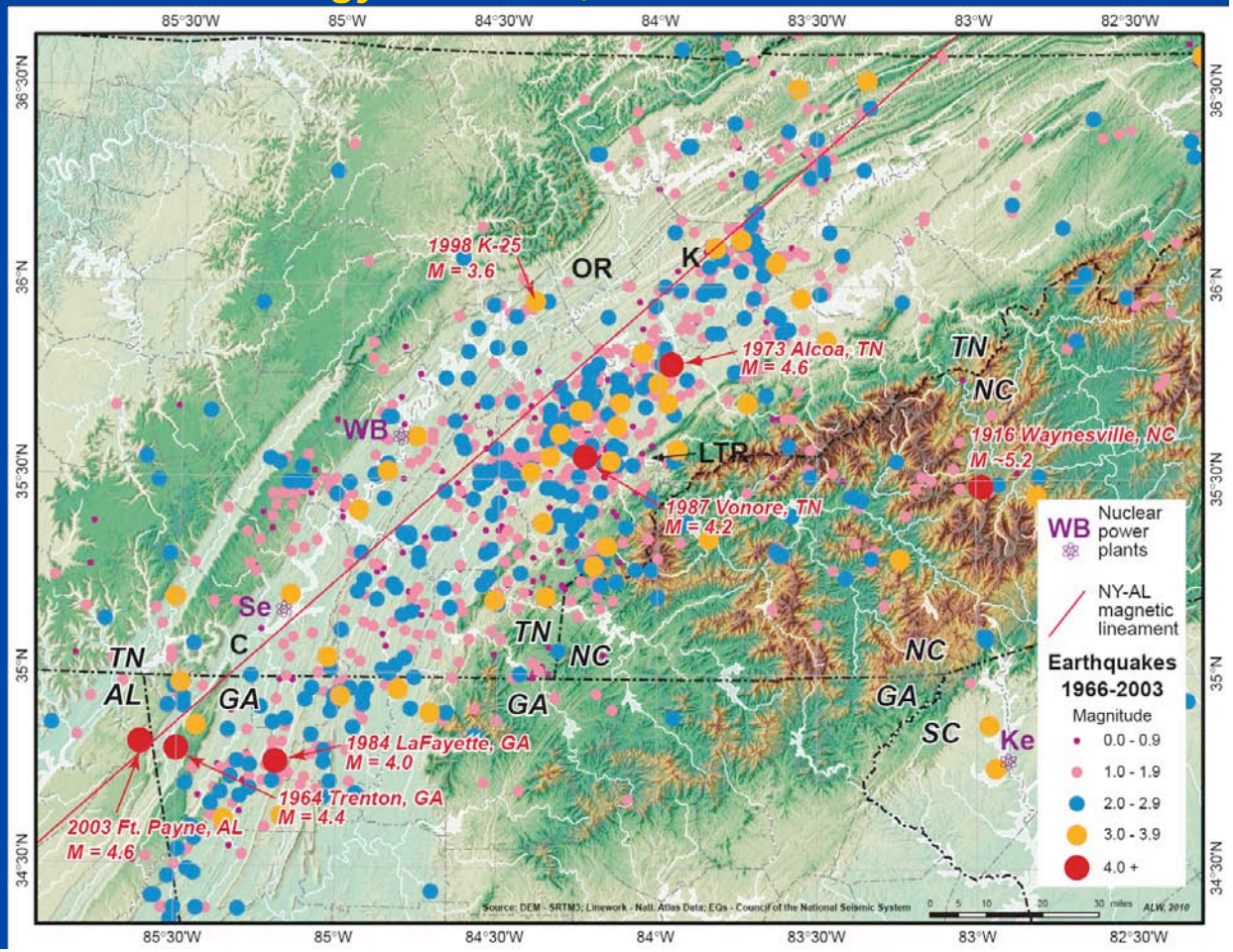
Is there an Earthquake Hazard in East Tennessee?

Robert D. Hatcher, Jr., Ph.D., P.G.

UT Distinguished Scientist and Professor
Tectonics and Structural Geology Research, UT–Knoxville

Emergency Management Workshop
New Hope Center
Oak Ridge, TN
September 8, 2011



Acknowledgments

Stephen F. Obermeier
USGS Emeritus

James D. Vaughn
MO Geological Survey (retired)

Earthquake Study Funding:
U.S. Nuclear Regulatory Commission

Charleston & New Madrid Earthquake Images:
Prof. Pradeep Talwani, USC–East
Prof. Roy van Arsdale, Univ. Memphis
USGS

Cooperation:
TVA
UTK Institute of Agriculture
Research Farms
Wildlife Resources
UTK Anthropology Dept.

Major Natural Disasters

津(tsu) 波(nami)
harbor wave

08 China M = 7.8
70,000 (official)

10 Haiti M = 7.0
200,000+ (official)

10 Chile M = 8.8
<30,000?

11 Japan M = 8.9
>30,000? (RDH est.)

DEATHS	EVENT	LOCATION	YEAR
3,700,000	Flood	China	1931
300,000	Cyclone	Bangladesh	1970
255,000	Earthquake	China	1976
143,000	Earthquake	Japan	1923
139,000	Cyclone	Bangladesh	1991
120,000+*	Tsunami	South Asia	2004
100,000	Tsunami	Japan	1703
70,000	Tsunami	Portugal	1755
50,000	Earthquake	Iran	1990
31,000	Earthquake	Iran	2003

*As of Dec. 31, 2004
Sources: *World Almanac*, U.S. Geological Survey, Associated Press

From US N & W R

Some questions:

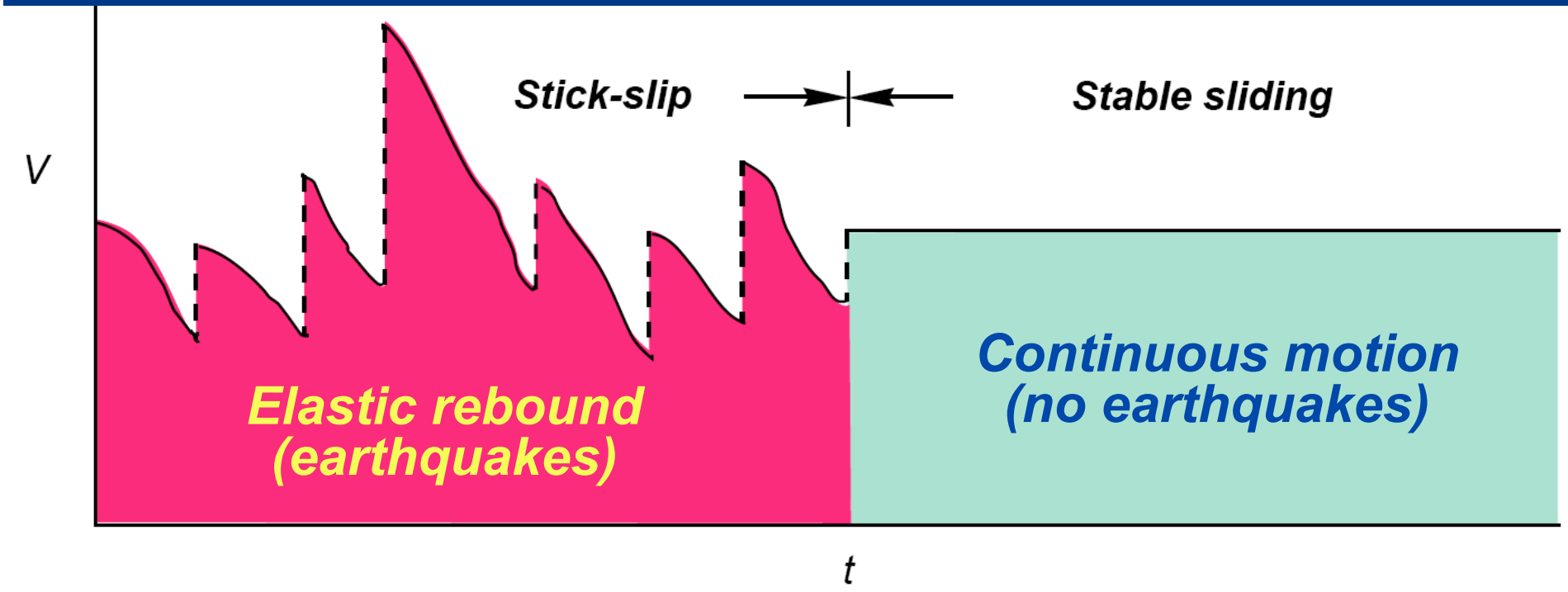
What is an earthquake?

What is earthquake magnitude?

What does it mean in terms of energy release when the newspaper says that the January, 2010, Haitian earthquake had a magnitude of 7, or that the January, 2010 Chilean EQ had a magnitude of 8.8?

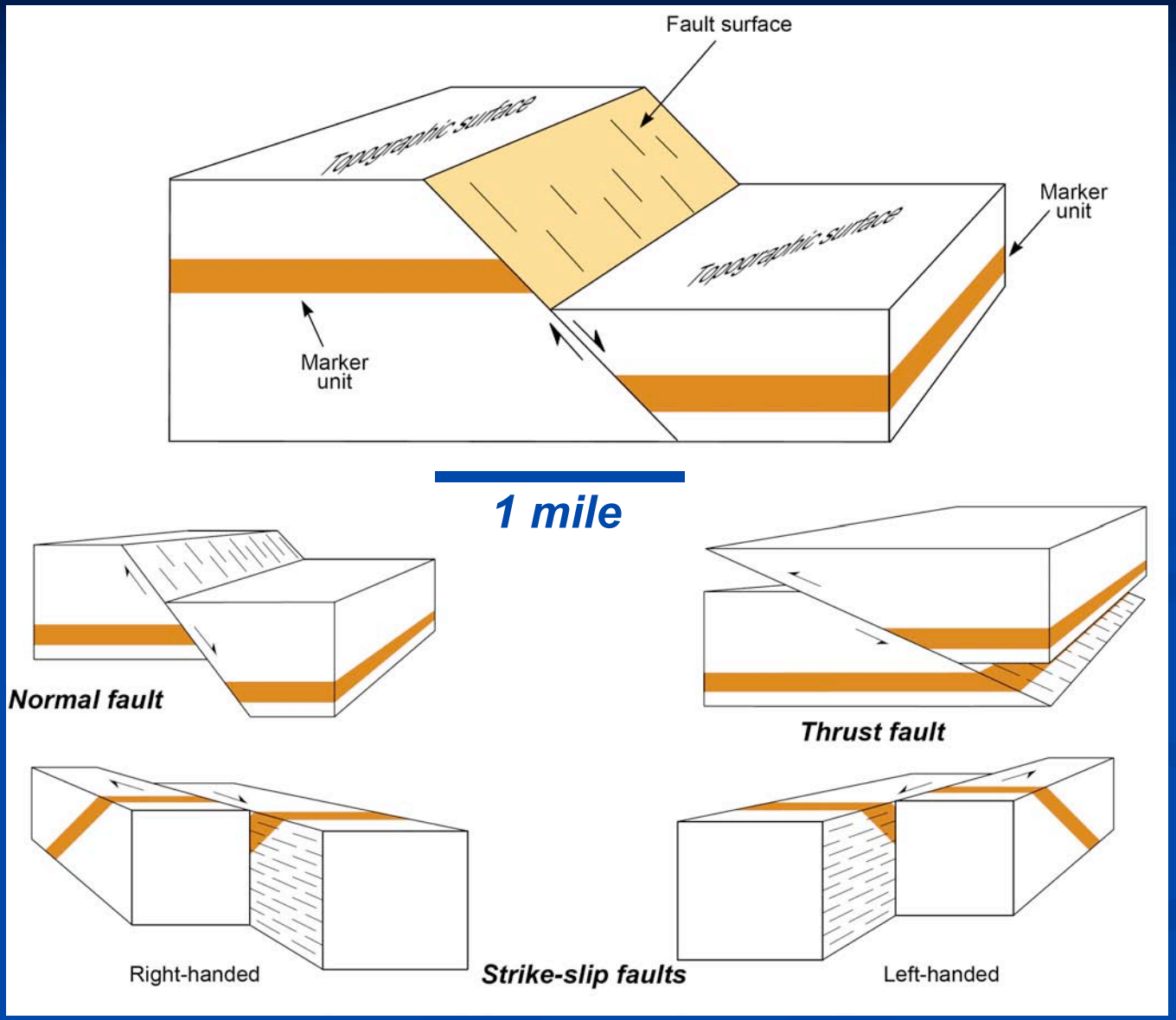
How do we locate earthquakes?

Fault Behavior that Produces Earthquakes, or does not



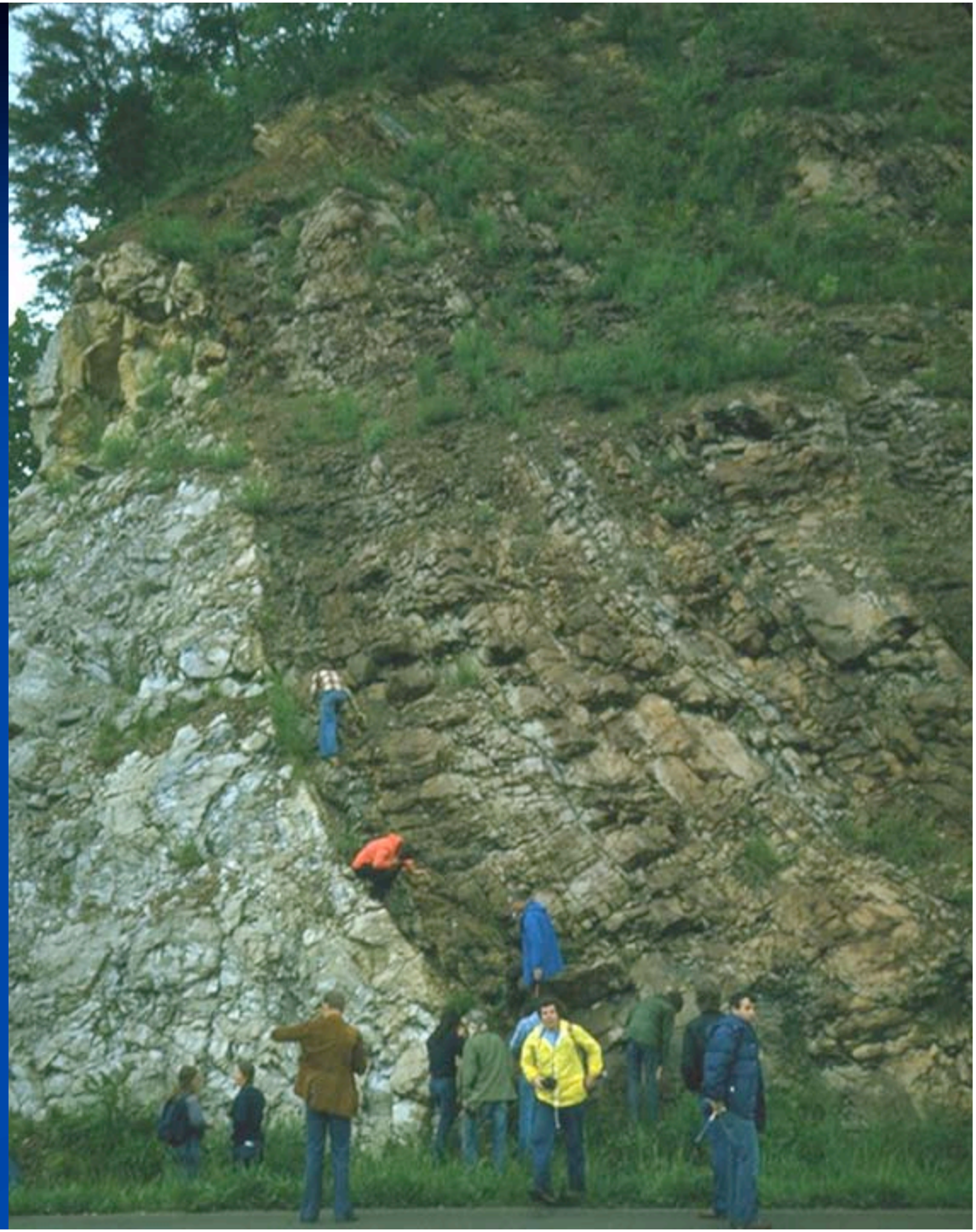
Segments of some active faults, e.g., San Andreas, release energy continuously, so these segments are not dangerous.

Idealized Fault Types



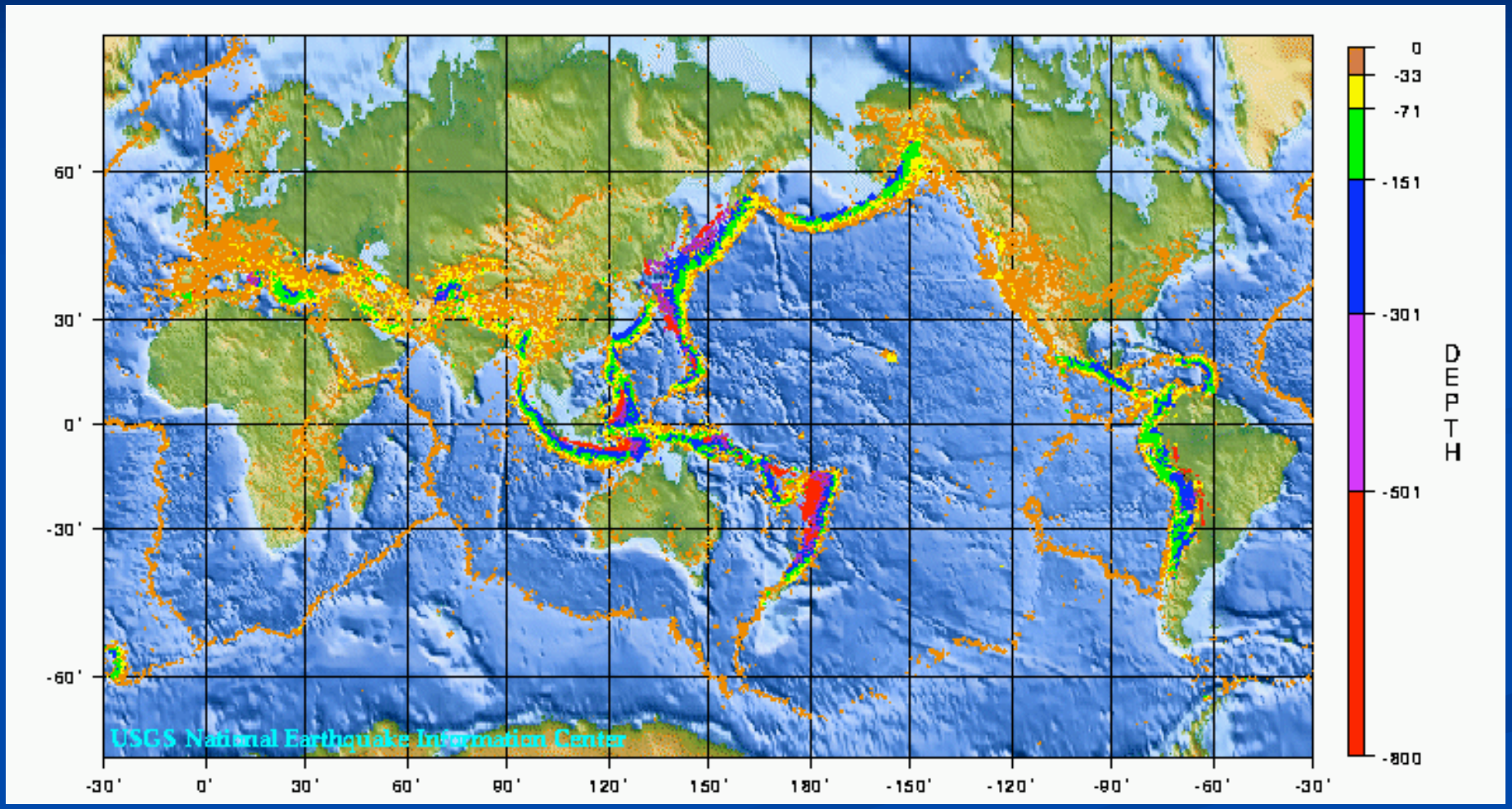
McConnell Thrust Fault in Alberta

Saltville fault on Broadway at I-640 In Knoxville

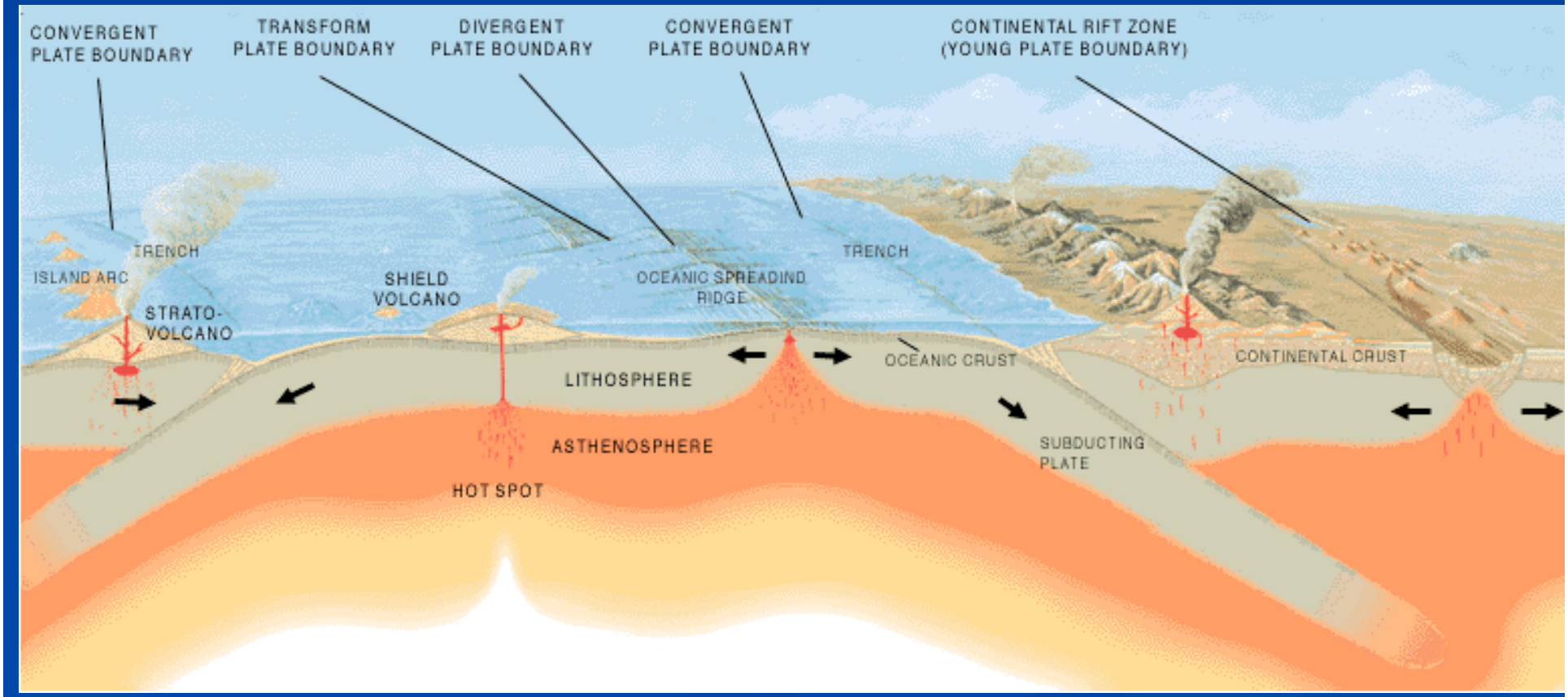


Where do most earthquakes occur?

World Earthquakes 1975–1995

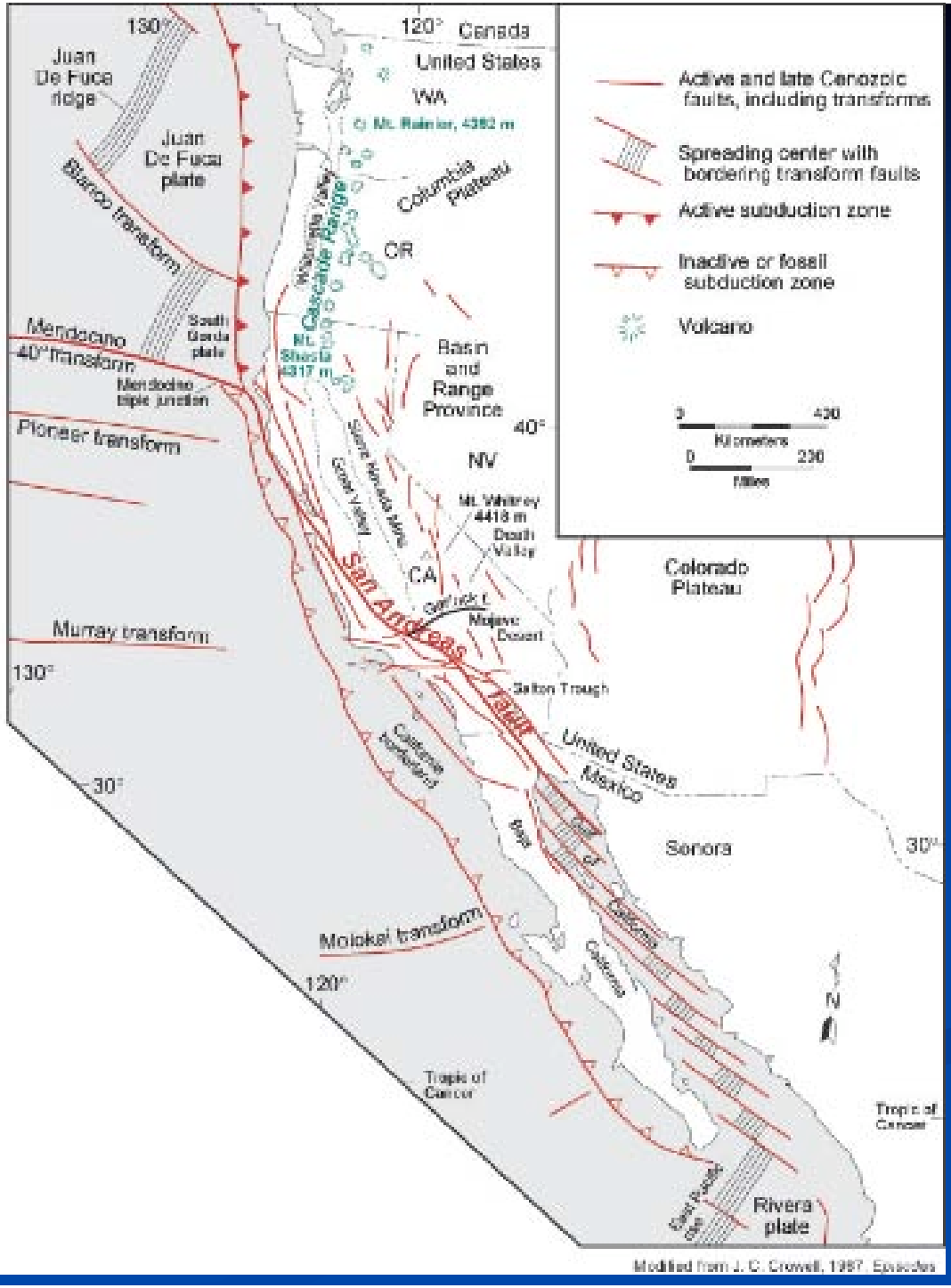


Plates and Plate Boundaries

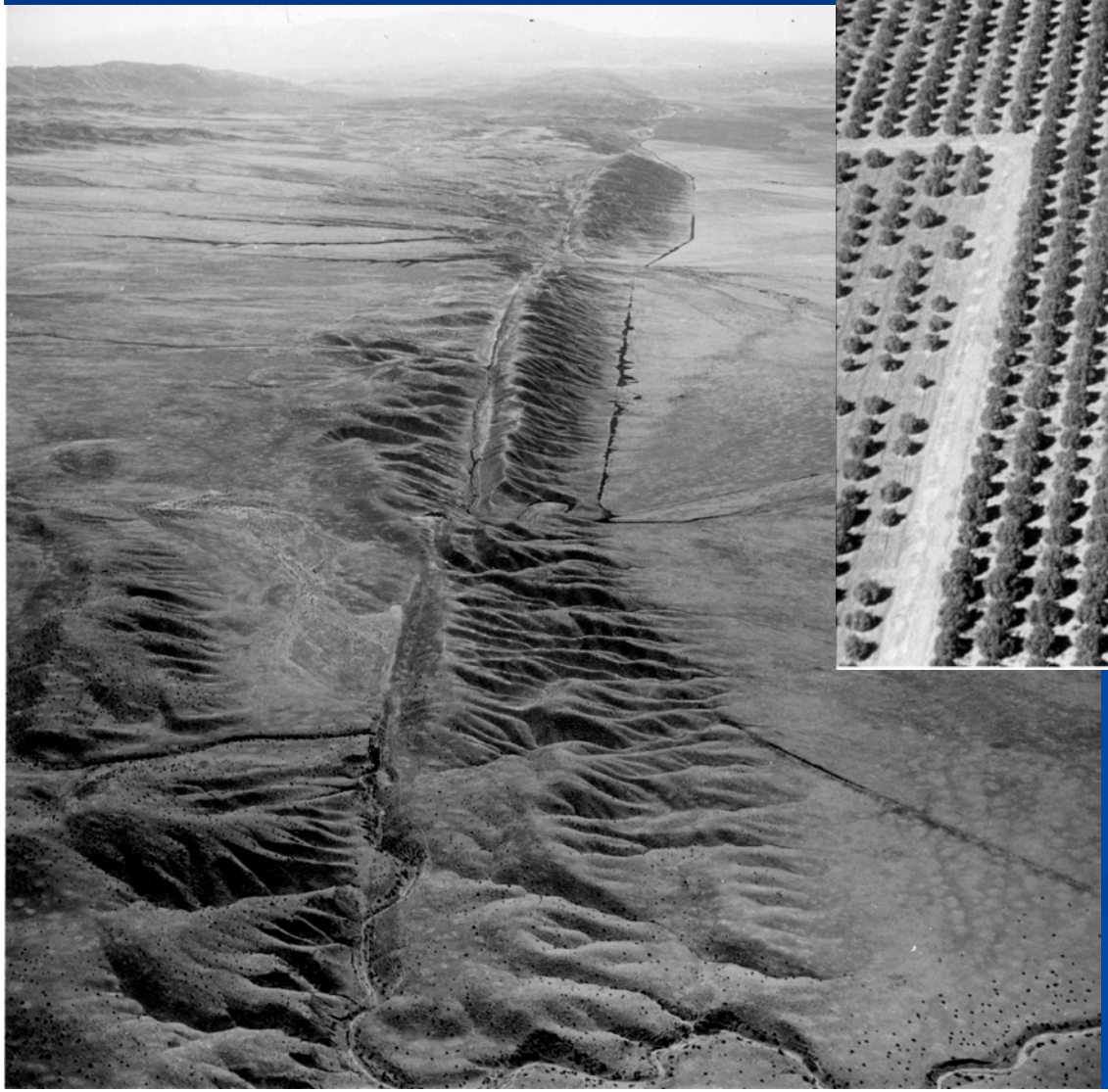


USGS

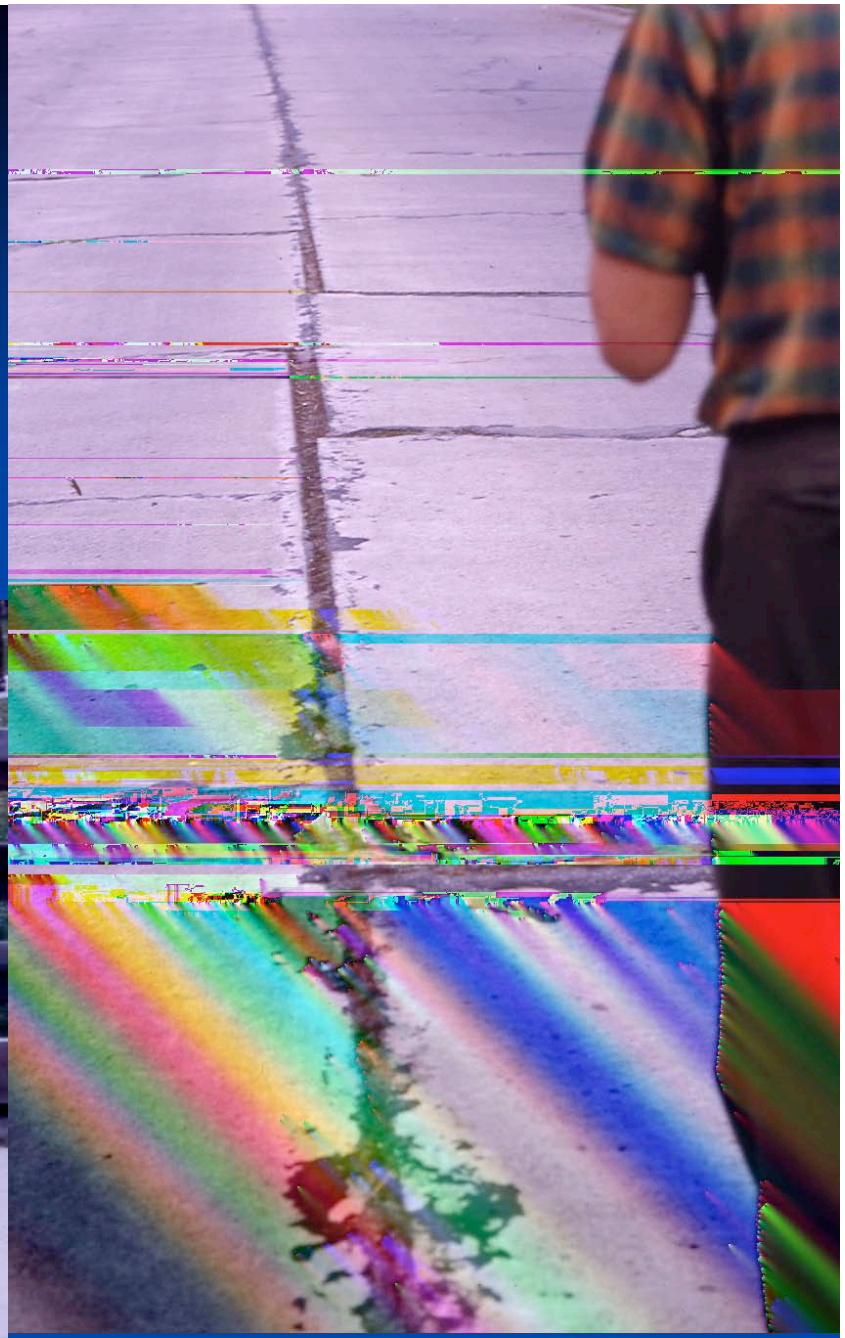
San Andreas and related faults



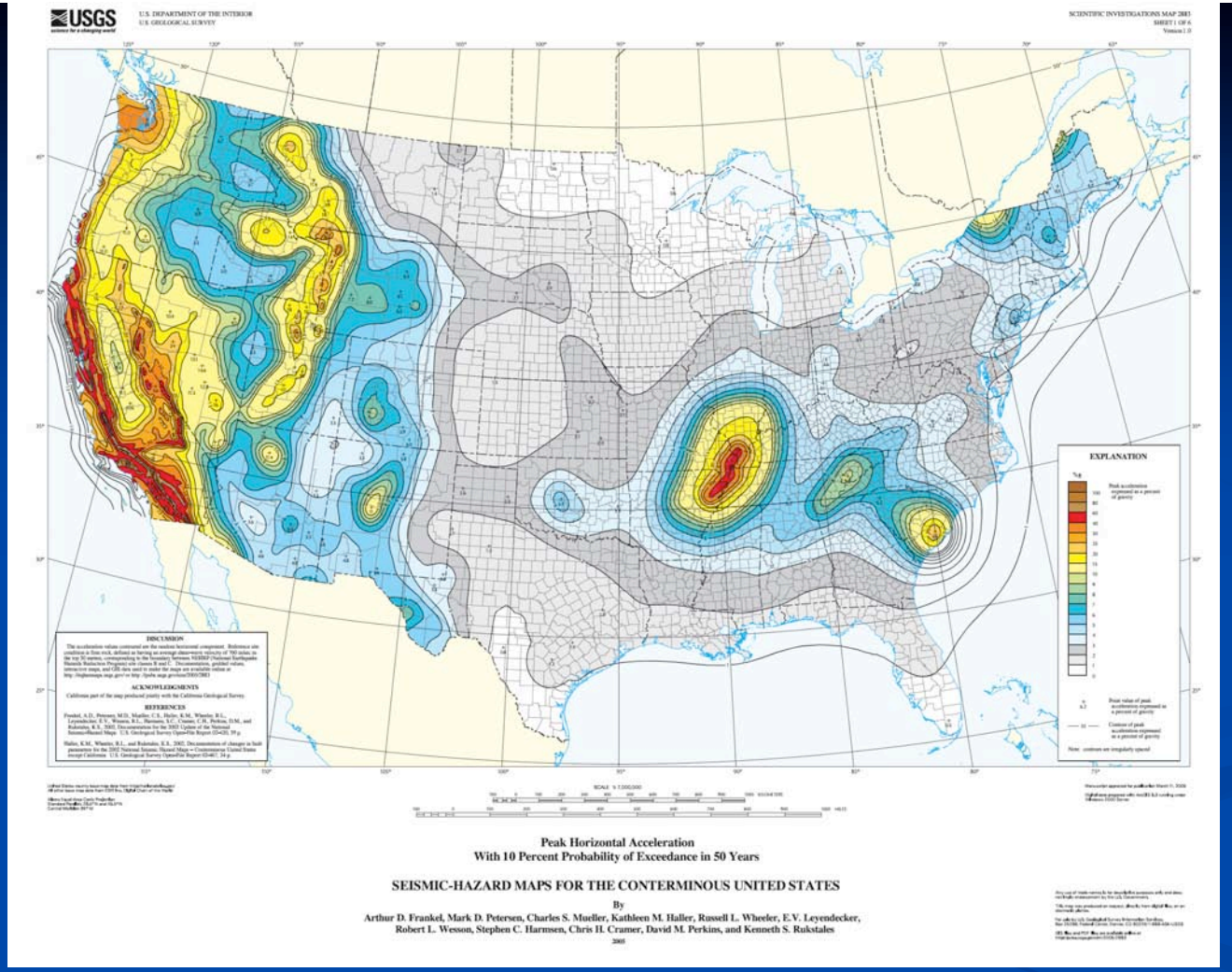
San Andreas fault



Stable Sliding:
Offset concrete road segments & sidewalk in Hollister, California



Sidewalk built 1928

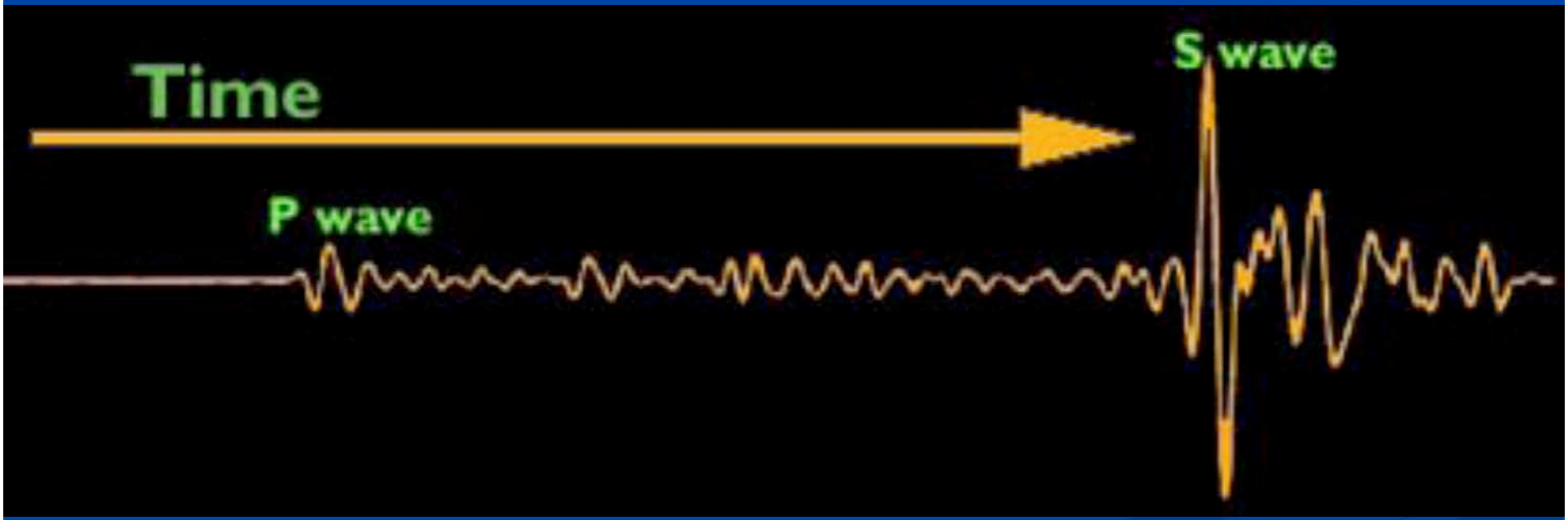


Earthquakes within continental plates are an embarrassing stepchild of modern earthquake seismology.

Seth Stein & Stephane Mazzoti, 2007
Geological Society of America Special Paper 425

Locating Earthquakes

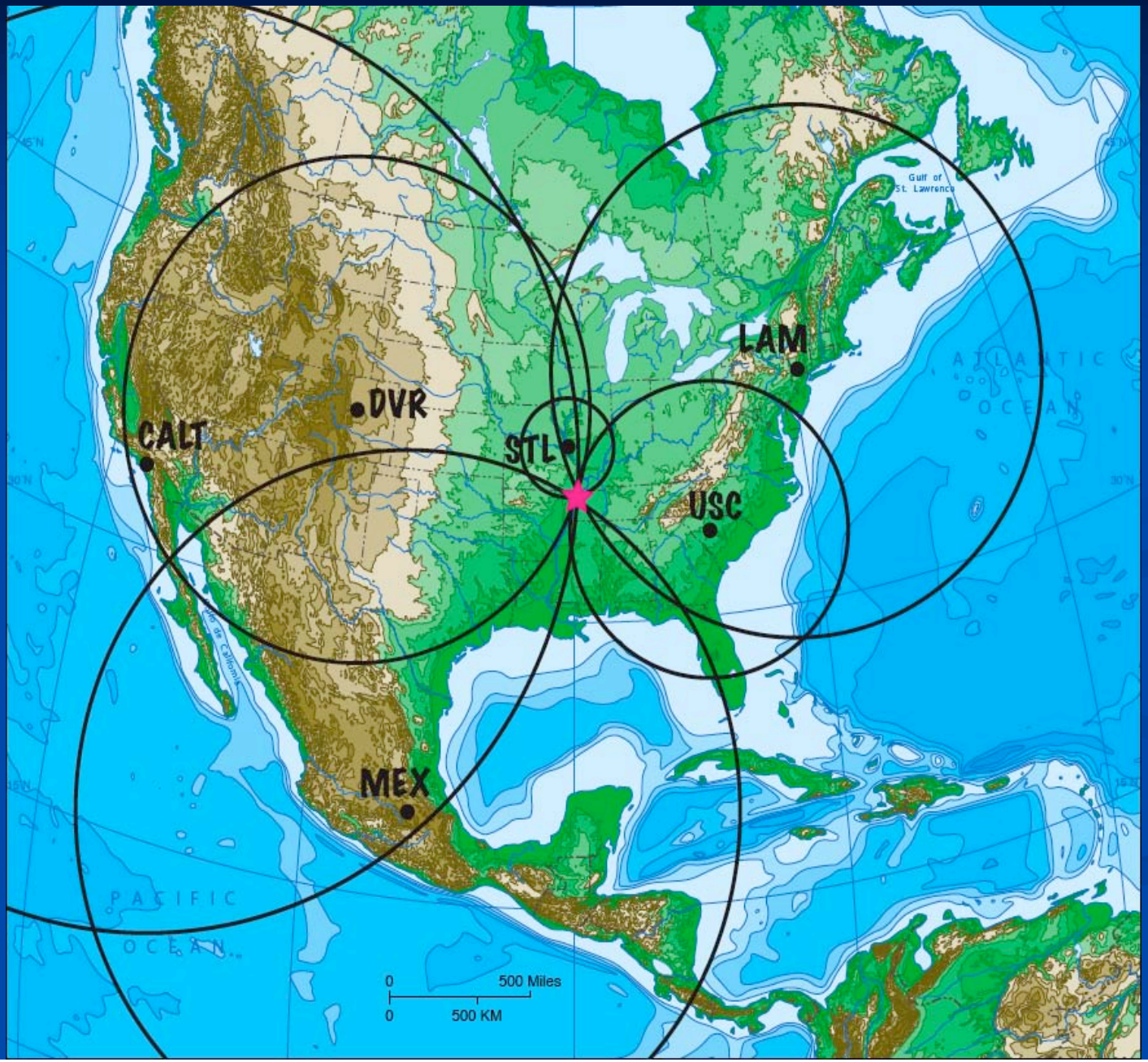
1989 M = 6.9 Loma Prieta (World Series) EQ recorded at Königsberg, Norway



Separation time of P and S waves = distance from source

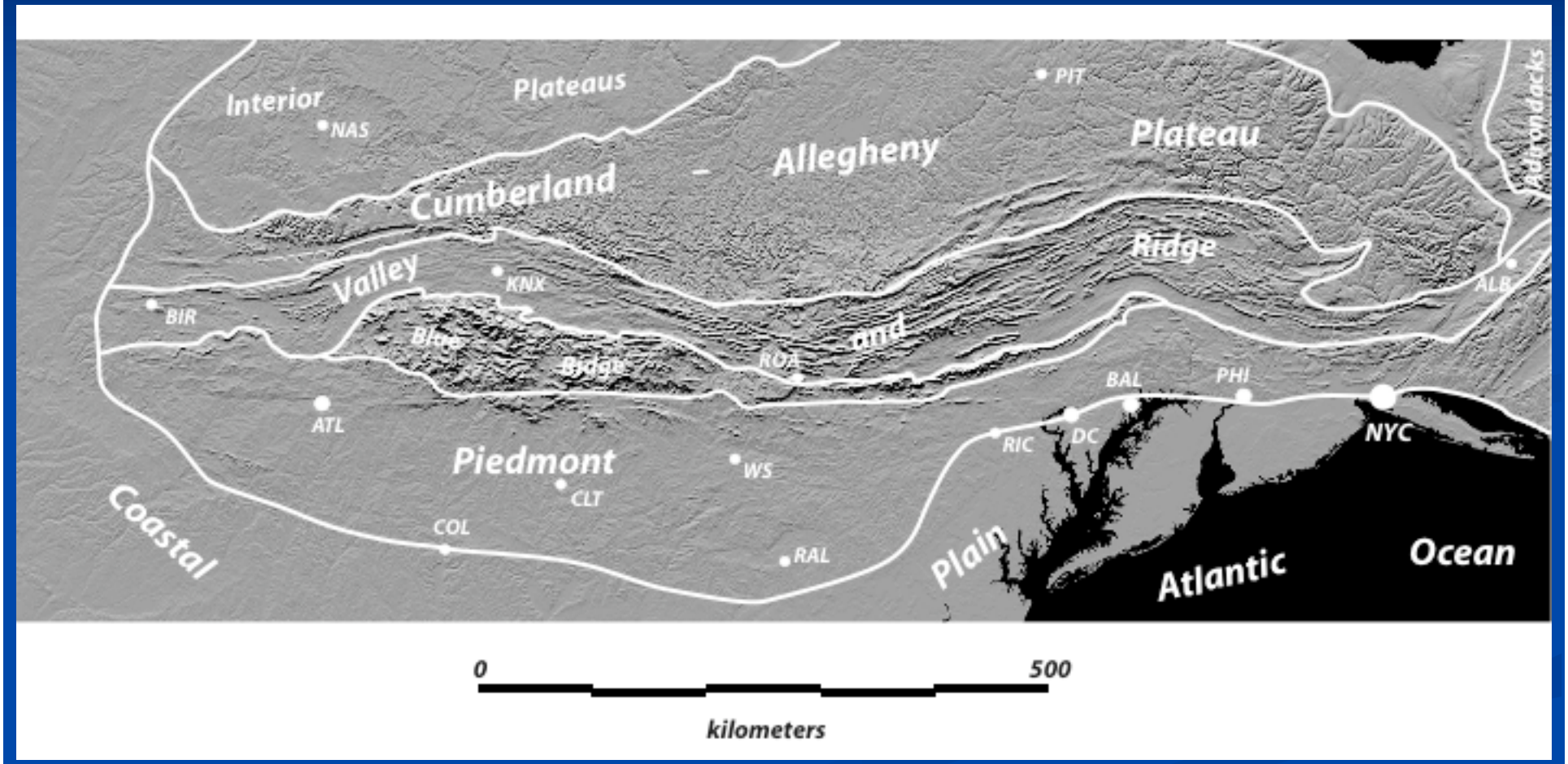
Locating Earthquakes—Need at Least 3 Seismographs

Locating Earthquakes with Multiple Seismic Stations

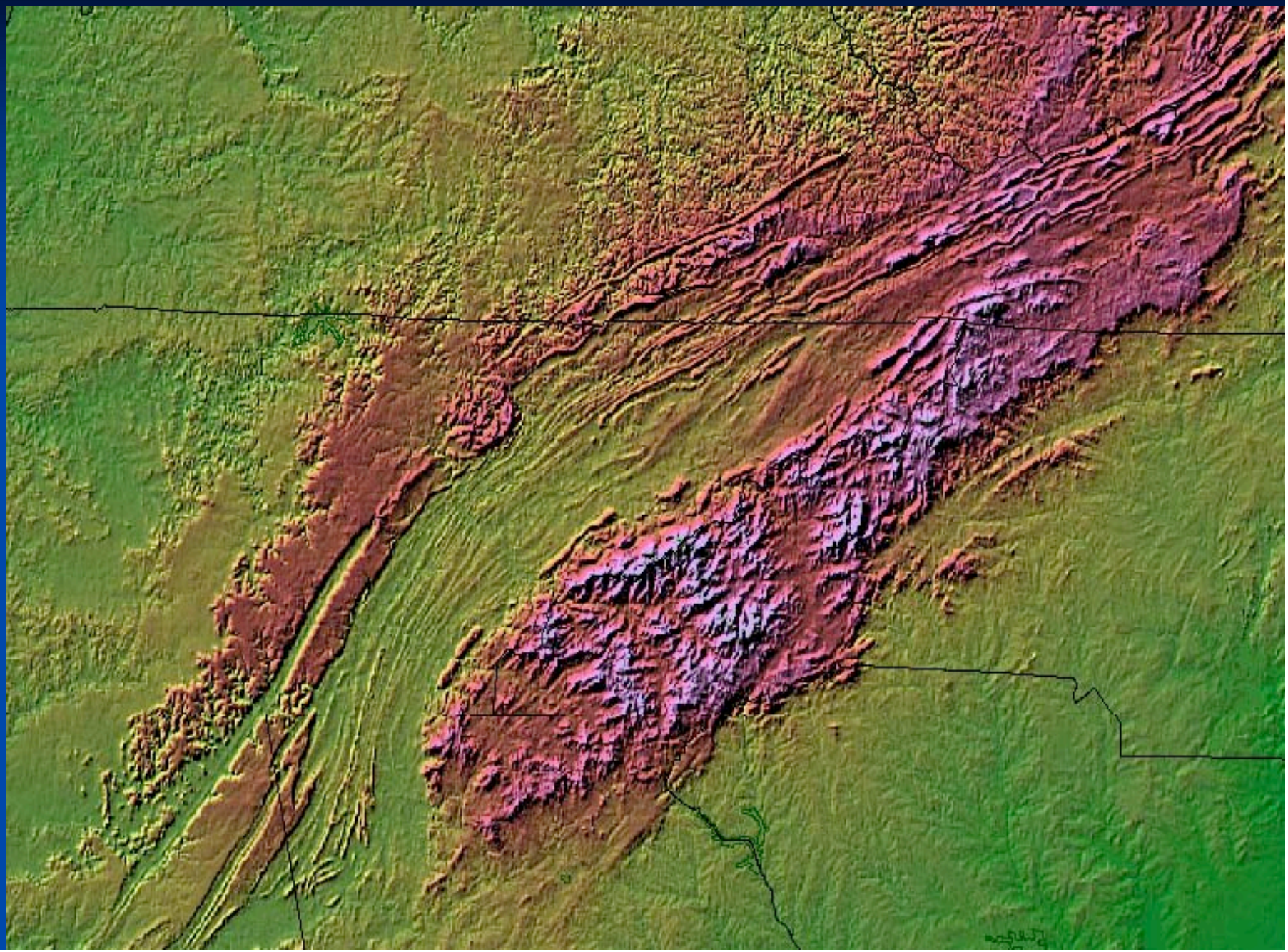


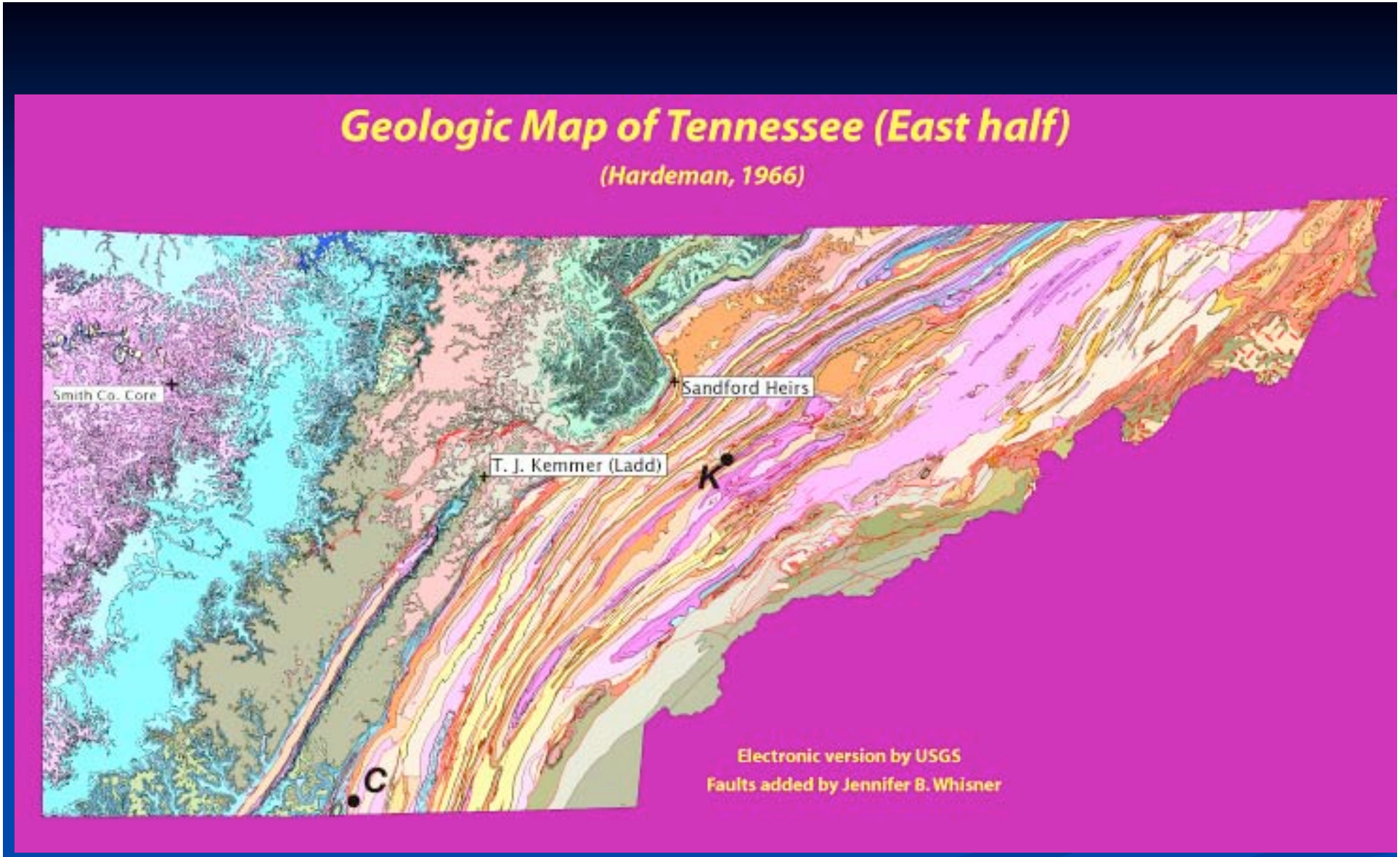
Geologic Setting of E TN

Appalachians Topography



Southern Appalachians Topography



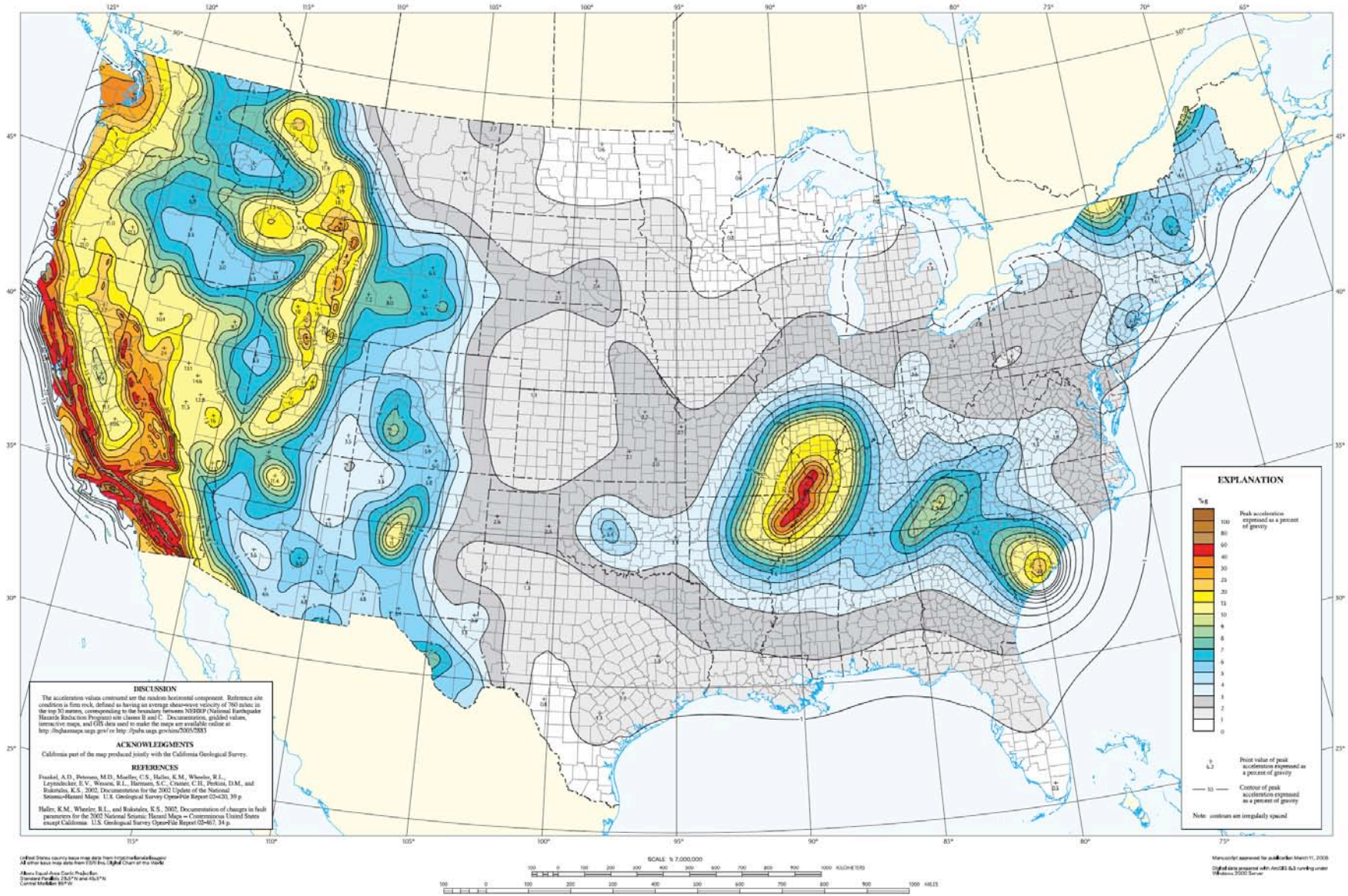


No relationship between surface geology & earthquakes that occur in the eastern U.S.

Copper Creek thrust fault, Raccoon Valley, I–75 N

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

SCIENTIFIC INVESTIGATIONS MAP 2883
SHEET 1 OF 6
Version 1.0



DISCUSSION

The acceleration values contoured are the random horizontal component. Reference site condition is firm rock, defined as having an average shear-wave velocity of 760 m/sec in the top 30 meters, corresponding to the boundary between NEHRP (National Earthquake Hazards Reduction Program) site classes B and C. Documentation, gridded values, interactive maps, and GIS data used to make the maps are available online at http://eqhazmaps.usgs.gov/ or http://pubs.usgs.gov/sim/2005/2883

ACKNOWLEDGMENTS

California part of the map produced jointly with the California Geological Survey.

REFERENCES

Frankel, A.D., Petersen, M.D., Mueller, C.S., Haller, K.M., Wheeler, R.L., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Cramer, C.H., Perkins, D.M., and Rukstales, K.S., 2002, Documentation for the 2002 Update of the National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 02-420, 39 p.

Haller, K.M., Wheeler, R.L., and Rukstales, K.S., 2002, Documentation of changes in fault parameters for the 2002 National Seismic Hazard Maps — Conterminous United States except California: U.S. Geological Survey Open-File Report 02-467, 34 p.

United States county base map data from http://edcwww.cr.usgs.gov/
All other base map data from ESRI Inc. Digital Chart of the World

Albers Equal-Area Conic Projection
Standard Parallels 29.5° N and 45.5° N
Central Meridian 96° W

SCALE 1:7,000,000

Manuscript approved for publication March 11, 2008

Digital data prepared with ArcGIS 8.3 running under Windows 2000 Server

Peak Horizontal Acceleration
With 10 Percent Probability of Exceedance in 50 Years

SEISMIC-HAZARD MAPS FOR THE CONTERMINOUS UNITED STATES

By

Arthur D. Frankel, Mark D. Petersen, Charles S. Mueller, Kathleen M. Haller, Russell L. Wheeler, E.V. Leyendecker, Robert L. Wesson, Stephen C. Harmsen, Chris H. Cramer, David M. Perkins, and Kenneth S. Rukstales

2005

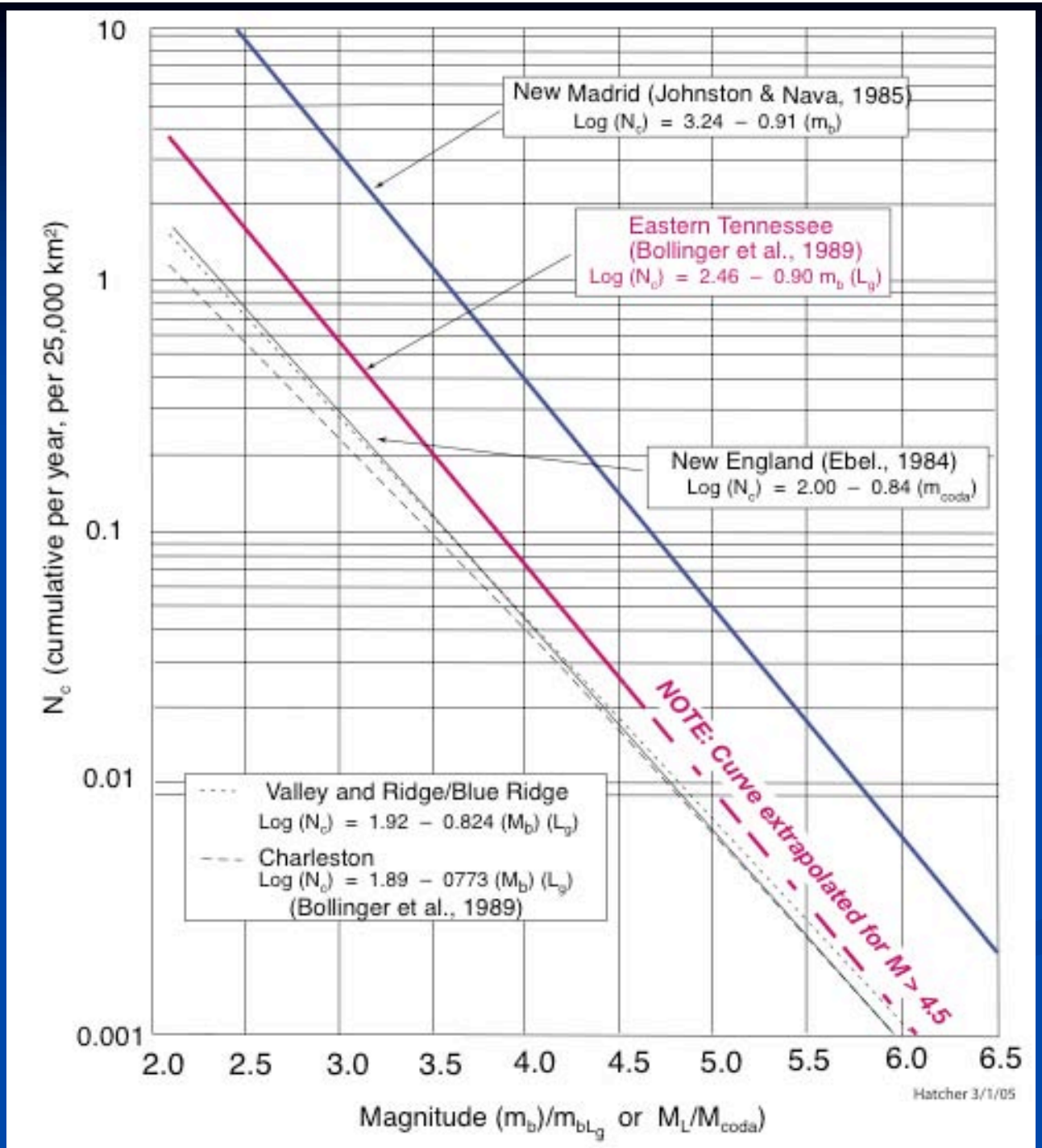
Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

This map was produced on request, directly from digital files, on an electronic plotter.

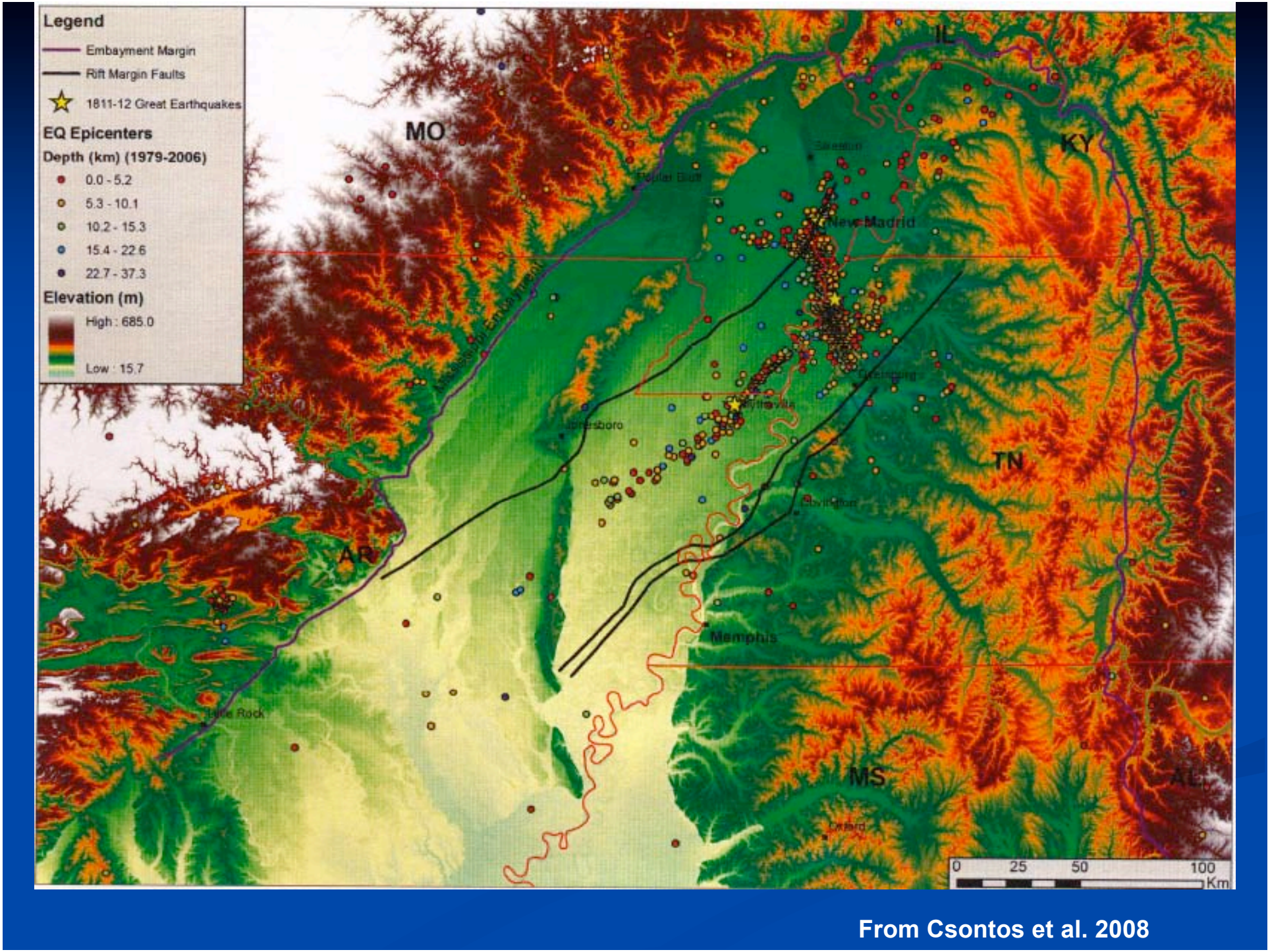
For sale by U.S. Geological Survey Information Services, Box 25286, Federal Center, Denver, CO 80225 1-888-ASK-USGS

GIS files and PDF files are available online at http://pubs.usgs.gov/sim/2005/2883

Eastern US Earthquake Frequency & Magnitude



Originally plotted by Martin Chapman, VA Tech; courtesy of Jeff Munsey, TVA.



From Csontos et al. 2008

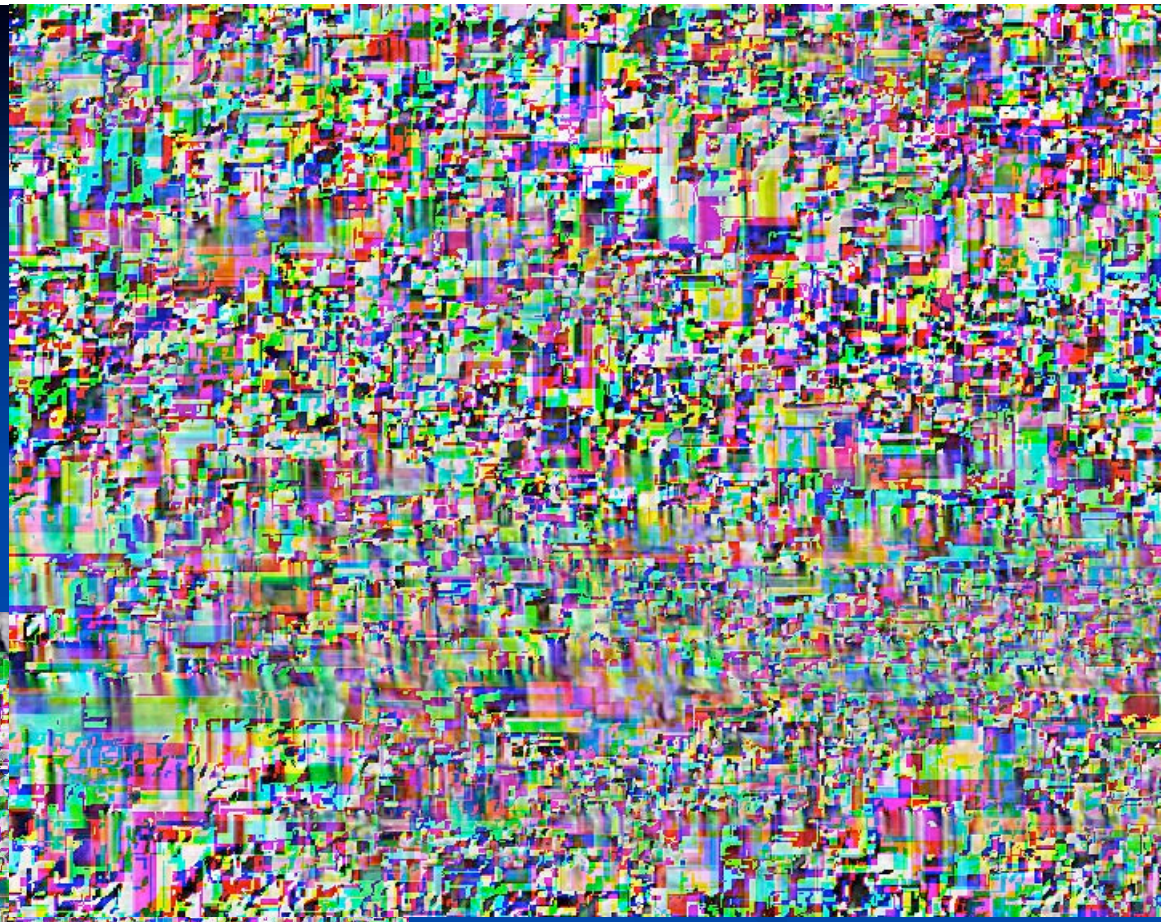
Earthquake-Generated Liquefaction

Eastern AR

New Madrid, MO

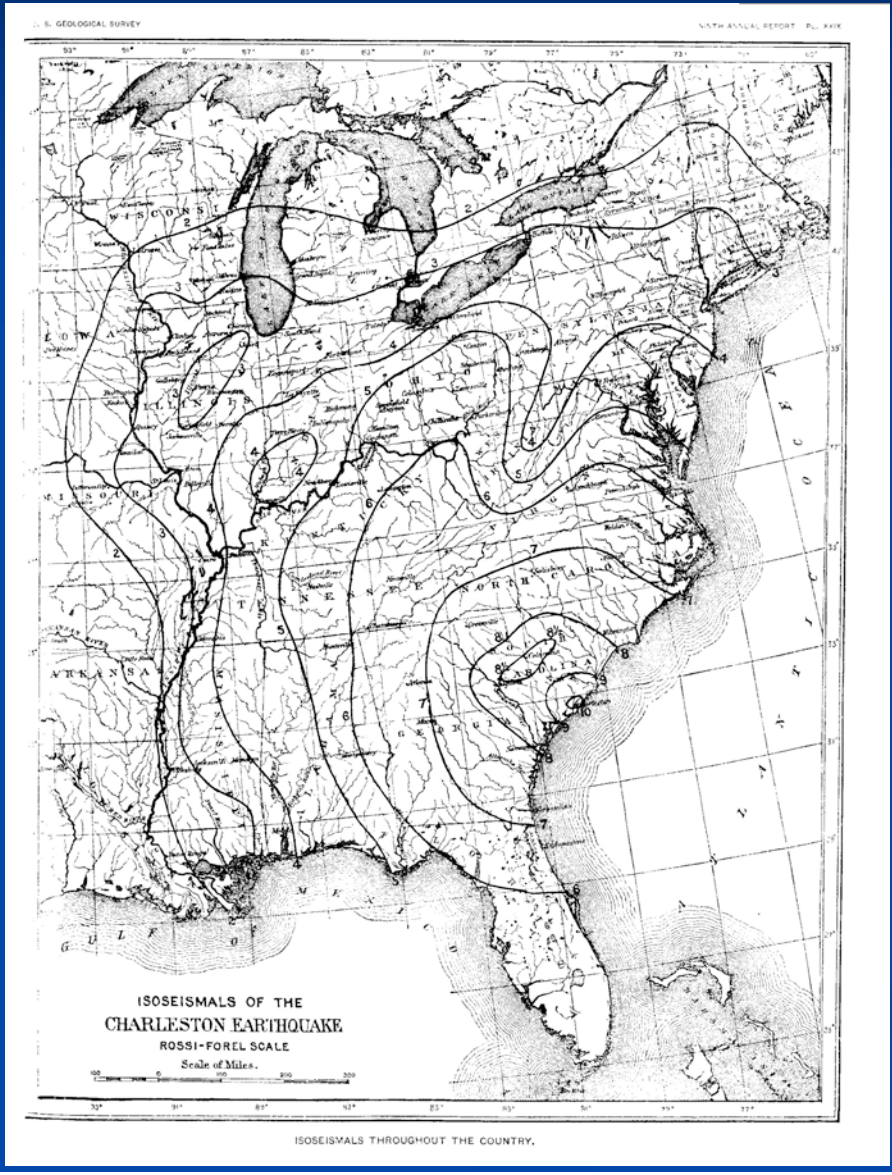
From Stewart & Knox, 1995

2011 VA EQ Mud Volcanoes



Photos courtesy of Jeff Munsey, TVA

ISOSEISMALS of 1886 Charleston, SC, Earthquake



Estimated M = 7.0

Dutton (1890)
Courtesy of P. Talwani
Univ. SC

At Charleston

Bent RR Tracks in 1886

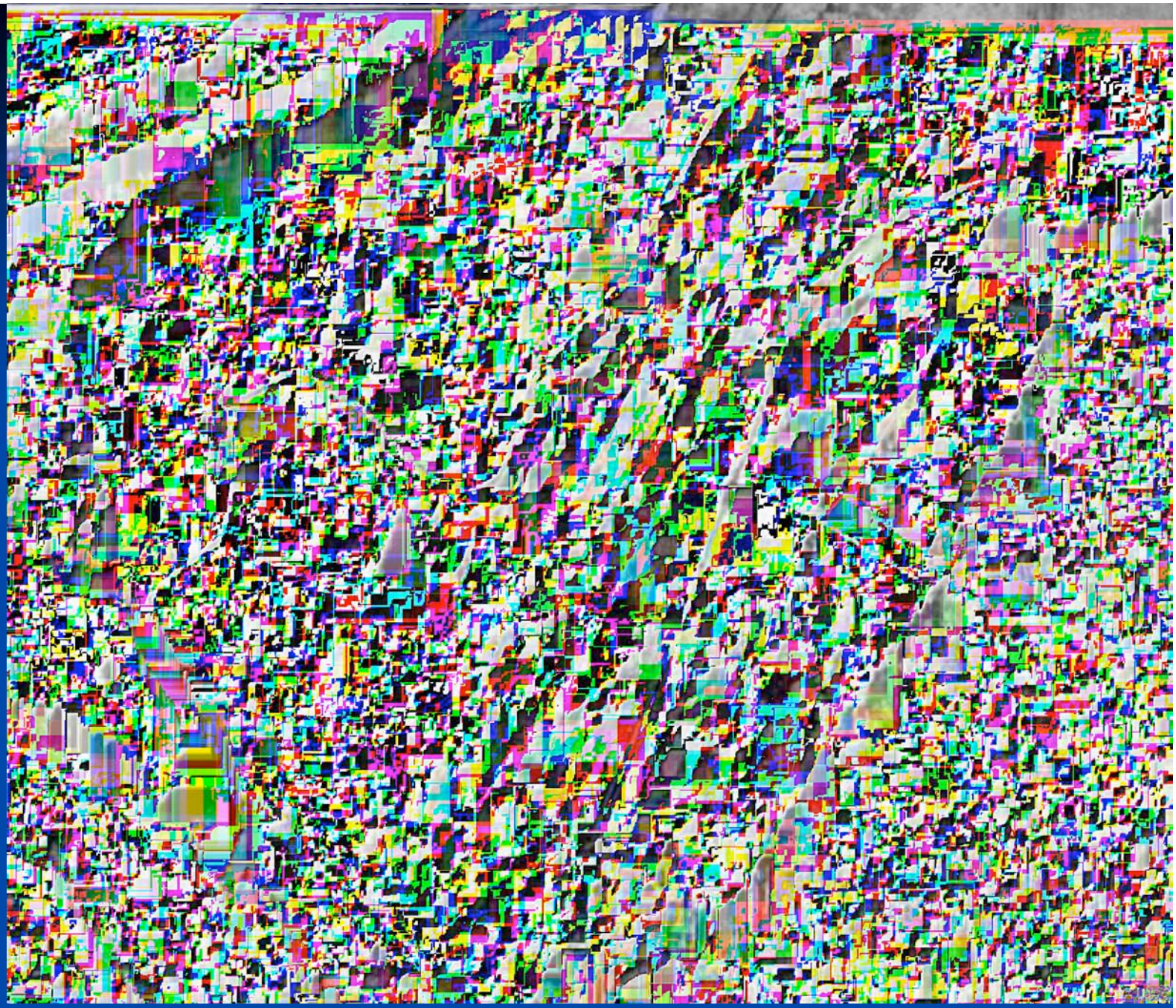
Earthquake-Generated Liquefaction

Eastern AR

Ancient Sandblow (~7 ka), Wabash Valley, southern Indiana

From Obermeier, 1986

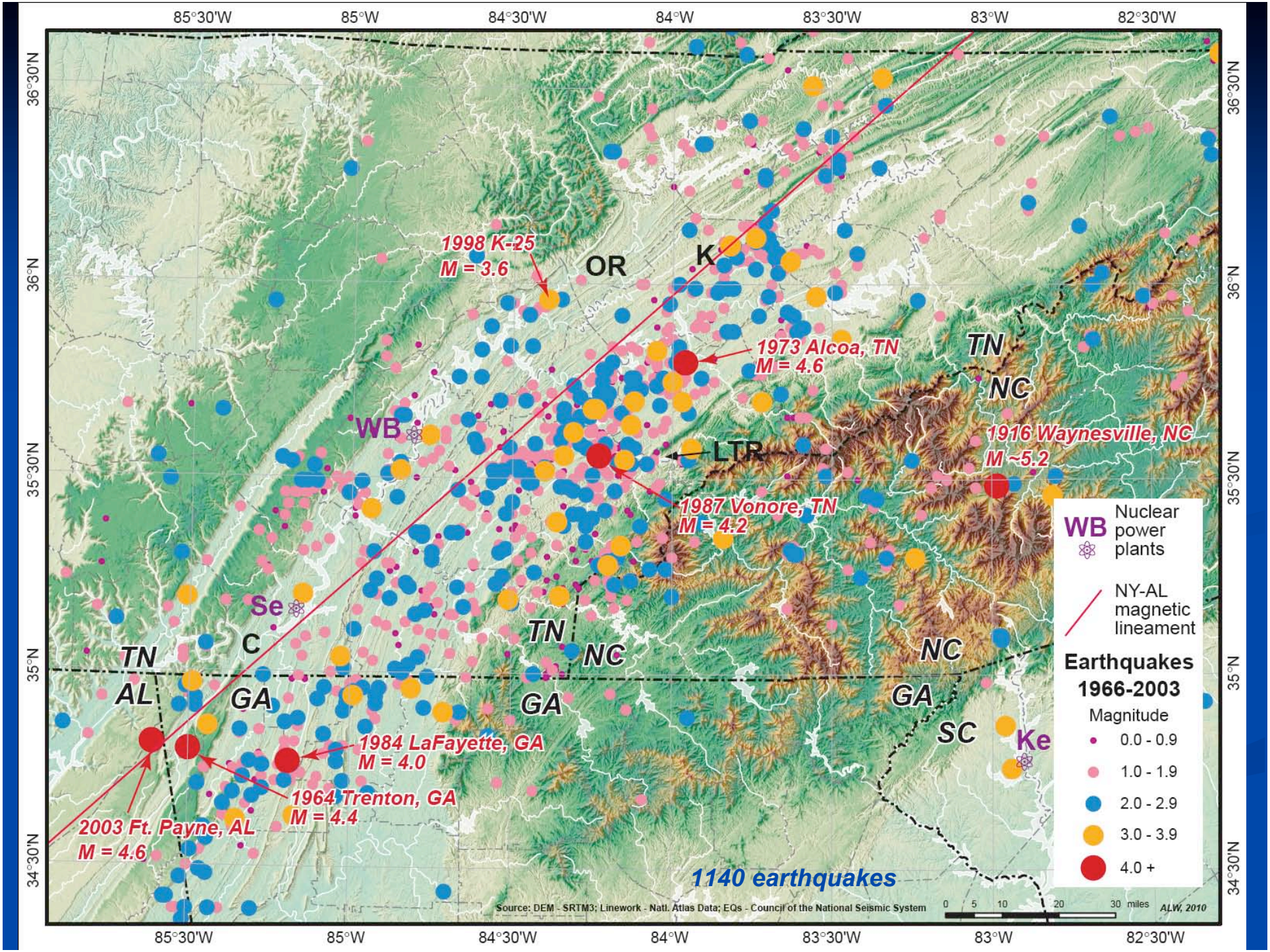
Possible ETSZ Liquefaction Features



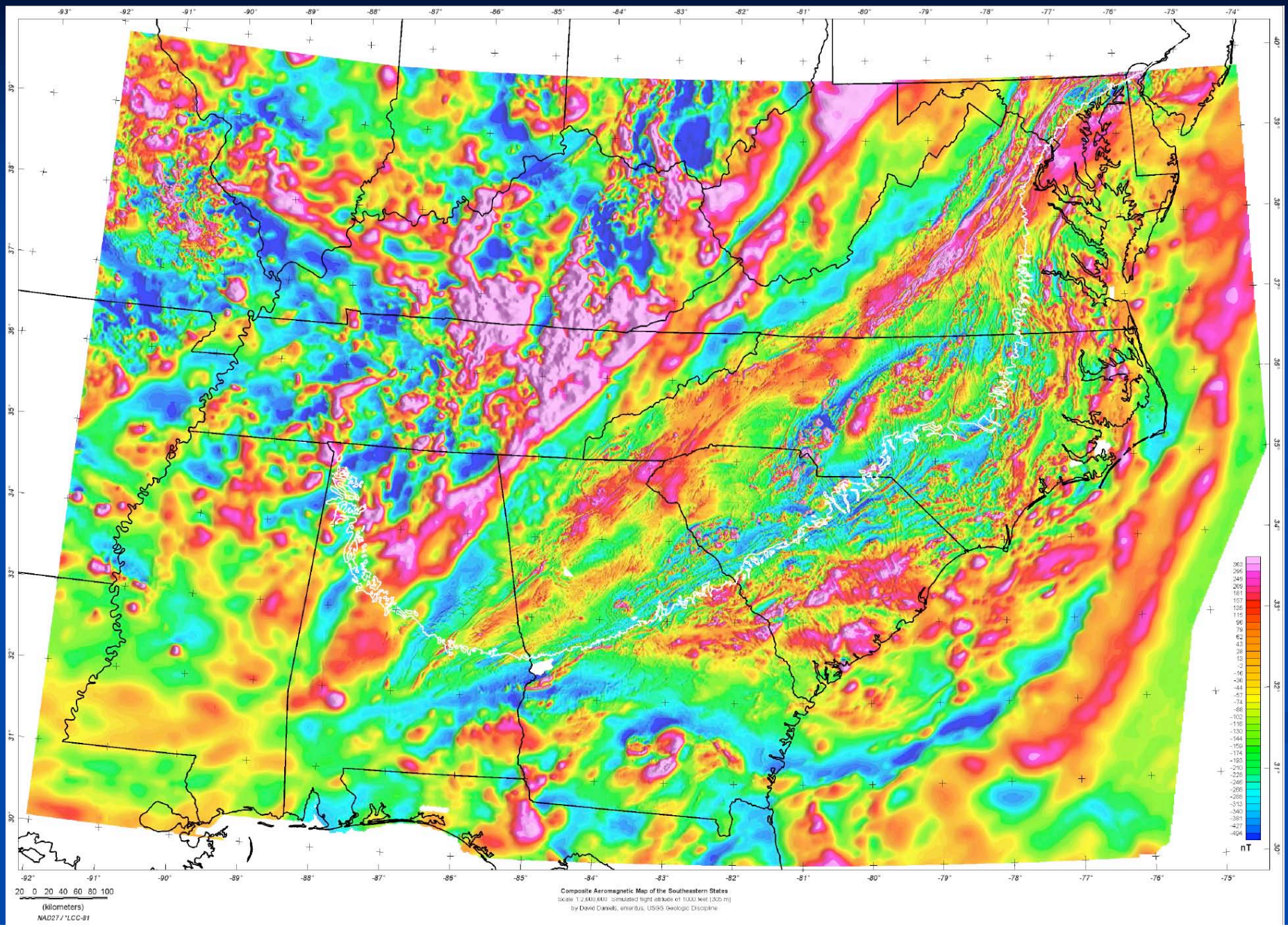
Near Lyerly, S of Summerville, GA

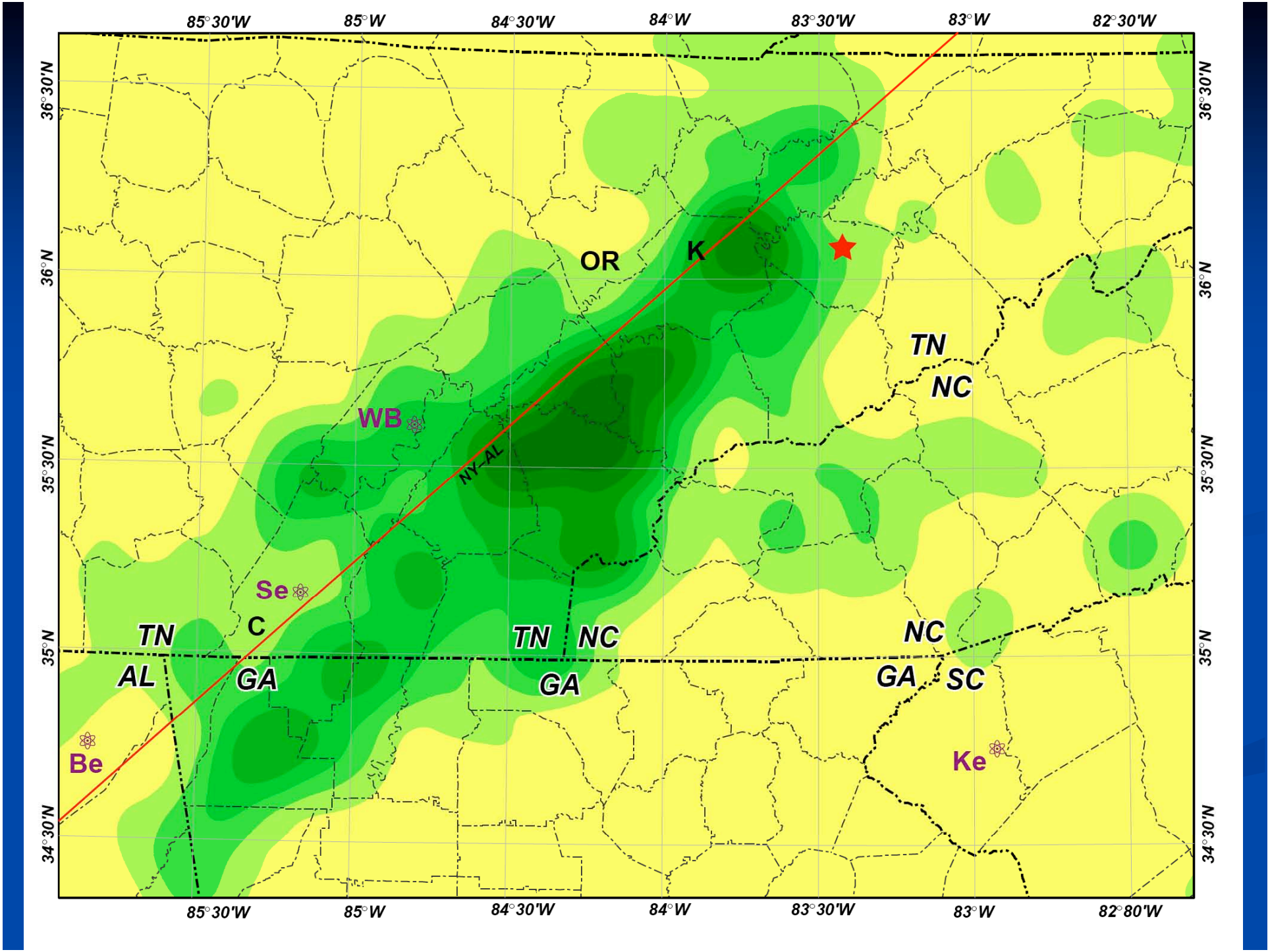
Possible ETSZ Liquefaction Features

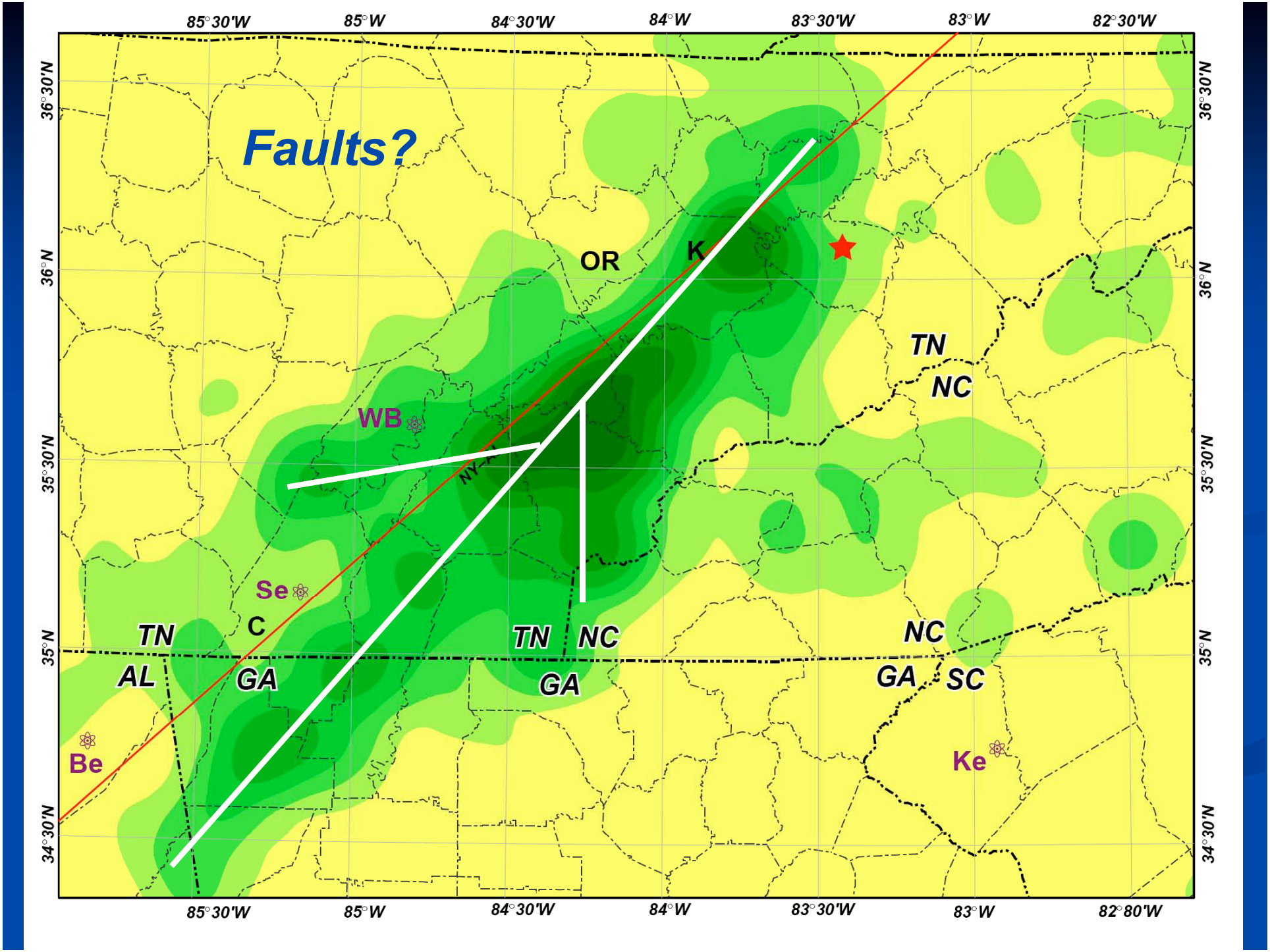
Taylor Farm, near Lyerly, S of Summerville, GA

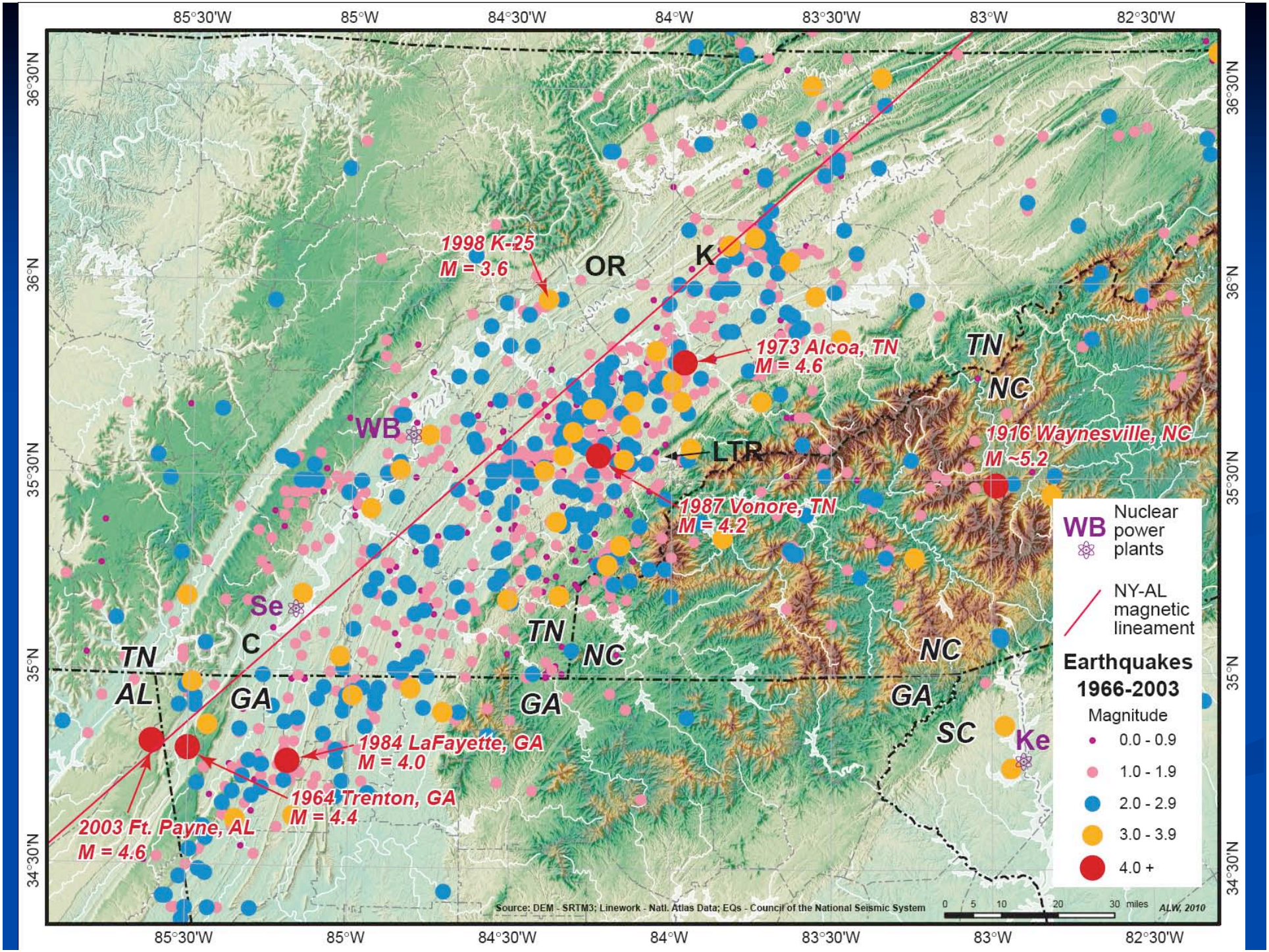

85°30'W
85°W
84°30'W
84°W
83°30'W
83°W
82°30'W
36°30'N
36°N
35°30'N
35°N
34°30'N
1998 K-25
M = 3.6
OR
K
1973 Alcoa, TN
M = 4.6
TN
NC
WB
LTR
1916 Waynesville, NC
M ~5.2
1987 Vonore, TN
M = 4.2
Se
C
TN
AL
GA
TN
NC
GA
NC
GA
SC
Ke
1984 LaFayette, GA
M = 4.0
1964 Trenton, GA
M = 4.4
2003 Ft. Payne, AL
M = 4.6
1140 earthquakes
WB Nuclear power plants
NY-AL magnetic lineament
Earthquakes 1966-2003
Magnitude
0.0 - 0.9
1.0 - 1.9
2.0 - 2.9
3.0 - 3.9
4.0 +
Source: DEM - SRTM3; Linework - Natl. Atlas Data; EQs - Council of the National Seismic System
0 5 10 20 30 miles
ALW, 2010

USGS Aeromagnetic Data




85°30'W
85°W
84°30'W
84°W
83°30'W
83°W
82°30'W
82°80'W
36°30'N
36°N
35°30'N
35°N
34°30'N
OR
K
TN
NC
WB
NY–AL
Se
C
TN
AL
GA
TN
NC
GA
NC
GA
SC
Be
Ke


Faults?
85°30'W
85°W
84°30'W
84°W
83°30'W
83°W
82°30'W
82°80'W
36°30'N
36°N
35°30'N
35°N
34°30'N
OR
K
TN
NC
WB
NY
Se
C
TN
AL
GA
TN
NC
GA
NC
GA
SC
Be
Ke


85°30'W
85°W
84°30'W
84°W
83°30'W
83°W
82°30'W
36°30'N
36°N
35°30'N
35°N
34°30'N
1998 K-25
M = 3.6
OR
K
1973 Alcoa, TN
M = 4.6
TN
NC
WB
LTR
1916 Waynesville, NC
M ~5.2
1987 Vonore, TN
M = 4.2
Se
C
TN
AL
GA
TN
NC
GA
NC
GA
SC
Ke
1984 LaFayette, GA
M = 4.0
1964 Trenton, GA
M = 4.4
2003 Ft. Payne, AL
M = 4.6
WB Nuclear power plants
NY-AL magnetic lineament
Earthquakes 1966-2003
Magnitude
0.0 - 0.9
1.0 - 1.9
2.0 - 2.9
3.0 - 3.9
4.0 +
Source: DEM - SRTM3; Linework - Natl. Atlas Data; EQs - Council of the National Seismic System
0 5 10 20 30 miles
ALW, 2010

Some Facts

None of our surface faults in E TN are active, but we have earthquakes, so there must be active faults here.

We do not live on a plate boundary, but we have earthquakes in both W and E TN. Why?

Powell et al. (1996, Science) suggested that the ETSZ is ephemeral and will cease activity in ~100-200 years. S. Stein has published a similar statement in Nature about the NMSZ based on GPS data.

Facts about E TN Earthquakes

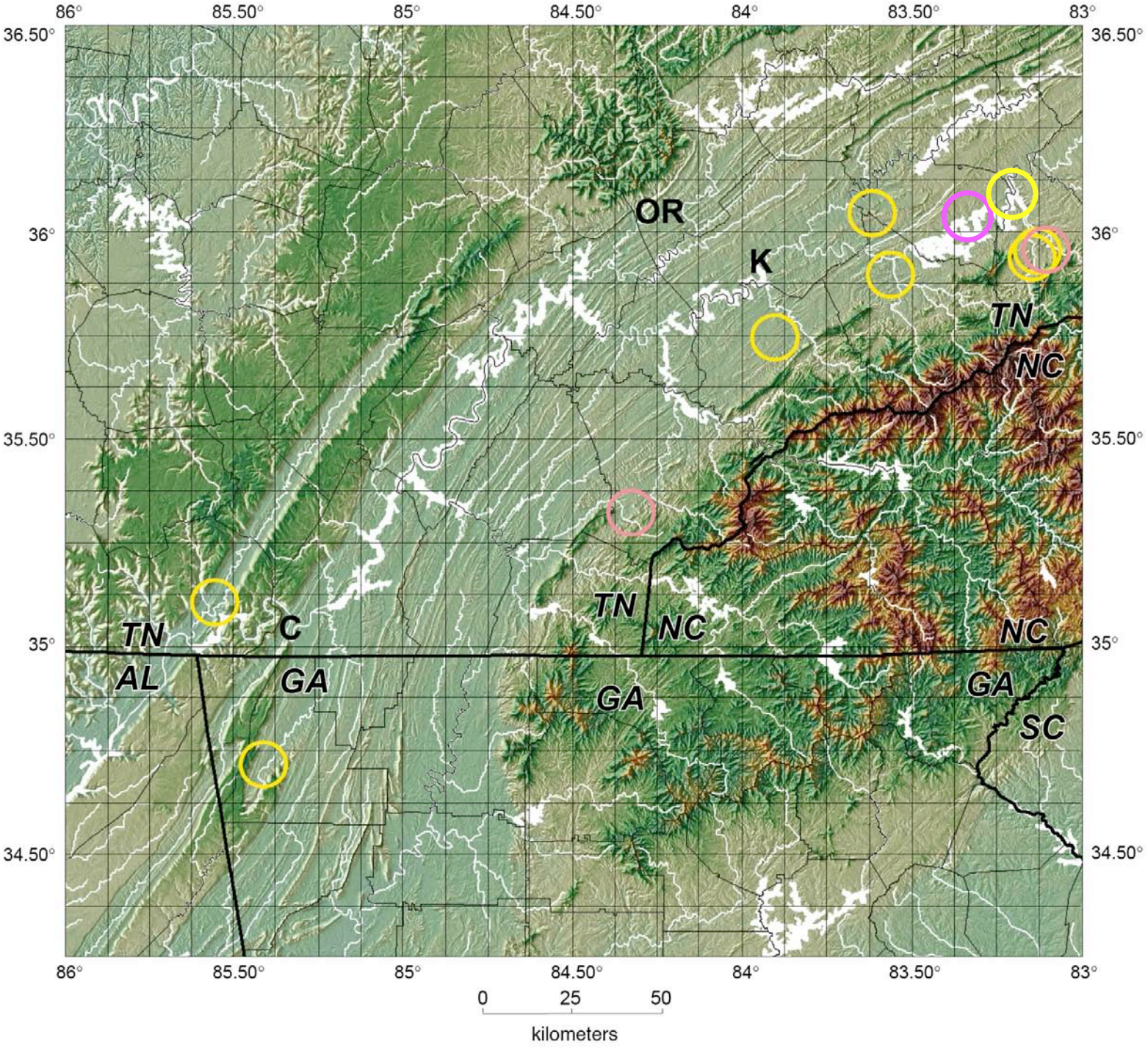
- *High frequency: 2nd in eastern U.S.*
- *No historic > M = 4.6 earthquake.*
- *No surface faulting, except those produced by collateral damage.*
- *Focal depths 8 to 25 km; most ~15.*
- *Not enough known yet to delimit recurrence interval of large earthquakes.*

ETSZ

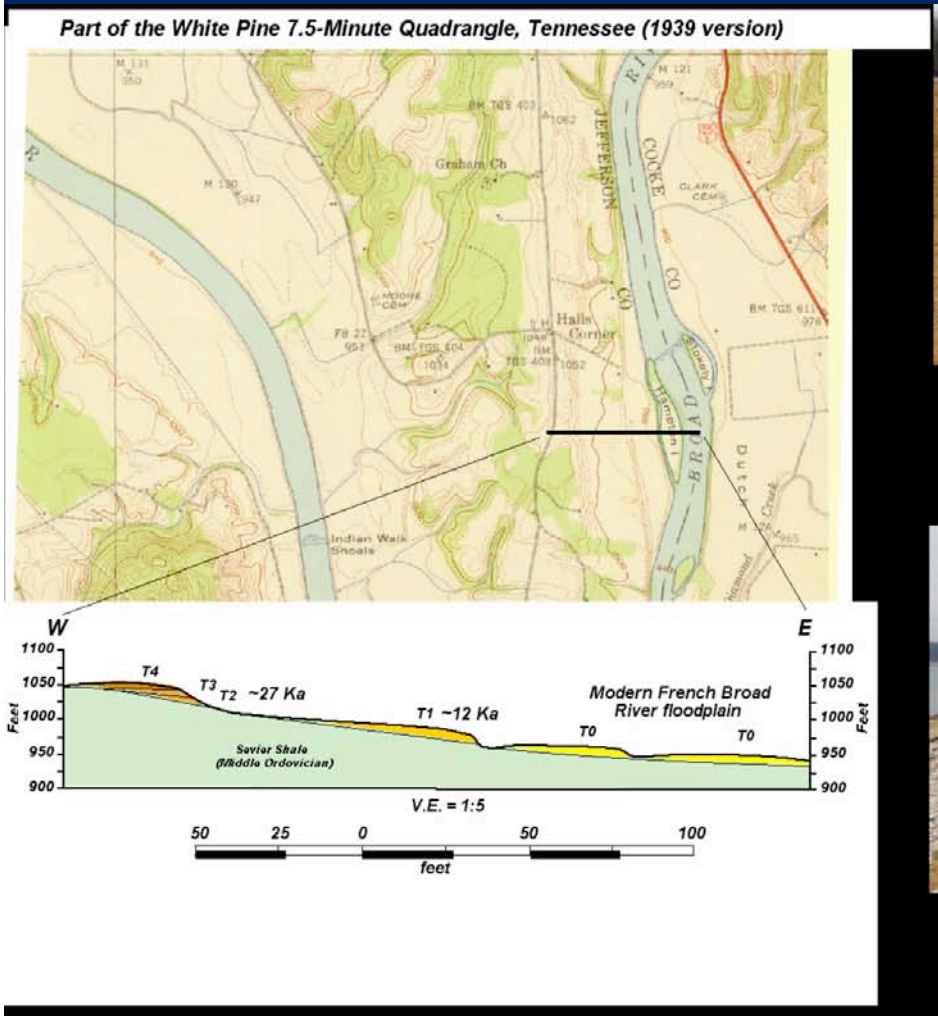
Locations of some examples

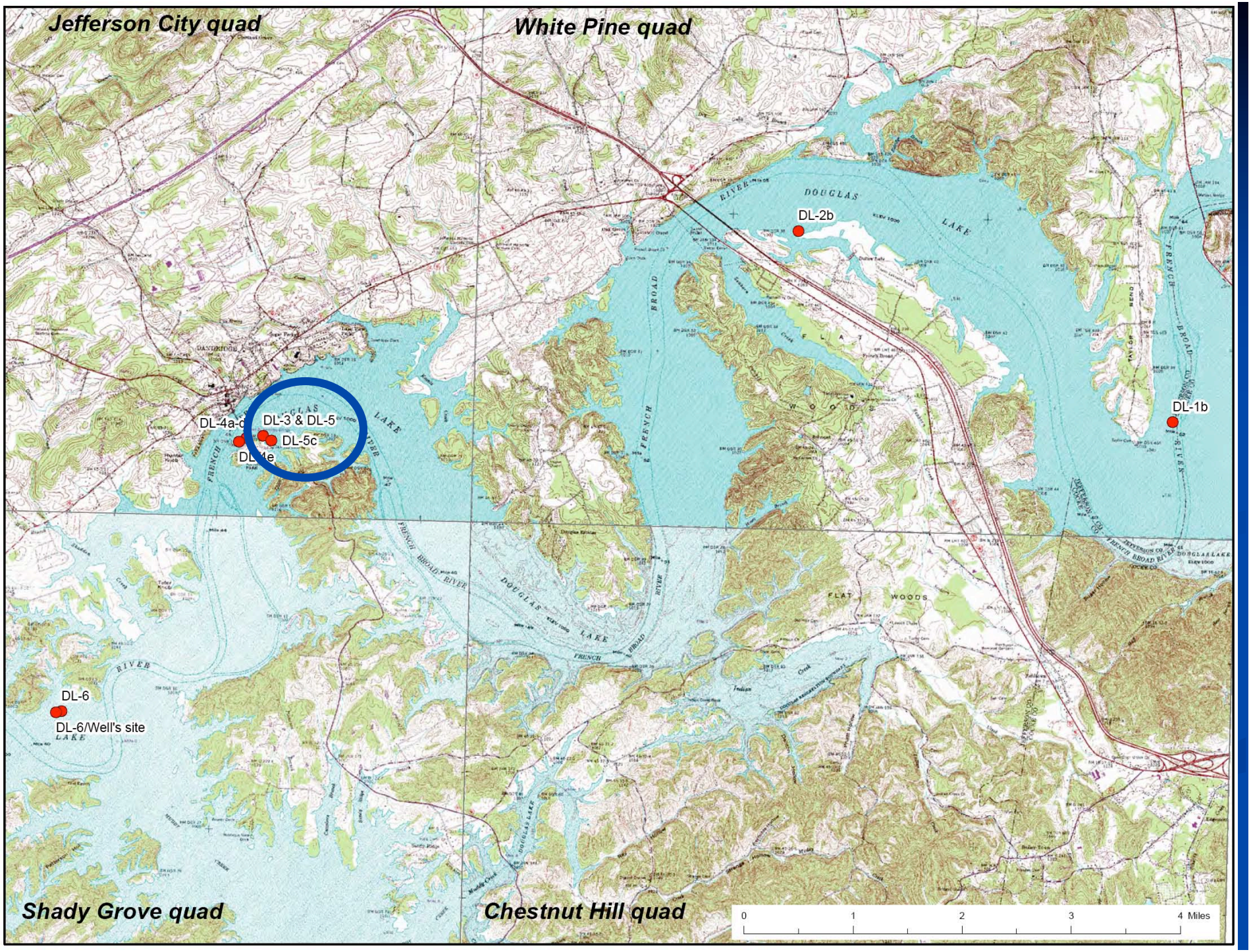
Possible Liquefaction (2008-10)

Possible Deformation (2008-10)



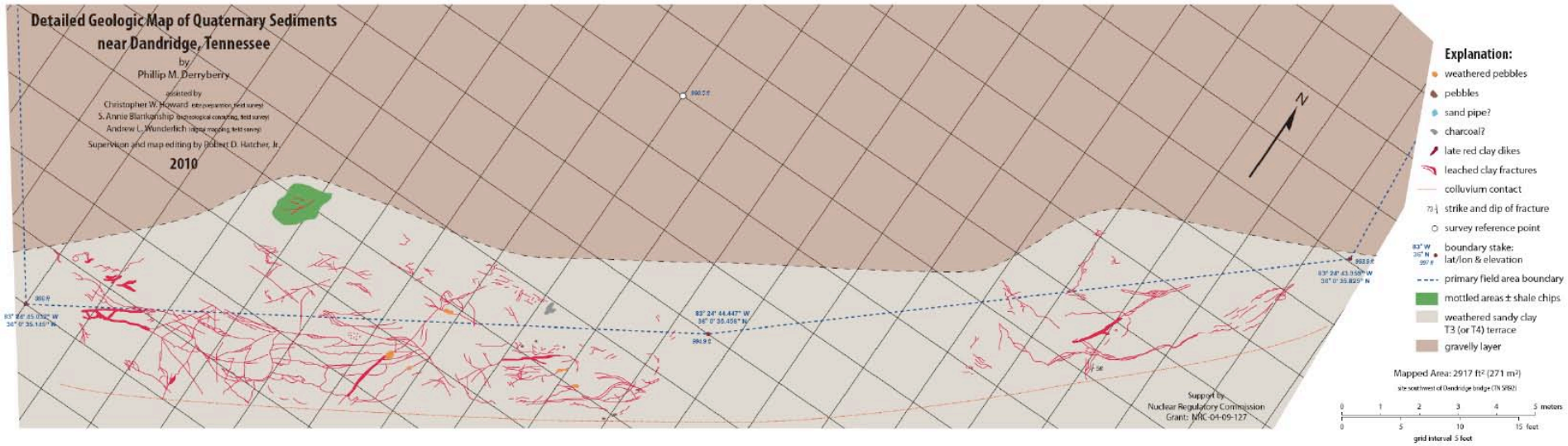
French Broad River Terraces and Possible Paleoseismic Features Around Douglas Reservoir



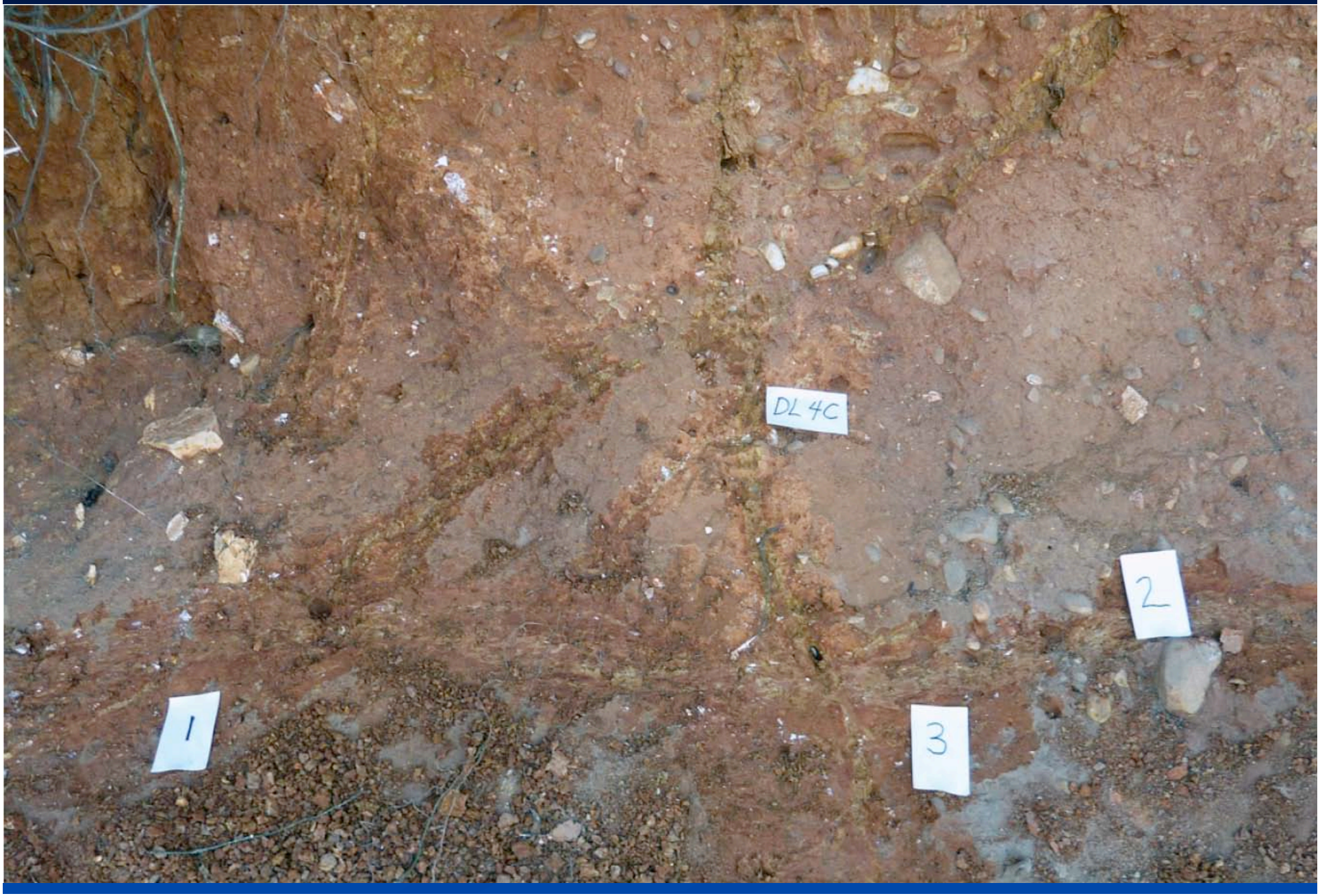

Jefferson City quad
White Pine quad
Shady Grove quad
Chestnut Hill quad
DL-2b
DL-1b
DL-3 & DL-5
DL-5c
DL-4a-c
DL-4e
DL-6
DL-6/Well's site
DOUGLAS LAKE
FRENCH BROAD RIVER
FLAT WOODS
0 1 2 3 4 Miles

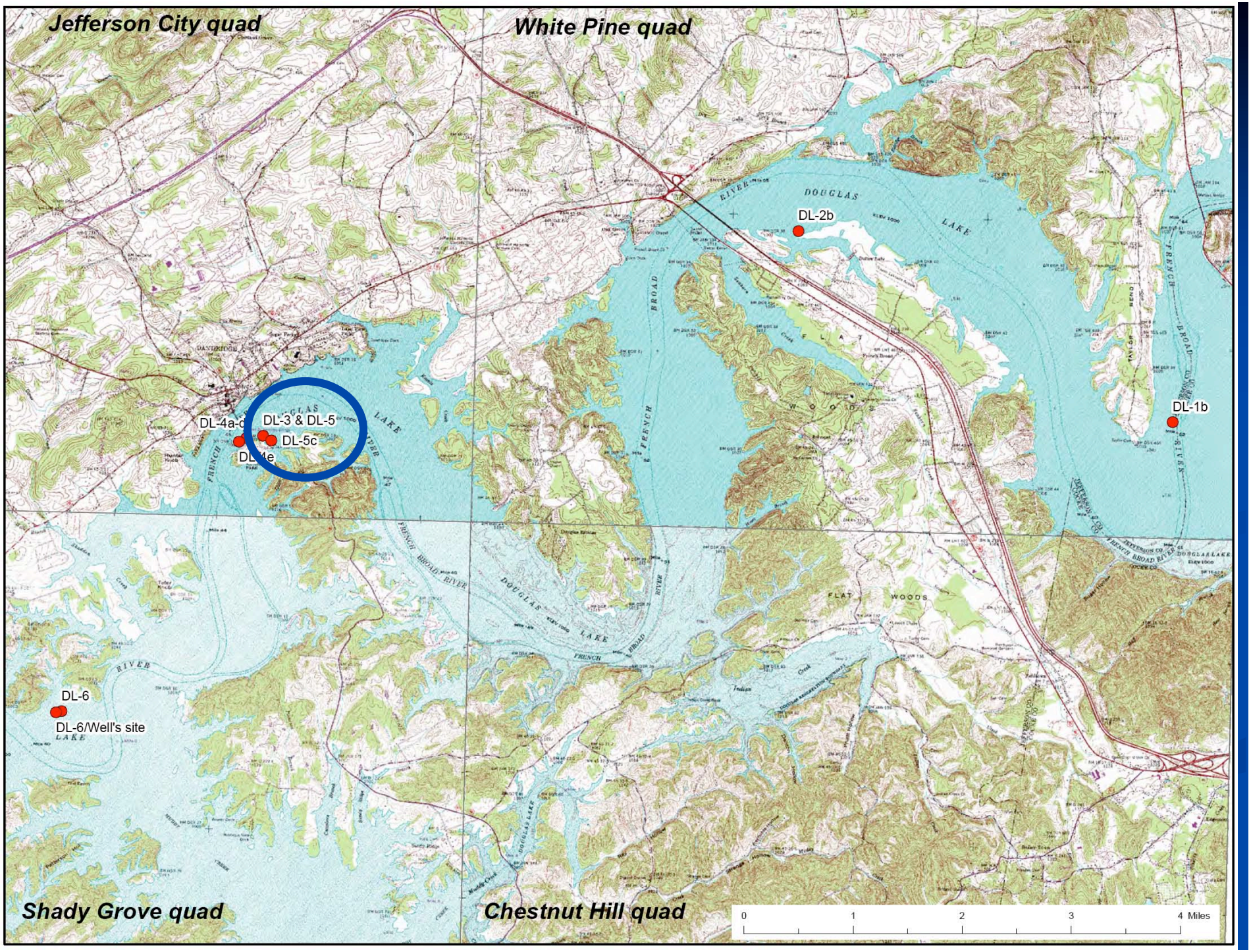
Graded & Gridded Dandridge Bridge W

Detailed Geologic Map Dandridge Bridge W

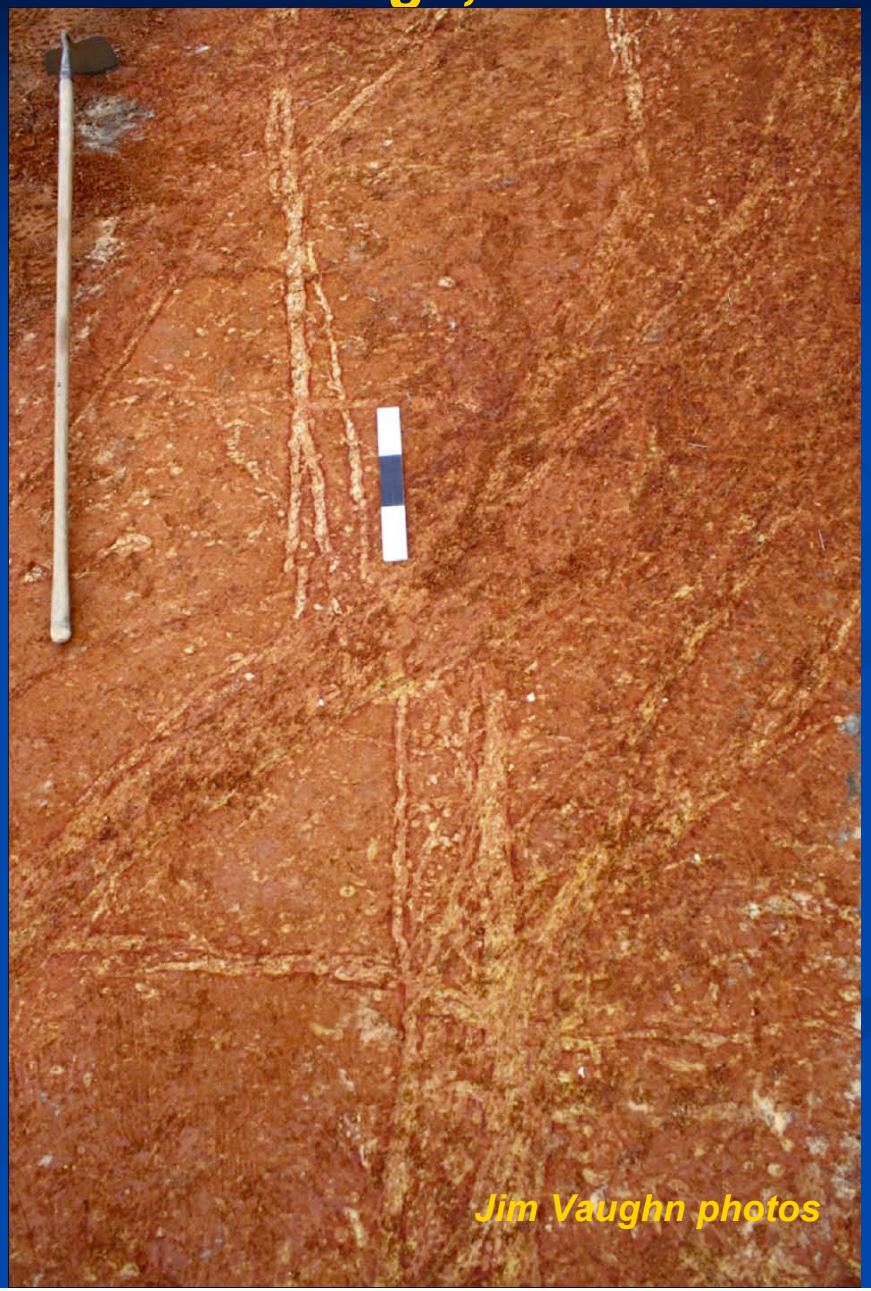


Fracture Chronology



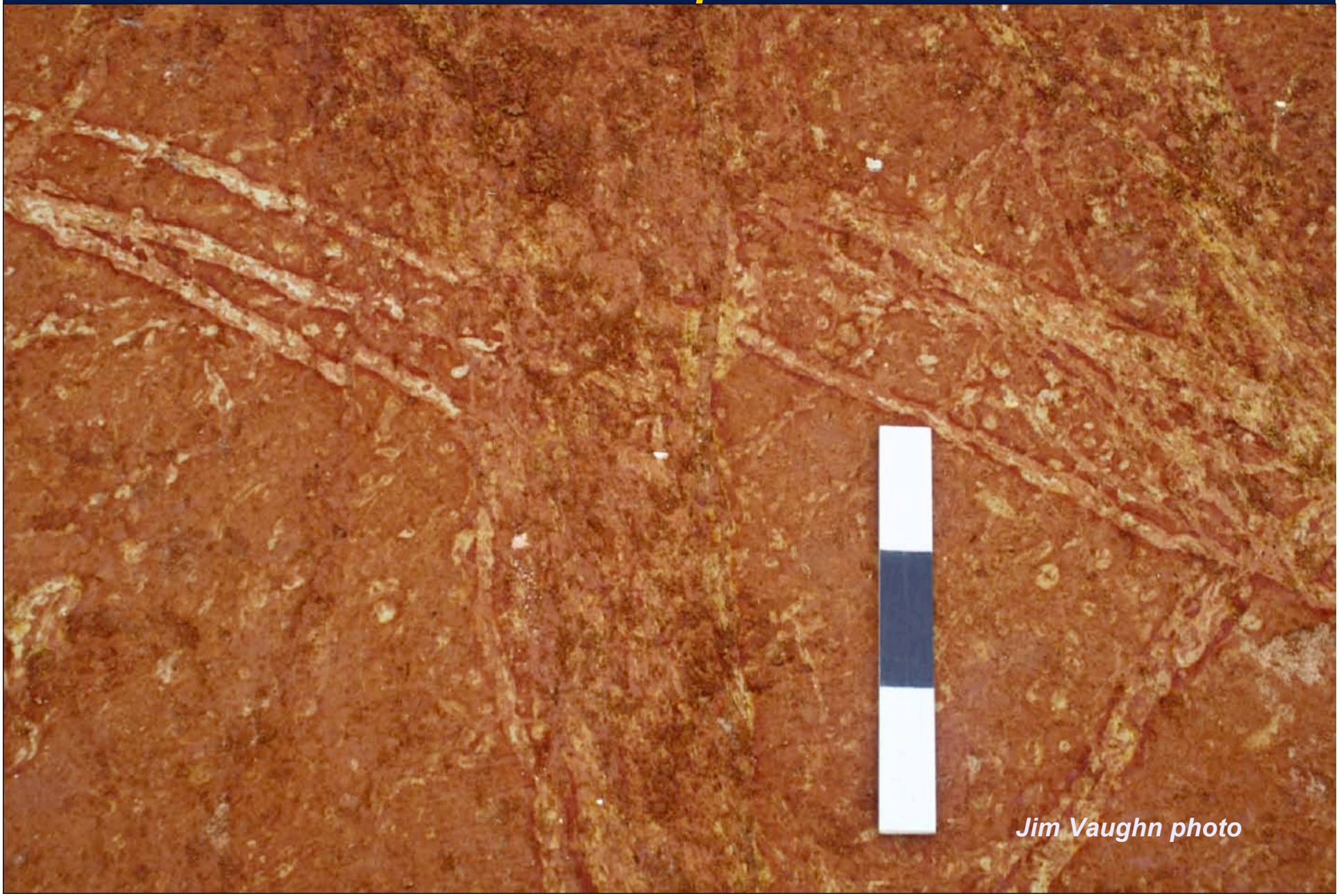

Jefferson City quad
White Pine quad
Shady Grove quad
Chestnut Hill quad
DL-2b
DL-1b
DL-3 & DL-5
DL-5c
DL-4a-c
DL-4e
DL-6
DL-6/Well's site
DOUGLAS LAKE
FRENCH BROAD RIVER
FLAT WOODS
0 1 2 3 4 Miles

Fractures & Sinistral Fault in High Terrace (T3 or T4, >28 ka) Douglas Reservoir S of Dandridge, TN



Jim Vaughn photos

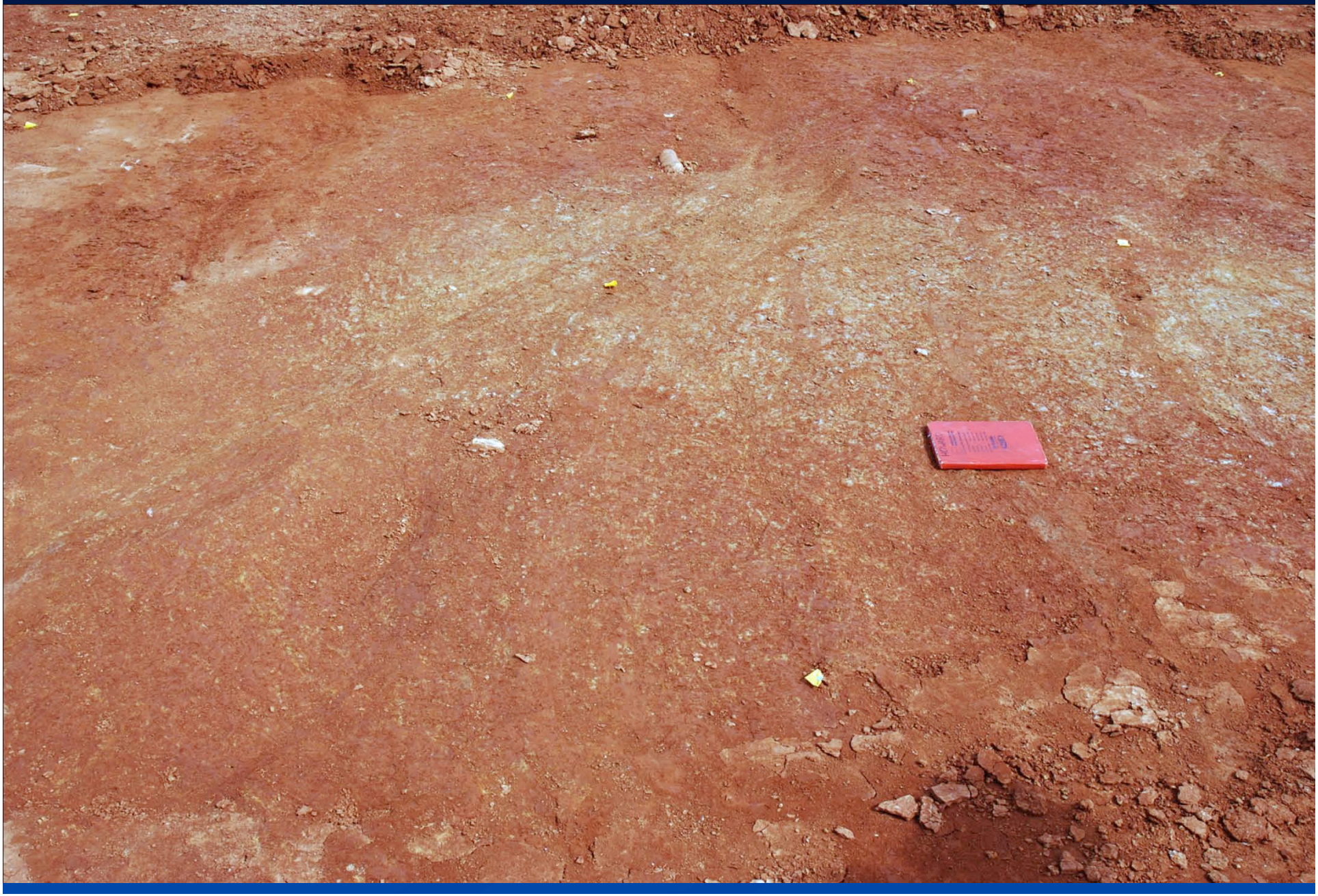
Early fractures cut by younger fault with ~15 cm of sinistral displacement.



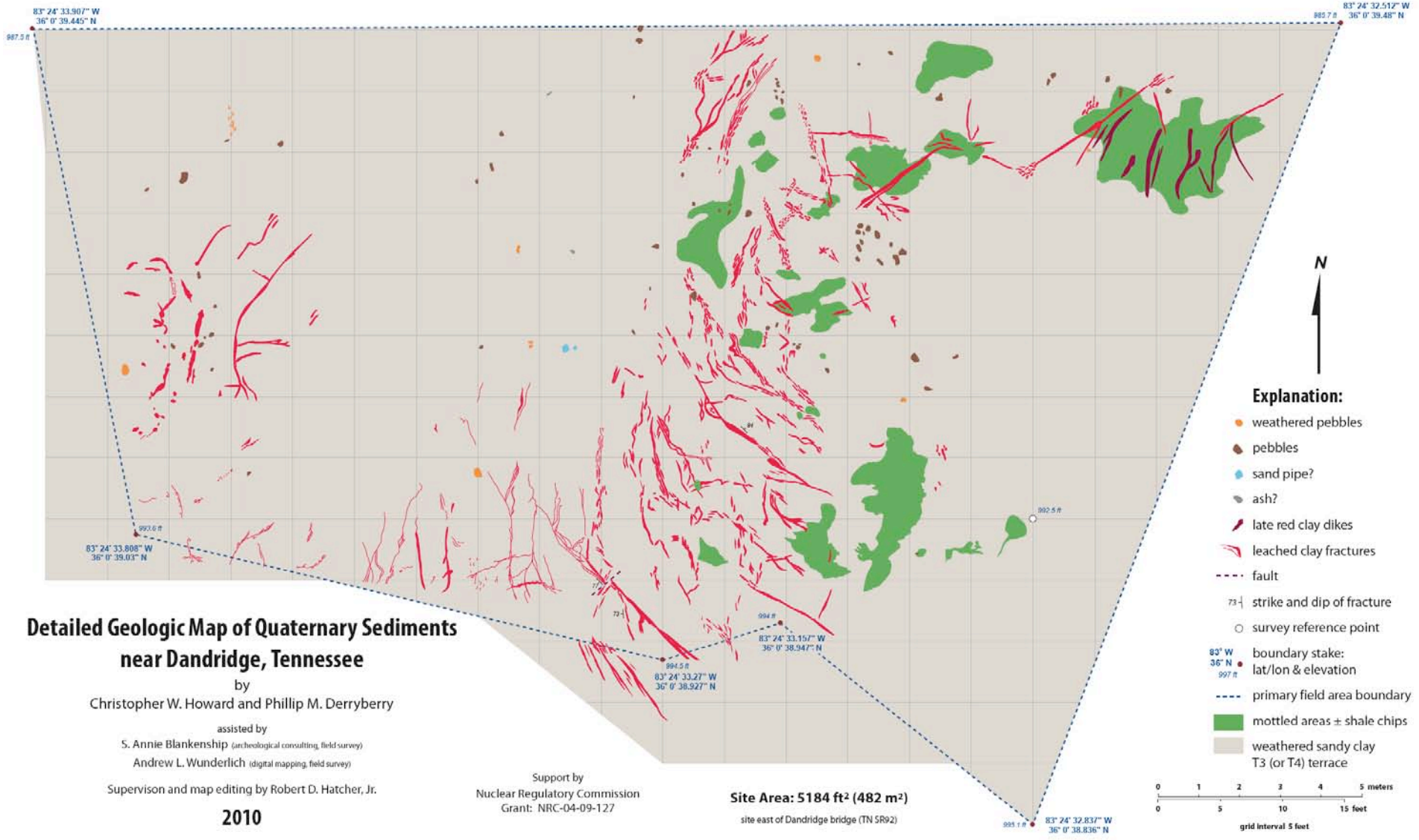
Shale Chips along Fracture

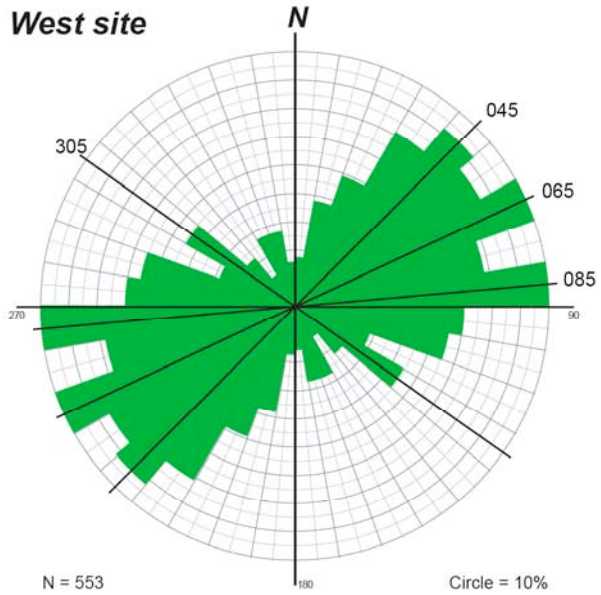
Graded & Gridded Dandridge Bridge E

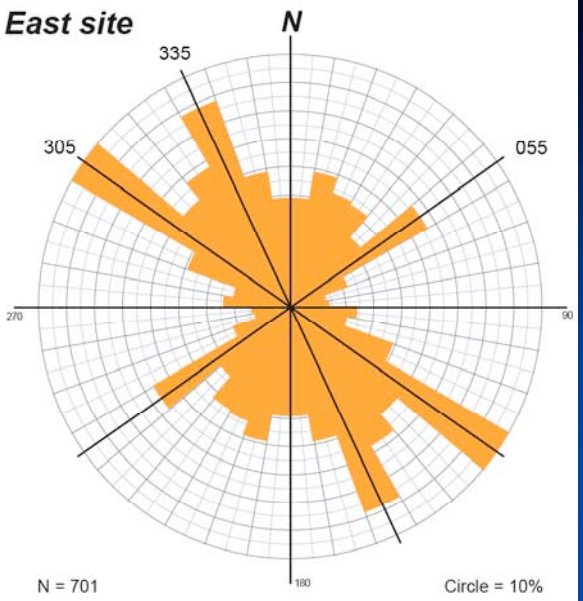
Liquefied Shale Chips Cut by Fractures



Detailed Geologic Map–E T3 Site

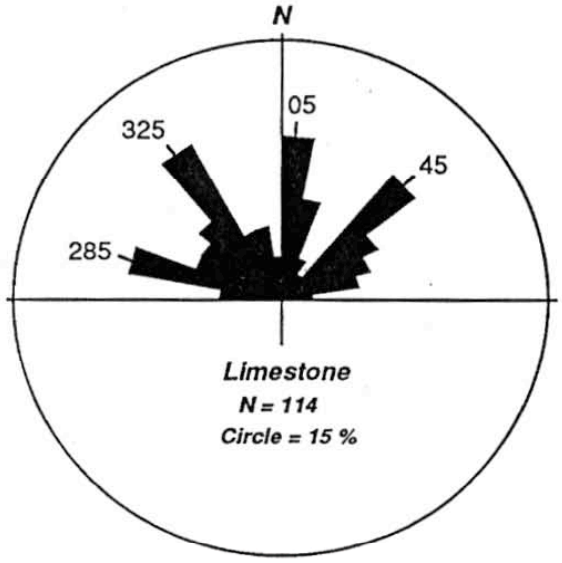


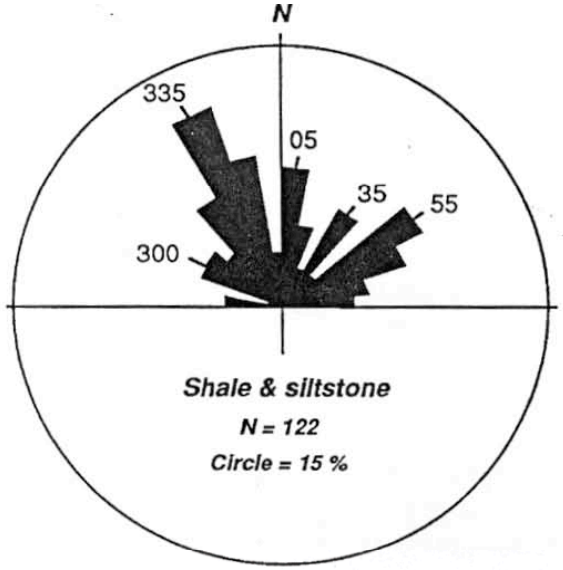


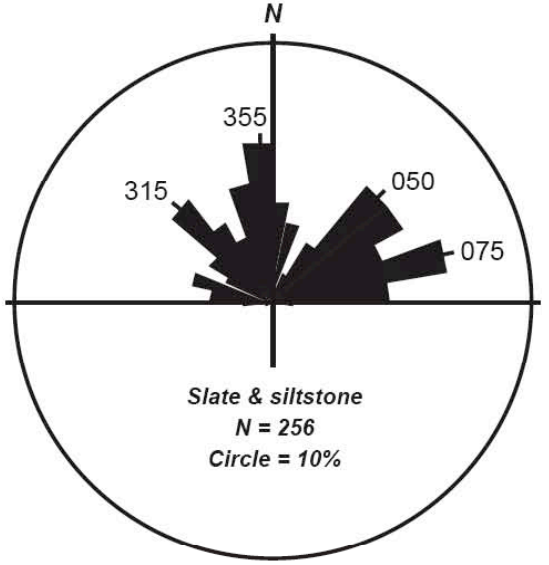


Quaternary sediment Fractures

Bedrock Fractures

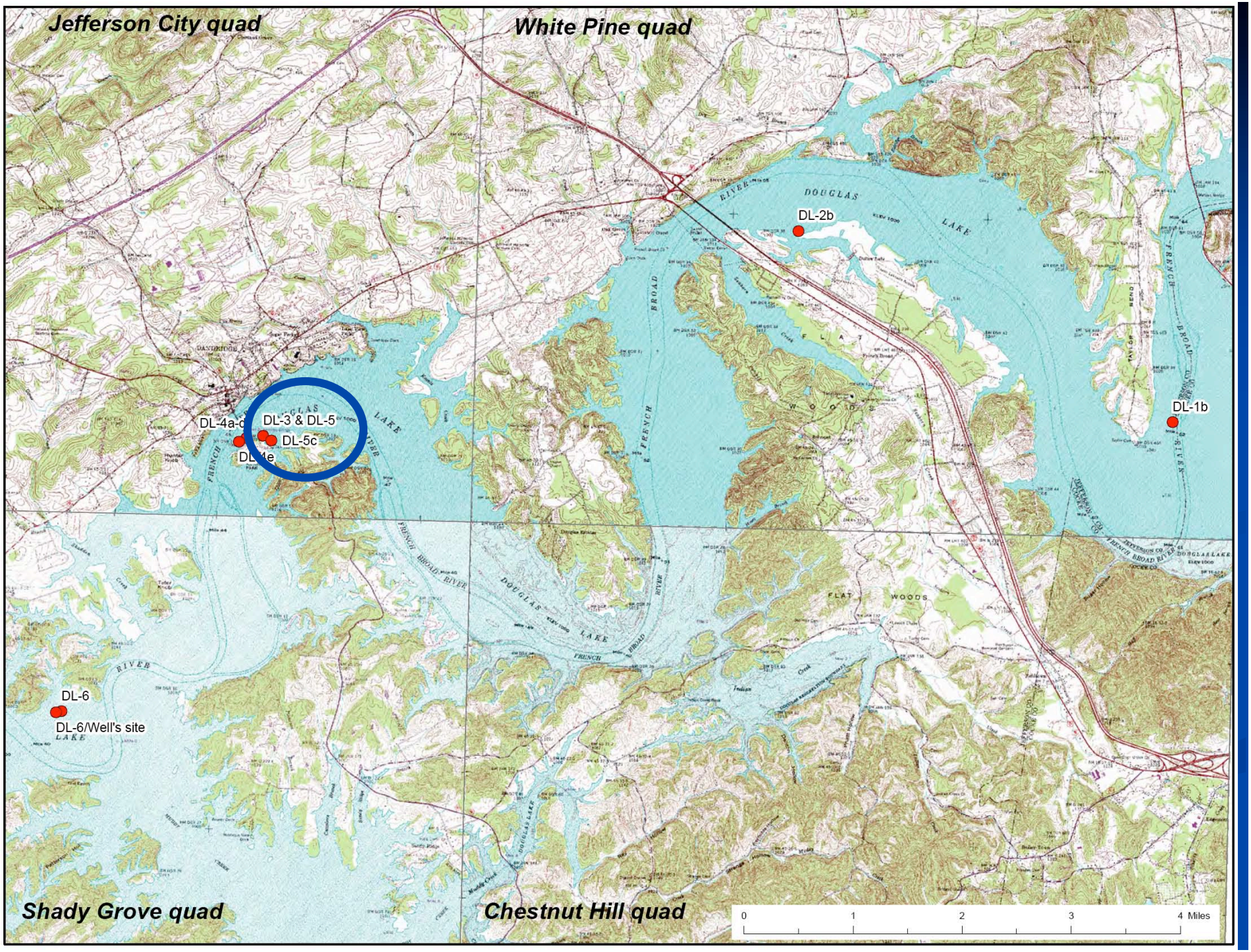






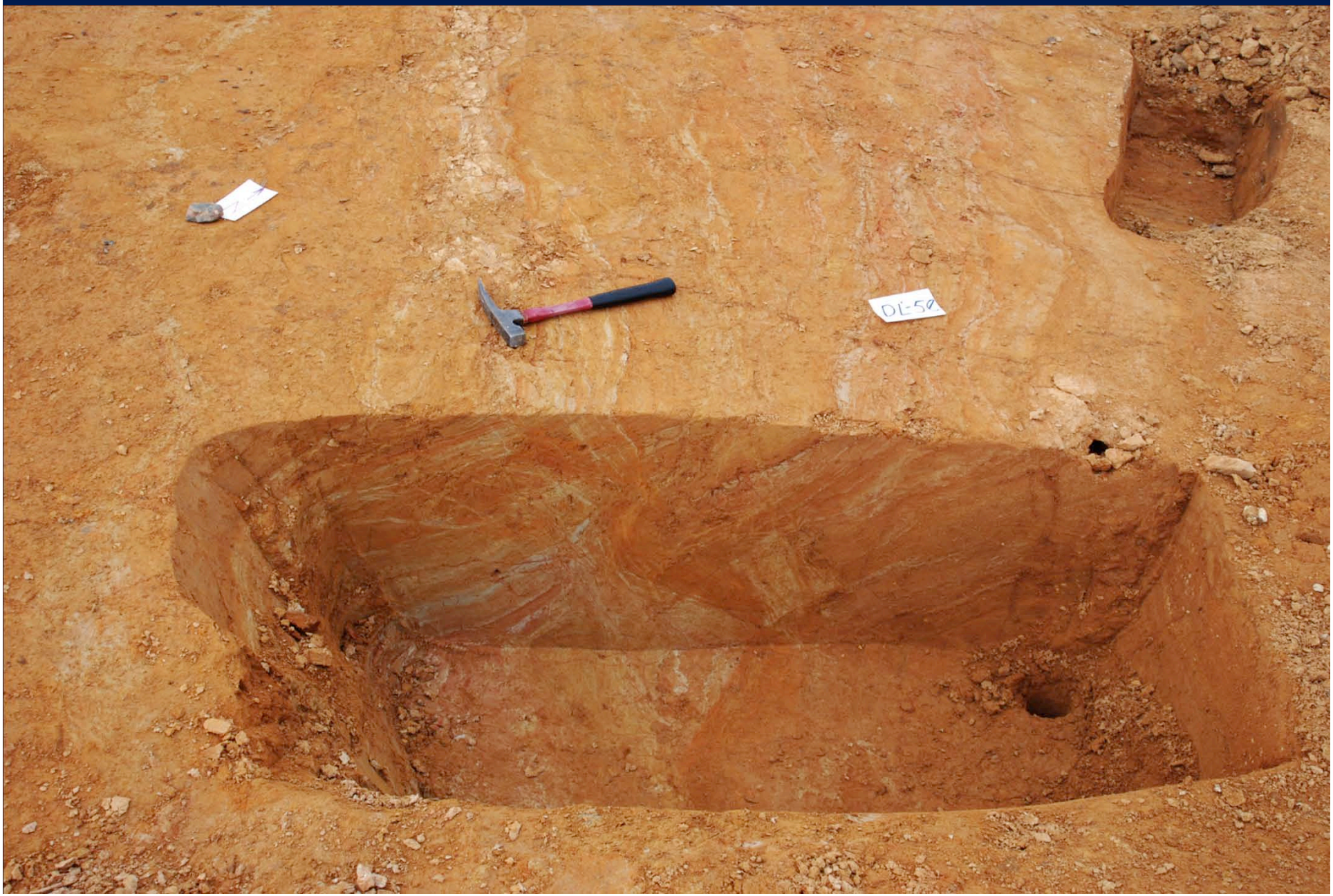
Valley and Ridge near Oak Ridge, TN

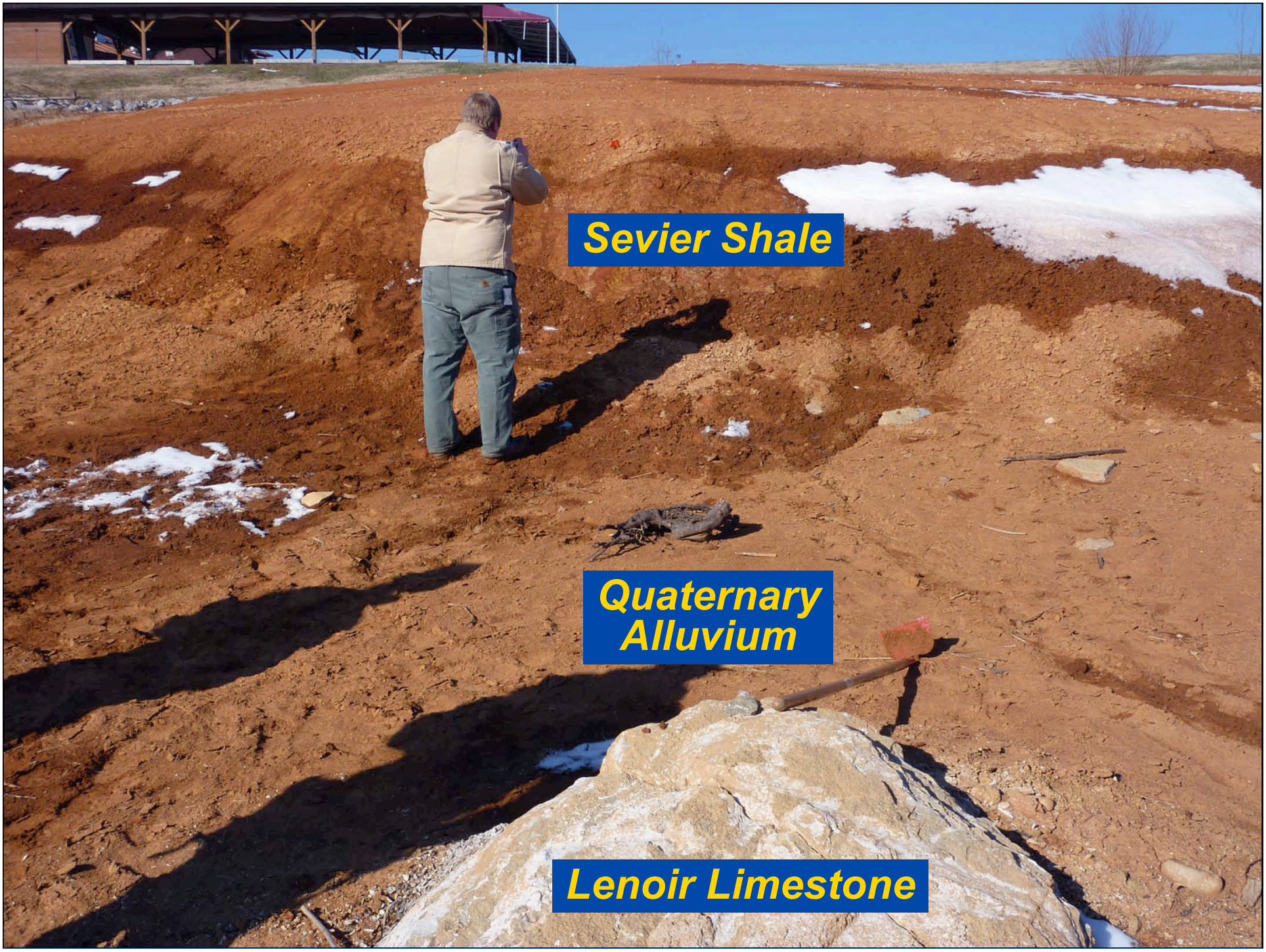
Blue Ridge Foothills near Pigeon Forge, TN


Jefferson City quad
White Pine quad
Shady Grove quad
Chestnut Hill quad
DL-2b
DL-1b
DL-3 & DL-5
DL-5c
DL-4a-c
DL-4e
DL-6
DL-6/Well's site
DOUGLAS LAKE
FRENCH BROAD RIVER
FLAT WOODS
0 1 2 3 4 Miles

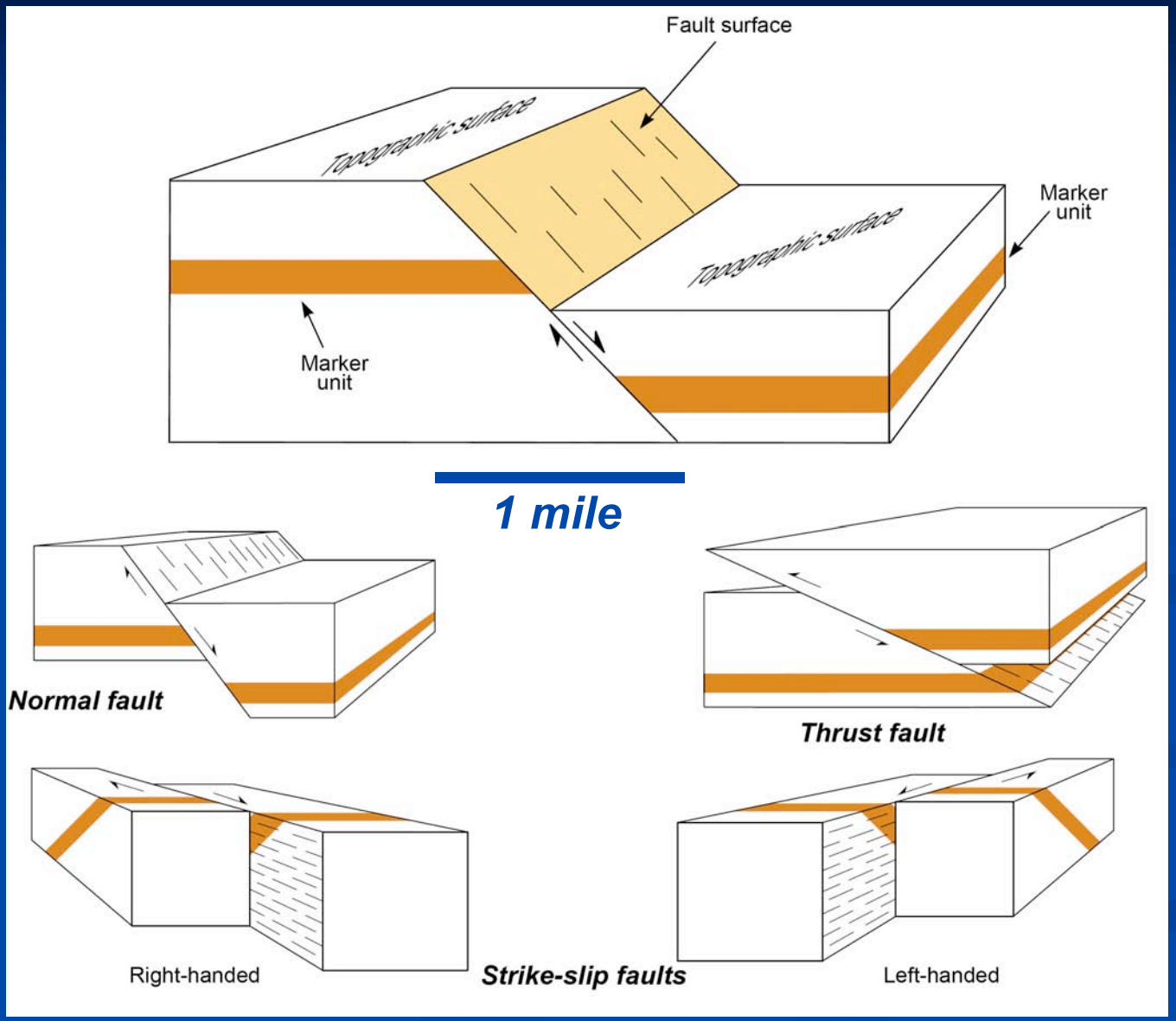
Site in Lower Terrace

Faulted Tilted River Sediment




Sevier Shale
Quaternary Alluvium
Lenoir Limestone

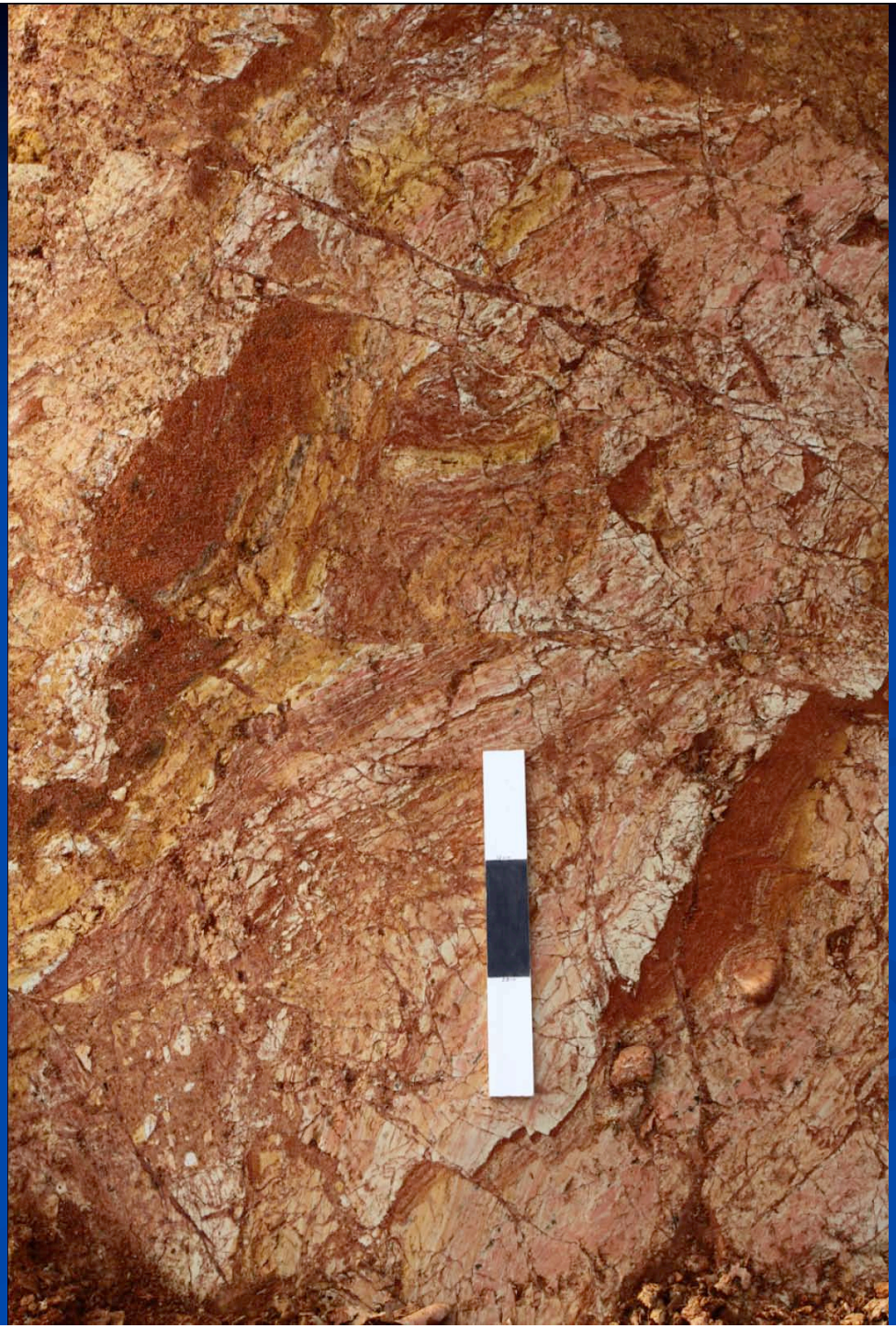
What kind(s) of faults are these?

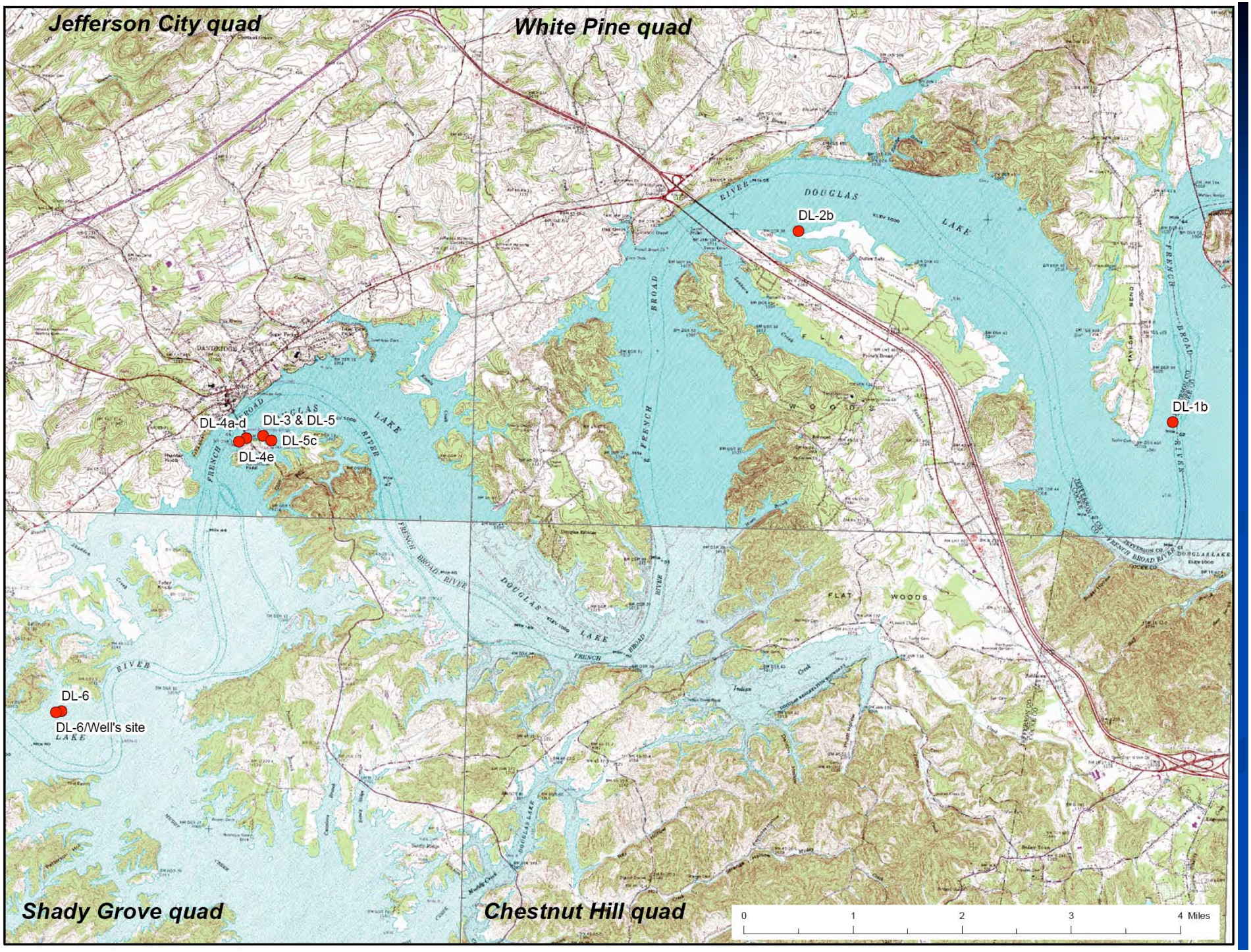


Idealized fault types

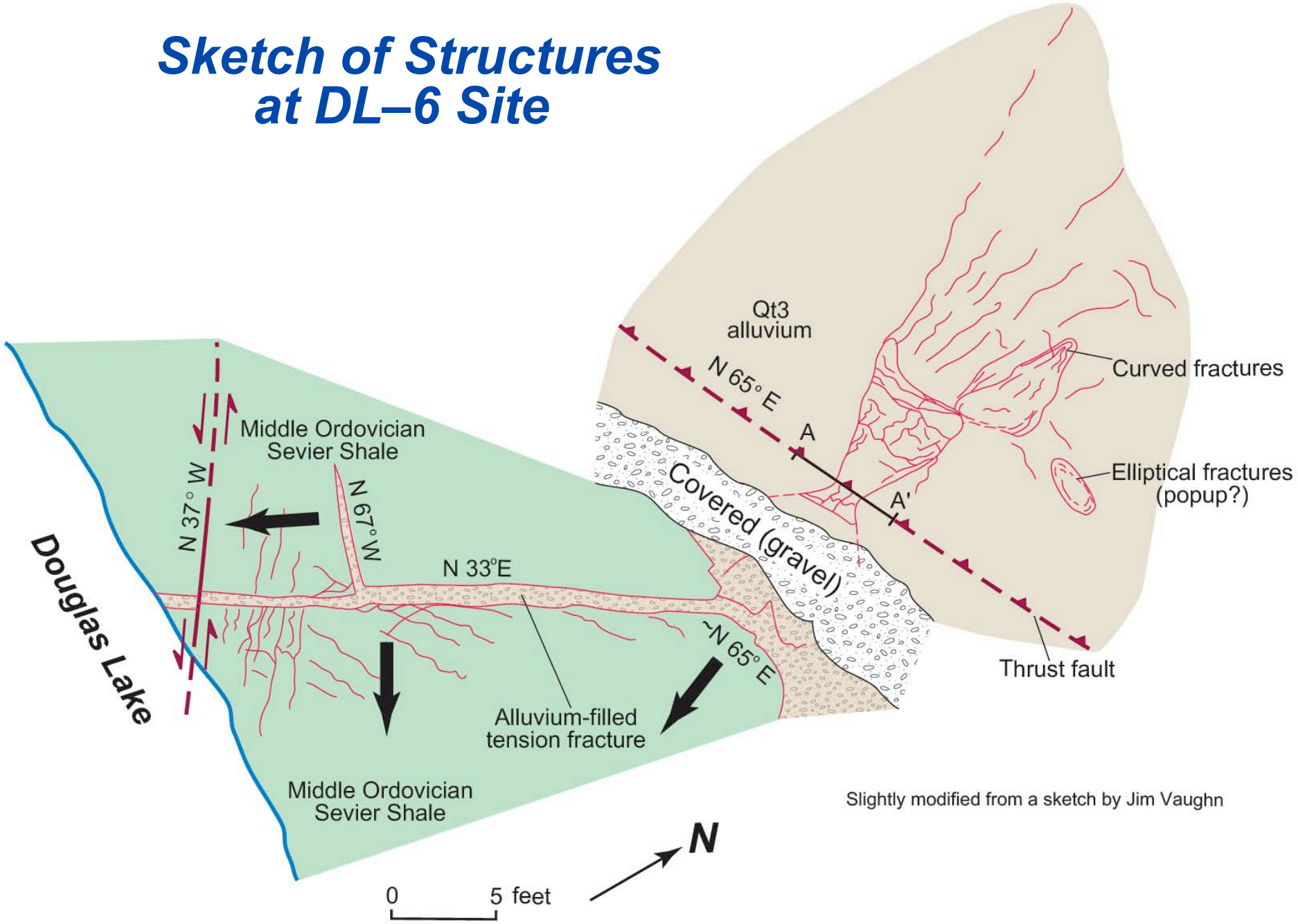
Fractured Weathered Shale

Near Dandridge bridge E site




Jefferson City quad
White Pine quad
Shady Grove quad
Chestnut Hill quad
DL-2b
DL-1b
DL-4a-d
DL-3 & DL-5
DL-5c
DL-4e
DL-6
DL-6/Well's site
DOUGLAS LAKE
FRENCH BROAD RIVER
FLAT WOODS
0 1 2 3 4 Miles

Sketch of Structures at DL–6 Site



Slightly modified from a sketch by Jim Vaughn

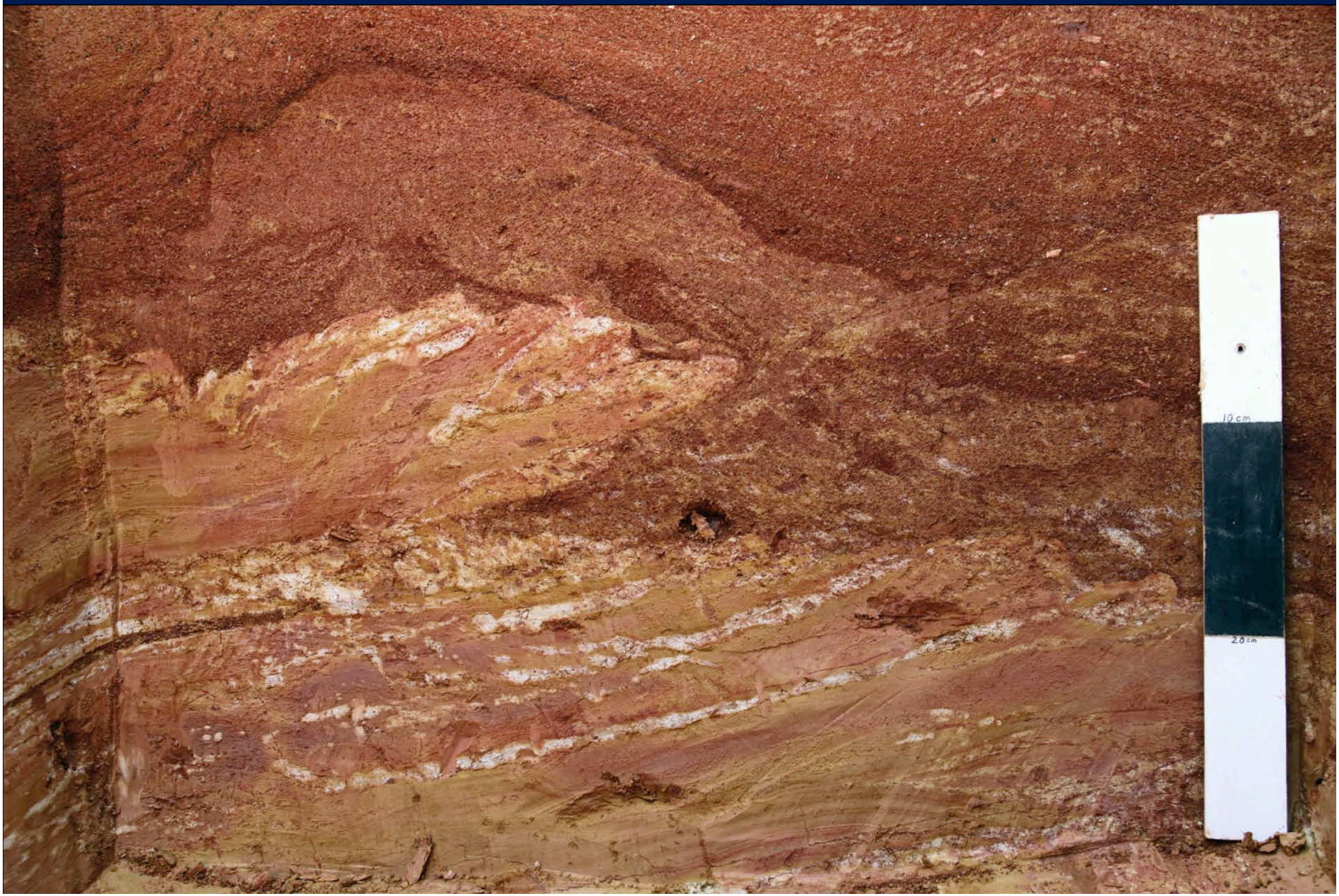
Large, River Deposit-Filled Branching Fracture

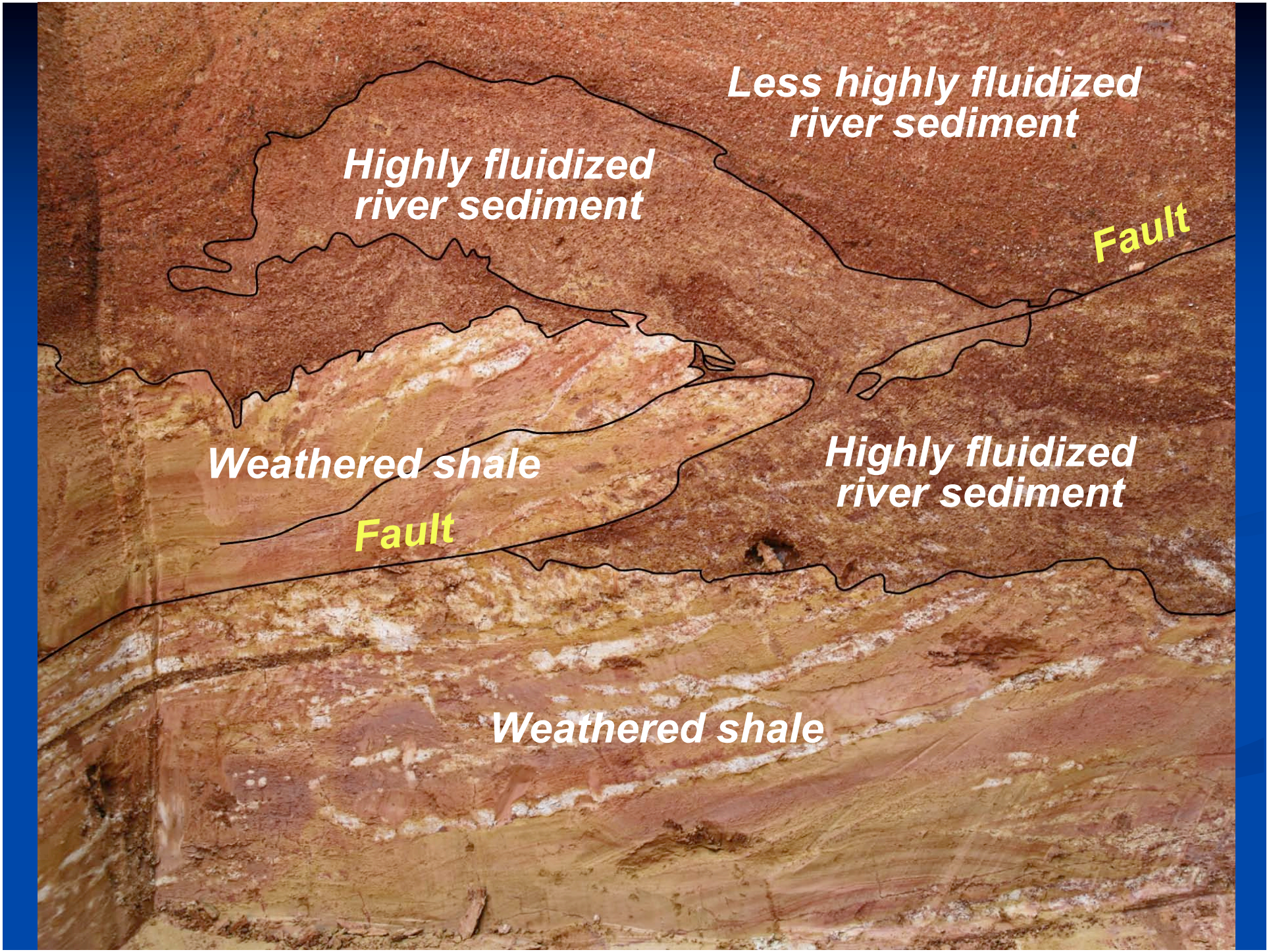
Fault at Lower End of Large Fracture

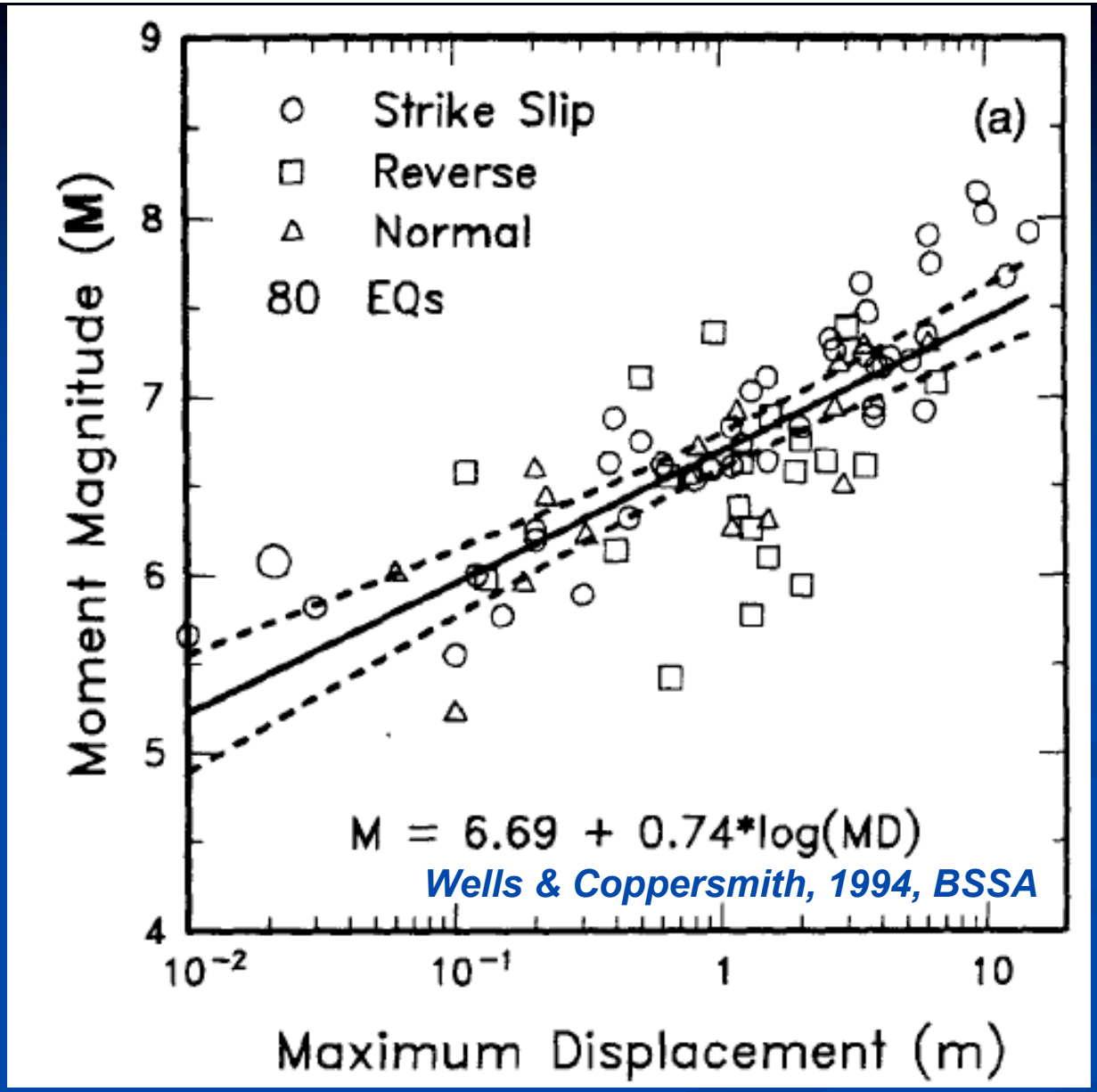
Upper End of Large Fracture

Note that the shale here is 65 cm higher than in the pit to the left.

Faulted Shale & Liquefied River Sediment

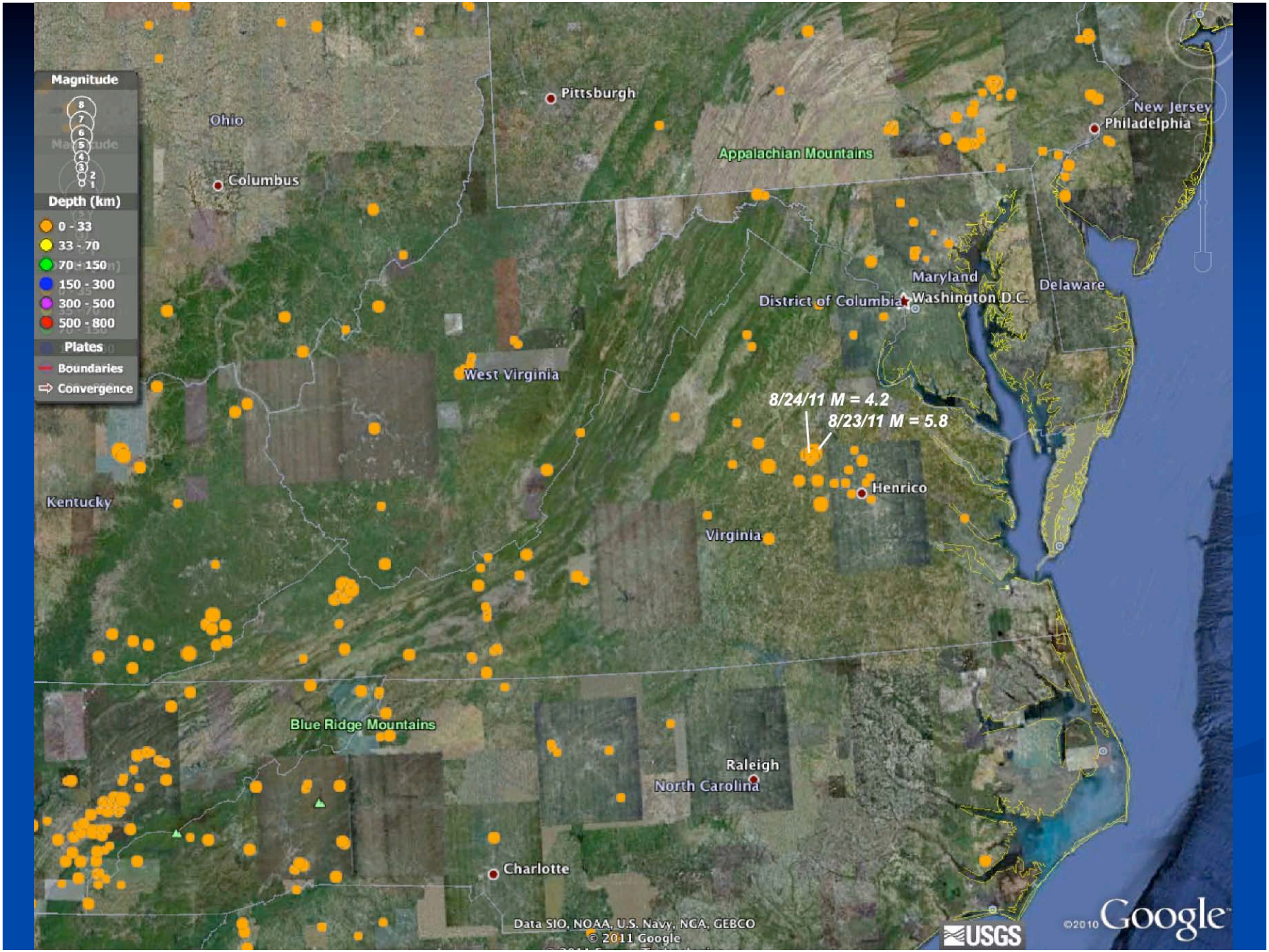


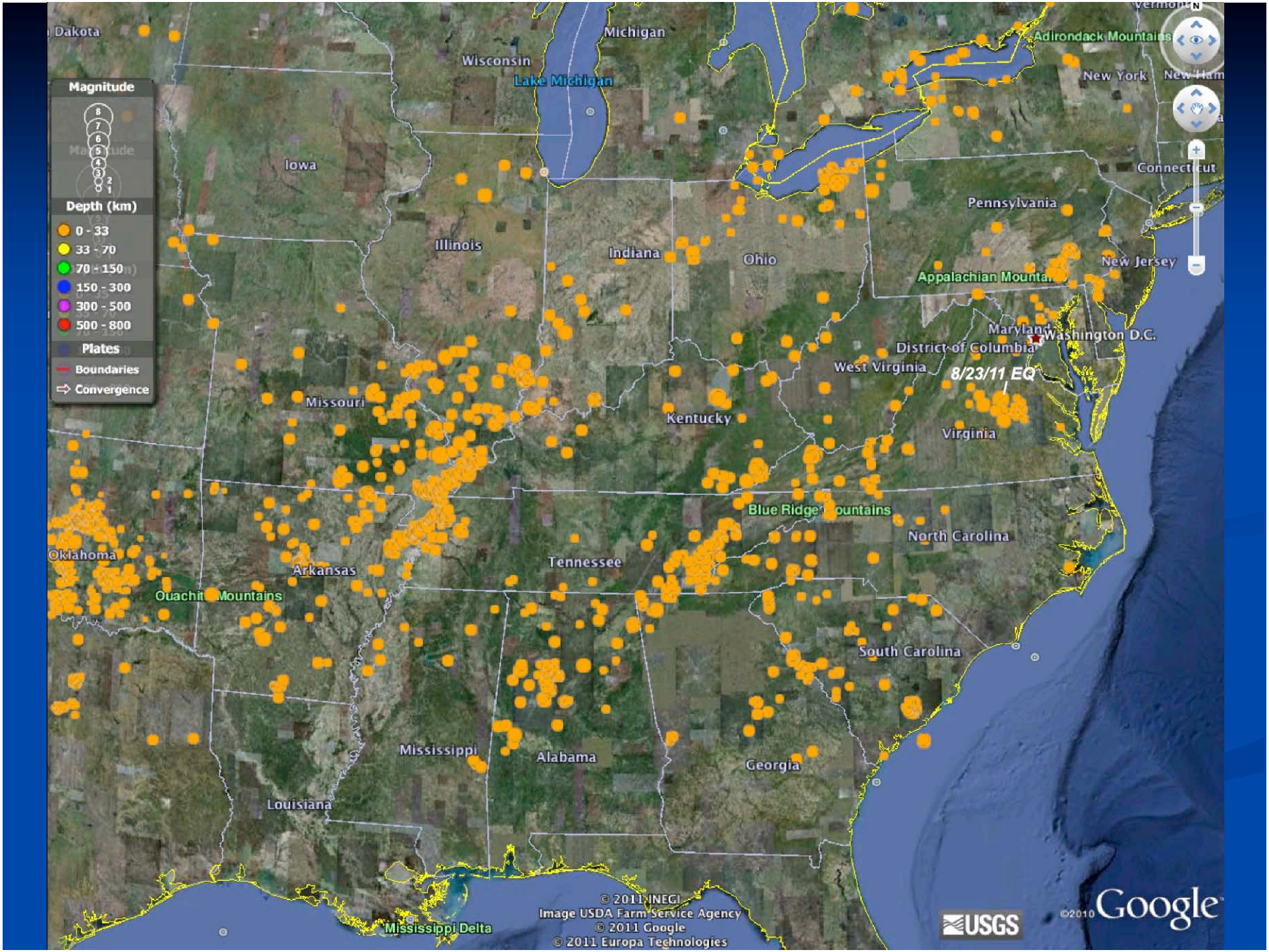

Less highly fluidized river sediment
Highly fluidized river sediment
Fault
Weathered shale
Fault
Highly fluidized river sediment
Weathered shale



What magnitude earthquake would be required to produce the observed displacements?

August 23, 2011, M = 5.8 EQ Central Virginia


Magnitude
8
7
6
5
4
3
2
1
Depth (km)
0 - 33
33 - 70
70 - 150
150 - 300
300 - 500
500 - 800
Plates
Boundaries
Convergence
Ohio
Pittsburgh
Columbus
Appalachian Mountains
New Jersey
Philadelphia
Maryland
Delaware
District of Columbia
Washington D.C.
West Virginia
8/24/11 M = 4.2
8/23/11 M = 5.8
Henrico
Kentucky
Virginia
Blue Ridge Mountains
Raleigh
North Carolina
Charlotte
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2011 Google
USGS
©2010 Google


Magnitude
Depth (km)
0 - 33
33 - 70
70 - 150
150 - 300
300 - 500
500 - 800
Plates
Boundaries
Convergence
8/23/11 EQ
Dakota
Michigan
Wisconsin
Lake Michigan
Adirondack Mountains
New York
Iowa
Connecticut
Pennsylvania
Illinois
Indiana
Ohio
New Jersey
Appalachian Mountains
Maryland
Washington D.C.
District of Columbia
West Virginia
Missouri
Kentucky
Virginia
Blue Ridge Mountains
North Carolina
Oklahoma
Arkansas
Tennessee
Ouachita Mountains
South Carolina
Mississippi
Alabama
Georgia
Louisiana
Mississippi Delta
© 2011 INEGI
Image USDA Farm Service Agency
© 2011 Google
© 2011 Europa Technologies
USGS
©2010 Google

Kitchen Pantry Damage

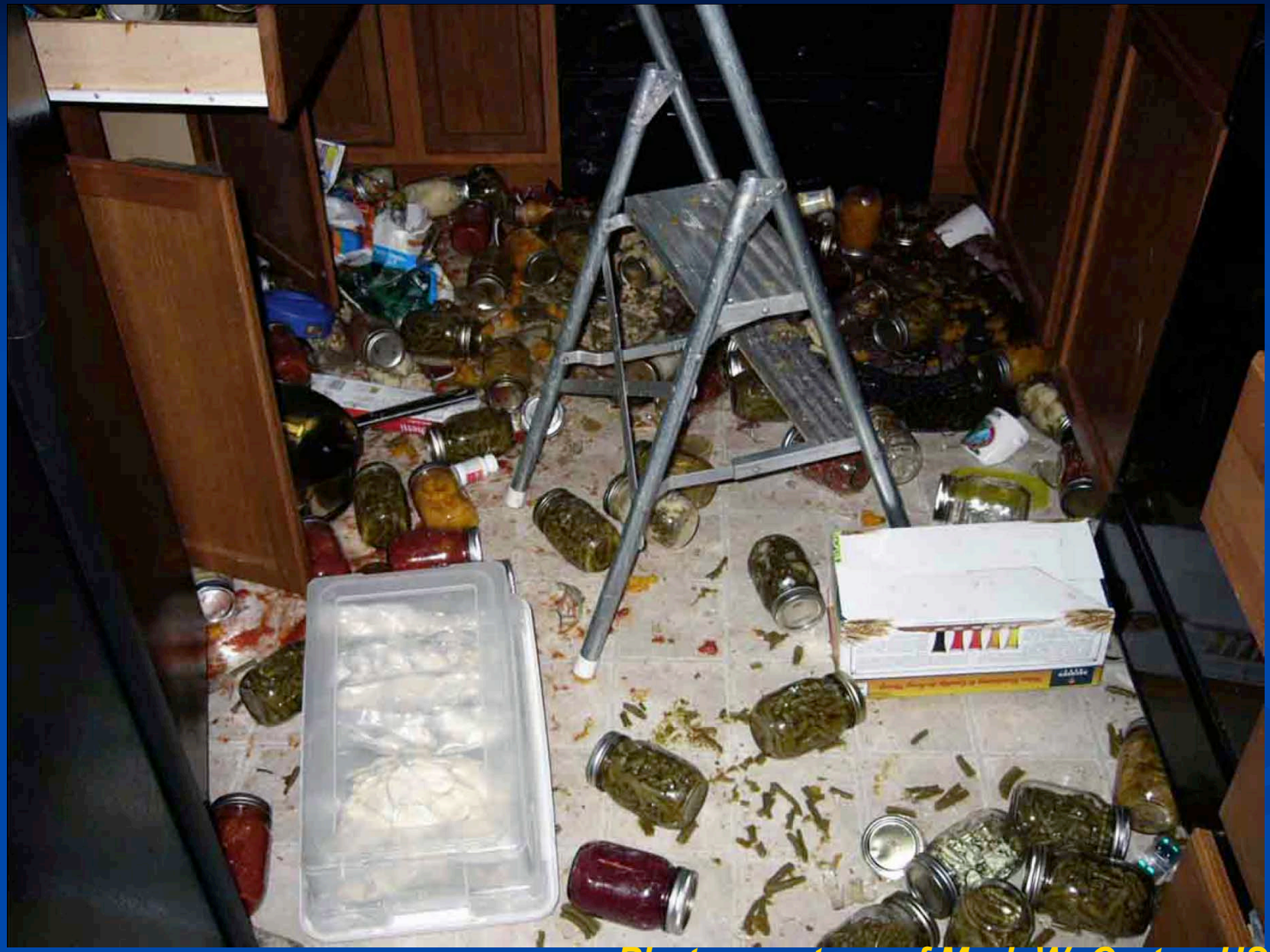


Photo courtesy of Mark W. Carter, USGS

2011 VA EQ: Chimney & Carport Damage

Photo courtesy of Jeff Munsey, TVA

2011 VA EQ: Cracked Cinder Block Wall

Photo courtesy of Jeff Munsey, TVA

2011 VA EQ: Broken Weld in Floor Post

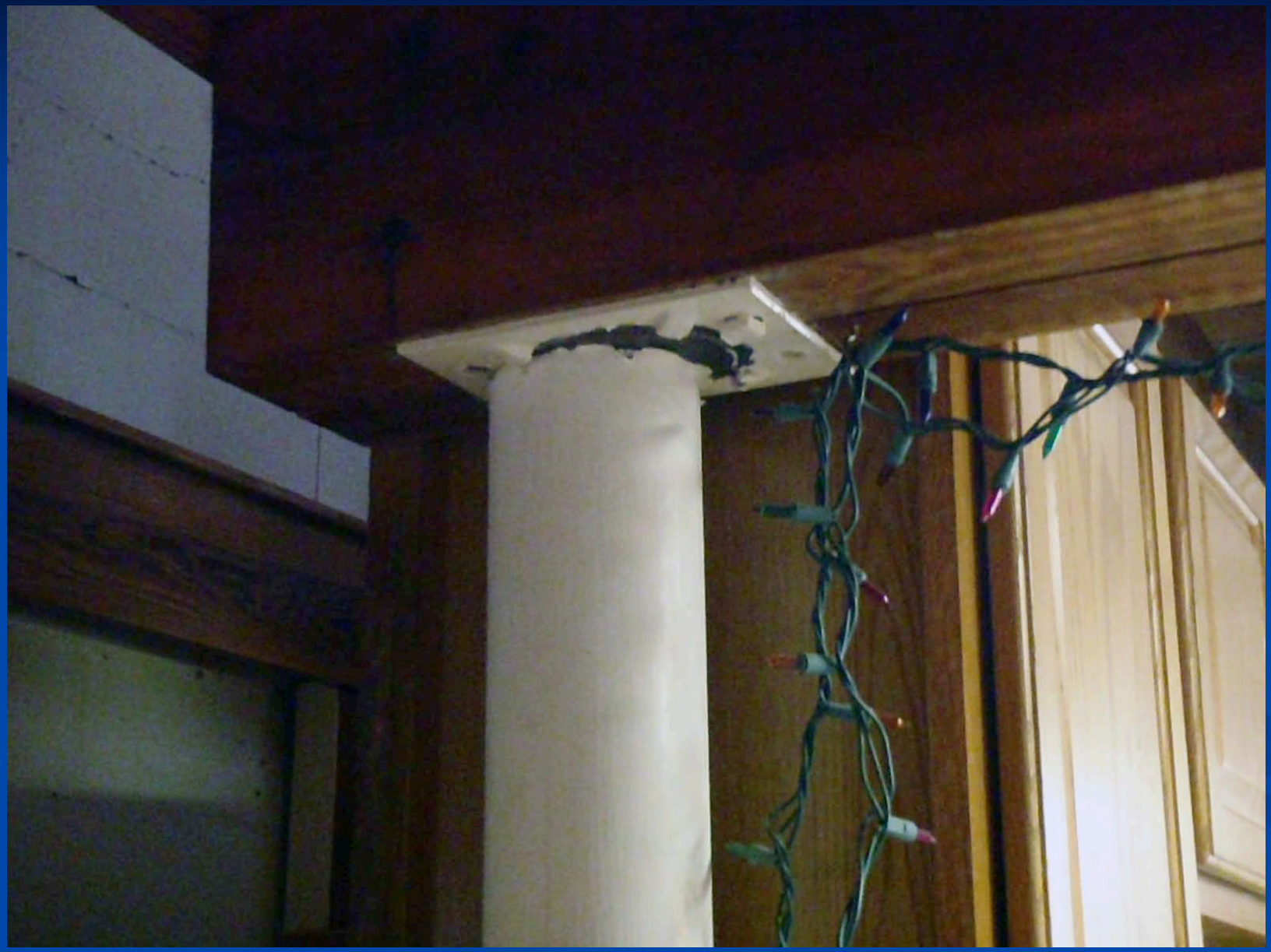
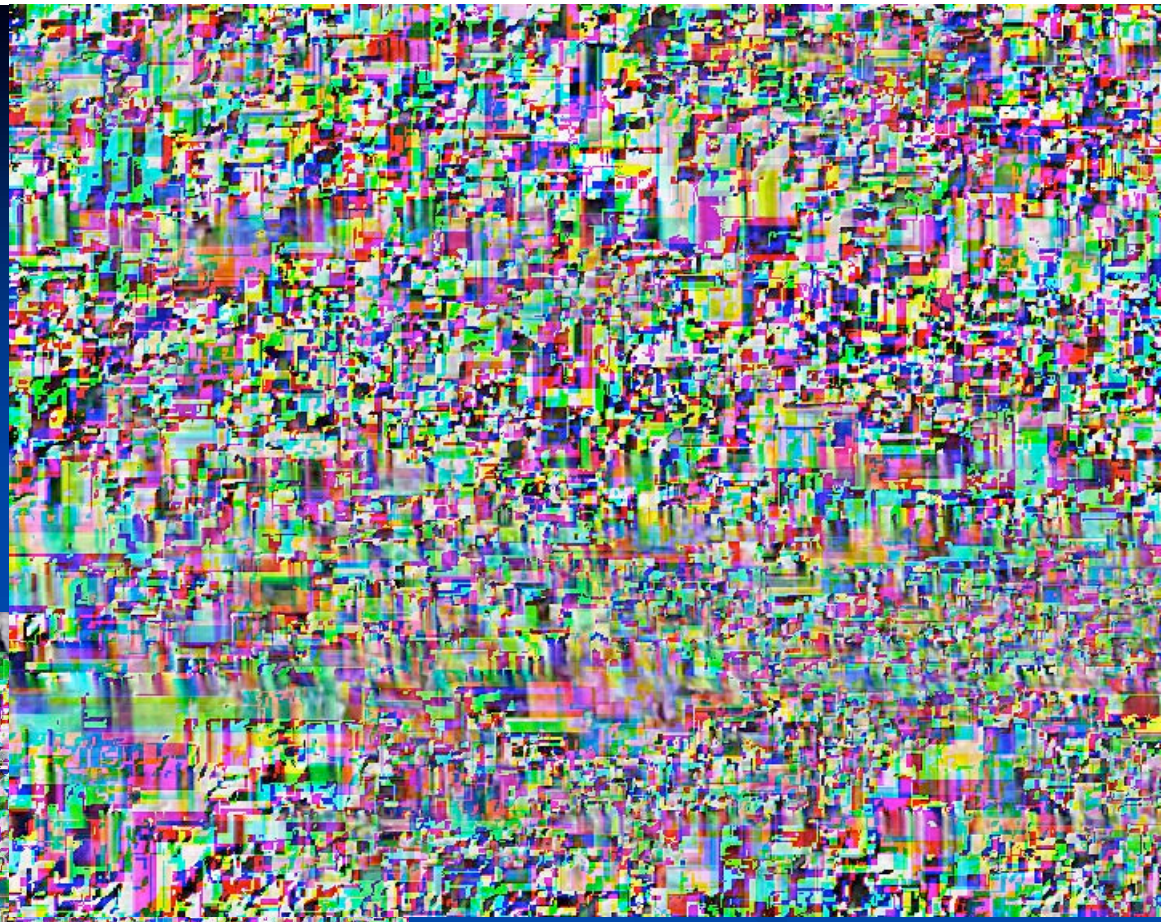


Photo courtesy of Jeff Munsey, TVA

2011 VA EQ Mud Volcanoes



Photos courtesy of Jeff Munsey, TVA

Conclusions Regarding the August 23, 2011, VA EQ

- *Damage was widespread in the vicinity of the August 23 EQ in Central VA.*
- *Damage was consistent with a M = 5.8 EQ*
- *Reaffirms our M $\geq$ 6.5 assessment of the magnitude of the prehistoric ETSZ EQs.*

ETSZ Conclusions

- *Seismologists have said (before our recent work) that the ETSZ is ephemeral and will die out within a few hundred years.*
- *During the past 2.5 years, we have documented late Quaternary fracture arrays and small faults on and in shale bedrock that are evidence of $M \geq 6.5$ earthquakes in the ETSZ.*
- *We have shown that the ETSZ has a history of activity spanning thousands of years.*

So, is there an earthquake hazard In East Tennessee?

Yes, but the level of the hazard must be better evaluated with more primary scientific data.

Additional funded research is needed!

We are awaiting funds transfer of a 2.5-y grant from the NRC.

Do I have earthquake insurance? ***Not at present.***