Türkiye's Recent Earthquakes, and What They Can Teach Us About Preparation and Response Here

Eric Sandvol[1], Ekrem Zor[2], Mehmet Ergin[2], Oguzhan Yalvac[1], Mustafa Cengiz Tapirdamaz[2], Phuc Mach[3], Chang Ding[3], Adil Tarancioglu[2], Fatih Sevim[2], and Zhigang Peng[3]

[1]University of Missouri, Columbia, Missouri, USA
[2]TUBITAK, The Scientific and Technological Research Council of Turkiye, Marmara Research Center, Earth and Marine Sciences Institute, Turkiye
[3]Georigia Institute of Technology, Atlanta GA USA

National Science Foundation

TÜBİTAK MAM

Outline

I. Introduction to the Kahramanmaras Earthquakes

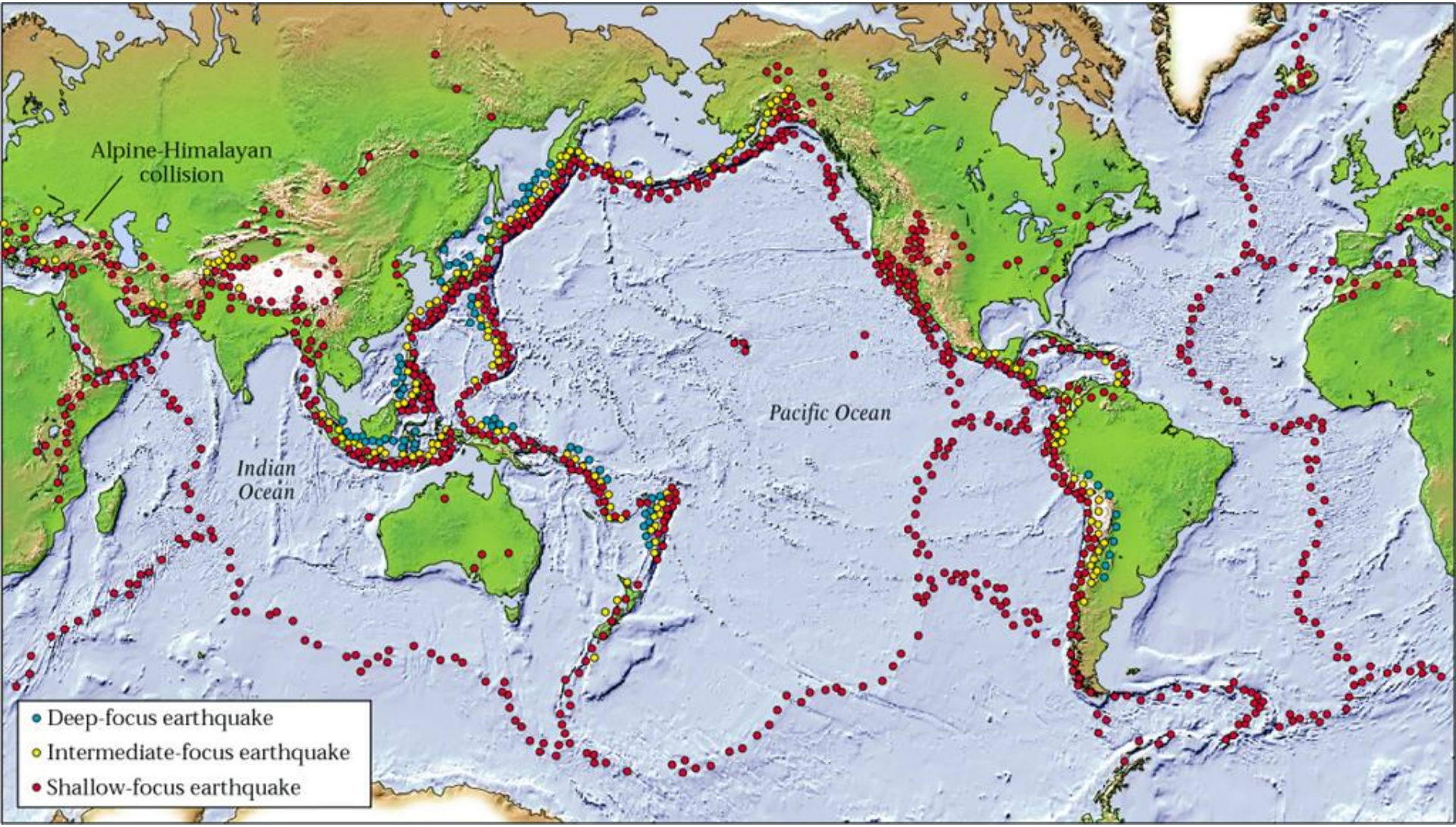
II. Some Comparisons of the New Madrid and Kahramanmaras Earthquakes

A. Earthquake Sequences and stress triggering

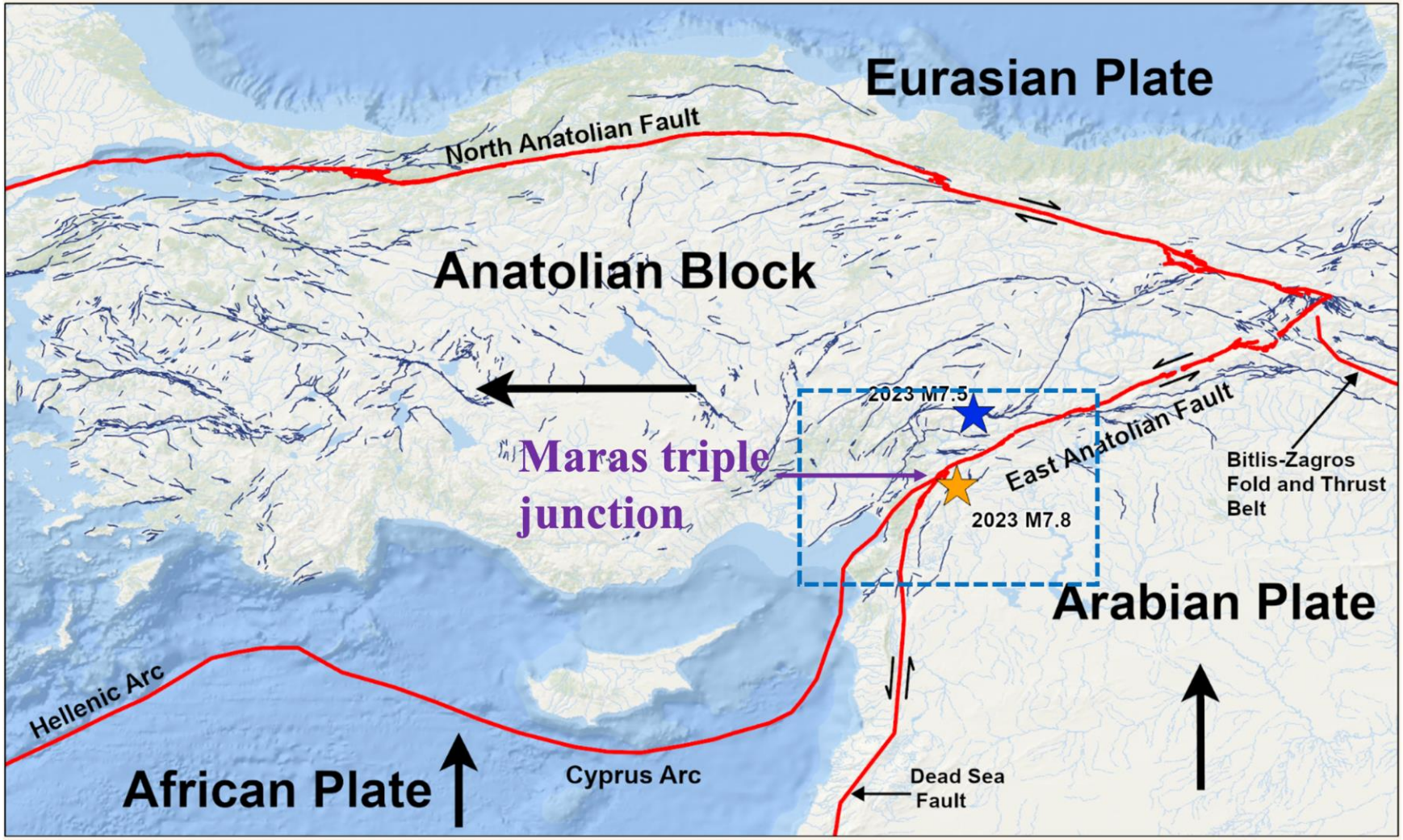
B. Ground motions in the Amik Basin and Mississippi Embayment

III. 2023 Rapid Aftershock Deployment

Earthquake Locations:

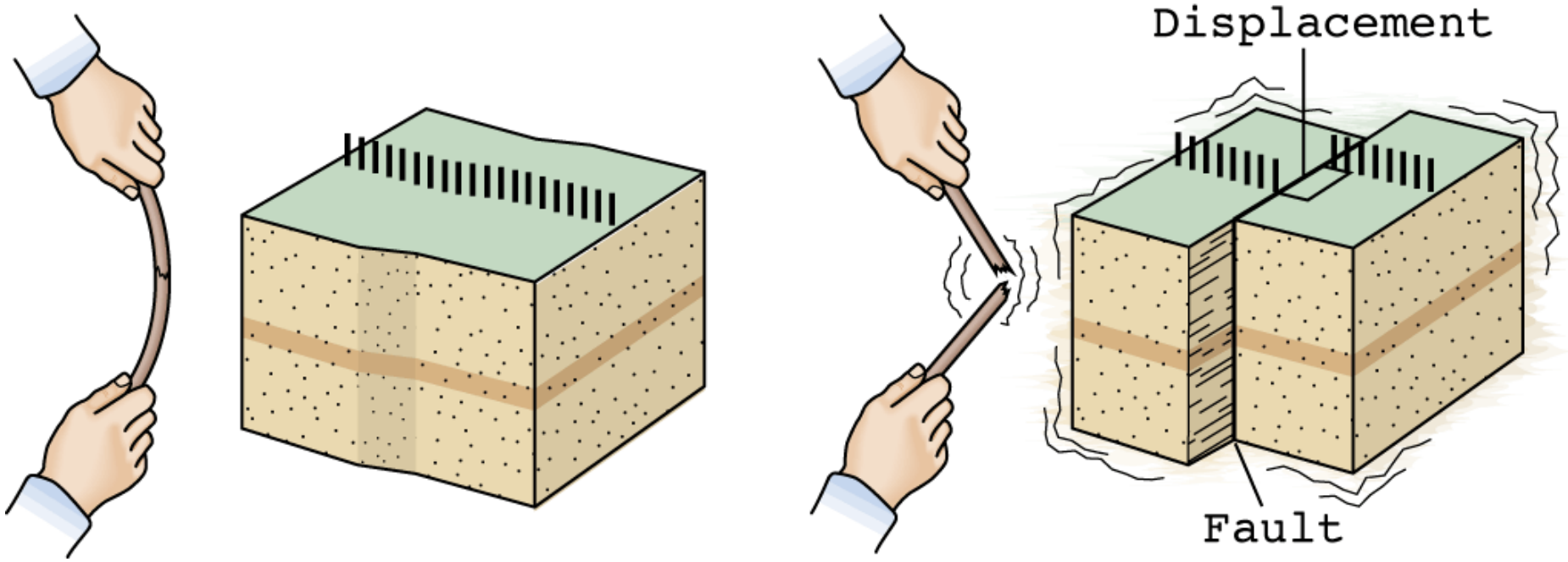


Differences between the NMSZ and EAFZ



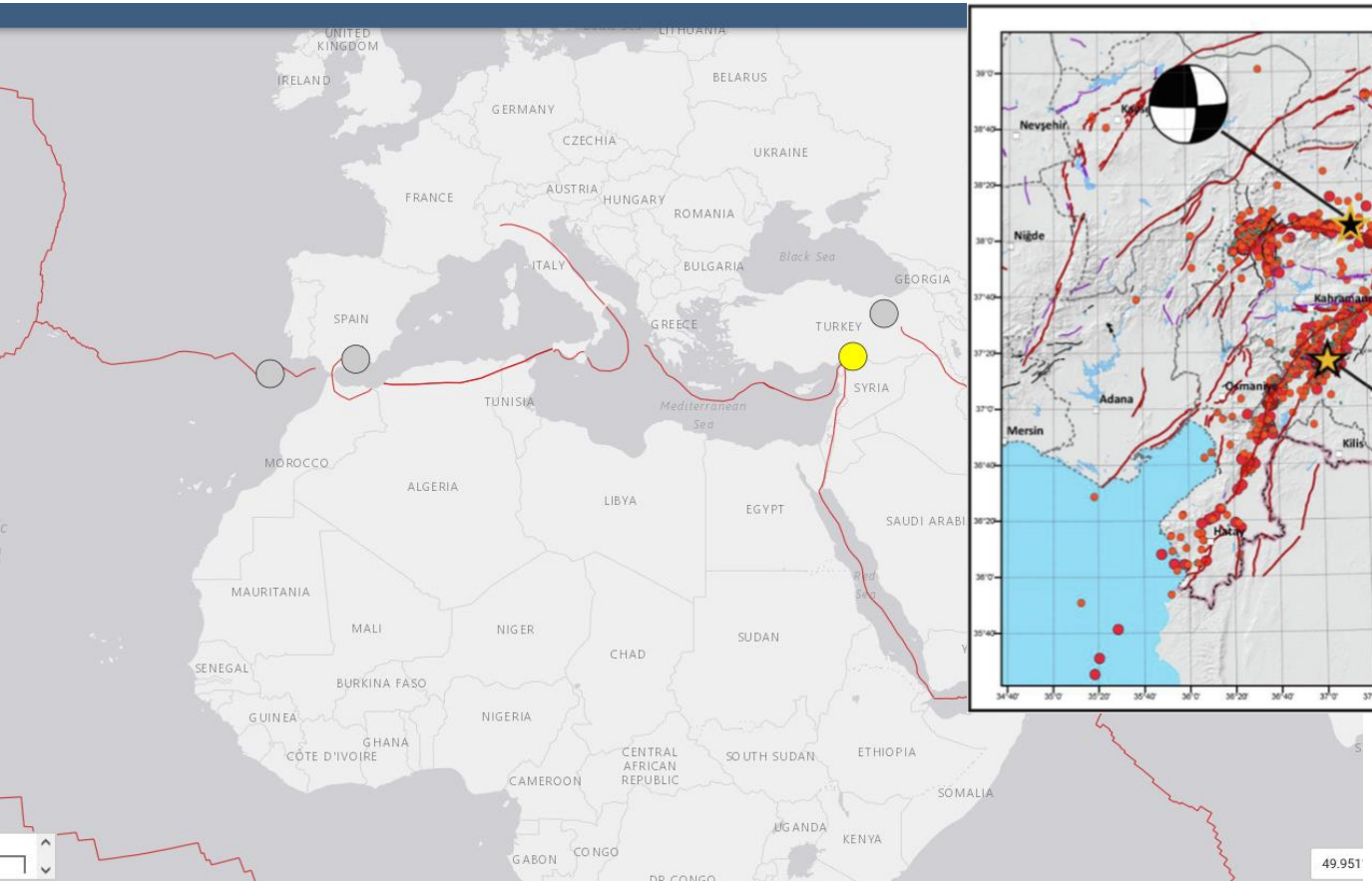
What is an Earthquake?

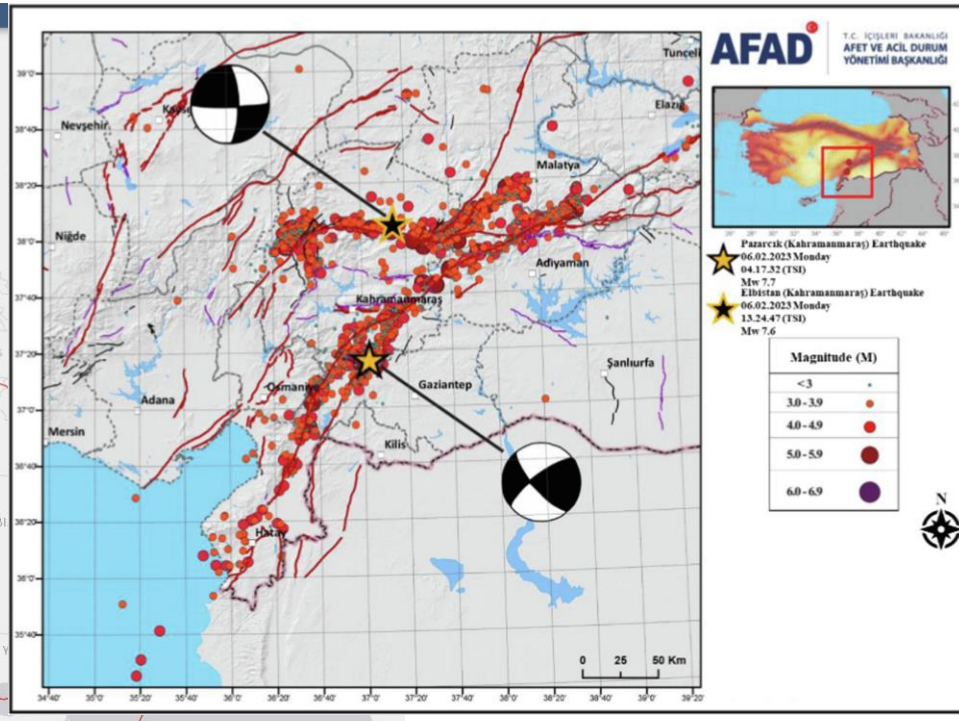
Earthquakes occur when the earth's crust "breaks" along a fault

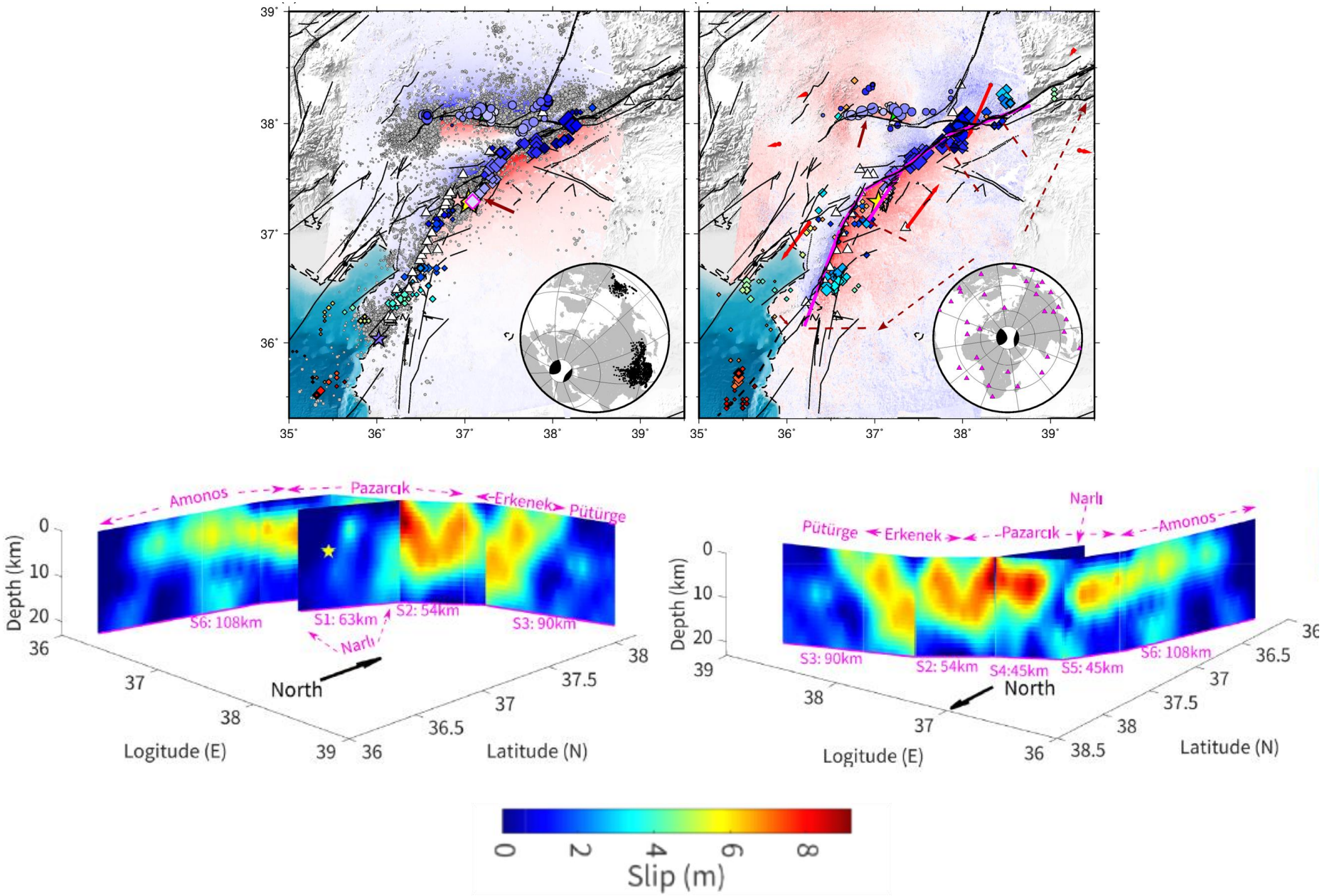


This process generates waves that travel through the earth called seismic waves

February 6th, 2023 Kahramanmaras Earthquake Sequence

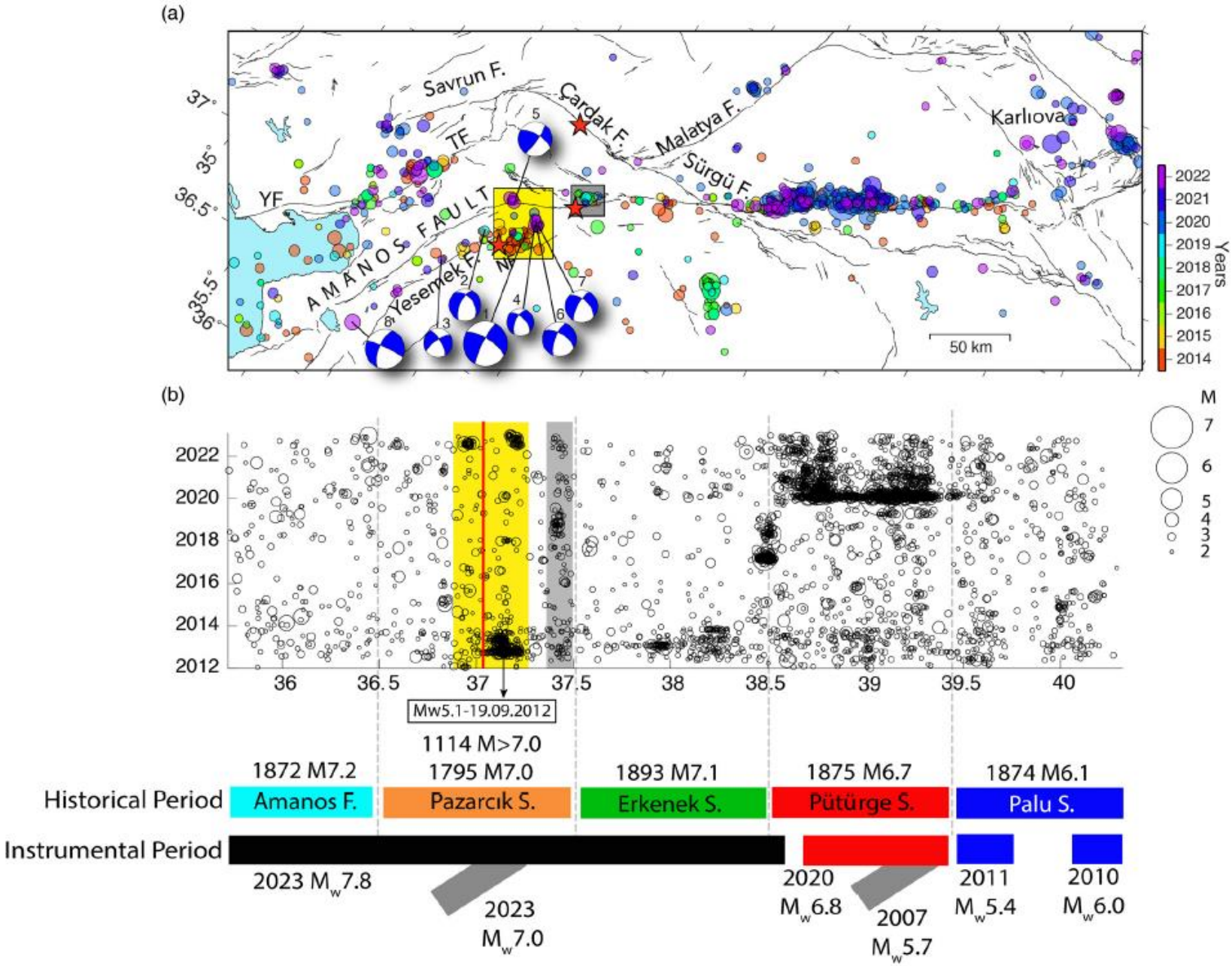




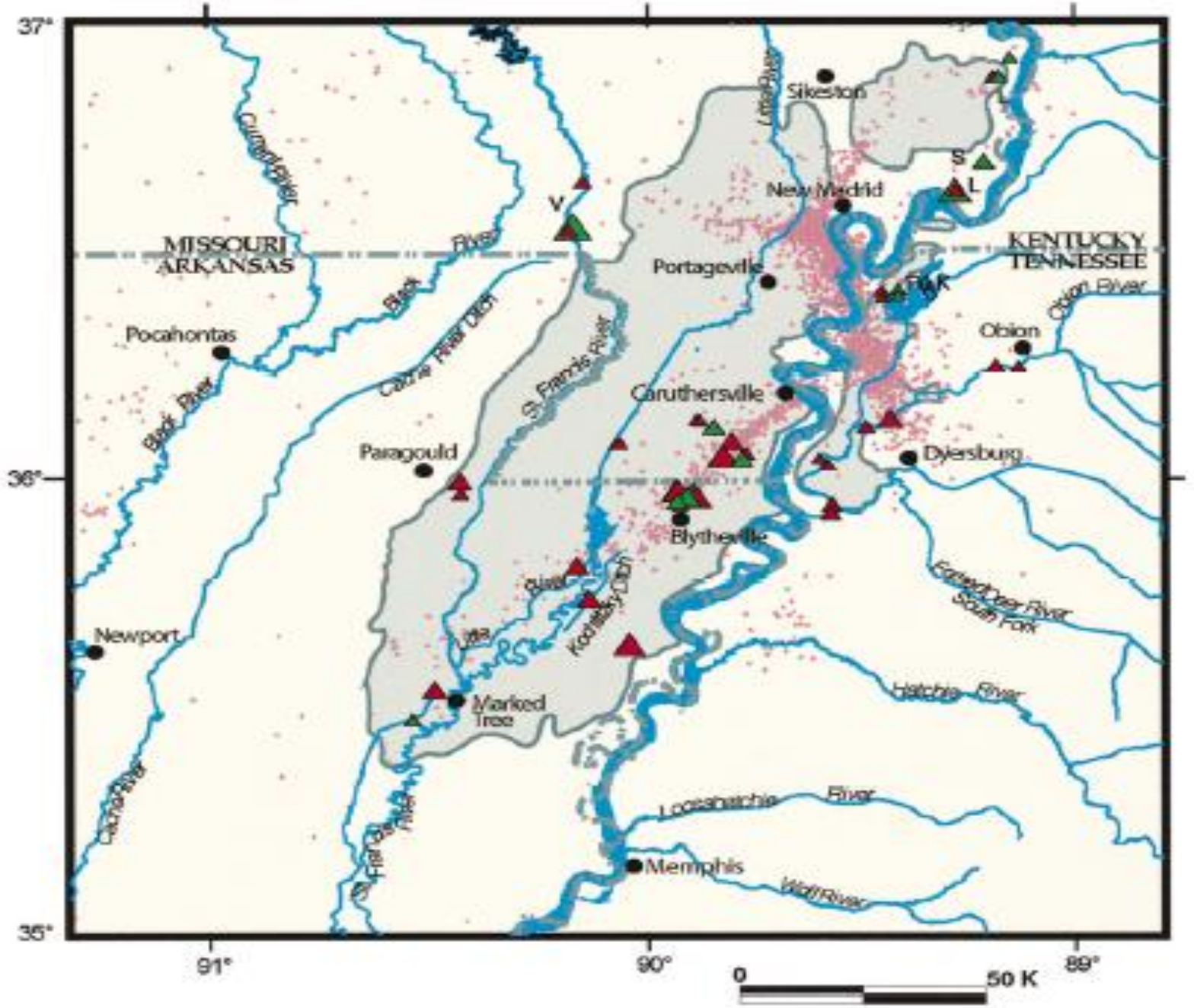

39°
38°
37°
36°
35°
36°
37°
38°
39°
Amonos
Pazarcık
Erkenek
Pütürge
Narlı
Depth (km)
0
10
20
S6: 108km
S1: 63km
S2: 54km
S3: 90km
North
36
37
38
39
Logitude (E)
36
36.5
37
37.5
38
Latitude (N)
Pütürge
Erkenek
Pazarcık
Narlı
Amonos
0
10
20
39
S3: 90km
S2: 54km
S4:45km
S5: 45km
S6: 108km
North
38
37
36
Logitude (E)
36
36.5
37
37.5
38
38.5
Latitude (N)
0
2
4
6
8
Slip (m)

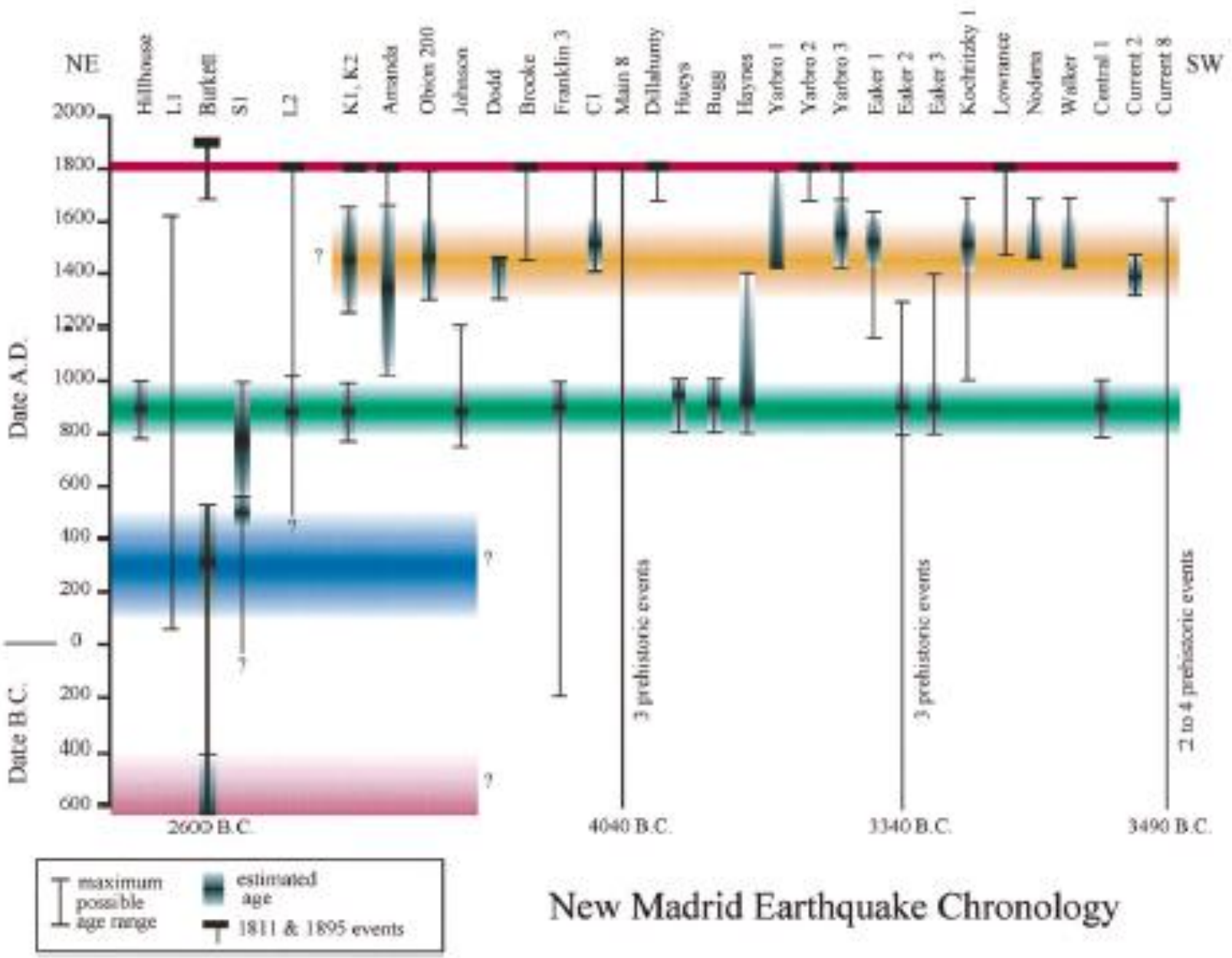
Xu et al., 2023

Historical Seismicity Along the EAFZ



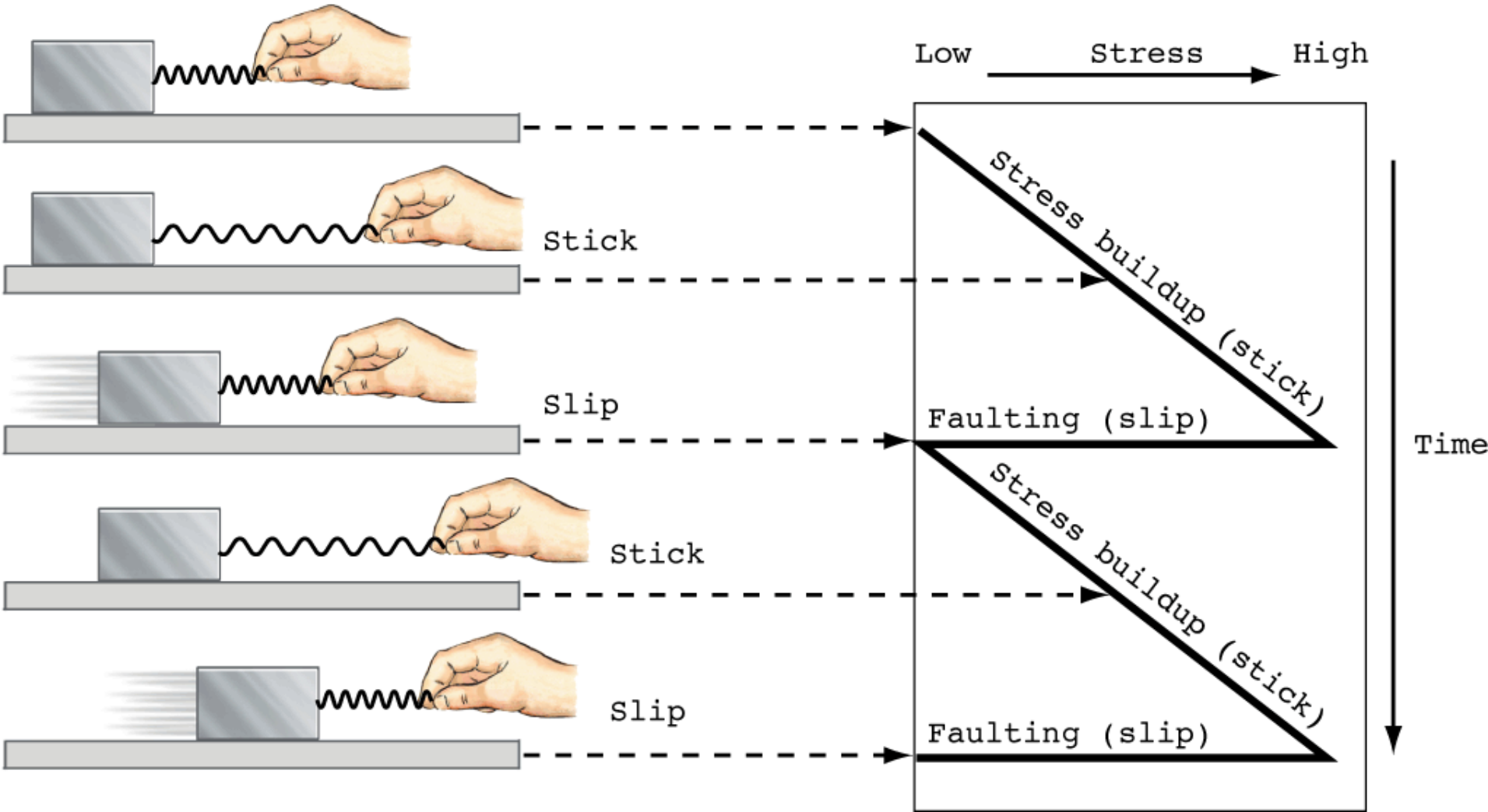
A.D. 900 and 1811-1812 Earthquake Features



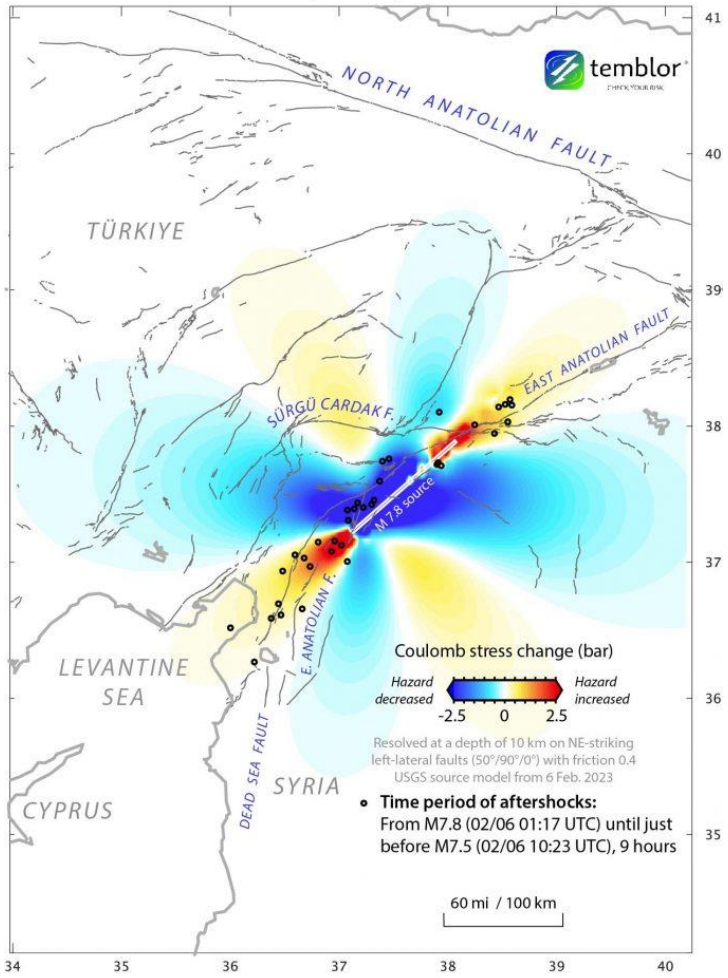


Tuttle et al., 2002 SSB

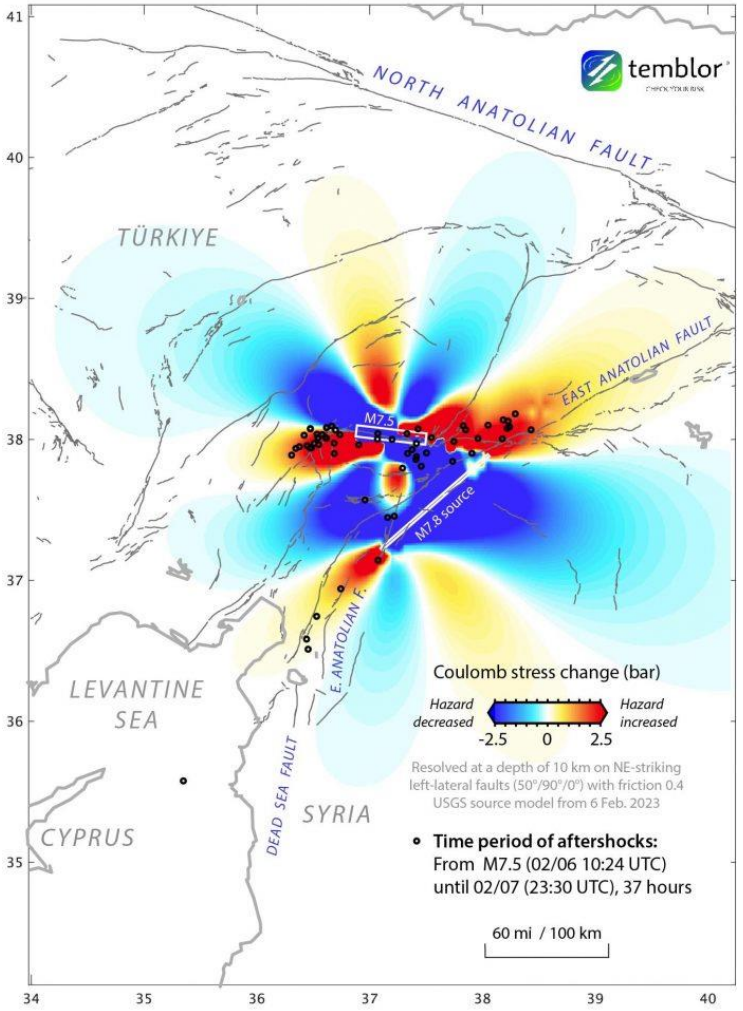
Forecasting Earthquakes: The Earthquake Cycle



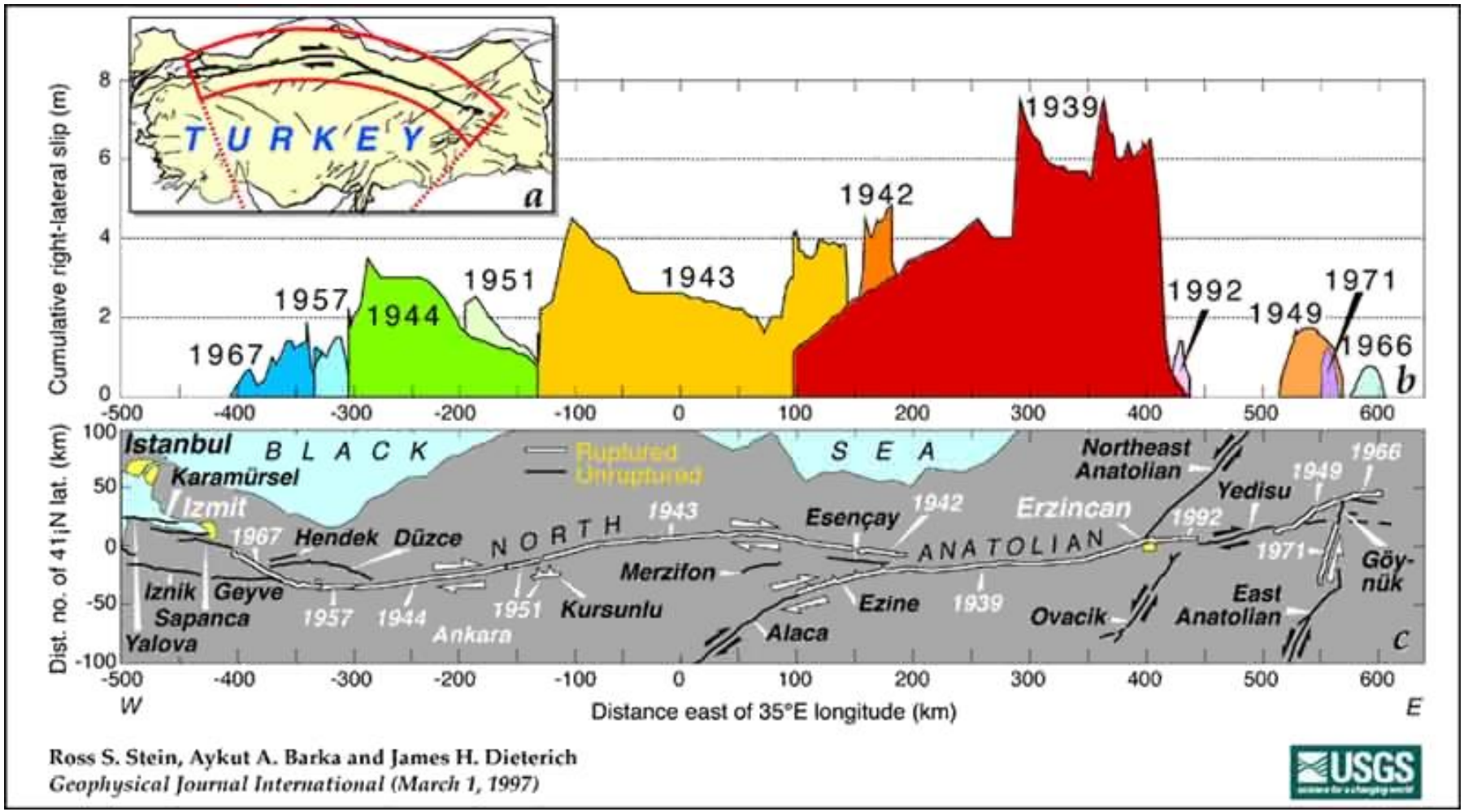
Calculated stress imparted by M 7.8 mainshock



Calculated stress imparted by M 7.8 and M 7.5 shocks

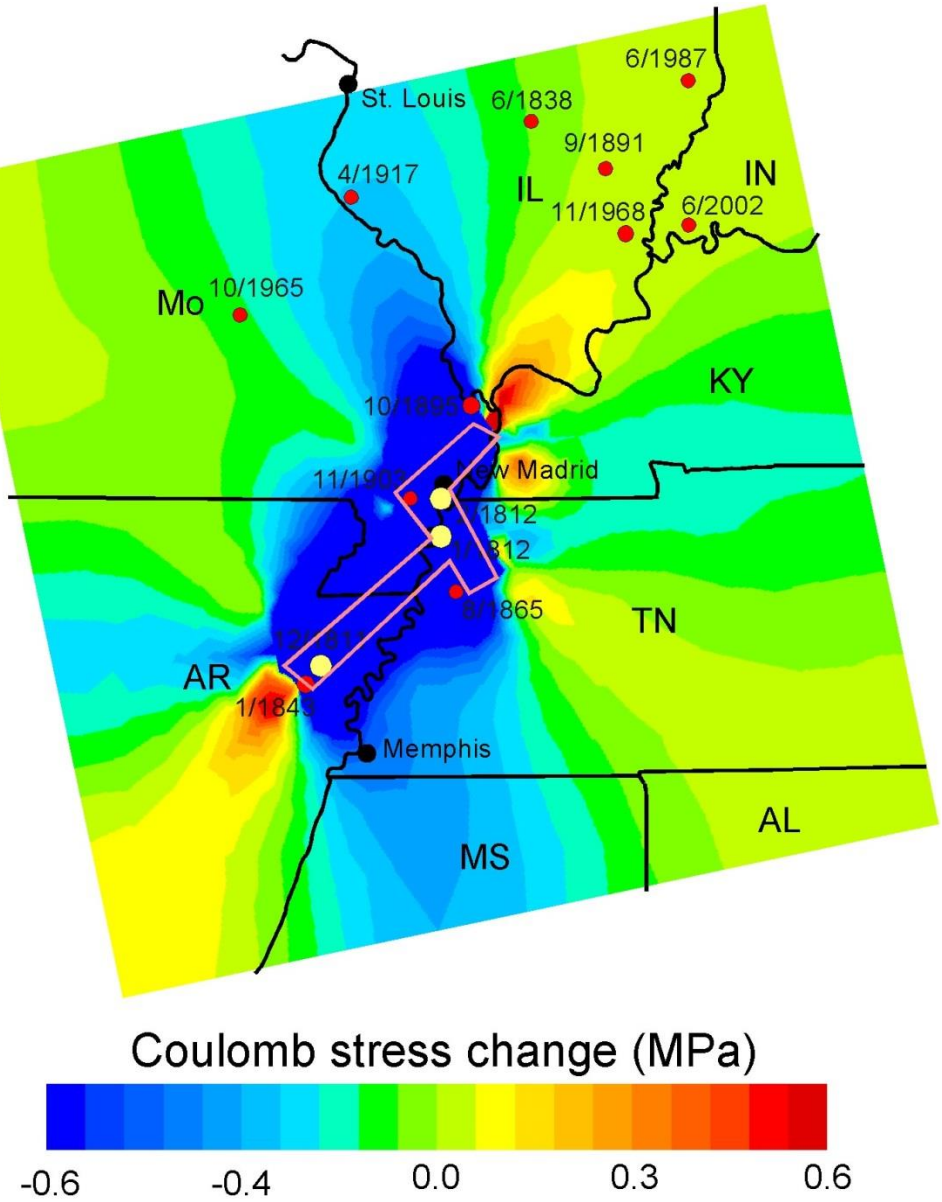


An analog for these events and a window into the future?

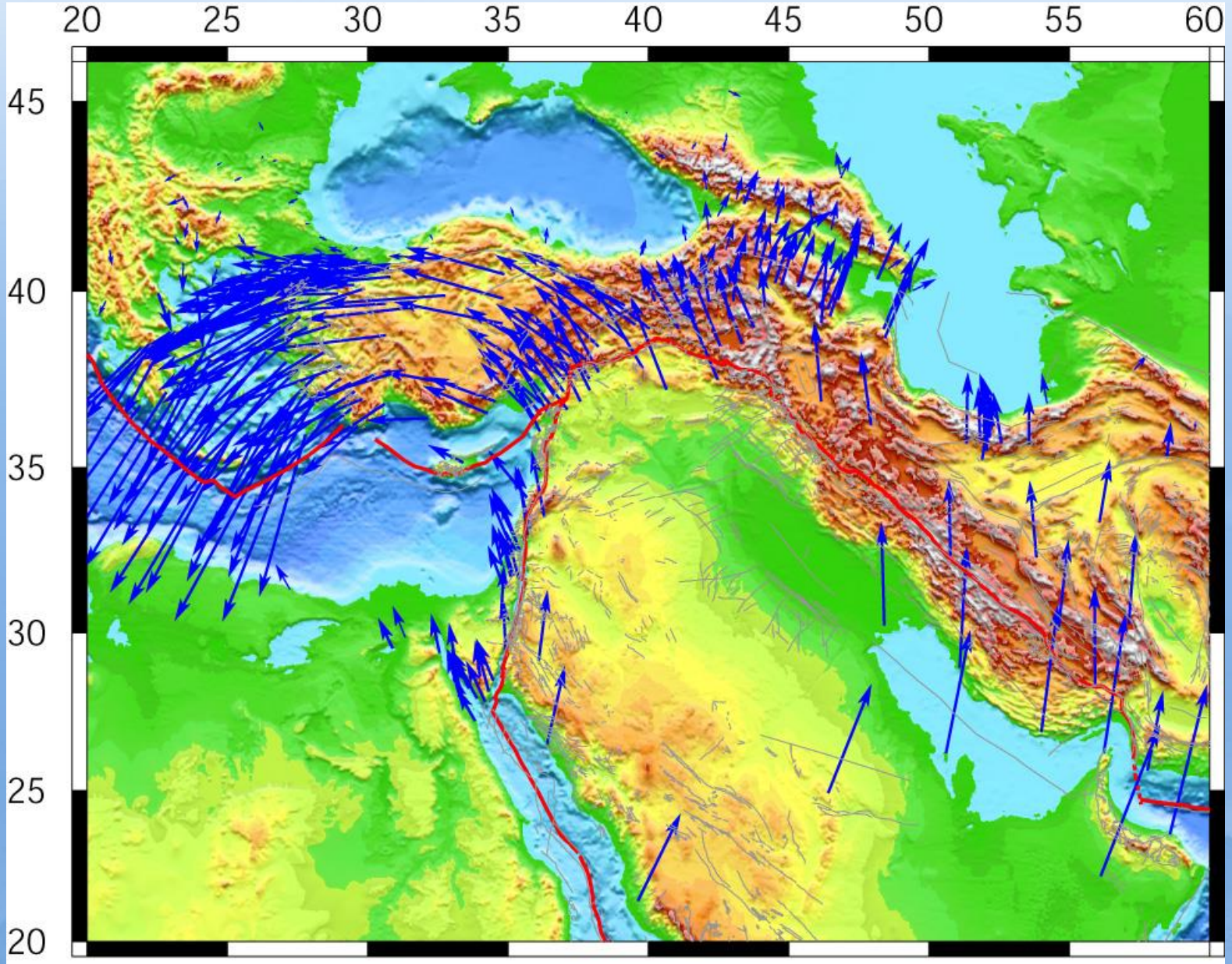


Ross S. Stein, Aykut A. Barka and James H. Dieterich
Geophysical Journal International (March 1, 1997)

Predicted change of Coulomb stress change 200 year after the 1811-1812 events

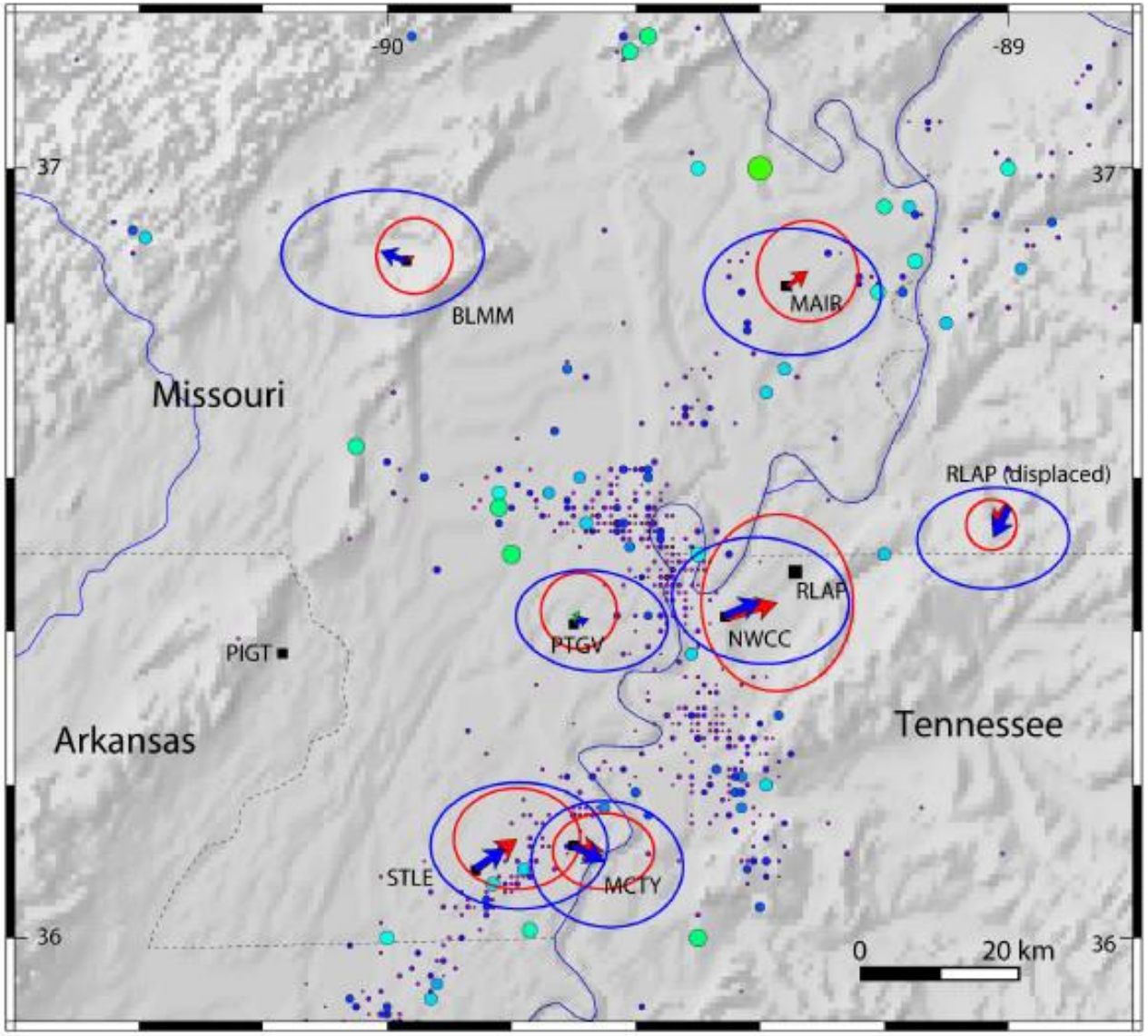


GPS Vectors (Reilinger et al., 2006)

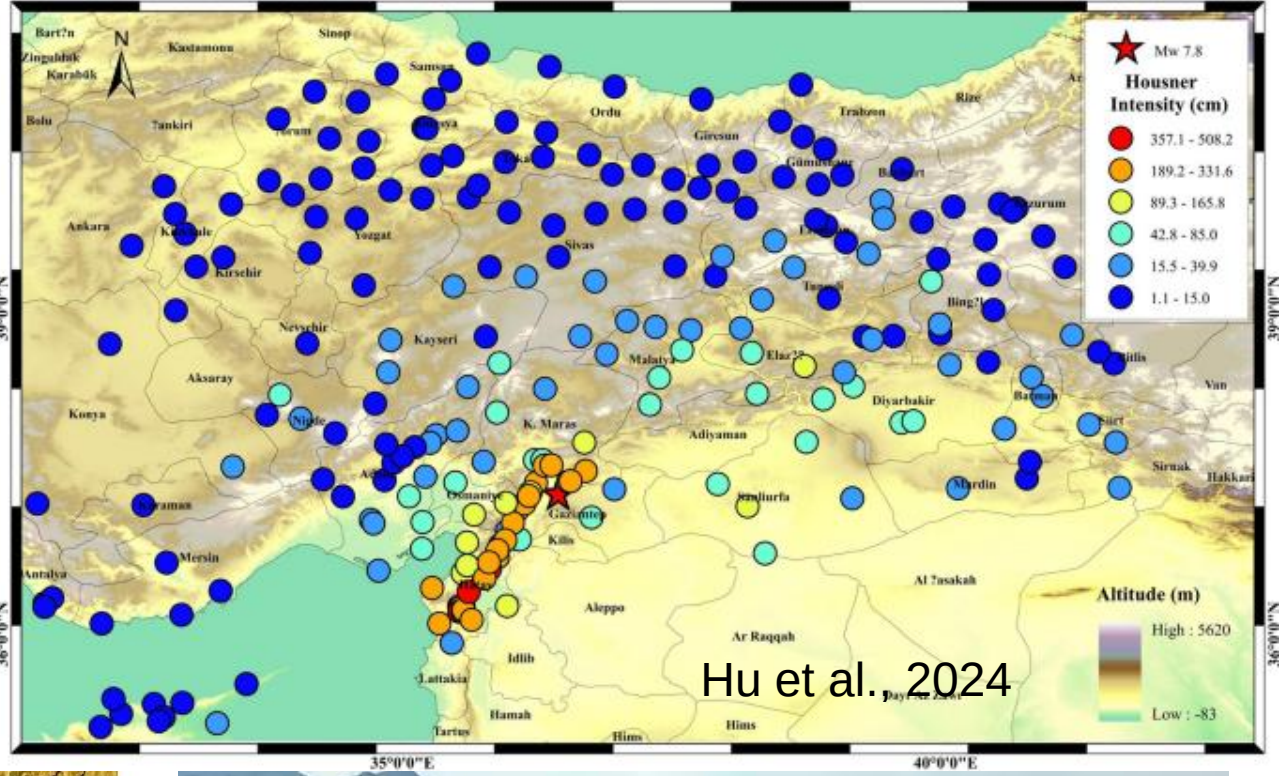


NMSZ Strain Accumulation?

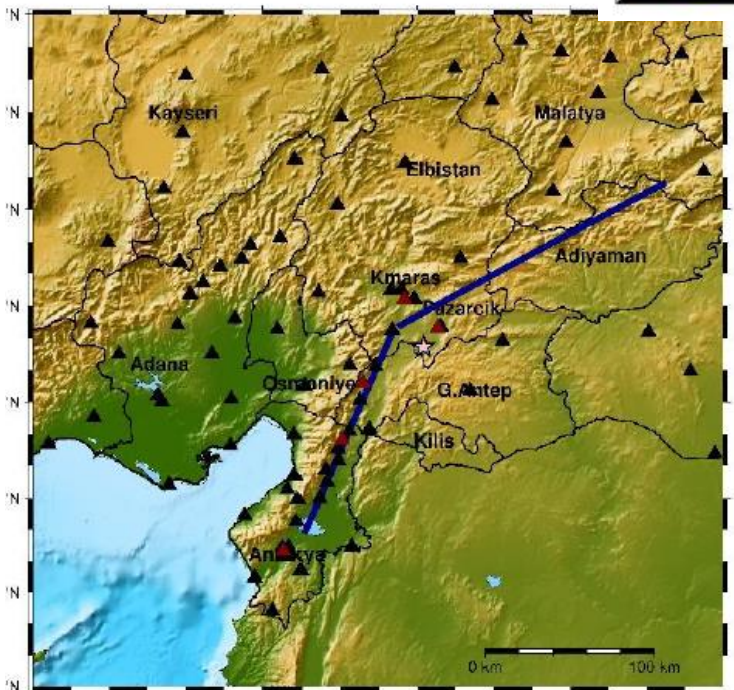
Calais et al., 2005



Ground Motions

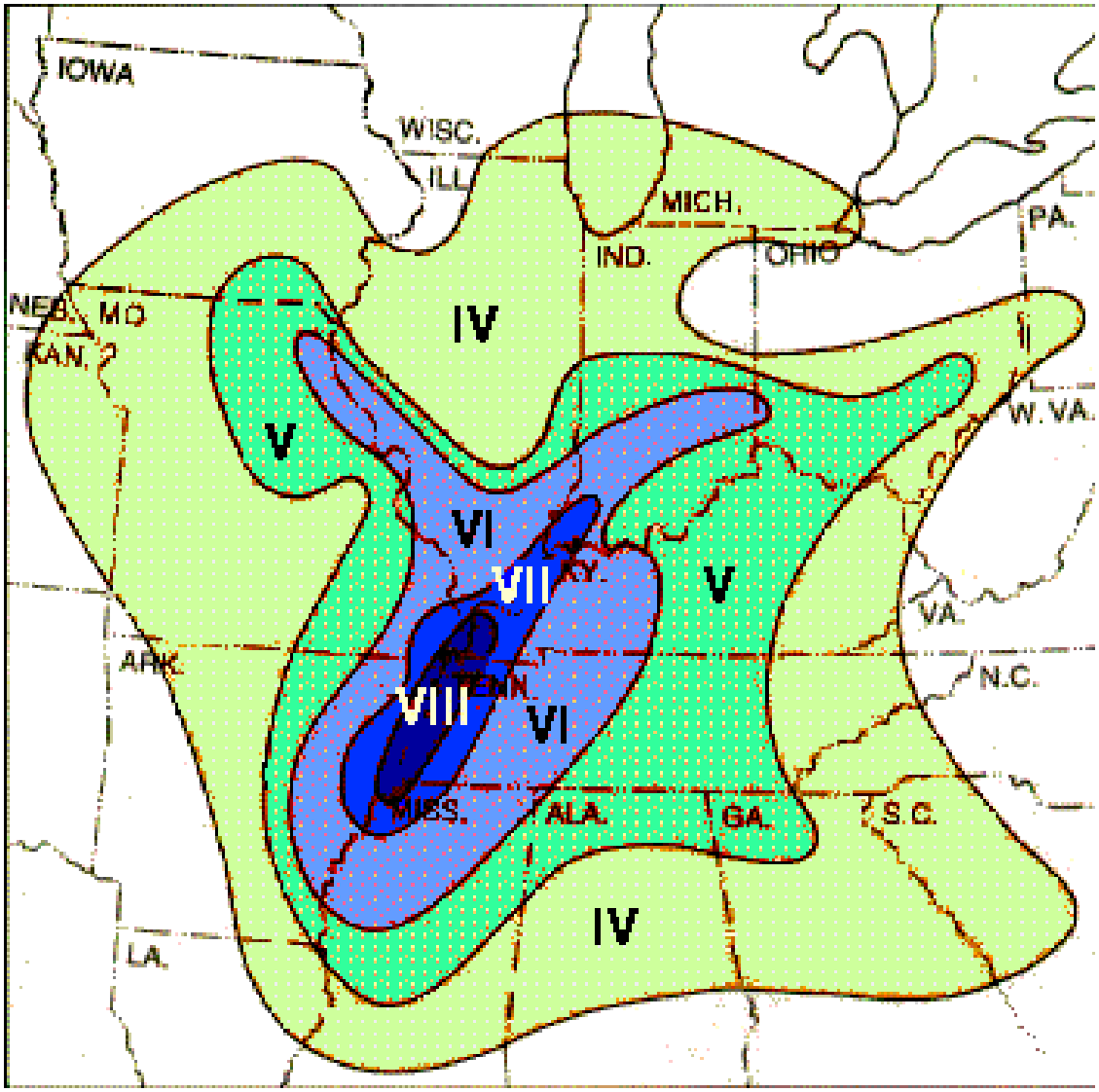


Hu et al., 2024

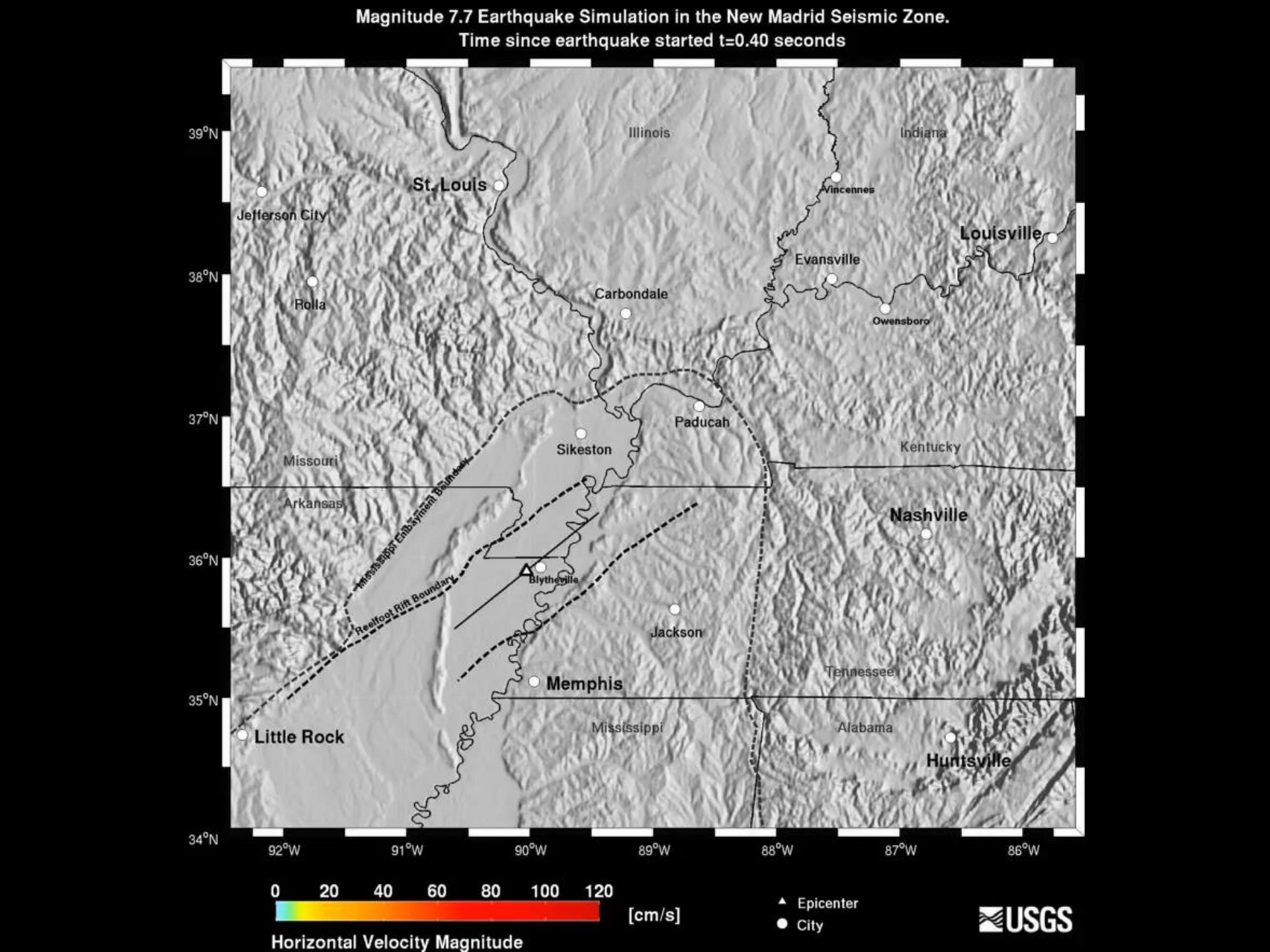



VOLVO

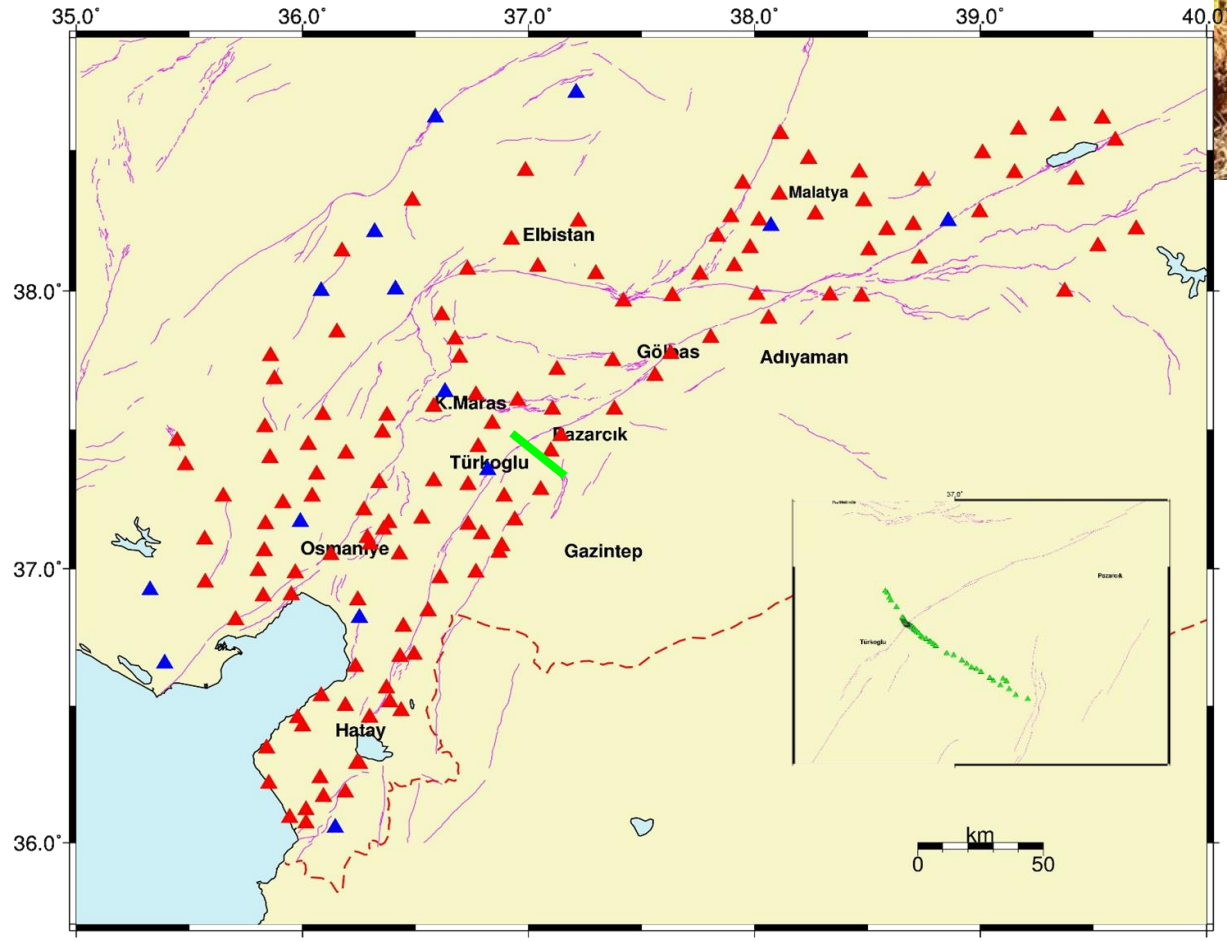
New Madrid Ground Motions



Woodcut by Henry Howe, from Historical Collections of the Great West (Cincinnati, 1854, p.239)


Magnitude 7.7 Earthquake Simulation in the New Madrid Seismic Zone.
Time since earthquake started t=0.40 seconds
39°N
38°N
37°N
36°N
35°N
34°N
92°W
91°W
90°W
89°W
88°W
87°W
86°W
Illinois
Indiana
St. Louis
Jefferson City
Vincennes
Louisville
Evansville
Rolla
Carbondale
Owensboro
Paducah
Sikeston
Missouri
Kentucky
Arkansas
Mississippi Embayment Boundary
Nashville
Reelfoot Rift Boundary
Blytheville
Jackson
Memphis
Tennessee
Little Rock
Mississippi
Alabama
Huntsville
0 20 40 60 80 100 120
[cm/s]
Horizontal Velocity Magnitude
Epicenter
City
USGS

EAFZ Seismic Network



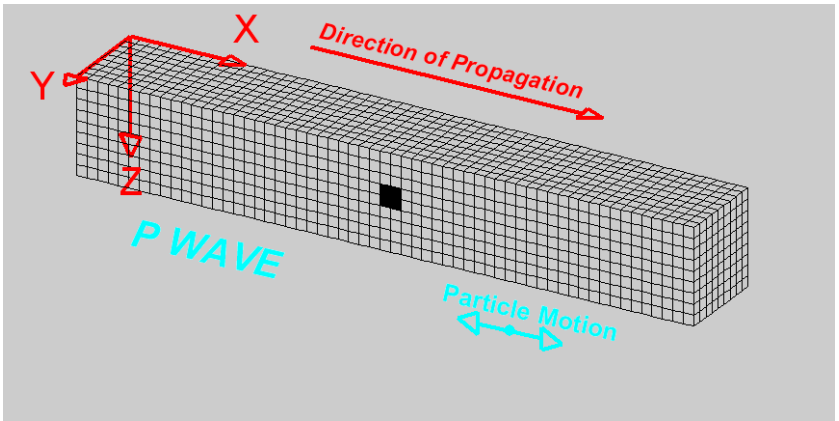
(Adapted from SmartSolo website)

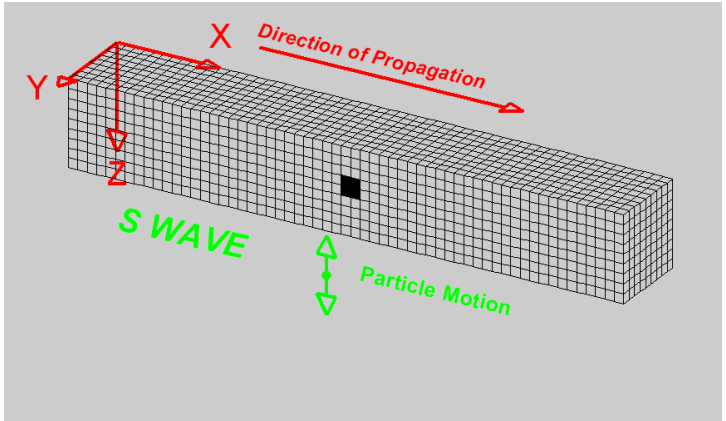
Seismic Velocity: *Rate at which seismic wave propagates through a given material. The seismic velocity is proportional to the *rigidity* of a material. The harder or more rigid a rock is, the faster a seismic wave will travel through it:* $Vs = [\mu / \rho]^{1/2}$;

$Vp = [(\mu + 4/3\kappa)/\rho]^{1/2}$

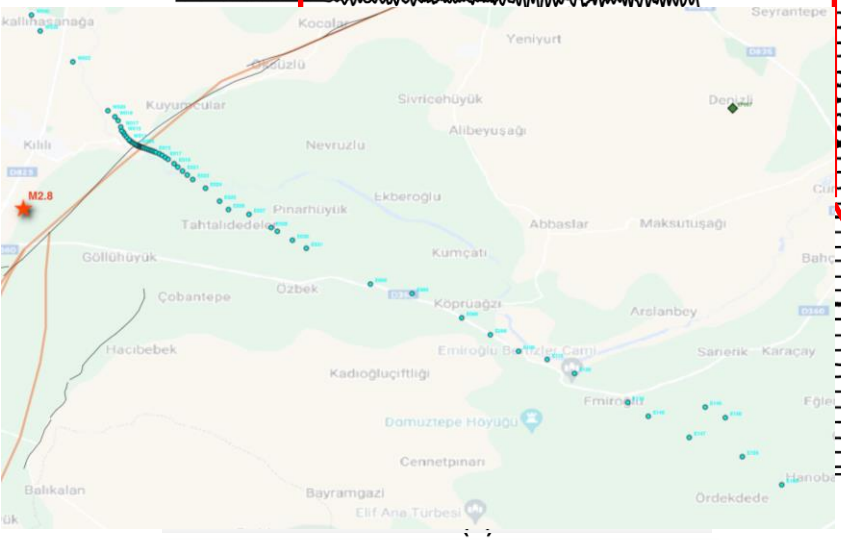
Examples:

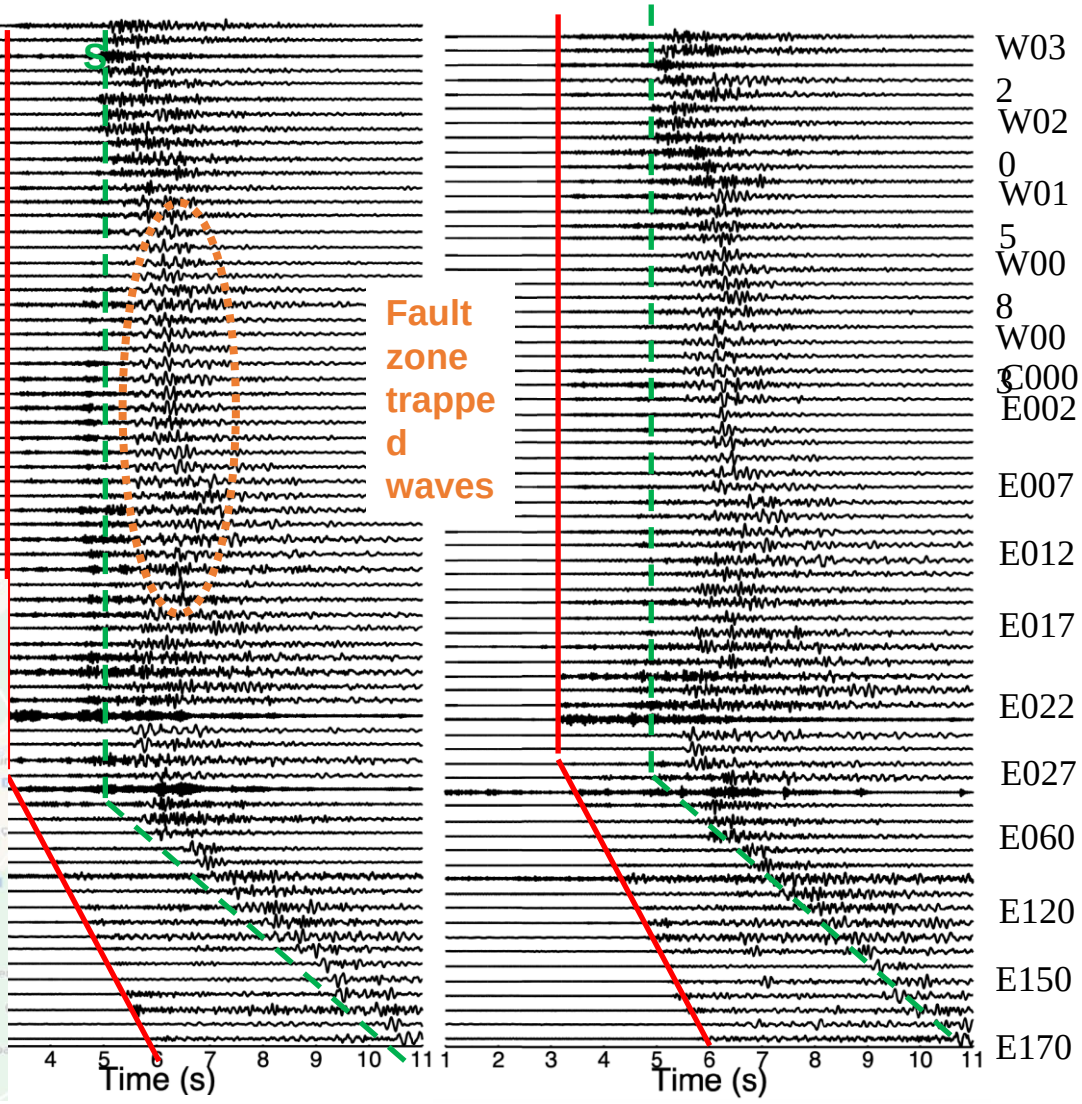
Water:	1400-1600 m/s
Clay:	200-2500 m/s
Soil:	300-600 m/s
Alluvium:	1000-3000 m/s
Limestone (unweathered):	2000-5000 m/s
Granite (unweathered):	5000-6000 m/s
Sandstone (weathered):	2500-4500 m/s



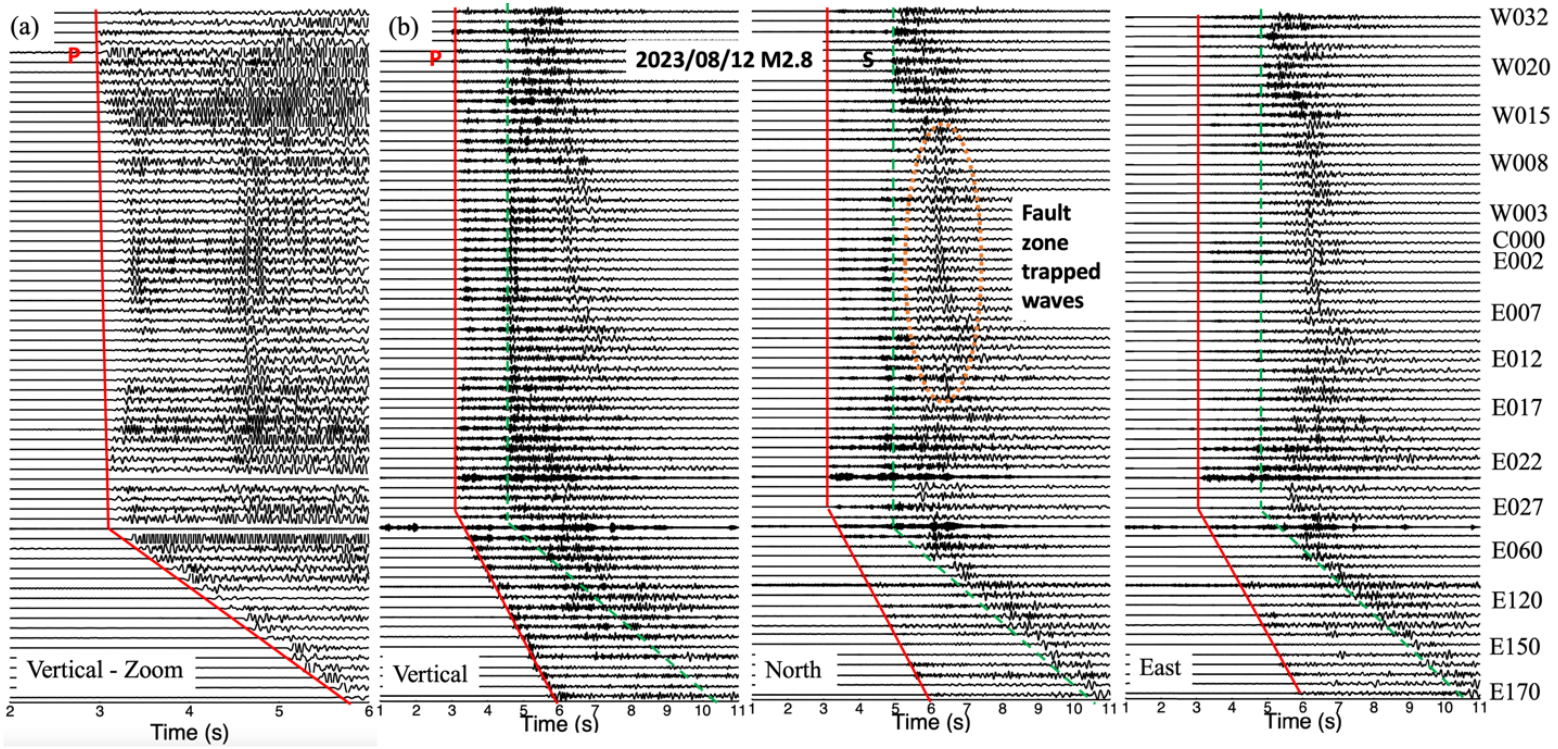


2023/08/1
M2.8

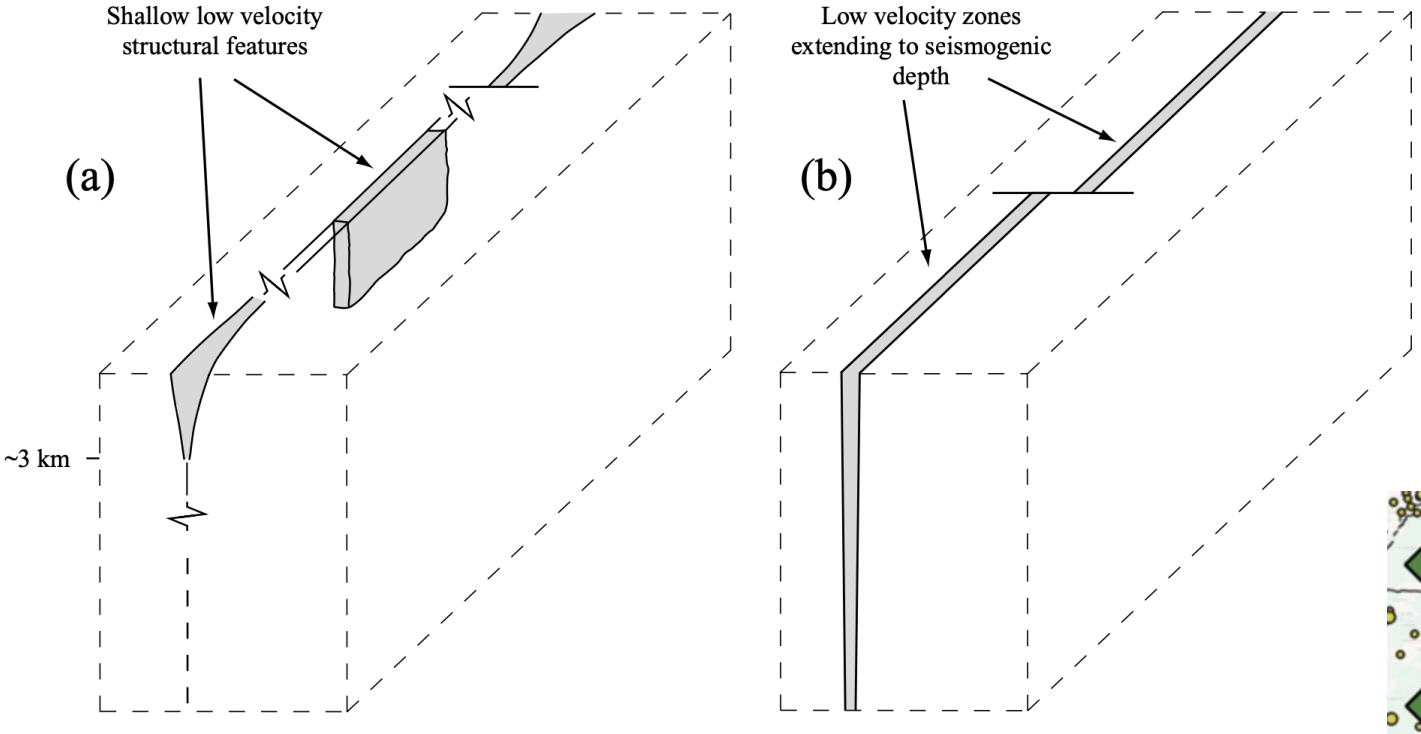

Yeniyurt
Sivricehüyük
Alibeyuşağı
Nevruzlu
Ekberoğlu
Pınarhüyük
Tahtalidedeler
Abbastar
Maksutuşağı
Kumçatı
Göllühüyük
Çobantepe
Özbek
Köpruağzı
Arslanbey
Hacıbebek
Kadıoğluçiftliği
Domuztepe Höyüğü
Cennetpınarı
Bayramgazi
Ordekdede
M2.8


S
Fault zone trapped waves
W032
W020
W015
W008
W001
C000
E002
E007
E012
E017
E022
E027
E060
E120
E150
E170
4 5 6 7 8 9 10 11
Time (s)
1 2 3 4 5 6 7 8 9 10 11
Time (s)


a
W032
C000
E060
E080
E110
E170
EAF Pazarcık S.
DSF Sakçagöz-Narlı S.

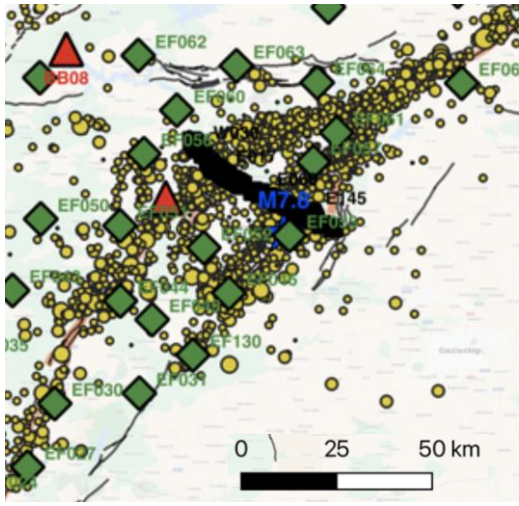

(a)
(b)
P
2023/08/12 M2.8
S
Fault zone trapped waves
W032
W020
W015
W008
W003
C000
E002
E007
E012
E017
E022
E027
E060
E120
E150
E170
Vertical - Zoom
Vertical
North
East
Time (s)

Testing shallow versus deep low-velocity fault zone structures with ultra-long dense array and two parallel rupture zones



Different fault zone trapped waves are expected for these models from on and off-fault seismicity.

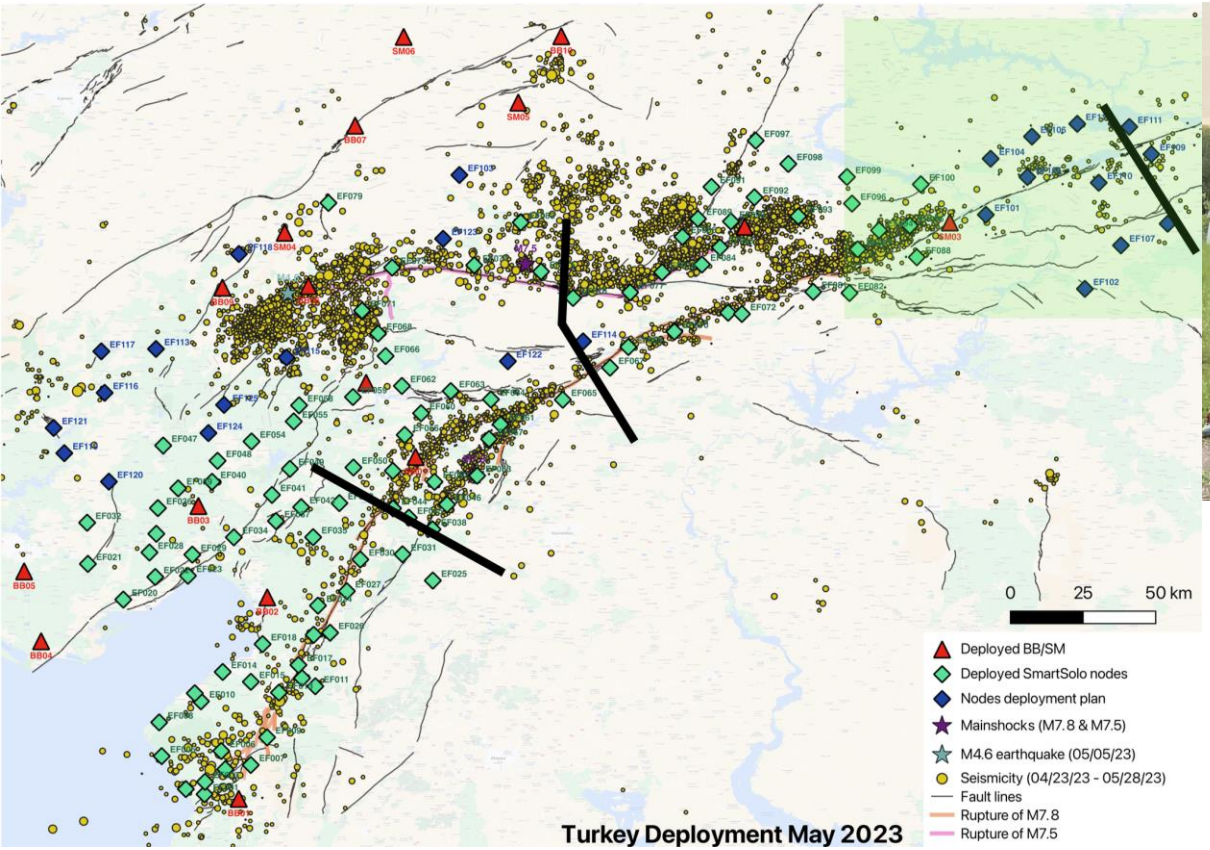
Ben-Zion et al. (GJI, 2003) for the 1999 Izmit/Duzce earthquake sequence



Things we can learn from the Turkiye earthquakes:

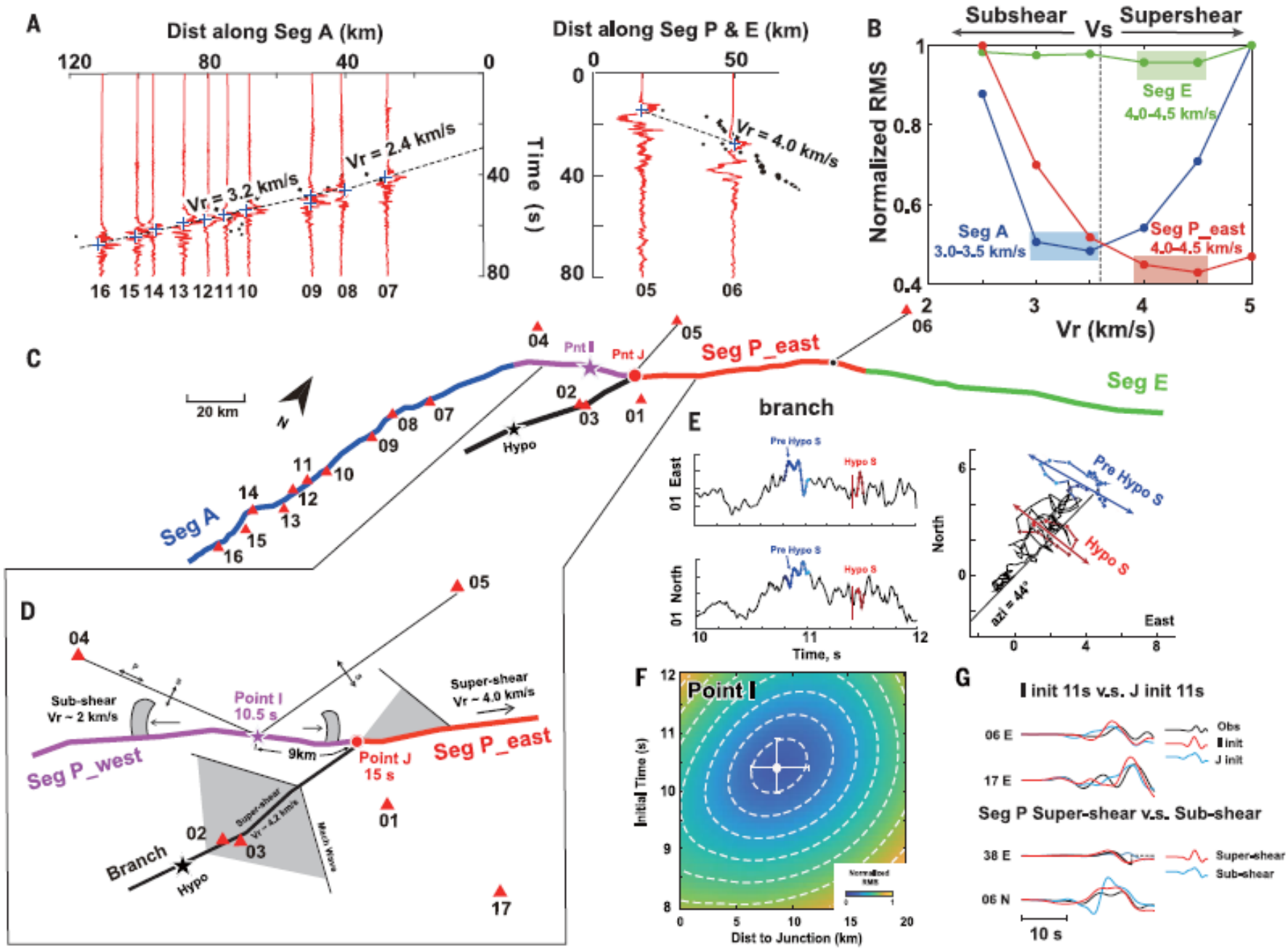
- We can expect a sequence of earthquakes rather than just one event (similar to what happened in 1811-812)
- Strongest ground motions and liquefaction will occur primarily in the Mississippi embayment (i.e. the effect of shallow, young, water saturated sediments)
- Recovery time will likely be years rather than days

QUESTIONS?

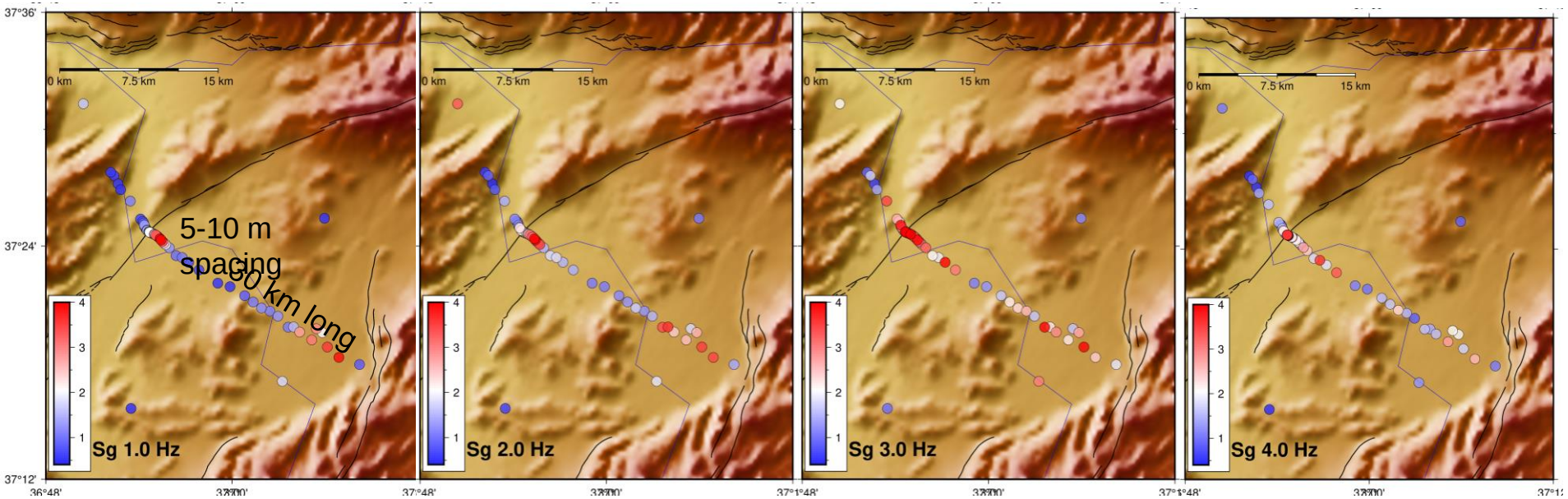


This deployment would not have been possible without support from the United States National Science Foundation's Geophysics Program (**RAPID EAR-2322461**). Thanks to SmartSolo Inc. for providing 150 nodes.

Ren et al., Science, 2024



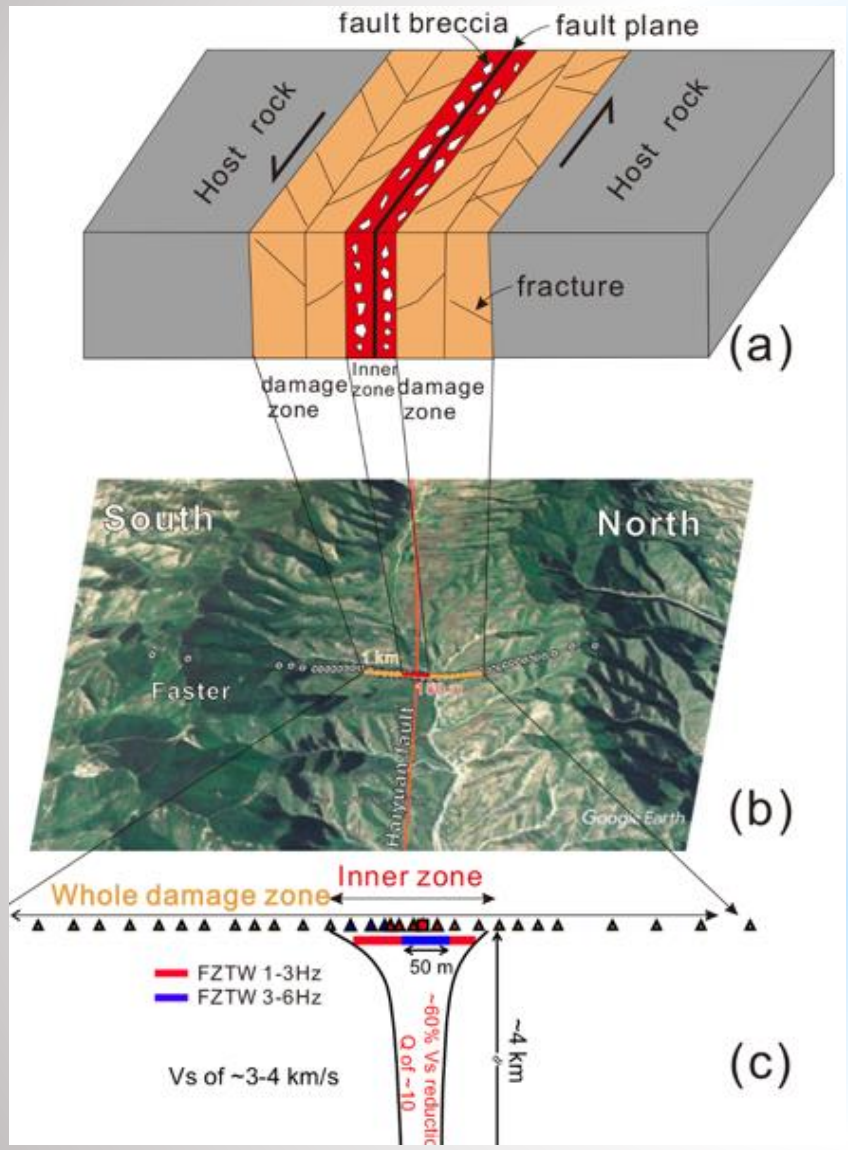
Ground Motions Along the August Profile:



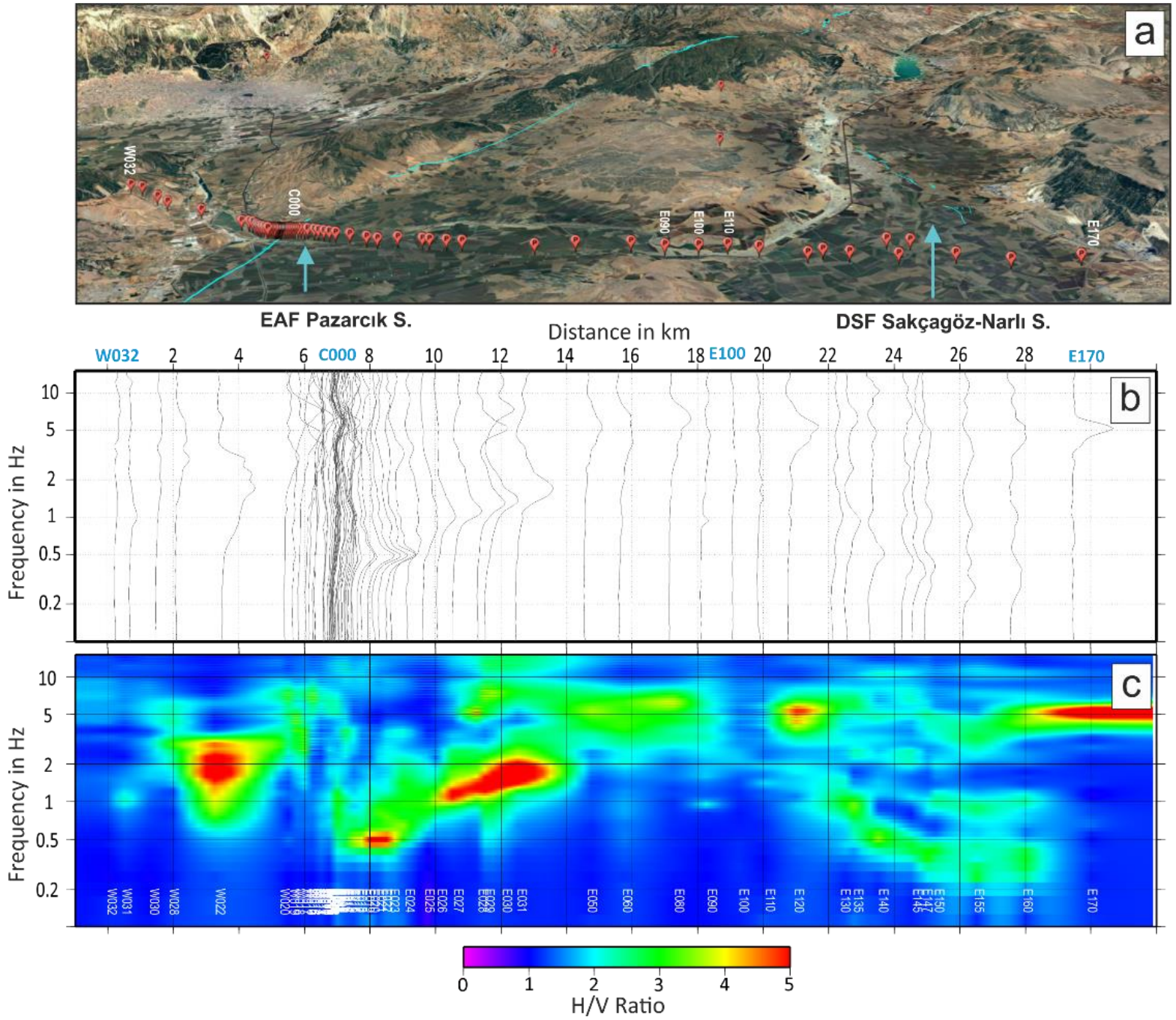
1.0 Hz **2.0 Hz** **3.0 Hz** **4.0 Hz**

$$A_j^i(\omega) = S_j(\omega,\theta) I^i(\omega) E_j(\omega) G_j^i(\Delta) \exp\left[-\frac{\pi f \Delta_j^i}{vQ(f)}\right]$$

Proposed Array Objectives



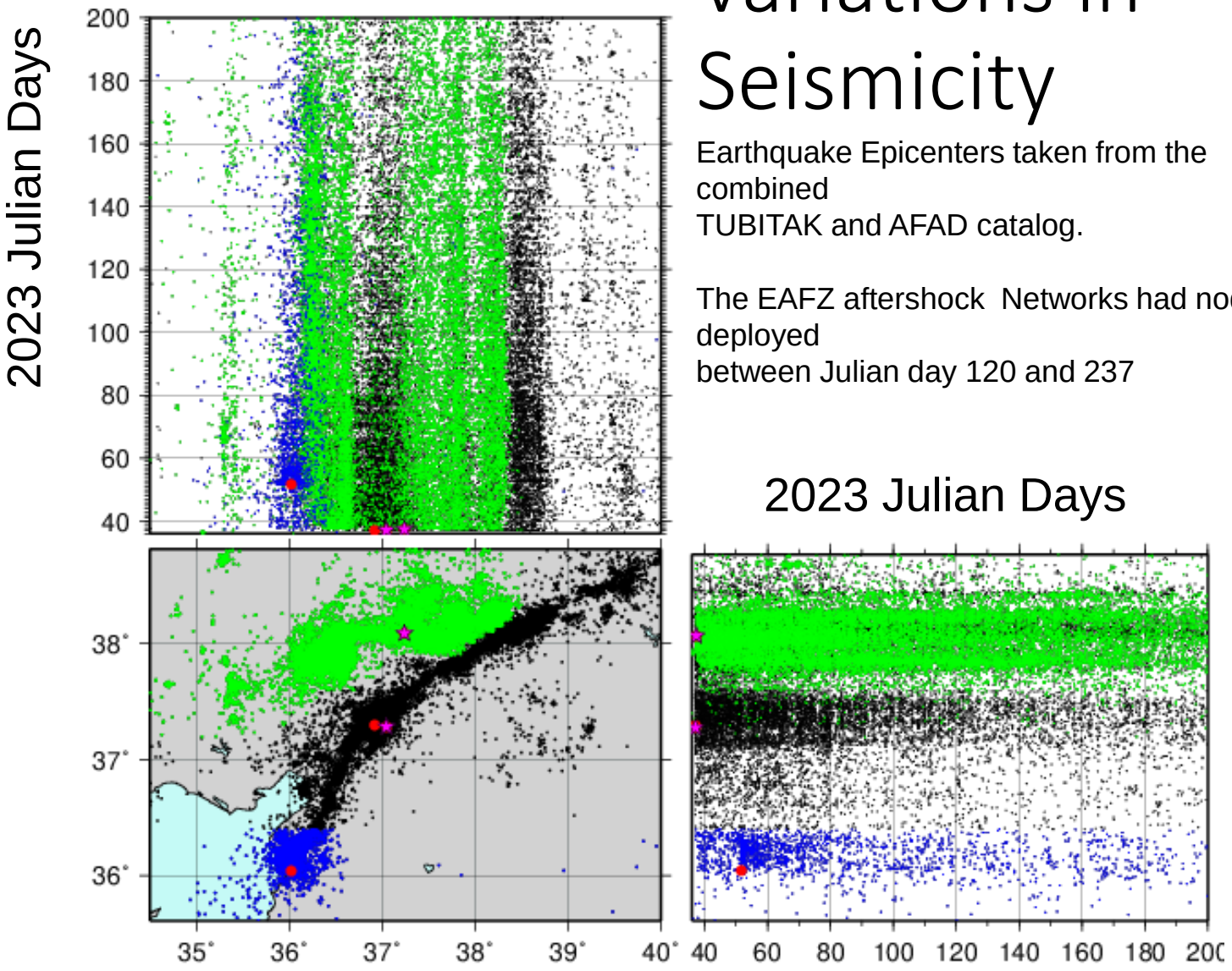
- Create comprehensive EQ catalog with detection thresholds near zero
- Use the catalog to image detailed 3D structural images of the active faults zones with an emphasis on bends, fault intersections, and step-overs
- Construct frequency dependent model of site amplification across EQ zone
- Detailed images of upper crustal seismic anisotropy

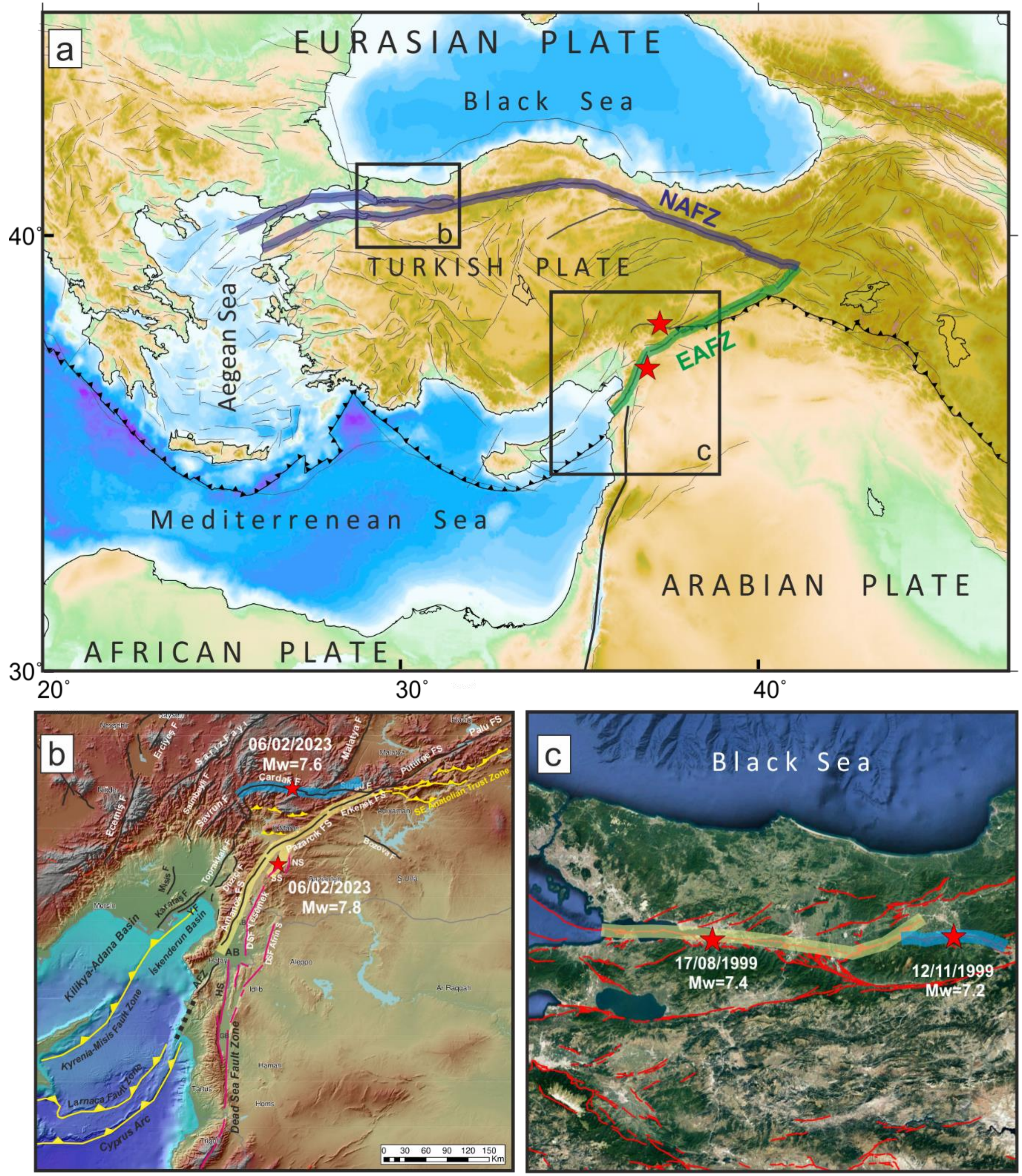

a
W032
C000
E090
E100
E110
E170
EAF Pazarcık S.
DSF Sakçagöz-Narlı S.
Distance in km
W032
C000
E100
E170
b
Frequency in Hz
10
5
2
1
0.5
0.2
c
Frequency in Hz
W032
W031
W030
W028
W022
W020
E024
E025
E026
E027
E028
E029
E030
E031
E050
E060
E080
E090
E100
E110
E120
E130
E135
E140
E145
E150
E155
E160
E170
0
1
2
3
4
5
H/V Ratio

Spatial-Temporal Variations in Seismicity

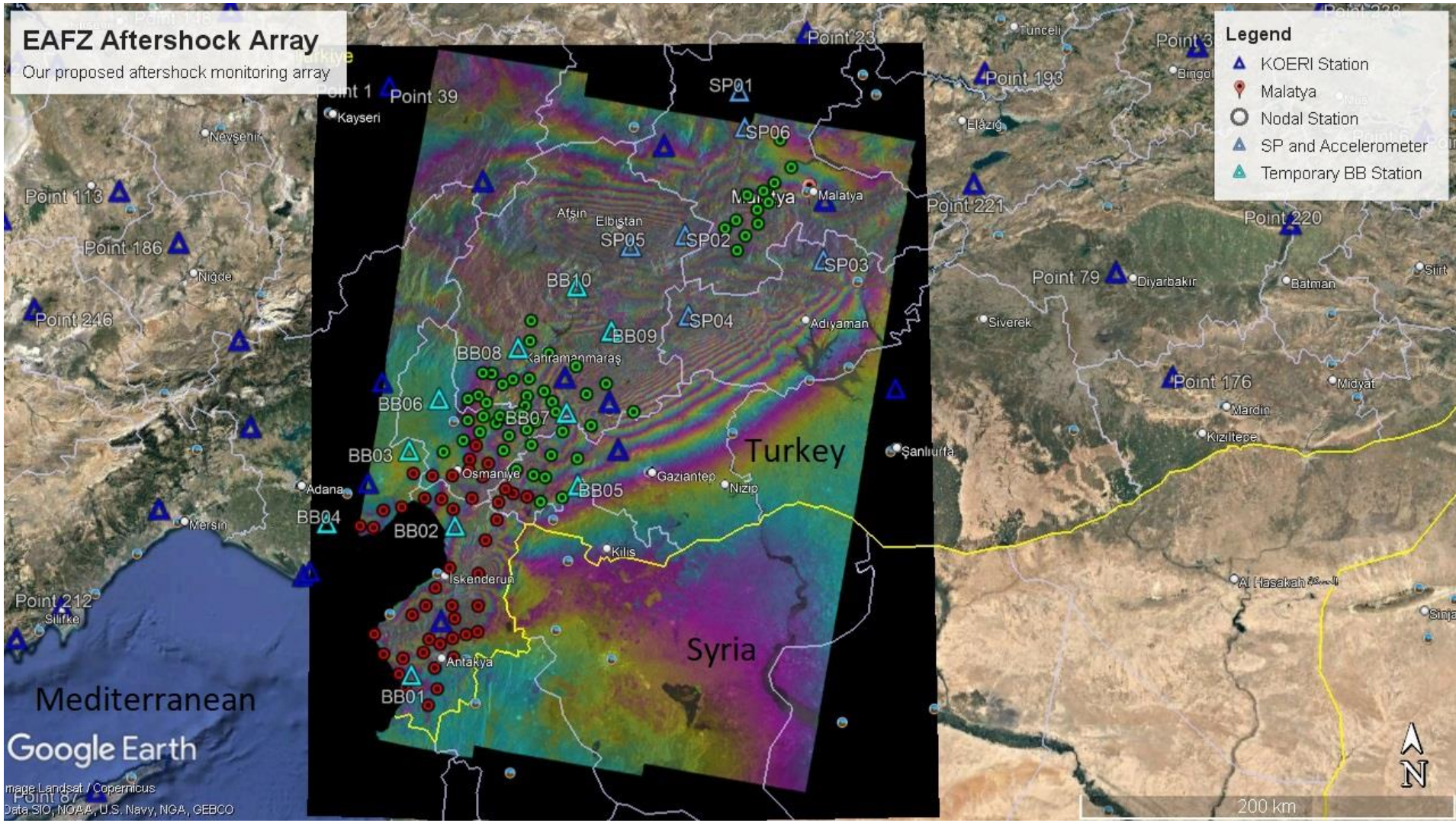
Earthquake Epicenters taken from the combined
TUBITAK and AFAD catalog.

The EAFZ aftershock Networks had nodes deployed
between Julian day 120 and 237

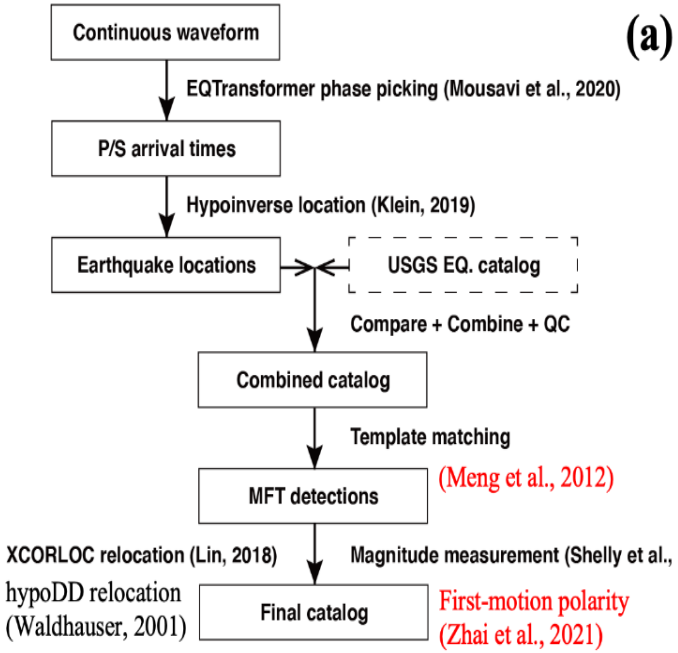


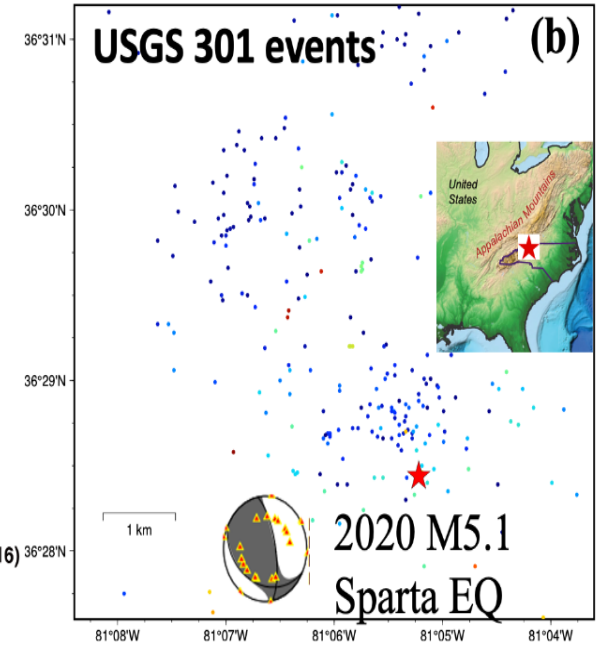

a
EURASIAN PLATE
Black Sea
NAFZ
b
40°
TURKISH PLATE
Aegean Sea
EAFZ
c
Mediterrenean Sea
ARABIAN PLATE
AFRICAN PLATE
30°
20°
30°
40°
b
06/02/2023
Mw=7.6
06/02/2023
Mw=7.8
Cardak F
Surgu F
Erkenek FS
Pazarcik FS
SE Anatolian Trust Zone
Palu FS
Puturge FS
Malatya F
Savrun F
Ecemis F
Iskenderun Basin
Kilikya-Adana Basin
Kyrenia-Misis Fault Zone
Larnaca Fault Zone
Cyprus Arc
Dead Sea Fault Zone
Aleppo
AB
NS
SS
0 30 60 90 120 150
Km
c
Black Sea
17/08/1999
Mw=7.4
12/11/1999
Mw=7.2

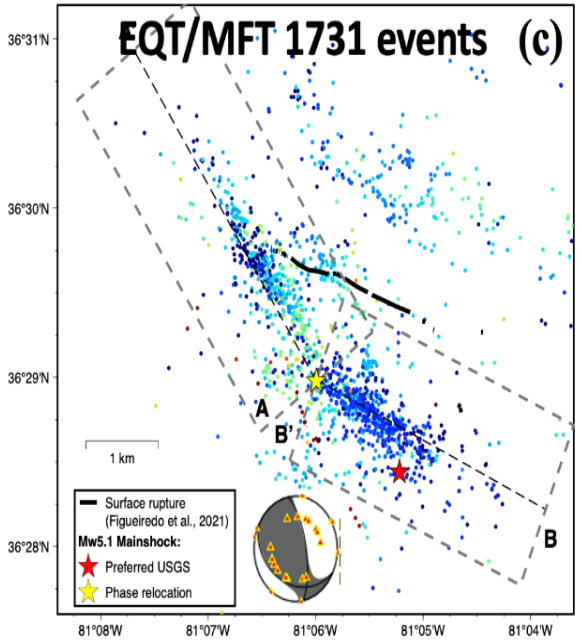
Array Deployed in April 2023



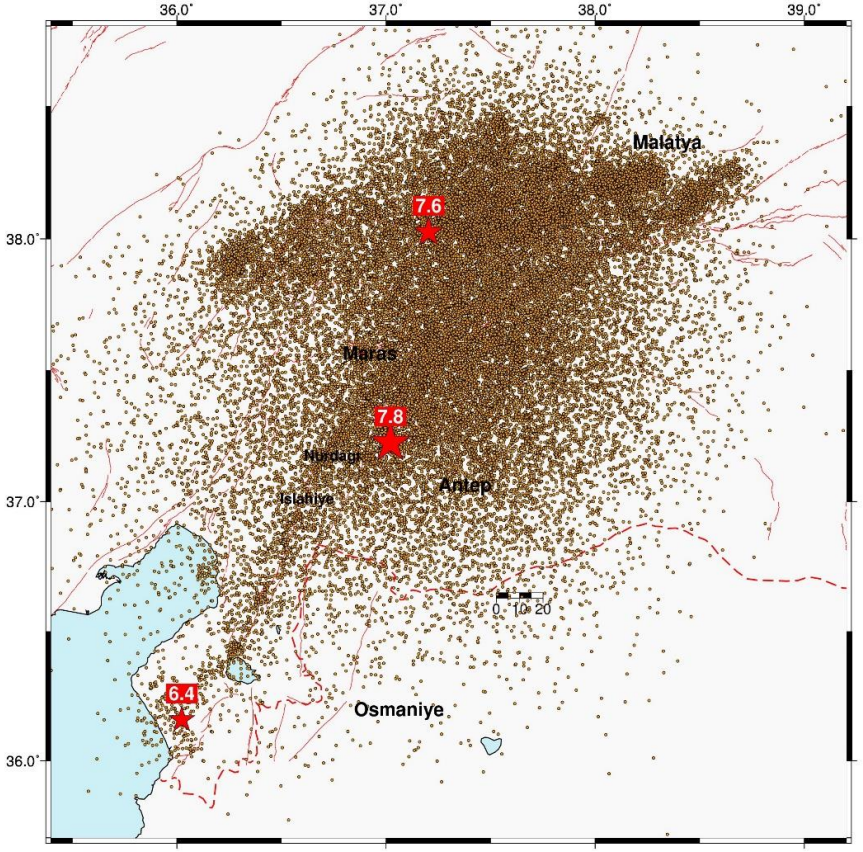
Planned Analysis

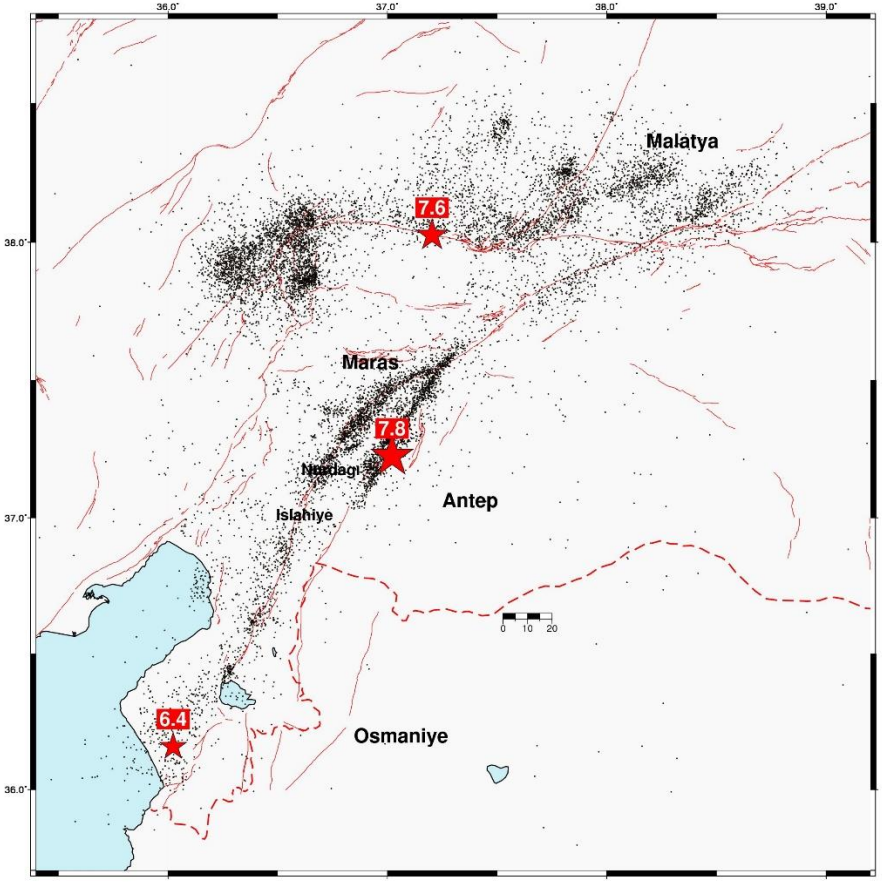




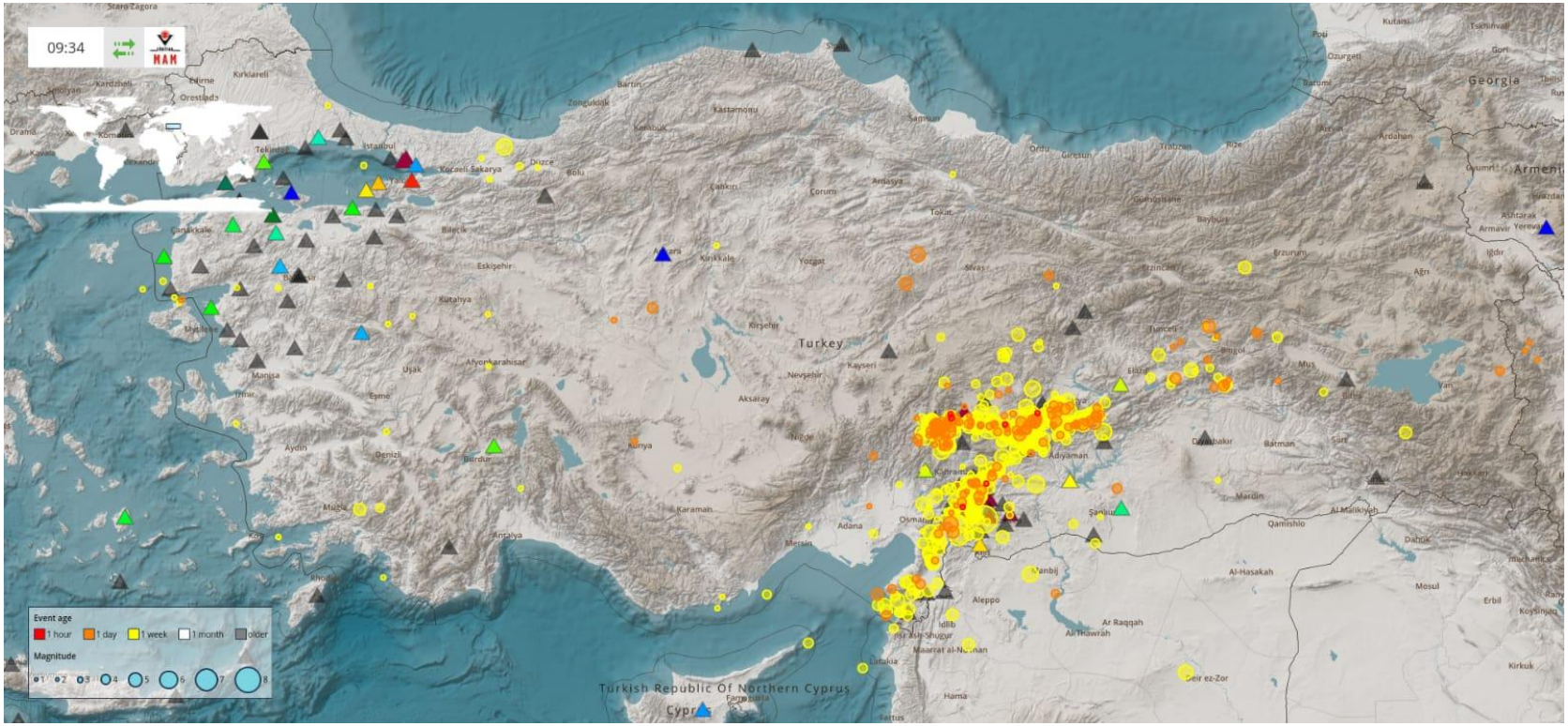


Preliminary EAFZ Nodal Earthquake Locations from May 1st- June 12th
EQTransformer (Mousavi et al., 2020)

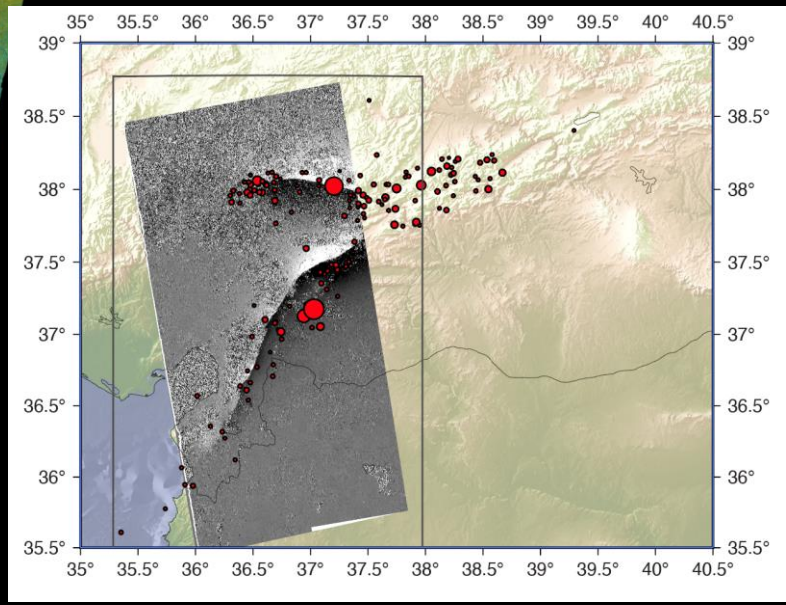




Latest Aftershock map from our collaborators at TUBITAK:



Interferogram



Broadband vs Nodal