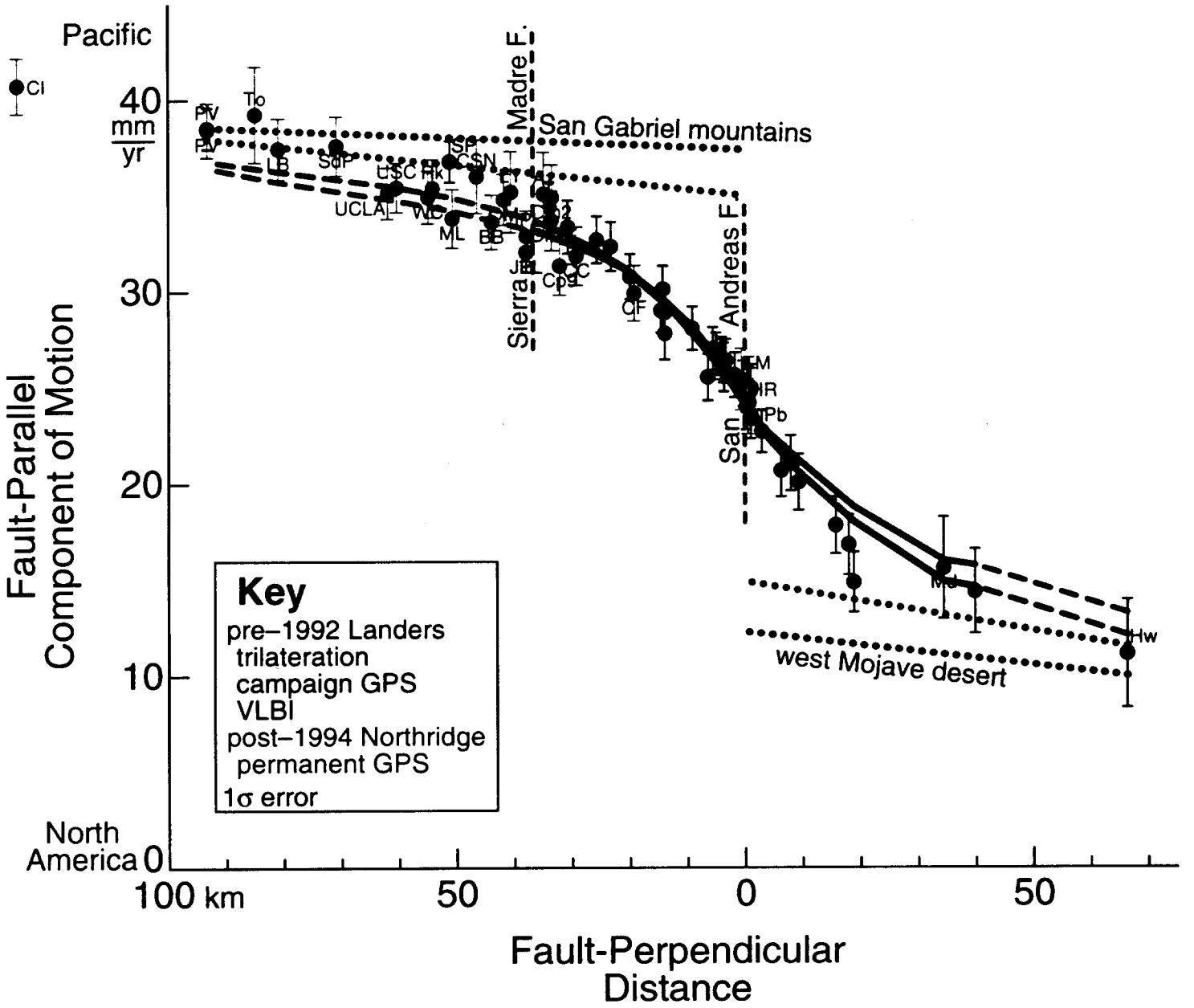
PART 2
Elastic Microplate Model of Southern California
San Andreas Fault Strain Accumulation

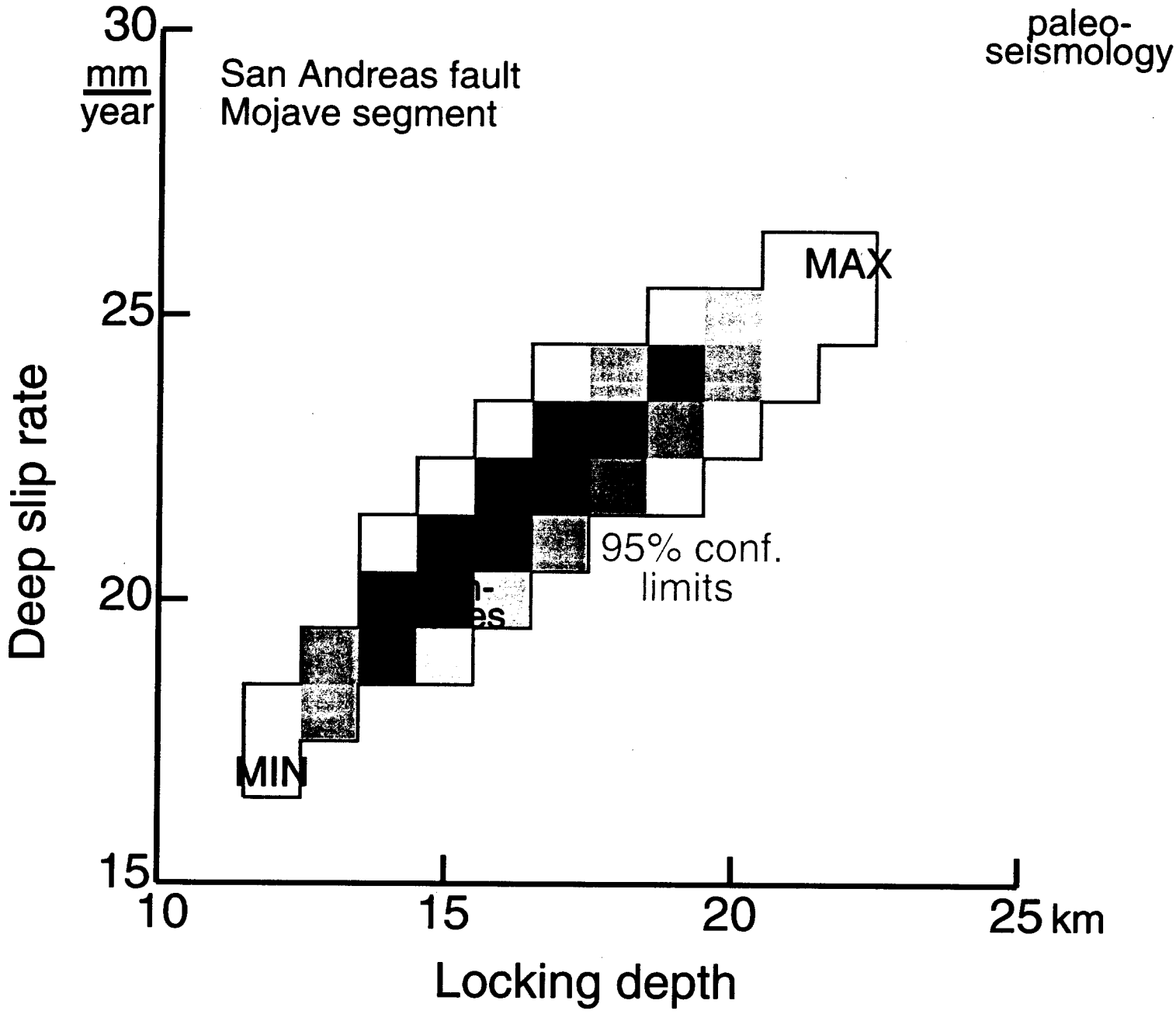

begin
interseismic period:
elastic strain buildup
earthquake:
elastic strain release

3–D Screw Dislocation Models

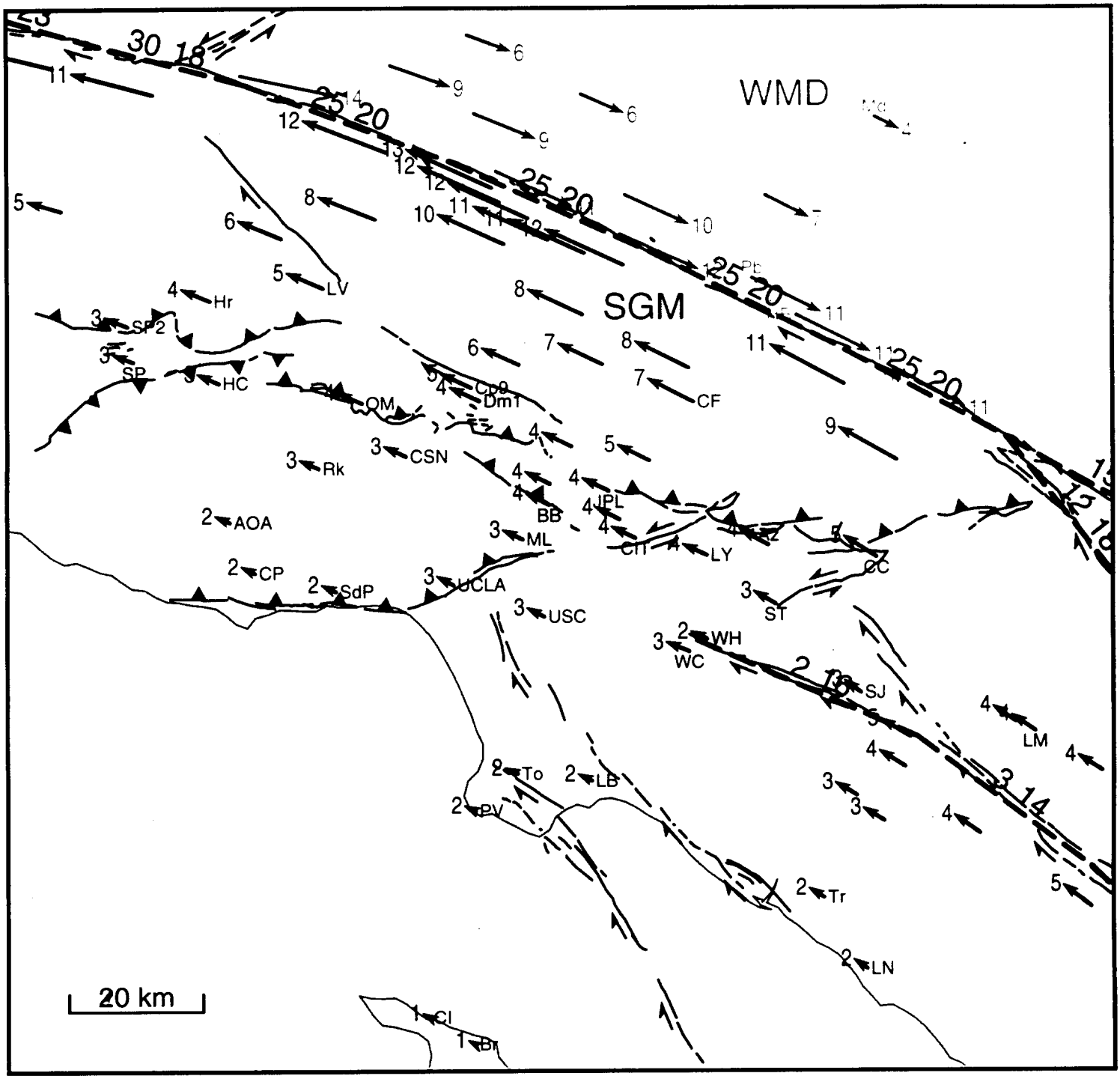
	strike slip fault	deep slip rate	locking depth
1	San Andreas	25 mm/yr	20 km
2	San Andreas	20 mm/yr	15 km


Pacific
North America
Fault-Parallel Component of Motion
mm/yr
40
30
20
10
0
100 km
50
0
50
Fault-Perpendicular Distance
San Gabriel mountains
Sierra Madre F.
San Andreas F.
west Mojave desert
Key
pre–1992 Landers
trilateration
campaign GPS
VLBI
post–1994 Northridge
permanent GPS
1σ error


Pacific
North America
Fault-Parallel Component of Motion
40
mm/yr
30
20
10
0
100 km
50
0
50
Fault-Perpendicular Distance
Madre F.
Sierra
San Andreas F.
San
San Gabriel mountains
west Mojave desert
Key
pre–1992 Landers
trilateration
campaign GPS
VLBI
post–1994 Northridge
permanent GPS
1σ error


30
mm
year
San Andreas fault
Mojave segment
paleo-
seismology
MAX
25
Deep slip rate
95% conf.
limits
20
MIN
15
10
15
20
25 km
Locking depth

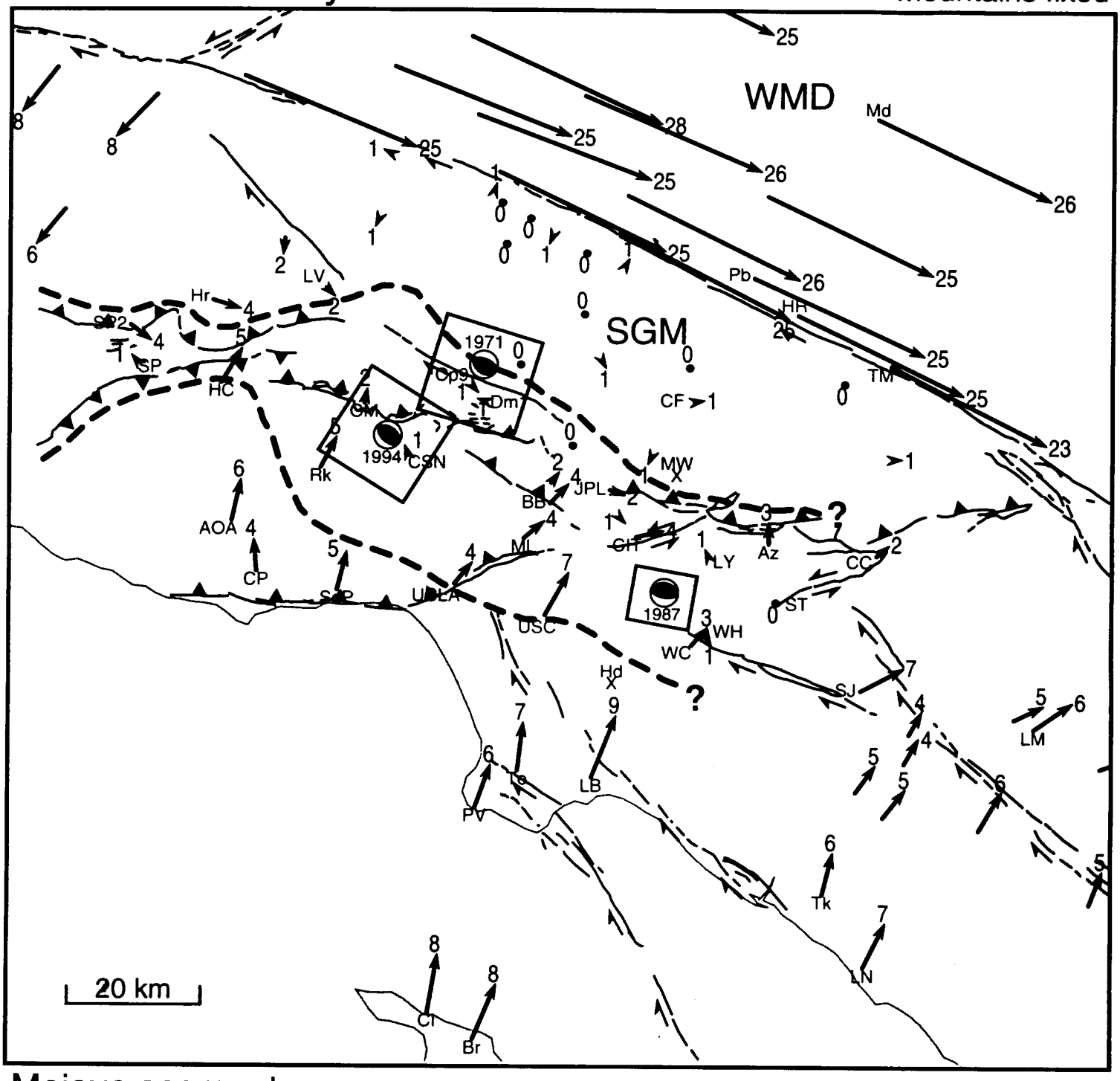
Dislocation Model



Mojave segment
San Andreas Fault
Optimal 25 mm/yr 20 km

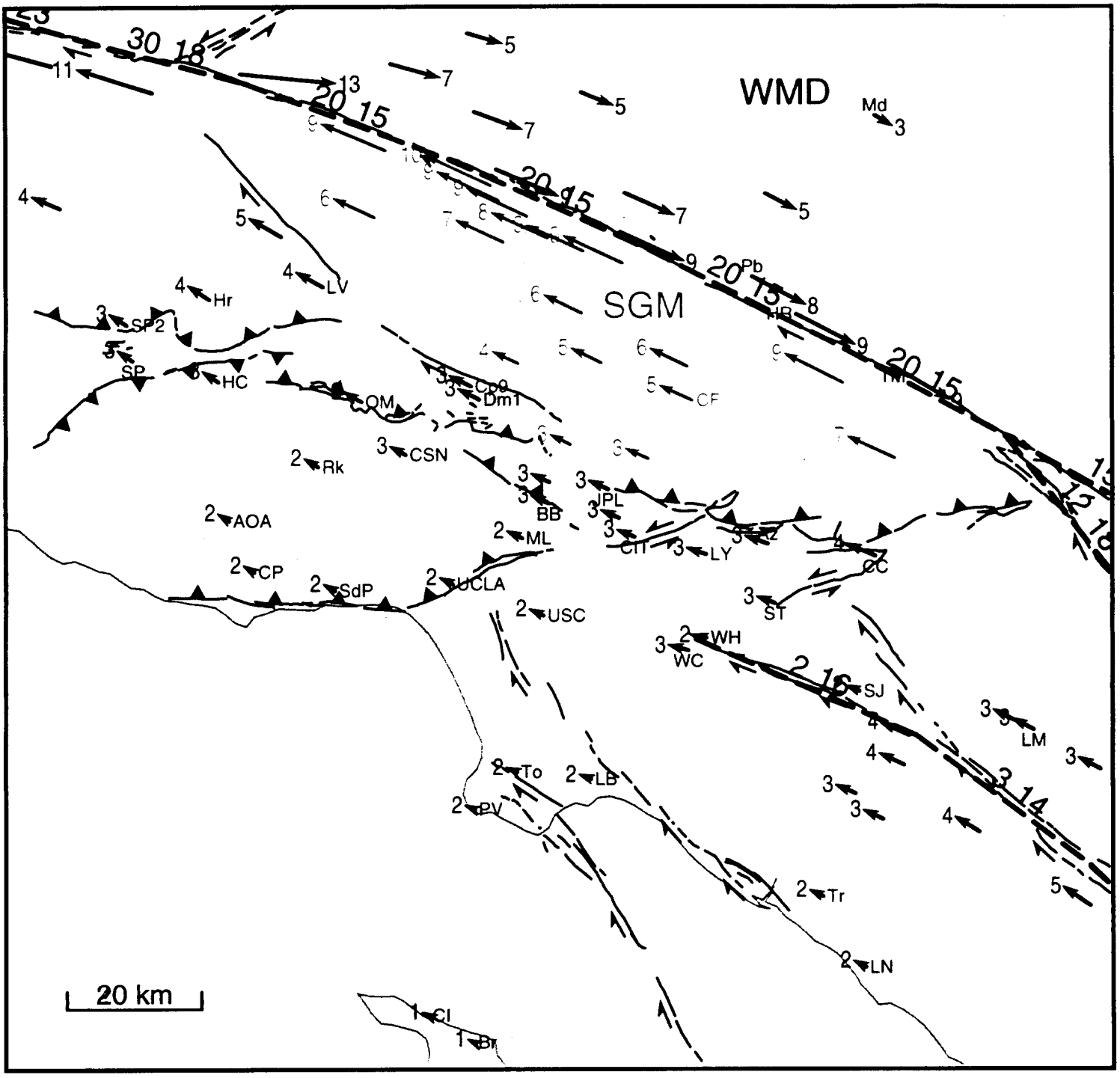
Residual Velocity Field

San Gabriel Mountains fixed



Mojave segment
San Andreas Fault
Optimal 25 mm/yr 20 km

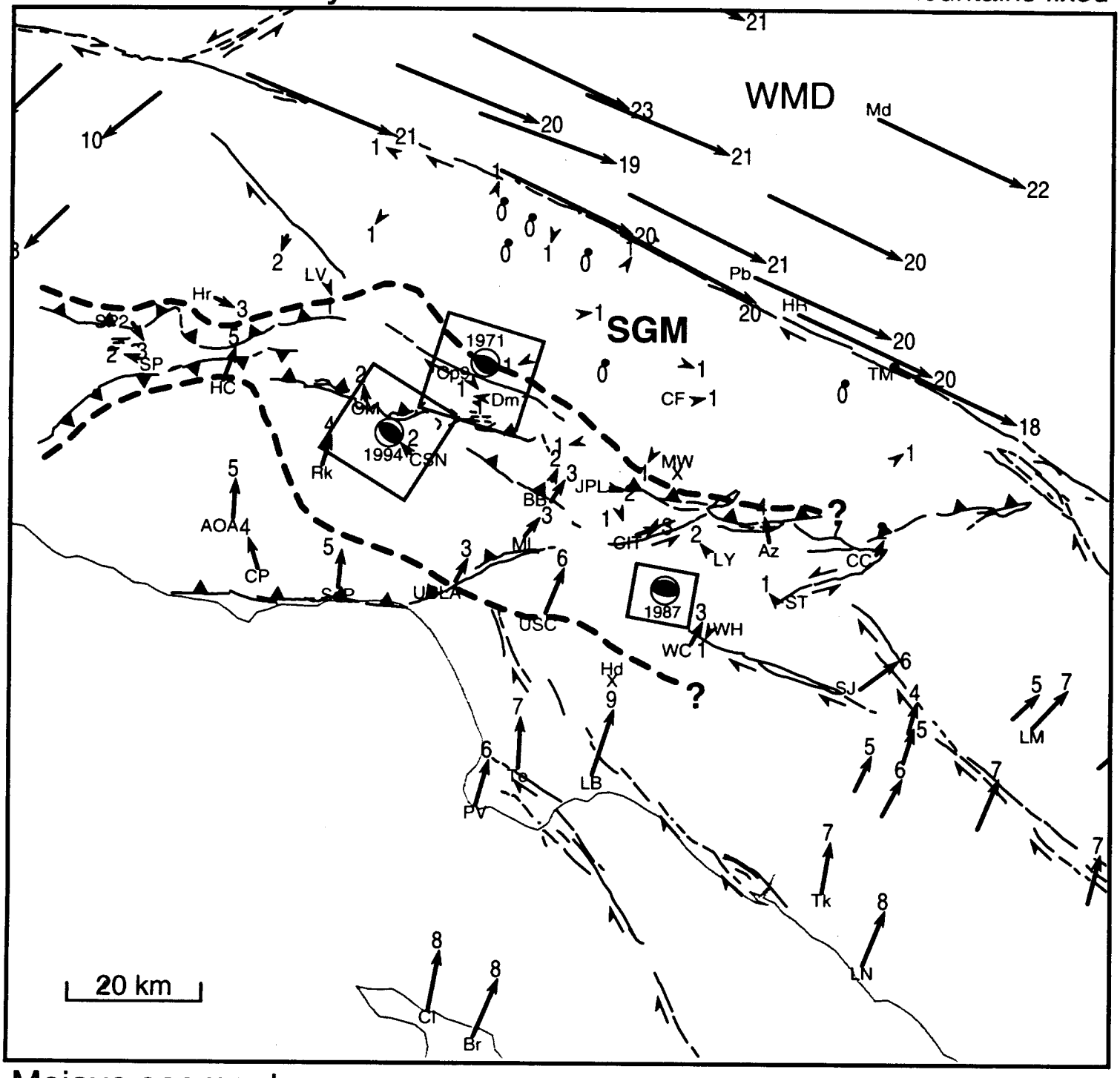
Dislocation Model



Mojave segment
San Andreas Fault
Minimum 20 mm/yr 15 km

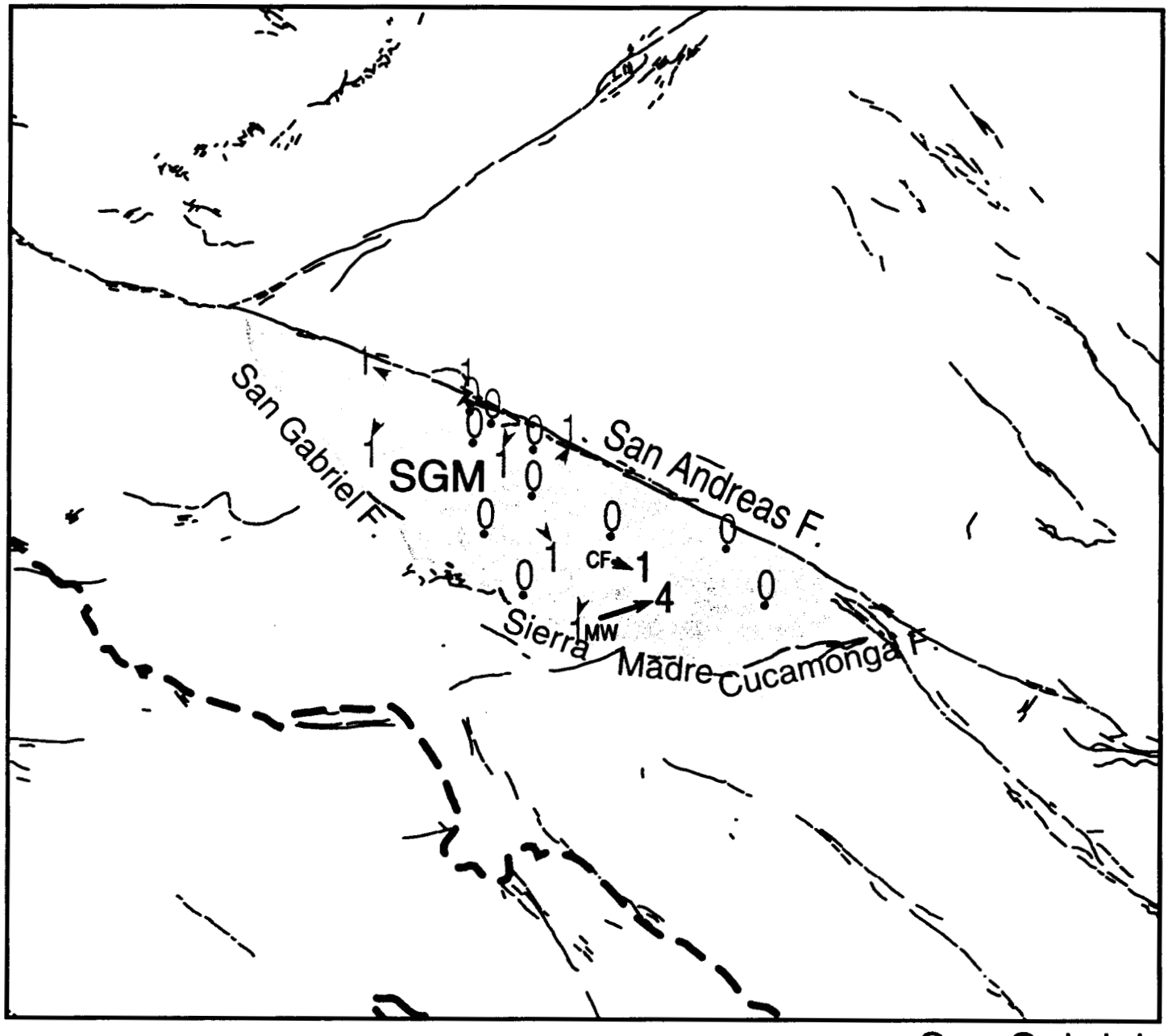
Residual Velocity Field

San Gabriel Mountains fixed



Mojave segment
San Andreas Fault
Minimum 20 mm/yr 15 km

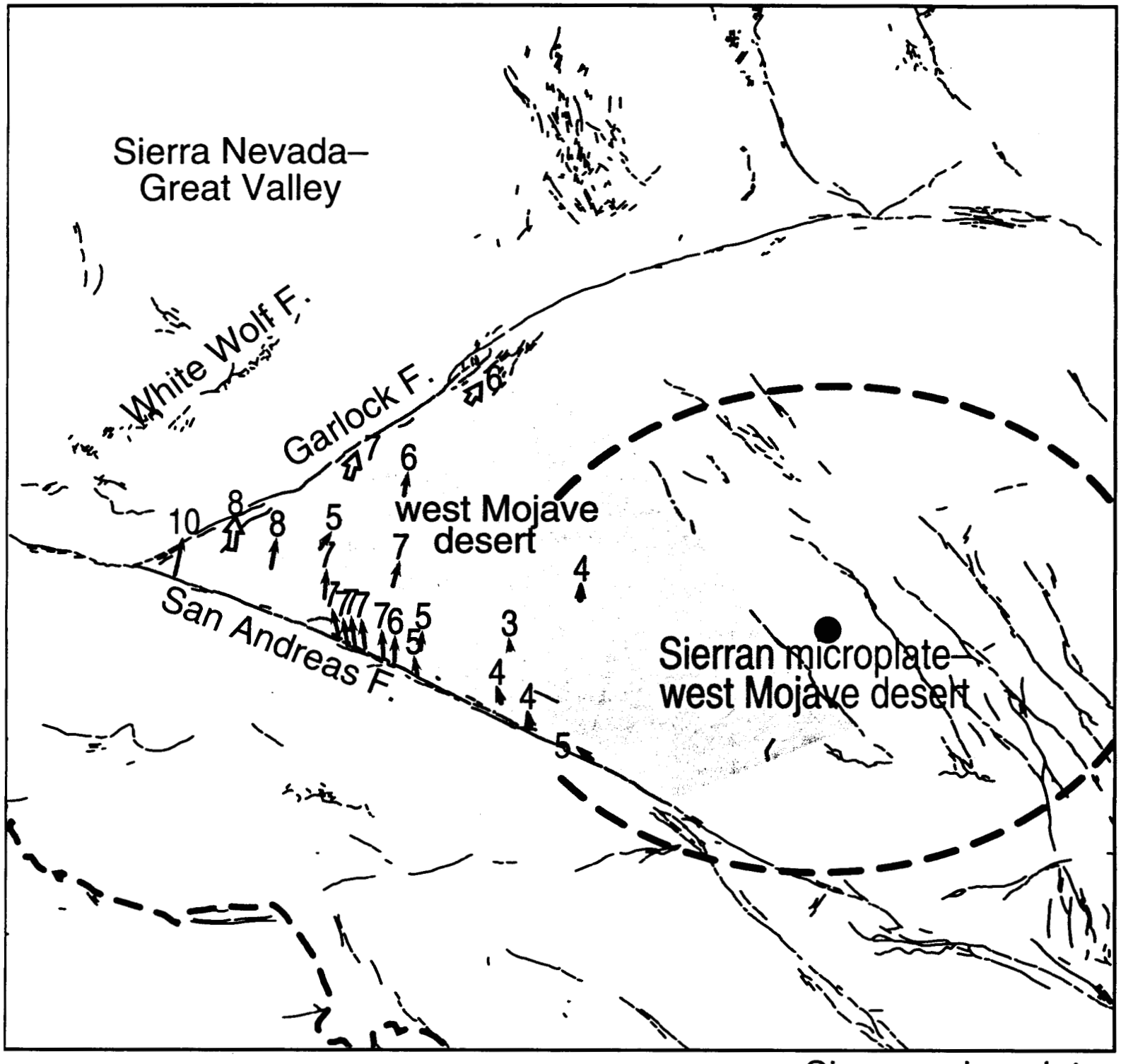
San Gabriel Mountains residuals



San Gabriel
mountains fixed

west Mojave desert–
Sierran microplate
CW 3.1 ±1.8°/Myr

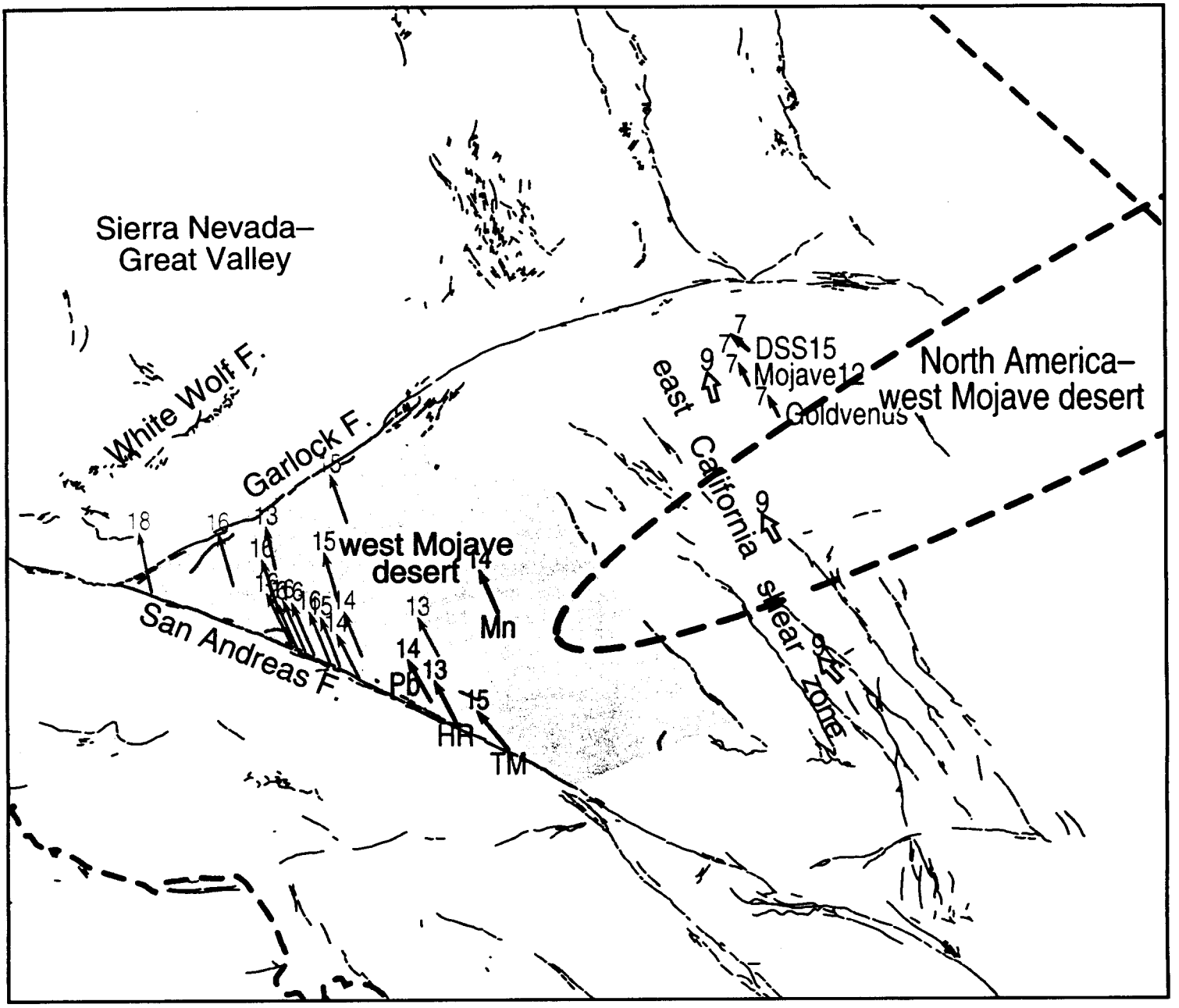
Garlock fault and
White Wolf fault



Sierran microplate
fixed

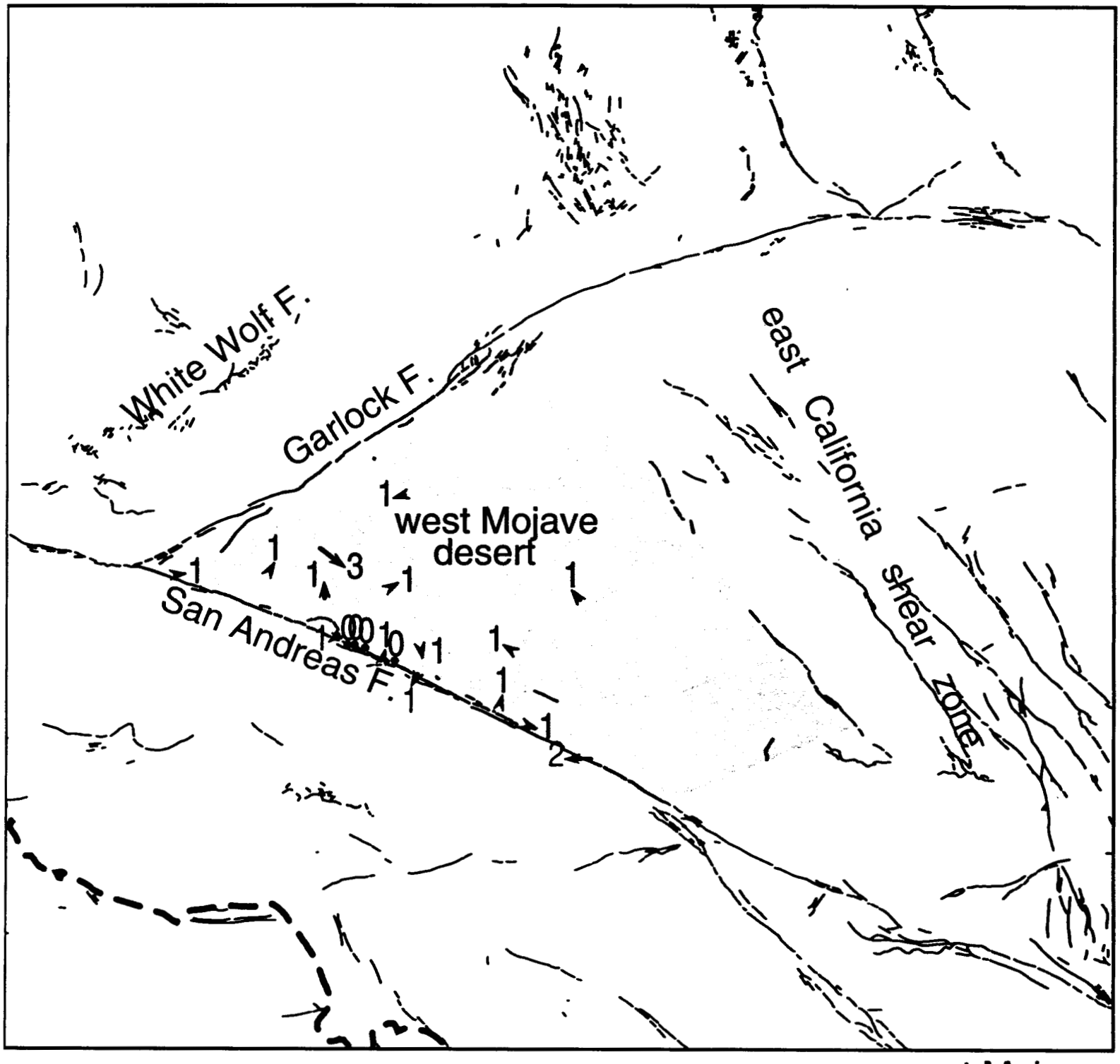
west Mojave desert–
North America
CW 2.8 ±1.8°/Myr

east California
shear zone



North America
fixed

west Mojave desert residuals



west Mojave
desert fixed

PART 3
Los Angeles Metropolis
Shortening and Thickening
Thrust Fault Strain Build Up
Aquifers and Oil Fields

oblique Mercator projection
about pole fit to Mojave
segment of San Andreas F.

residual velocity field
SGM fixed

Mojave segment, San Andreas F.
best 25 mm/yr 20 km

Residual Velocity

rel. San Gabriel Mountains

locking San Andreas F. removed

permanent GPS

after 1994 Northridge

trilateration, campaign GPS, VLBI, SLR

before 1992 Landers

95% conf. limits

San Gabriel M. rigid

San Andreas F. dextral slip

contractional belt 5 mm/yr, 10 to 40 km

Ventura basin	narrow	
San Fernando valley	wide	
Pasadena	narrow	USC
San Gabriel valley	?	

profile Puente Hills thrust

Shortening and Thickening of Metropolitan Los Angeles

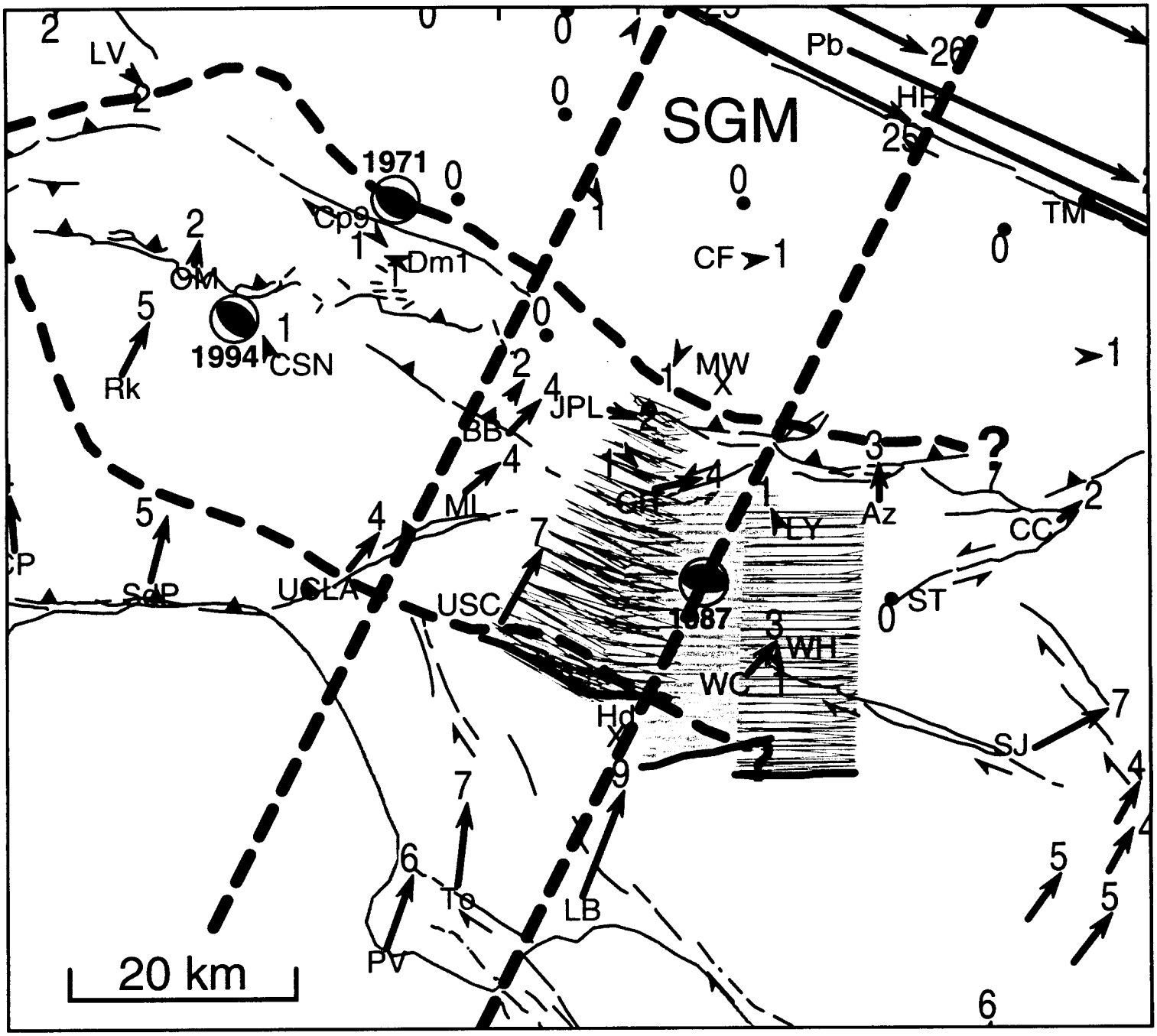
Residual Velocity Field

San Gabriel Mountains fixed

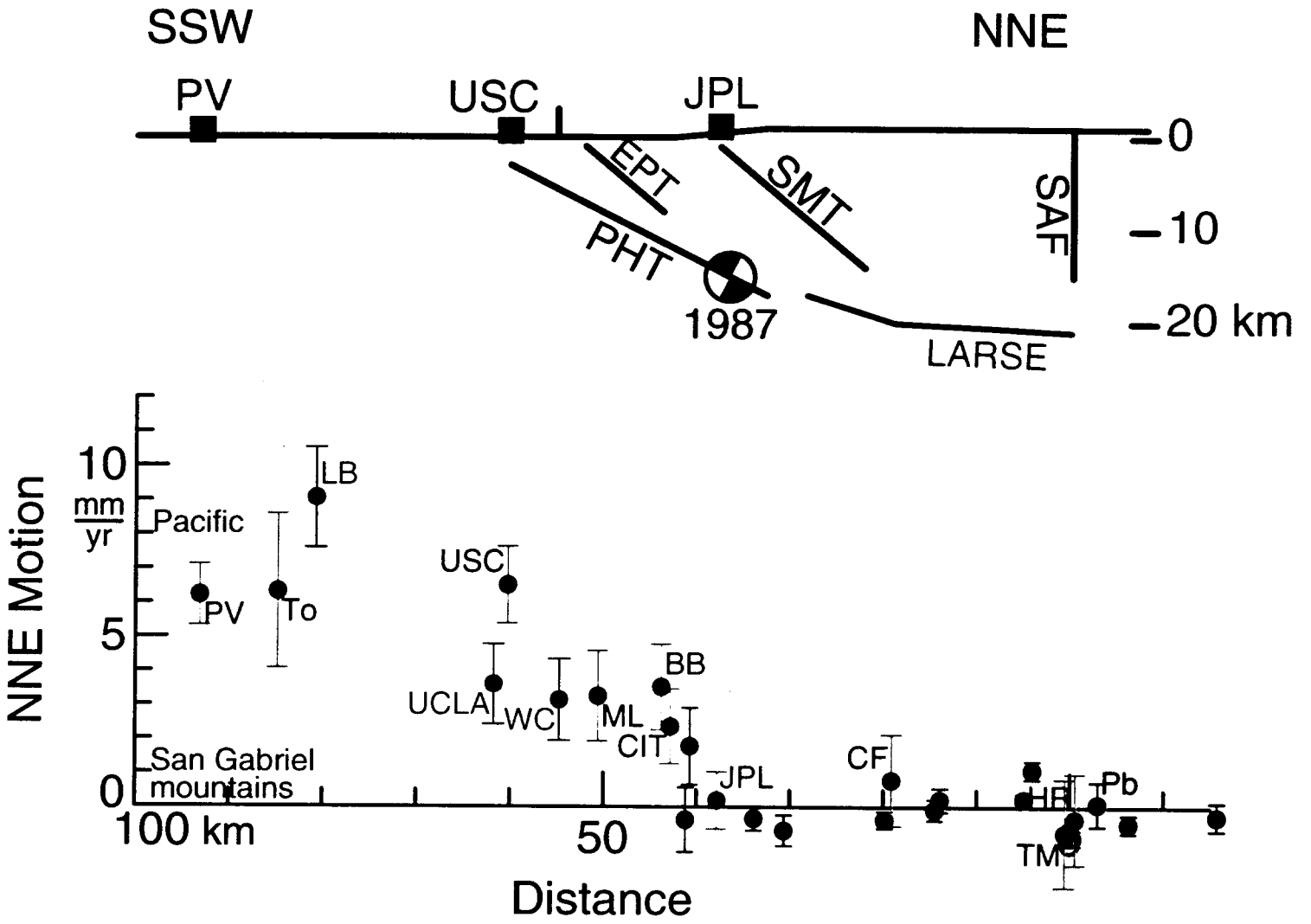
Mojave segment
San Andreas Fault
Optimal 25 mm/yr 20 km

Residual Velocity Field

San Gabriel
Mountains fixed



Mojave segment
San Andreas Fault
Optimal 25 mm/yr 20 km



pre–1992 Landers trilateration campaign GPS VLBI

post–1994 Northridge permanent GPS

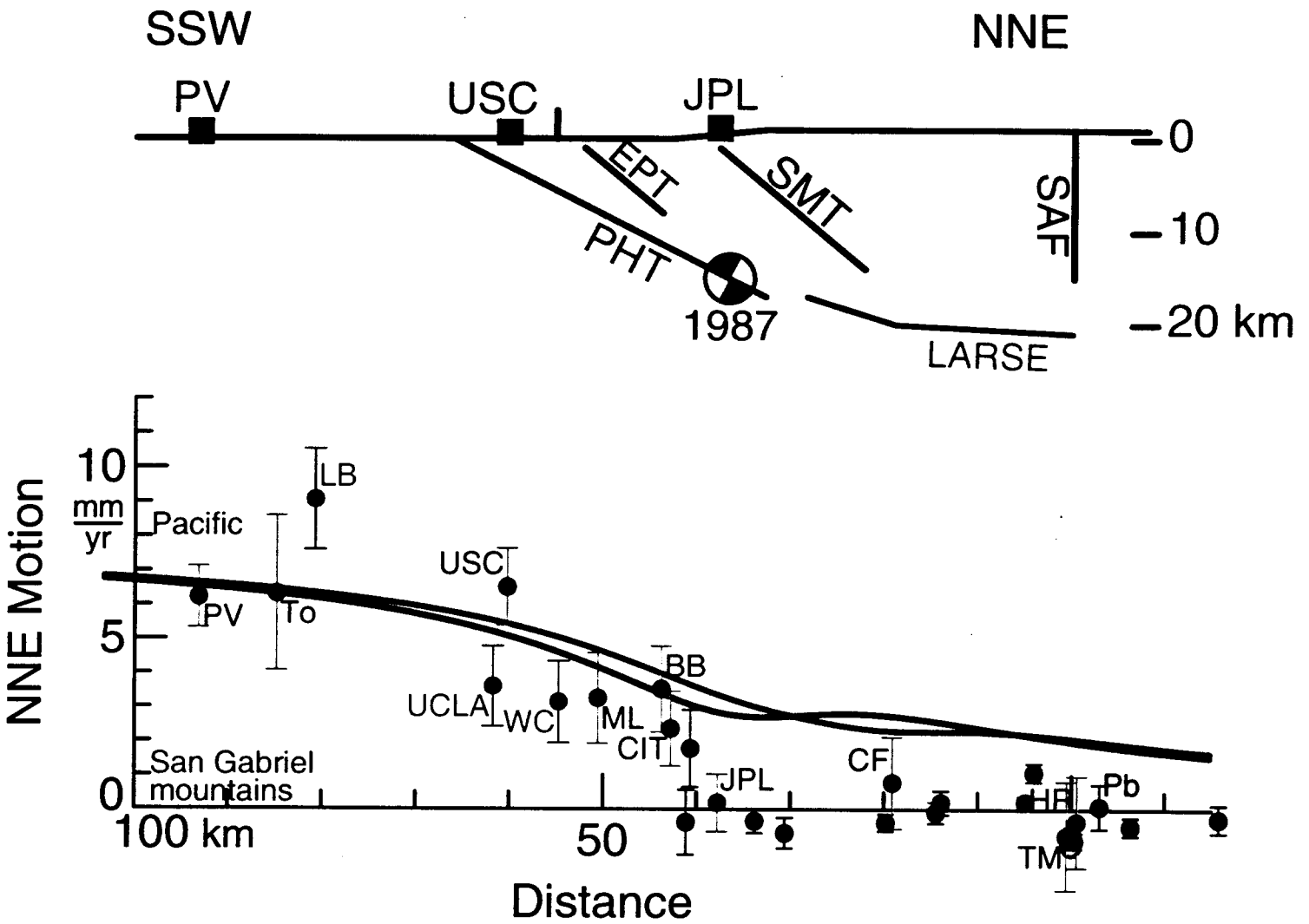
post–1994 Northridge permanent GPS off profile

2–D Edge Dislocation Models

	thrust fault	deep slip rate	locking depth
1	Puente Hills	8 mm/yr	17 km
2	Puente Hills	4 mm/yr	17 km
	Sierra Madre	4 mm/yr	17 km

shallow locking depth?

aseismic creep?


SSW
NNE
PV
USC
JPL
EPT
SMT
PHT
SAF
1987
LARSE
0
10
20 km
NNE Motion
mm/yr
10
5
0
Pacific
San Gabriel mountains
LB
USC
PV
To
UCLA
WC
ML
BB
CIT
JPL
CF
HR
Pb
TM
100 km
50
Distance

2–D Edge Dislocation Models

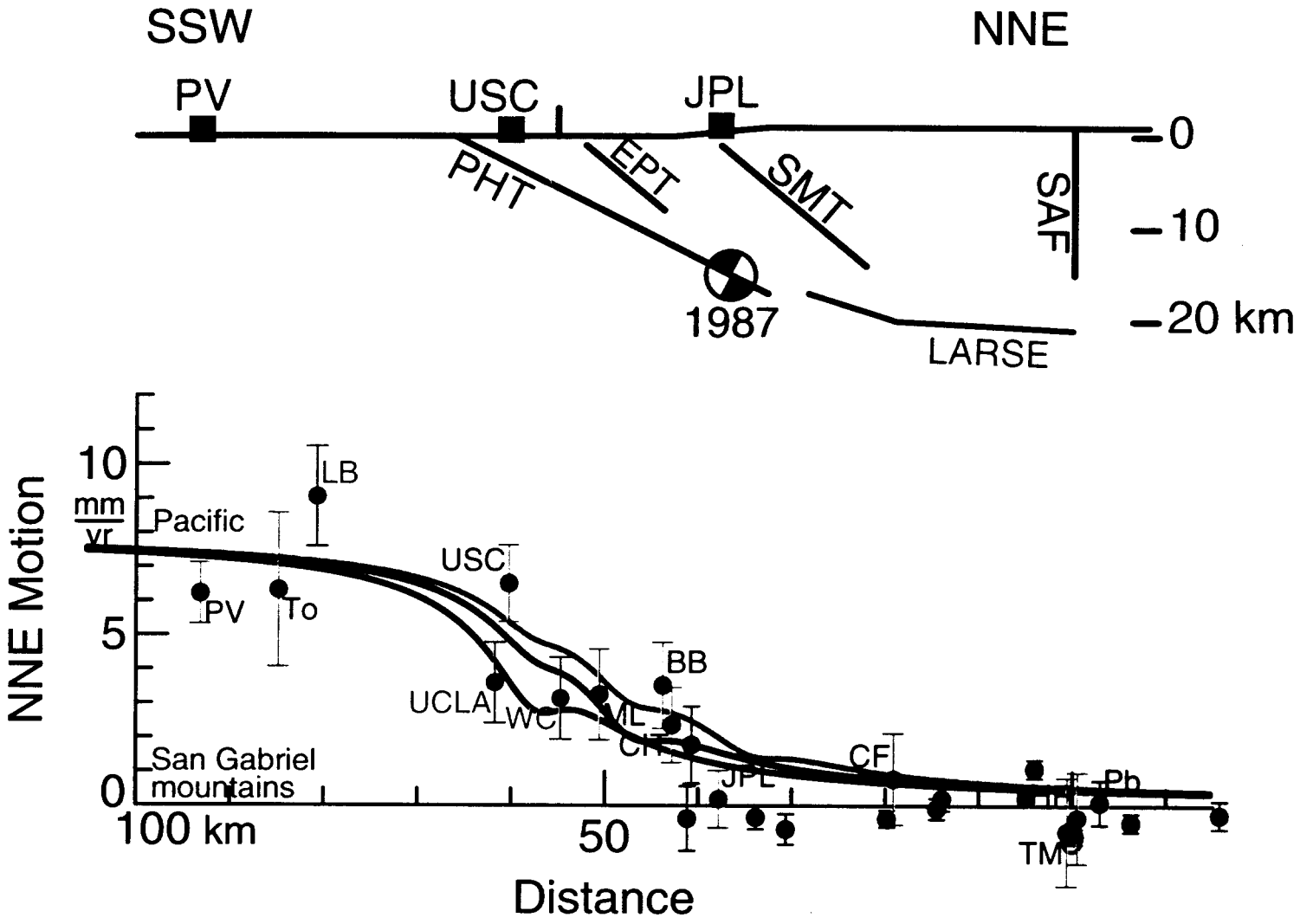
	thrust fault	deep slip rate	locking depth
1	Puente Hills	8 mm/yr	5 km
2	Puente Hills	4 mm/yr	5 km
	Elysian Park	4 mm/yr	5 km
3	Puente Hills	3 mm/yr	5 km
	Elysian Park	3 mm/yr	5 km
	Sierra Madre	2 mm/yr	5 km

but seismogenic zone is deeper!

1987 Whittier Narrows 13–17 km

1971 San Fernando 0–15 km

1994 Northridge 8–19 km


SSW
NNE
PV
USC
JPL
PHT
EPT
SMT
SAF
1987
LARSE
0
10
20 km
NNE Motion
mm/yr
10
5
0
Pacific
San Gabriel mountains
LB
PV
To
USC
UCLA
WC
ML
BB
CF
JPL
Pb
TM
100 km
50
Distance

Research Outstanding

more permanent GPS data at more sites

spatial variation

inteseismic velocity

3–D dislocation model

complex fault geometry

3–D geologic model

minimize inelastic strain

low stiffness of Los Angeles basin sediments

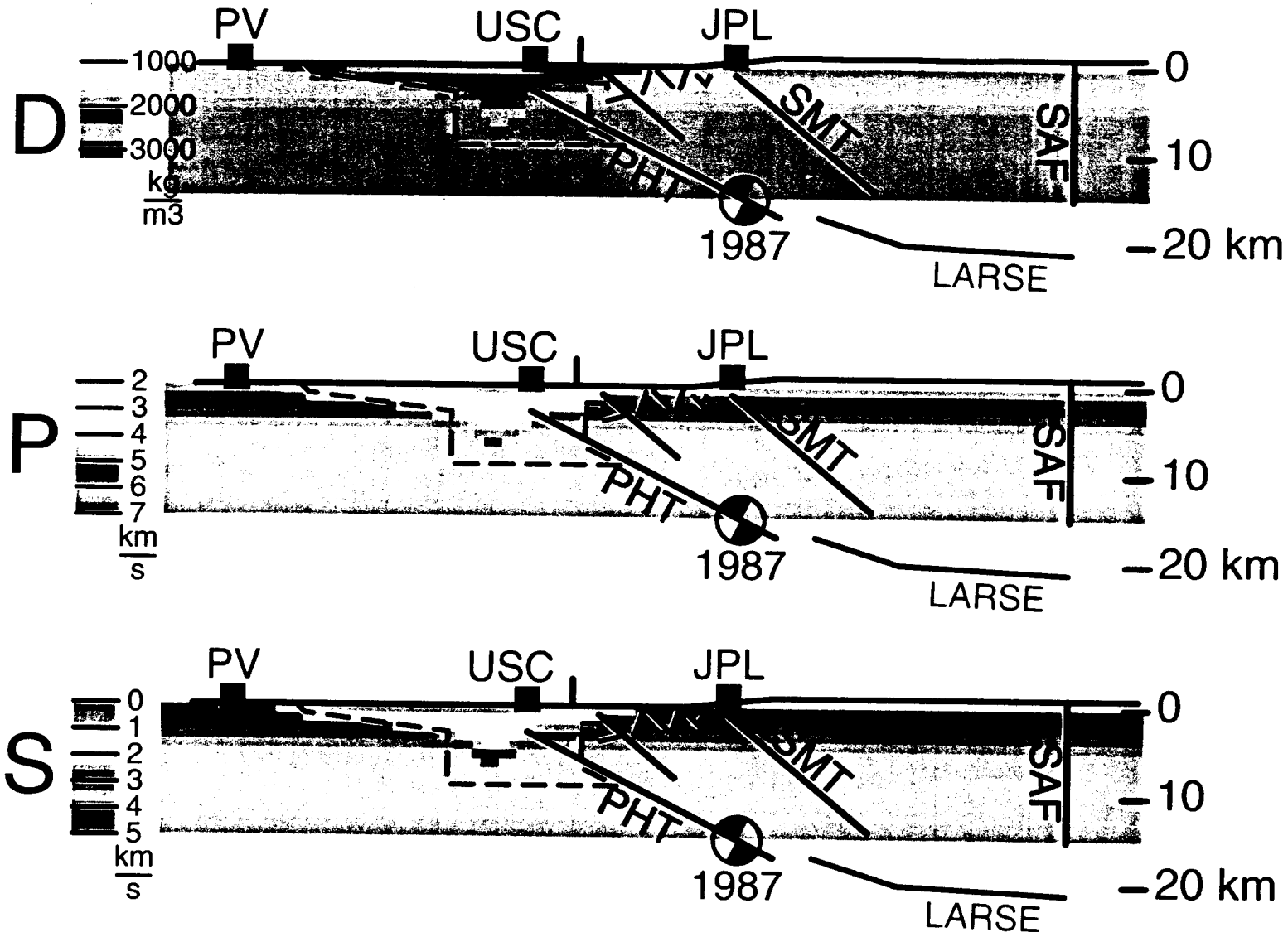
Hager et al. 1999

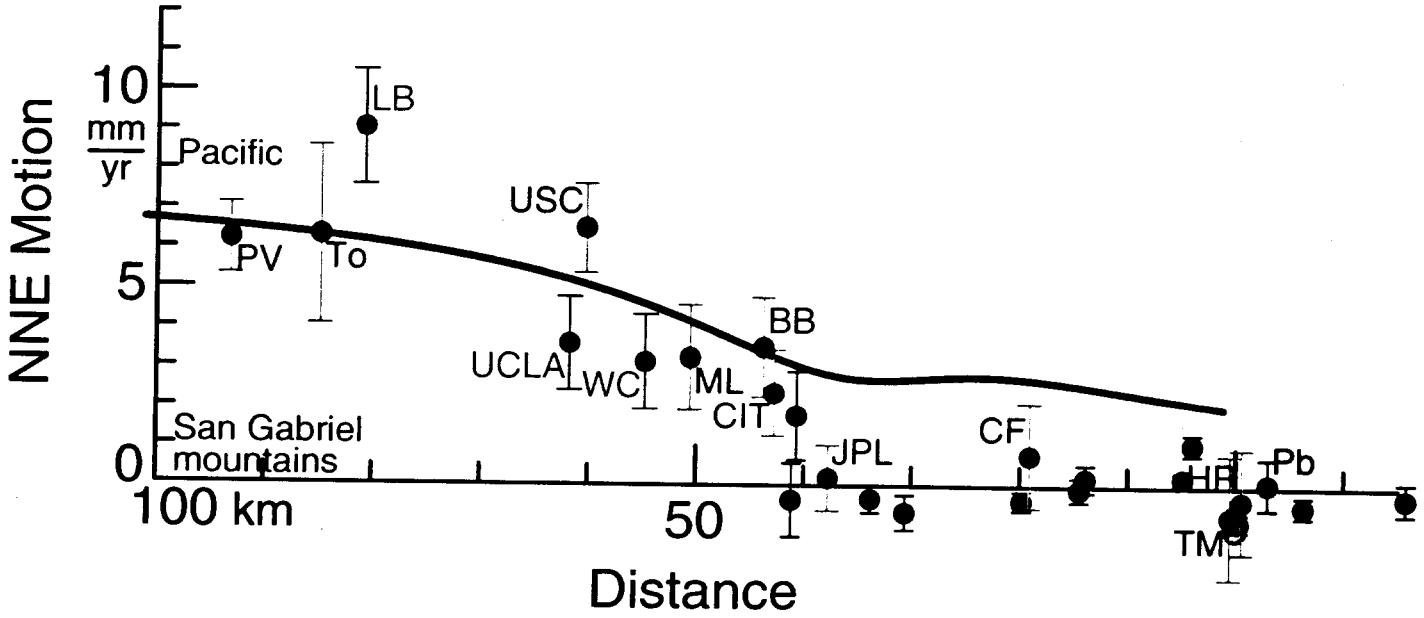
Ventura basin

viscous

temporal variation

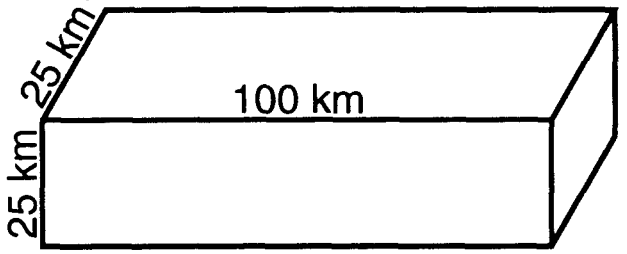
interseismic strain


D
PV
USC
JPL
1000
2000
3000
kg/m3
0
10
20 km
SMT
PHT
SAF
1987
LARSE
P
2
3
4
5
6
7
km/s
S
0
1
2
3
4
5

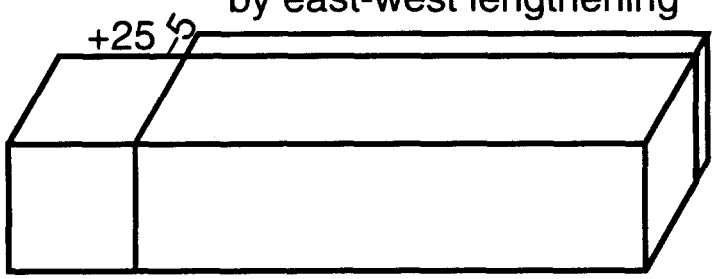

NNE Motion
10
mm/yr
5
0
Pacific
San Gabriel mountains
LB
PV
To
USC
UCLA
WC
ML
BB
CIT
JPL
CF
HR
Pb
TM
100 km
50
Distance

How is north-south shortening accommodated?

undeformed shortening belt

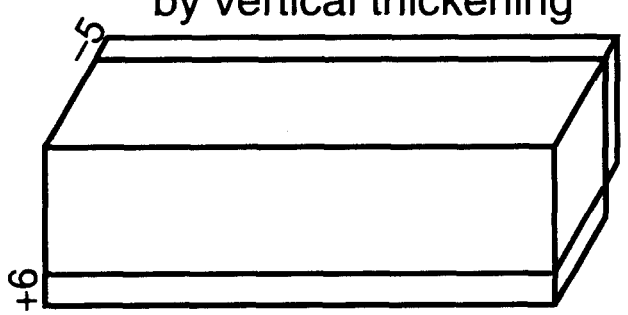


by east-west lengthening



belt length >> belt width
E–W lengthening >> N–S shortening

by vertical thickening



belt length ~ belt thickness
vertical thickening ~ N–S shortening

mainly by vertical thickening