USGS science for a changing world

Earthquake Hazards Program

Double-Difference Earthquake Locations and Their Implications for Hazards and Earthquake Physics

Bill Ellsworth, Lauro Chiaraluce, Eiichi Fukuyama, Hisao Ito, Shinobu Ito, Stephanie Prejean, Anna Stork,

and Felix Waldhauser

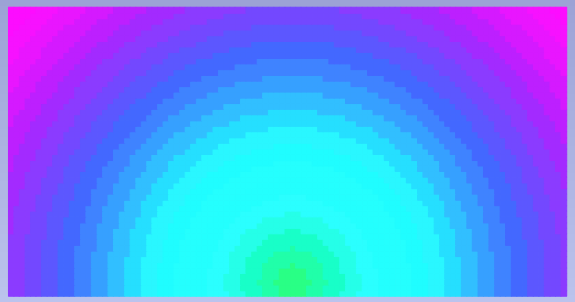
Outline

- Overview of double-difference method.
- Fine structure of active fault zones.
- Fine structure of rupture zones.
- Double difference tomography.
- Implications for hazards and earthquake physics.
- Conclusions.

Basic Concepts

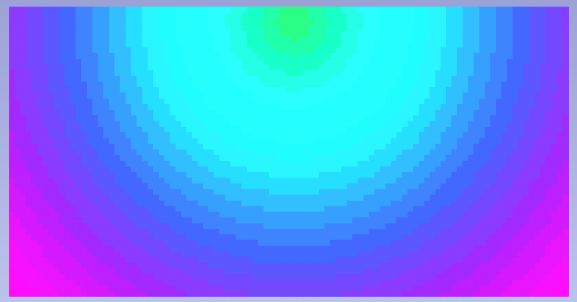
- Ordinary location methods (one event at a time) require accurate Earth models.
- Knowledge of seismic velocities in the Earth is incomplete.
- Double-difference algorithm reformulates the location problem to solve for changes in the distance between pairs of events.
- By forming differences in this manner, travel time errors due to the unknown Earth structure cancel out.

Travel Time from Source
to All Possible Single Scatters



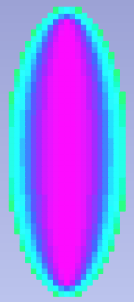
+

Travel Time to Receiver
from All Possible Single Scatters

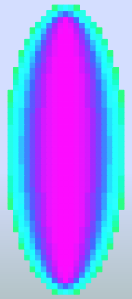


=

Frechet Travel Time Kernel
f 1 Hz

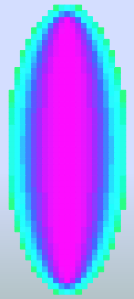


Frechet Travel Time Kernel
for One Source



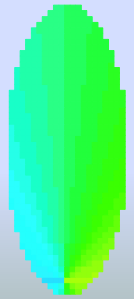
-

Frechet Travel Time Kernel
for a Nearby Source

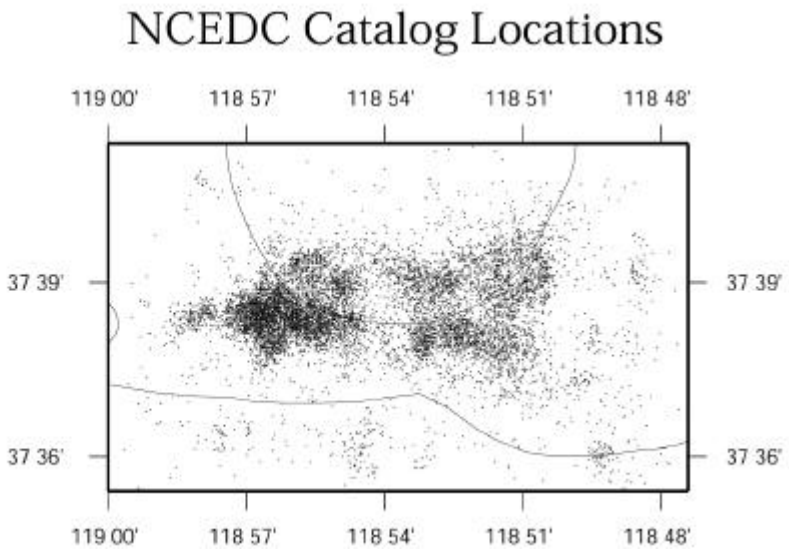


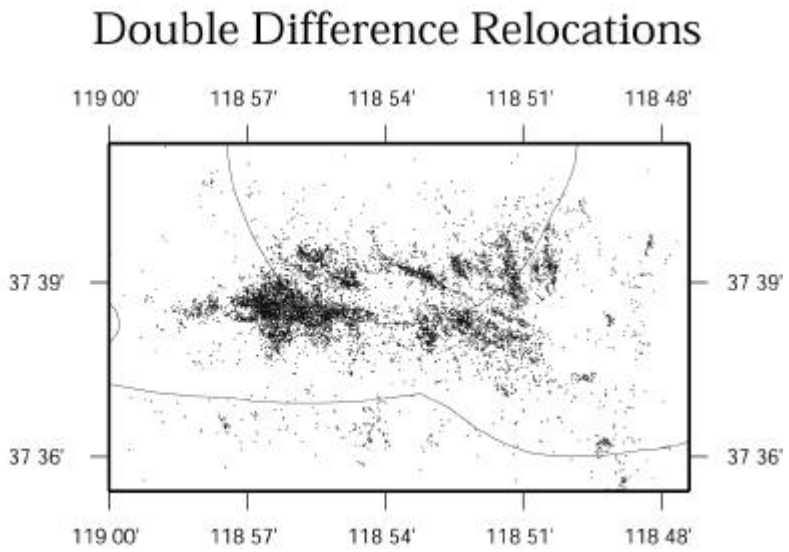
=

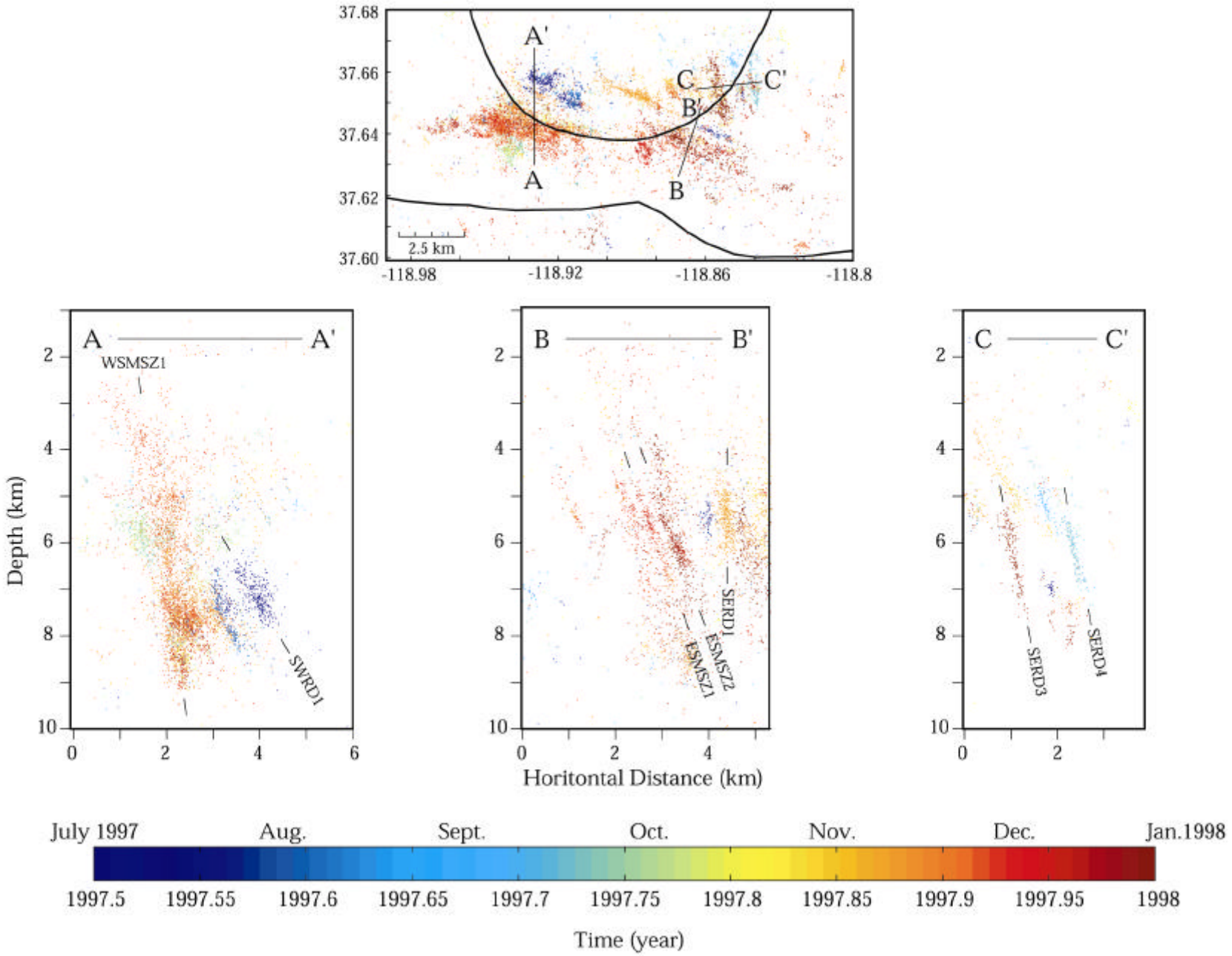
Frechet Travel Time Kernel
for a Nearby Source



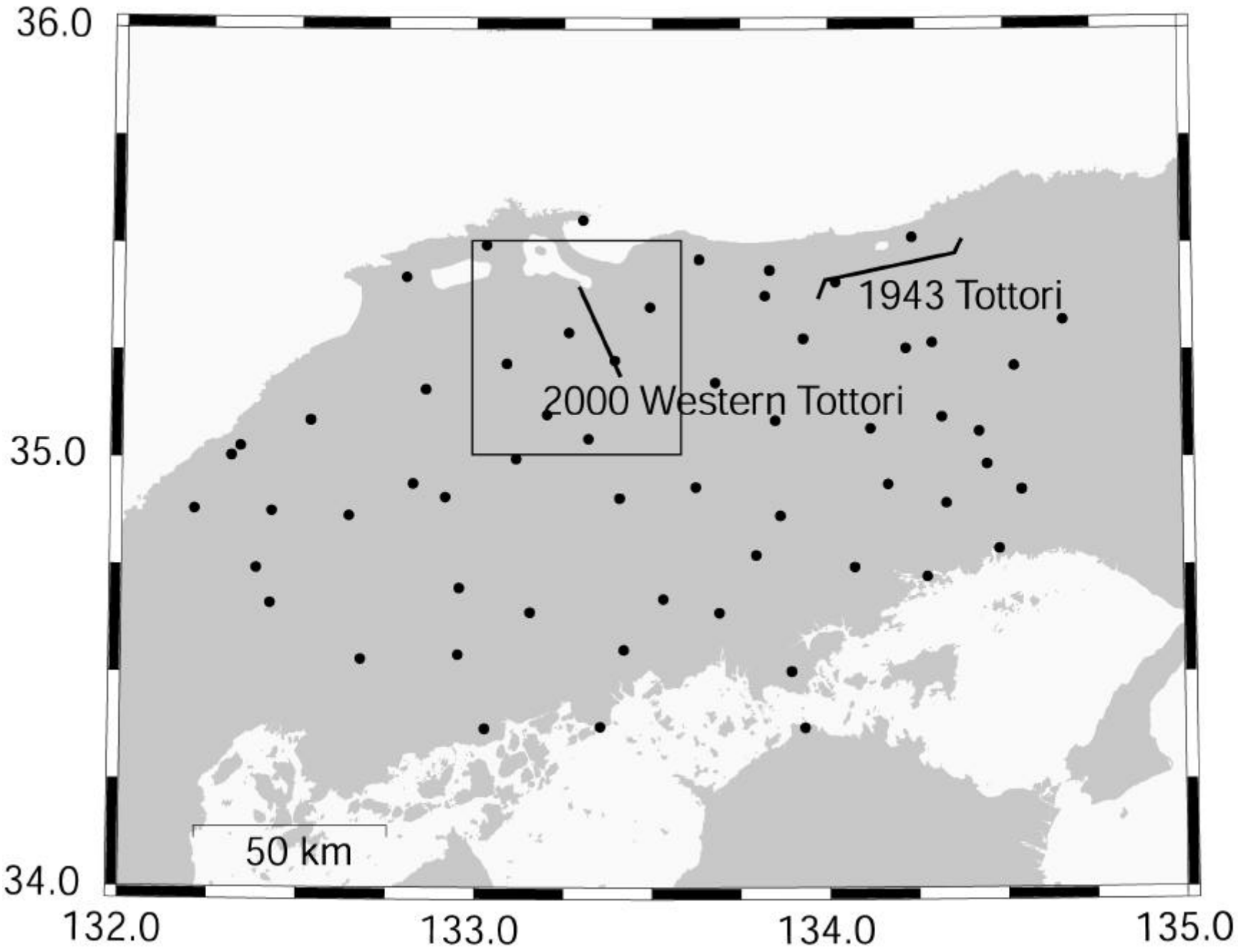
South Moat of Long Valley Caldera

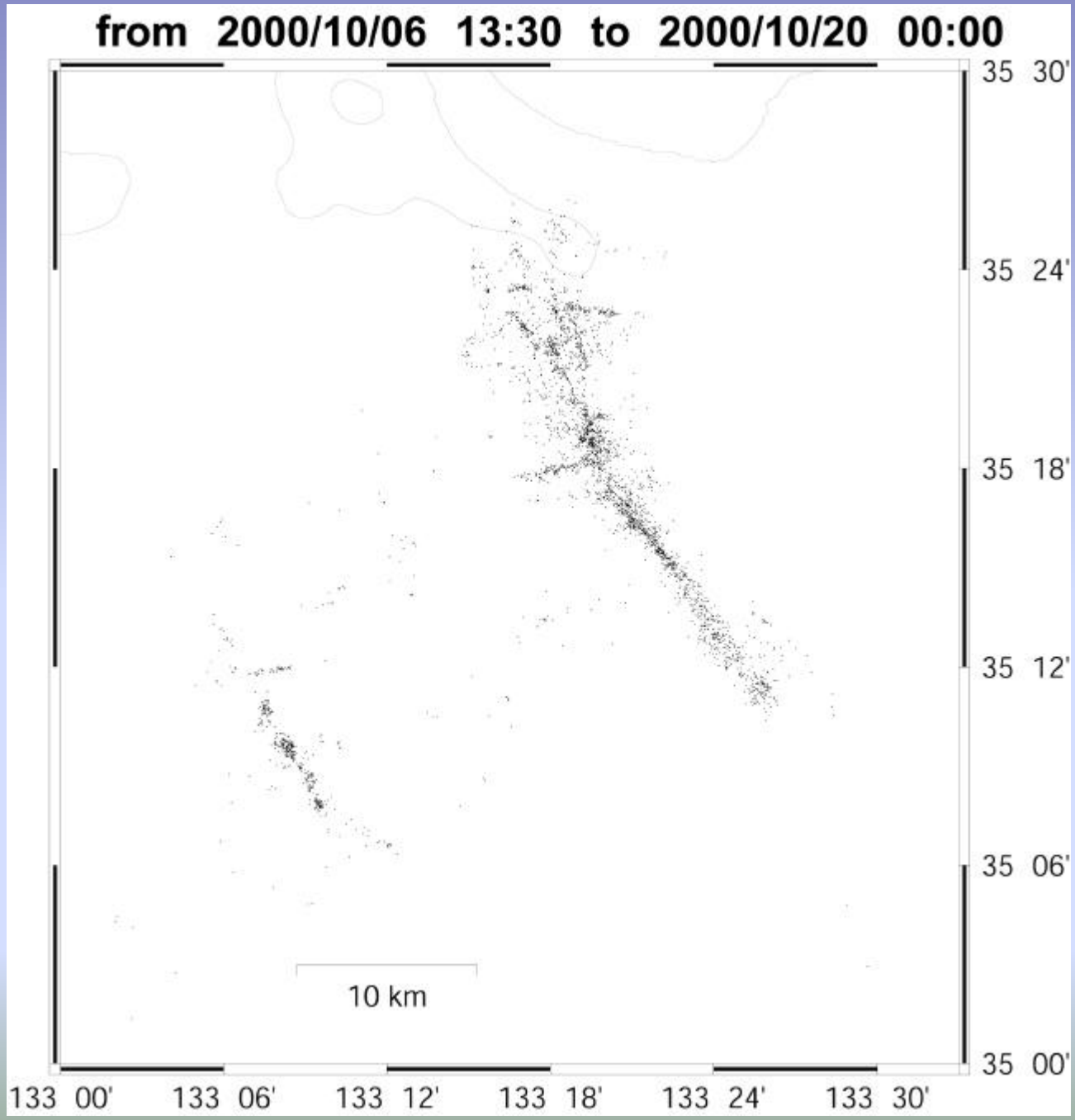




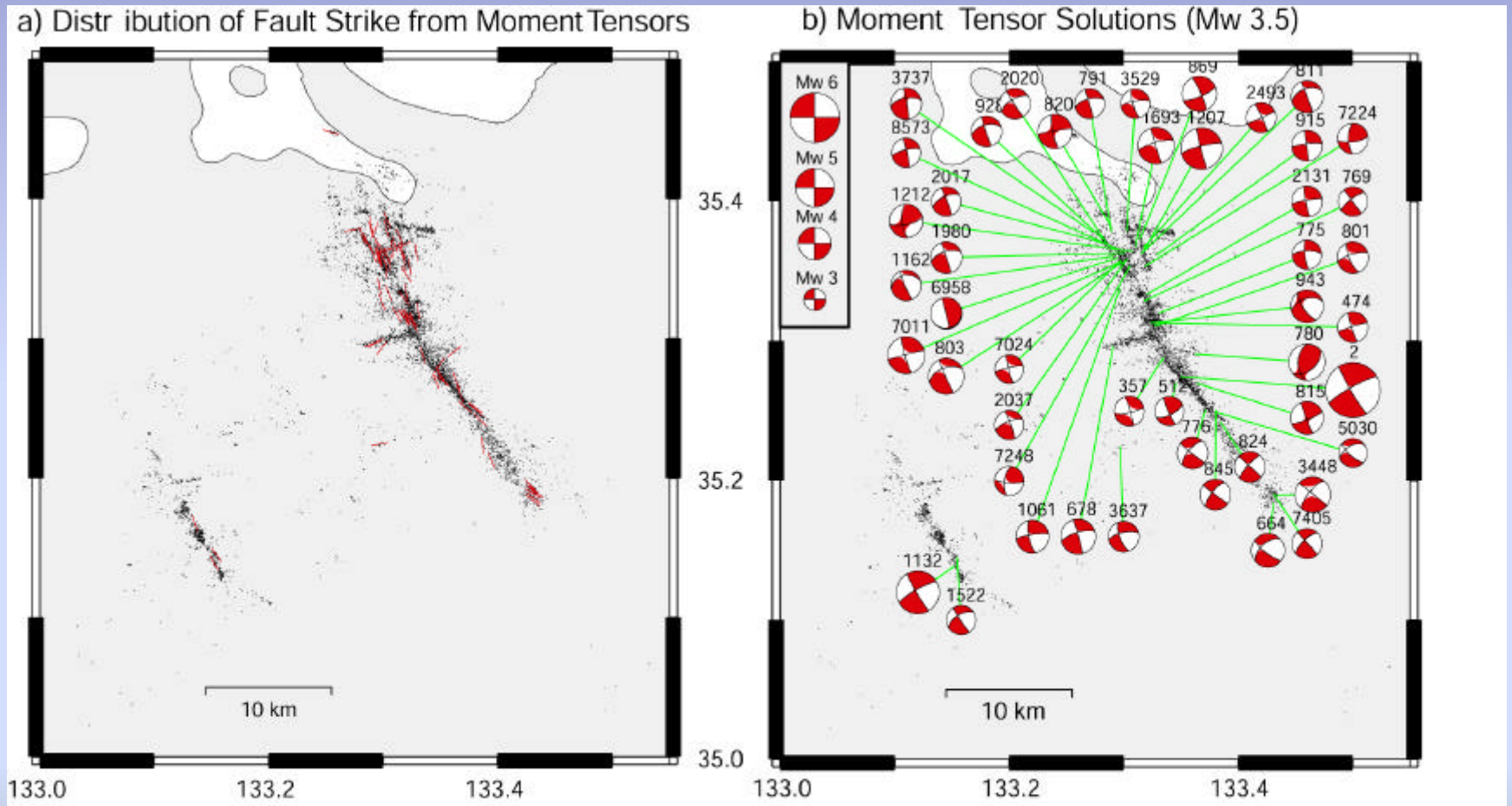

37.68
37.66
37.64
37.62
37.60
-118.98
-118.92
-118.86
-118.8
A'
A
C
C'
B'
B
2.5 km
A
A'
WSMSZ1
SWRD1
B
B'
SERD1
ESMSZ2
ESMSZ1
C
C'
SERD3
SERD4
Depth (km)
Horitontal Distance (km)
July 1997
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.1998
1997.5
1997.55
1997.6
1997.65
1997.7
1997.75
1997.8
1997.85
1997.9
1997.95
1998
Time (year)

Very Fine Fault Structure of the M 6.6 2000 Tottori Ken Seibu Earthquake


Distribution of Stations for P- and S- Phase Pick Data
36.0
35.0
34.0
132.0
133.0
134.0
135.0
1943 Tottori
2000 Western Tottori
50 km

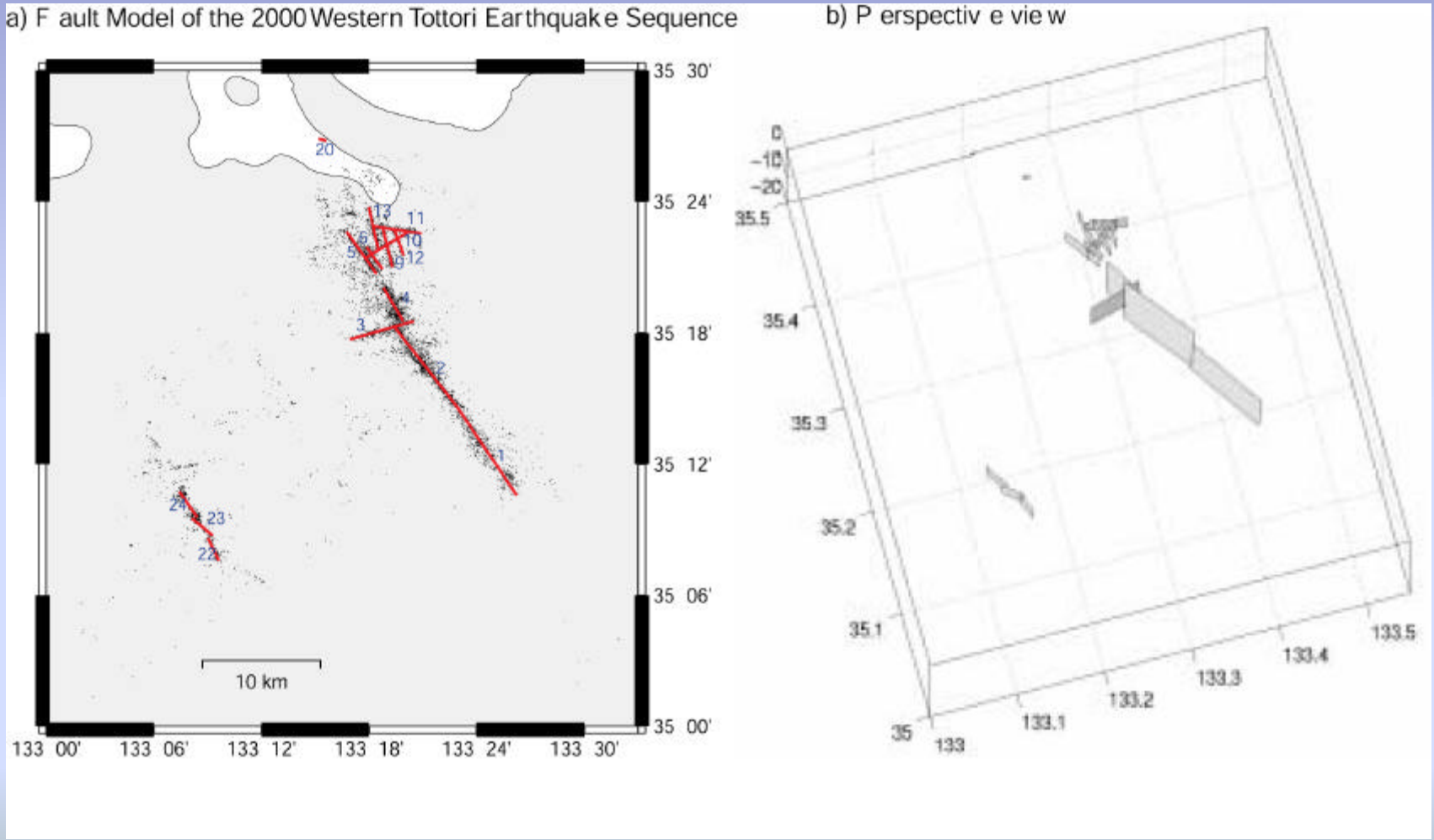

from 2000/10/06 13:30 to 2000/10/20 00:00
35 30'
35 24'
35 18'
35 12'
35 06'
35 00'
10 km
133 00'
133 06'
133 12'
133 18'
133 24'
133 30'

Hypocenters define faults that agree with focal mechanisms



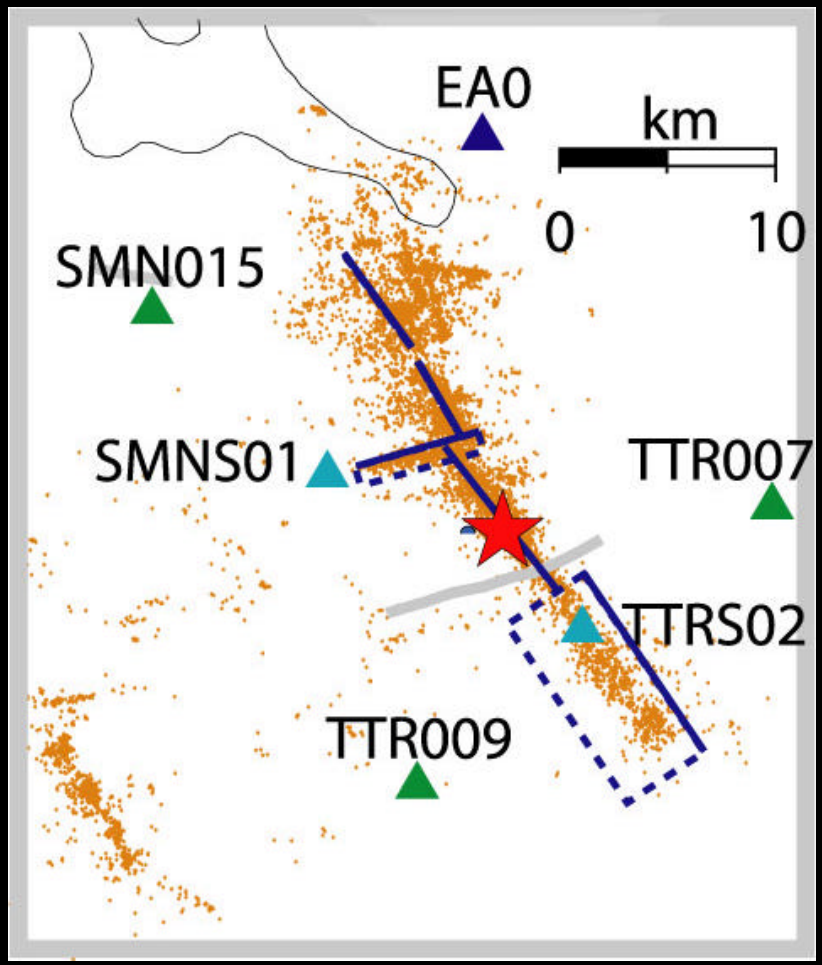
Fukuyama, et al., 2002

Interpretation of Fault Structures



Fukuyama, et al., 2002

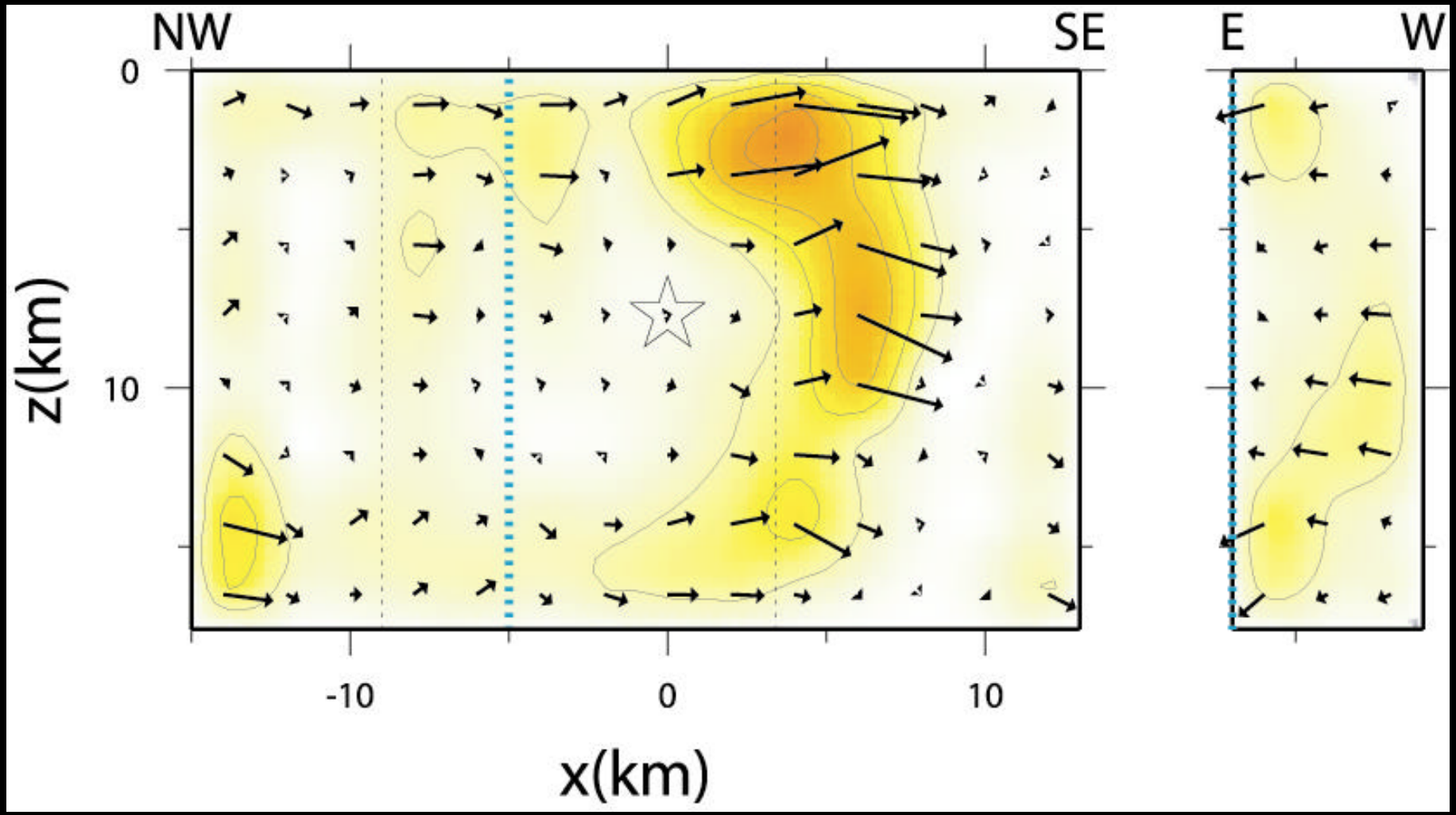
Fault Plane Model (map view)



- Aftershock location by Fukuyama et al.(2001)
- Fault Plane Model modified from Fukuyama et al.(2001)

Sekiguchi and Iwata (2001)

Final Slip Distribution



Sekiguchi and Iwata (2001)

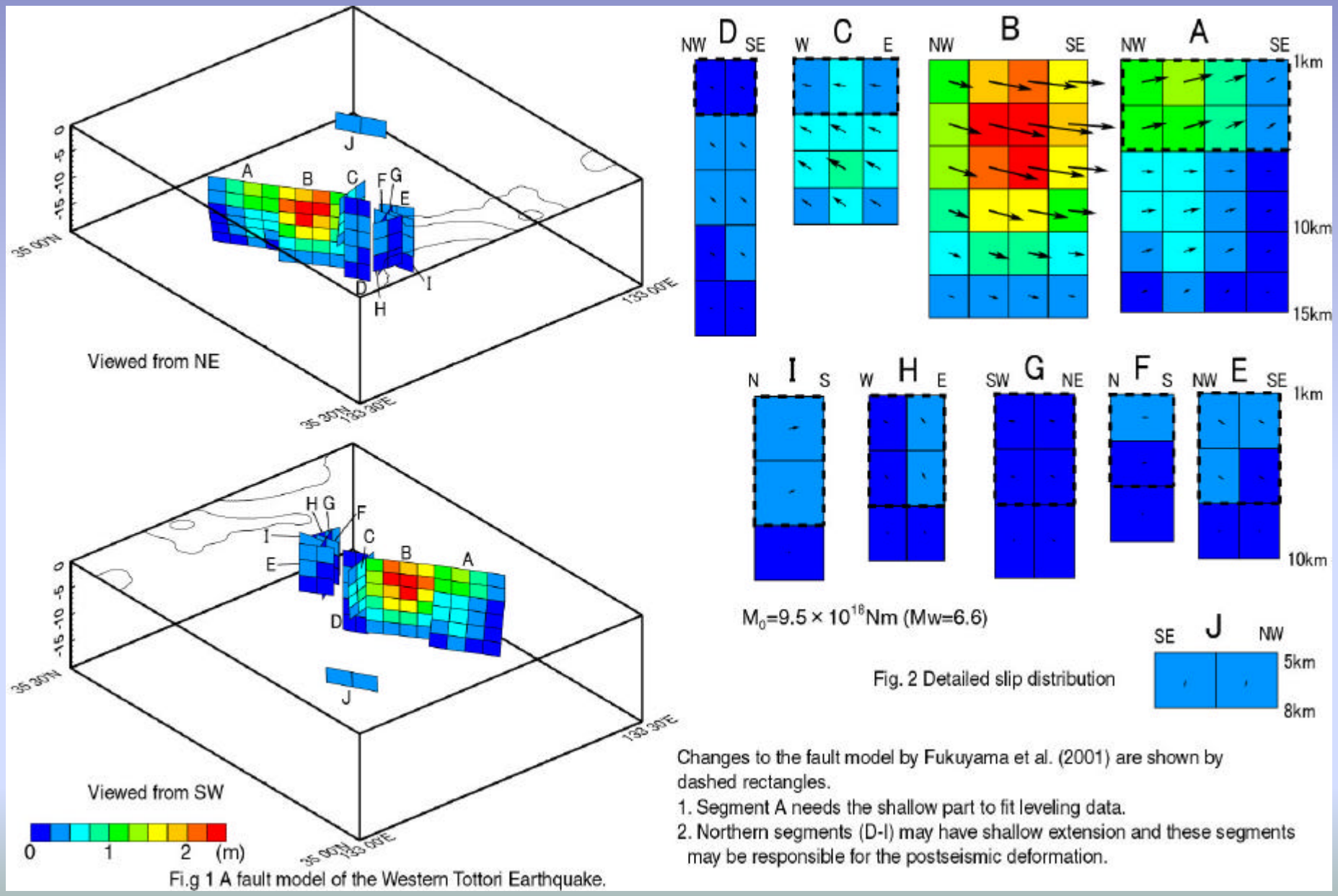
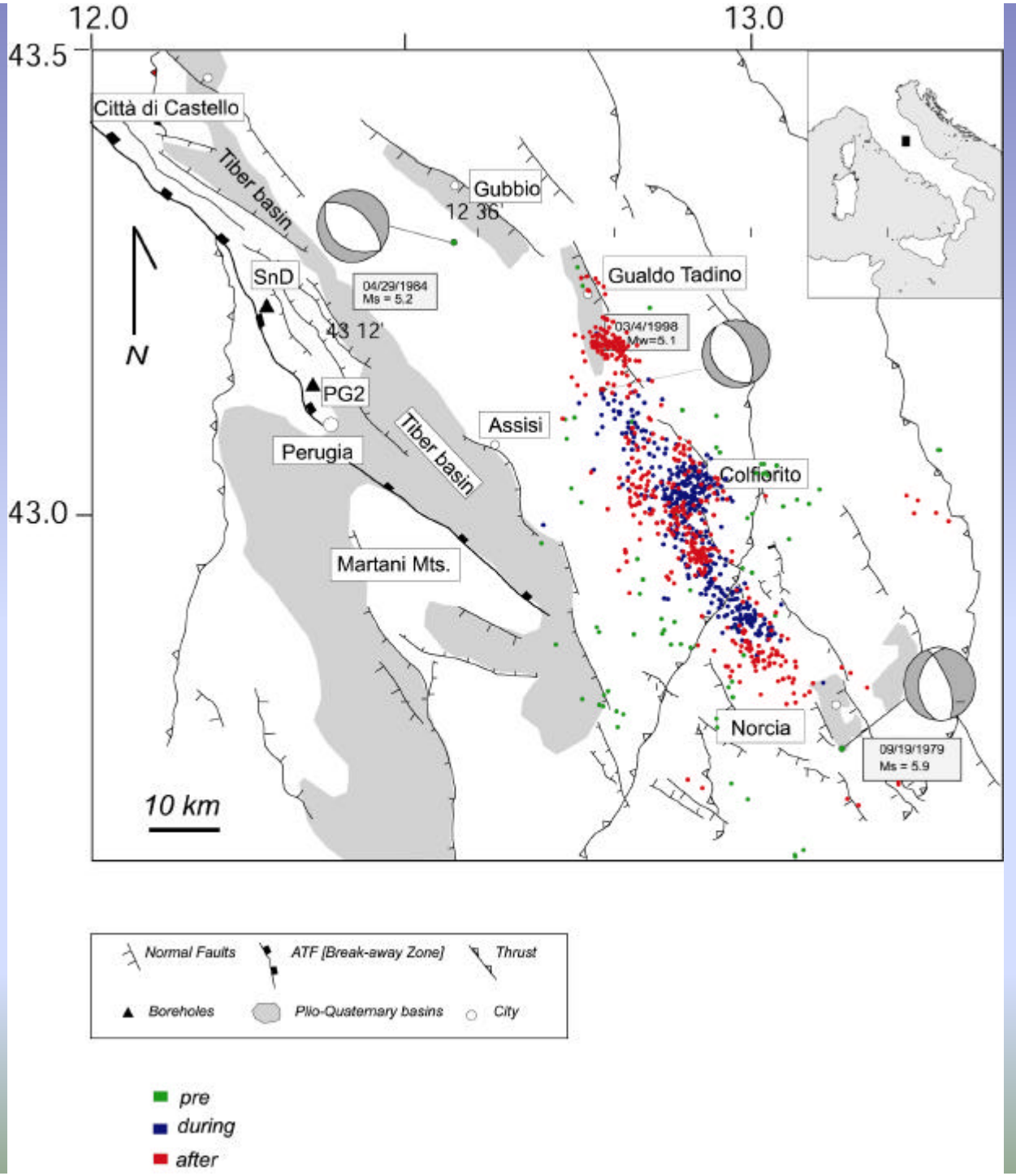


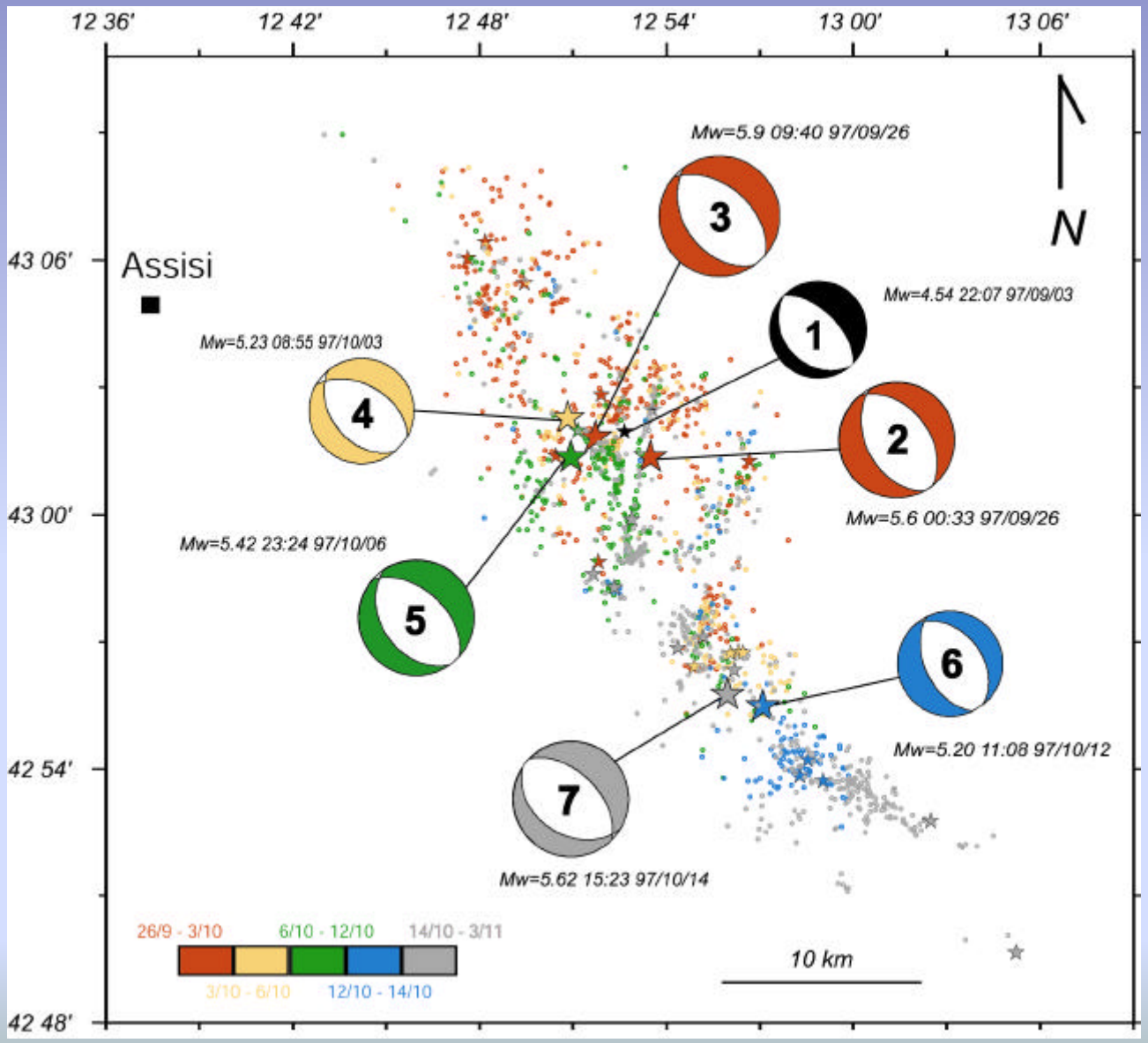
Fig. 2 Detailed slip distribution

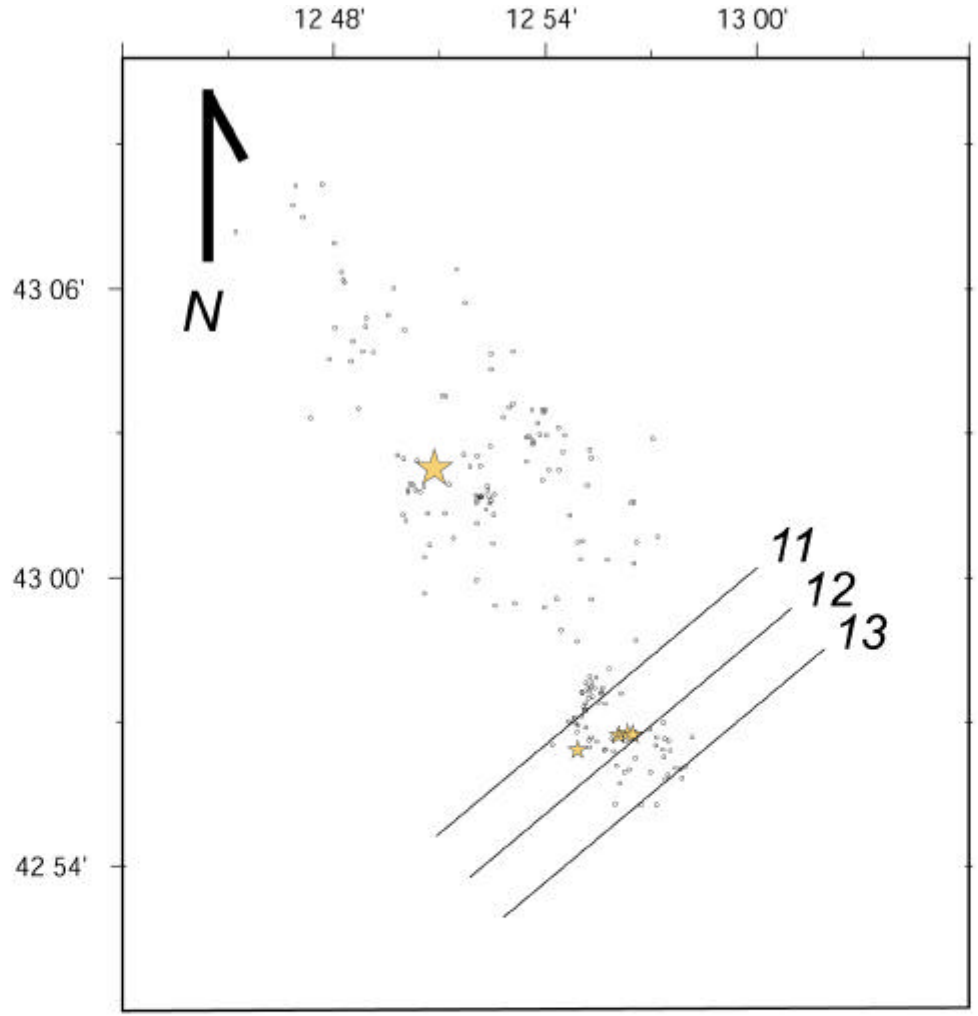
Fi.g 1 A fault model of the Western Tottori Earthquake.

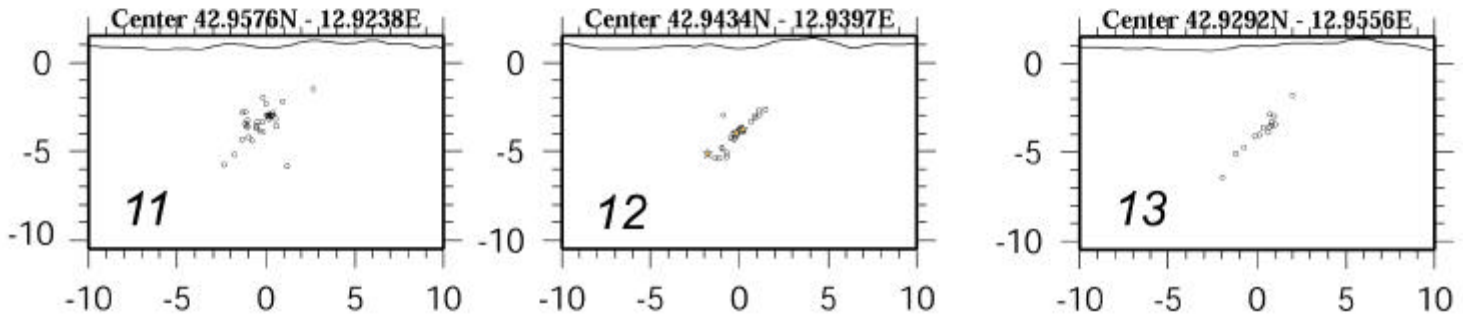
Sagiya, et al., 2002

Imaging the complexity of an active normal fault system:
the 1997 Colfiorito (Central Italy) case study

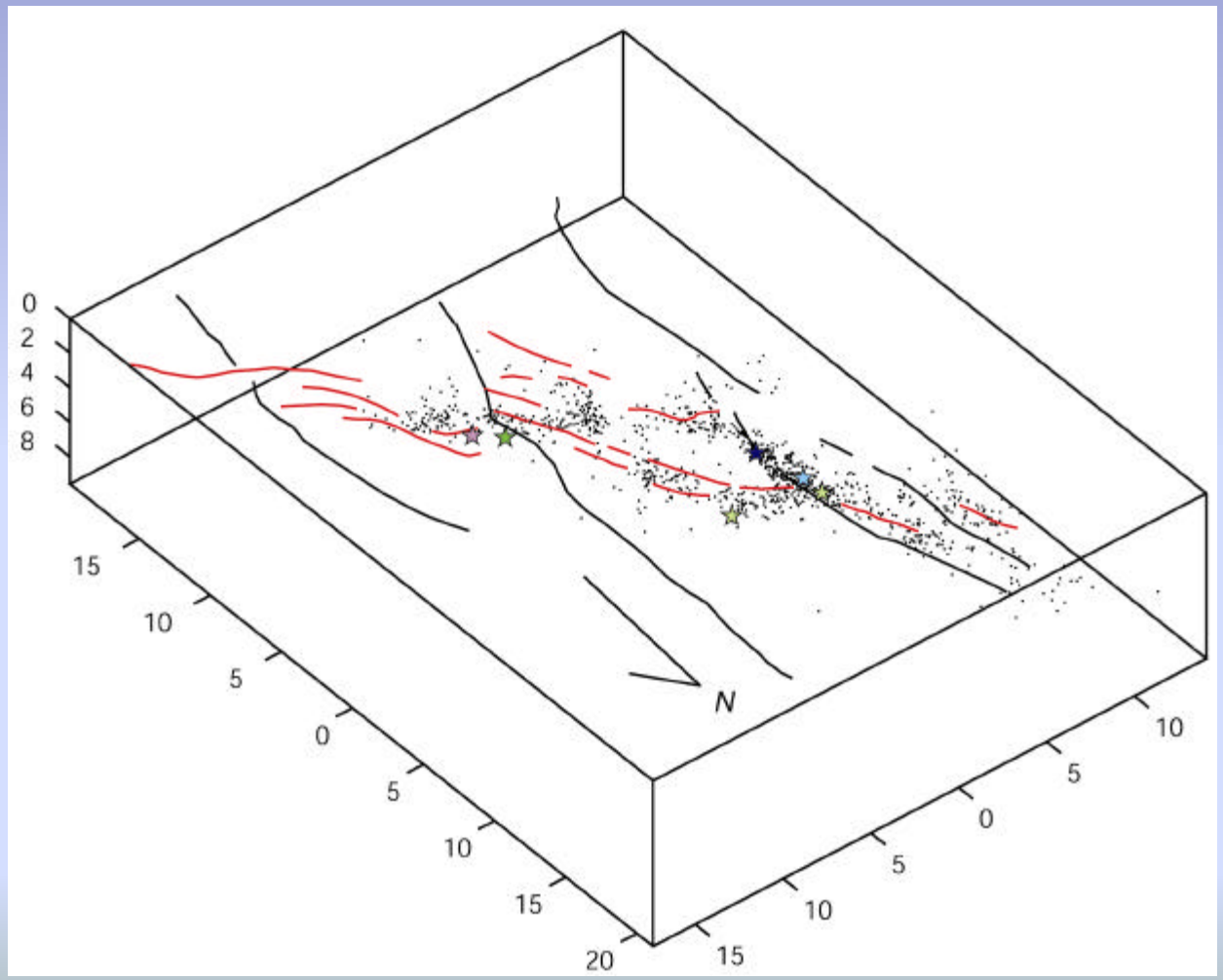

12.0
13.0
43.5
43.0
Città di Castello
Tiber basin
Gubbio
12 36'
SnD
04/29/1984
Ms = 5.2
43 12'
N
Gualdo Tadino
03/4/1998
Mw=5.1
PG2
Perugia
Assisi
Tiber basin
Colfiorito
Martani Mts.
Norcia
09/19/1979
Ms = 5.9
10 km
Normal Faults
ATF [Break-away Zone]
Thrust
Boreholes
Plio-Quaternary basins
City
pre
during
after


12 36'
12 42'
12 48'
12 54'
13 00'
13 06'
43 06'
43 00'
42 54'
42 48'
N
Assisi
Mw=5.9 09:40 97/09/26
Mw=4.54 22:07 97/09/03
Mw=5.23 08:55 97/10/03
Mw=5.6 00:33 97/09/26
Mw=5.42 23:24 97/10/06
Mw=5.20 11:08 97/10/12
Mw=5.62 15:23 97/10/14
1
2
3
4
5
6
7
26/9 - 3/10
3/10 - 6/10
6/10 - 12/10
12/10 - 14/10
14/10 - 3/11
10 km

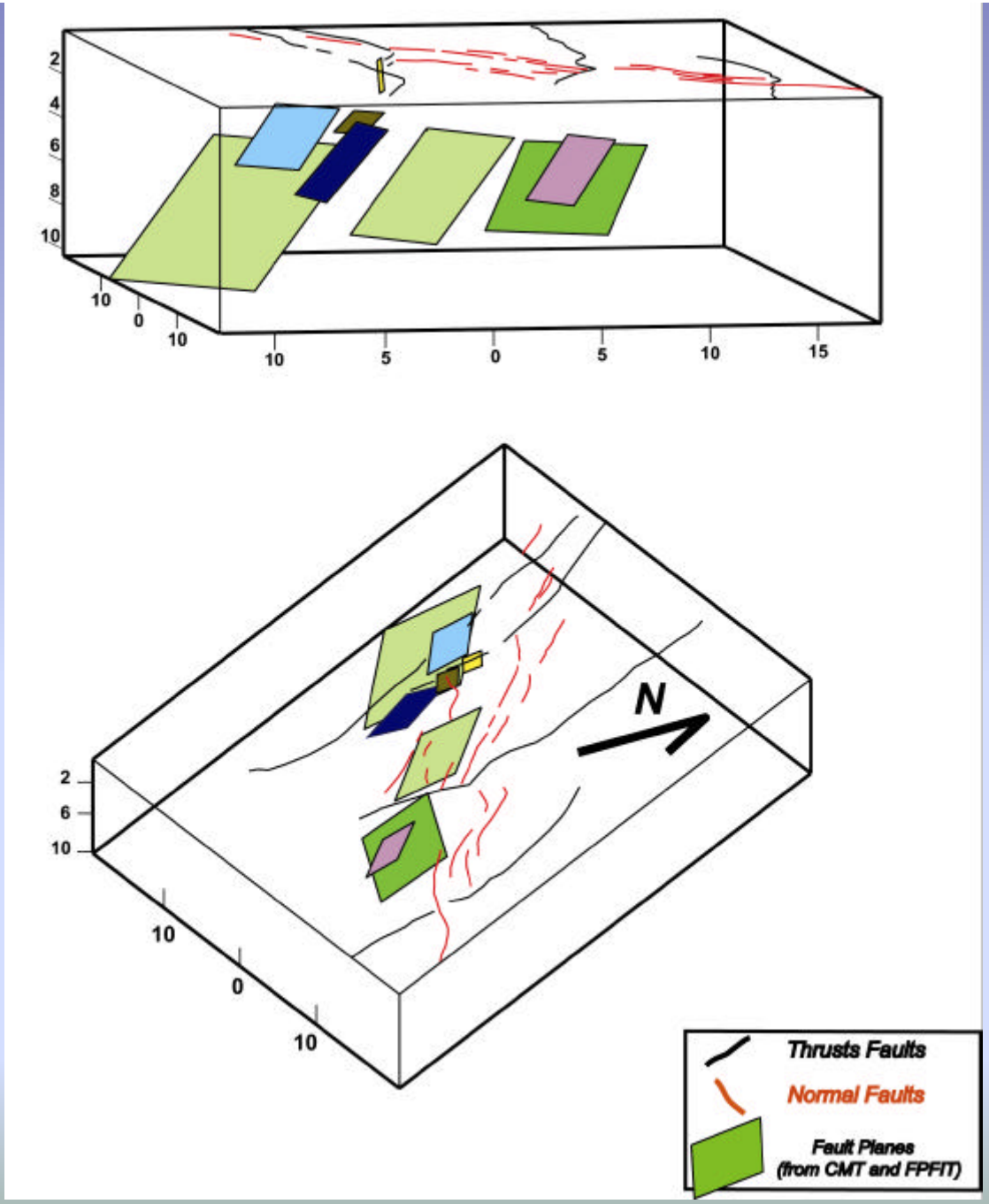

12 48'
12 54'
13 00'
43 06'
43 00'
42 54'
N
11
12
13


Center 42.9576N - 12.9238E
Center 42.9434N - 12.9397E
Center 42.9292N - 12.9556E
0
-5
-10
-10
-5
0
5
10
11
12
13

Oblique view of Colfiorito Earthquakes



Chiaraluce, et al., 2002



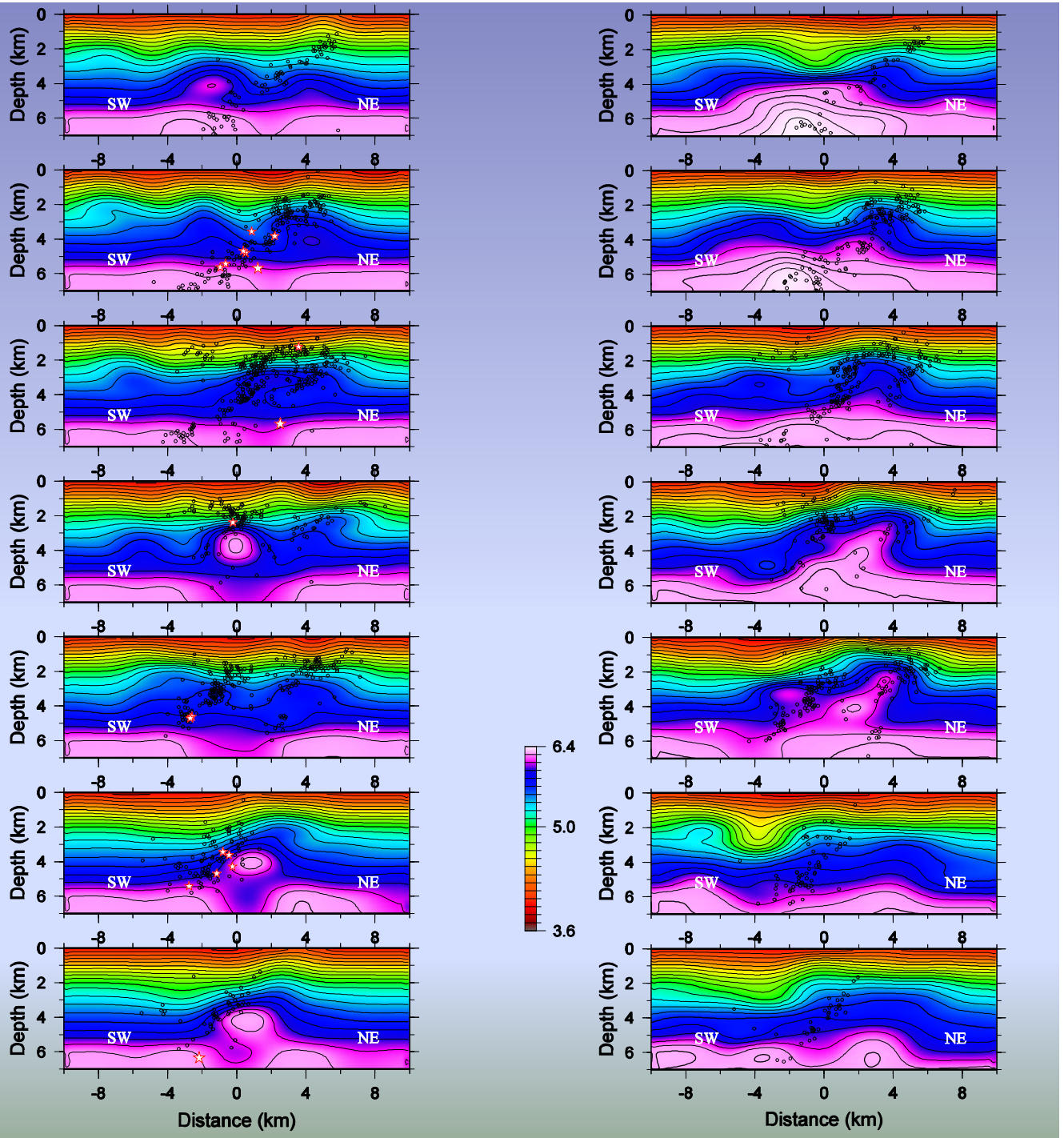
Chiaraluce, et al., 2002

Double Difference Tomography

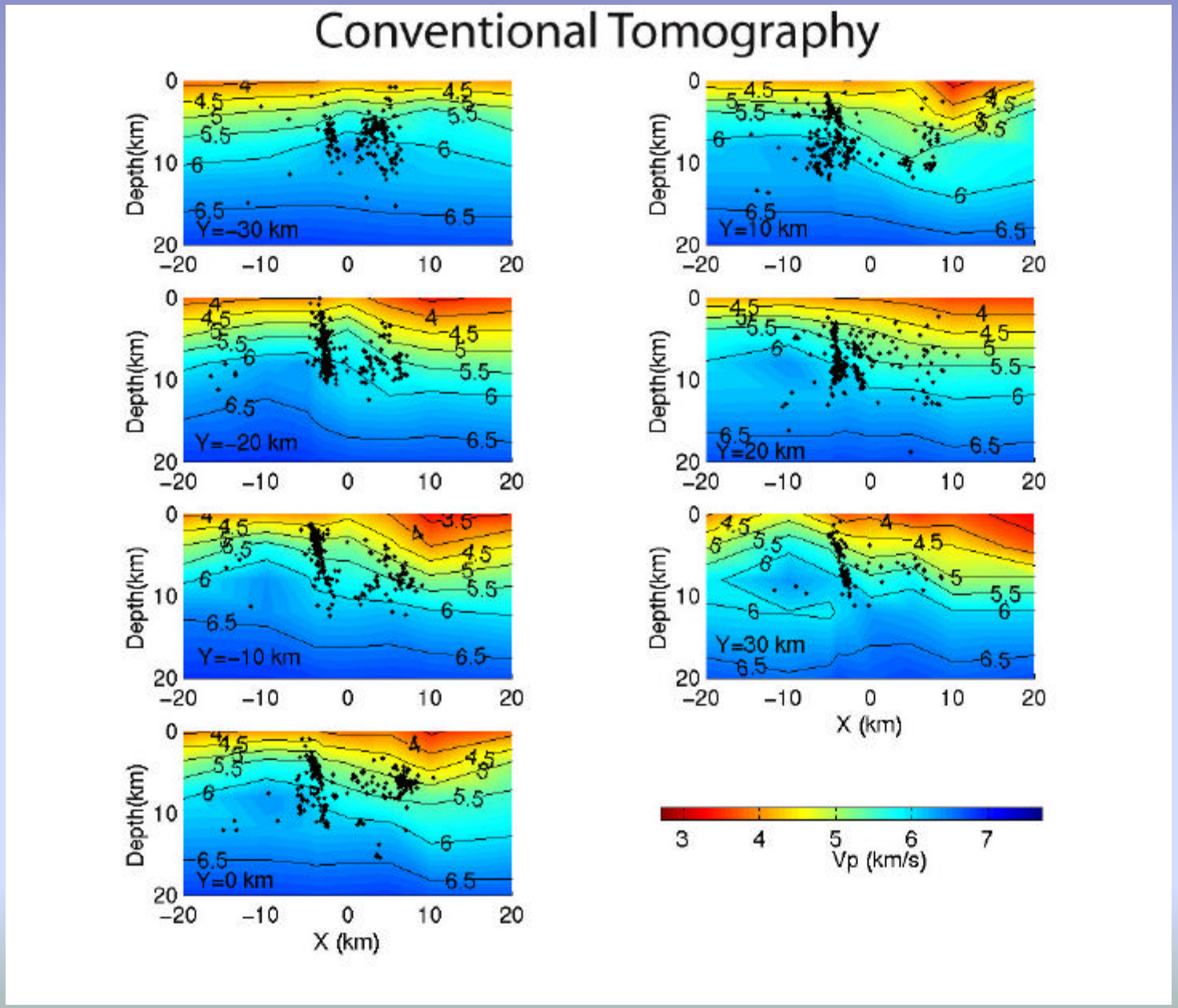
Tomographic Image of Colfiorito, Italy Region by Chiaraluce and Chiarabba

Left: Conventional tomography

Right: Double difference hypocenters used as initial locations

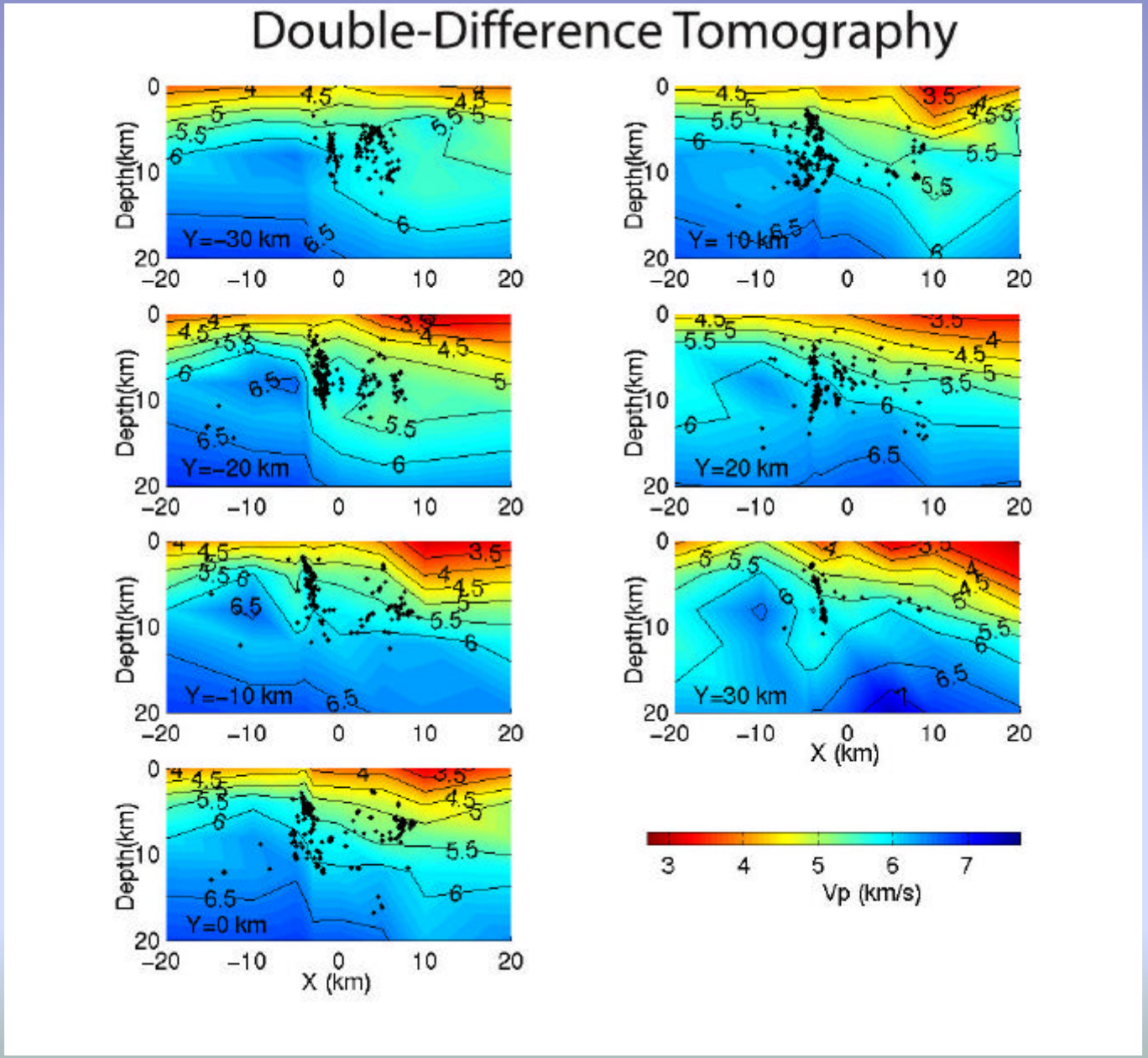


Hayward Fault, California



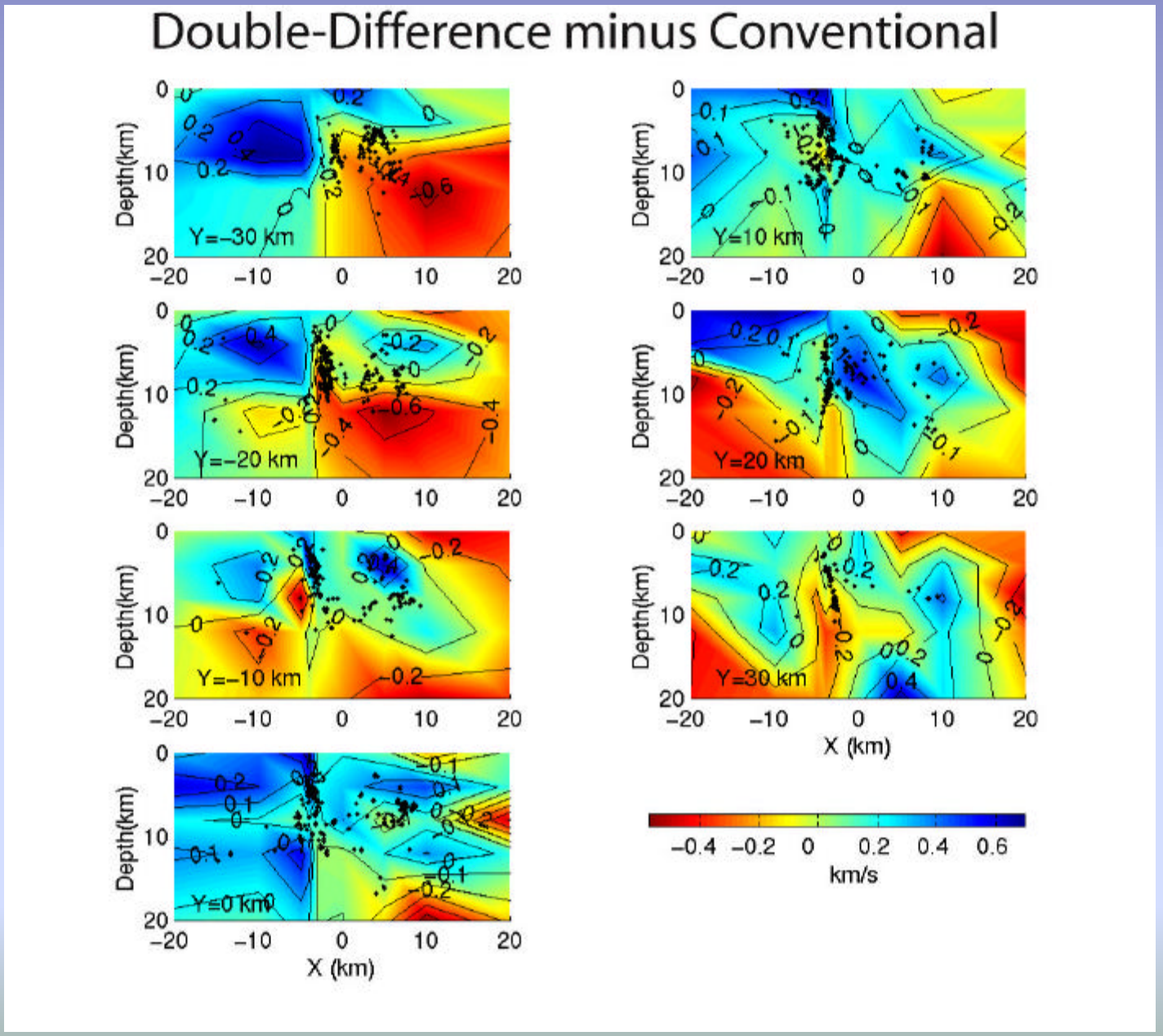
Zhang and Thurber, BSSA, submitted

Hayward Fault, California



Zhang and Thurber, BSSA, submitted

Hayward Fault, California



Zhang and Thurber, BSSA, submitted

Conclusions

- The Double-difference method efficiently determines high-precision earthquake locations over extended distances without the use of station corrections.
- The D-D method is resilient to measurement errors and robust against misspecification of the earth model.
- The long-term observation of active faults and of aftershock sequences from around the world show that:
  - Faults are generally planar, narrow (~100 m or less), and segmented on multiple scales.
  - Seismicity commonly localizes in regions of stress concentration between locked and slipping zones, or at the edges of ruptures.
  - The termination of rupture in earthquakes can commonly be associated with geometric segmentation of the fault.
- Double-difference tomography shows great promise.