The velocity change caused by the 2004 M 6.0 Parkfield earthquake on the San Andreas Fault

Speaker: Kuei-Mei Lin

2010/10/14

Reference

- Li, Y. G., Chen, P., Cochran, E. S., Vidale, J. E., and Burdette, T., (2006). Seismic evidence for rock damage and healing on the San Andreas Fault associated with the 2004 M6.0 Parkfield earthquake, Bull. Seism. Soc. Am., **96**, 349-363

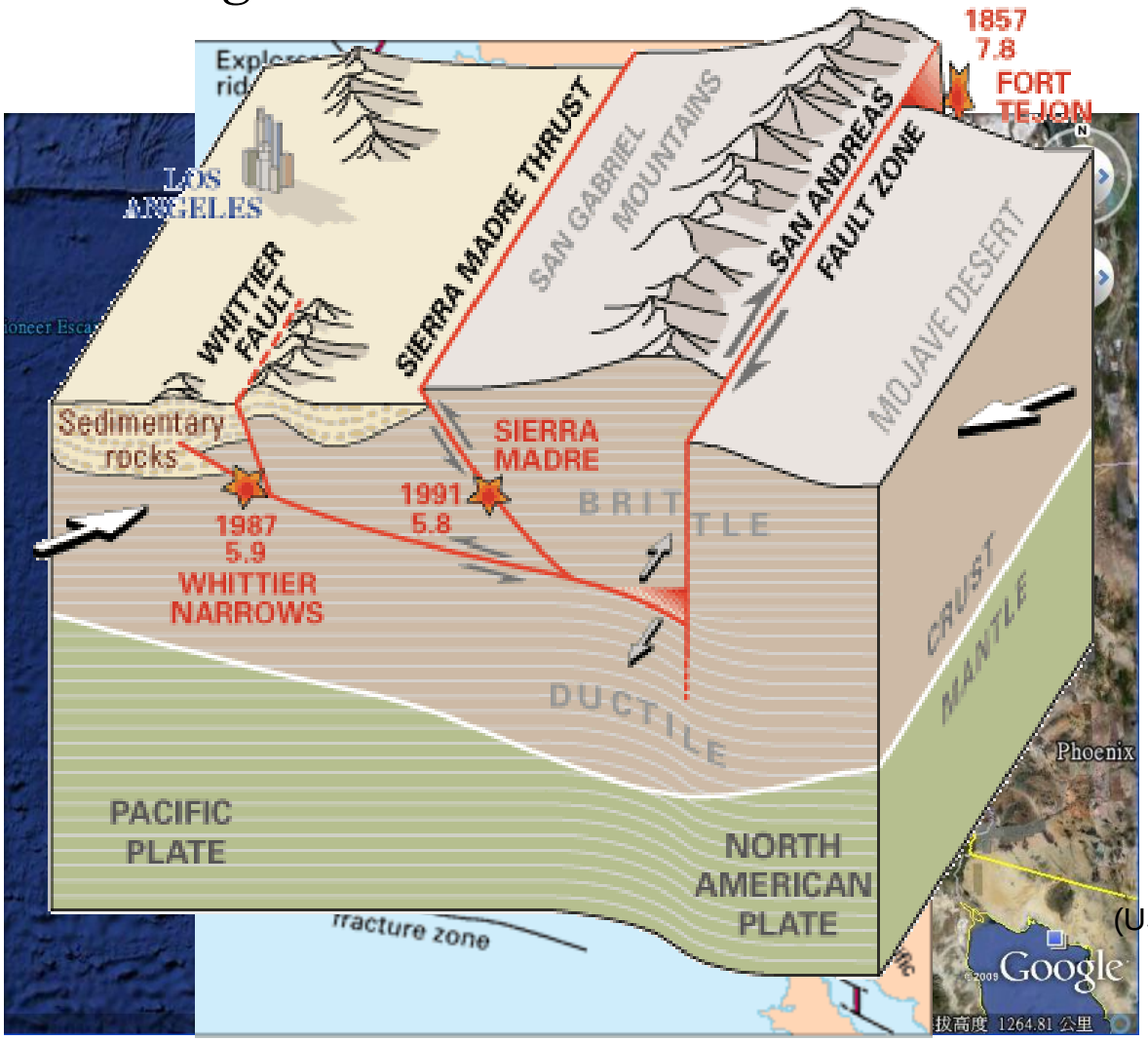
- Cochran, E. S., Li, Y. G., and Vidale, J. E., (2006). Anisotropy in the shallow crust observed around the San Andreas Fault before and after the 2004 M 6.0 Parkfield earthquake, Bull. Seism. Soc. Am., **96**, 364-375

Outline

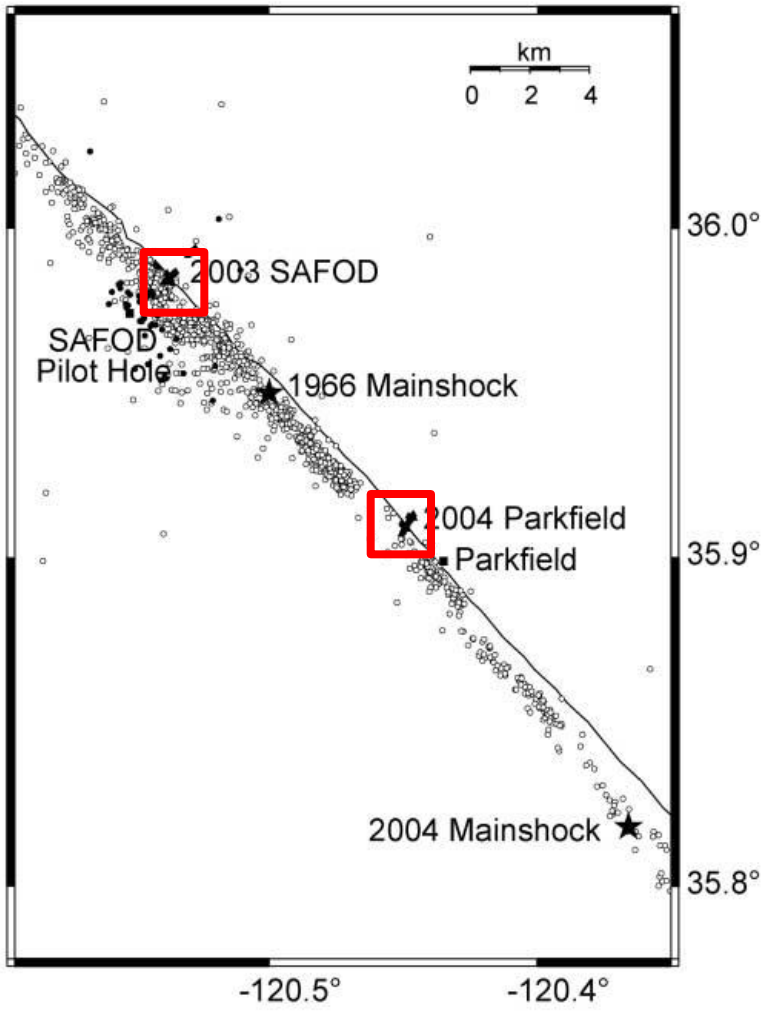
- Introduction
- Data and Results
- Discussion and Conclusion

Introduction

- Tectonic background



(USGS)



First array: fall in 2002

2003/1/1

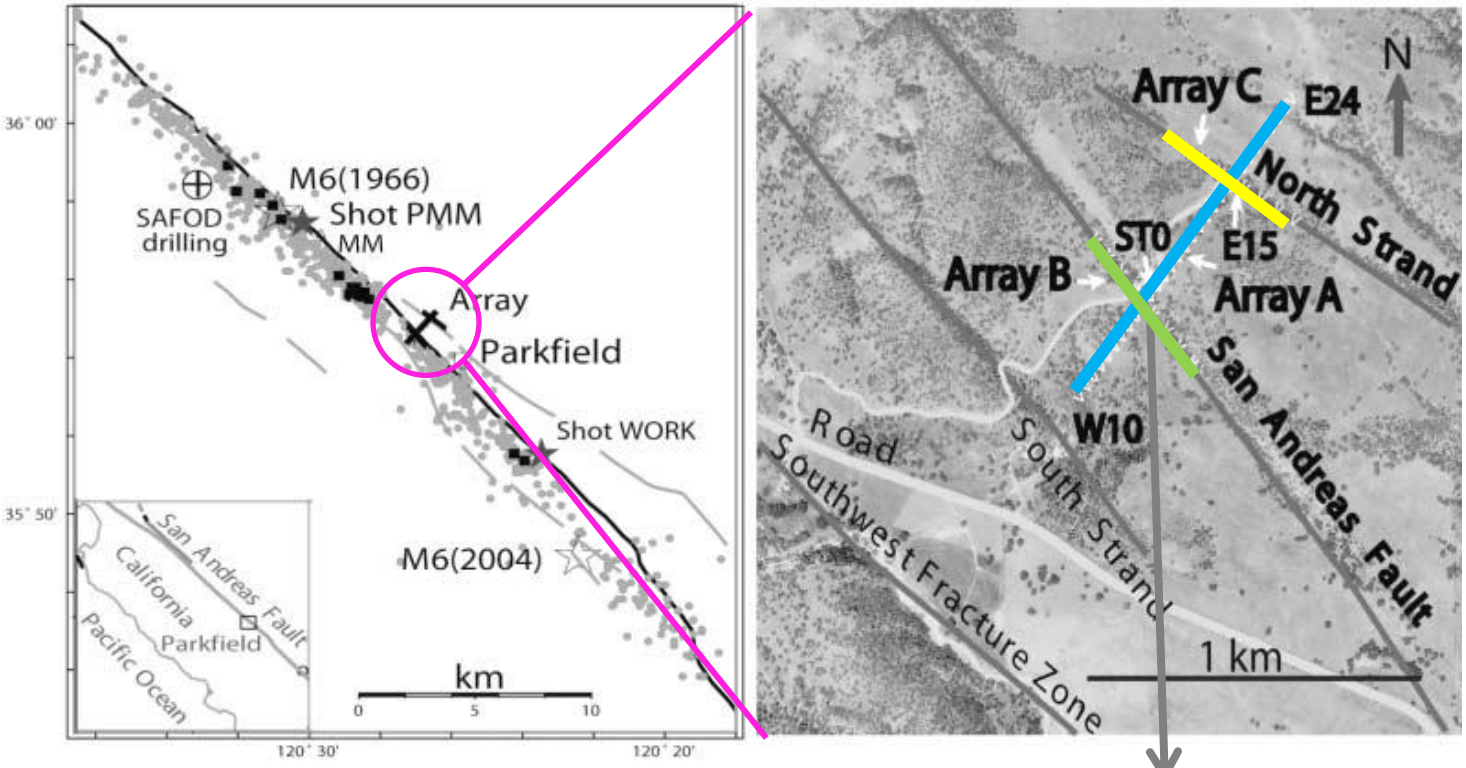
Second array: 2003/10~11

2004/1/1

2004/09/28
M6.0 Parkfield earthquake

Third array: 2004/10~12

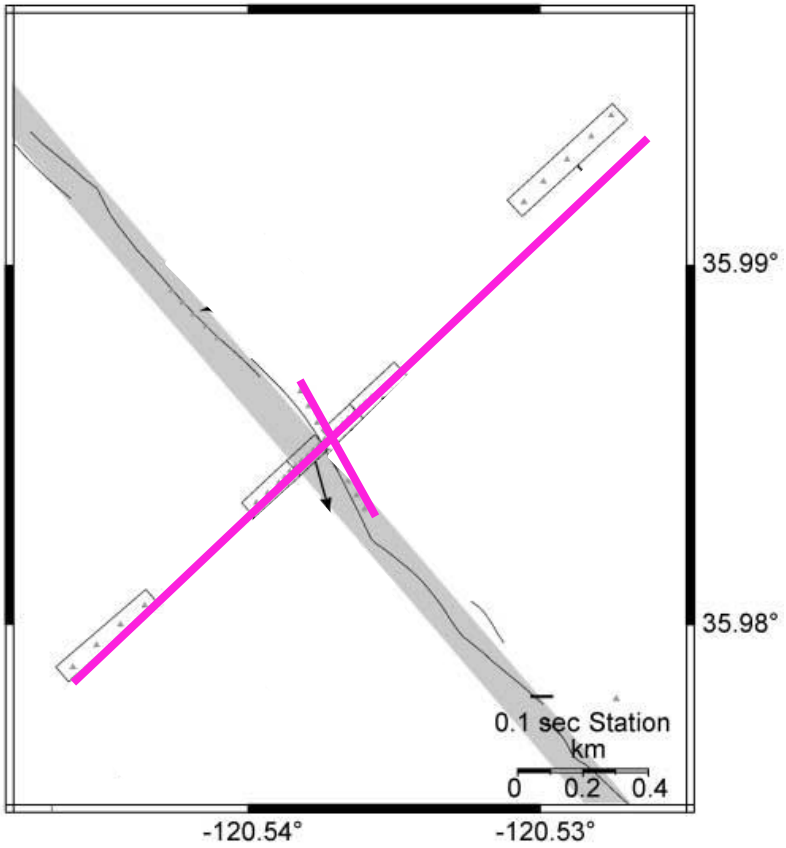
2005/1/1



(Li et al., 2004)

First array: Array A: 35 PASSCAL RT130s and 2-Hz L22 sensors, spacing of 25m.
Array B and C: 9 RT130s, spacing of 50m.(2002)
Data: 3 explosions, PASO experiment, 3 earthquakes

Third array: Array A: 35 PASSCAL RT130s and 2-Hz L22 sensors, spacing of 25m.
Array B and C: 6 RT130s, spacing of 50m.(2004)
Data: 2 explosions, about 1000 aftershocks



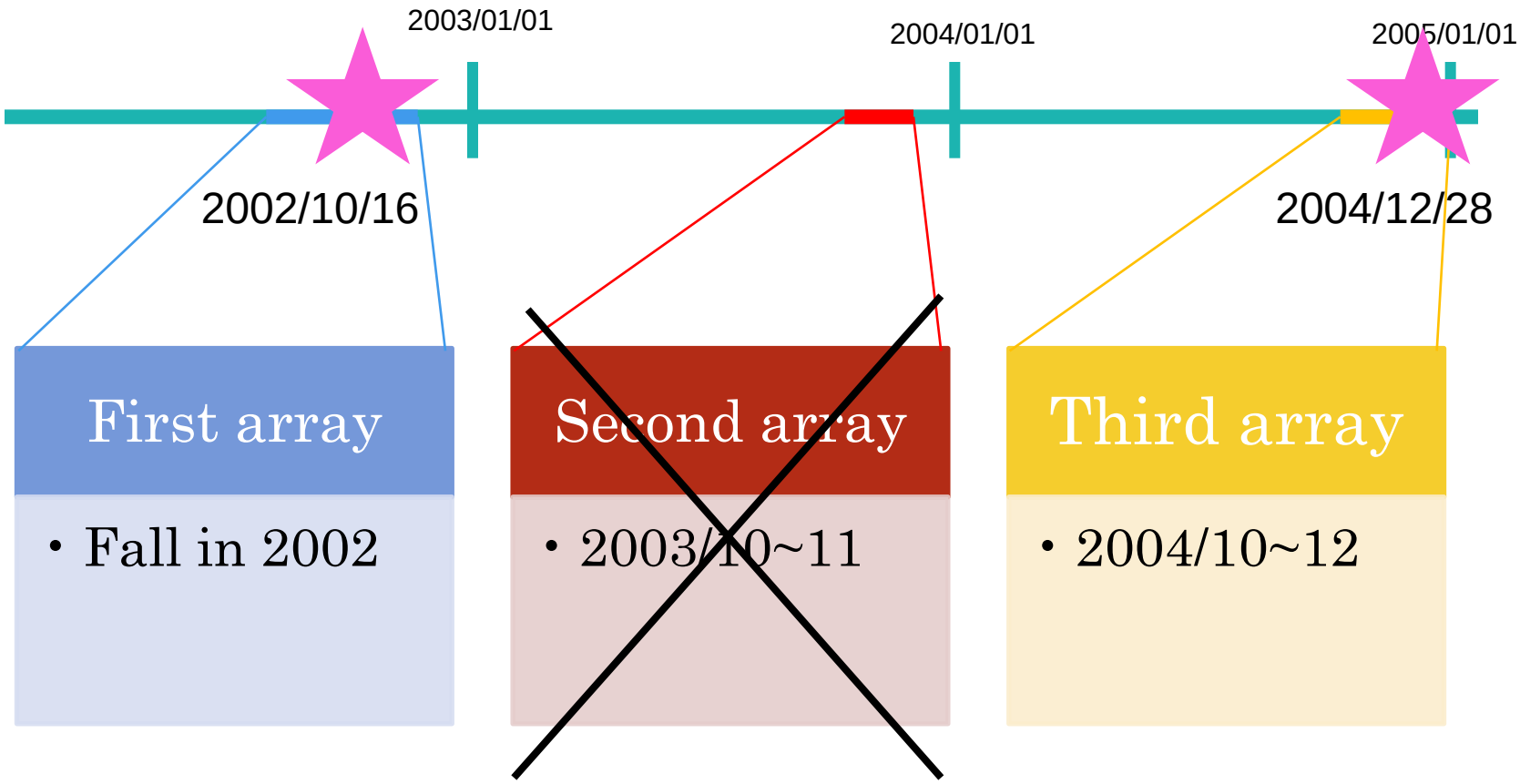
Second array:

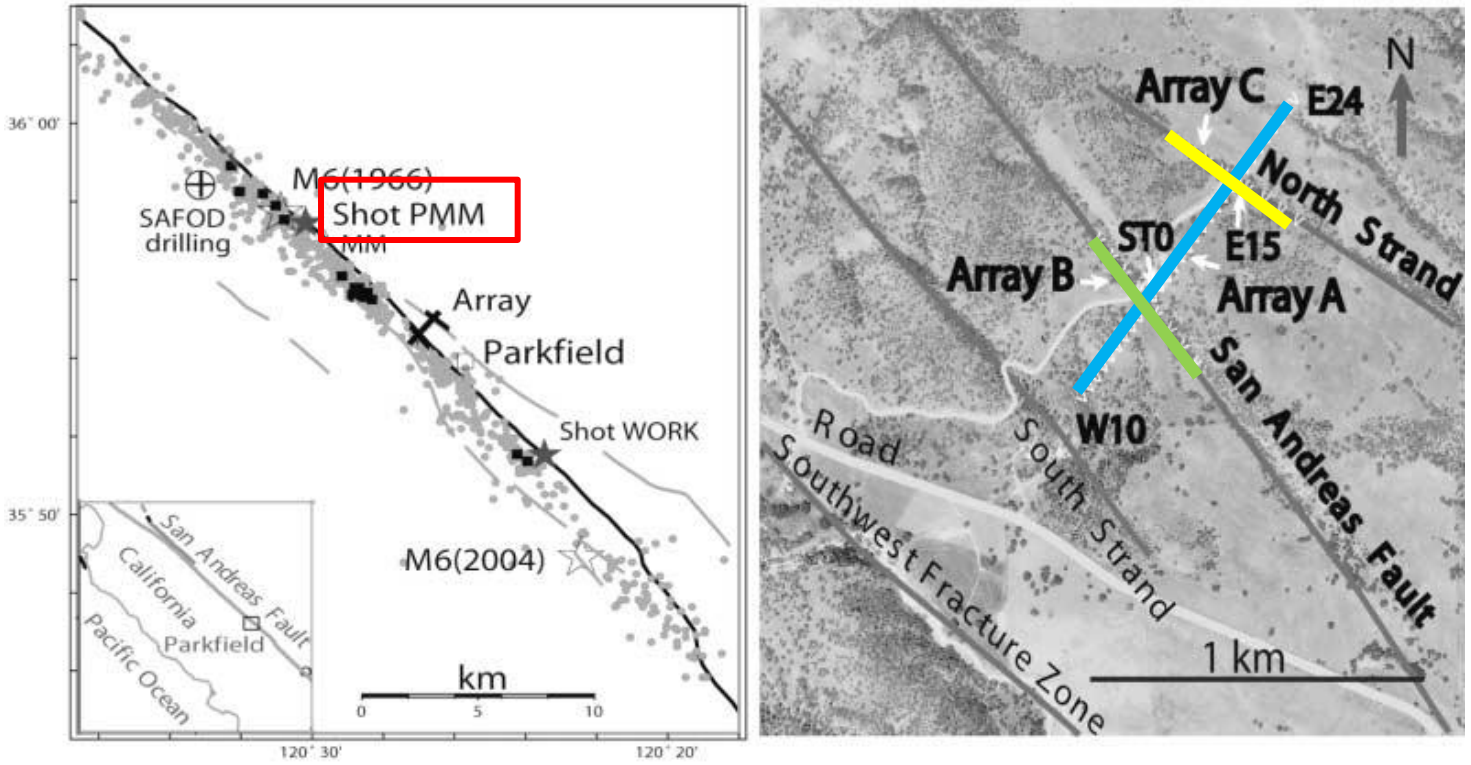
Instruments: 30 RT130s in a 2400-m-long cross-fault array
12 RT130s for 400 m along the main trace of the SAF
Station spacing: 50m~200m
Time: six-week, from mid-October to the end of November, 2003
Data: over 200 earthquakes with magnitudes less than 2.0

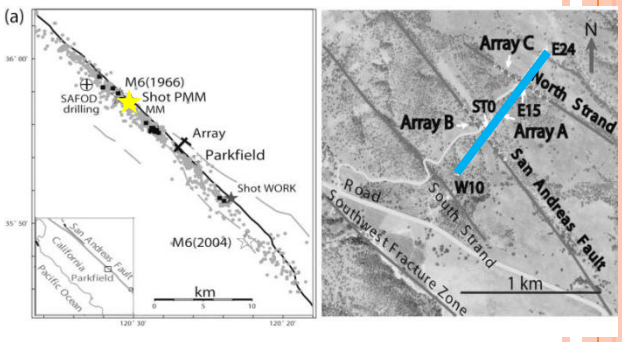
Data and results

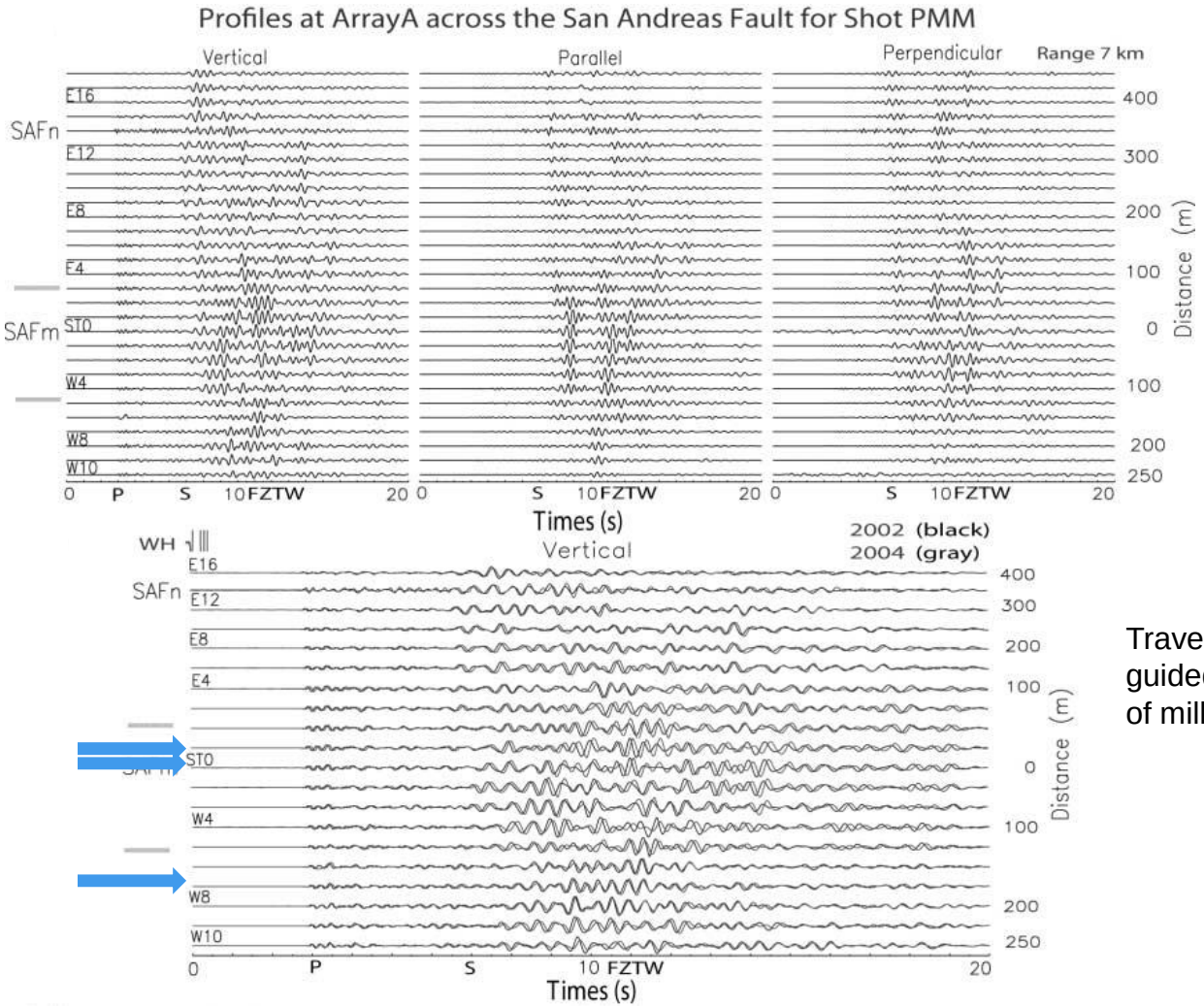
- Explosions data
  - Repeated shots
- Earthquake data
  - Before earthquake
  - After earthquake
- Aftershocks data
  - Test1:site effect
  - Test2:time effect

- Repeated shots



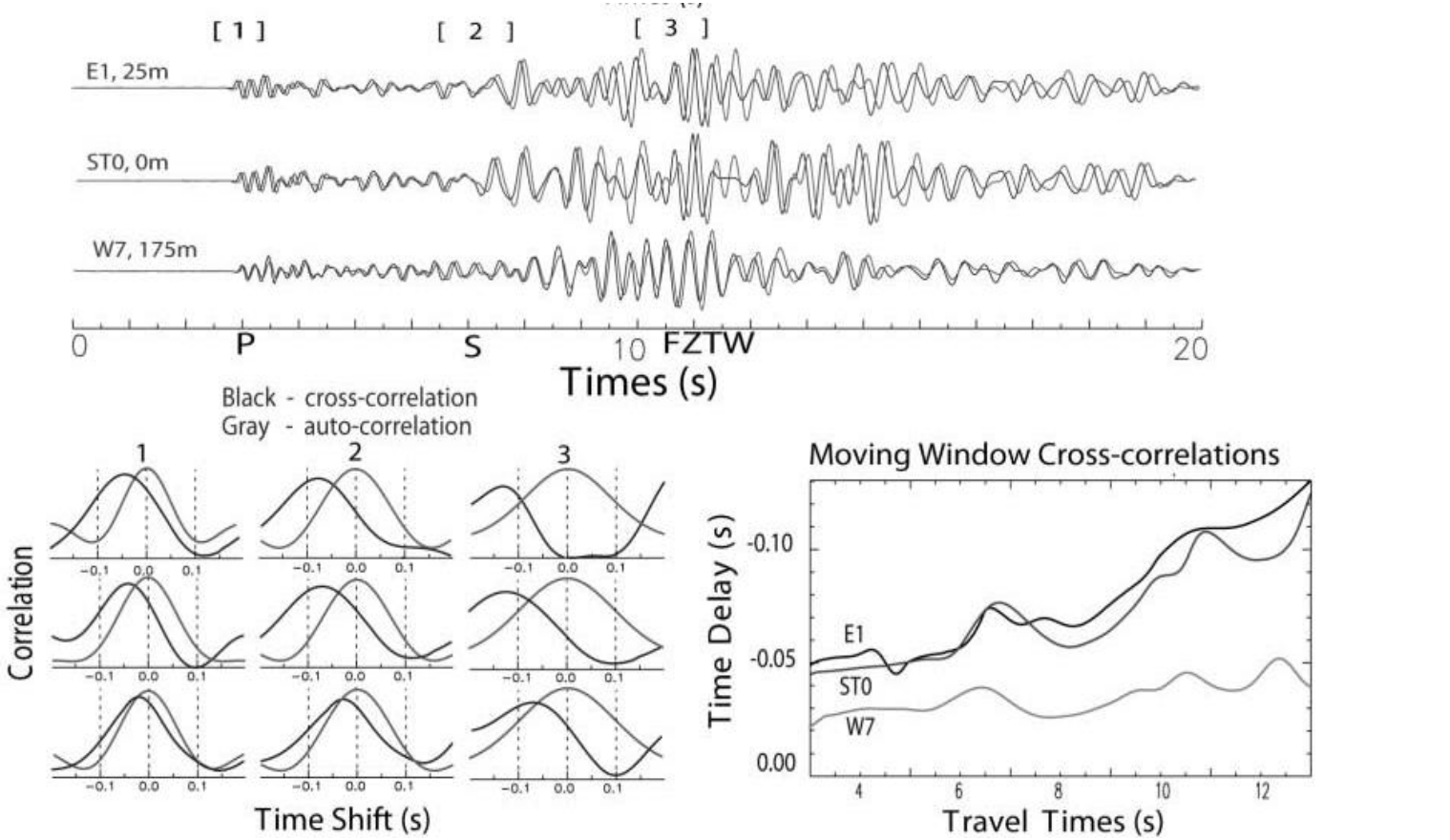

36° 00'
35° 50'
120° 30'
120° 20'
SAFOD drilling
M6(1966)
Shot PMM
Array
Parkfield
Shot WORK
M6(2004)
San Andreas Fault
California
Parkfield
Pacific Ocean
km
0
5
10
N
Array C
E24
North Strand
ST0
E15
Array B
Array A
San Andreas Fault
W10
Road
South Strand
Southwest Fracture Zone
1 km



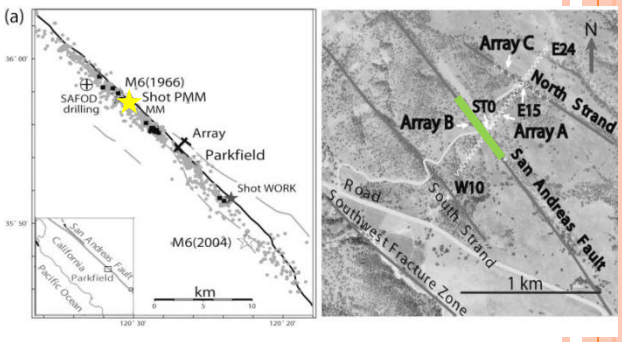


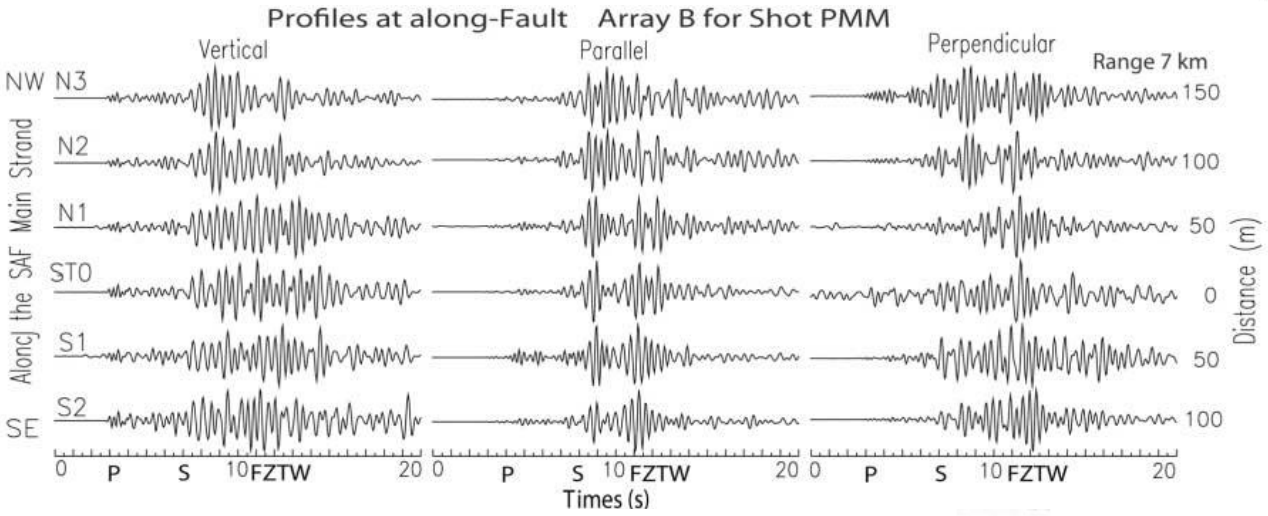
Traveltimes of P, S, and fault-zone guided were delayed by several tens of milliseconds.

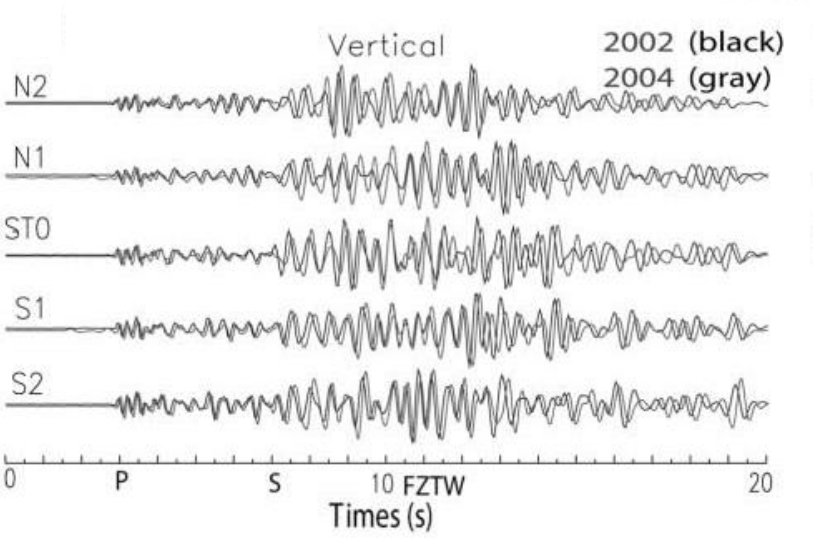
Figure exhibits vertical-component seismograms recorded at three stations of array A for shots in 2002 and 2004.

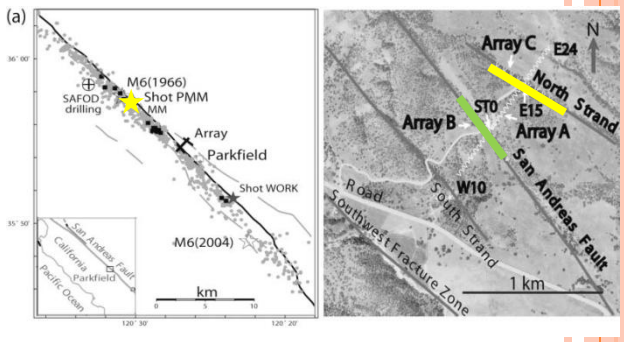


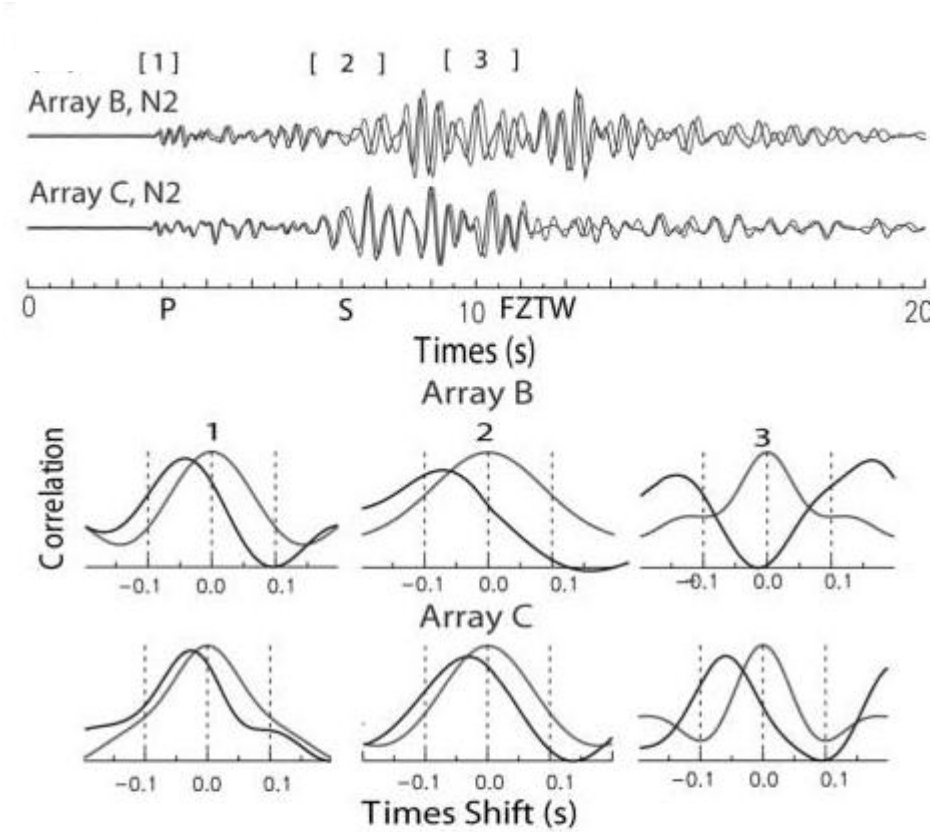
moving-window cross-correlation technique(Niu et al. 2003)


(a)
M6(1966)
Shot PMM
MM
SAFOD drilling
Array
Parkfield
Shot WORK
M6(2004)
San Andreas Fault
California
Pacific Ocean
Parkfield
km
Array C
E24
N
North Strand
ST0
E15
Array B
Array A
San Andreas Fault
W10
Road
South Strand
Southwest Fracture Zone
1 km

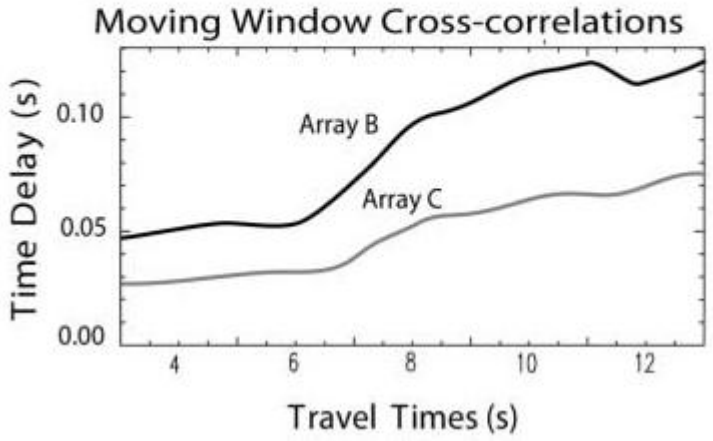

Profiles at along-Fault Array B for Shot PMM
Vertical
Parallel
Perpendicular
Range 7 km
NW
SE
Along the SAF Main Strand
N3
N2
N1
ST0
S1
S2
150
100
50
0
50
100
Distance (m)
0 P S 10 FZTW 20
Times (s)


Vertical
2002 (black)
2004 (gray)
N2
N1
ST0
S1
S2
0 P S 10 FZTW 20
Times (s)

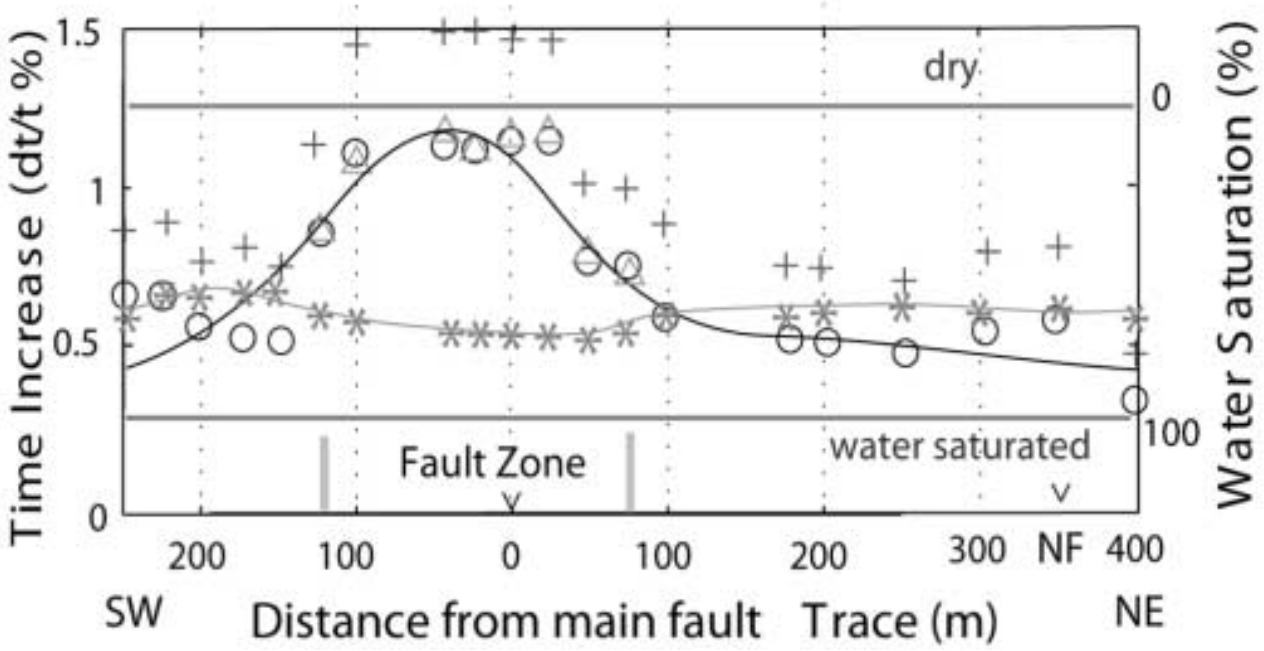




Vertical-component seismograms recorded for repeated shot PMM.



$$\frac{dVs}{Vs} = \frac{85ms}{\sim 6.8s} = \sim 1.25\%$$



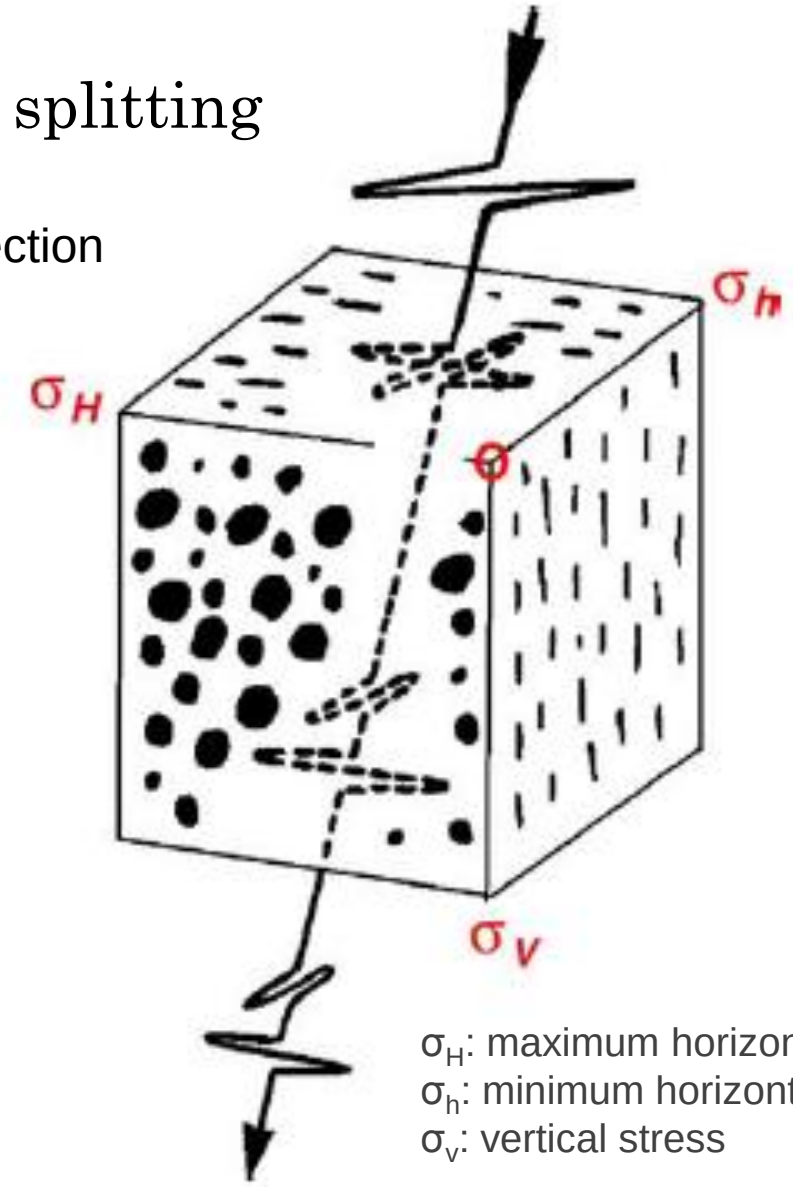
P(crosses)
S(circles)
trapped waves(triangles)

Travel-time increases, for P, S, and trapped waves measured from cross-correlations of seismograms at array A for repeated shot PMM in 2002 and 2004.

Data and results

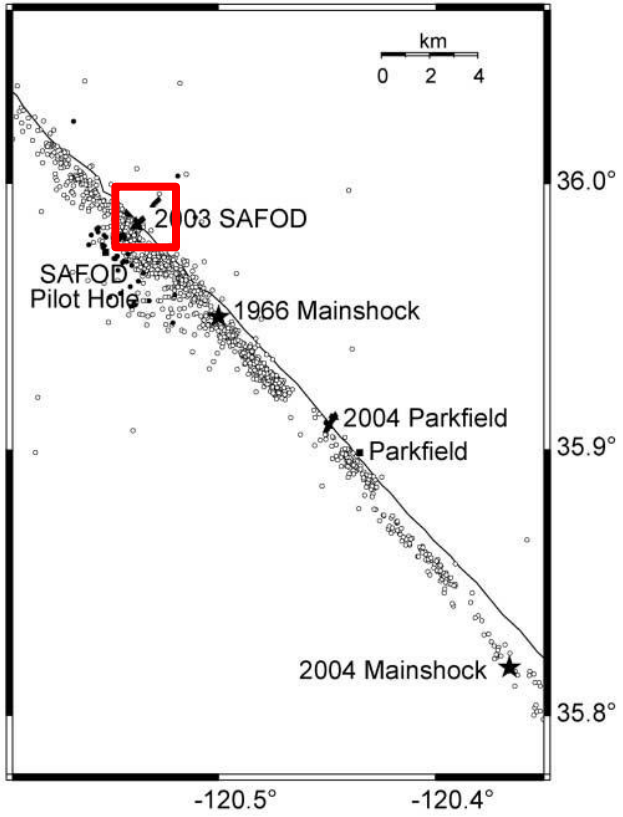
- Explosions data
  - Repeated shots
- Earthquake data
  - Before earthquake
  - After earthquake
- Aftershocks data
  - Test1:site effect
  - Test2:time effect

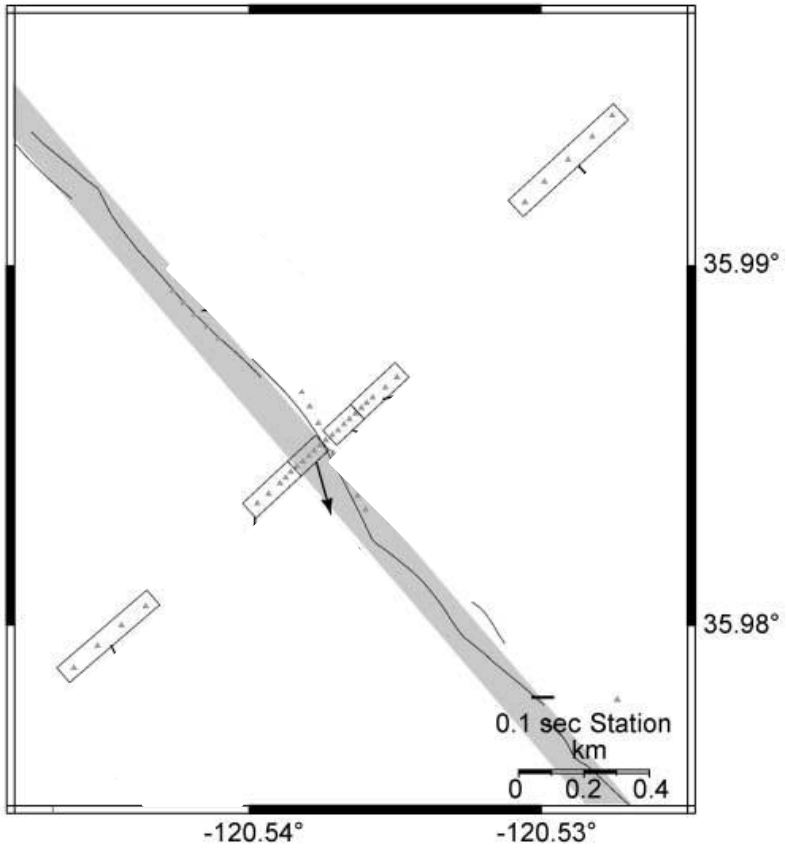
- Shear-wave splitting
  - polarization direction
  - delay time



σ_H: maximum horizontal compressive stress
σ_h: minimum horizontal compressive stress
σ_v: vertical stress

- Before earthquake





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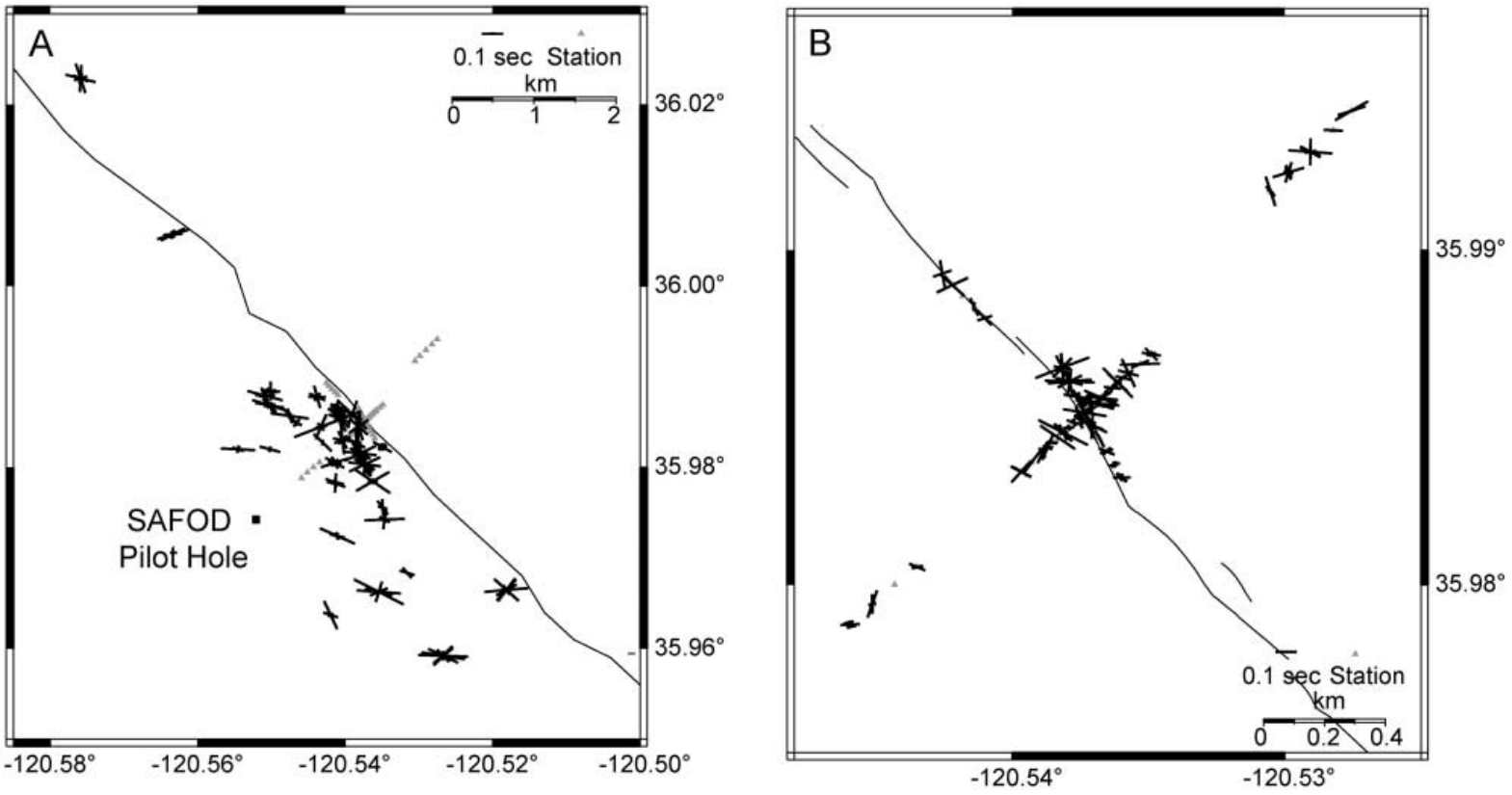
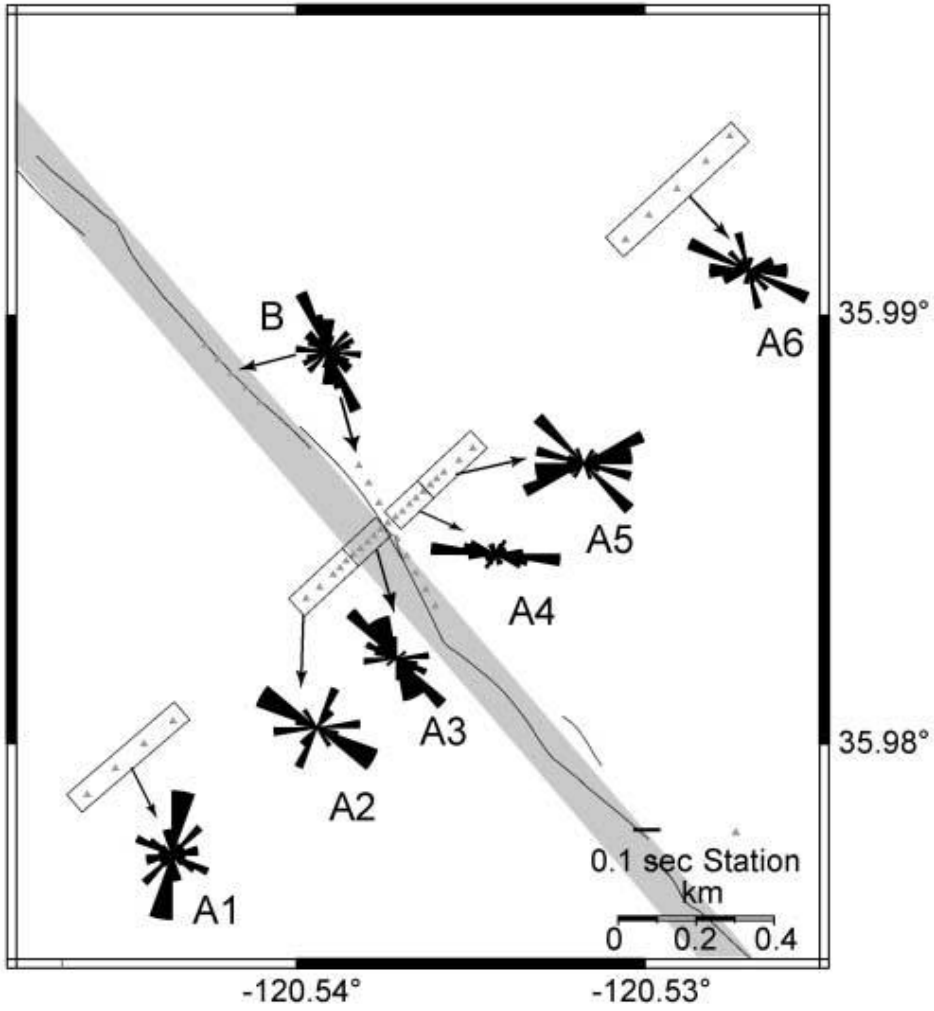
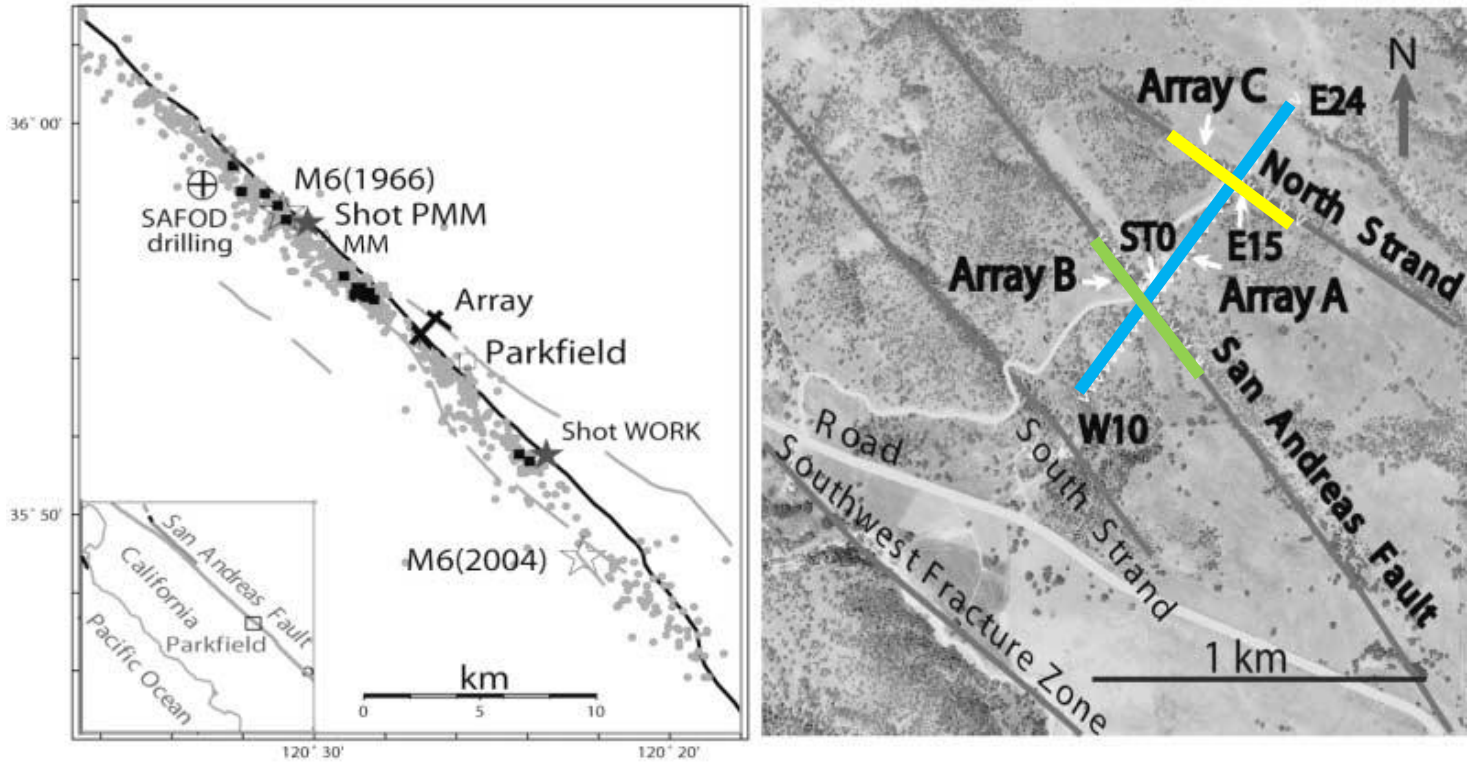
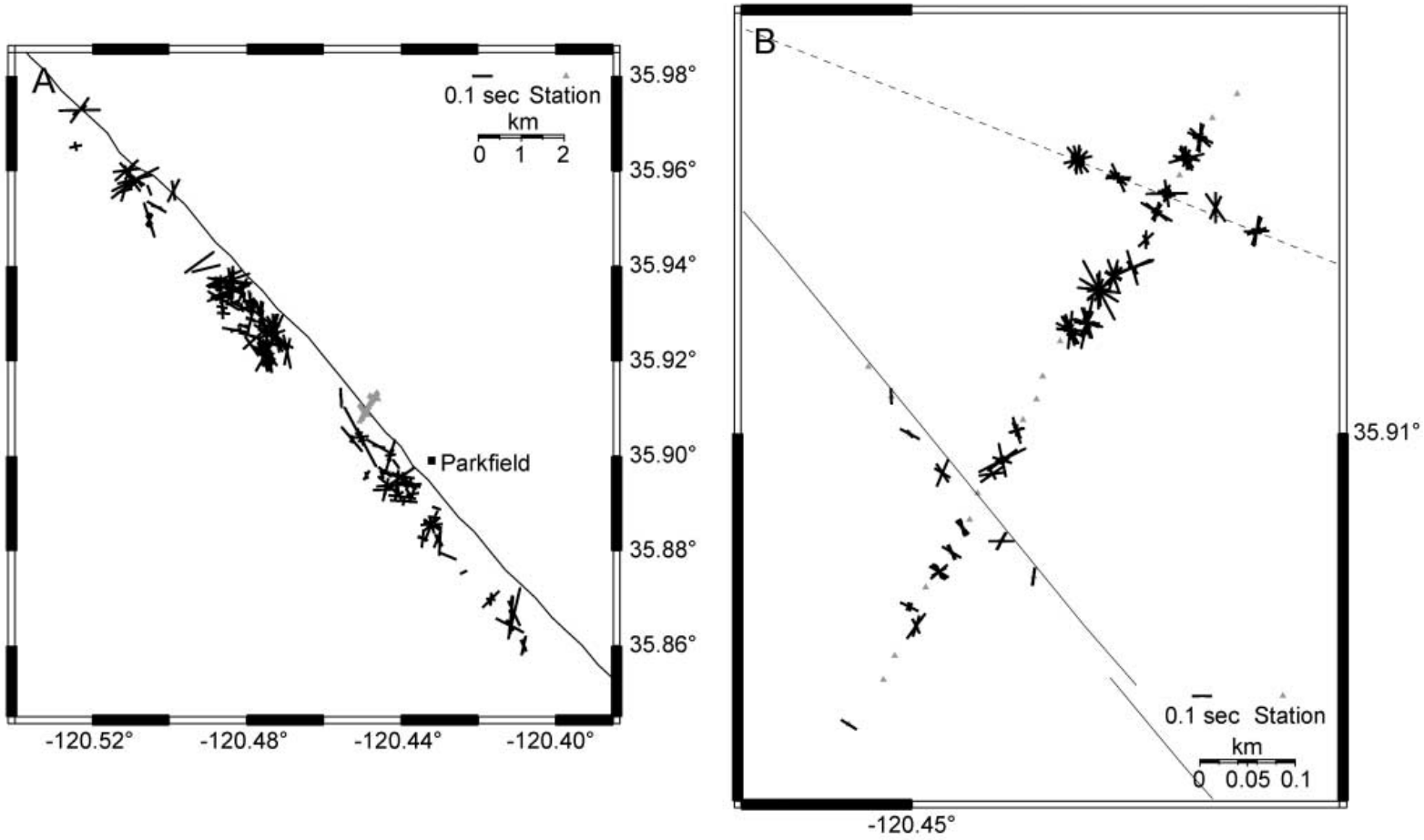
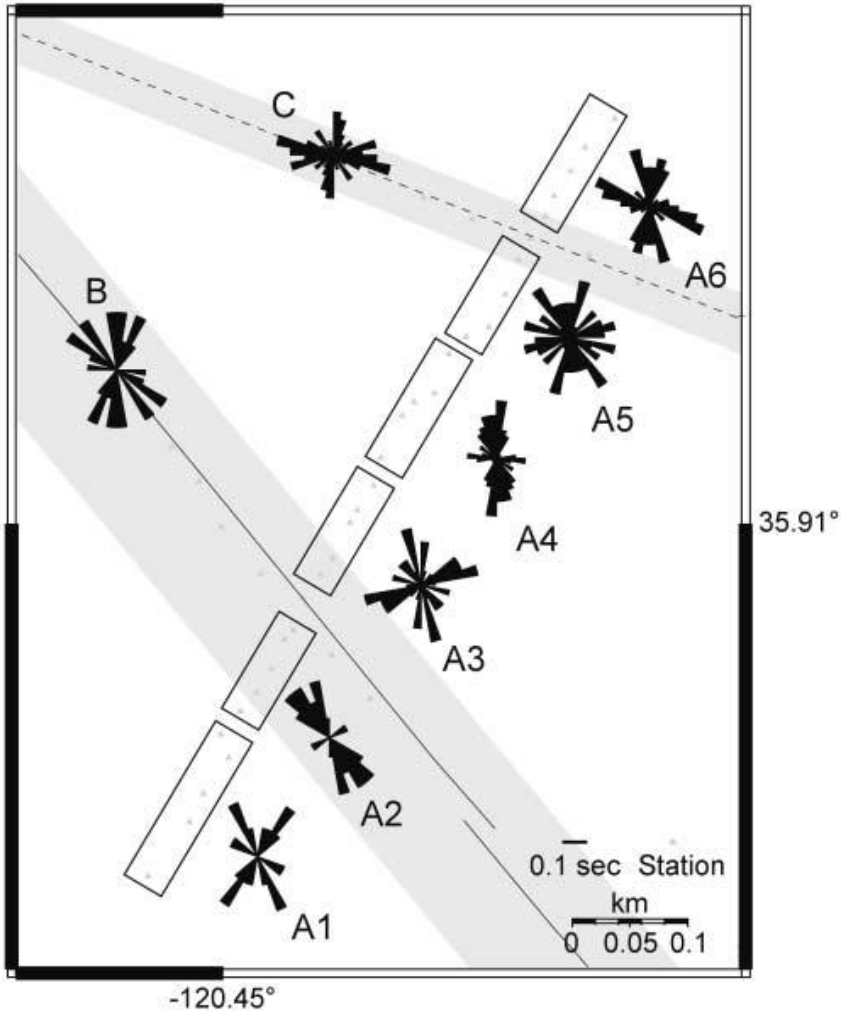

A
0.1 sec Station
km
0
1
2
SAFOD
Pilot Hole
36.02°
36.00°
35.98°
35.96°
-120.58°
-120.56°
-120.54°
-120.52°
-120.50°
B
35.99°
35.98°
0.1 sec Station
km
0
0.2
0.4
-120.54°
-120.53°


B
A6
A5
A4
A3
A2
A1
35.99°
35.98°
-120.54°
-120.53°
0.1 sec Station
km
0
0.2
0.4

- After earthquake




A
0.1 sec Station
km
0 1 2
Parkfield
35.98°
35.96°
35.94°
35.92°
35.90°
35.88°
35.86°
-120.52°
-120.48°
-120.44°
-120.40°
B
35.91°
0.1 sec Station
km
0 0.05 0.1
-120.45°


C
A6
B
A5
A4
35.91°
A3
A2
0.1 sec Station
km
0 0.05 0.1
A1
-120.45°

Data and results

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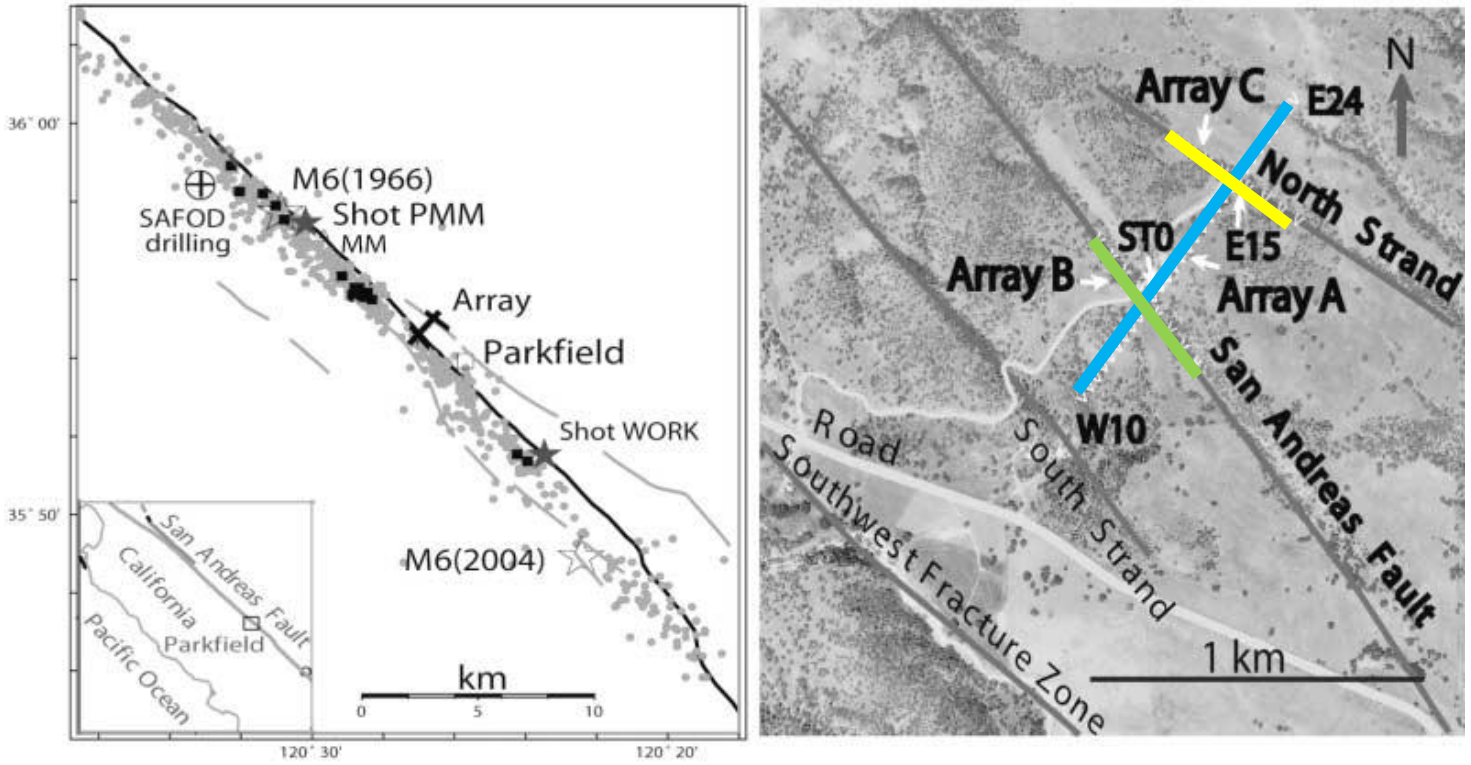
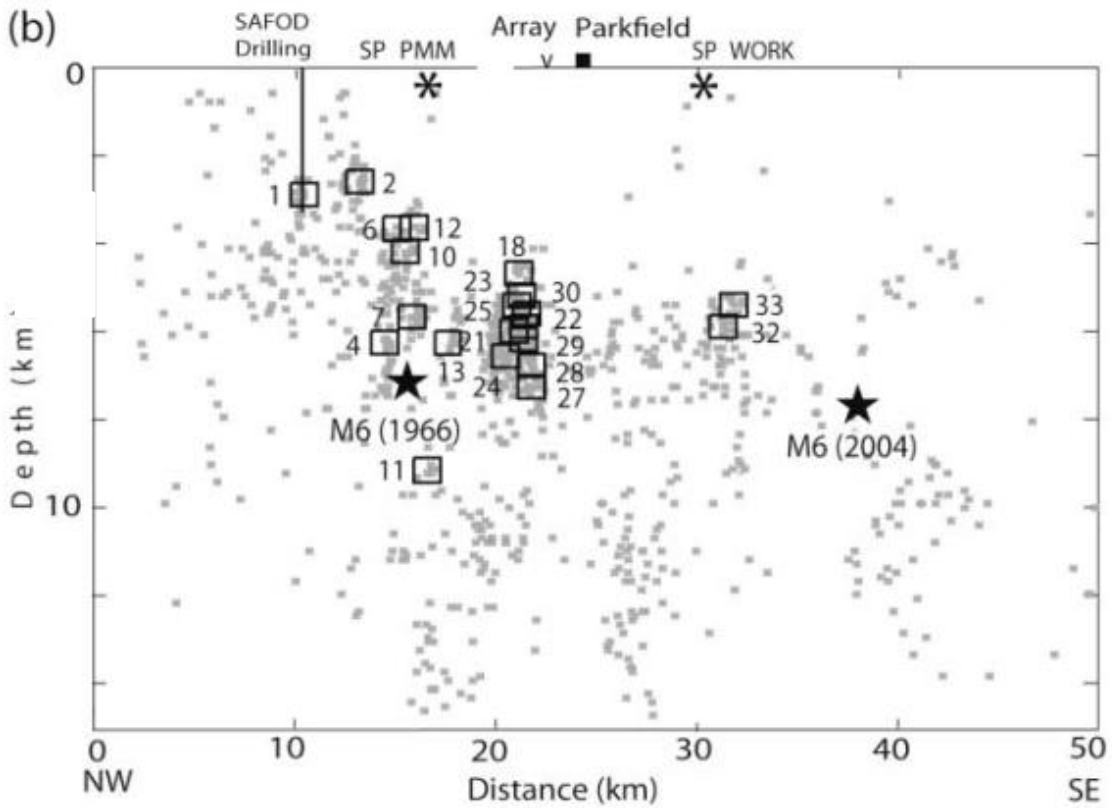
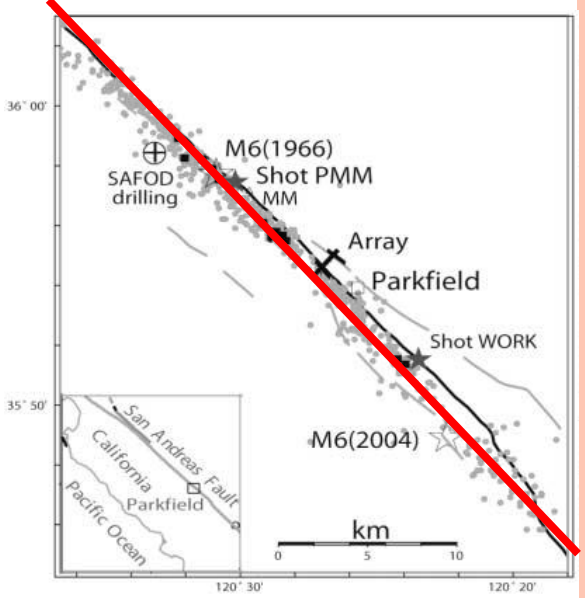
  - Repeated shots
- Earthquake data
  - Before earthquake
  - After earthquake
- Aftershocks data
  - Test1:site effect
  - Test2:time effect


36° 00'
35° 50'
M6(1966)
SAFOD drilling
Shot PMM
MM
Array
Parkfield
Shot WORK
M6(2004)
San Andreas Fault
California
Parkfield
Pacific Ocean
km
0
5
10
120° 30'
120° 20'
N
Array C
E24
North Strand
ST0
E15
Array B
Array A
San Andreas Fault
W10
Road
South Strand
Southwest Fracture Zone
1 km

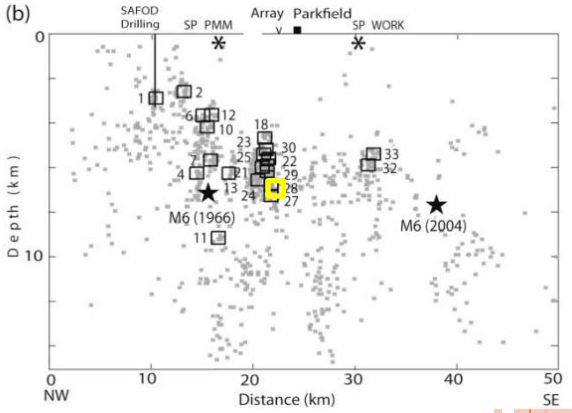




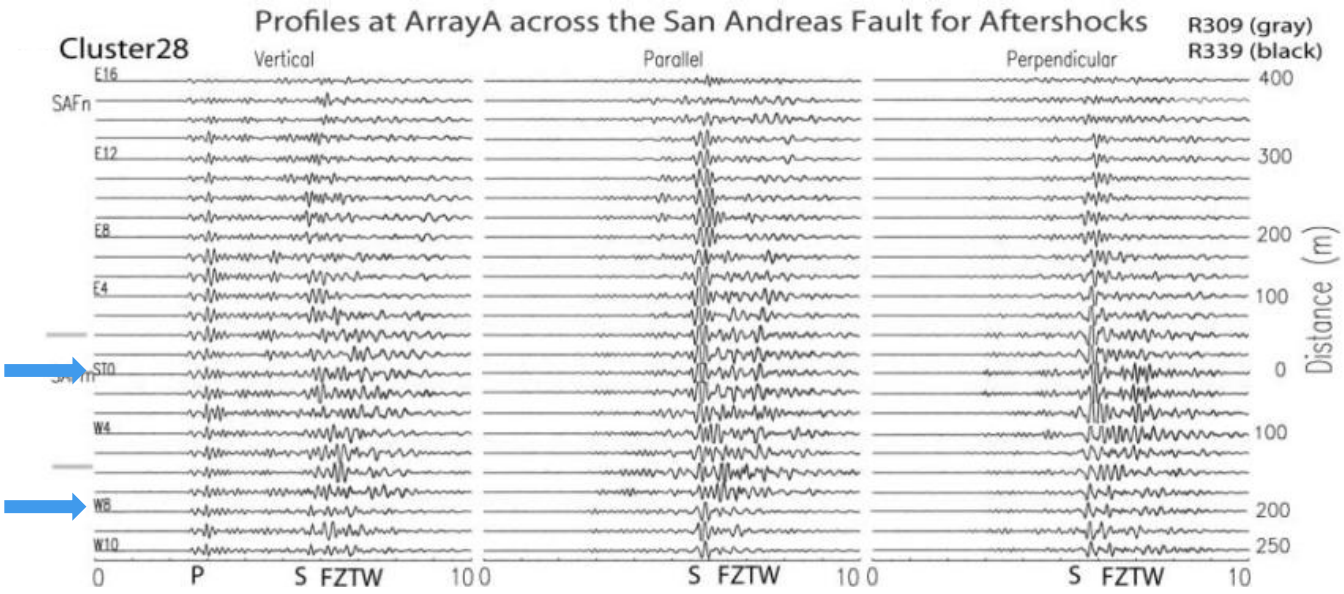
21 clusters of repeated aftershocks

1.at least five repeated aftershocks occurring at the same place
2.the location difference among them smaller than 200m
3.the difference in magnitude smaller than 0.5
4.similar waveforms with correlation coefficient higher than 0.8

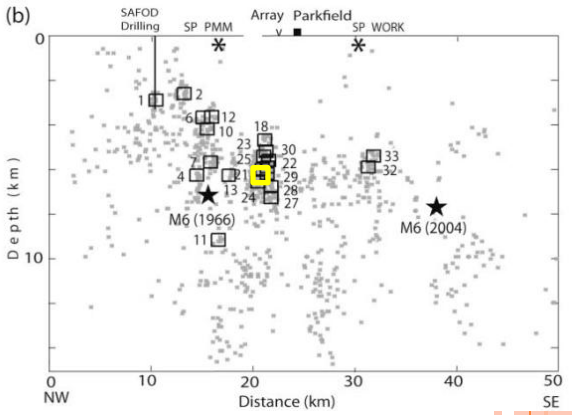
- Test 1: site effect



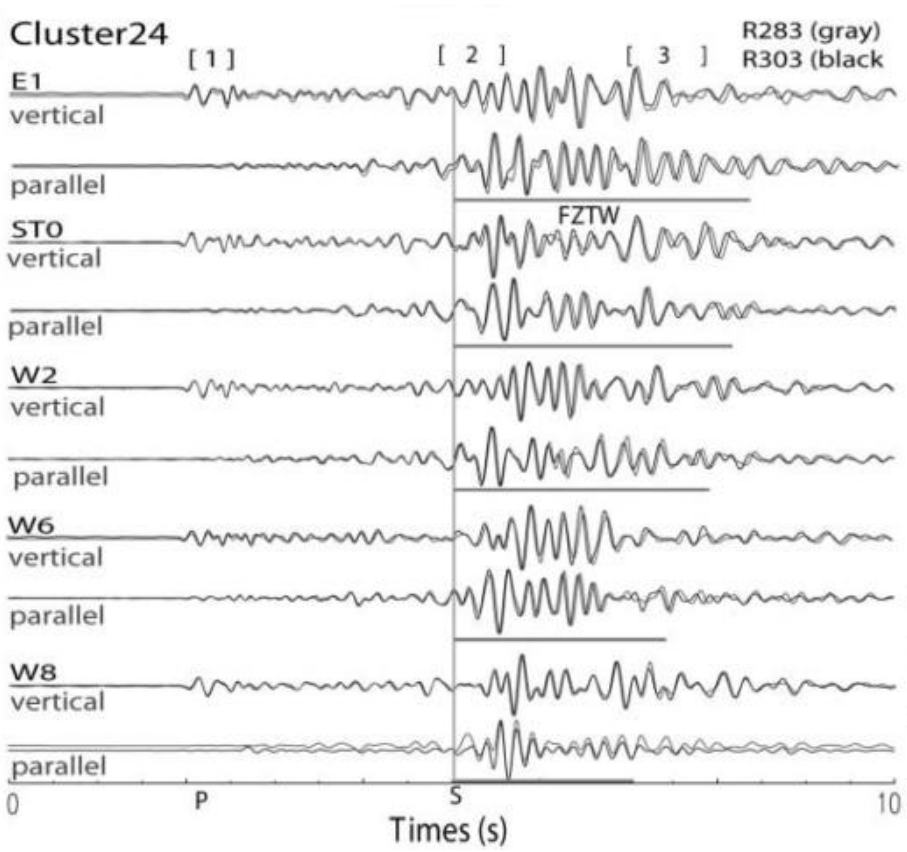
Cluster 28 at 6.9km depth and 2km northwest of the array site

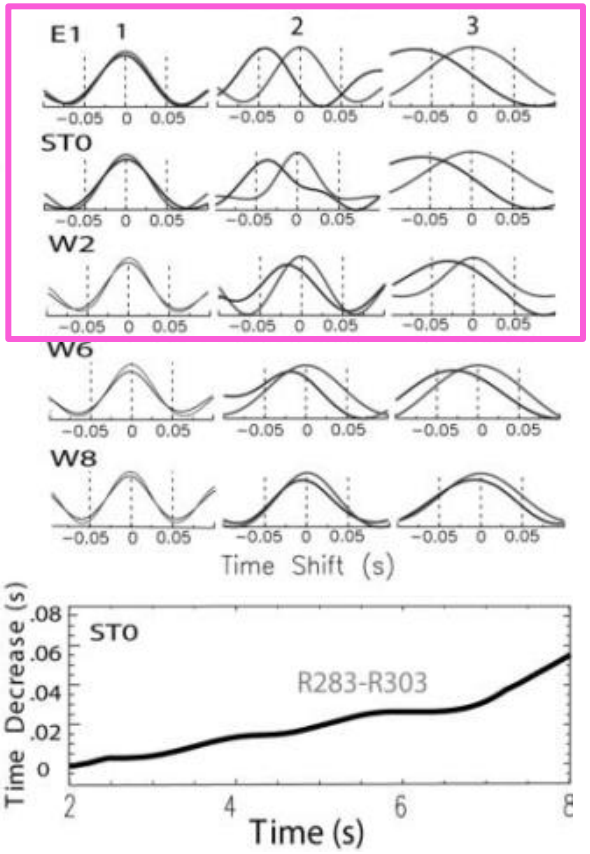


R309 2004/11/04
R339 2004/12/03

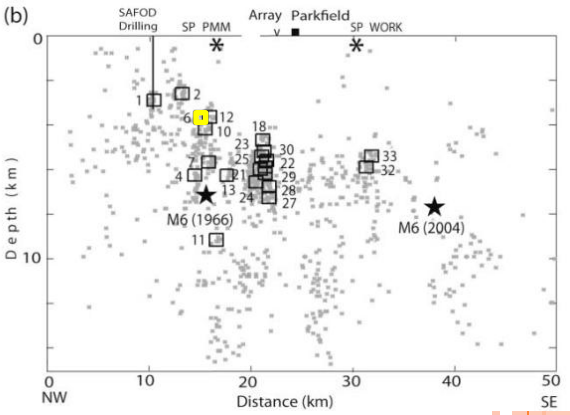


Cluster 24 at 6.4km depth and ~2km northwest of the array





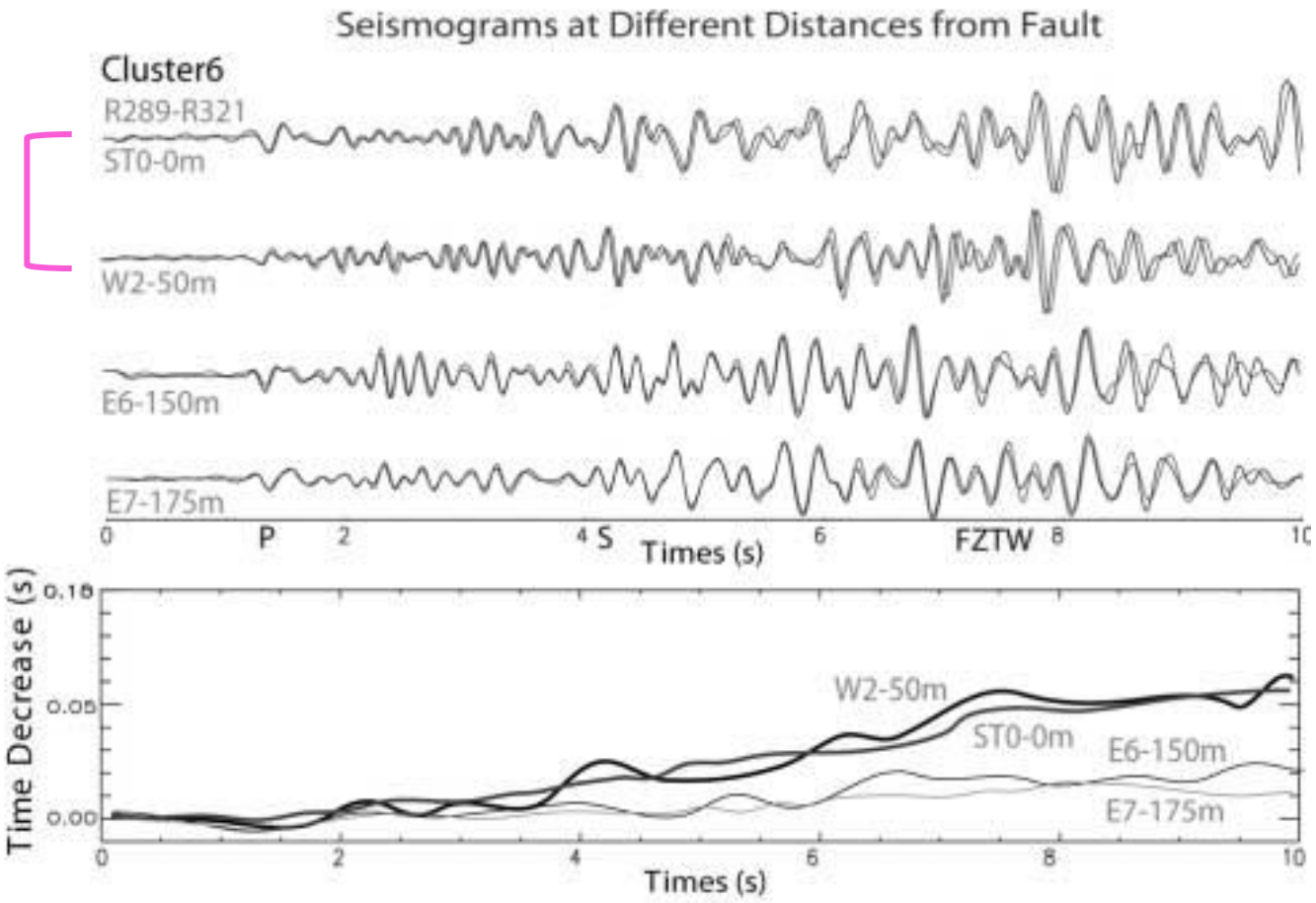
R283 2004/10/09
R303 2004/10/29



Cluster 6 at 3.9km depth and ~8km northwest of the array.

R289 2004/10/15

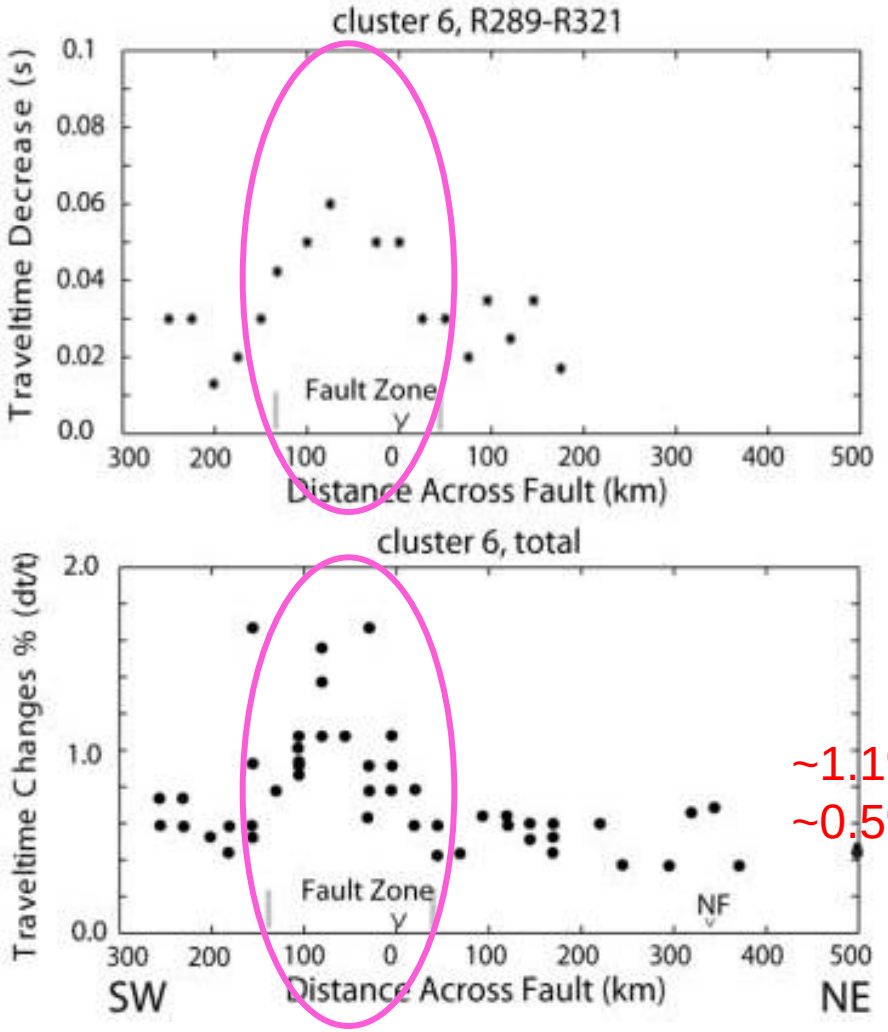
R321 2004/11/16



Cluster 6 at 3.9km depth and ~8km northwest of the array.

R289 2004/10/15

R321 2004/11/16

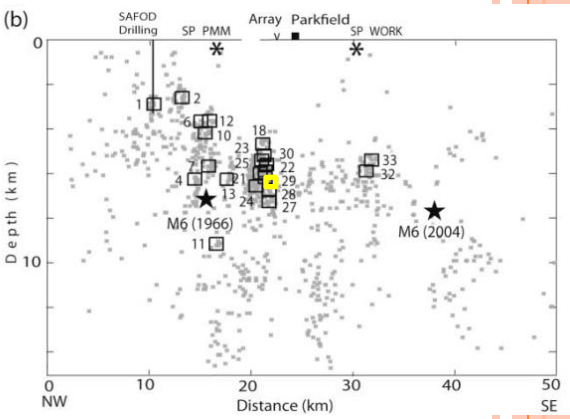


(2004/10/15~2004/12/15)

~1.1% within the rupture zone

~0.5% out of the zone

Test 2: time effect

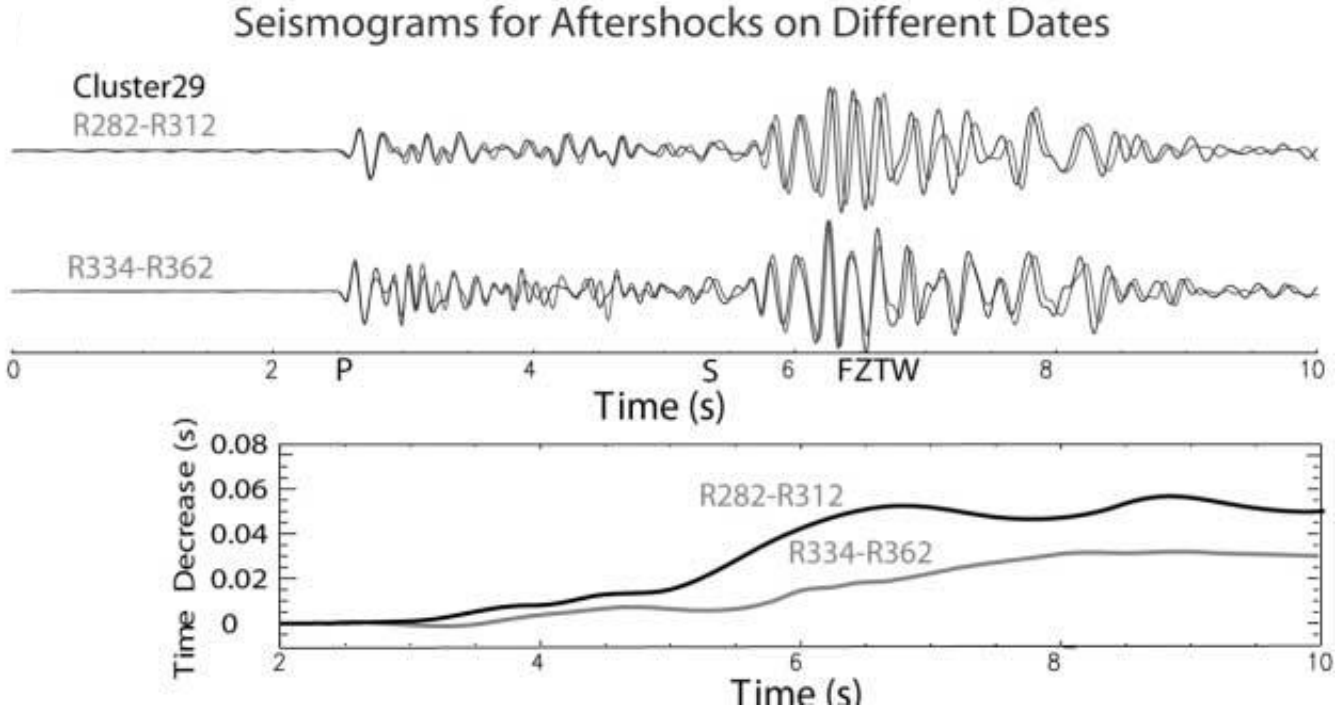


Cluster 29 at 6.5km depth and ~2km northwest of the array.

R282 2004/10/07
R312 2004/11/07 } 31 days

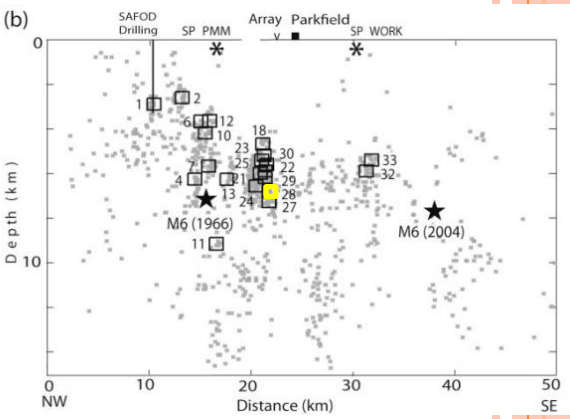
R334 2004/11/28
R362 2004/12/26 } 28 days

Vertical-component seismograms recorded at station W4 of array A

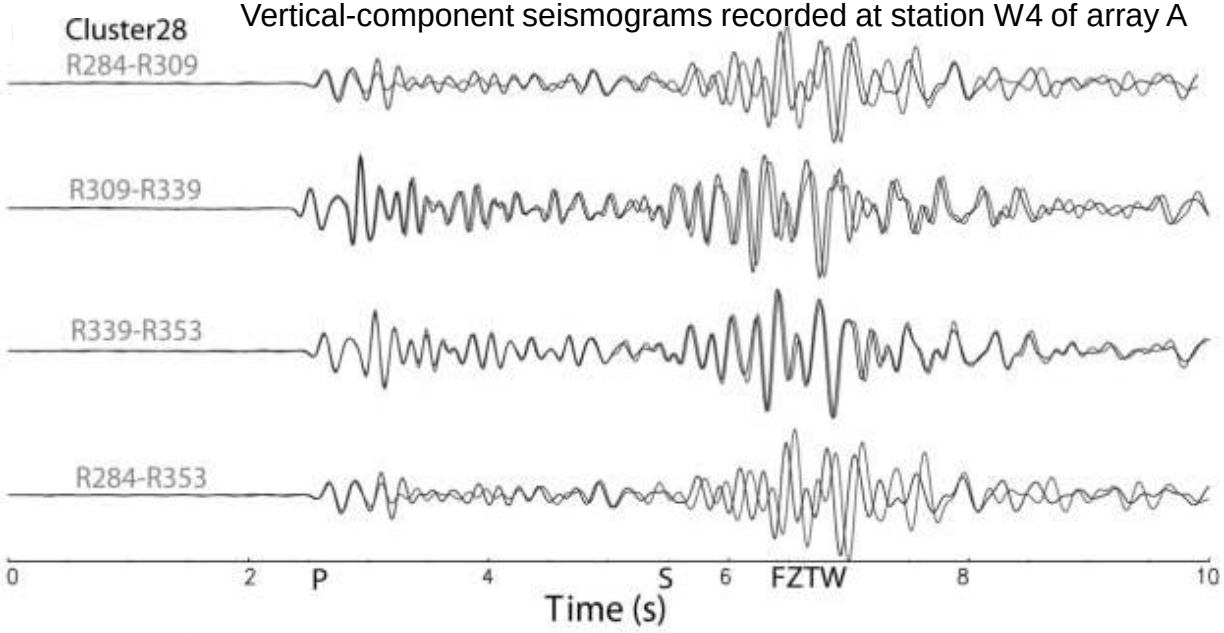


Cluster 28 at 6.9km depth and 2km northwest of the array.

R284 2004/10/10
R309 2004/11/04
R339 2004/12/03
R353 2004/12/17



Vertical-component seismograms recorded at station W4 of array A

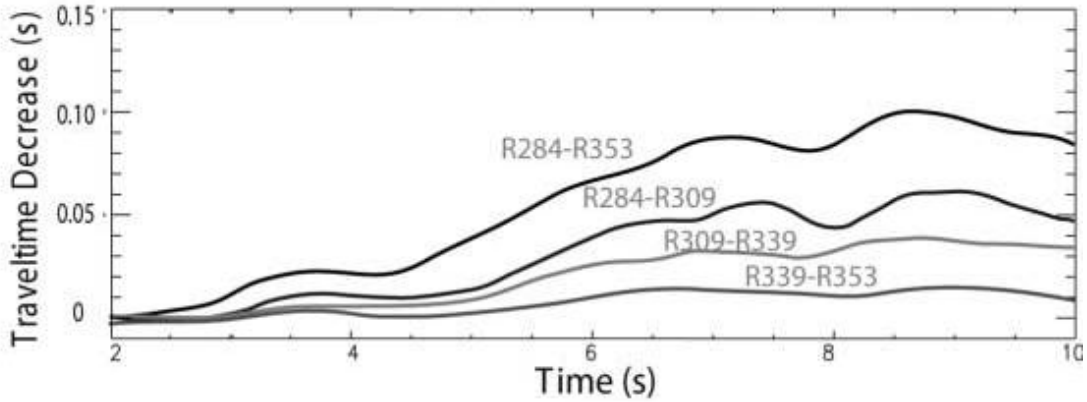


25 days

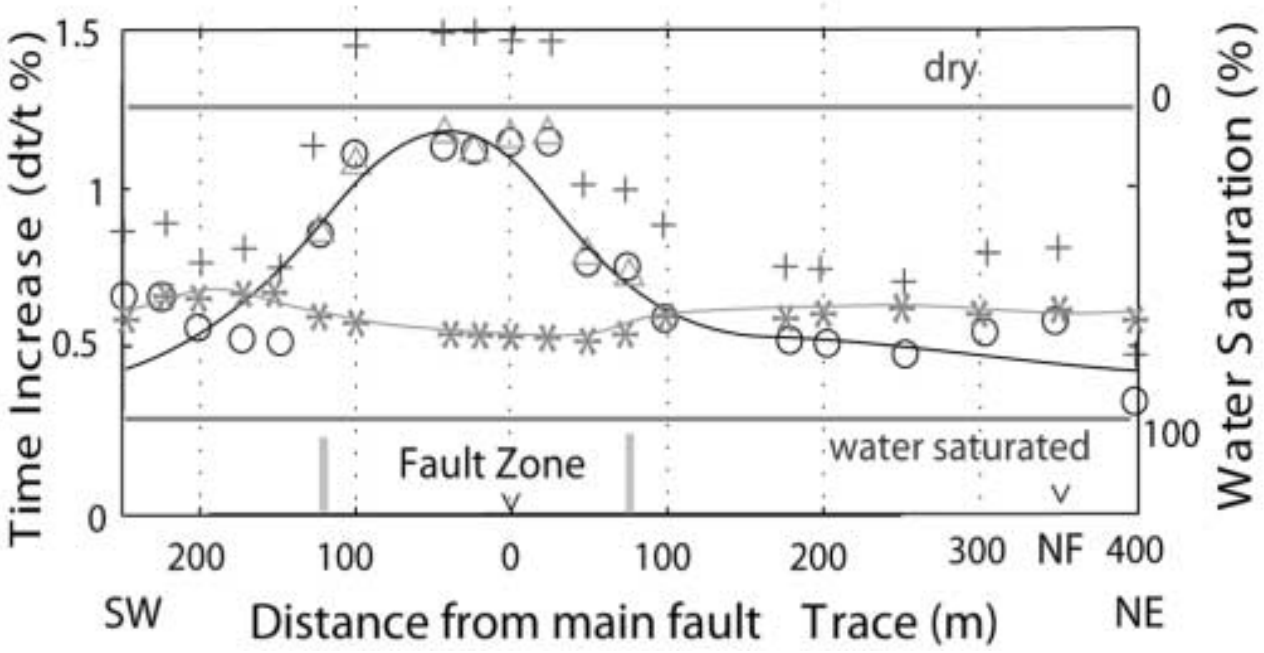
29 days

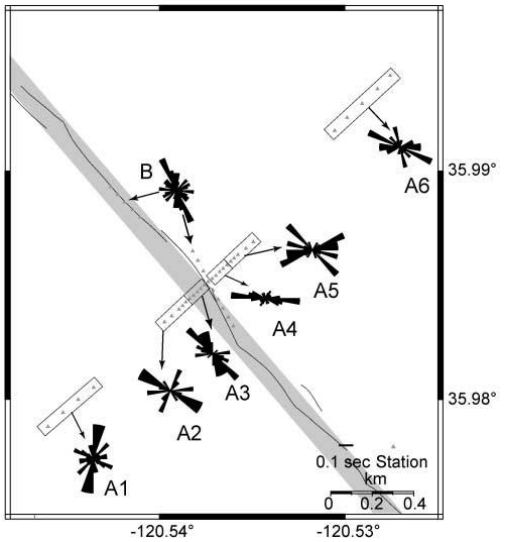
14 days

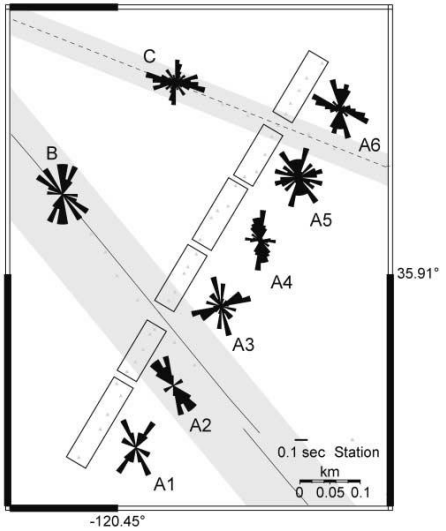
68 days

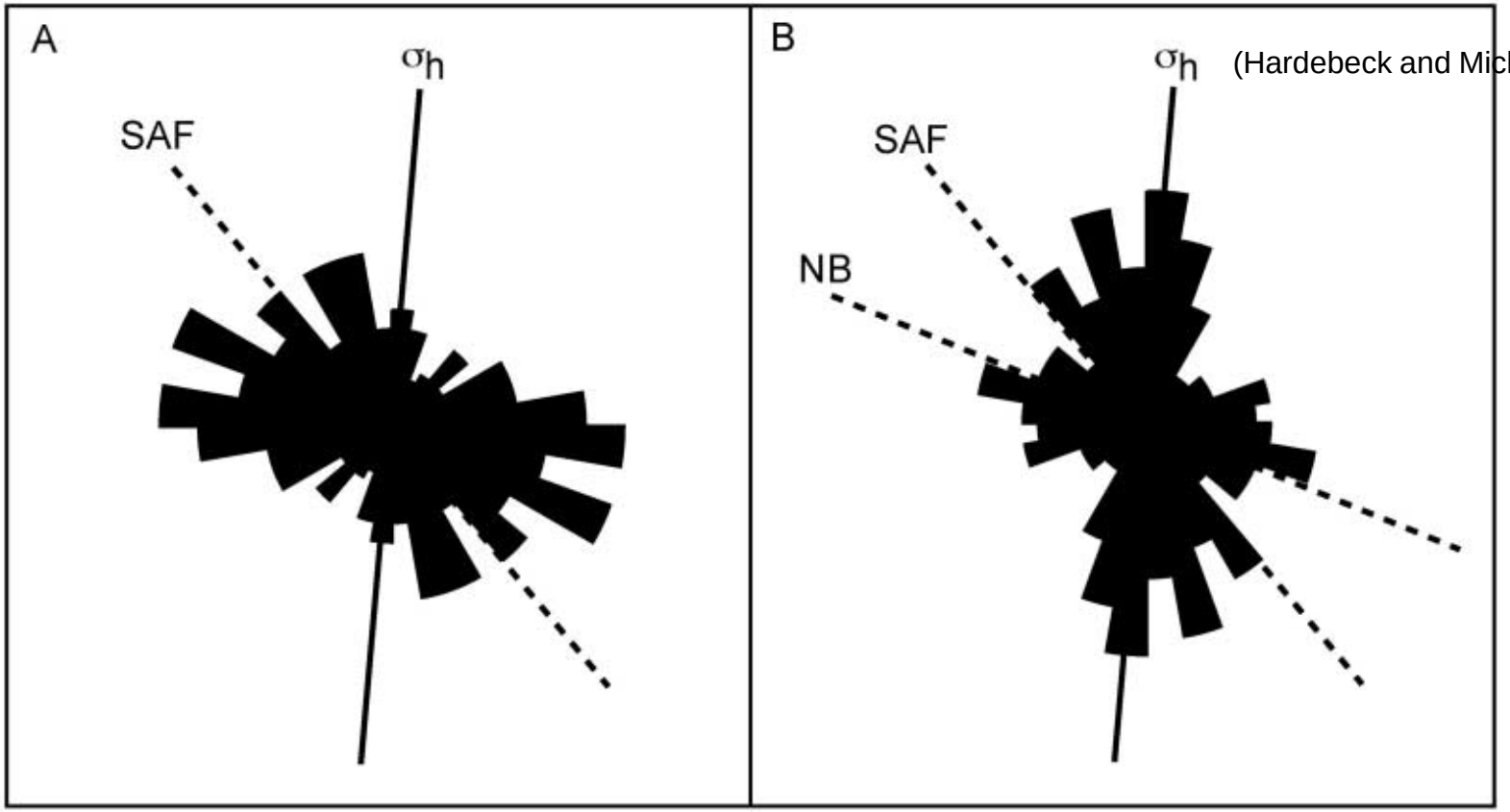


Discussions and conclusions

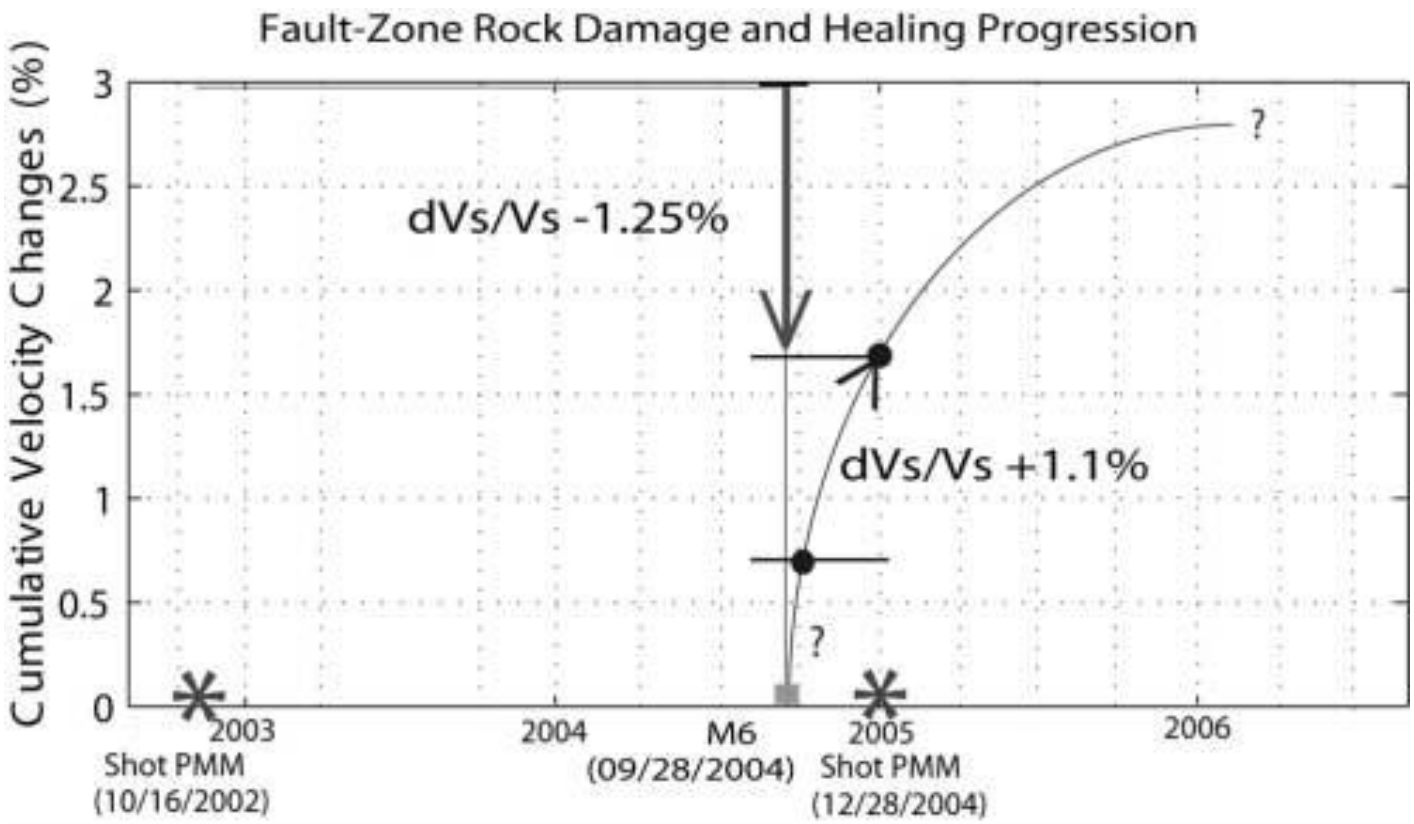








(Hardebeck and Michael,2004)


Fault-Zone Rock Damage and Healing Progression
Cumulative Velocity Changes (%)
3
2.5
2
1.5
1
0.5
0
dVs/Vs -1.25%
dVs/Vs +1.1%
?
?
2003
2004
M6
2005
2006
Shot PMM
(10/16/2002)
(09/28/2004)
Shot PMM
(12/28/2004)

Thank you for your attention.