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H4.SMR/1519-48

"Seventh Workshop on Non-Linear Dynamics and Earthquake Prediction"

29 September - 11 October 2003

ARE FRACTALITY AND SELF-ORGANIZED CRITICALITY RELEVANT TO PROBLEMS OF SEISMICITY?

Are there Critical Scales in the Earthquakes Environment?

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FRACTURE LENGTHS FOR SMALL EARTHQUAKES

M	L (km)
6	10
5	3
4	1
3	0.3
2	0.1

Statistical Facts about earthquakes

Gutenberg-Richter (1944) magnitude-frequency law for full catalog

$$\log N = a - b\,M, \qquad b \approx 1$$

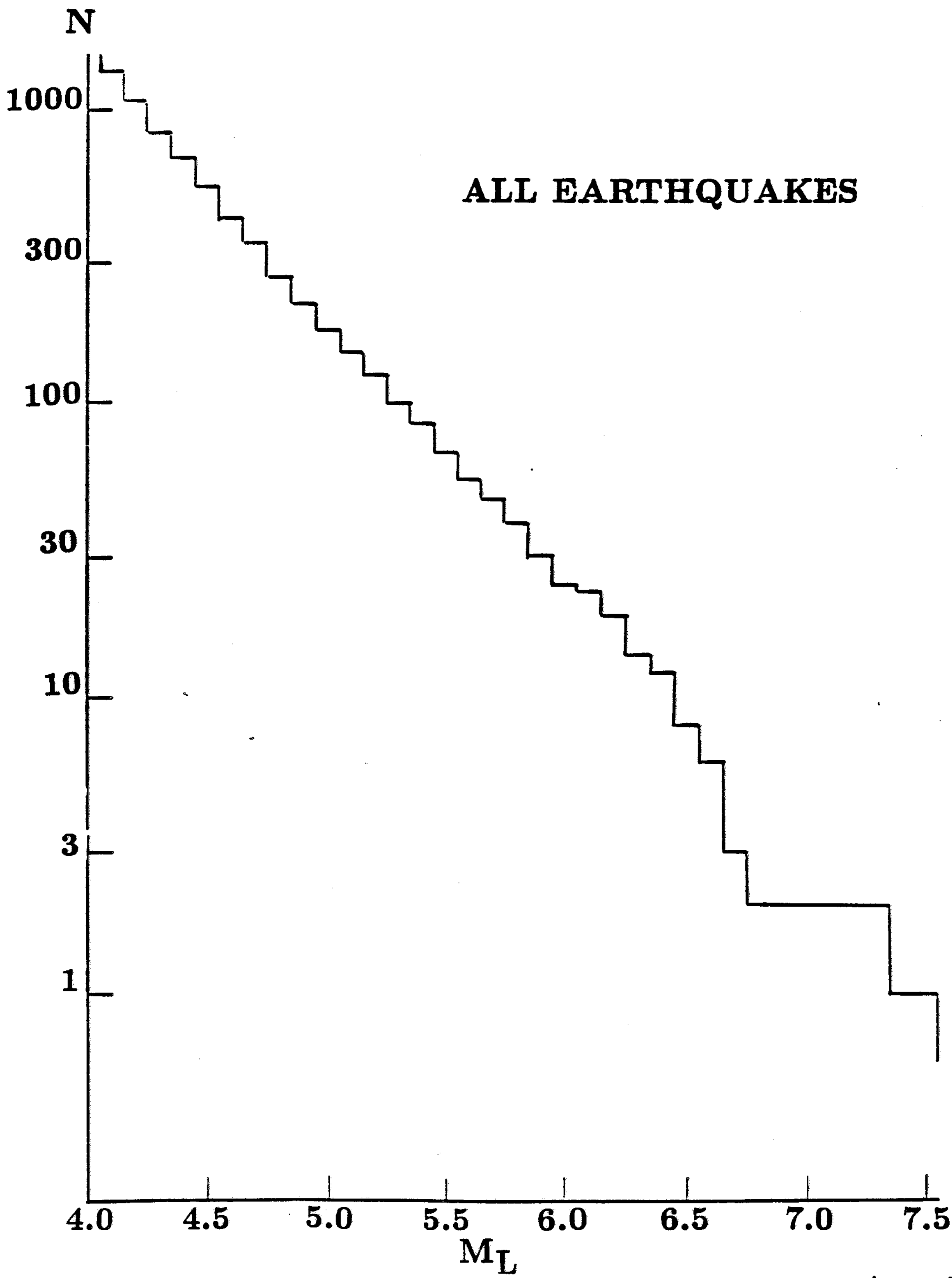
Utsu (1951) magnitude-frequency law for aftershocks

$$\log N = a - b\,M, \qquad b \approx 1$$

Omori (1894) aftershock rate law

$$\dot{n} \sim t^{-p}, \qquad p \approx 1$$

if $p \approx 1$, $n_{cum} \approx \log(t - t_0)$



$\Delta M = 0.1$

$t >$ July 6, 1944

So. Calif Region

Lat $> 32.5°$N

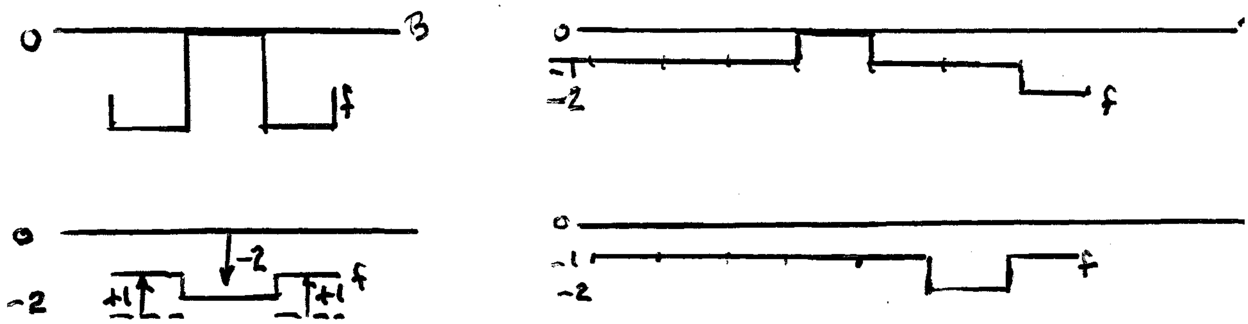
Speculations on Earthquake Forecasting

The linearity and self-similarity of the well known Gutenberg-Richter relationship demonstrate that the Earth behaves as a complex critical system with self-organized criticality, where minor disturbances (small earthquakes or fractures) may cascade into major fractures and large earthquakes. Such criticality is claimed to specifically exclude the possibility of the deterministic prediction of the time, magnitude, and location of impending large earthquakes. Resolving this fundamental difficulty is one of

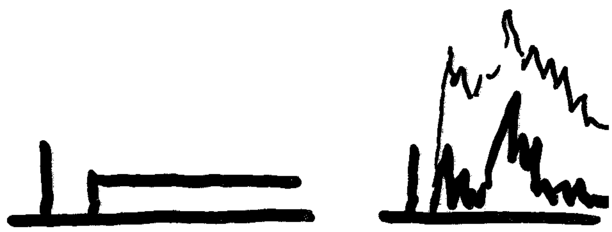
Seismological Research Letters May/June 2003 Volume 74, Number 3

P. 2

S. Crampin, et. al



Questions



1. Seismogram amplitude indept. of size of event

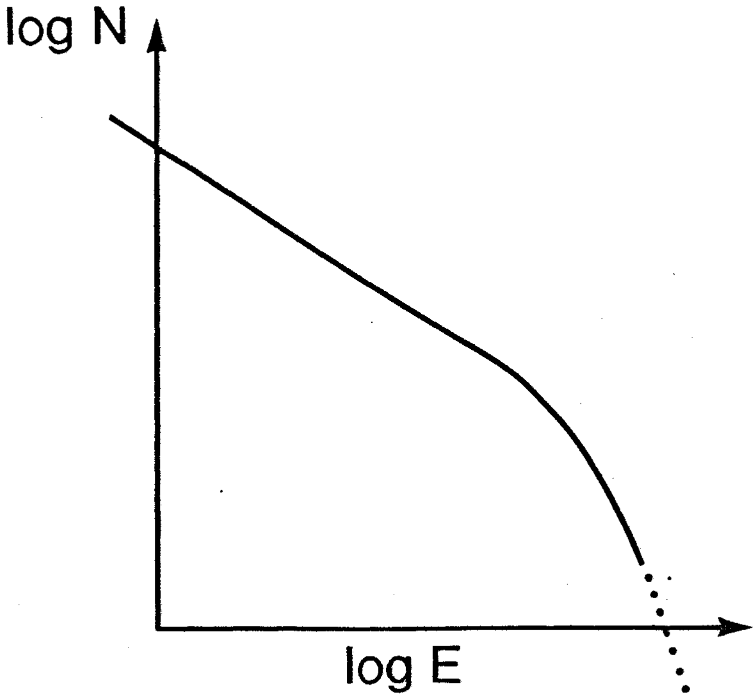
2. Long cracks tend to be periodic and of same length (approx) at same site

3. Do fluctuations in prestress (f) have any manifestation after event?

4. Does the system ~~st~~ stability depend on edge conditions?

5. Is the behavior of the system independant of fluctuations in fracture threshold (B)?

6. Is the model unique?



$$\log_{10} N_{cum} = a - bM$$

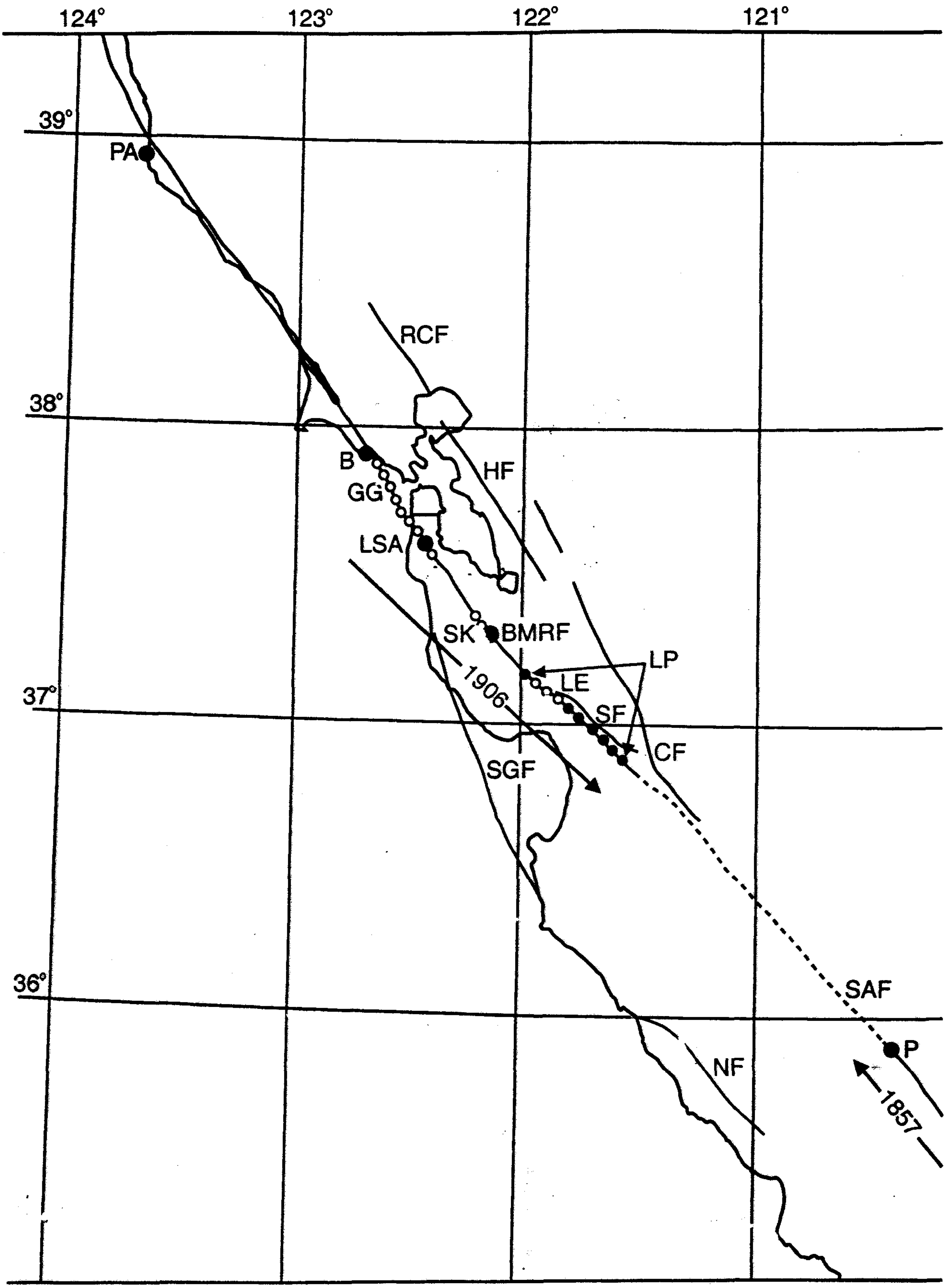
$$\log_{10} E = \alpha + \beta M$$

$$b \approx 1$$
$$\beta \approx 1.5$$

$$N_{cum} \sim E^{-b/\beta}$$

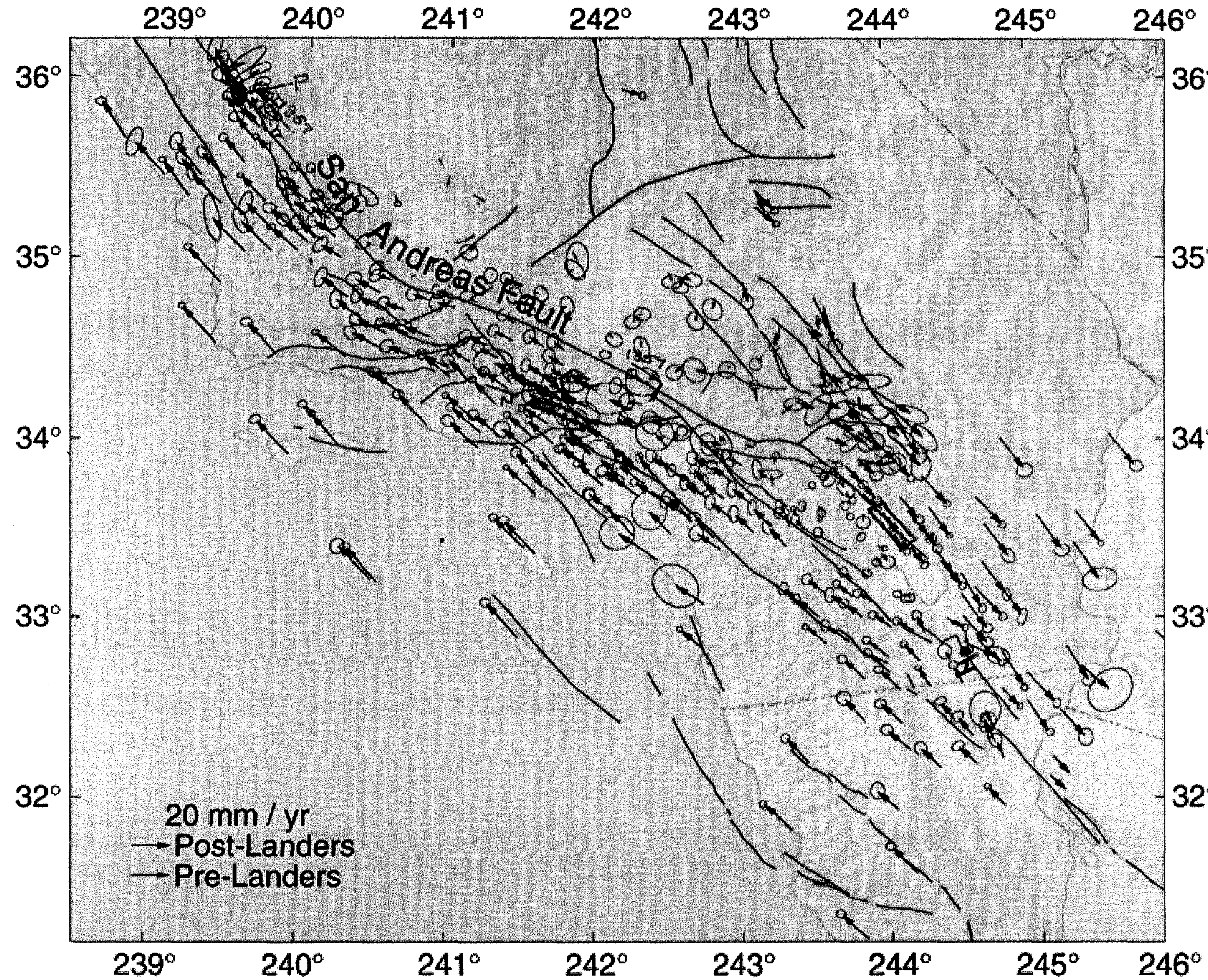
$$E_{tot} = \int E dN$$

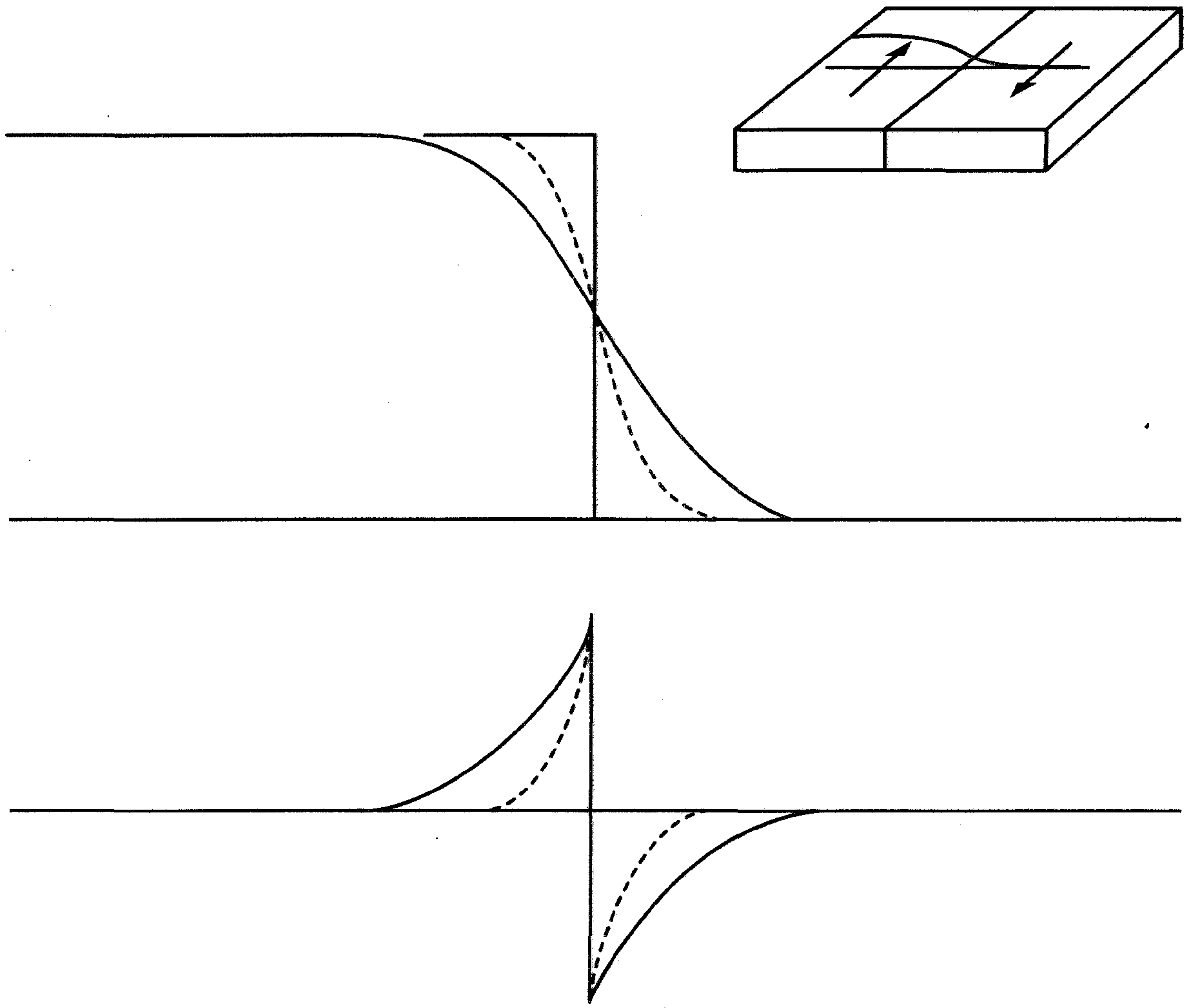
$$\sim \int E^{-b/\beta} dE = \int E^{-2/3} dE = E^{1/3} \Big|$$



124°
123°
122°
121°
39°
38°
37°
36°
PA
RCF
B
HF
GG
LSA
SK
BMRF
LP
LE
1906
SF
CF
SGF
SAF
P
NF
1857

FIG. 2


239° 240° 241° 242° 243° 244° 245° 246°
36° 35° 34° 33° 32°
San Andreas Fault
20 mm / yr
Post-Landers
Pre-Landers



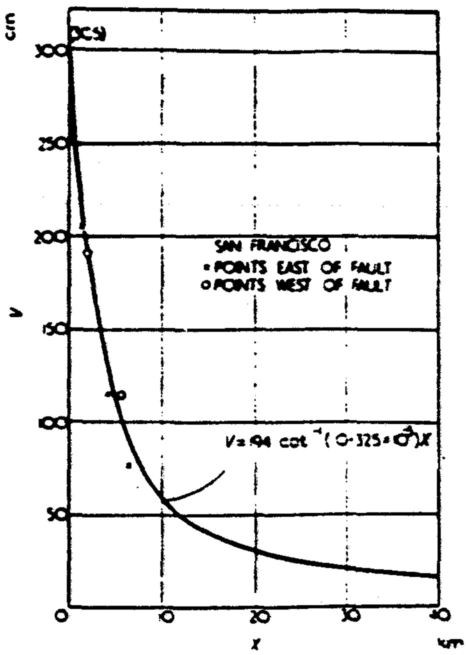


Fig. 1.

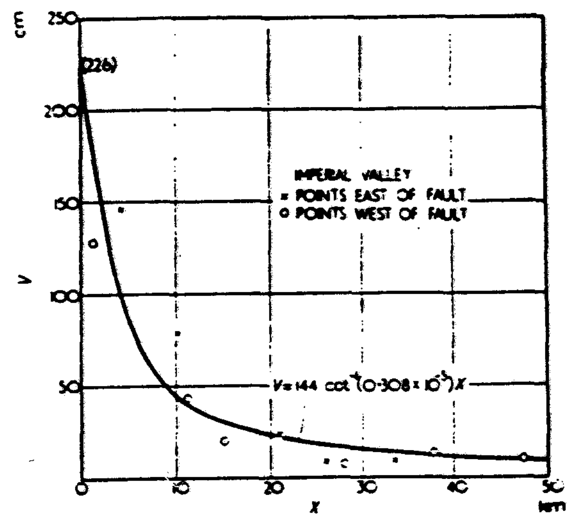


Fig. 2.

1958 Byerly & DeNoyer

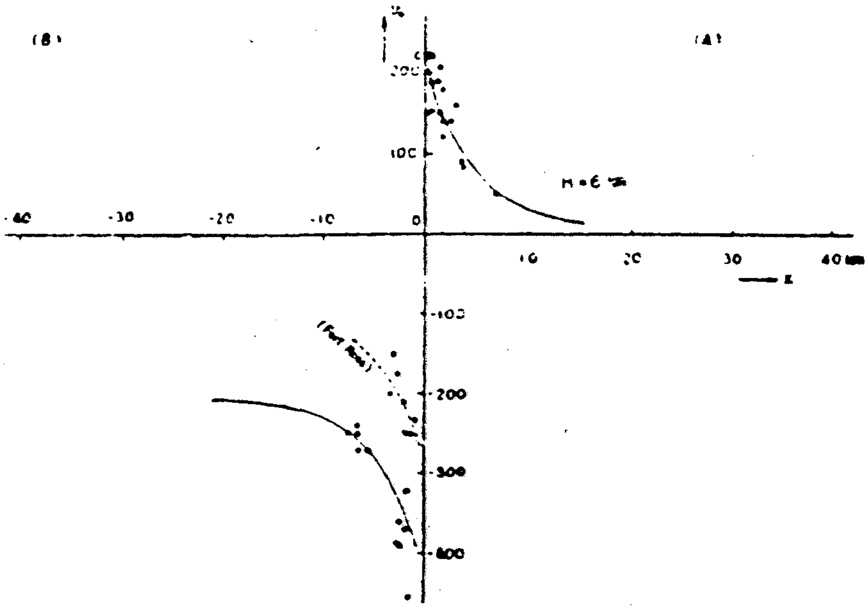
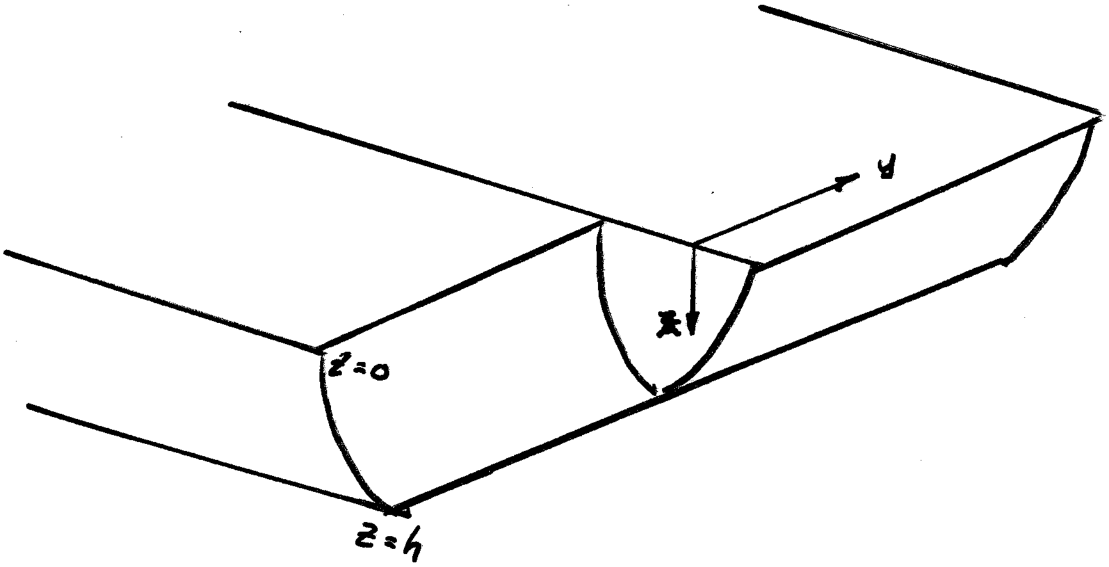
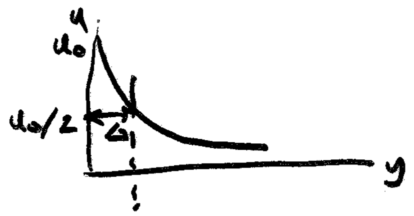


Fig. 37. Diminution of horizontal displacements with distance (the California district).

23

1957 Kasahara, Bull. ER





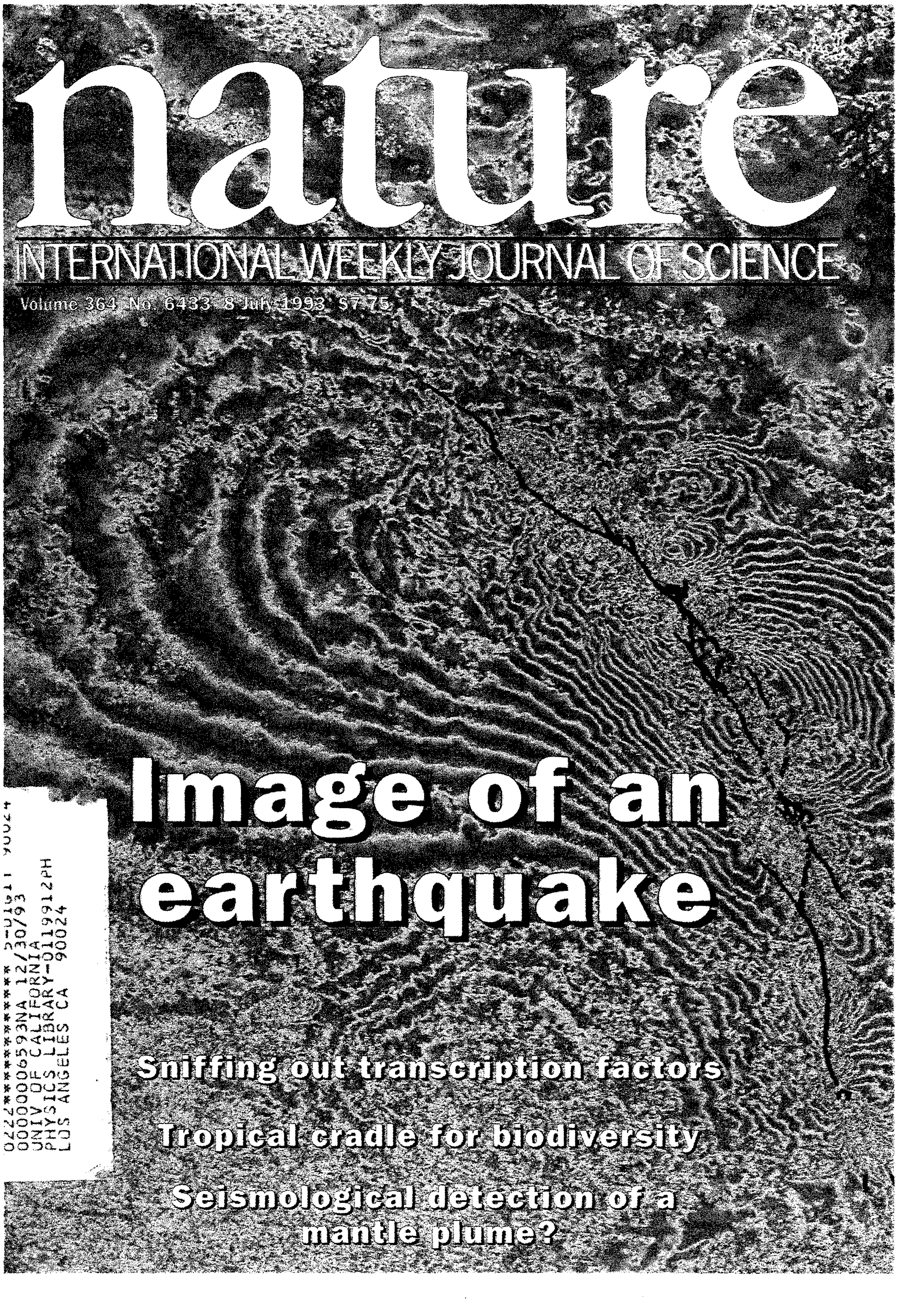
$$\underset{z=0}{u(y)} = A_0\left[\sqrt{y^2+h^2}-y\right]$$

$$\underset{y=0}{u(z)} = A_0\sqrt{h^2-z^2}$$

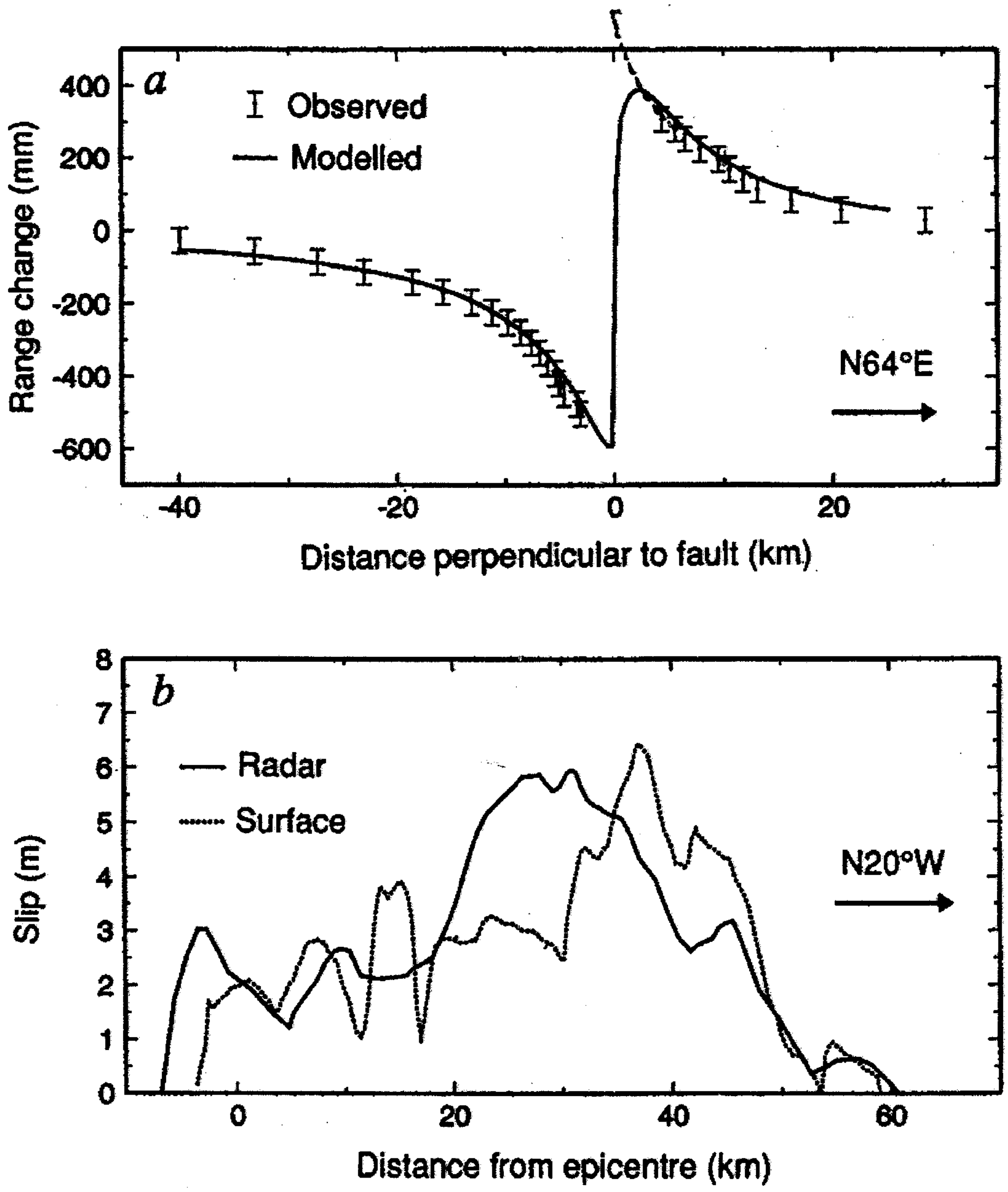
Knopoff (GJRAS, 1958)

SF 1906 $\quad h = 3.2$ km

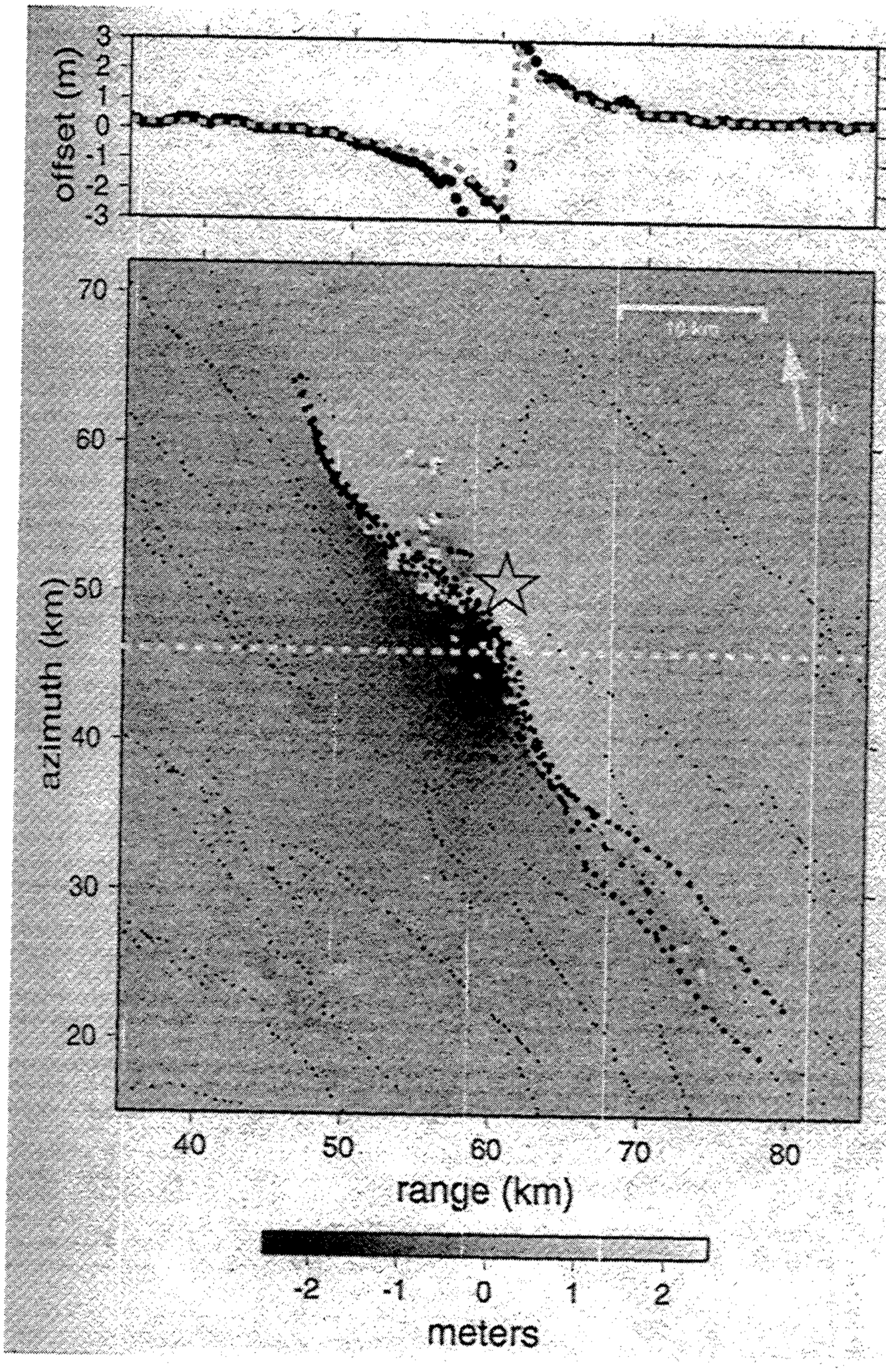
33 sta. $\quad \Delta = \frac{3}{4}h = 2.4$ km



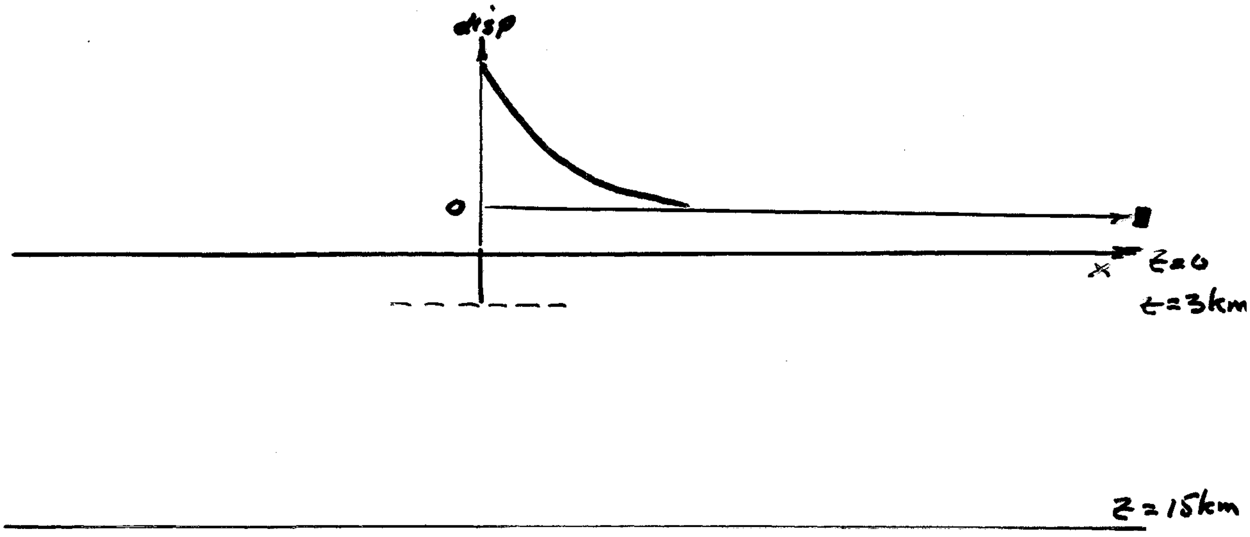
Massonnet, et al. 1993

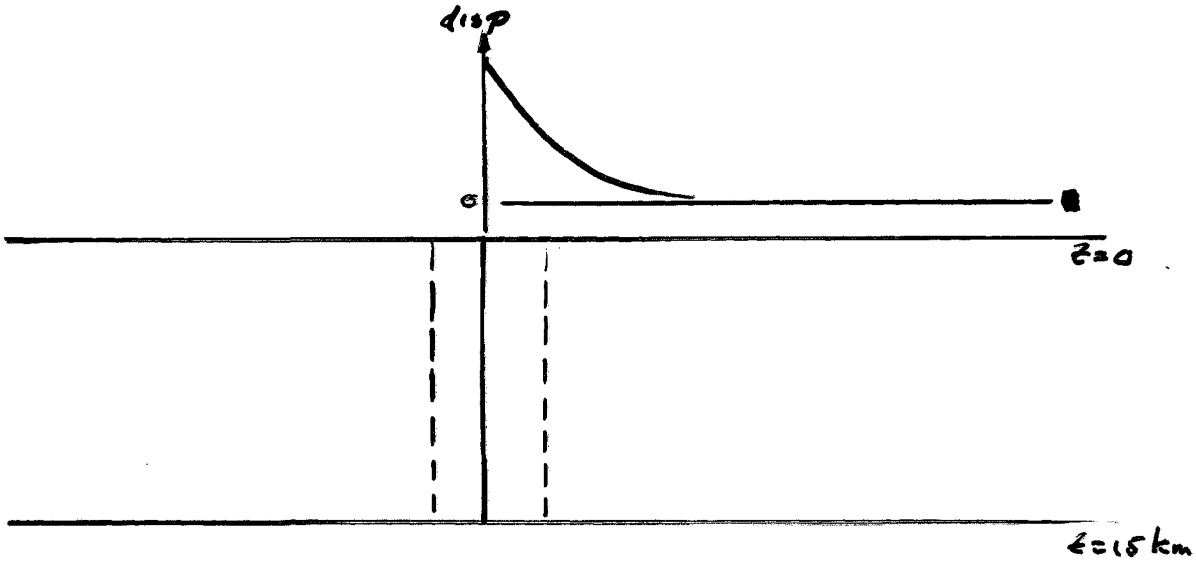


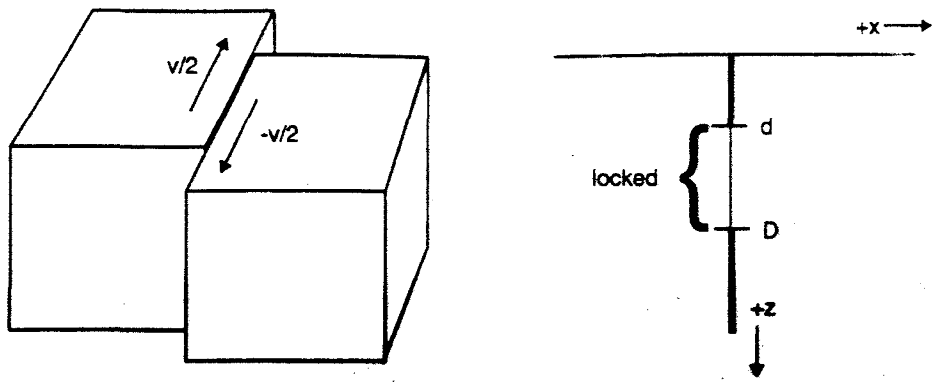
Massonnet et al. 1993

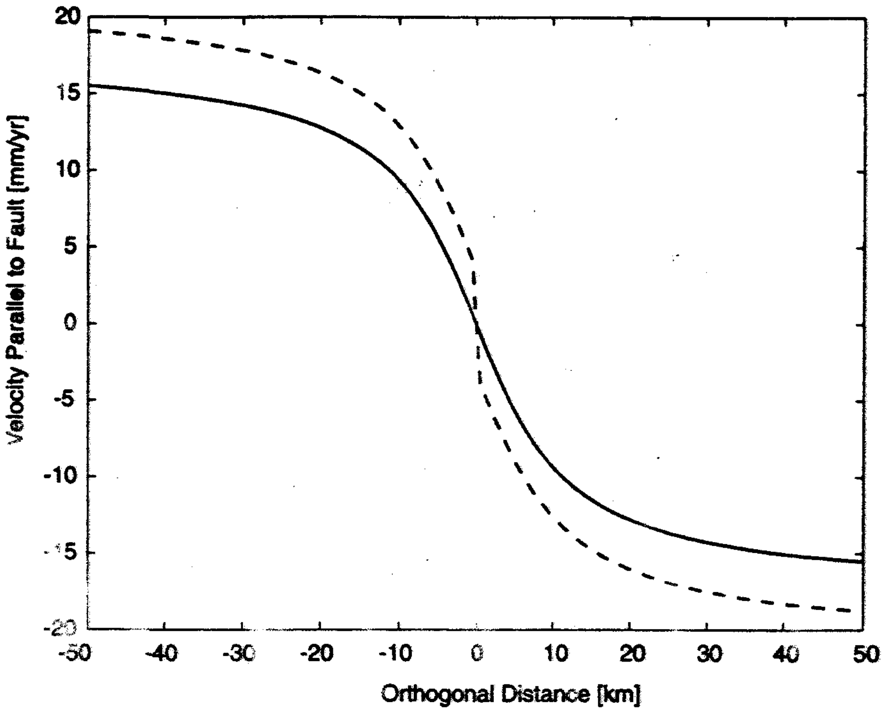


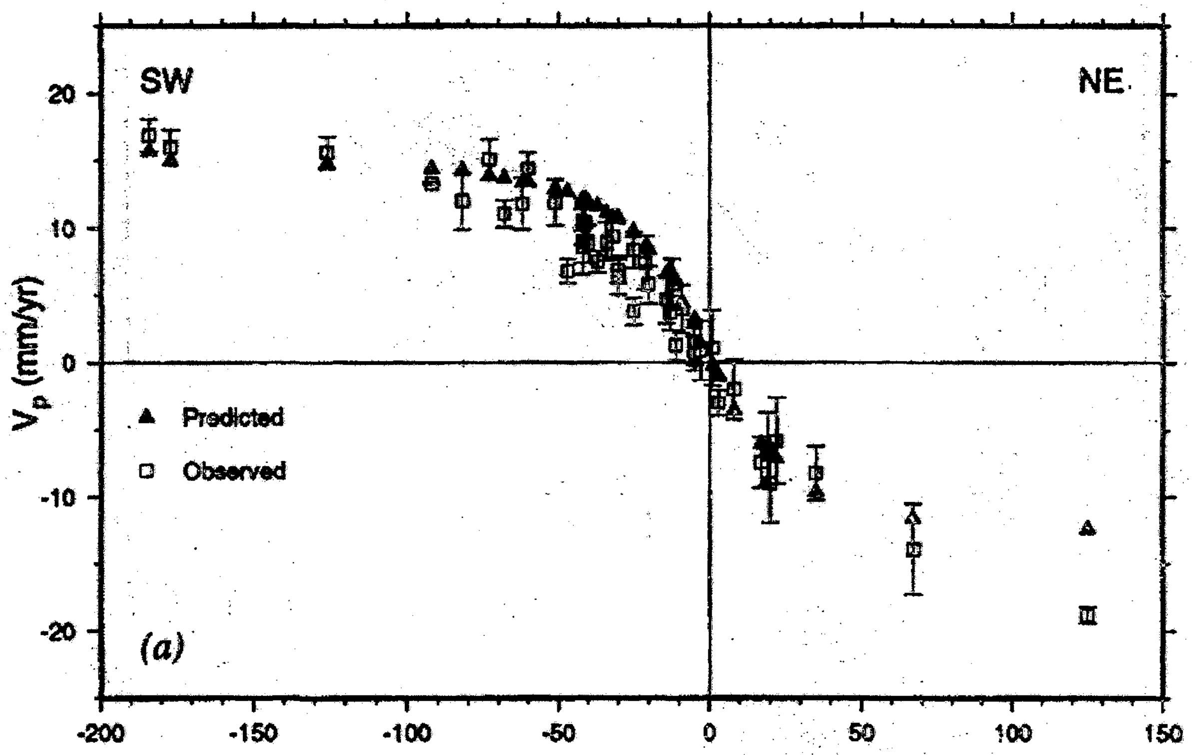
Sandwell et al. 2002


disp
0
x
z=0
t=3km
z=15km


disp
0
z=0
z=15 km

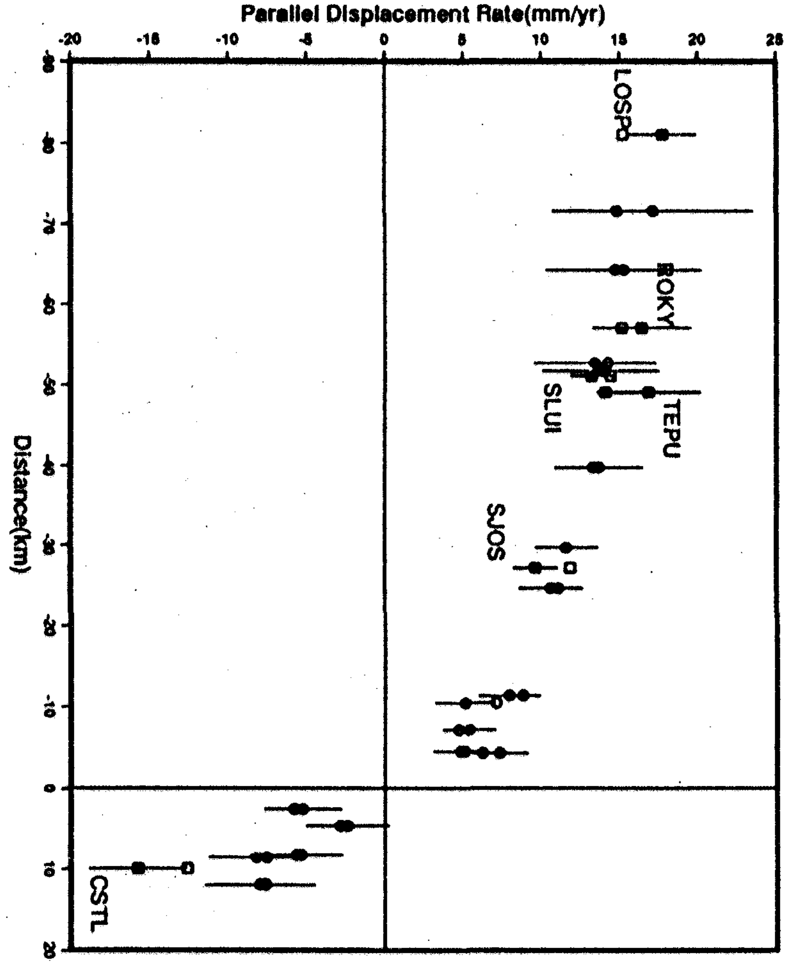

v/2
-v/2
+x
d
locked
D
+z


Velocity Parallel to Fault [mm/yr]
Orthogonal Distance [km]
20
15
10
5
0
-5
-10
-15
-20
-50
-40
-30
-20
-10
0
10
20
30
40
50



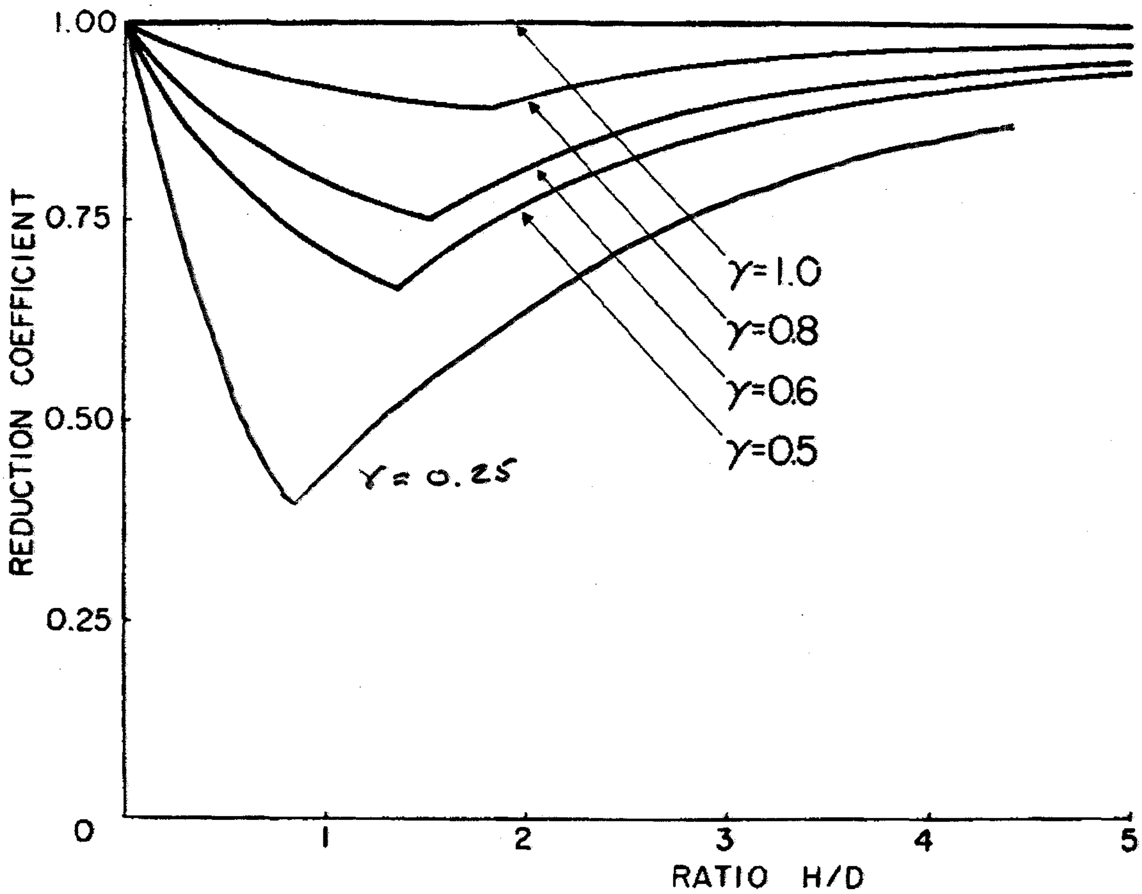
Mojave
Shen et al

CHOLAME



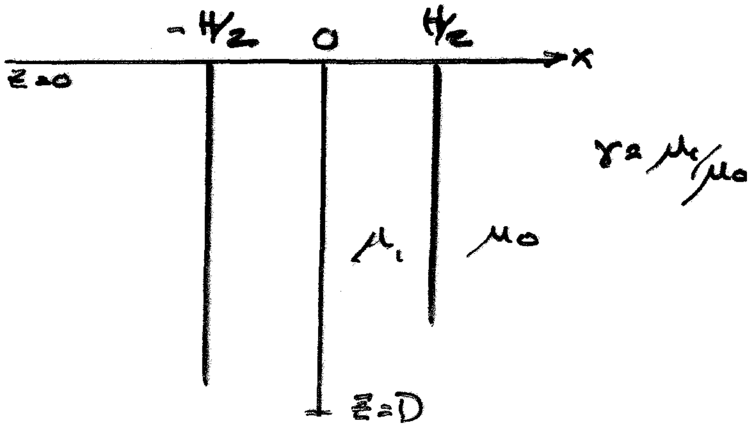
Cholame

Shen & Jackson, JGR 1993

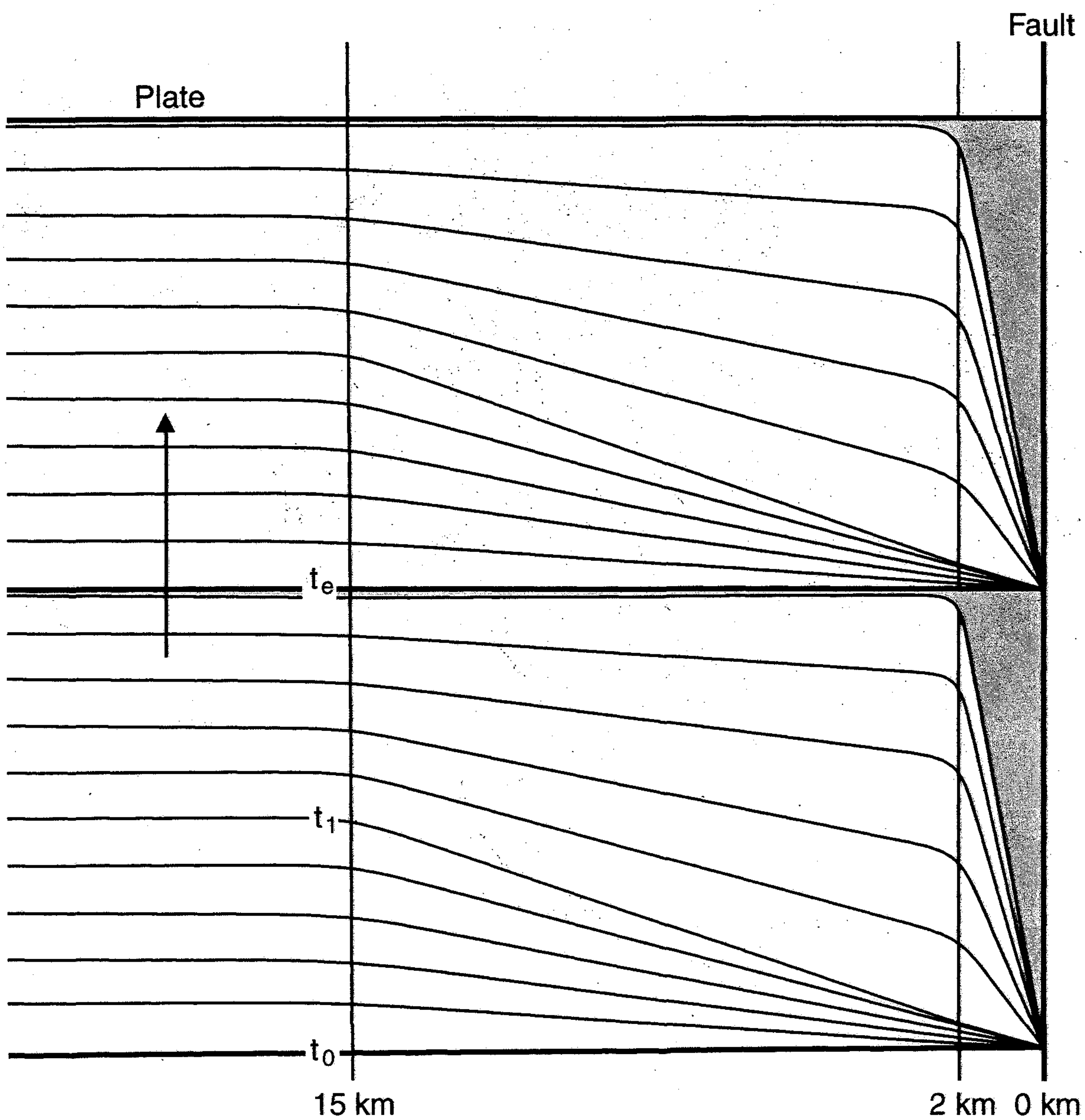


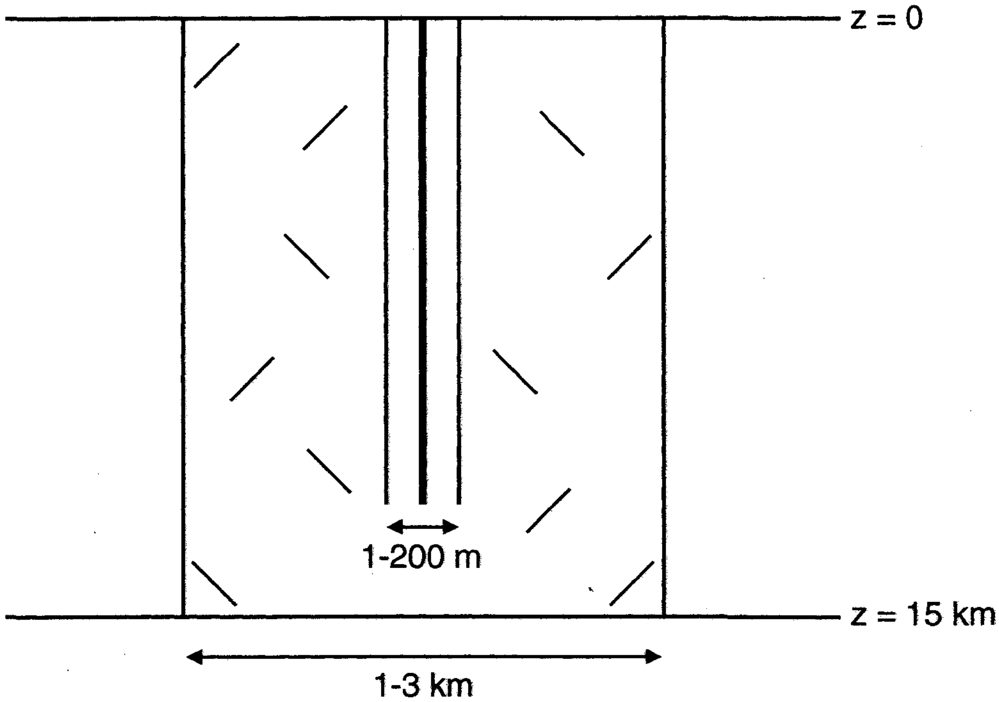
Red. Coeff.t

$= \dfrac{\text{half width of displacement}}{D}$

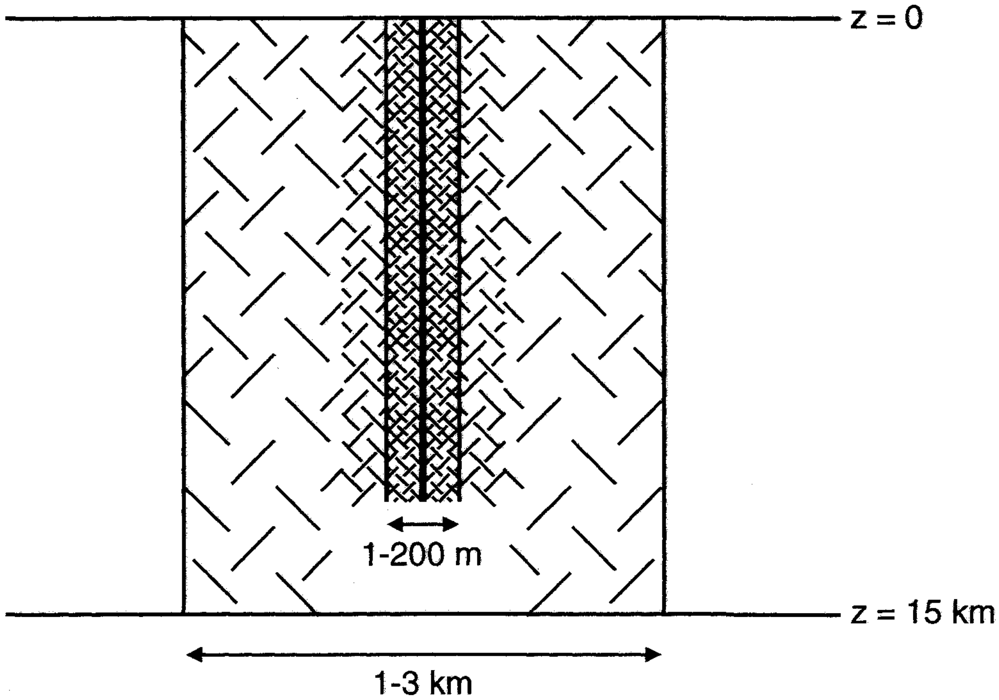


Rybicki and Kasahara, 1977


Fault
Plate
te
t1
t0
15 km
2 km
0 km



z = 0
1-200 m
z = 15 km
1-3 km

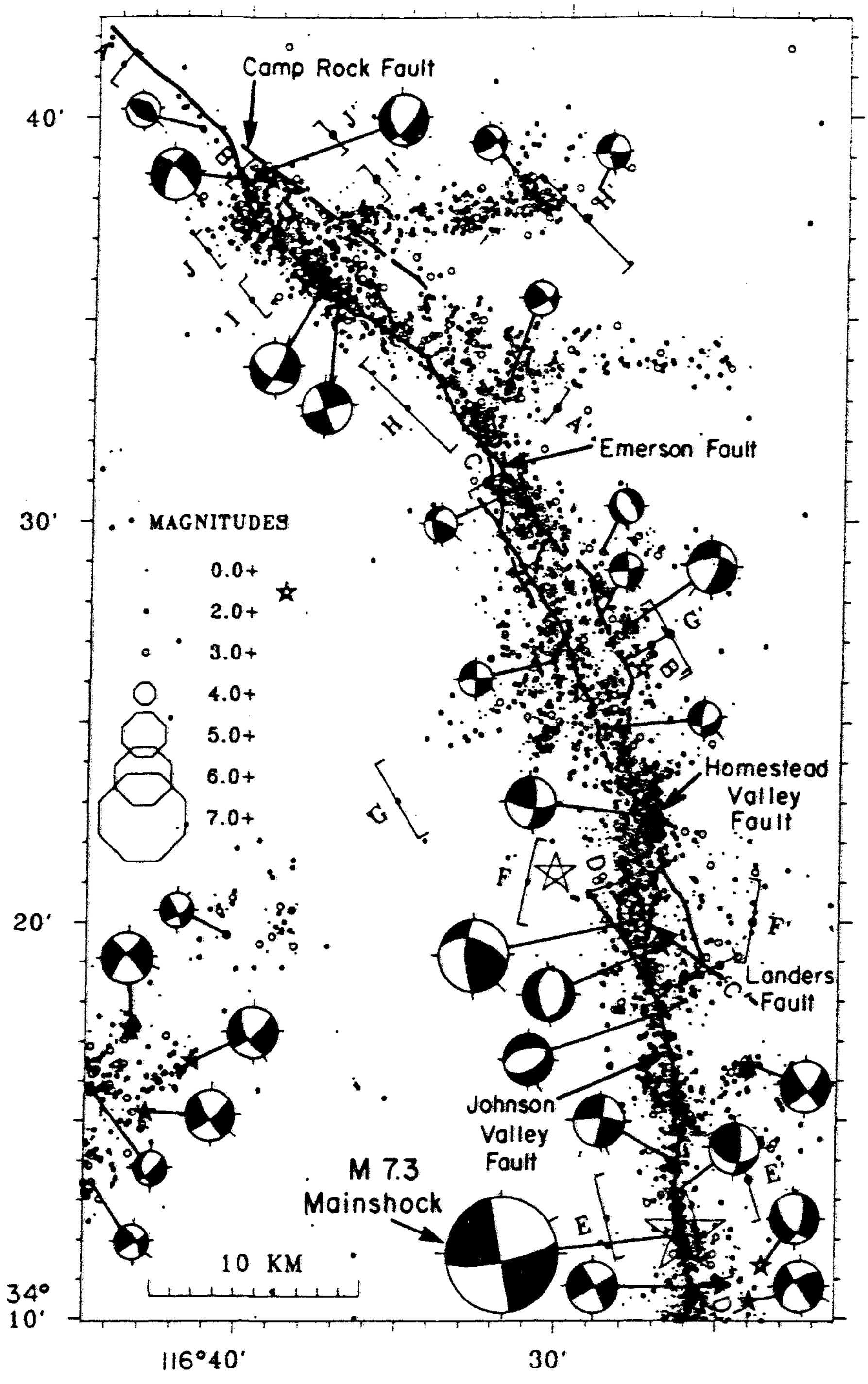


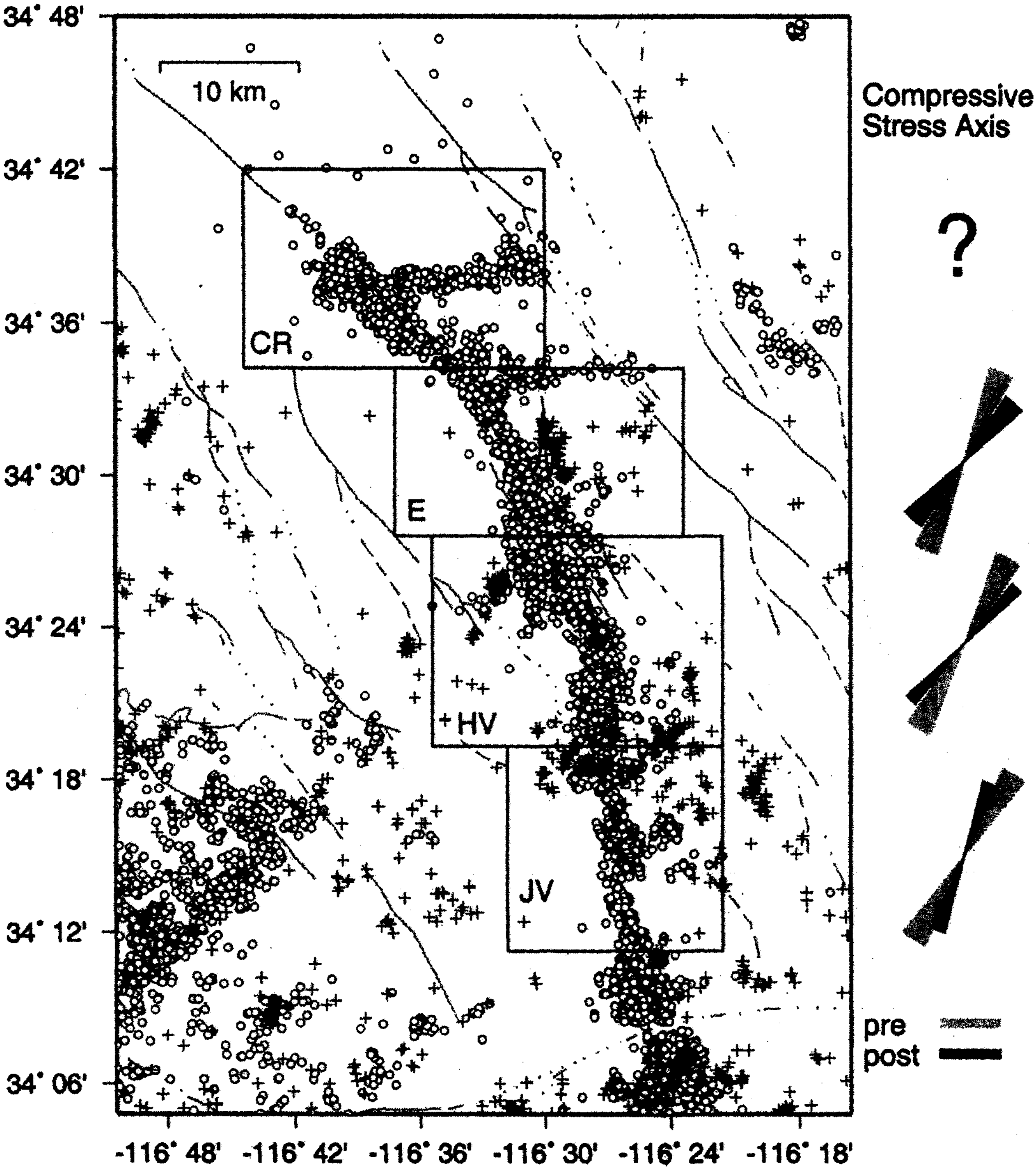
z = 0
1-200 m
z = 15 km
1-3 km

2 to 4 km scale in California Earthquake Faults

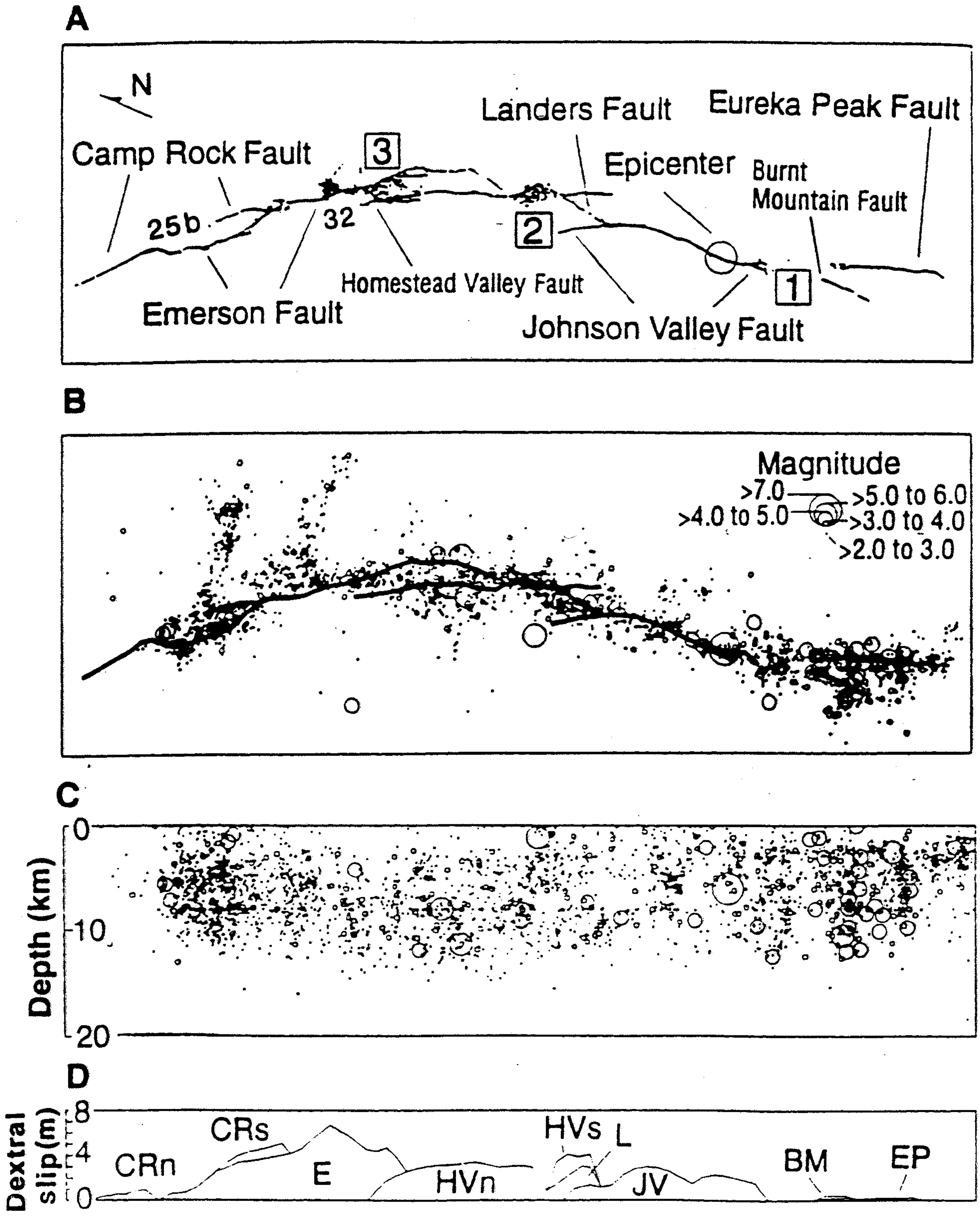
1. Coseismic displacements in large earthquakes
2. Displacements in the interseismic interval on southern SAF
3. Locations of aftershocks of large earthquakes
4. Failure of large aftershocks to fit Omori law
5. Reflection seismology and gravity on creeping section of SAF
6. Strain on creeping section of SAF
7. Spatial distributions of earthquakes near creeping section
8. Rotation of principal stresses on creeping section
9. Teleseismic moment of Parkfield earthquake
10. Triggered displacements after Landers and Hector mine earthquakes
11. Recent small mainshock activity on northern SAF
12. Seismic activity prior to Loma Prieta and Landers earthquakes
13. Mainshock magnitude-frequency distribution
14. Ratio of energy radiated to seismic moment
15. Contours of maximum Rossi-Forel intensities after 1906 earthquake
16. Spacing of parallel strands of major faults

Landers Earthquake Sequence
June - December 1992

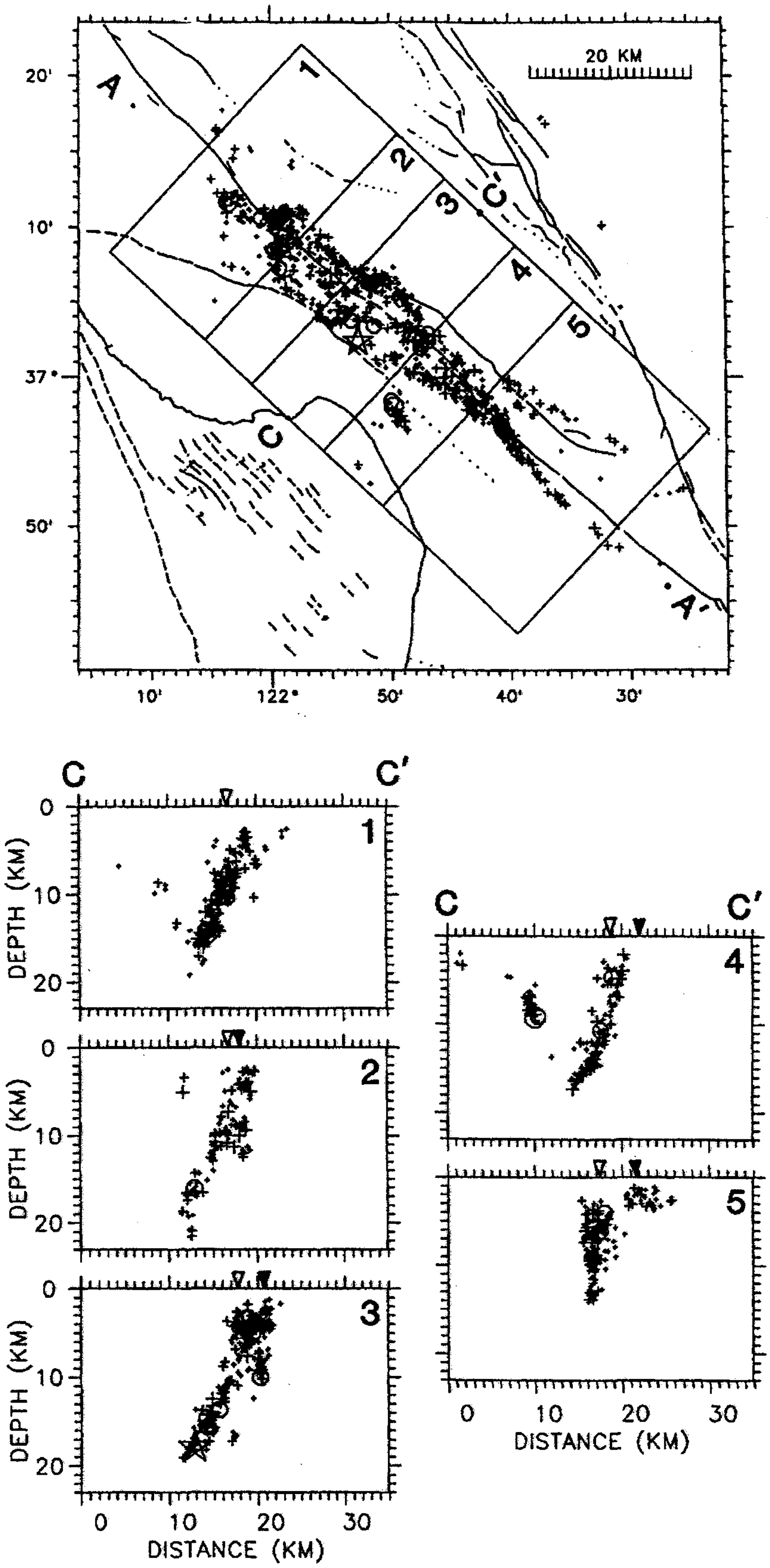


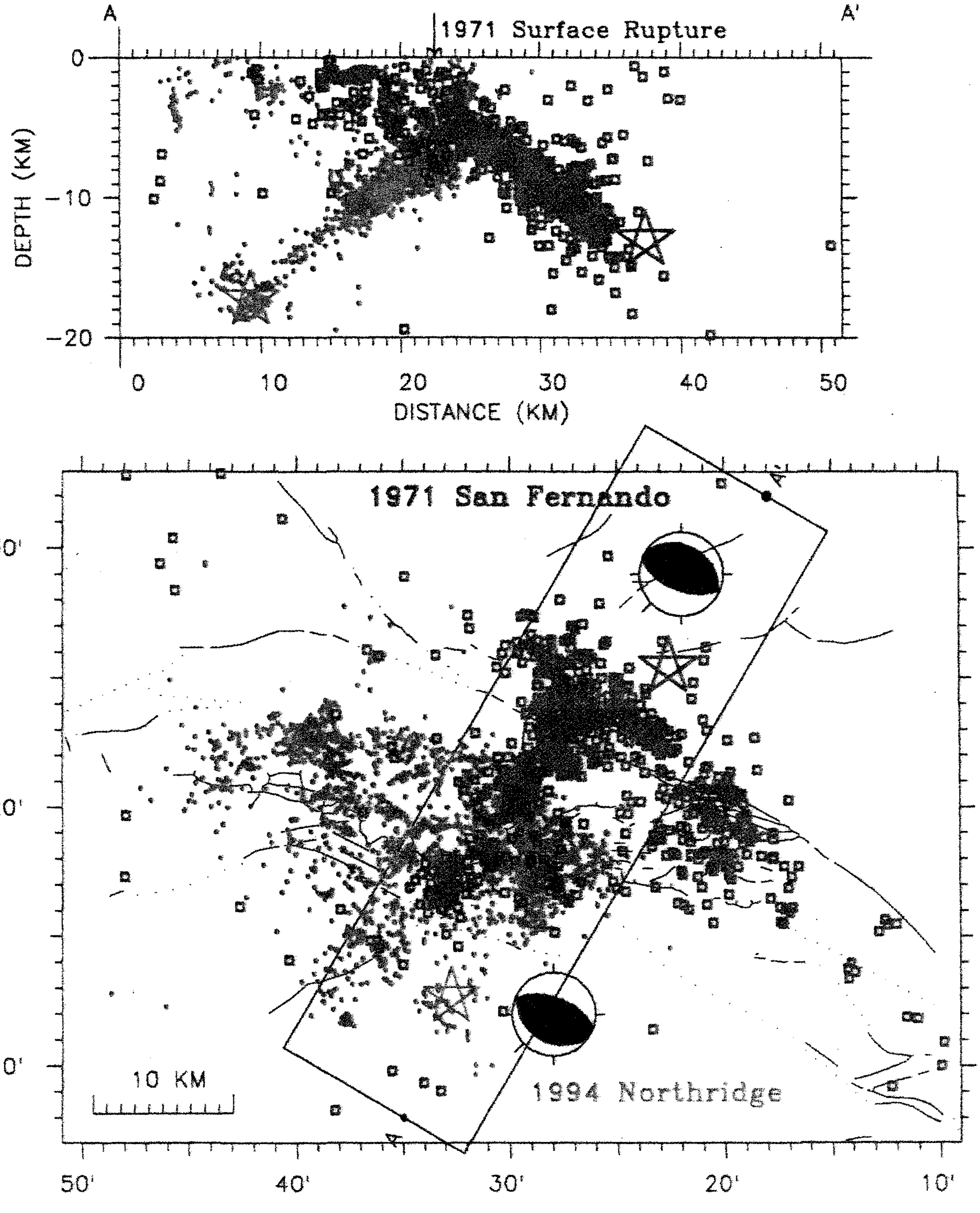


Hardebeck and Hauksson, 2001

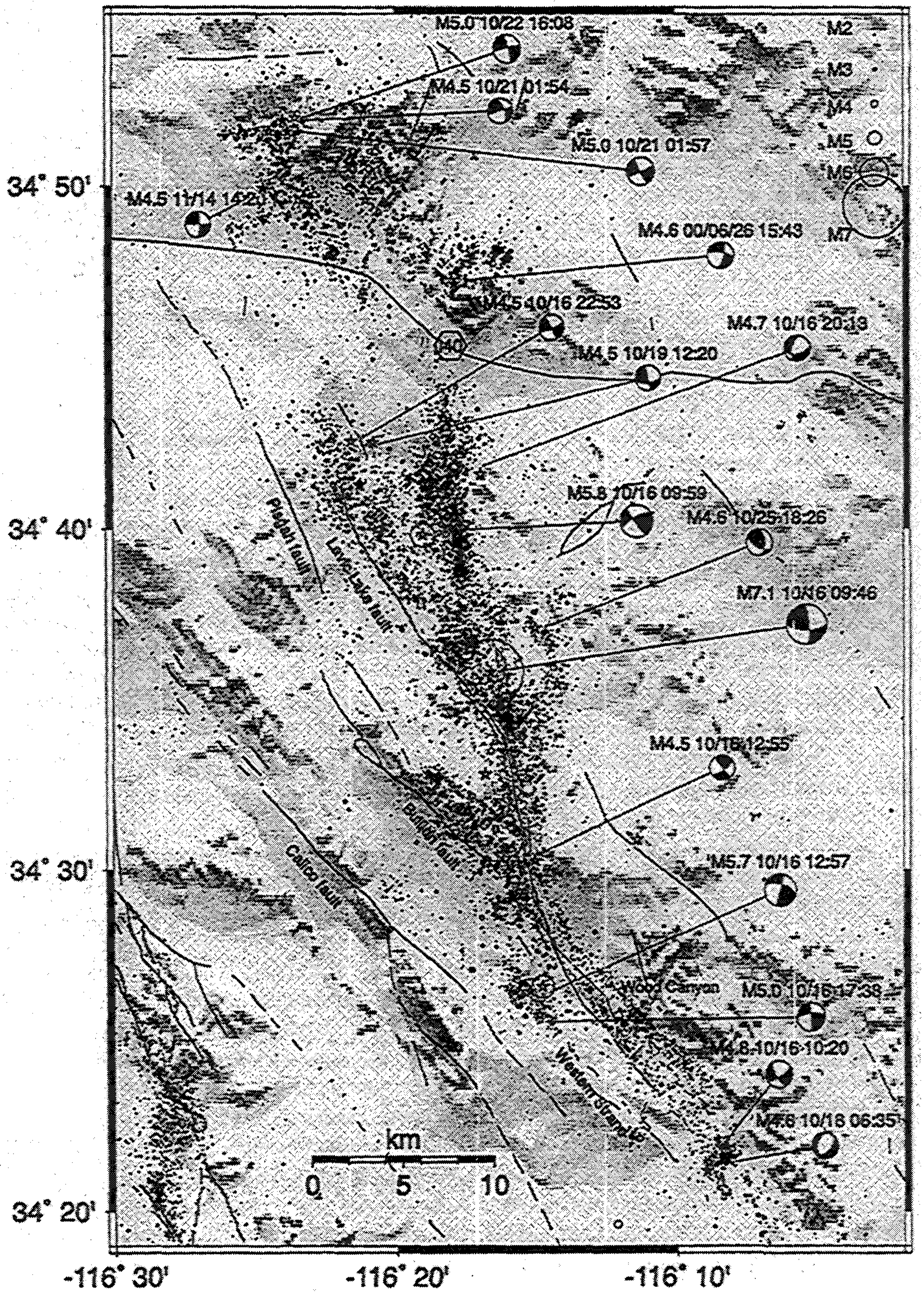


Sieh, et al. 1993


20 KM
A
A'
C
C'
1
2
3
4
5
20'
10'
37°
50'
10'
122°
50'
40'
30'
DEPTH (KM)
DISTANCE (KM)
0
10
20
30

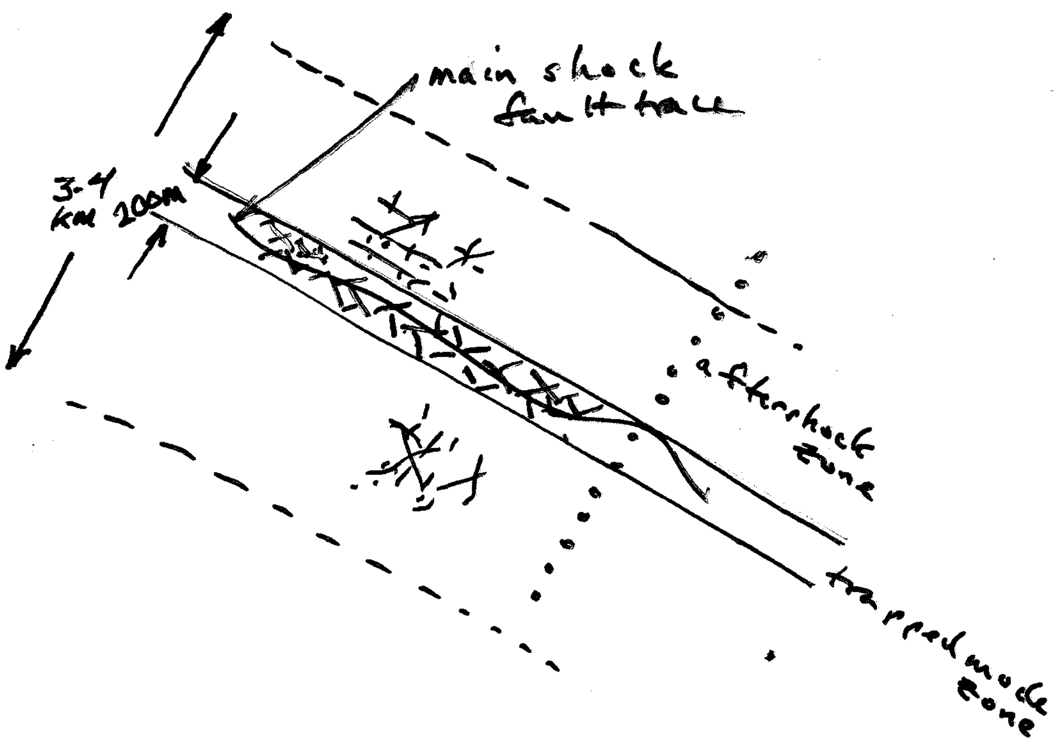


Mori et al. 1995



LK-087

Hauksson et al., 2002



If $L \sim 3$ km
$u \sim 5$ m

then $\sigma \sim 500$ bars.

Richter 1955
Benioff, 1955

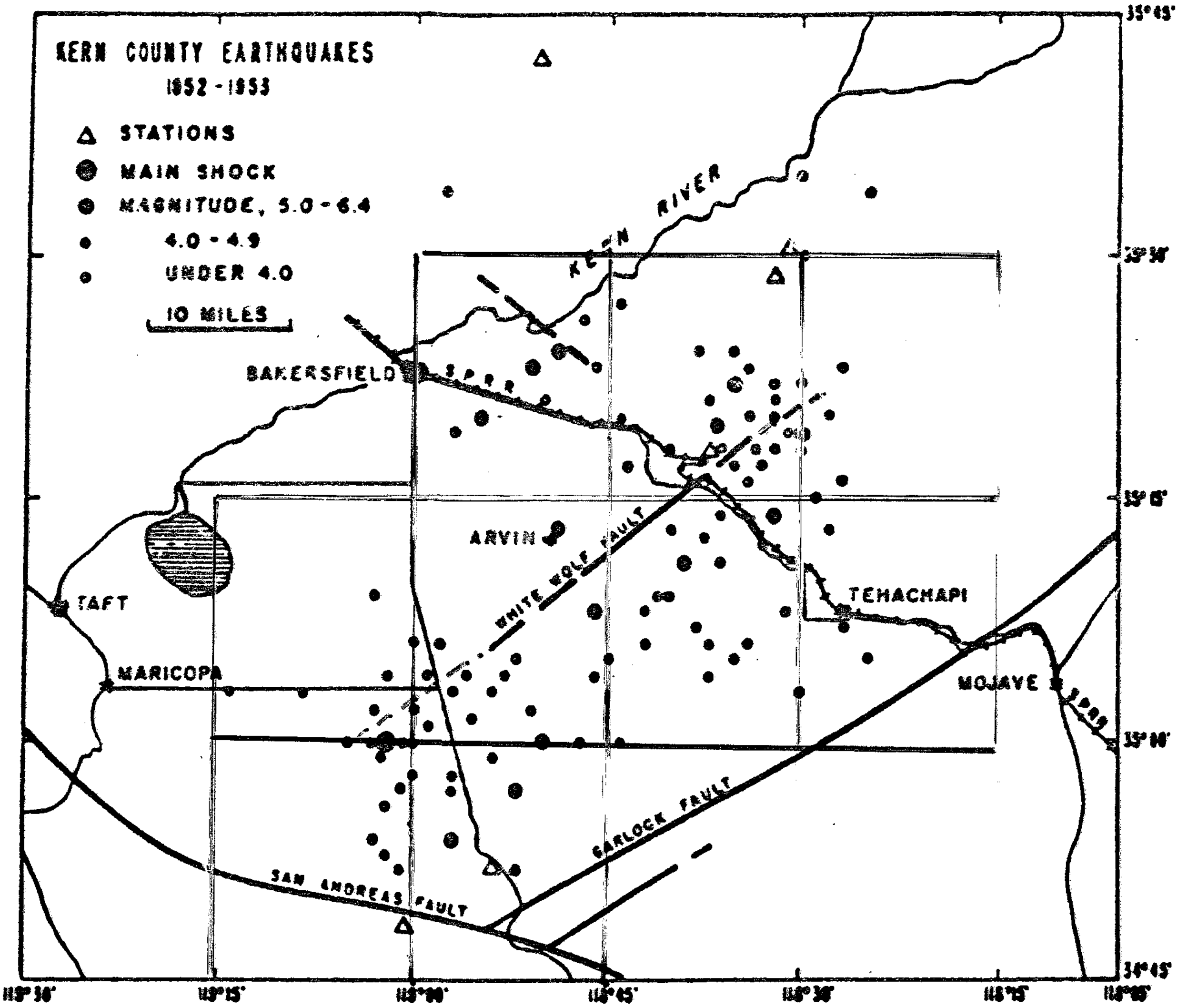
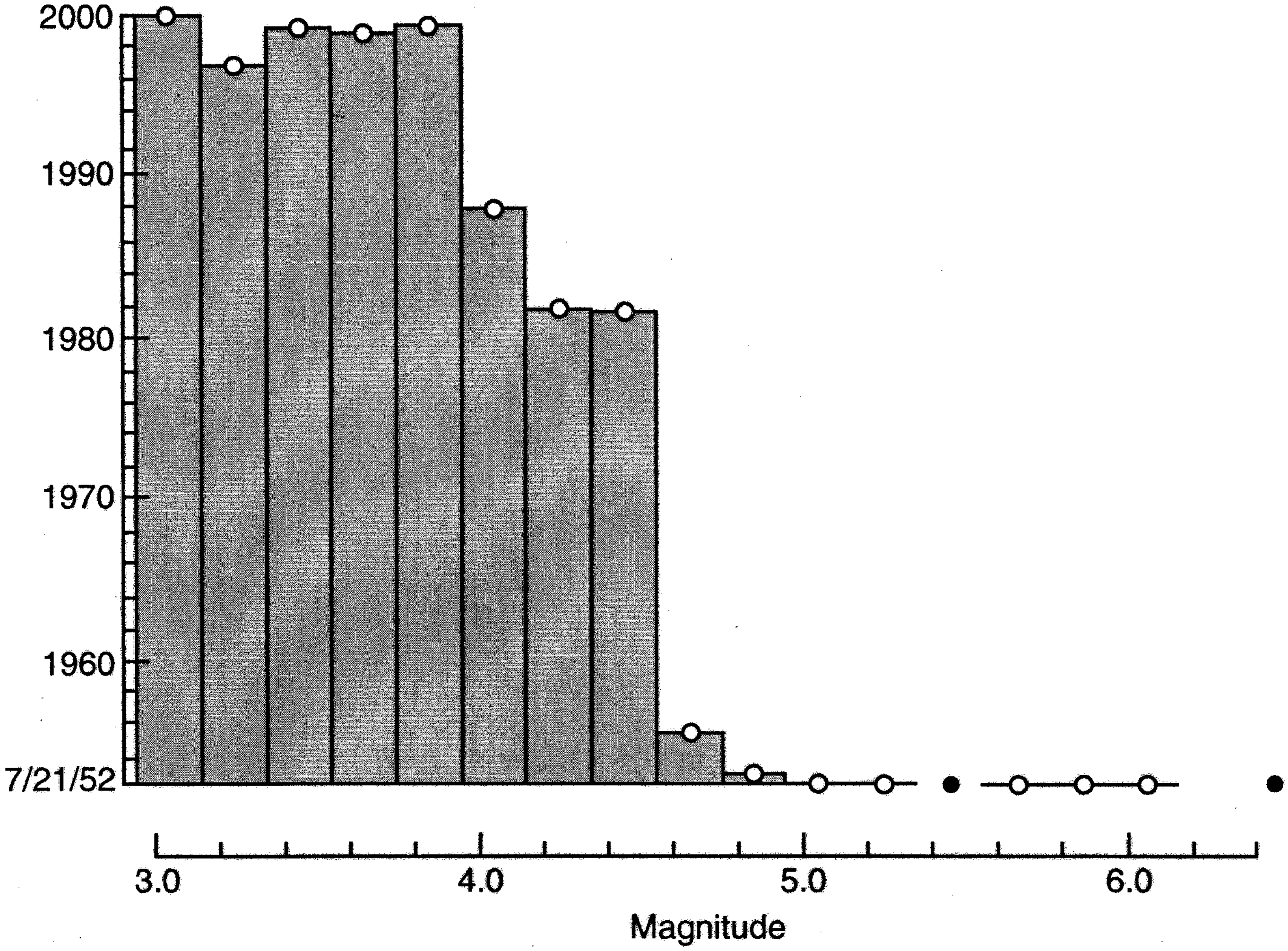


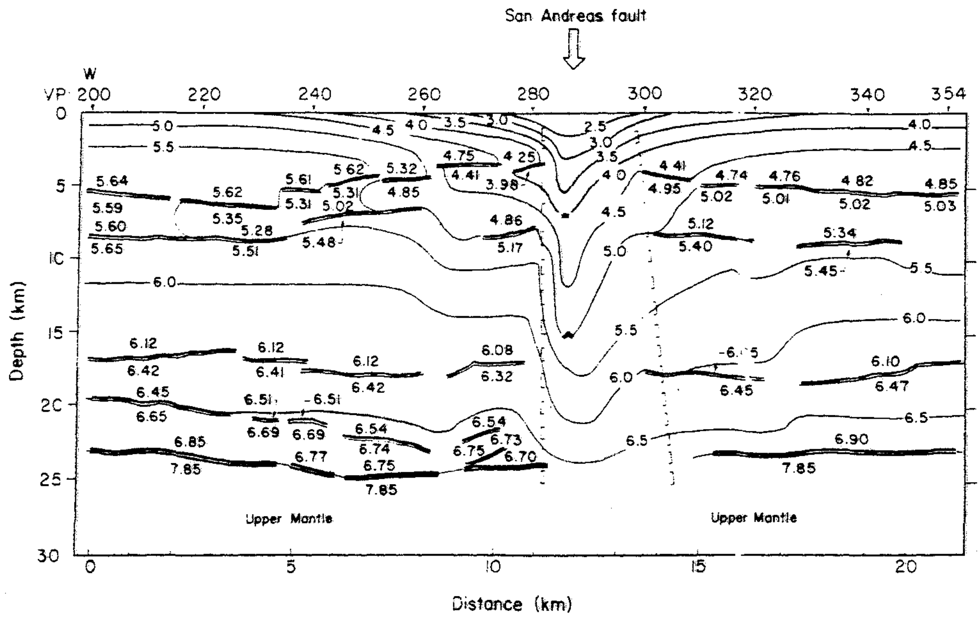
FIGURE 1. Epicenters of located shocks, July 21, 1952 through June 30, 1953. Coordinates as given in Table 1.

of the drive motor. After transfer to Fort Tejon in November the equipment functioned almost perfectly.

The Havilah station began recording on July 25, several hours after the large shocks of that date. The drum was out of gear July 26 for 6 hours, and on July 28/29 for 24 hours. Timing is uncertain for several days following August 13. The seismometer was disconnected from August 22 to August 29.

Recording at Knox Ranch was satisfactory except for

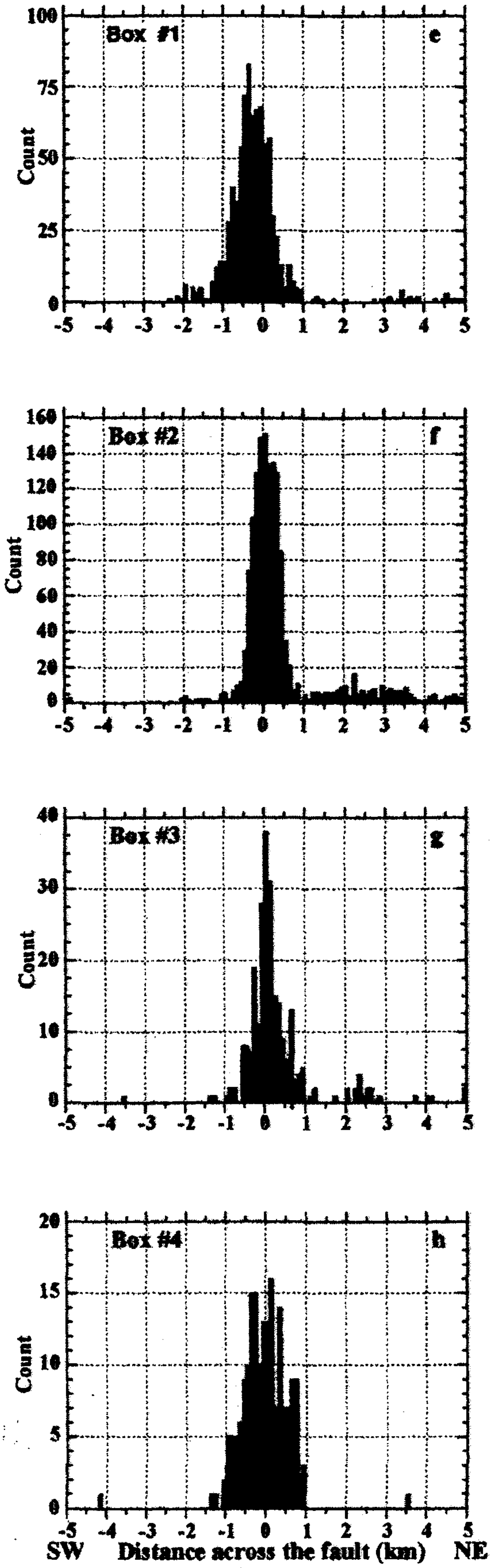

2000
1990
1980
1970
1960
7/21/52
3.0
4.0
5.0
6.0
Magnitude



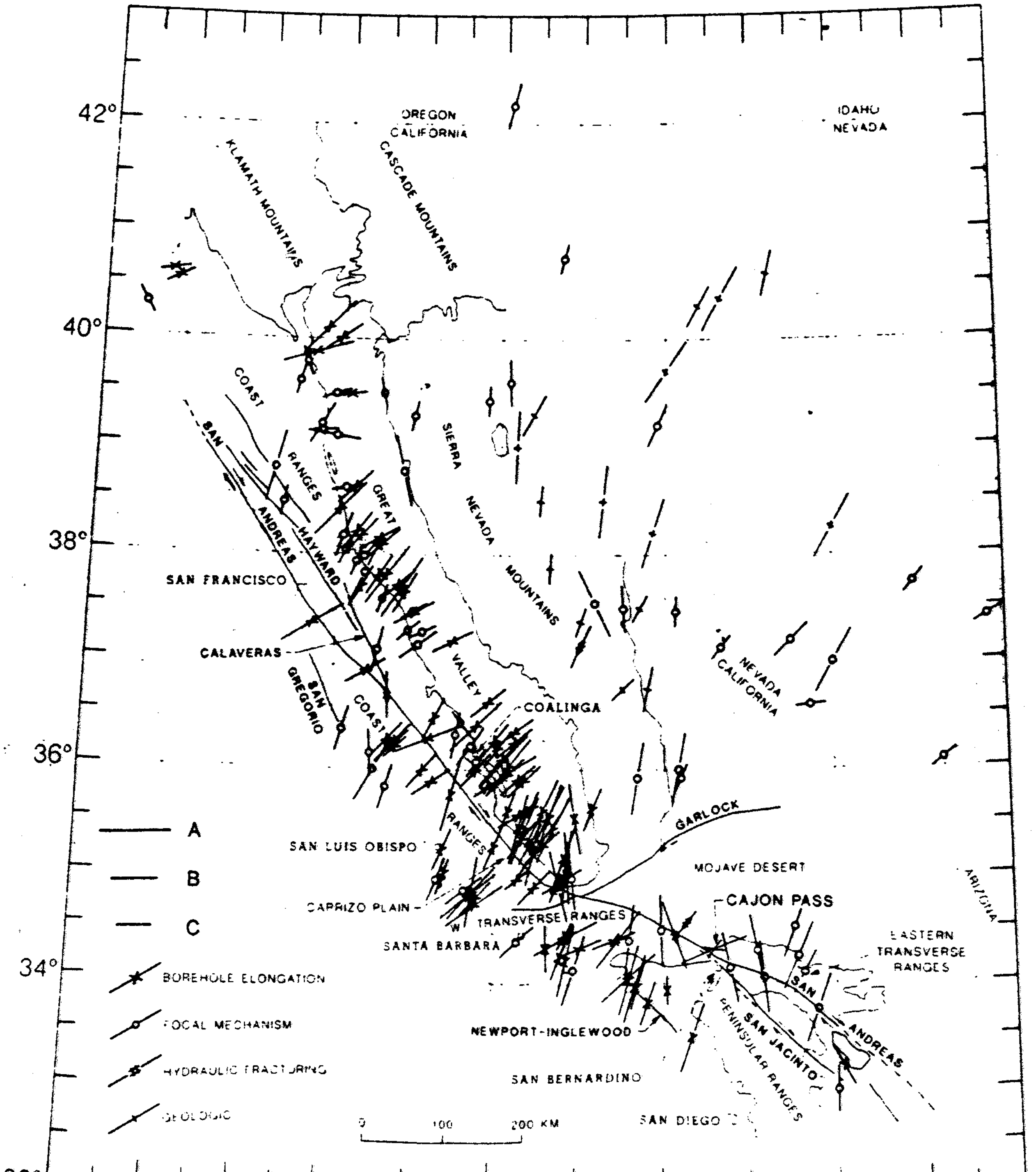
also

McBride + Brown BSSA 1986
Thurber et al. GRL 1997
Wang et al. GRL 1978 (gravity)
Mooney + Luetgert BSSA 1982
Stierman JGR 1984
Mooney + Ginsburg PAGEOPH 1986

FENG & MCEVILLY
BSSA 1983

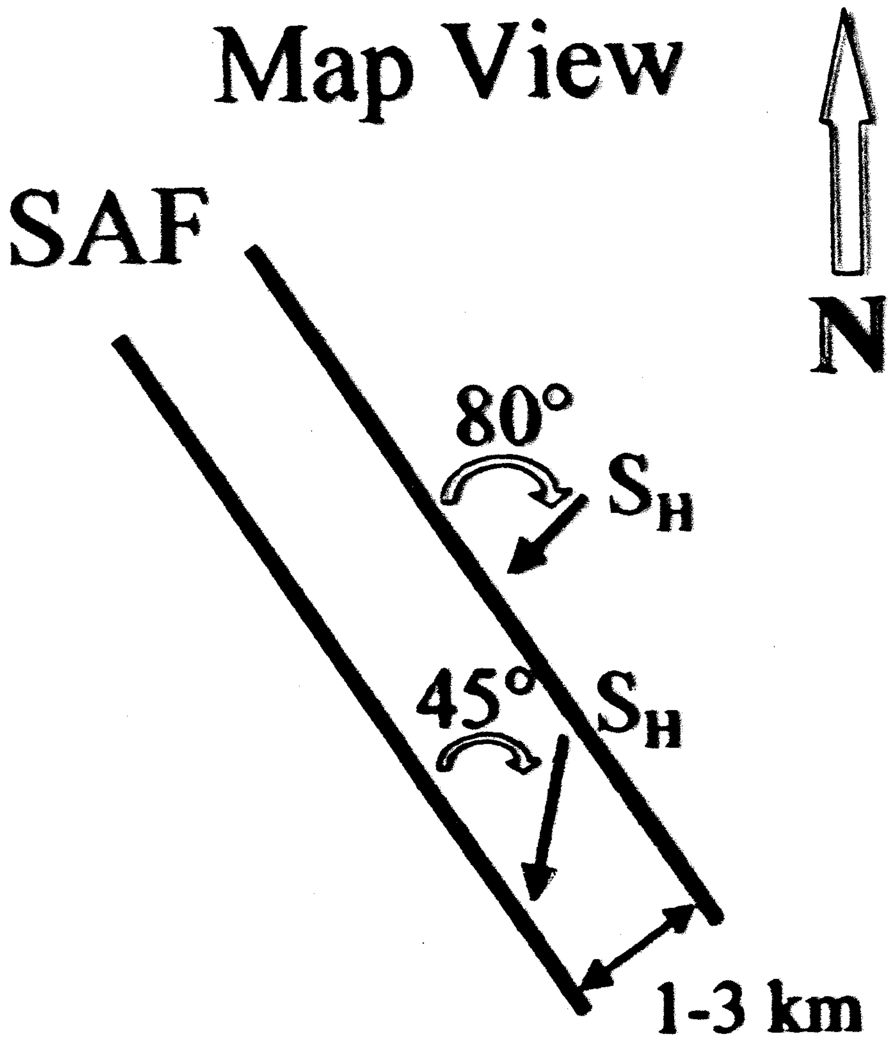


Box #1
e
Box #2
f
Box #3
g
Box #4
h
Count
SW Distance across the fault (km) NE



Generalized geologic map of California with data points showing the direction of maximum horizontal compression in the crust. The length of the bars attached to each data point is a measure of its quality (A, B, or C). The symbol associated with each data point indicates the type of stress indicator. No focal mechanisms from earthquakes directly on the San Andreas or major, right-lateral strike-slip subsidiary faults are included.

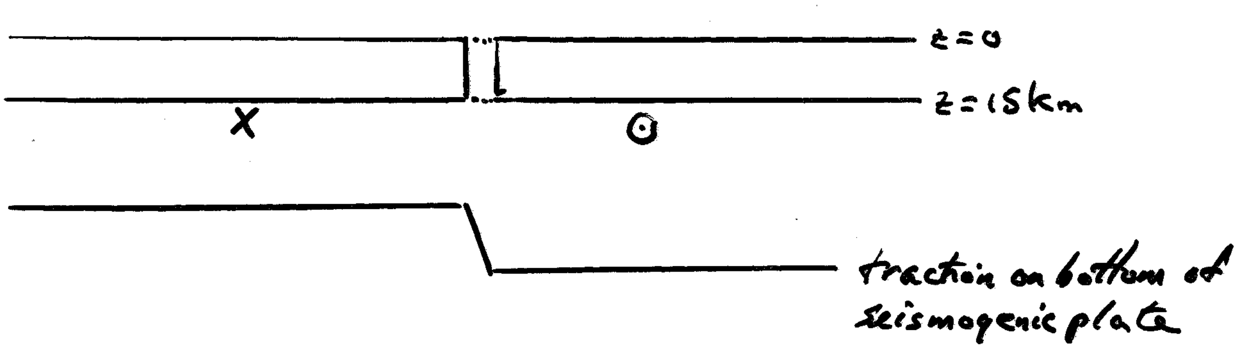
Science Zoback, et. al, 1987

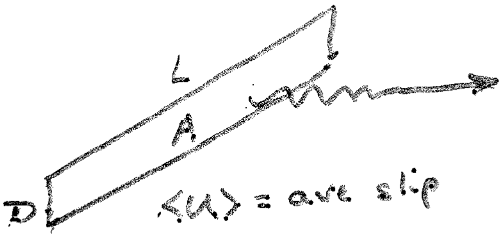


Provirosta Houston, JGR 2000

$$\sigma_{ij,j} = f_i$$

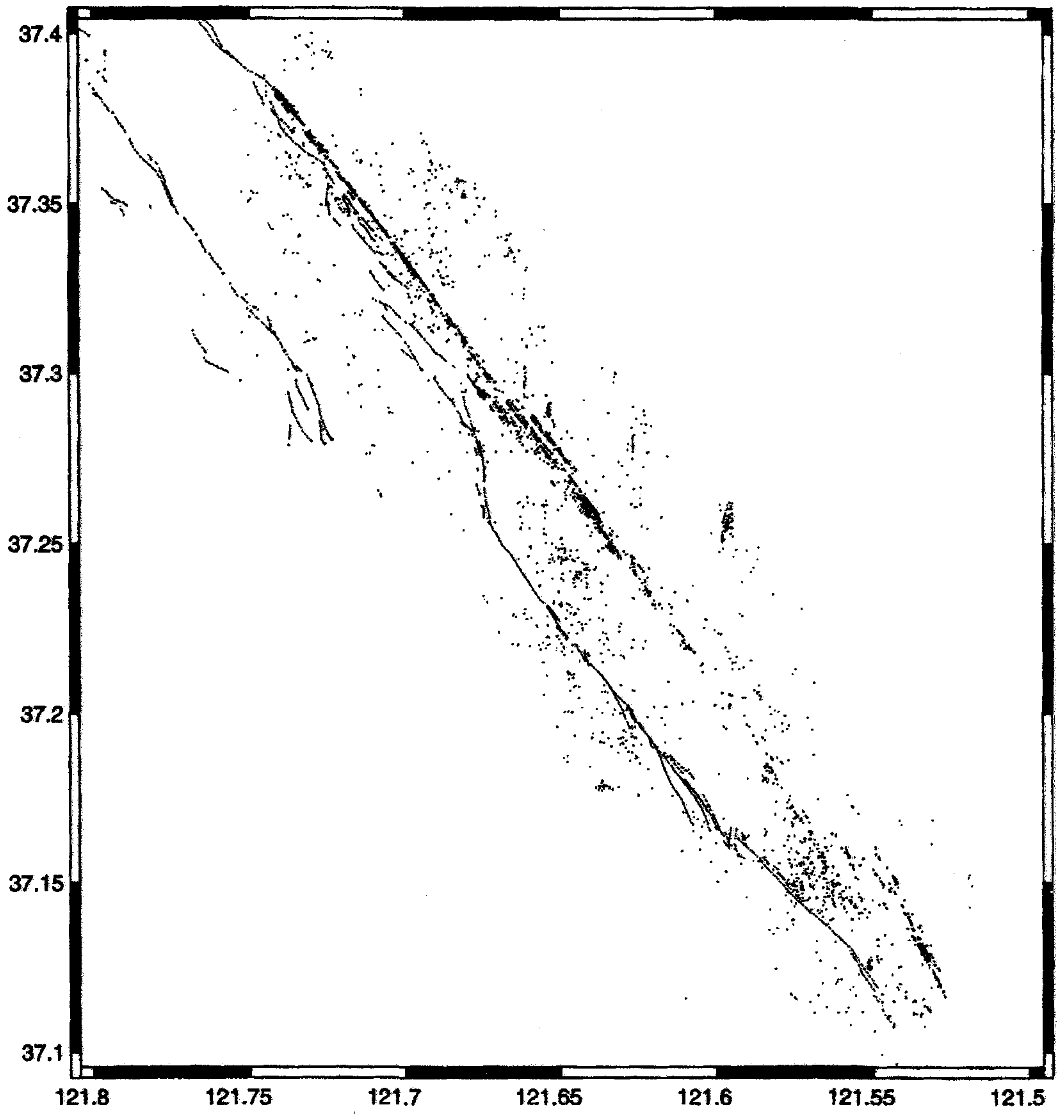
In the absence of body forces (f) stresses (σ) are continuous



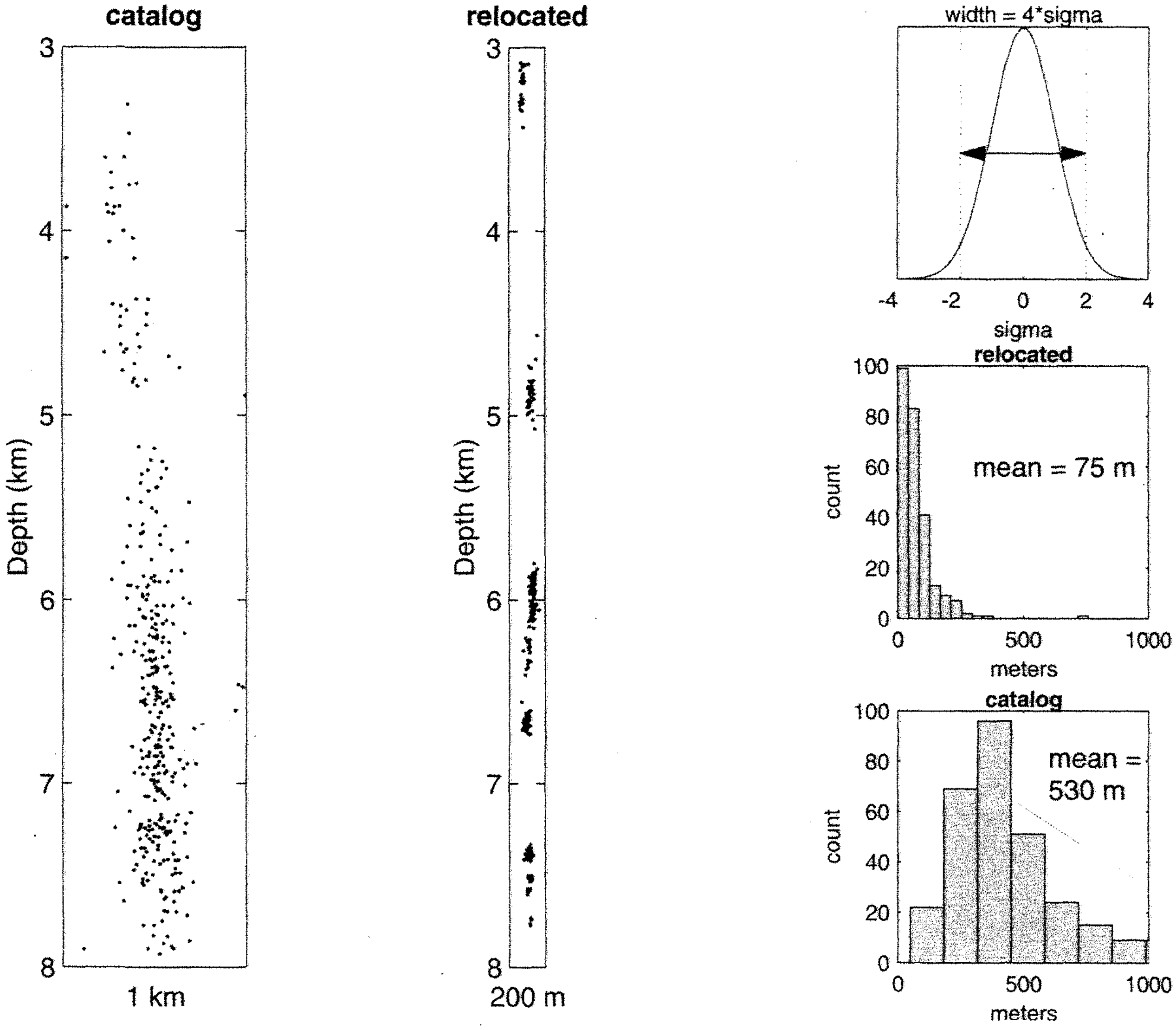


$A = LD$

Moment $= \mu \langle u \rangle$ A(rea)


37.4
37.35
37.3
37.25
37.2
37.15
37.1
121.8
121.75
121.7
121.65
121.6
121.55
121.5

Fault Zone Width



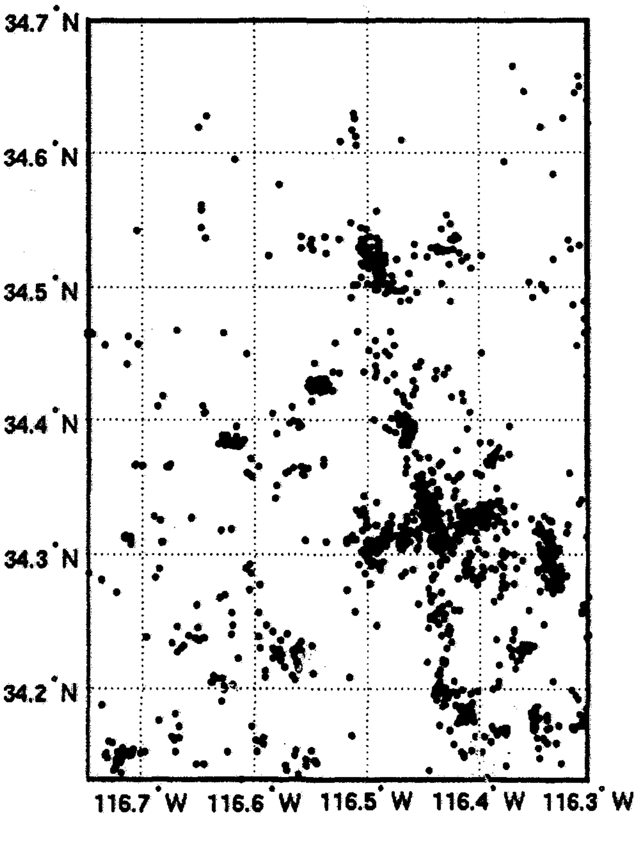
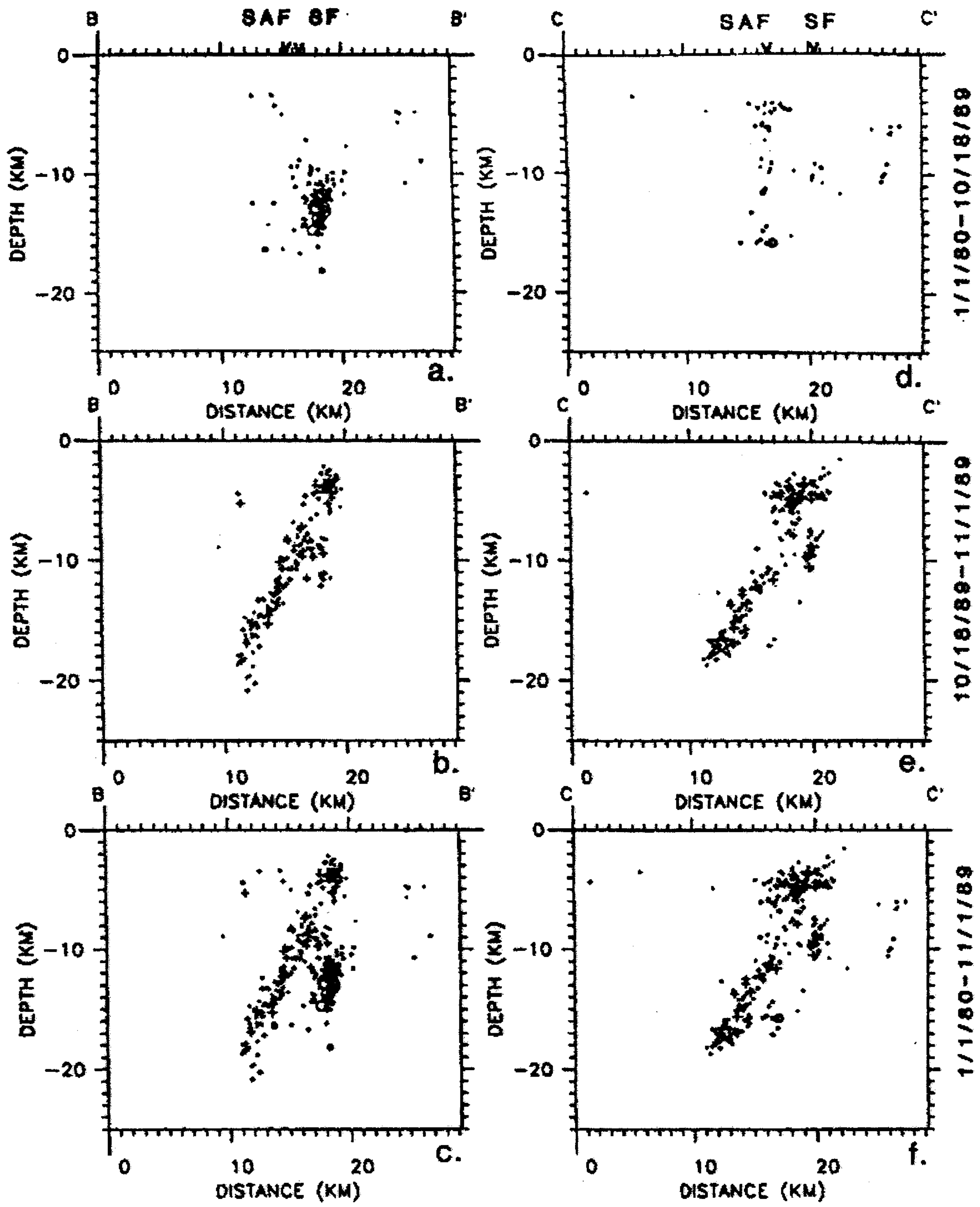
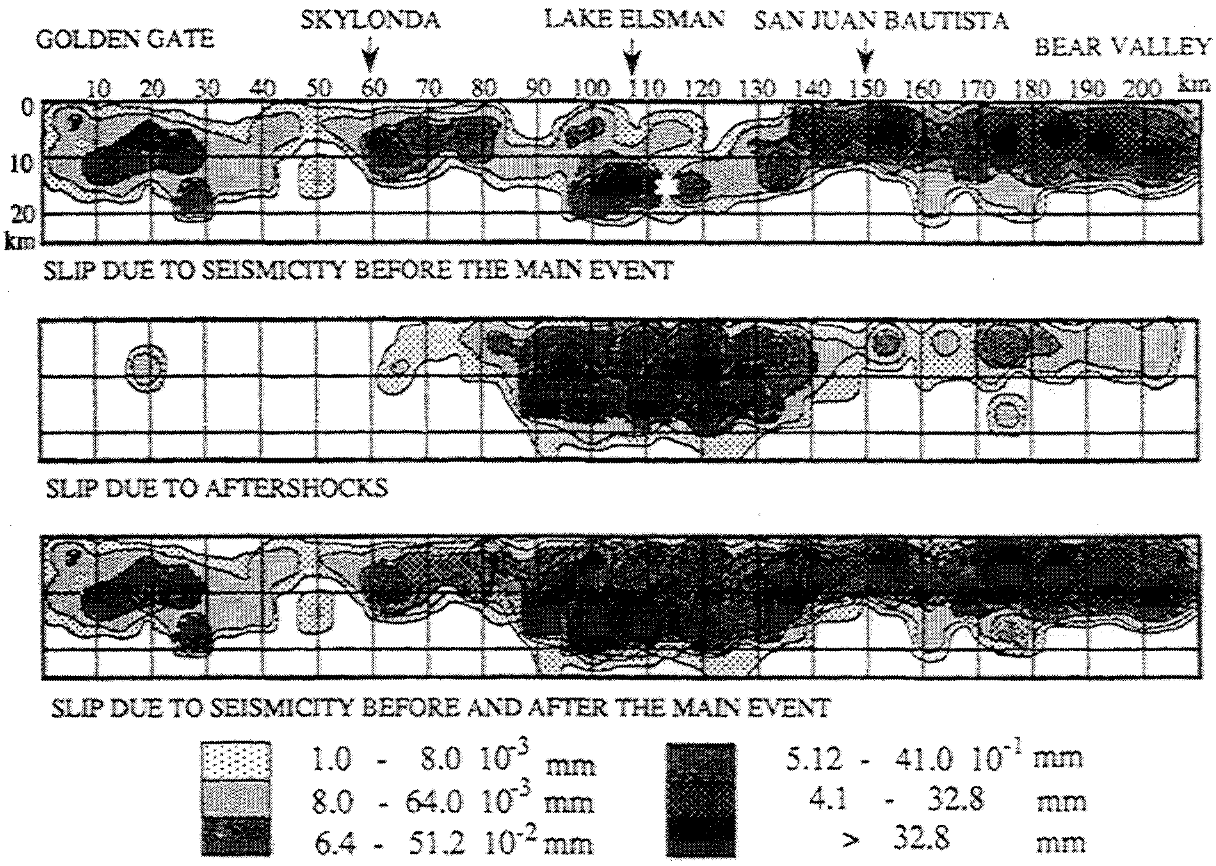
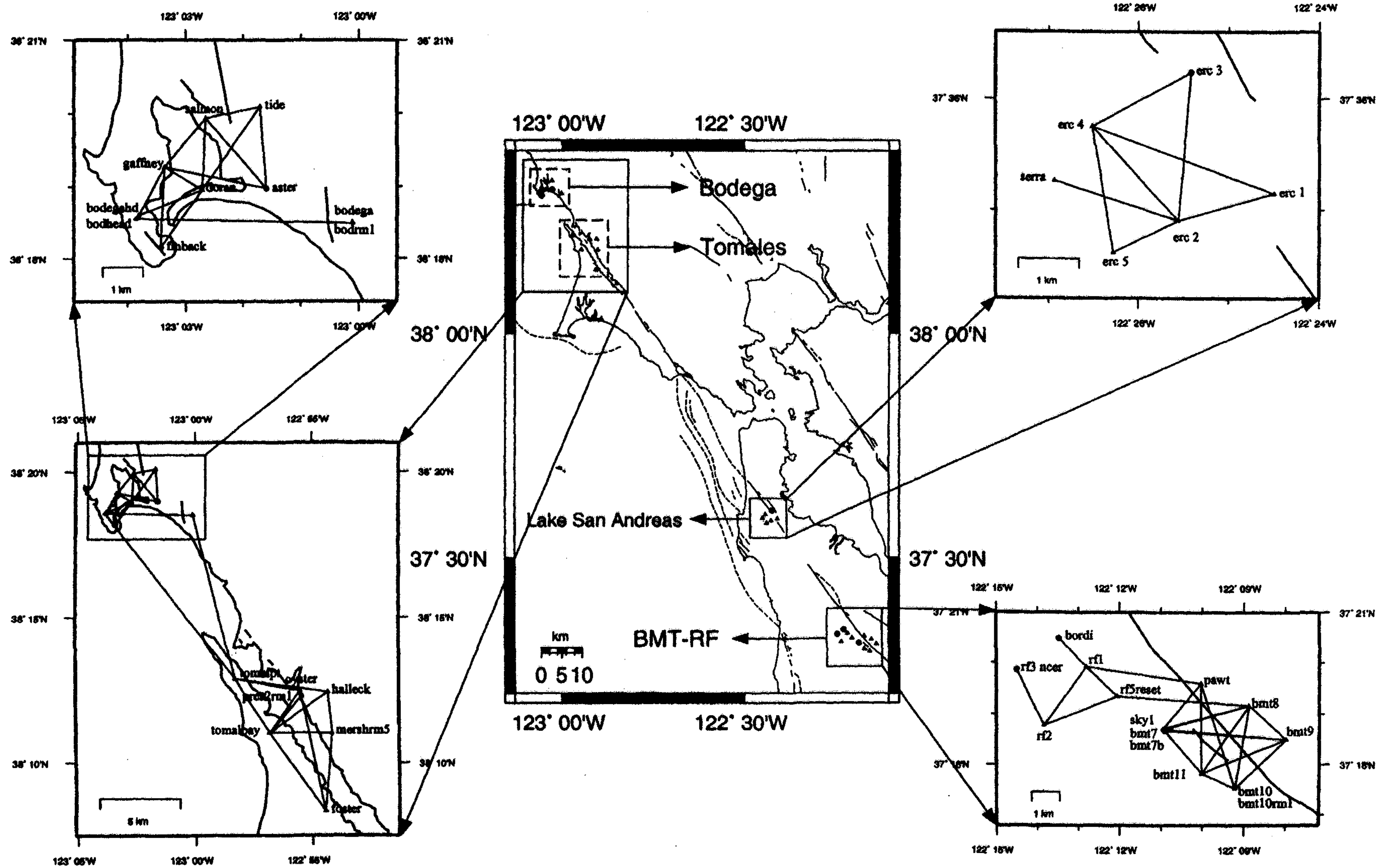

34.7° N
34.6° N
34.5° N
34.4° N
34.3° N
34.2° N
116.7° W
116.6° W
116.5° W
116.4° W
116.3° W
34.7° N
34.6° N
34.5° N
34.4° N
34.3° N
34.2° N
116.7° W
116.6° W
116.5° W
116.4° W
116.3° W

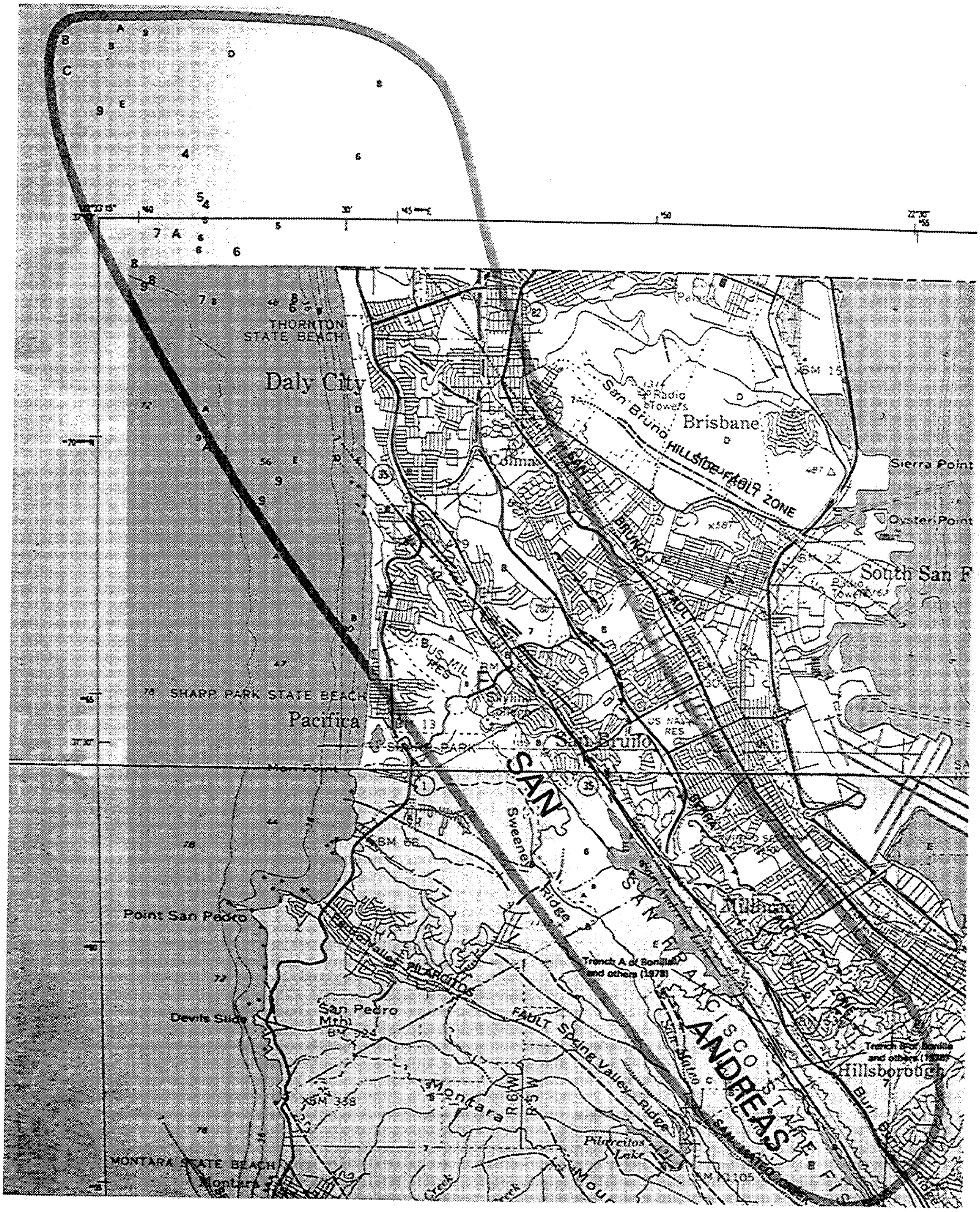
FIG. 4


B
SAF SF
B'
C
SAF SF
C'
DEPTH (KM)
DISTANCE (KM)
a.
b.
c.
d.
e.
f.
1/1/80-10/18/89
10/18/89-11/1/89
1/1/80-11/1/89

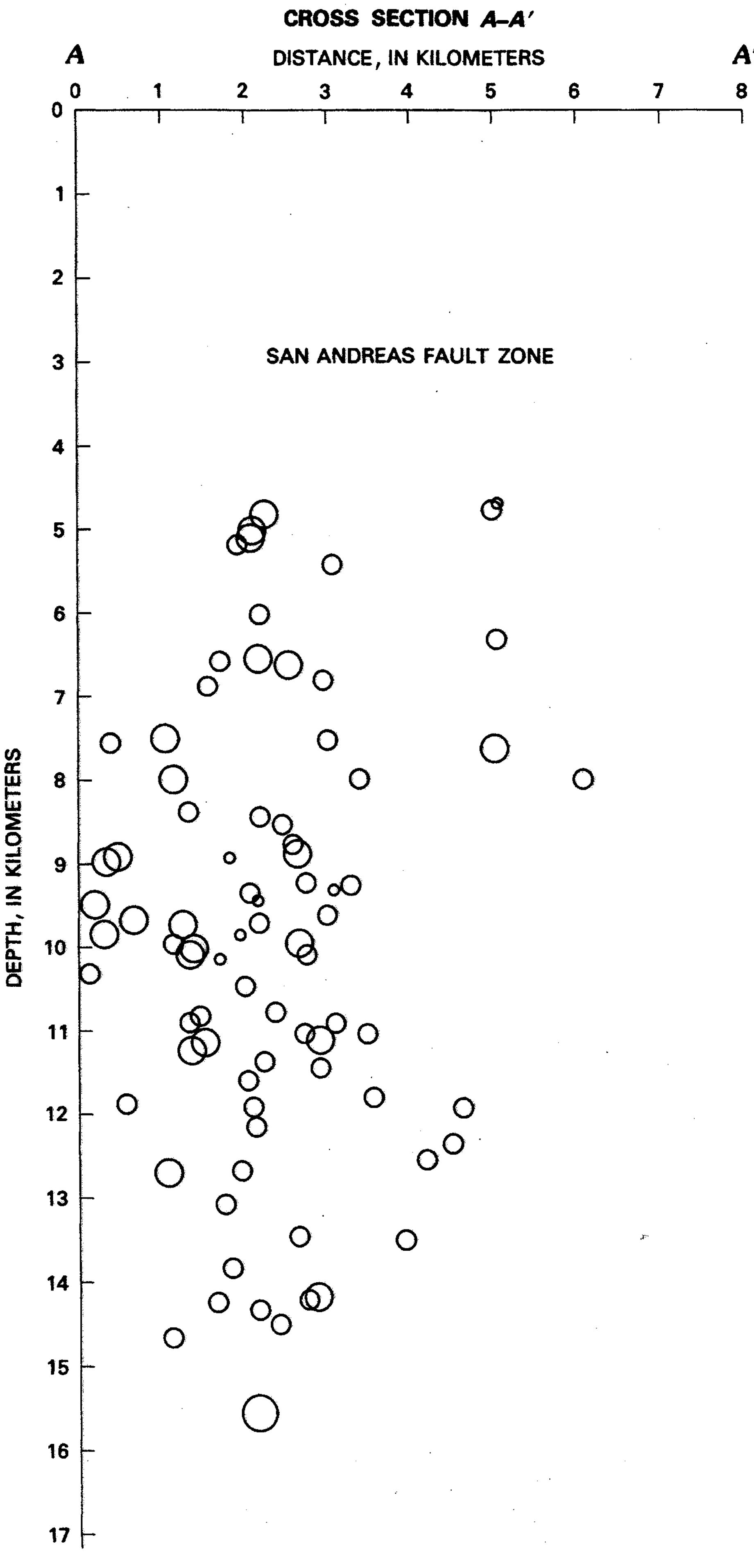

GOLDEN GATE
SKYLONDA
LAKE ELSMAN
SAN JUAN BAUTISTA
BEAR VALLEY
10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 km
0
10
20
km
SLIP DUE TO SEISMICITY BEFORE THE MAIN EVENT
SLIP DUE TO AFTERSHOCKS
SLIP DUE TO SEISMICITY BEFORE AND AFTER THE MAIN EVENT
1.0 - 8.0 10^{-3} mm
8.0 - 64.0 10^{-3} mm
6.4 - 51.2 10^{-2} mm
5.12 - 41.0 10^{-1} mm
4.1 - 32.8 mm
> 32.8 mm

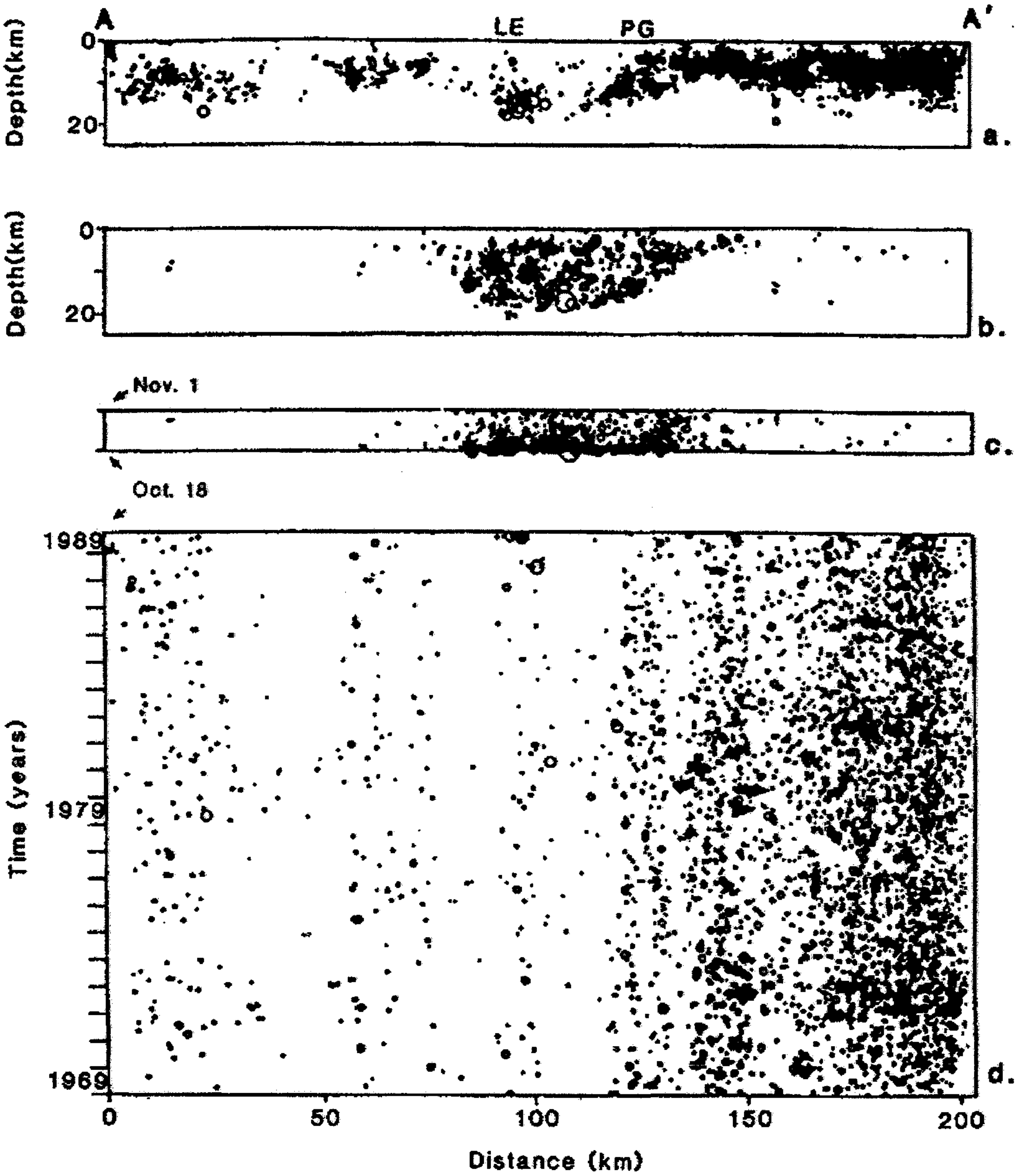


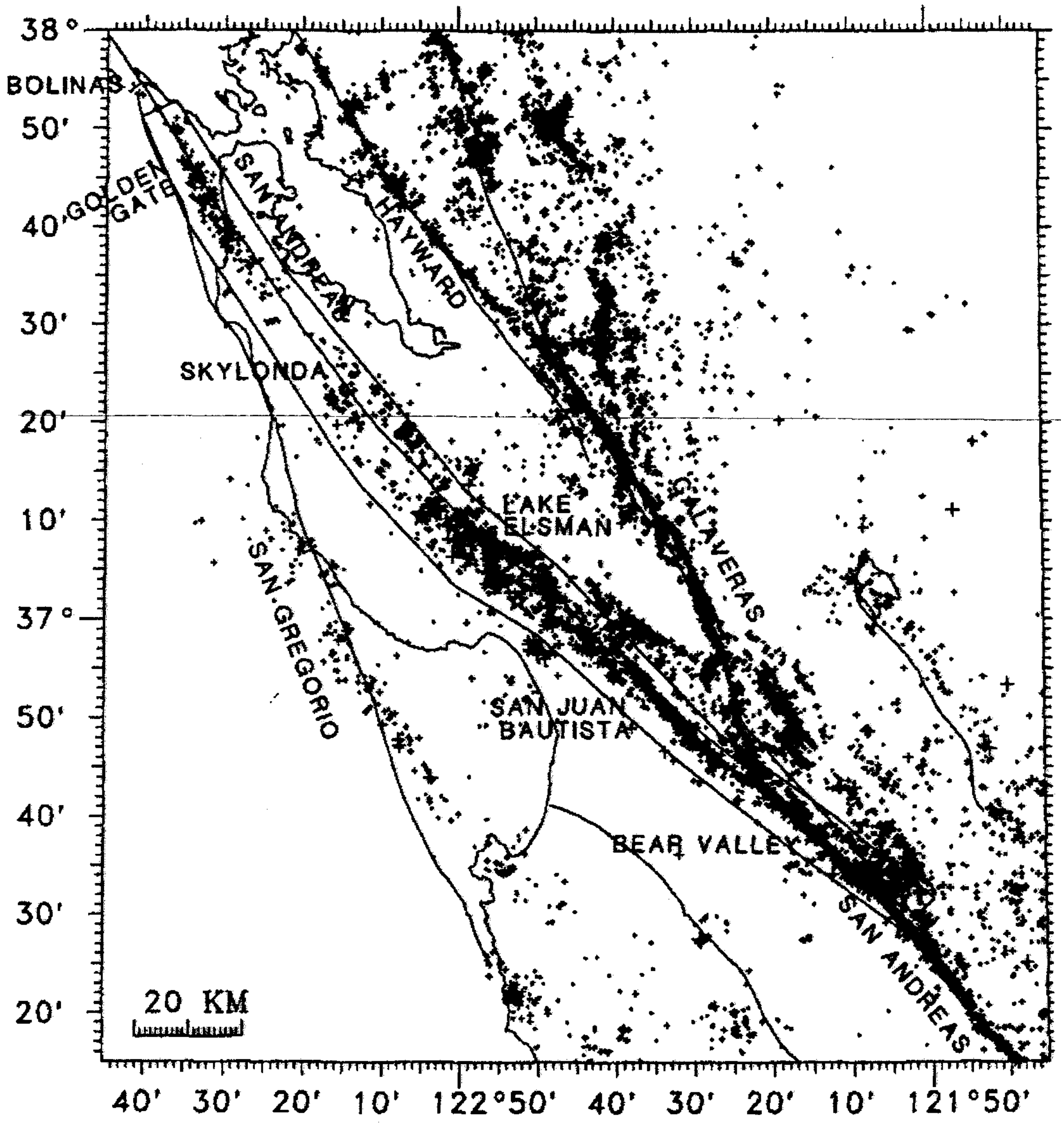
Chen and Freymueller 2002

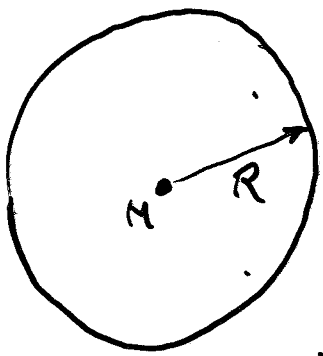


THORNTON STATE BEACH
Daly City
Colma
Brisbane
San Bruno
HILLSIDE FAULT ZONE
Radio Towers
Sierra Point
Oyster Point
South San F
SHARP PARK STATE BEACH
Pacifica
San Bruno
SAN
ANDREAS
Sweeney Ridge
Point San Pedro
PILARCITOS
FAULT
Sawyer Ridge
Devils Slide
San Pedro Mtn
Montara
Pilarcitos Lake
Trench A of Bonilla and others (1978)
Trench B of Bonilla and others (1978)
Hillsborough
Millbrae
MONTARA STATE BEACH


CROSS SECTION A–A′
A
DISTANCE, IN KILOMETERS
A′
0
1
2
3
4
5
6
7
8
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
SAN ANDREAS FAULT ZONE
DEPTH, IN KILOMETERS

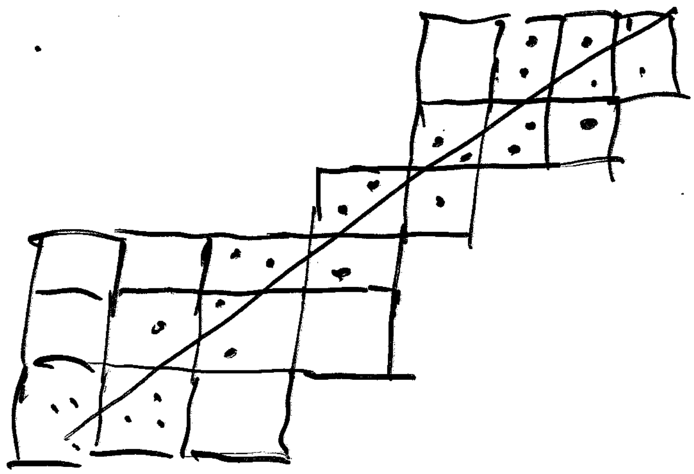

A
LE
PG
A'
Depth(km)
0
20
a.
Depth(km)
0
20
b.
Nov. 1
c.
Oct. 18
1989
1979
1969
Time (years)
d.
0
50
100
150
200
Distance (km)

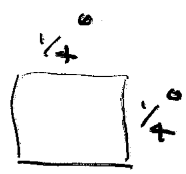

38°
50'
40'
30'
20'
10'
37°
50'
40'
30'
20'
BOLINAS
GOLDEN GATE
SAN ANDREAS
HAYWARD
SKYLONDA
LAKE ELSMAN
CALAVERAS
SAN GREGORIO
SAN JUAN BAUTISTA
BEAR VALLEY
SAN ANDREAS
20 KM
40'
30'
20'
10'
122°50'
40'
30'
20'
10'
121°50'

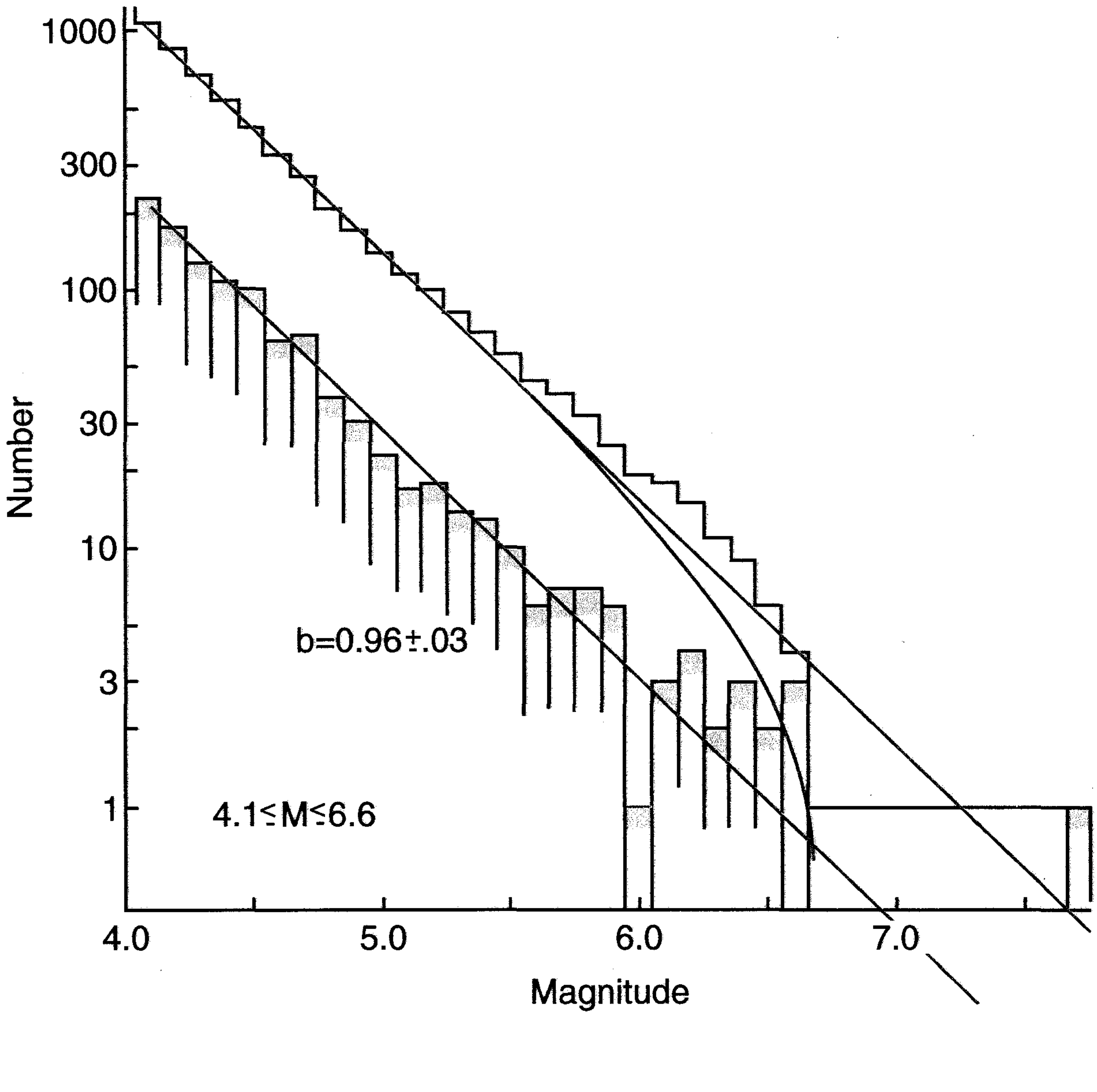


R(M)

$\Delta T(M)$







1944 - 1990
All Earthquakes

$$\frac{1}{b'} = \frac{1}{b \log_e 10} = \overline{M} - M_L$$

$$\sigma_b^2 = b^2/N$$

$N = e^{a-b'M}$

$\uparrow$

$\log_e N = a - b'M$

$N - 1/t_r$

$$\frac{\Delta M}{e^{b'\Delta M} - 1} - \frac{(M_U - M_L + \Delta M)}{e^{b'(M_U - M_L + \Delta M)} - 1} = \overline{M} - M_L$$

$$\sigma_b^2 = \frac{b^2}{N} \frac{(1 - e^{-x})^2}{(1 - e^{-x})^2 - x^2 e^{-x}}$$

$$x = b'(M_U - M_L + \Delta M)$$

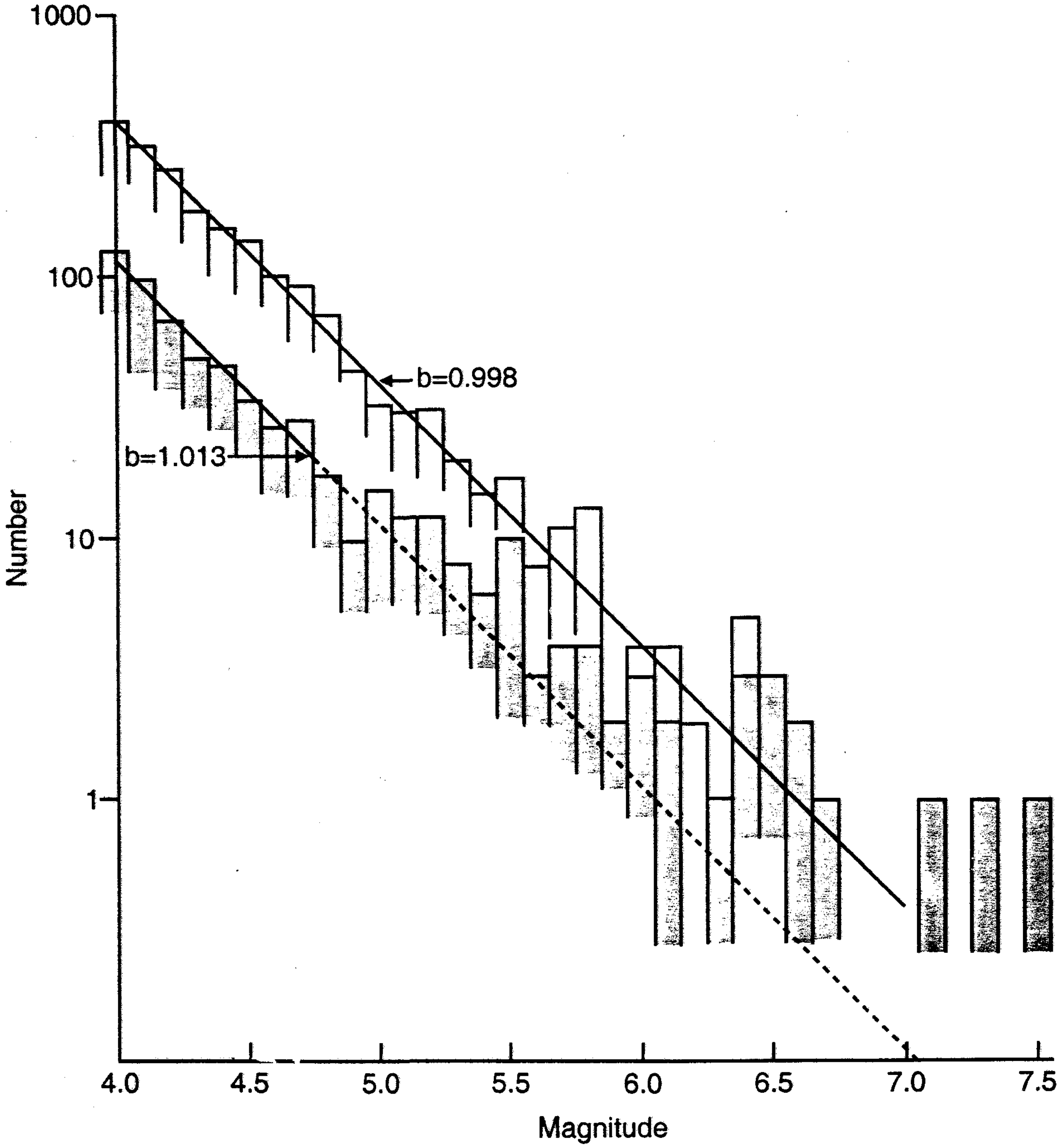

1000
100
10
1
Number
b=0.998
b=1.013
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
Magnitude

Fig.

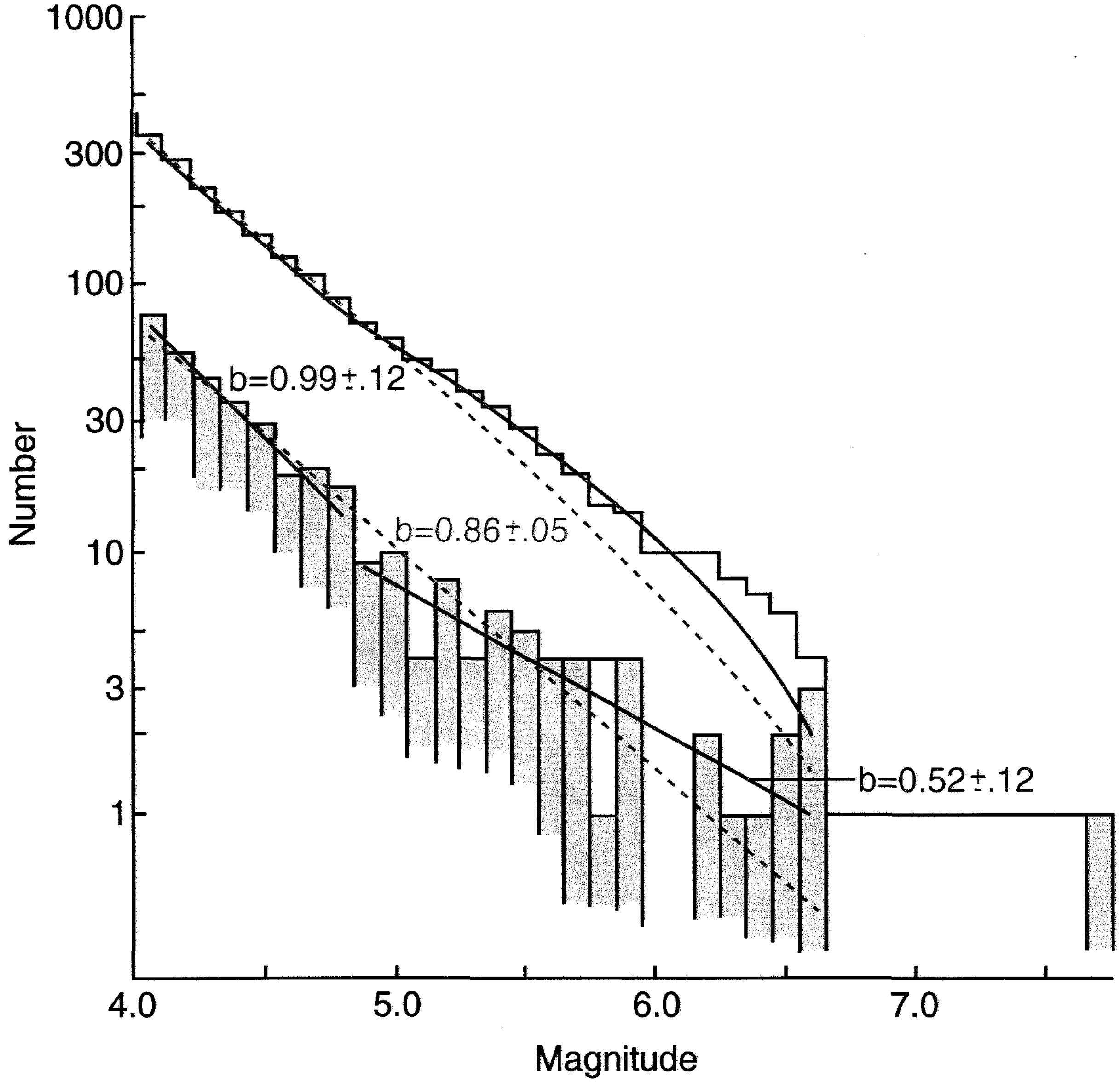
b-values

Mag. Range	Total	Clusters	Main Shocks
4.1-7.7	0.97±.03		0.87±.05
4.1-6.6	0.96±.03	1.01±.04*	0.86±.05
4.1-4.8	**0.98±.07**	1.01±.08	**0.99±.12**
4.9-7.7	0.82±.07		0.64±.10
4.9-6.6	**0.73±.08**	0.83±.11*	**0.52±.12**
4.9-5.9	0.74±.12	0.90±.16	0.50±.19

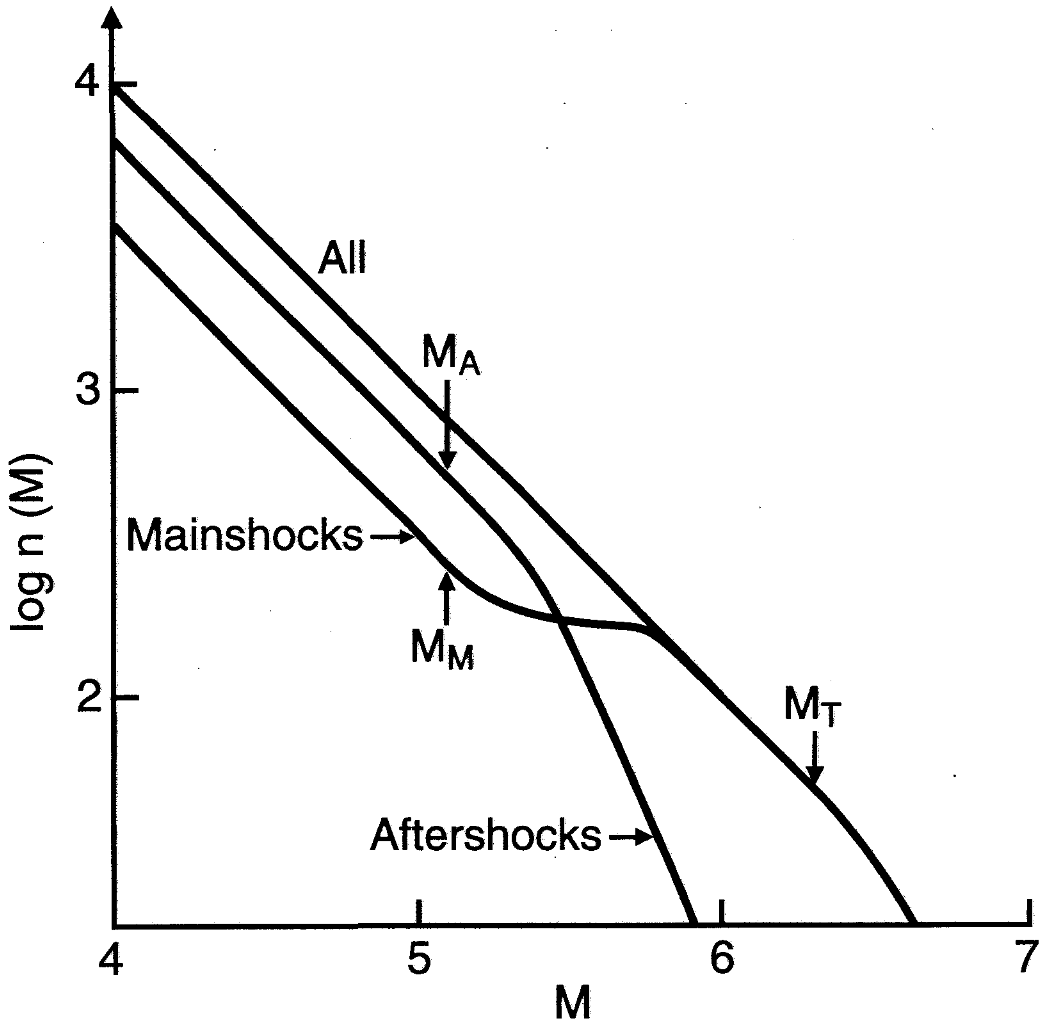
* upper Mag. limit = 6.4

KNOPOFF, PNAS, 2001

8

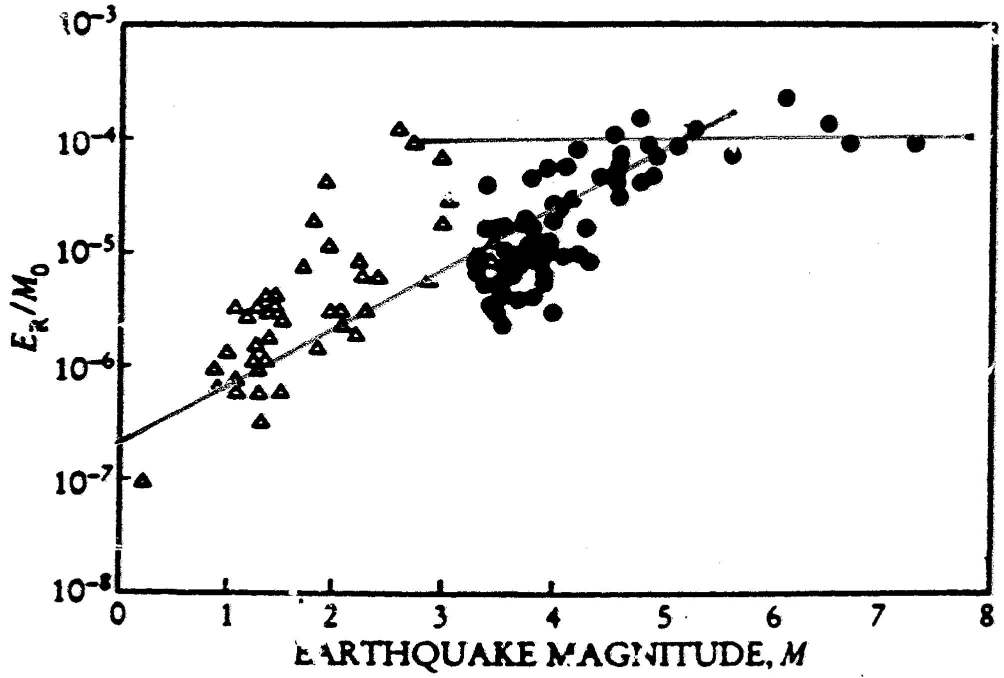


1000
300
100
30
10
3
1
Number
b=0.99±.12
b=0.86±.05
b=0.52±.12
4.0
5.0
6.0
7.0
Magnitude



4
3
2
log n (M)
All
M_A
Mainshocks
M_M
M_T
Aftershocks
4
5
6
7
M

21



For smooth, planar fractures

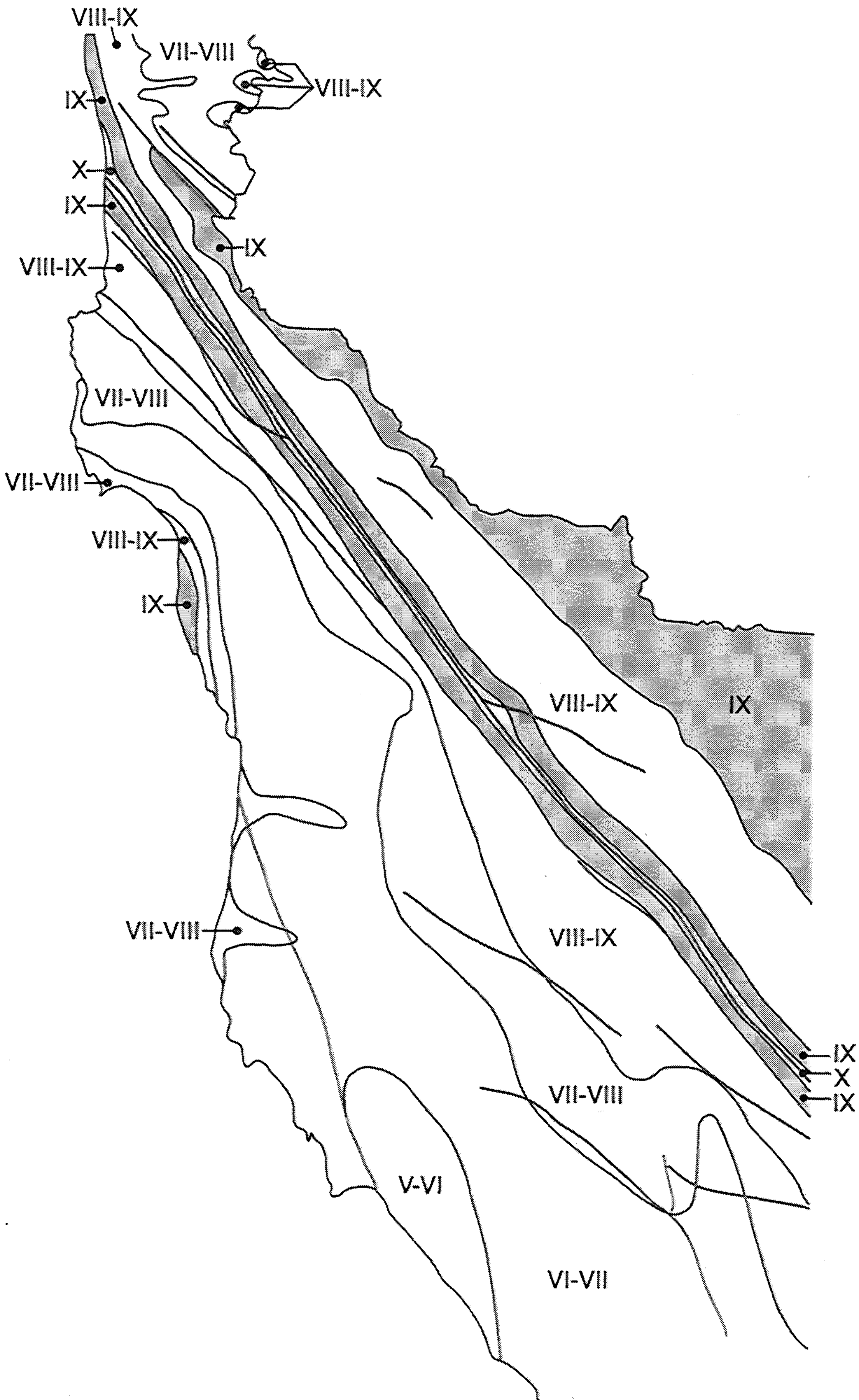
$M_0 \sim L^3$

$E_R \sim L^3$

suggesting $E_R \sim L^{p>3}$ for $M<5$.

if $p=4$, $\log \frac{E_R}{M_0} \sim M/2$

Kanamori + Brodsky, Phys. Today 2


VIII-IX
VII-VIII
VIII-IX
IX
X
IX
VIII-IX
IX
VII-VIII
VII-VIII
VIII-IX
IX
VIII-IX
IX
VIII-IX
VII-VIII
IX
X
IX
VII-VIII
V-VI
VI-VII

CONCLUSIONS

1. A large number of independent geophysical observations identify a transient, structurally heterogeneous zone of elevated compliance 2-4 km wide adjoining many major earthquake faults in California.

2. The standard elastic rebound model of deformation before a large eq. must be modified to allow for precursory accelerated strain and steady low-level seismicity in an emergent tabular compliant zone astride a major earthquake fault.

3. Three segments of the San Andreas Fault may have this precursor at this time.

4. The universality of usual scale-independent statistics arises from the universality of the properties of aftershocks, most of which are located in the compliant zone, heavily and irregularly damaged by repeated large earthquakes.

5. Model-based assertions that large earthquakes are unpredictable because of the absence of critical dimensions are not Tenable.