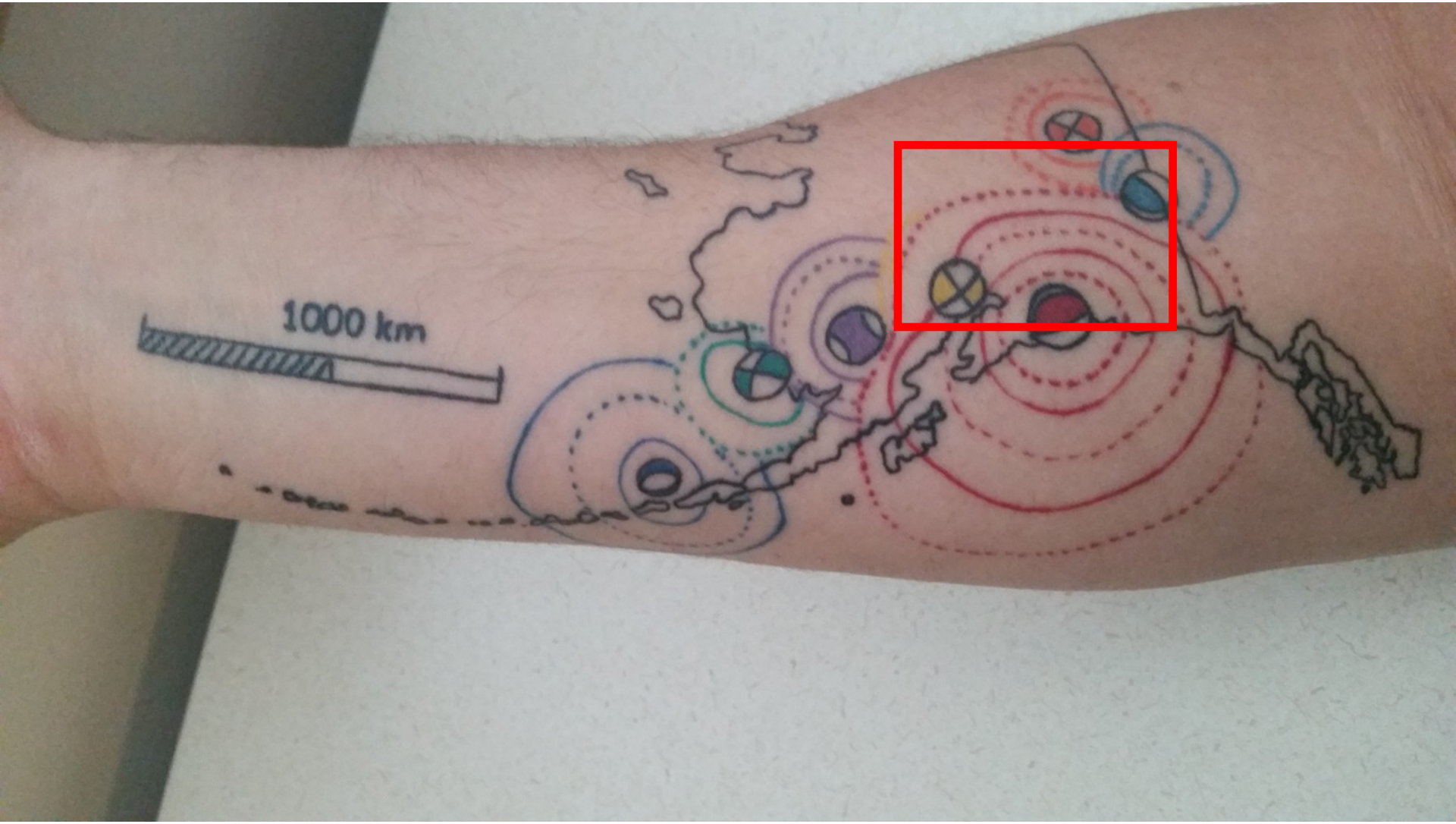
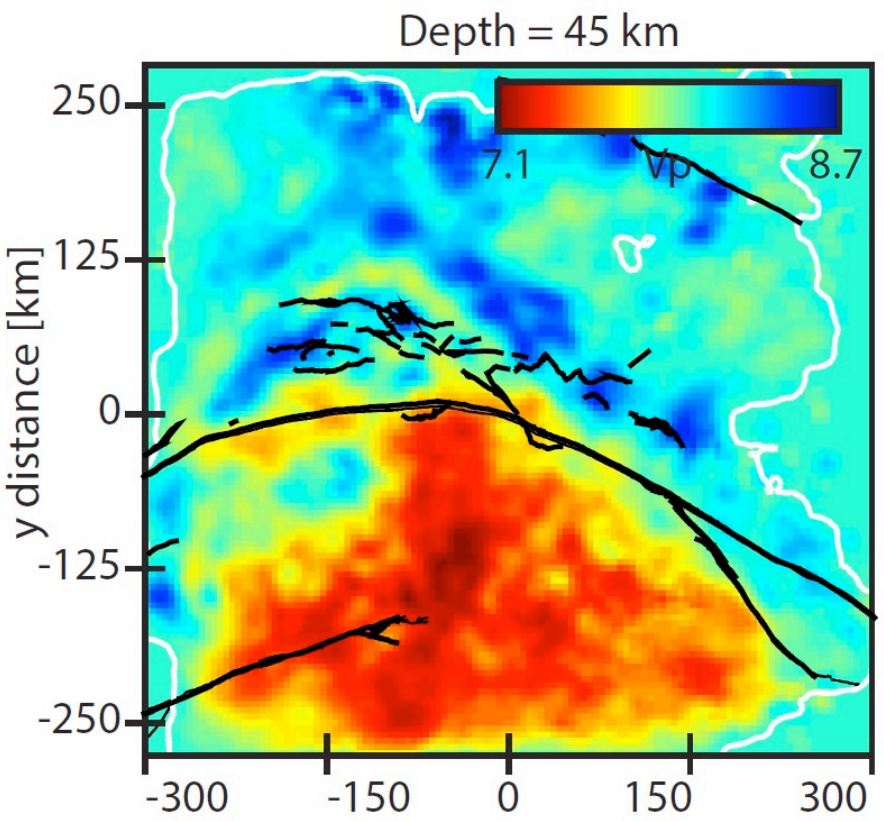
Ten-Kilometer Vertical Moho Offset and Shallow Velocity Contrast Along the Denali Fault from Double-difference Tomography, Receiver Functions, and Fault Zone Head Waves

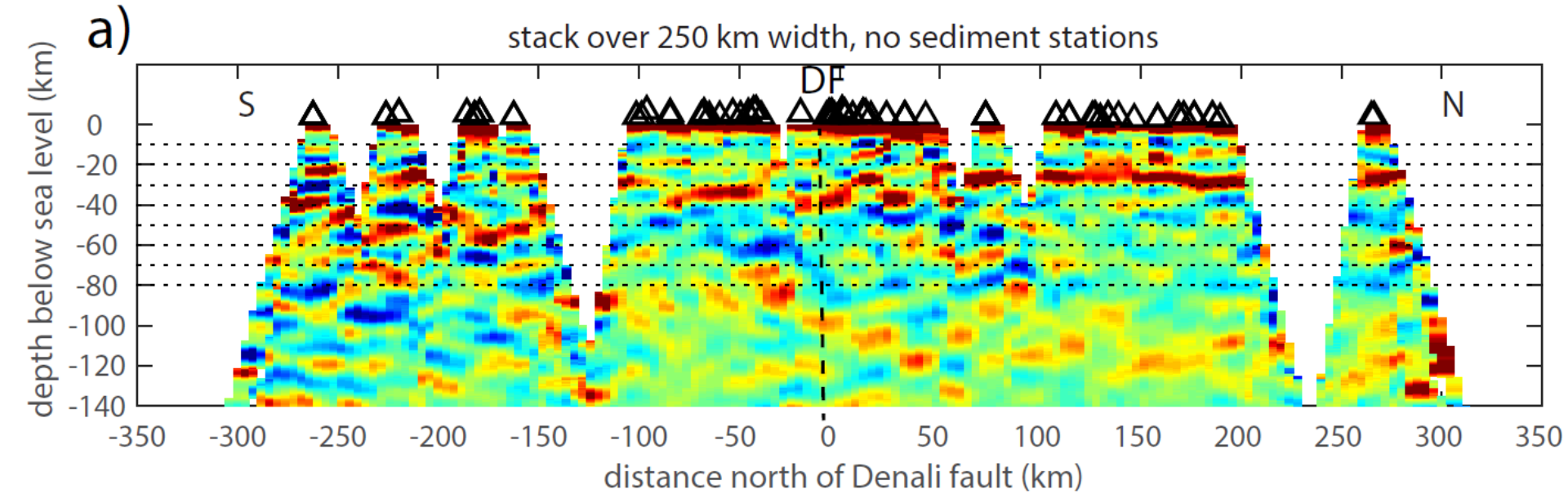
Yehuda Ben-Zion
Vera Schulte-Pelkum
Carl Tape
Zachary Ross
Fan-Chi Lin


1000 km

Outline

- Denali Fault Head Waves
- Denali Double-difference Tomography
- Central Alaska Receiver Functions



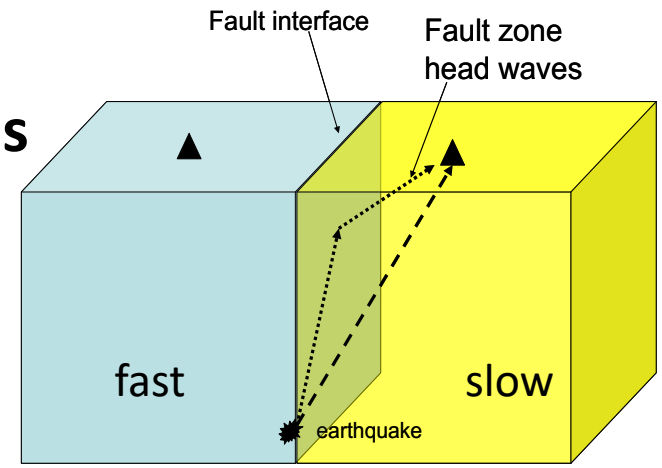


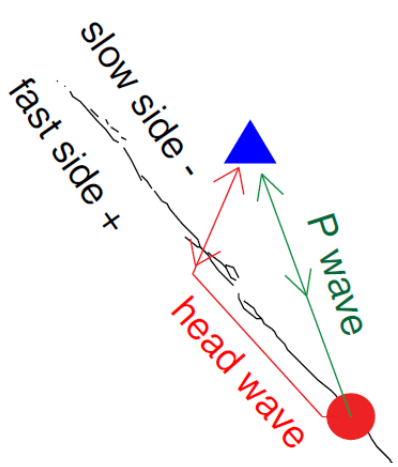
Head waves

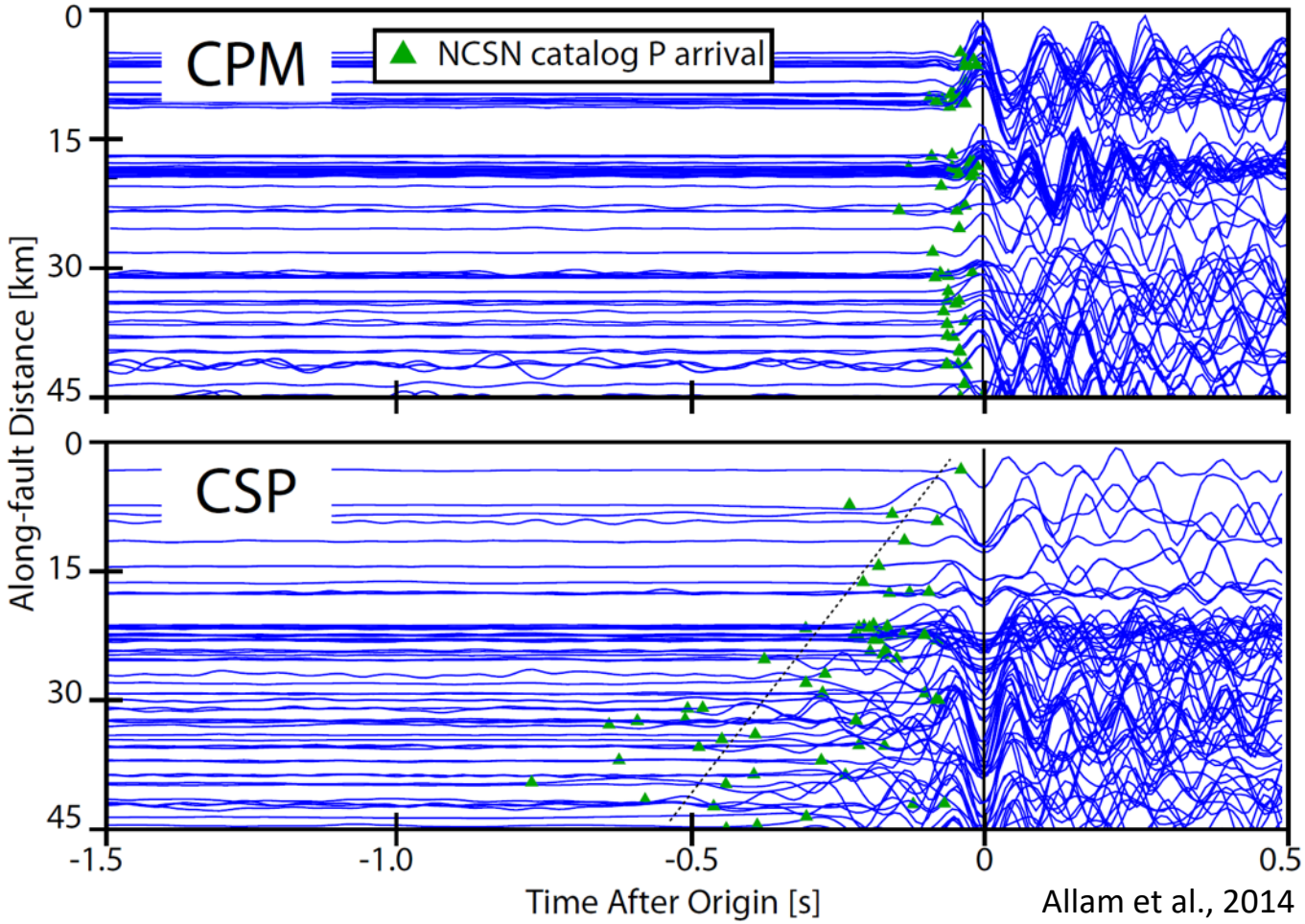
http://web.utah.edu/thorne

Mike Thorne

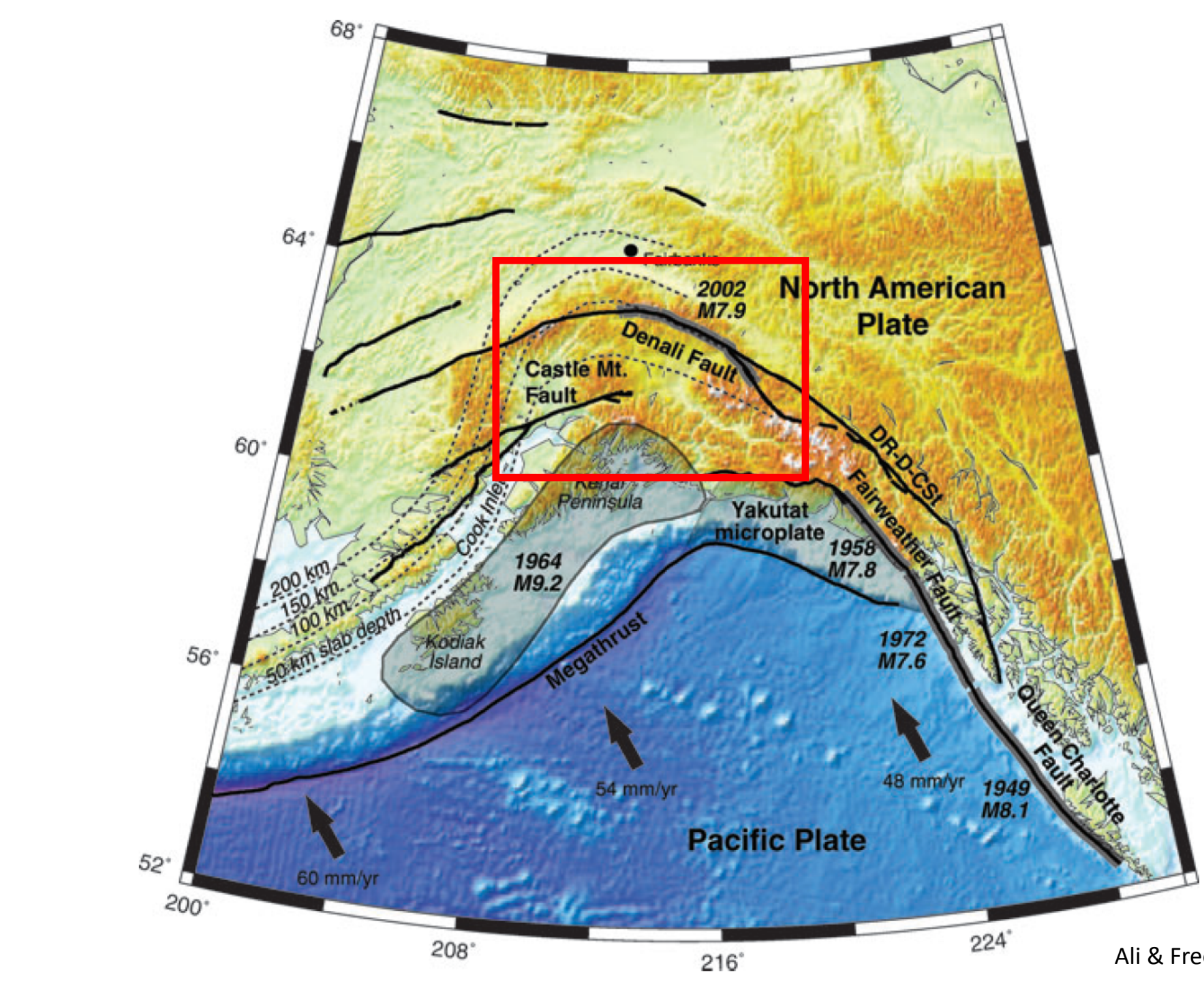
Fault Zone Head Waves



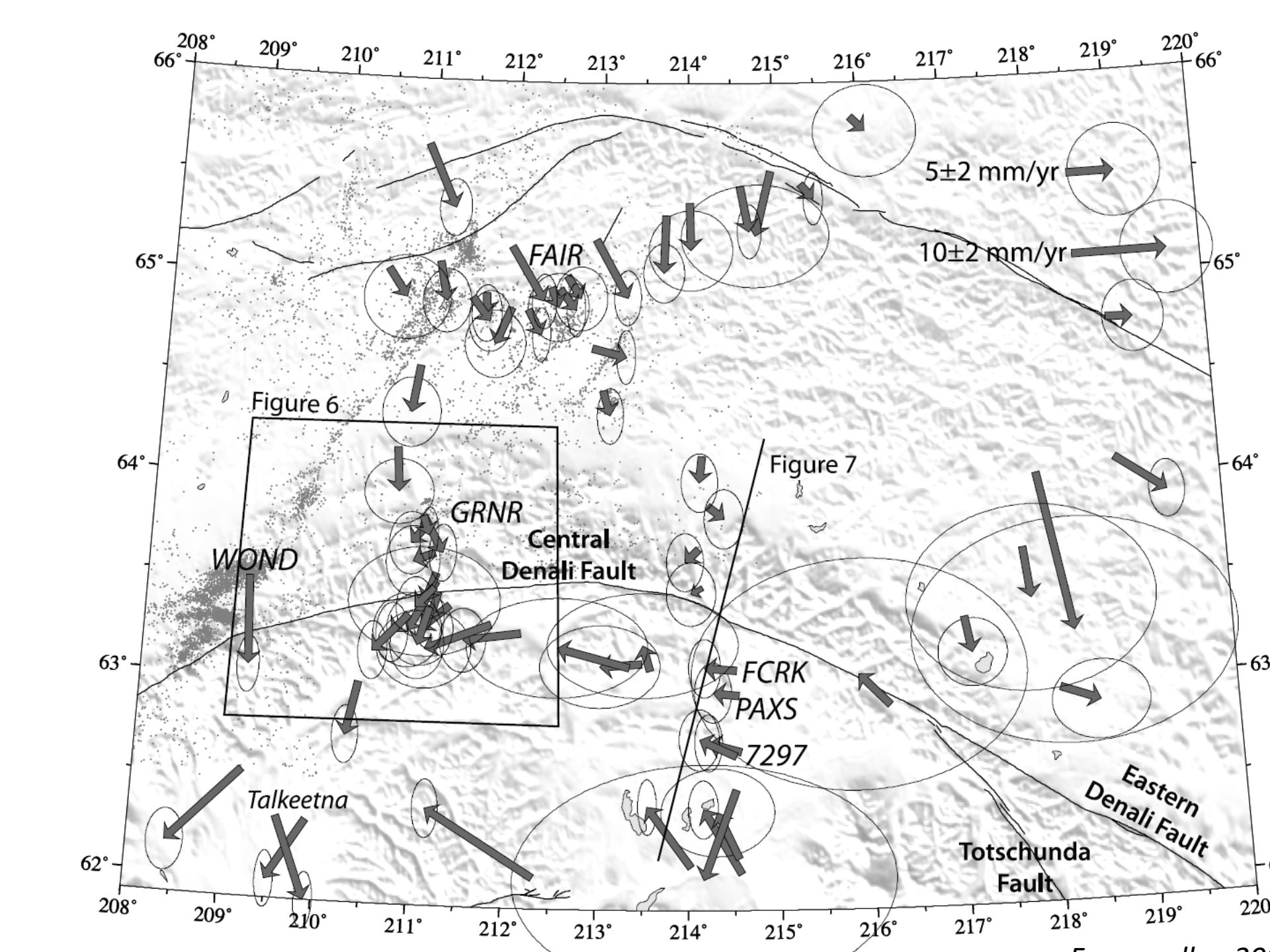


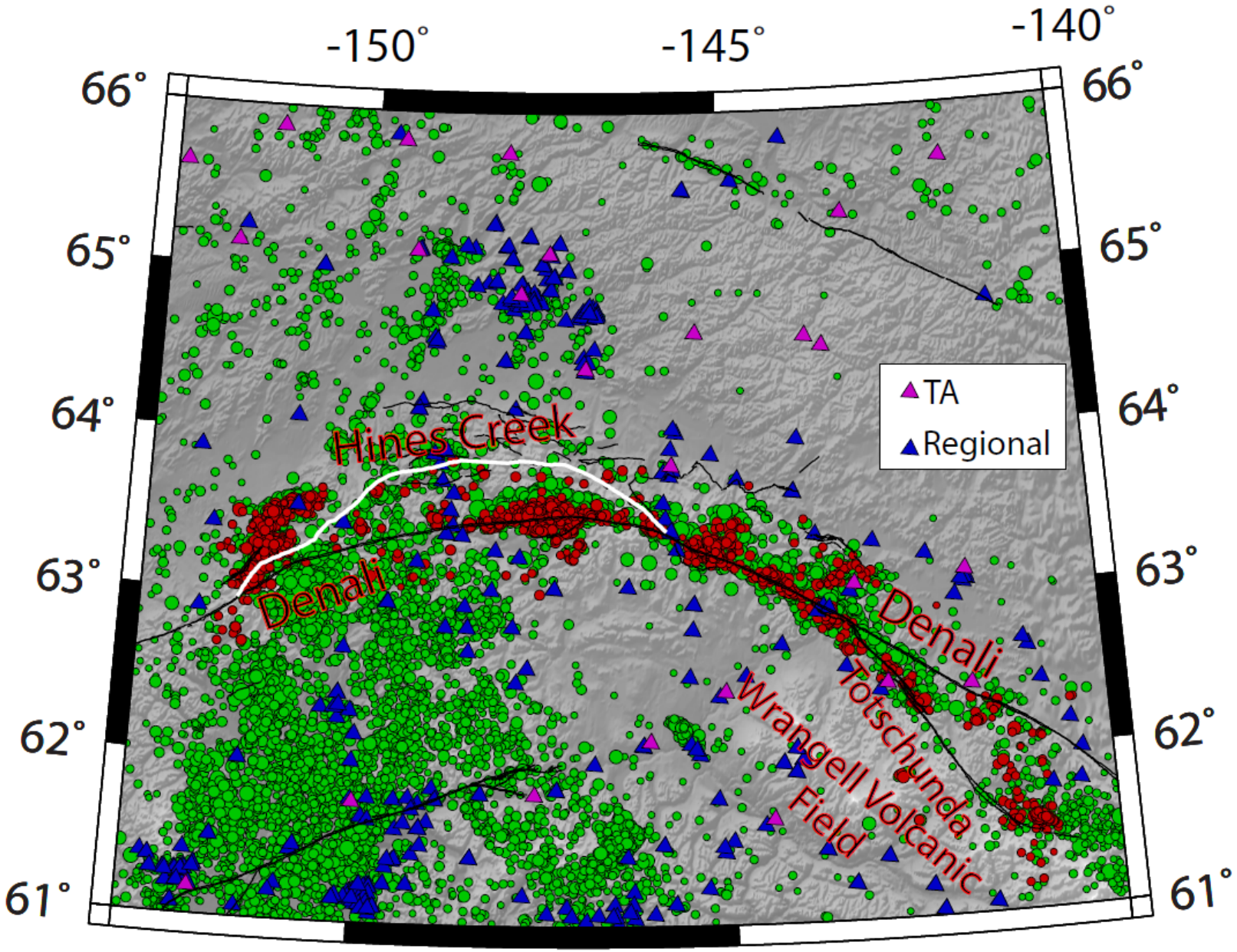


Allam et al., 2014

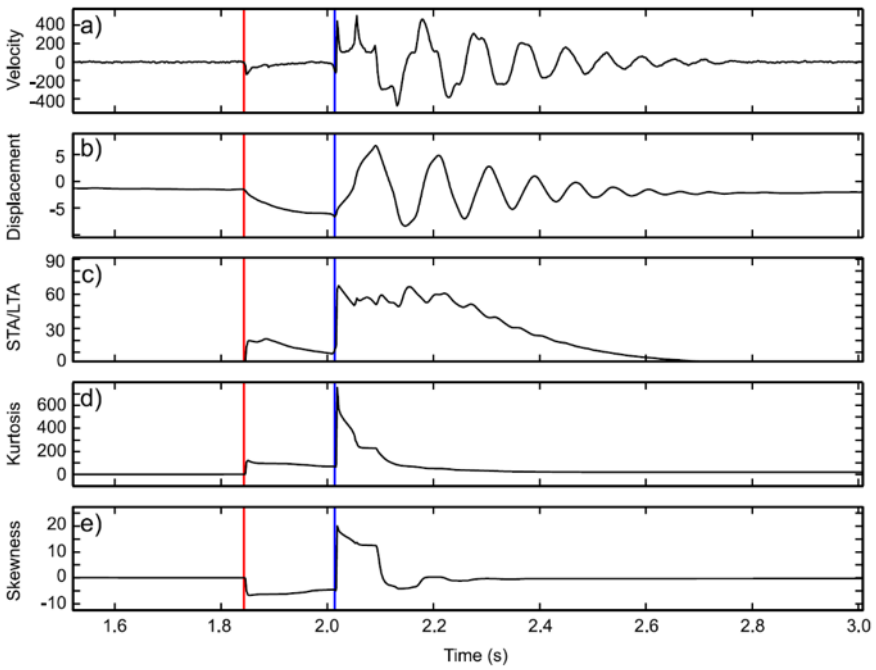


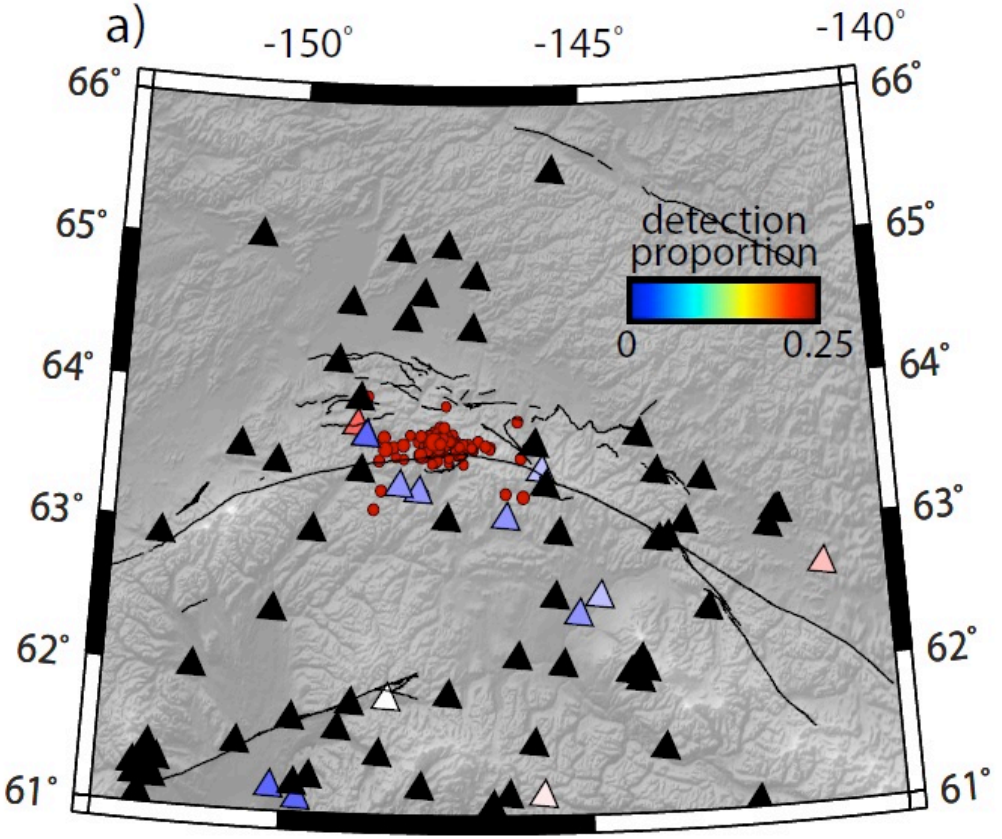
Ali & Freed, 2010


208°
209°
210°
211°
212°
213°
214°
215°
216°
217°
218°
219°
220°
66°
65°
64°
63°
62°
5±2 mm/yr
10±2 mm/yr
FAIR
Figure 6
Figure 7
GRNR
WOND
Central
Denali Fault
FCRK
PAXS
7297
Talkeetna
Eastern
Denali Fault
Totschunda
Fault

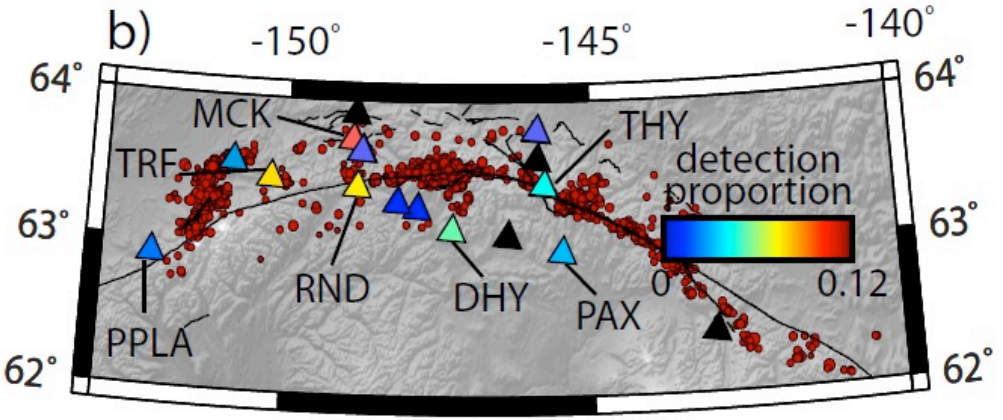

-150°
-145°
-140°
66°
65°
64°
63°
62°
61°
TA
Regional
Hines Creek
Denali
Denali
Totschunda
Wrangell Volcanic
Field

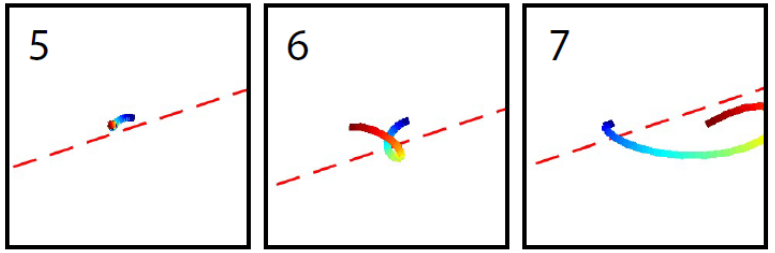
Denali Fault Head Waves

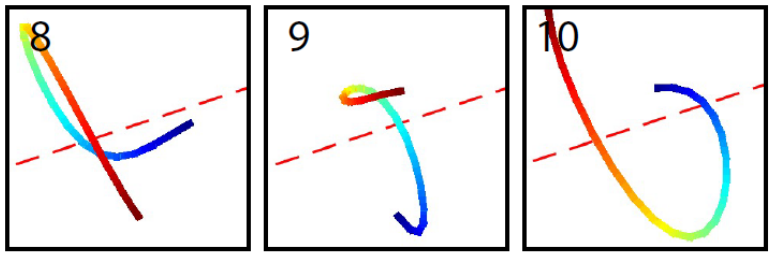


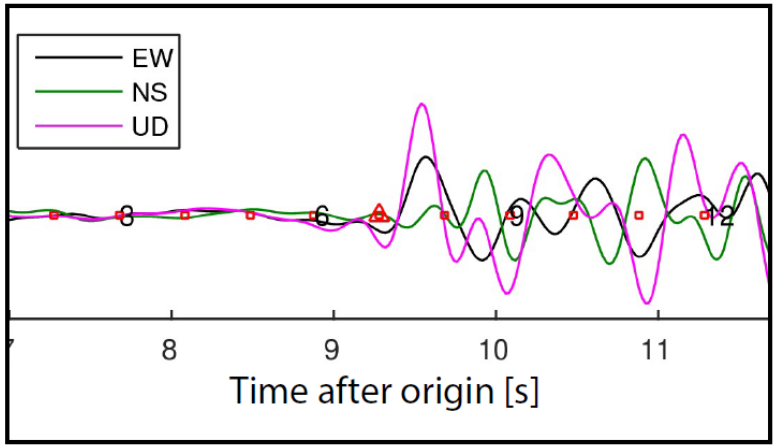


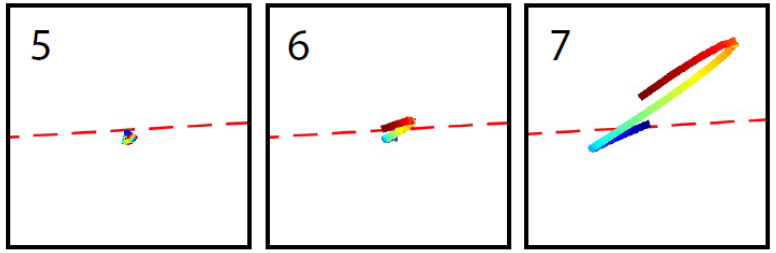
- Automated algorithm (Ross & Ben-Zion, 2015)
- 1,427 events
- Head waves detected at 15 stations
- Head waves on both sides of the fault!

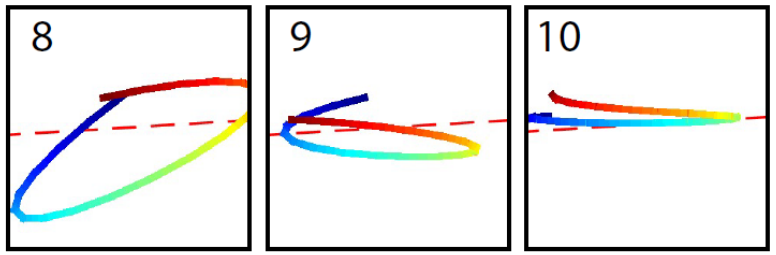


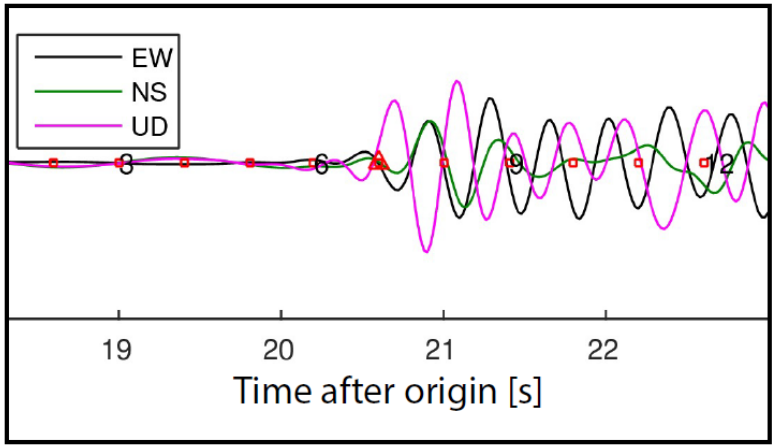

5
6
7

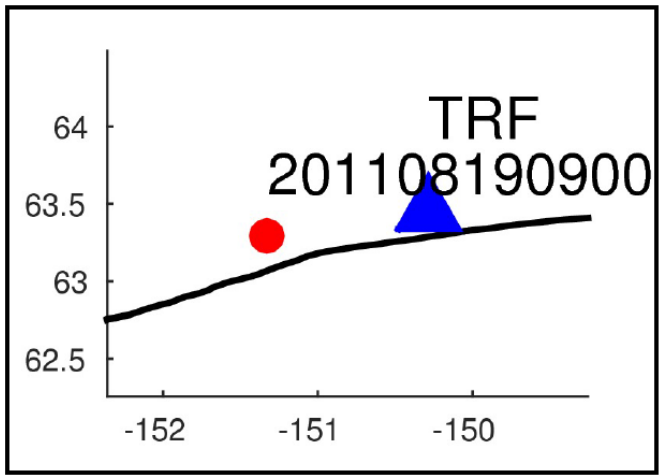

8
9
10

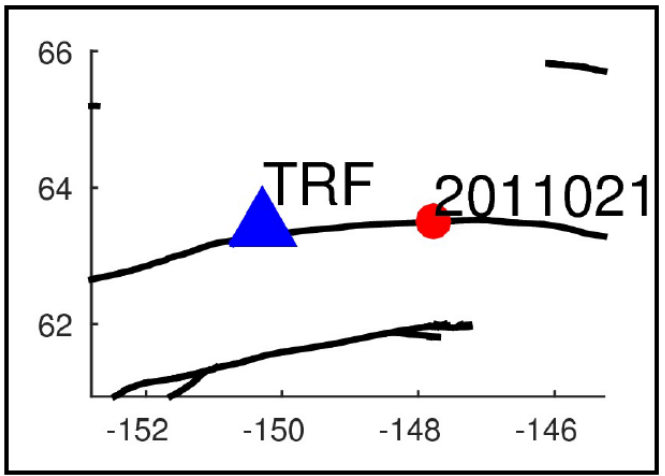

EW
NS
UD
3
6
9
12
8
9
10
11
Time after origin [s]

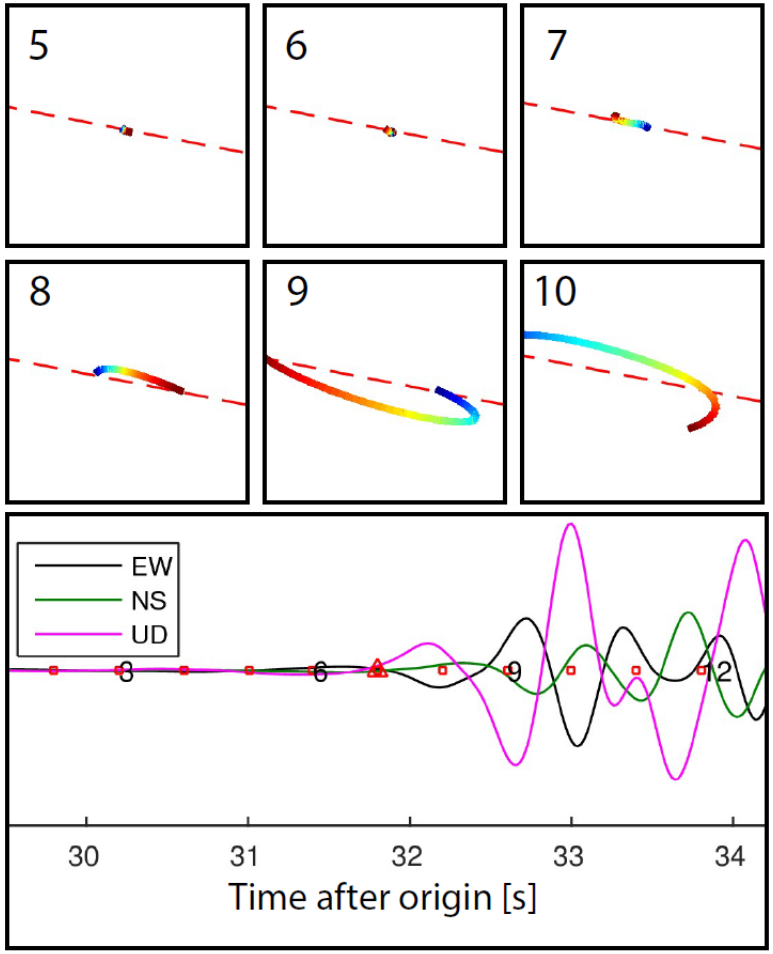

5
6
7

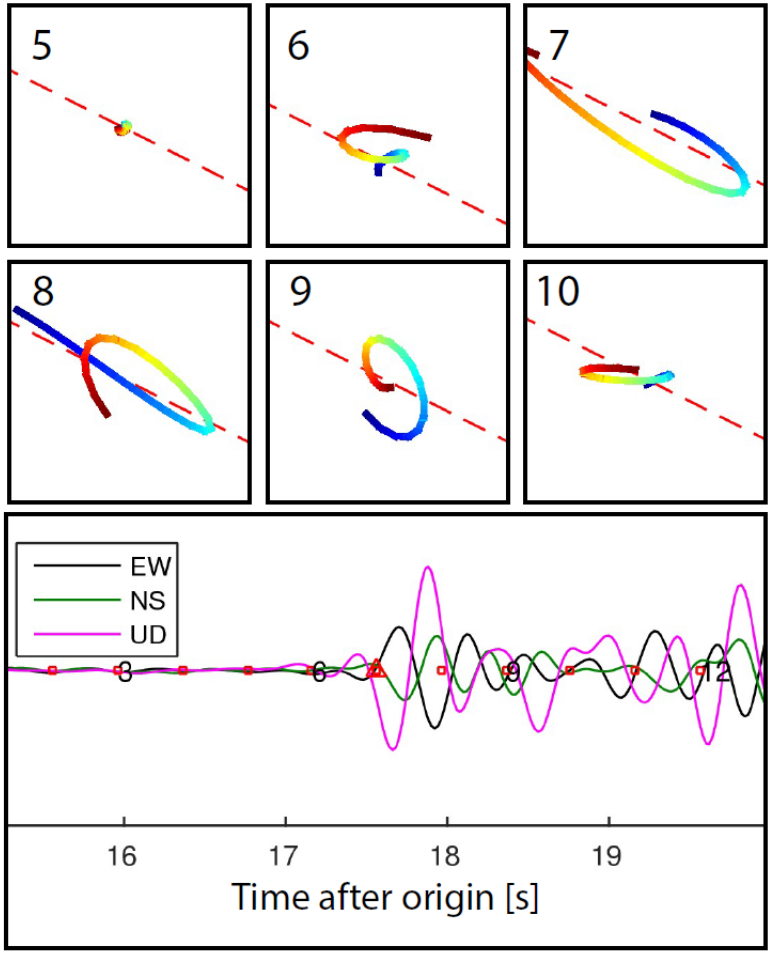

8
9
10

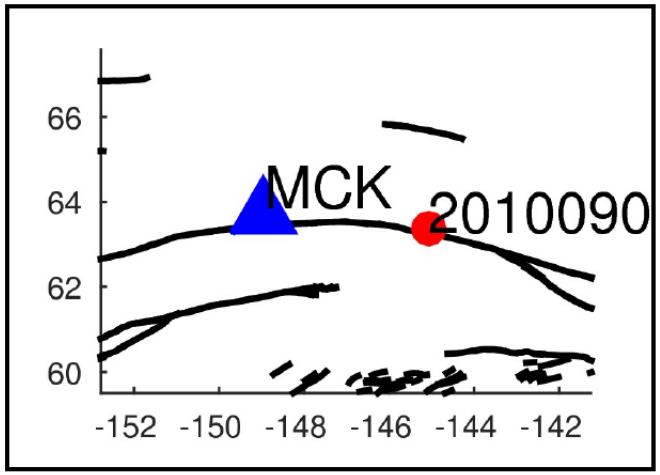

EW
NS
UD
3
6
9
12
19
20
21
22
Time after origin [s]

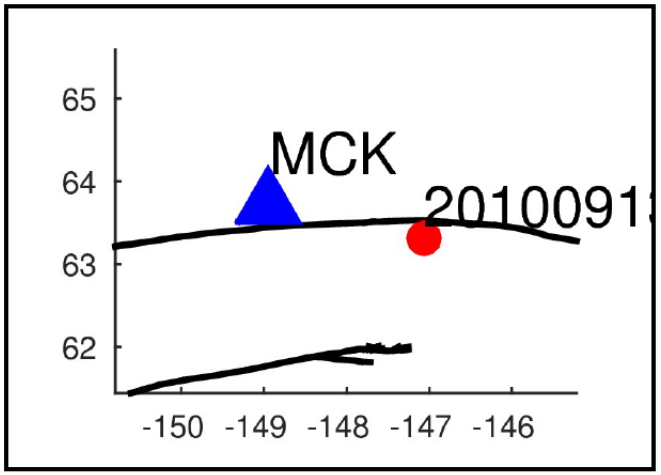

TRF
201108190900
64
63.5
63
62.5
-152
-151
-150

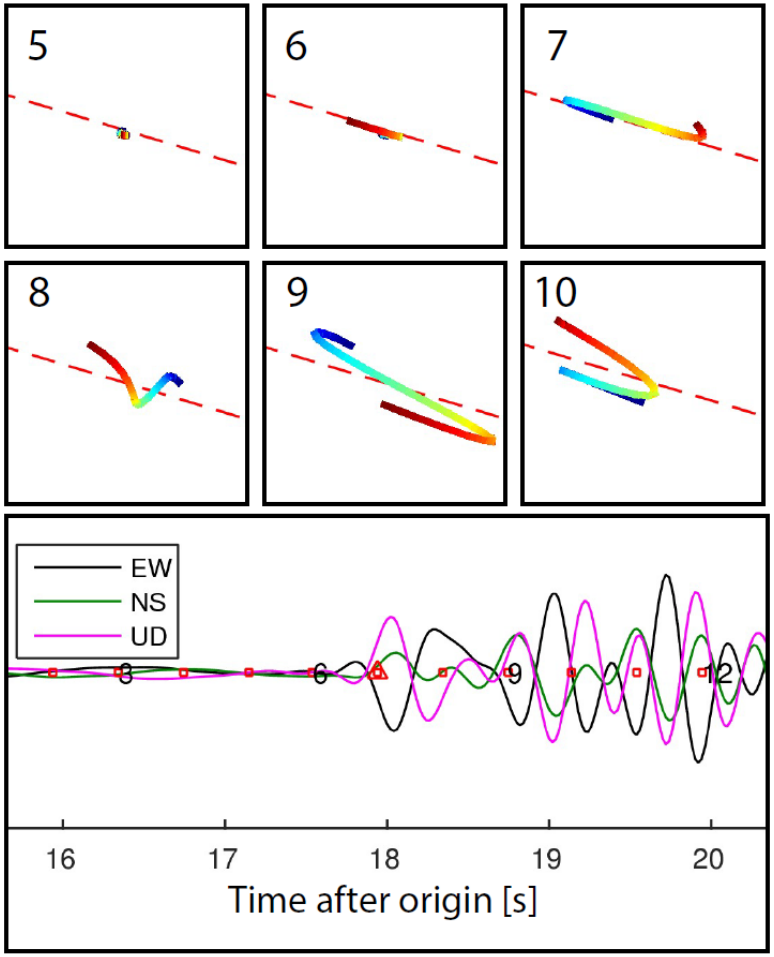

TRF
2011021
66
64
62
-152
-150
-148
-146

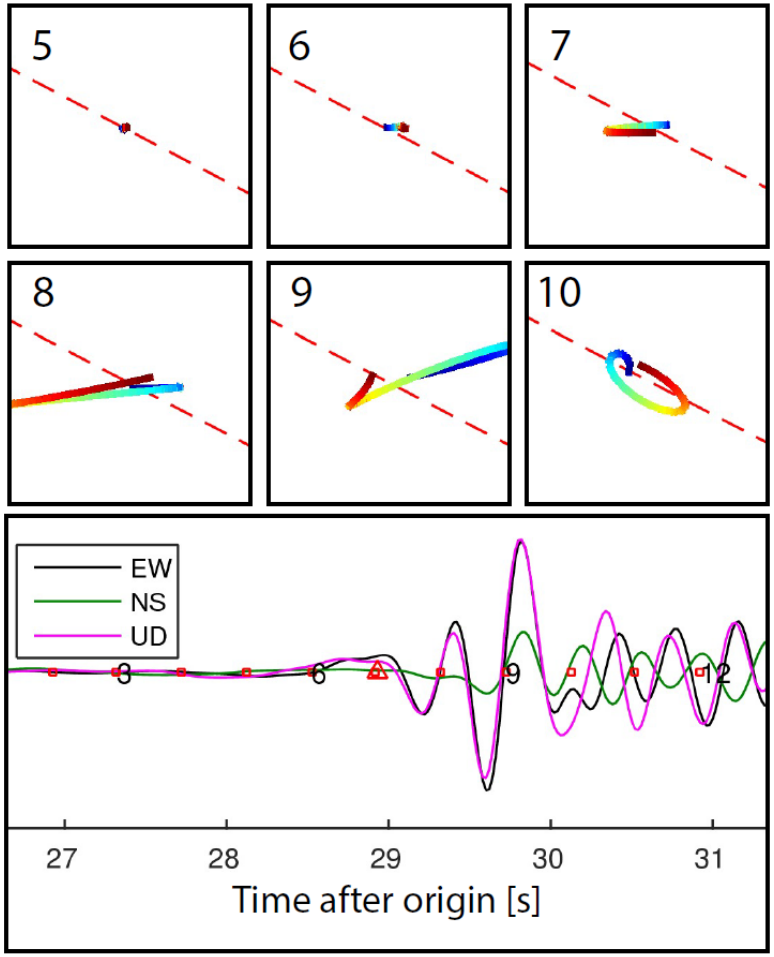

5
6
7
8
9
10
EW
NS
UD
3
6
9
12
30
31
32
33
34
Time after origin [s]

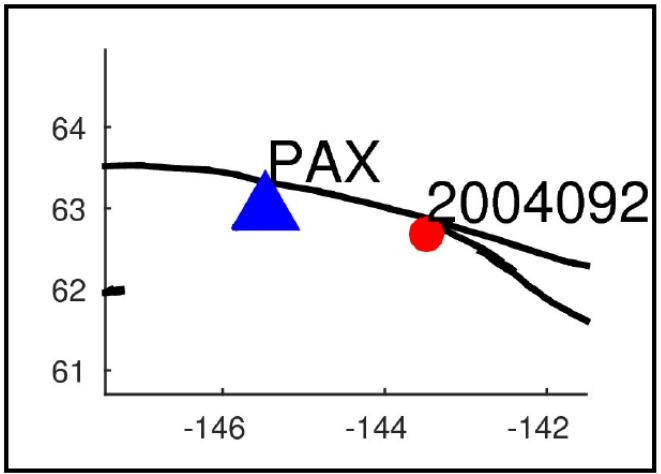

5
6
7
8
9
10
EW
NS
UD
3
6
9
12
16
17
18
19
Time after origin [s]

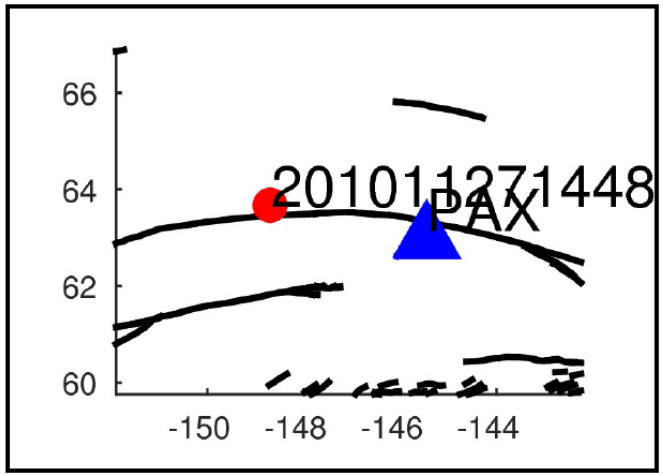

66
64
62
60
MCK
2010090
-152
-150
-148
-146
-144
-142

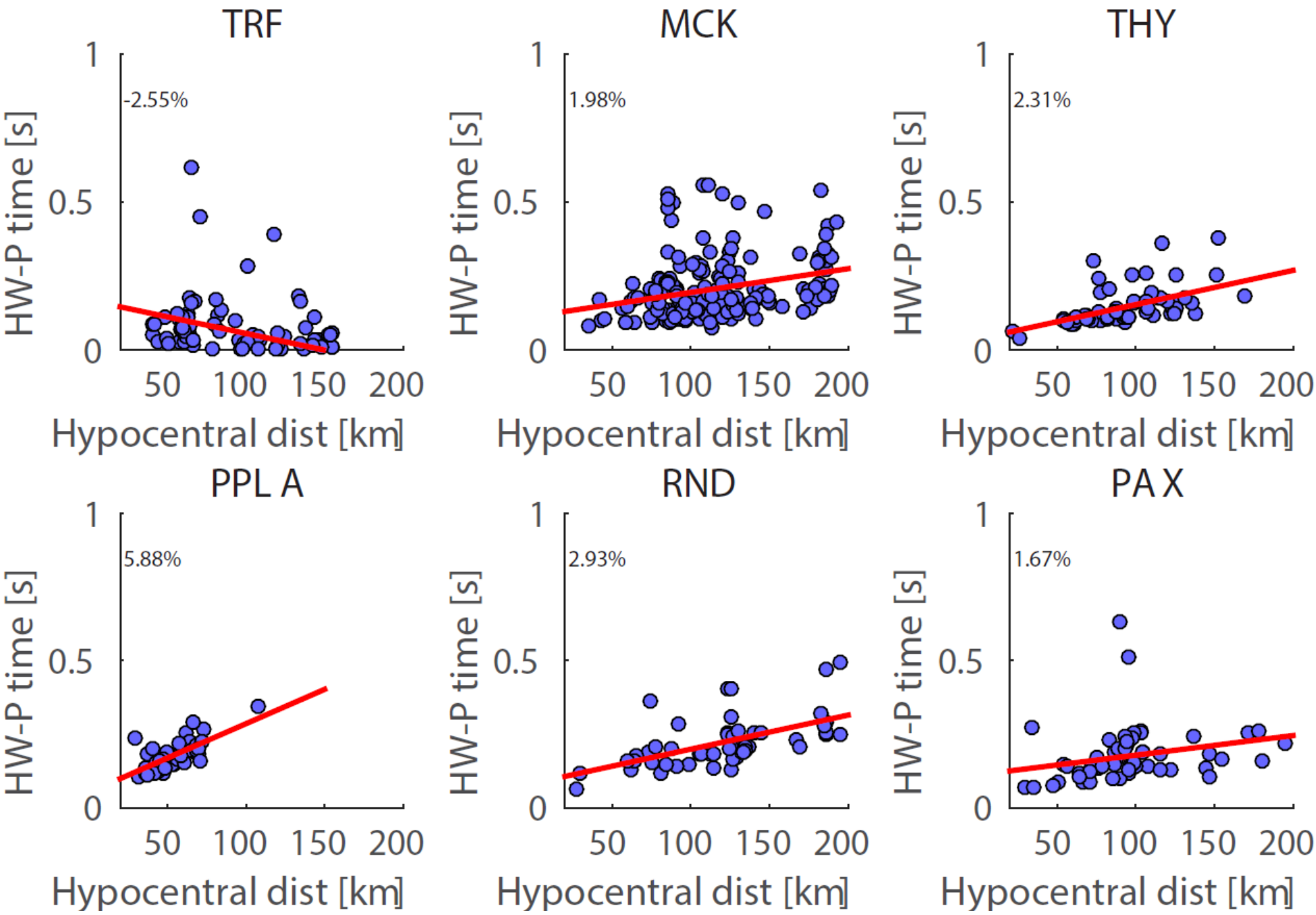

65
64
63
62
MCK
-150
-149
-148
-147
-146


5
6
7
8
9
10
EW
NS
UD
3
6
9
12
16
17
18
19
20
Time after origin [s]


5
6
7
8
9
10
EW
NS
UD
3
6
9
12
27
28
29
30
31
Time after origin [s]

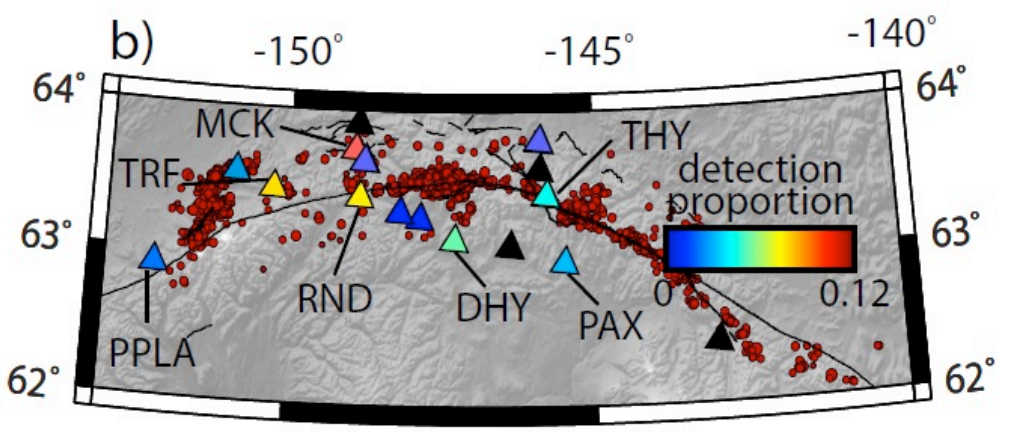

64
63
62
61
PAX
2004092
-146
-144
-142

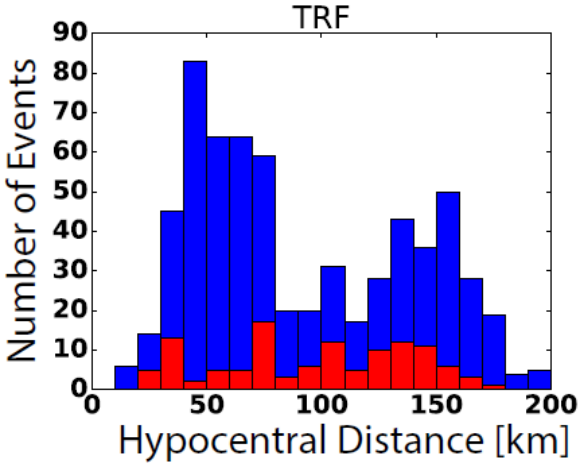

66
64
62
60
201011271448
PAX
-150
-148
-146
-144

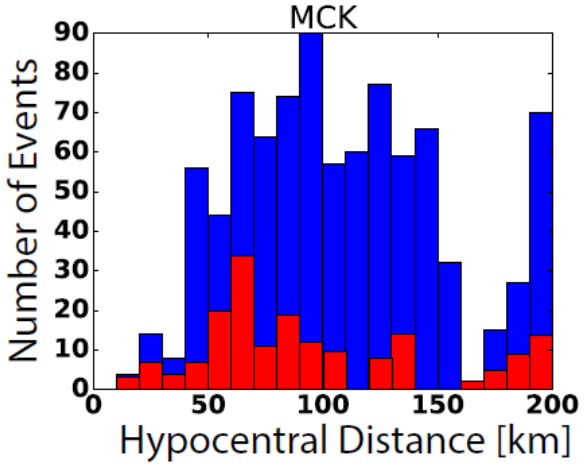

TRF
-2.55%
MCK
1.98%
THY
2.31%
PPL A
5.88%
RND
2.93%
PA X
1.67%
HW-P time [s]
Hypocentral dist [km]
0
0.5
1
50
100
150
200

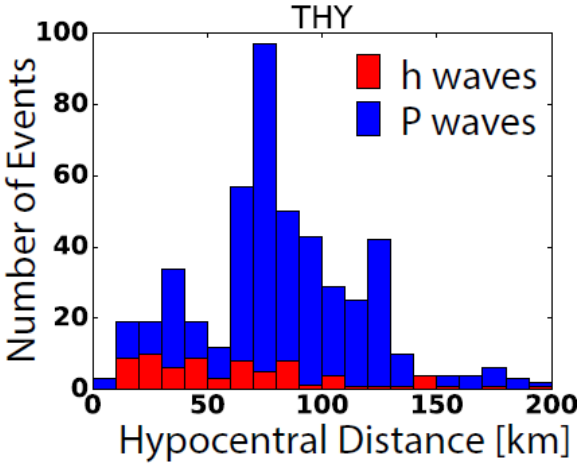
Head Wave Distance Distribution

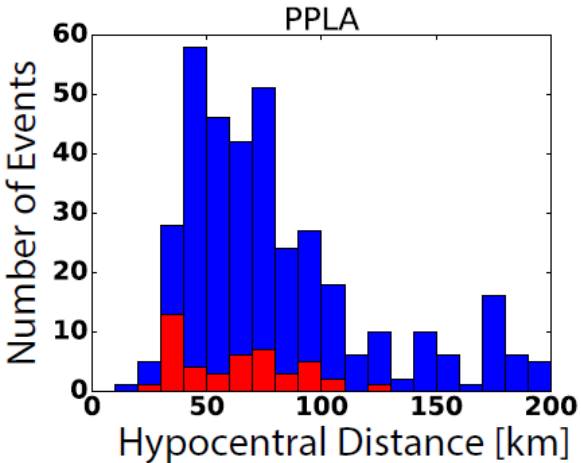
- Northern stations have head waves from shorter distances
- Southern stations have head waves from further

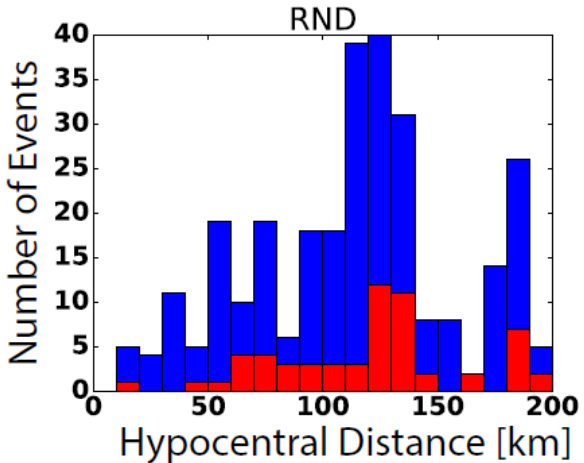


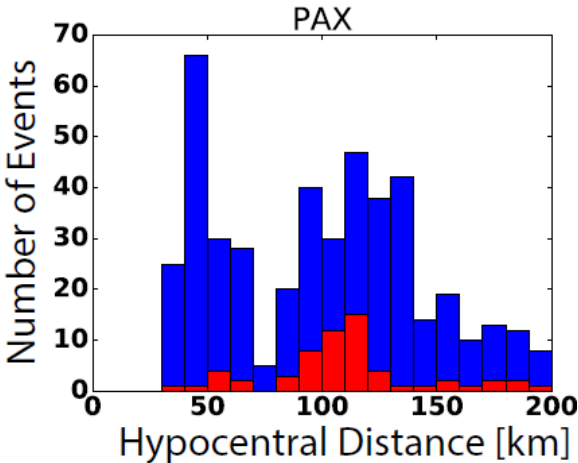




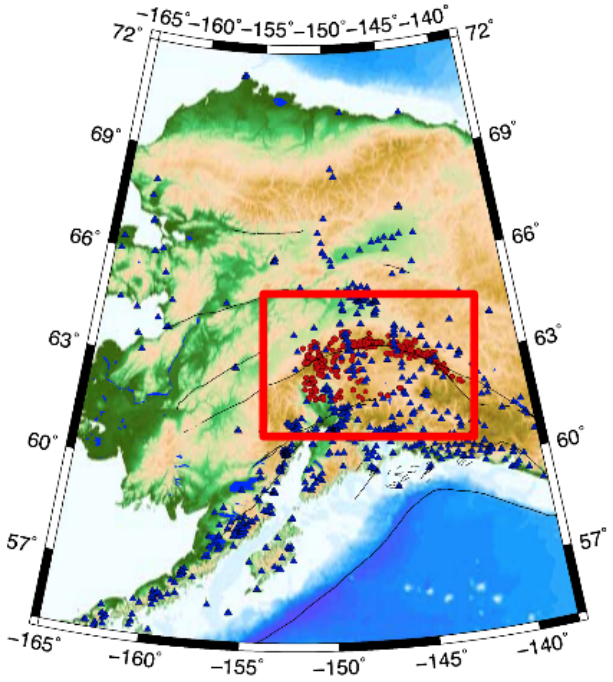


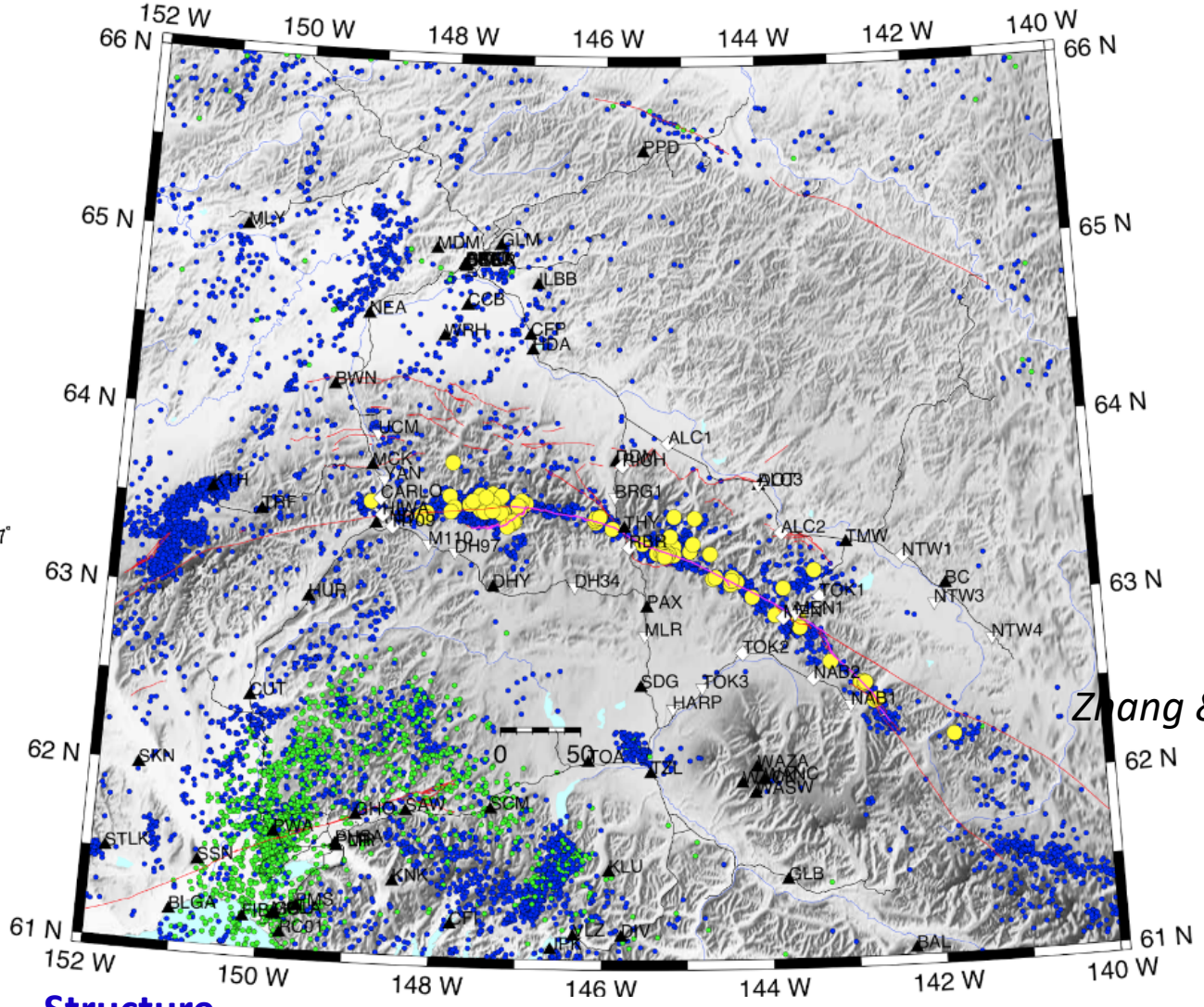






Double-difference Tomography





Zhang &

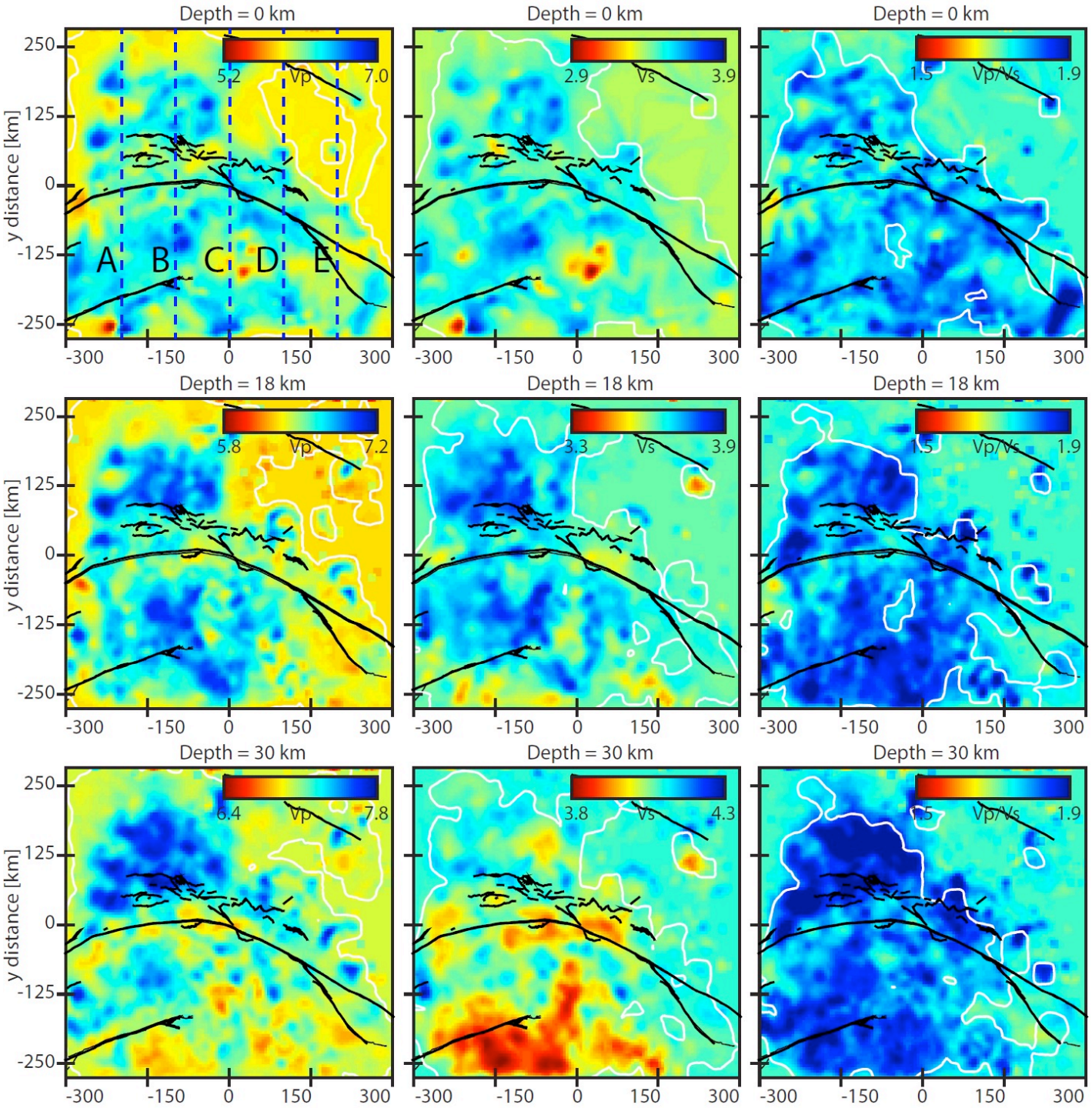
Tomography of the Denali Fault

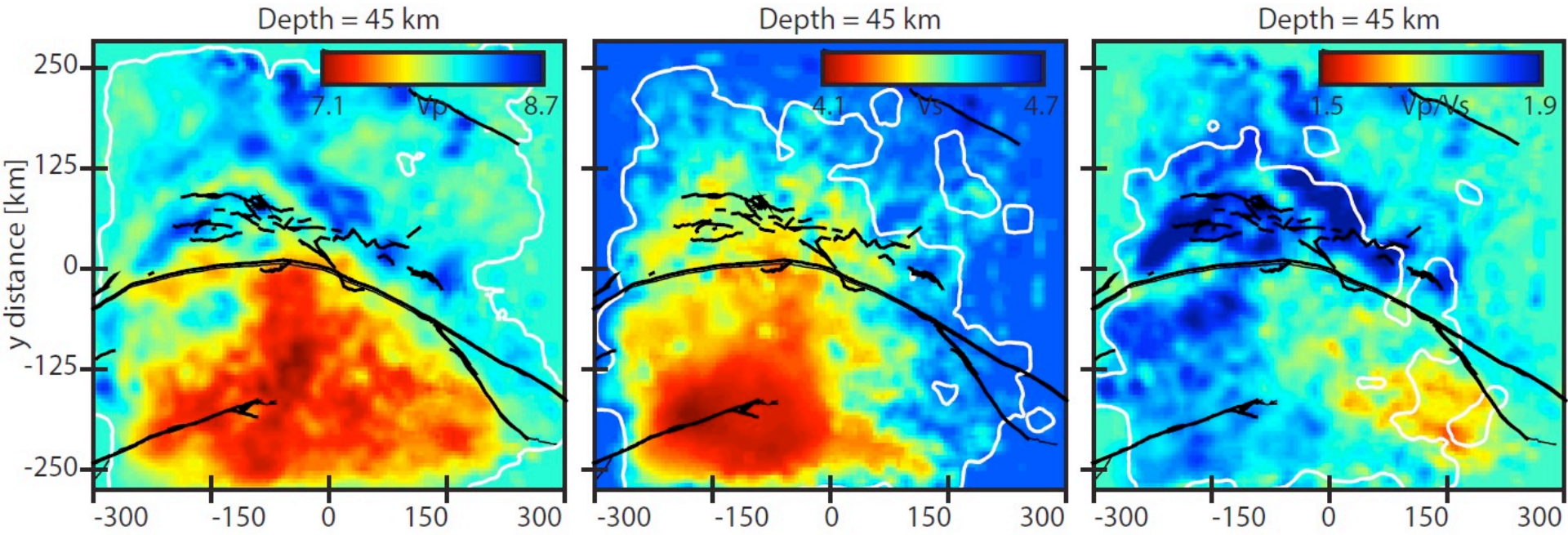
- 750,000 P wave arrivals
- 250,000 S wave arrivals
- 326 Stations

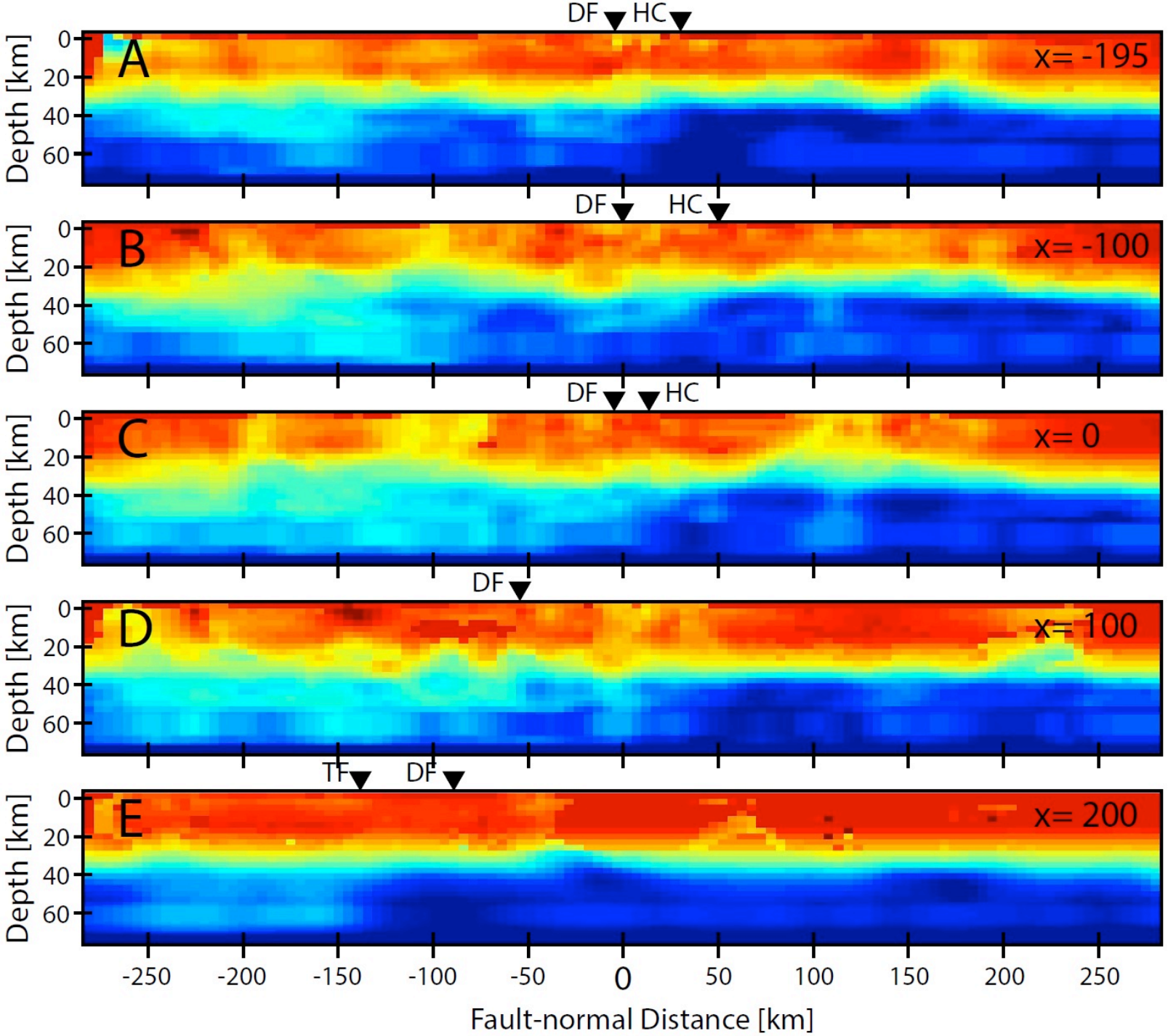
Source Location **Structure** **Time**

$$r_k^i = \sum_{l=1}^{3} \frac{\partial T_k^i}{\partial x_l^i} \Delta x_l^i + \Delta\tau^i + \int_i^k \delta u \, ds.$$

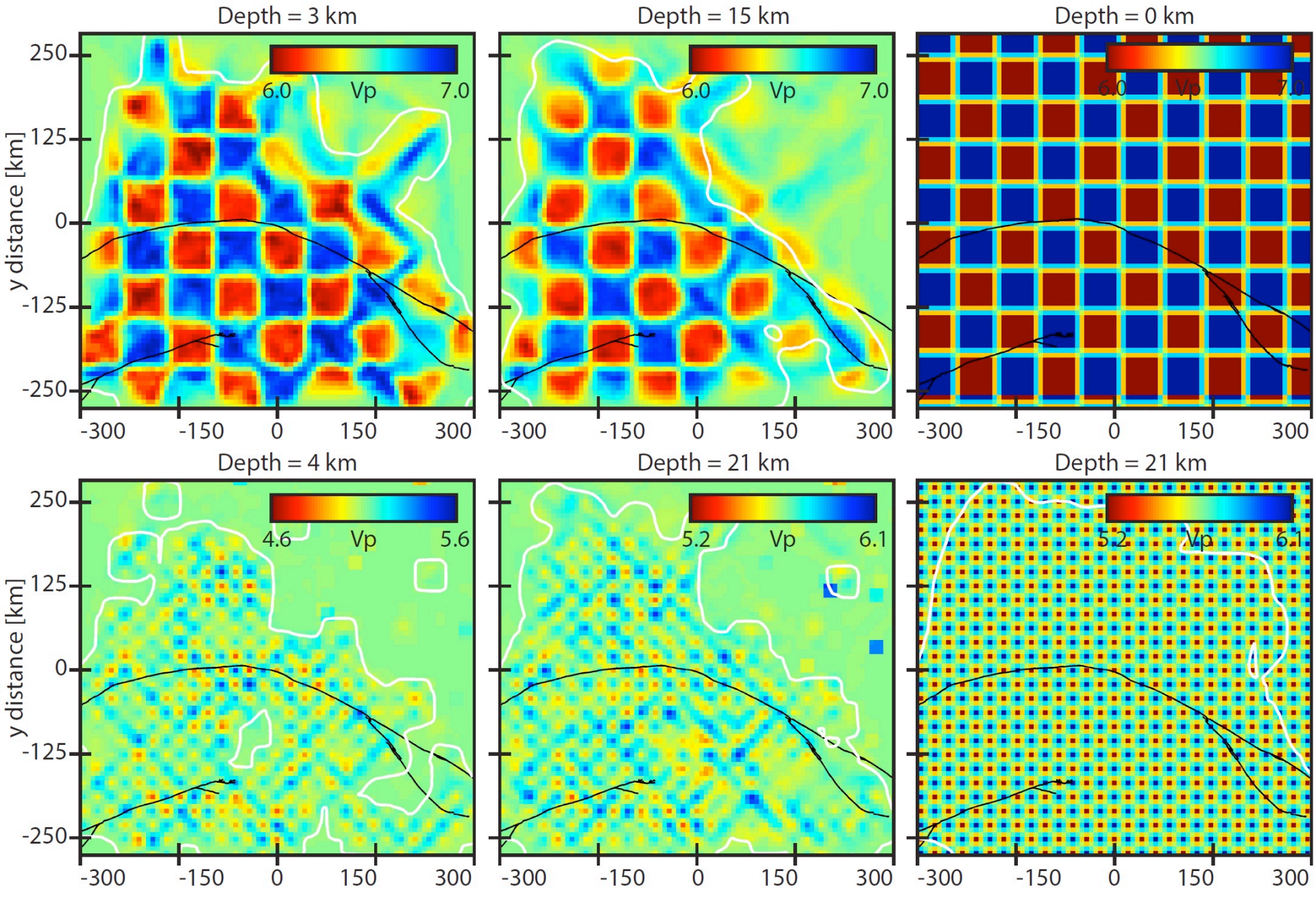
$$r_k^i - r_k^j = \sum_{l=1}^{3} \frac{\partial T_k^i}{\partial x_l^i} \Delta x_l^i + \Delta\tau^i + \int_i^k \delta u \, ds - \sum_{l=1}^{3} \frac{\partial T_k^j}{\partial x_l^j} \Delta x_l^j - \Delta\tau^j - \int_j^k \delta u \, ds.$$


Depth = 0 km
5.2 Vp 7.0
2.9 Vs 3.9
1.5 Vp/Vs 1.9
Depth = 18 km
5.8 Vp 7.2
3.3 Vs 3.9
1.5 Vp/Vs 1.9
Depth = 30 km
6.4 Vp 7.8
3.8 Vs 4.3
1.5 Vp/Vs 1.9
y distance [km]
250
125
0
-125
-250
-300
-150
0
150
300
A
B
C
D
E

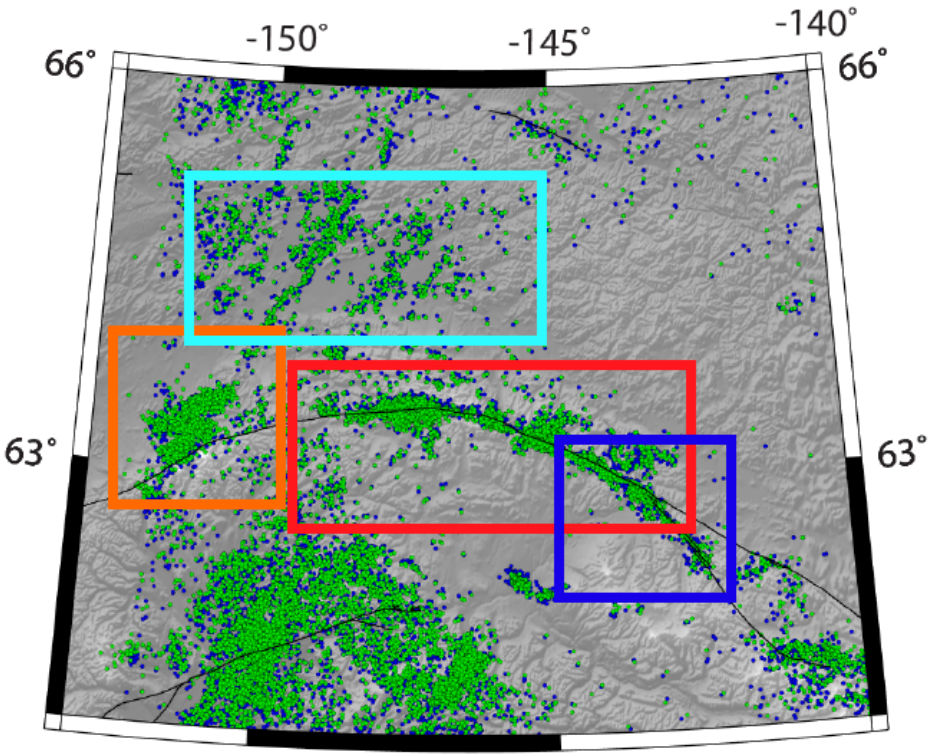

Depth = 45 km
Depth = 45 km
Depth = 45 km
7.1
Vp
8.7
4.1
Vs
4.7
1.5
Vp/Vs
1.9
y distance [km]
250
125
0
-125
-250
-300
-150
0
150
300


DF
HC
A
x= -195
Depth [km]
0
20
40
60
DF
HC
B
x= -100
Depth [km]
0
20
40
60
DF
HC
C
x= 0
Depth [km]
0
20
40
60
DF
D
x= 100
Depth [km]
0
20
40
60
TF
DF
E
x= 200
Depth [km]
0
20
40
60
-250
-200
-150
-100
-50
0
50
100
150
200
250
Fault-normal Distance [km]

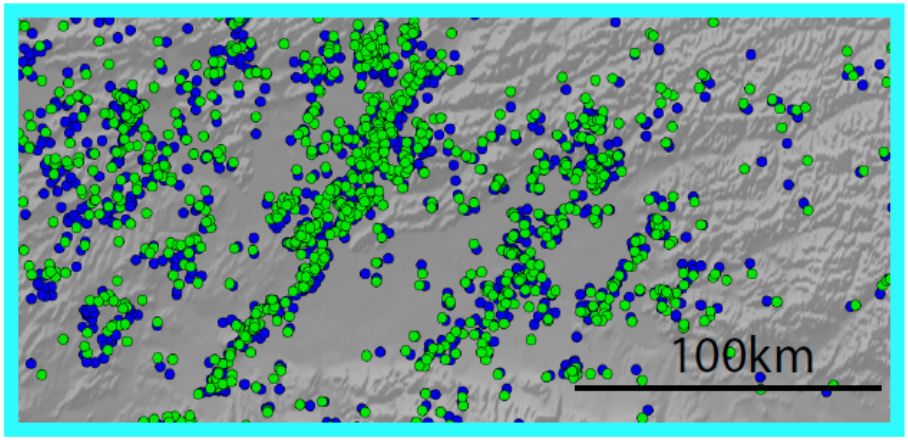
Checkerboard Tests



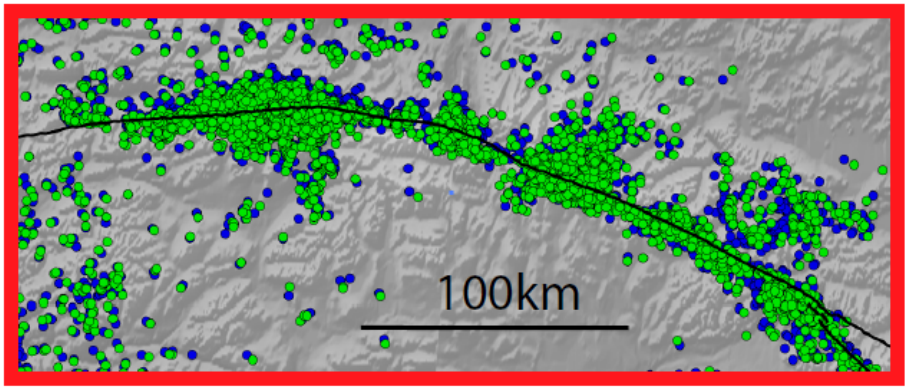
Earthquake Relocations



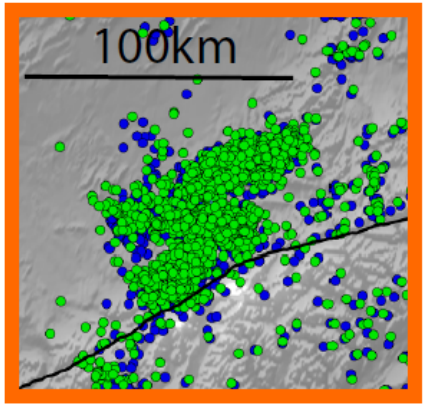
a)



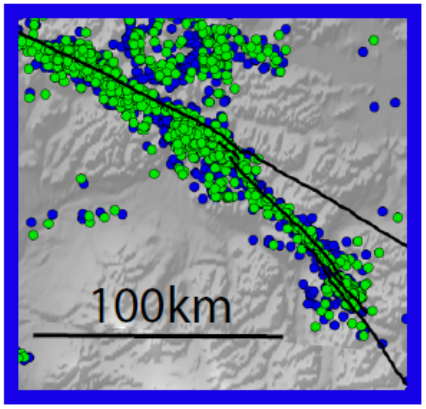
b)

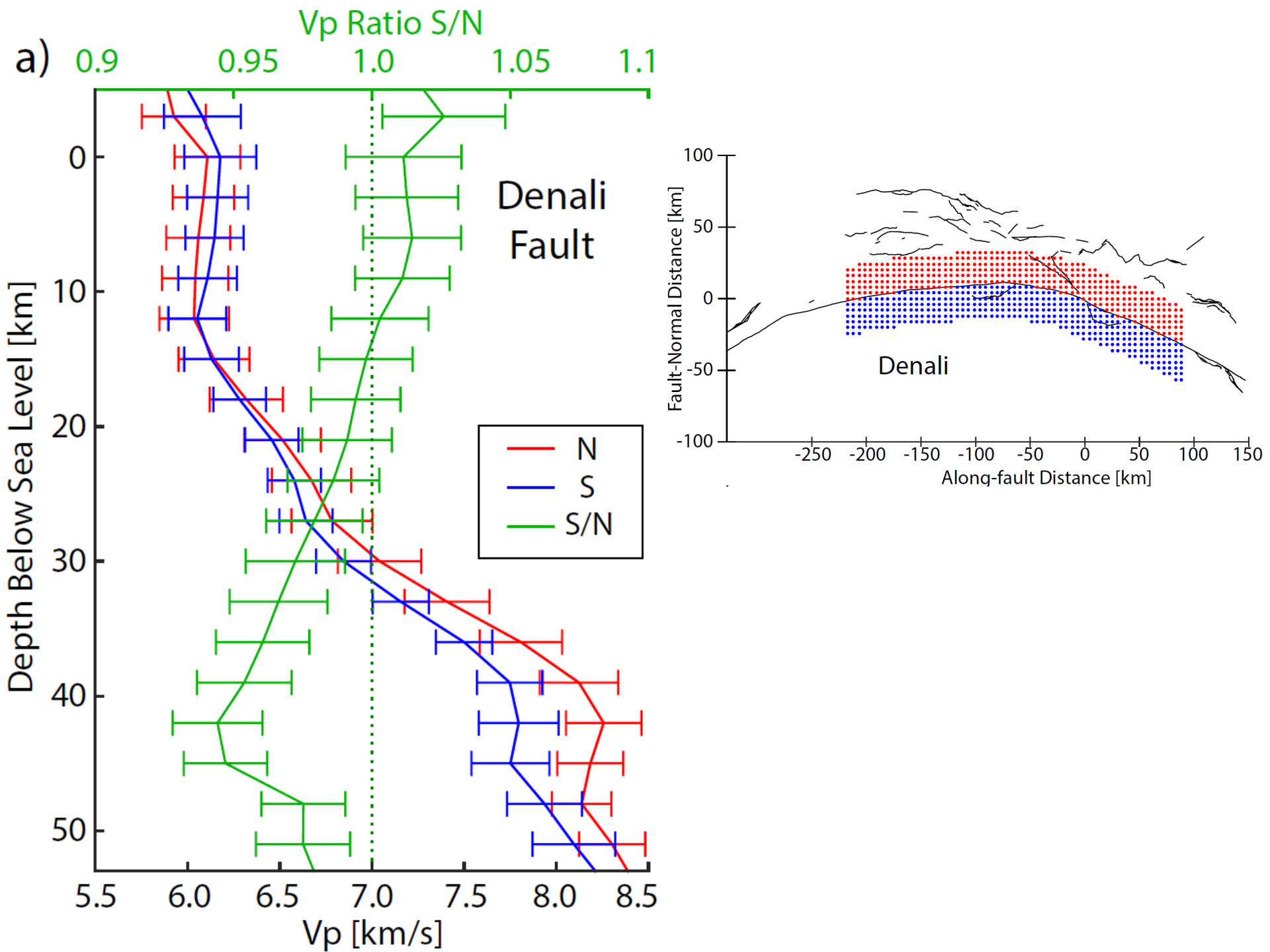


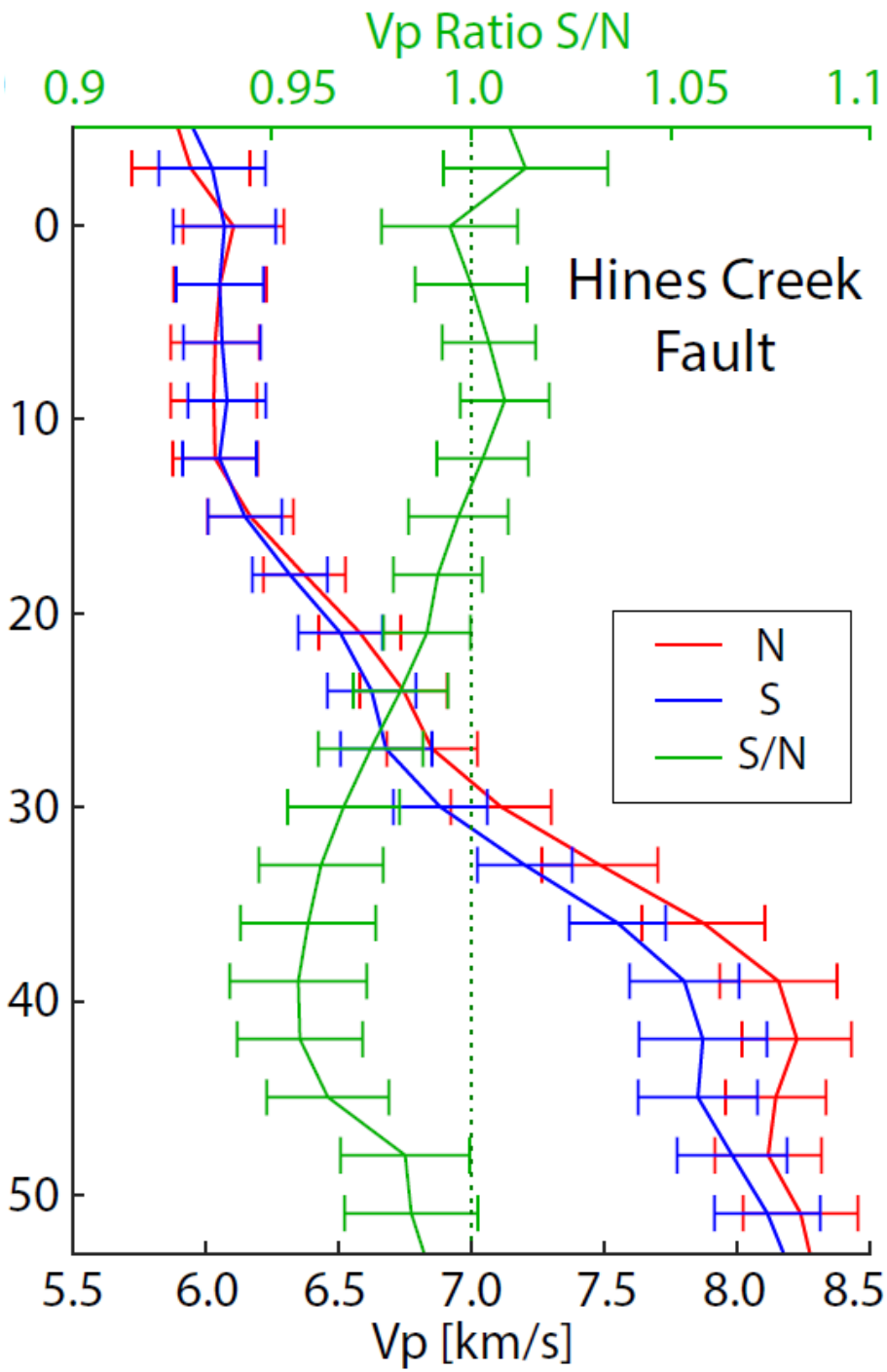
c)

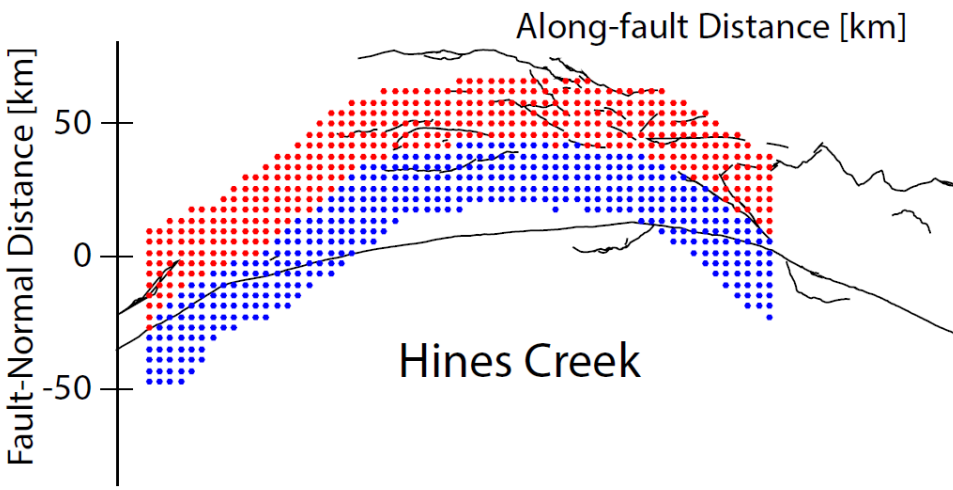


d)

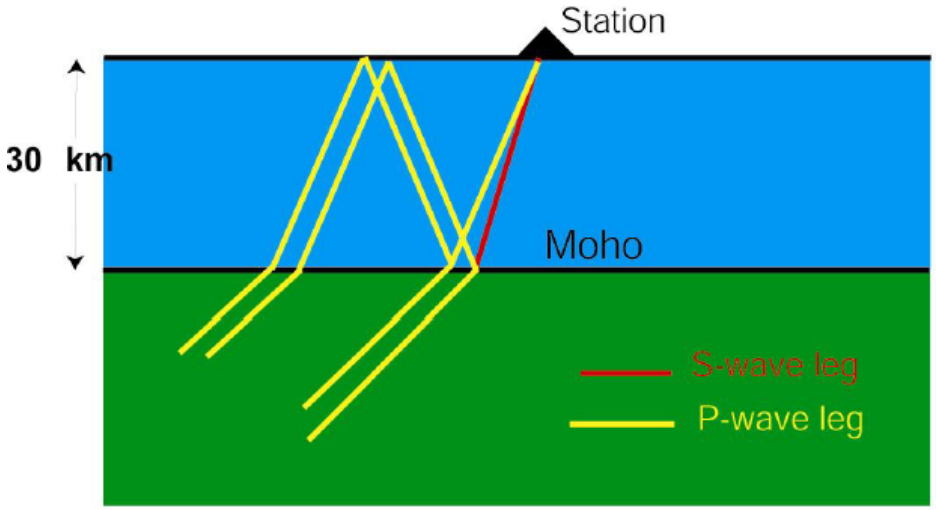


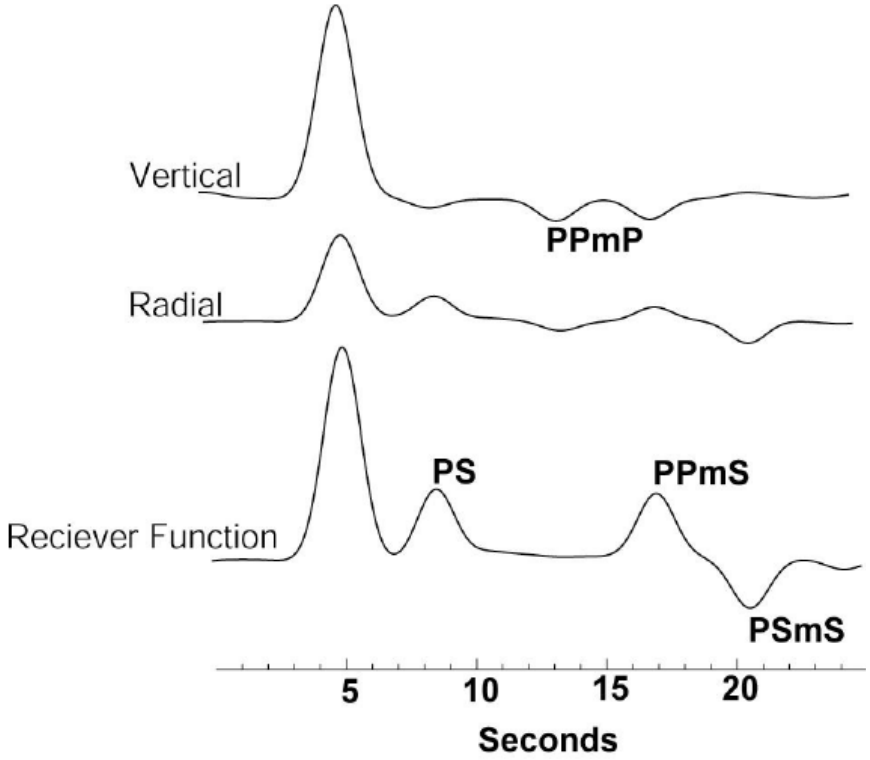

a)
Vp Ratio S/N
0.9
0.95
1.0
1.05
1.1
Denali
Fault
N
S
S/N
Depth Below Sea Level [km]
0
10
20
30
40
50
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Vp [km/s]
100
50
0
-50
-100
Fault-Normal Distance [km]
Denali
-250
-200
-150
-100
-50
0
50
100
150
Along-fault Distance [km]


Vp Ratio S/N
0.9
0.95
1.0
1.05
1.1
0
10
20
30
40
50
Hines Creek
Fault
N
S
S/N
5.5
6.0
6.5
7.0
7.5
8.0
8.5
Vp [km/s]


Along-fault Distance [km]
Fault-Normal Distance [km]
50
0
-50
Hines Creek

Receiver Functions

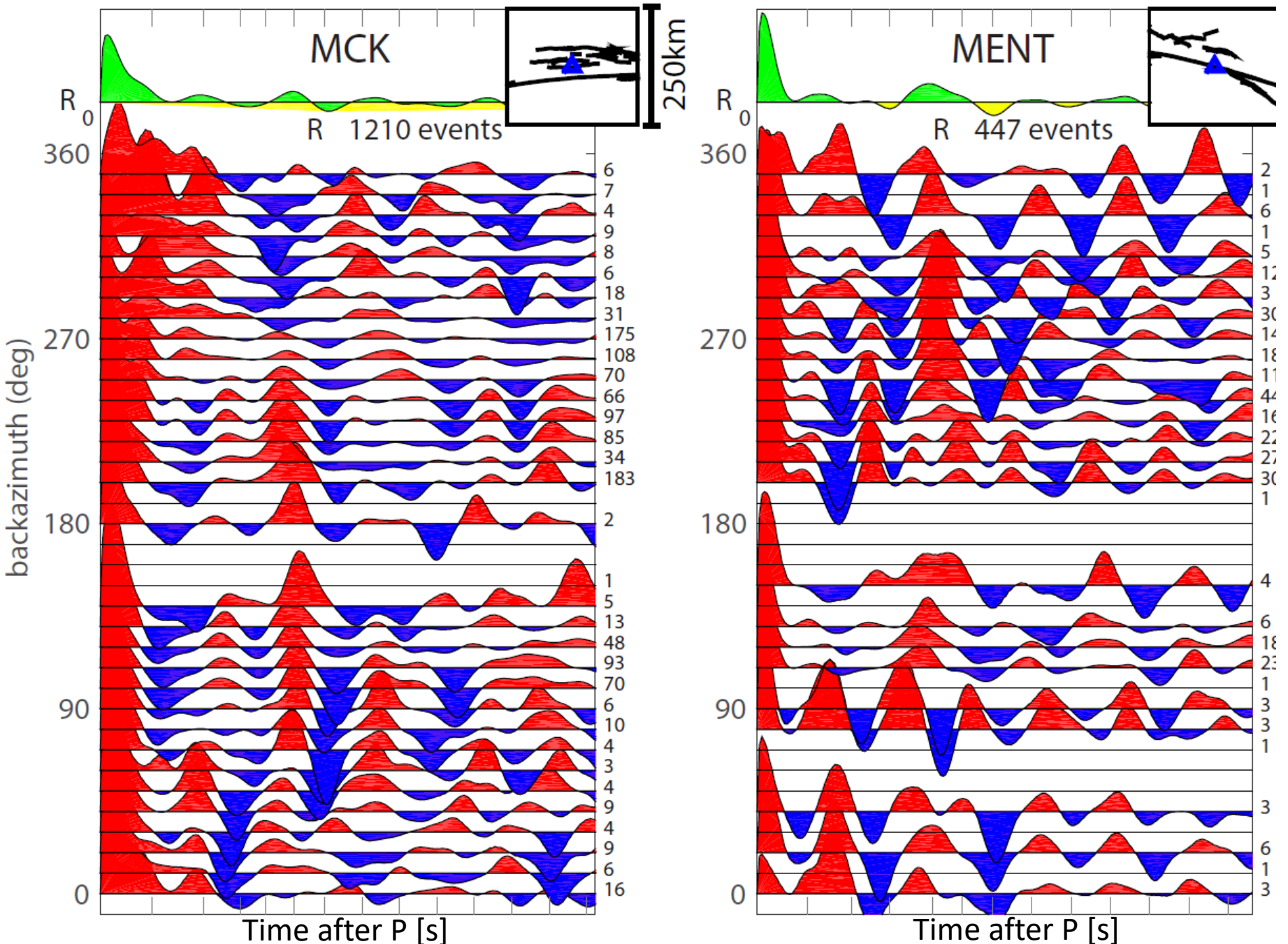




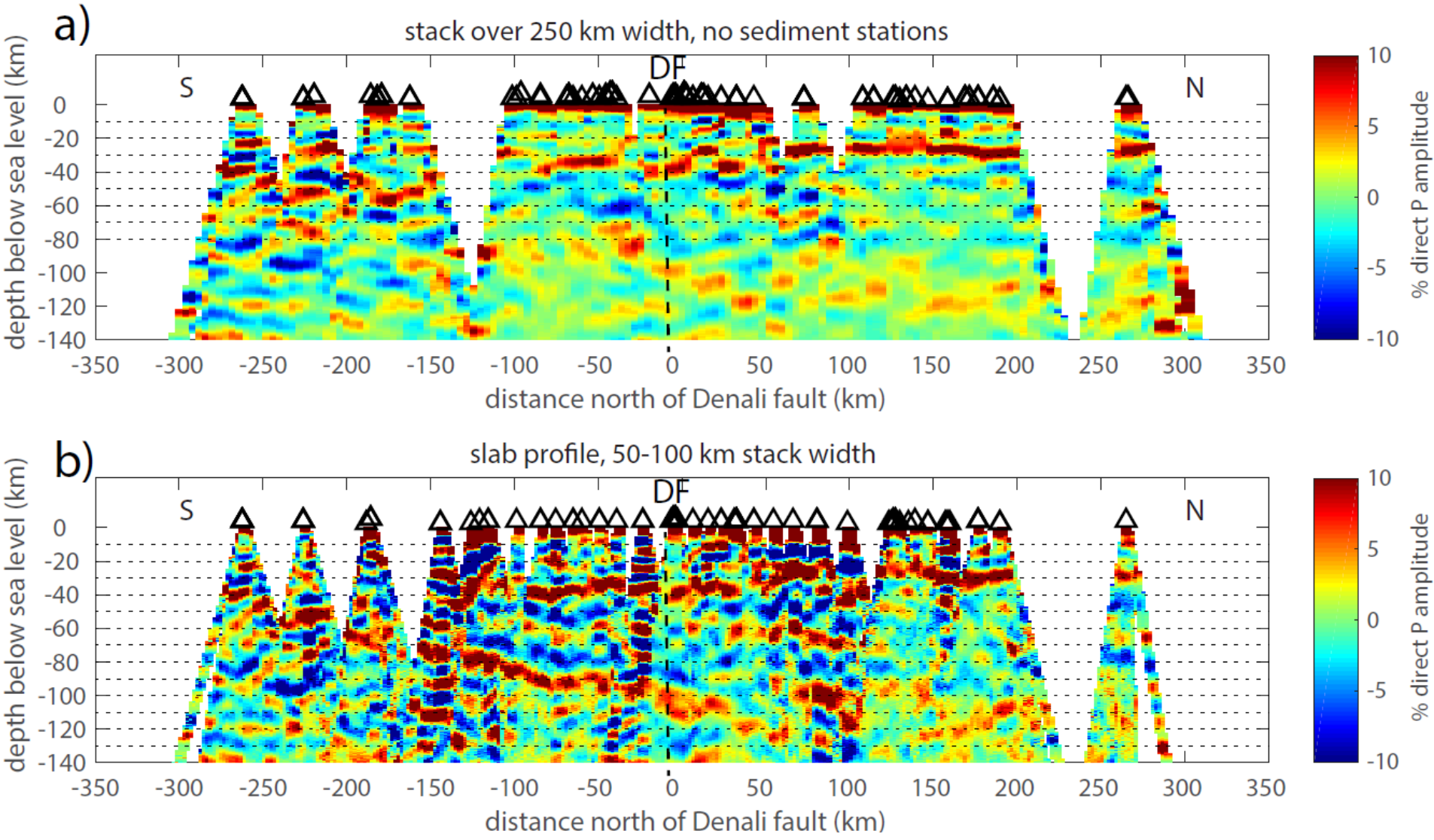
$$R(\omega) = \frac{U_R(\omega)}{U_V(\omega)}$$

Vera Schulte-Pelkum

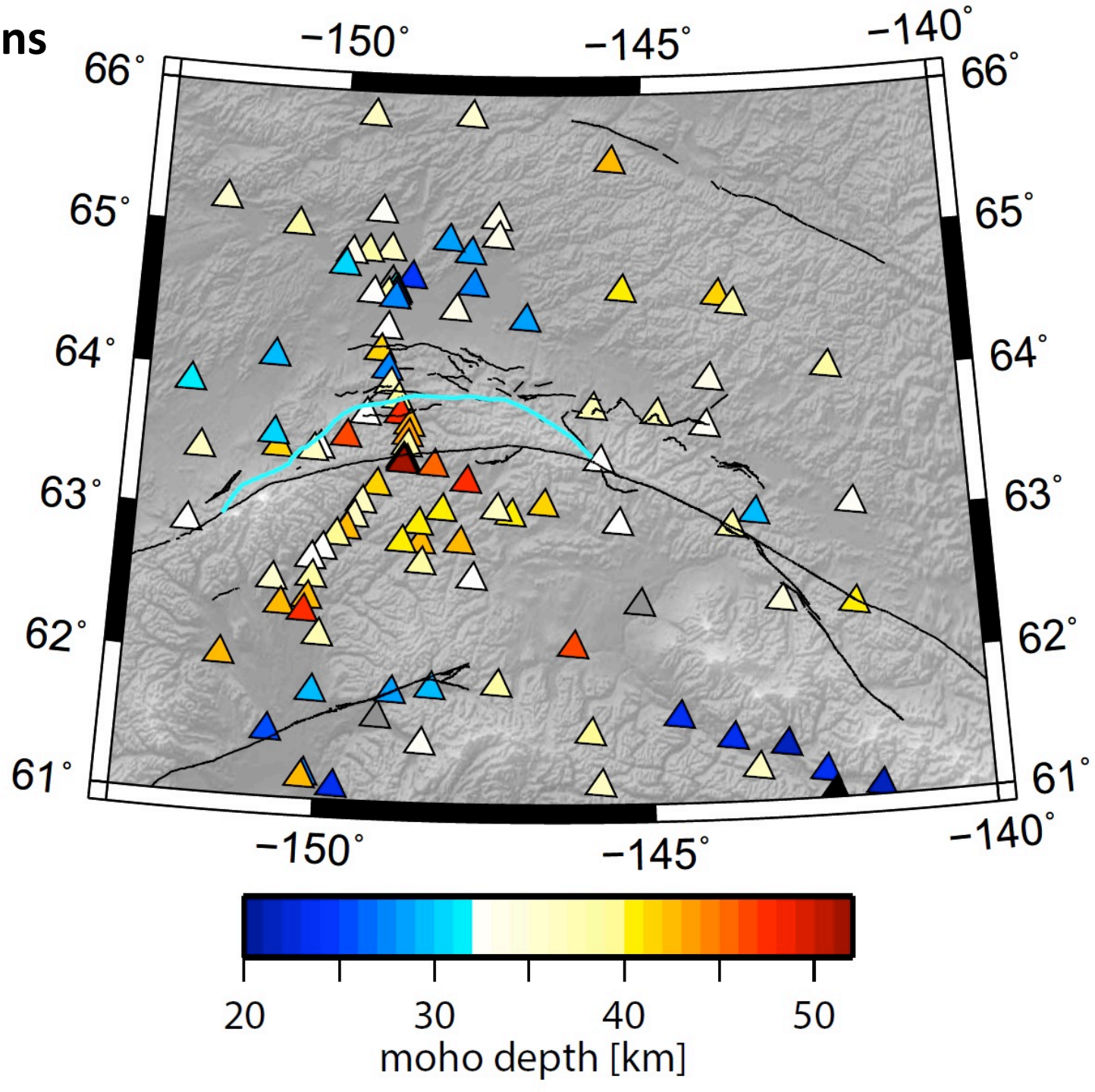
Receiver Functions



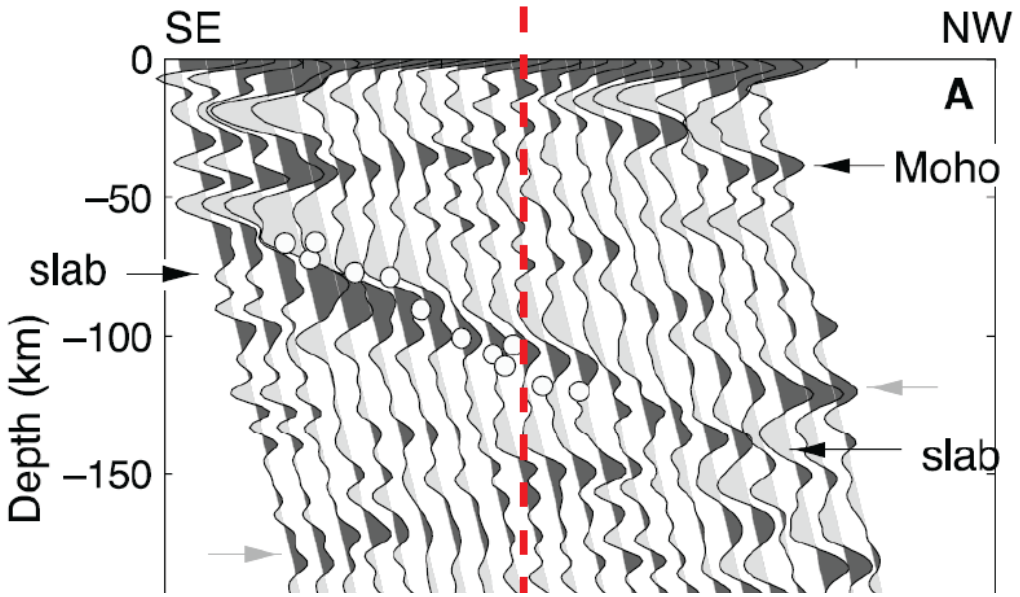
Receiver Functions – CCP Stack



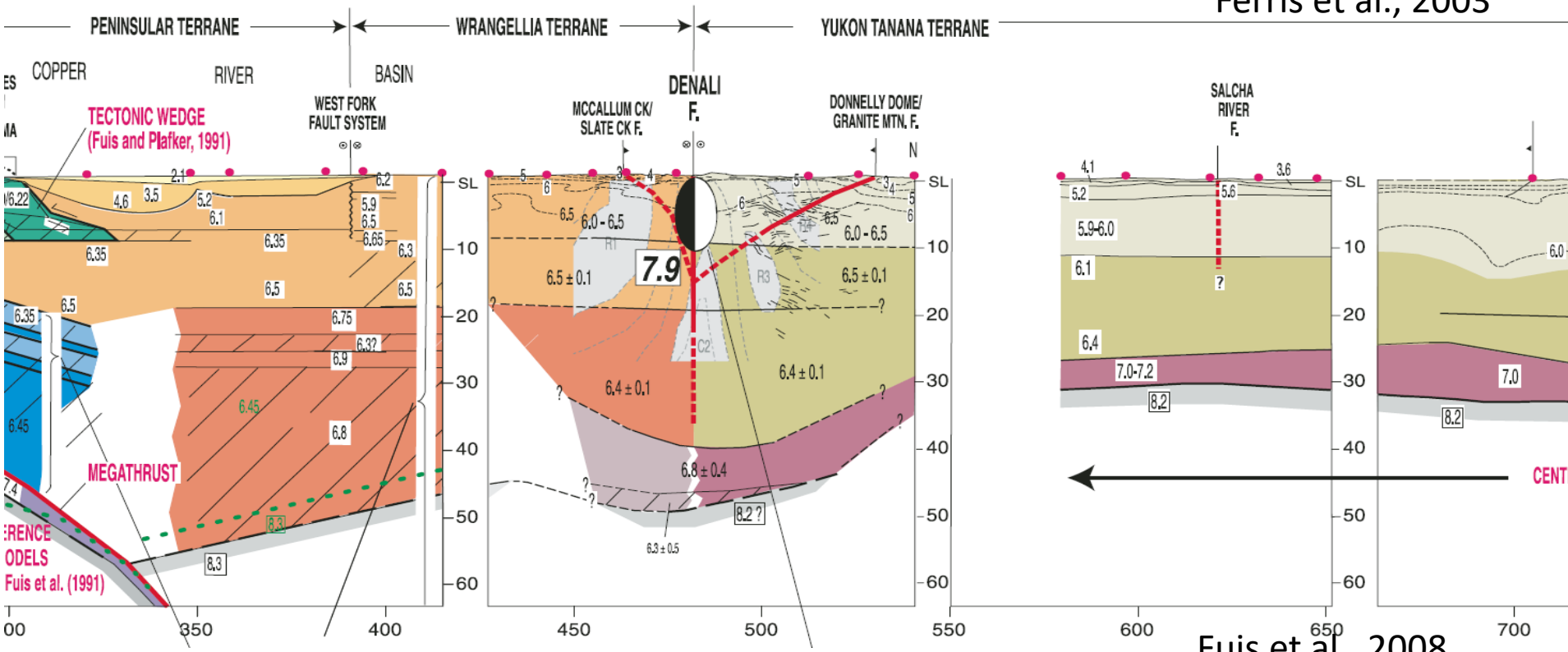
Receiver Functions
Moho Depth



Has the Moho offset been observed before?



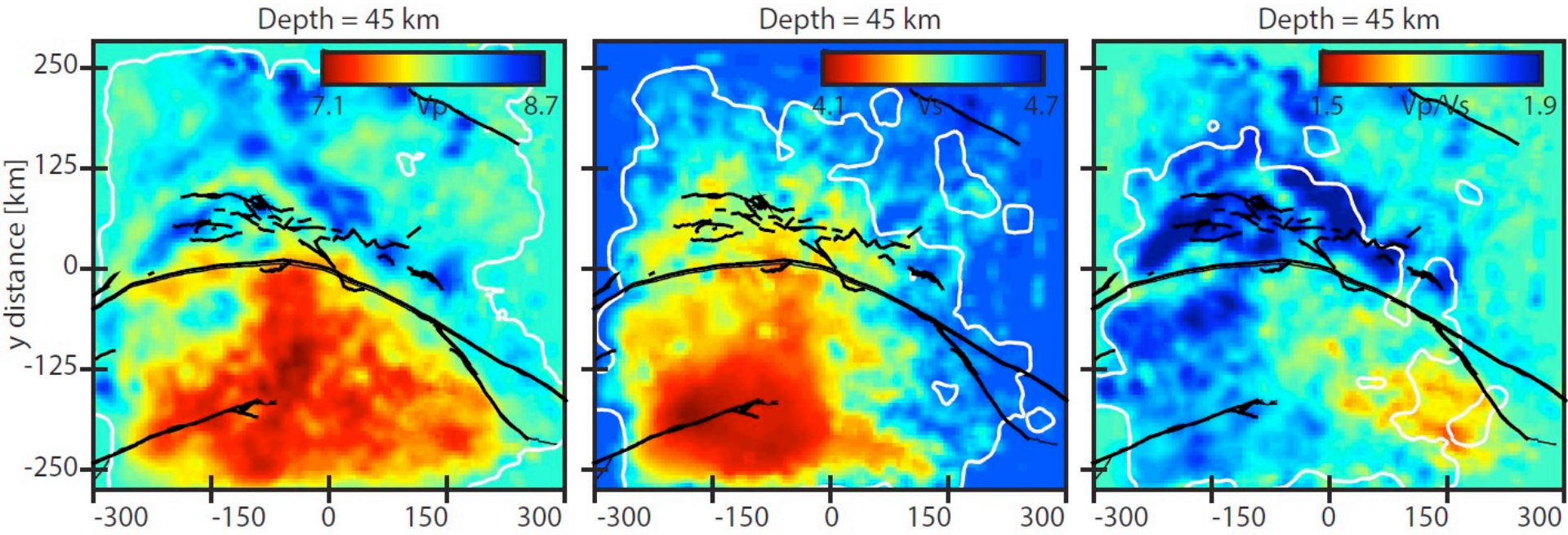
Ferris et al., 2003



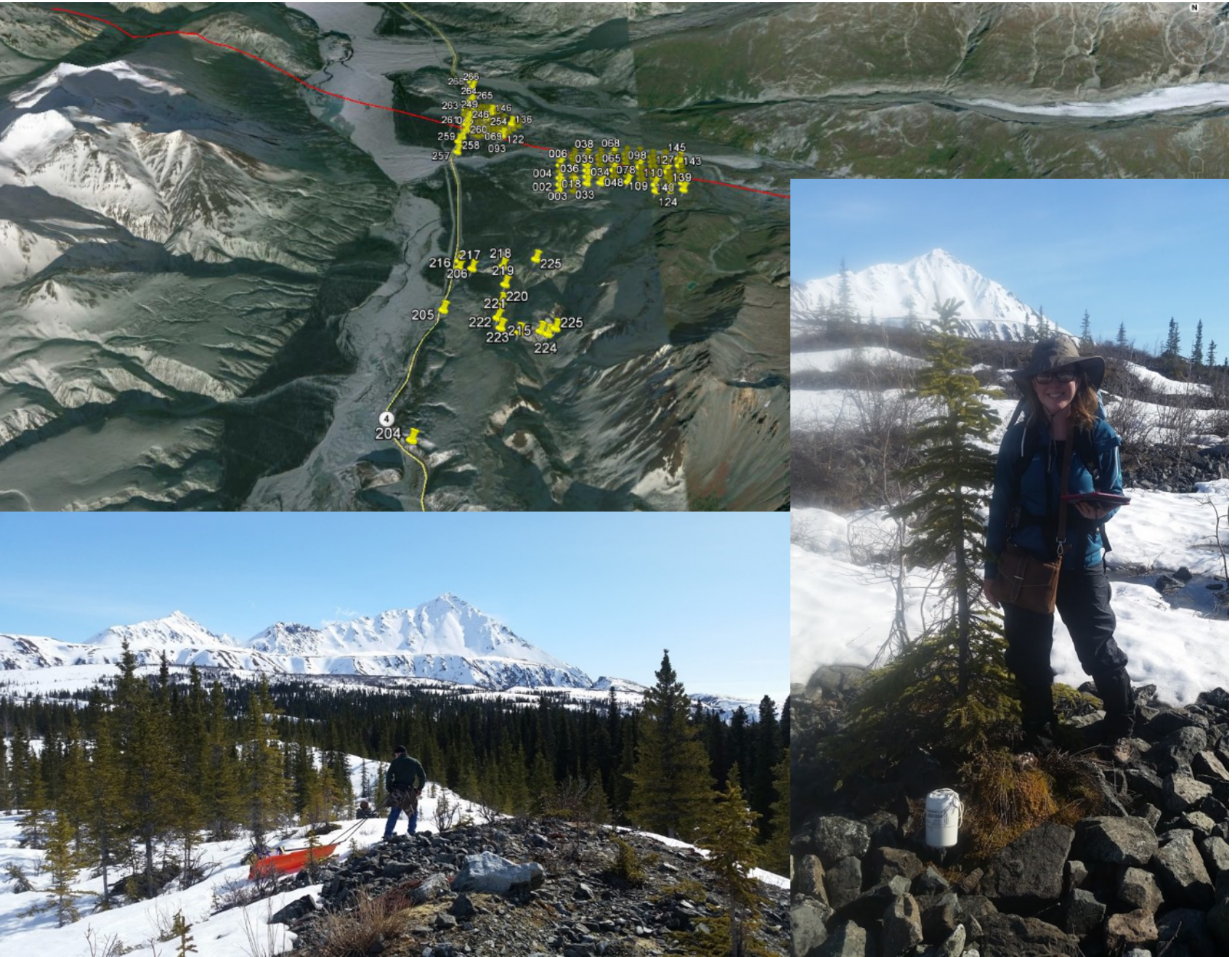
Fuis et al., 2008

Conclusions

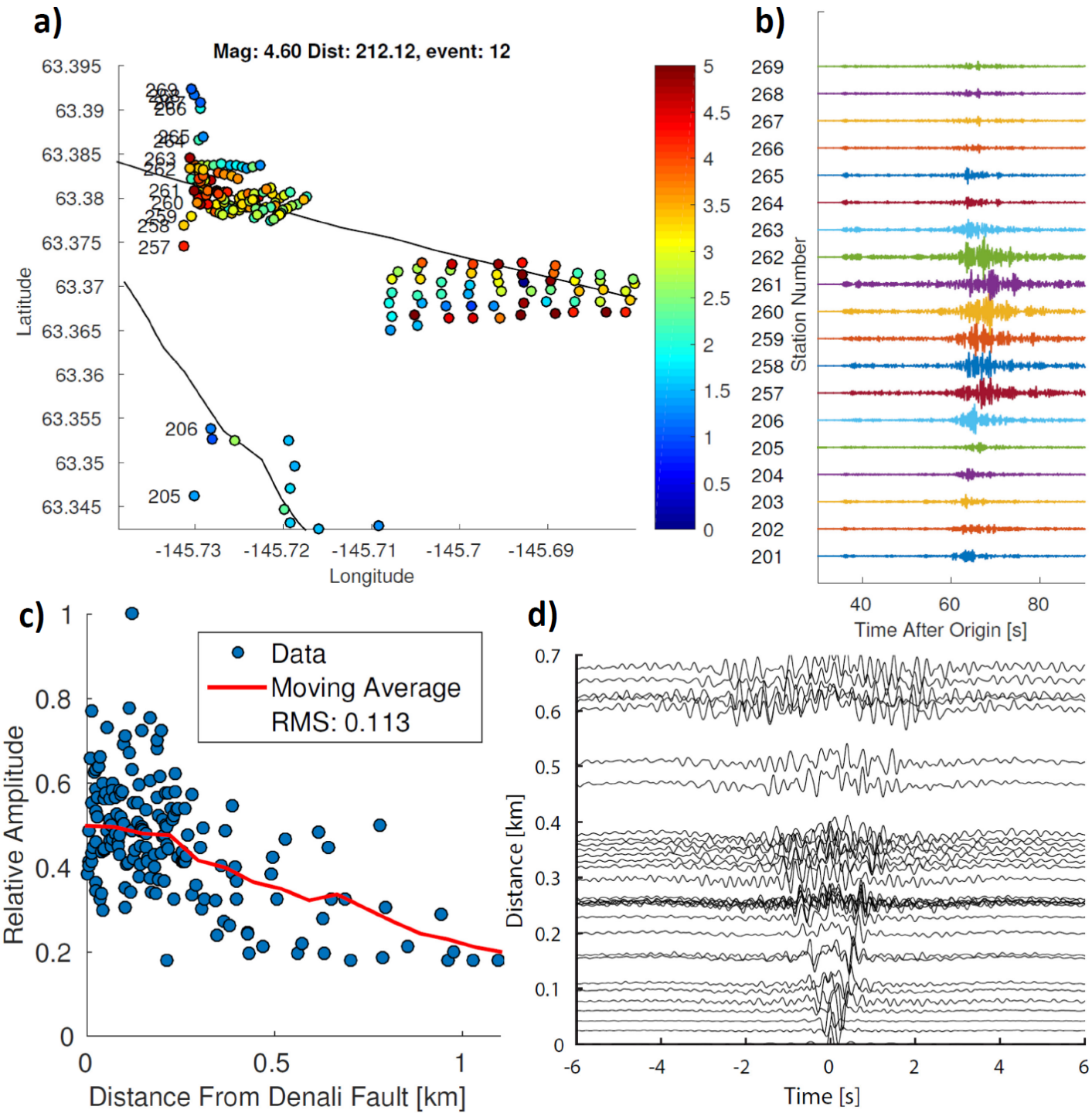
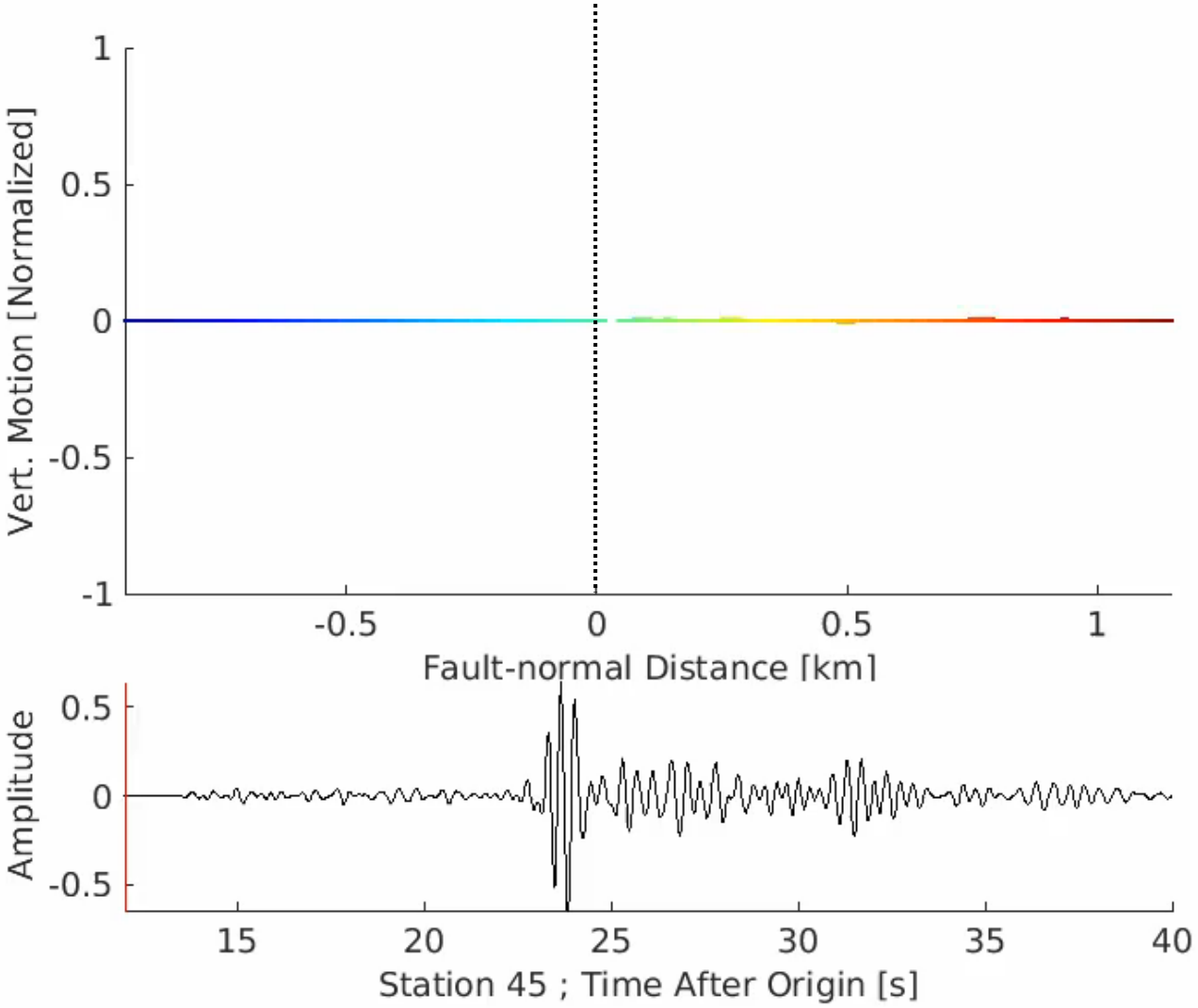
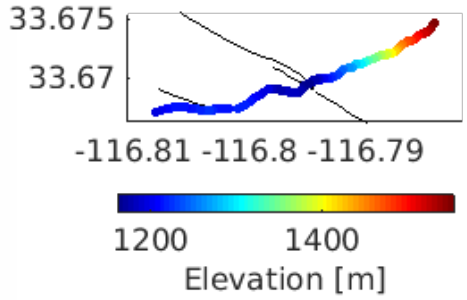
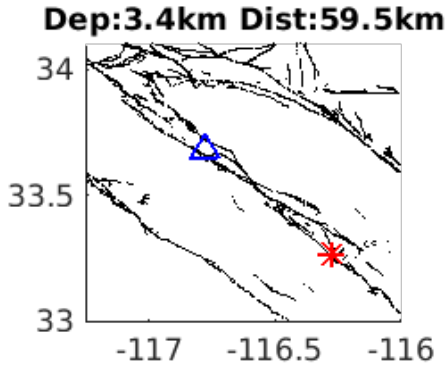
- There is a ~15km vertical offset along the entire Denali Fault
- The north side is faster at depths <10km, the south side is faster at depths >20km
- The Denali fault separates two distinct crustal blocks with decoupled motion (plate boundary?)



Future Work: Local Array Analysis



Future Work: Array Analysis



Future Work: Trapped Wave Normal Modes