2. REGIONAL SEISMICITY AND GEOLOGY

Regional Tectonic Setting and Southeastern US Seismicity

The tectonic regime in the eastern US involves compression of the Atlantic Coast region presumably due to ridge-push from the Mid-Atlantic Ridge, and/or the formation of the Appalachian Mountains due to collision between North America and Africa about 300 million years ago (Zobach and Zobach, 1980; USGS, 2011a). Principal compressive stresses are oriented in the west-northwest to east-southeast direction, as depicted in Figure 2-1. As discussed below, moment tensor solutions from the M5.8 earthquake indicate thrust faulting with the direction of compressive stresses consistent with the regional stress field. A more thorough discussion of regional tectonics and crustal stress states is presented in Zoback and Zoback (1980).

As shown in Figure 2-2, the eastern US is an area of diffuse low-level seismicity with concentrations of activity both parallel and normal to the northeasterly structural trend of the Appalachian Mountains. The largest historical earthquake in the region was the 1886 Charleston, SC Earthquake estimated at M7.3. The previous largest historical earthquake in Virginia was the Giles County Earthquake of 1897, estimated at M5.9.

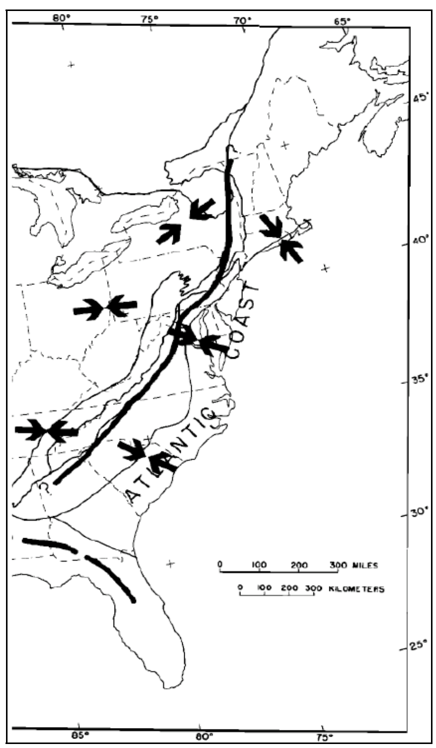


Figure 2-1 – Orientation of regional stress field along the Atlantic Coast (adapted from Zoback and Zoback, 1980).

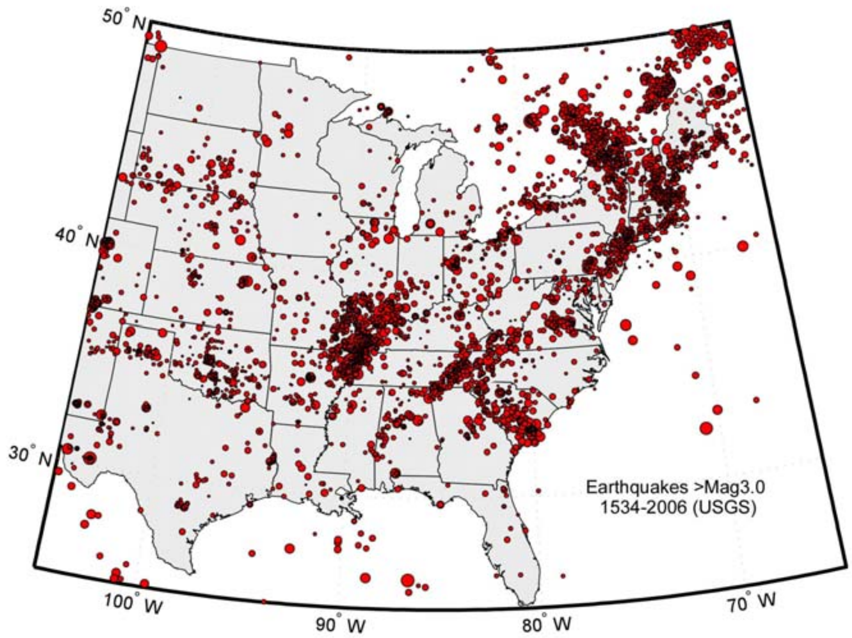


Figure 2-2 – Eastern and central US seismicity for M>3 since the mid-16th century (USGS)

Central Virginia Seismicity.

The epicenter of the August 2011 M5.8 earthquake and its aftershocks fall within the Central Virginia Seismic Zone (CVSZ), a cluster of earthquakes centered about halfway between Richmond and Charlottesville, Virginia. The CVSZ can be seen in Figure 2-3, delineated by earthquakes located by the Virginia Tech Seismological Observatory (VTSO). The region is well-known for frequent small-to-moderate shocks that have occurred since at least 1774. Small earthquakes that cause little to no damage are felt abut once a year. USGS catalogs indicate more than 175 felt events over the past 235 years. The previous largest historical CVSZ earthquake occurred in 1875. This shock is estimated at M4.8 based on felt area. The earthquake shook bricks from chimneys, broke plaster and windows, and overturned furniture at several locations. More recently, an M4.5 earthquake occurred in December 2003, causing minor damage. This event was located about 20 km southwest of the M5.8 shock.

The CVSZ has been of particular interest to regional seismologists, especially VTSO researchers who have instrumentally recorded seismicity there since 1978. Data from their studies, along with historical accounts, have been used for regional seismic hazard assessments. The higher rate of seismicity relative to other mid-Atlantic locations is reflected in national seismic hazard maps, such as that shown in Figure 2-4. Seismicity data from VTSO is available at: http://www.geol.vt.edu/outreach/vtso/.

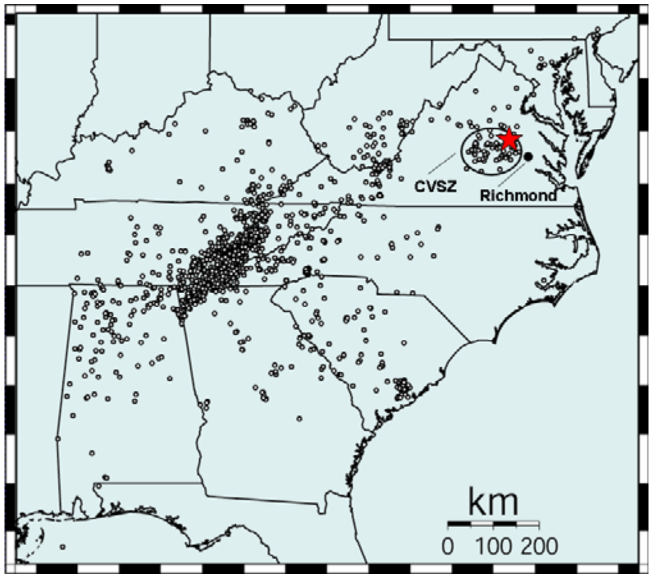


Figure 2-3 – Southeastern seismicity recorded by VTSO from 1977-1999 for M> 0.0; CVSZ shown along with M5.8 epicenter (red star).

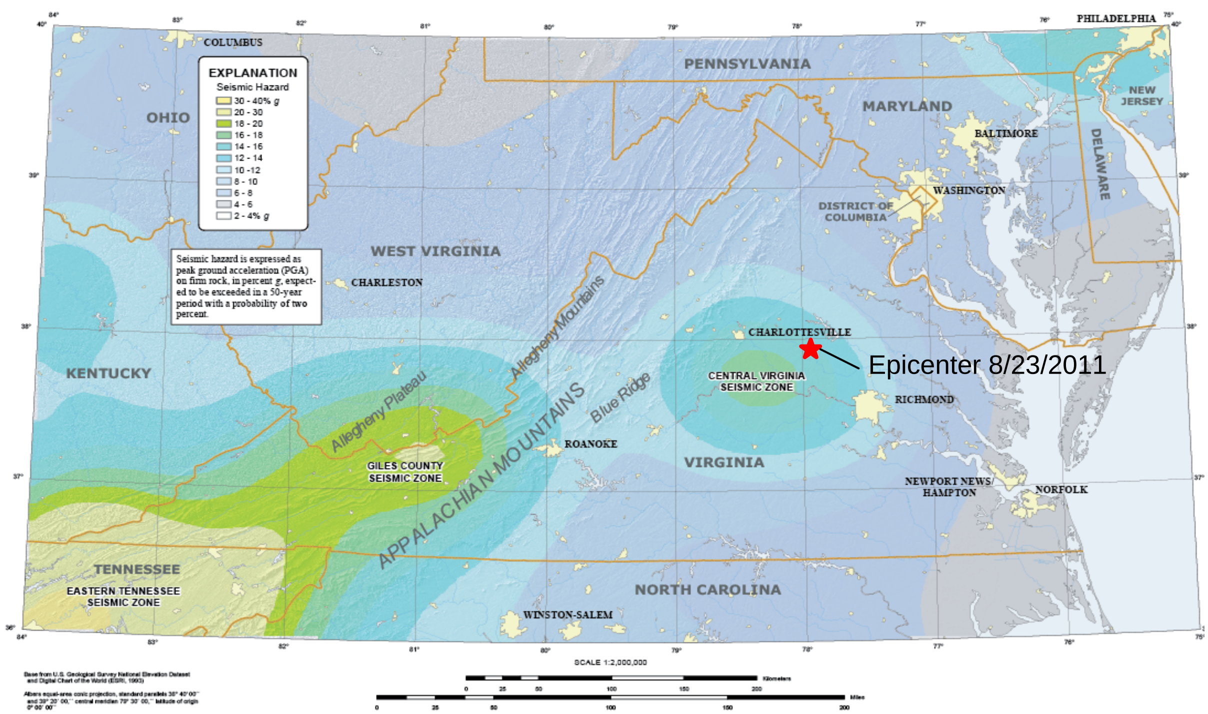


Figure 2-4 - National seismic hazard map showing the higher hazard of the CVSZ (figure adapted from USGS).

Regional Geologic Structure

The regional geologic structure in central Virginia is oriented mainly southwest-northeast, along the strike of the Appalachian Mountains. A map showing known faults in Virginia, adapted from the State Geologic Map of Virginia (VDMR, 1993), is presented in Figure 2-5. Numerous faults in this region have been well mapped, although numerous smaller and/or deeply-buried faults remain undetected. Moreover, mapped faults are typically poorly located at earthquake depths. Few, if any, earthquakes in the CVSZ can be linked to named faults, meaning that regional seismic hazard assessments are based primarily on the locations of the earthquakes themselves (a commonly encountered situation east of the Rockies).

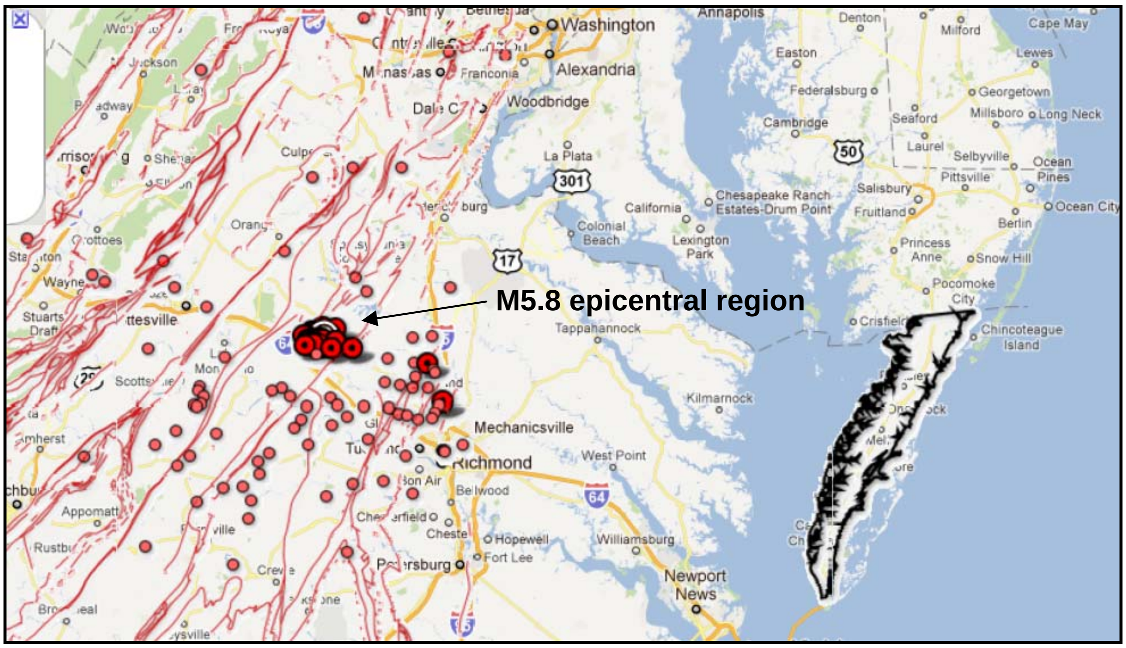


Figure 2-5 – Known faults in Virginia and locations of regional earthquakes (adapted from VDMR, 1993).

In the vicinity of the M5.8 epicenter near Mineral, VA, there are several well-known faults including the Chopawamsic Fault, the Lakeside Fault, and the Spotsylvania Shear Zone, as shown in Figure 2-6. These faults, like those throughout most of the state, are very old and related to tectonic events that assembled Pangea more than 300 million years ago. Even though these faults are old, and most are considered inactive, occasional earthquakes continue to occur in the region.

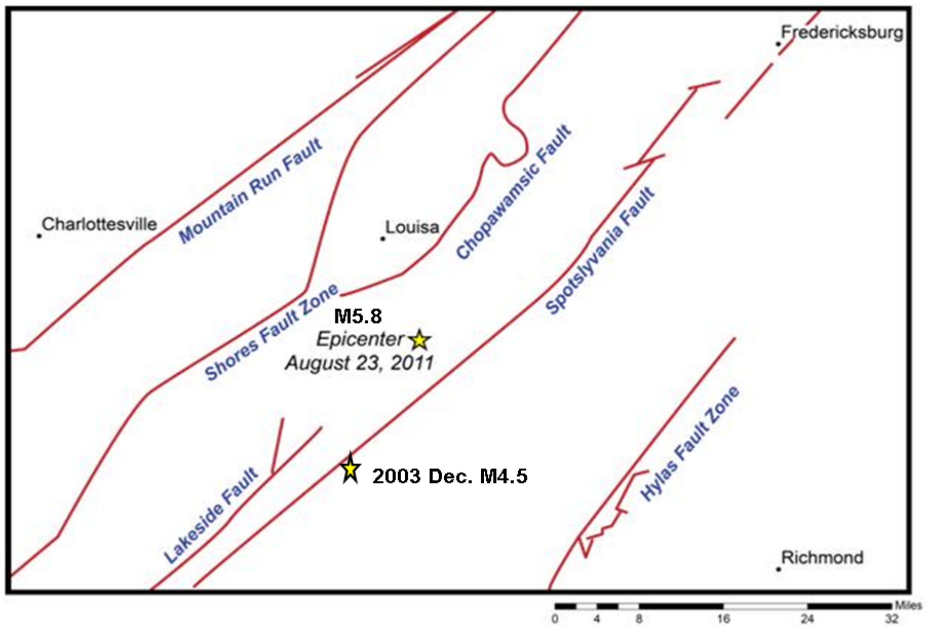
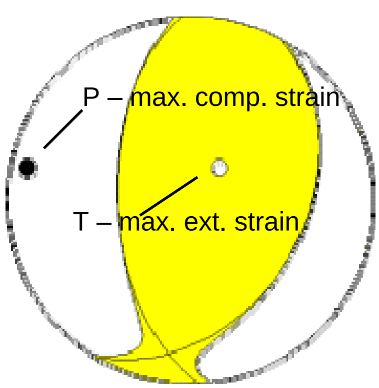


Figure 2-6 – Known faults in the epicentral region of the 2011 M5.8 and 2003 M4.5 Earthquakes (adapted from VA DMME, 2011).

As shown in Figure 2-7, moment tensor solutions developed by the USGS (2011b) indicate the M5.8 earthquake occurred due to reverse faulting on a north or northeast-striking plane, but neither this event nor previous earthquakes have been causally associated with mapped faults. Previous, smaller instrumentally-recorded earthquakes from the CVSZ have had shallow focal depths occurring at an average depth of about 8 km. These events have had diverse focal mechanisms and have occurred over an area with a length and width of approximately 120 km. They have not been aligned in a pattern that might suggest they occurred on a single causative fault.

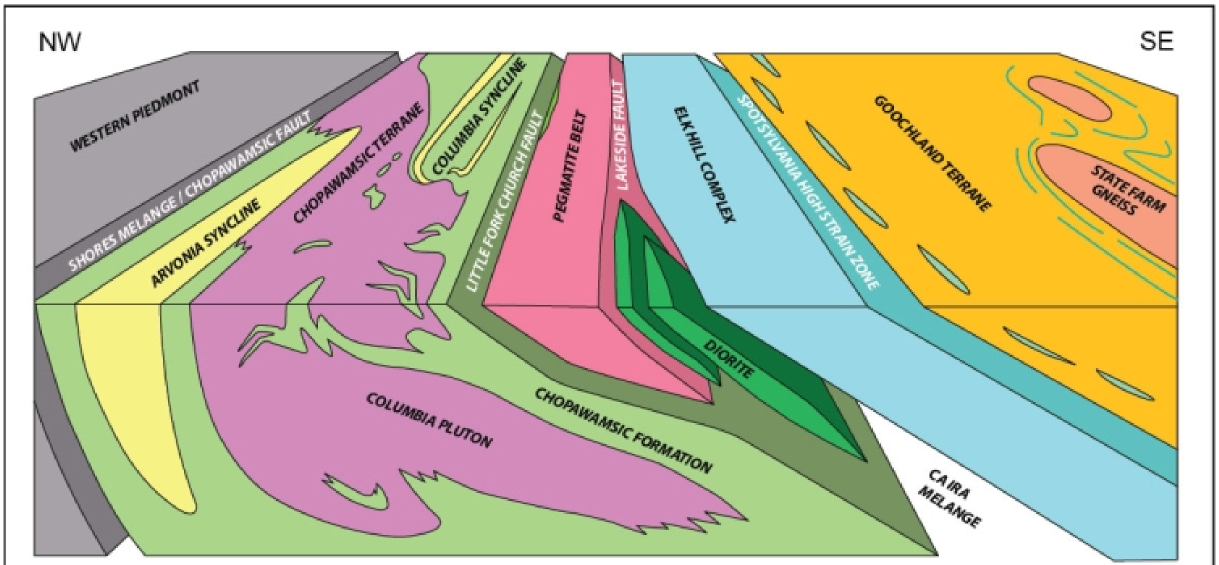


USGS/WPHASE CENTROID MOMENT TENSOR
11/08/23 17:51: 3.00 (UTC) Mw 5.8
Epicenter: 37.974 -77.968
Centroid: 37.974 -77.715
Depth 11 km No. of sta: 73
Moment Tensor; Scale 10**17 Nm
Mrr= 4.85 Mtt= 0.29
Mpp=-5.13 Mrt= 1.03
Mrp=-2.13 Mtp=-1.37
Principal axes:
T Val= 5.60 Plg=71 Azm= 42
N = 0.19 15 188
P = -5.79 10 281
Best Double Couple: Mo=5.7*10**17
NP1:Strike= 30 Dip=37 Slip= 117
NP2: 177 57 71

Figure 2-7 – Moment tensor solution of the M5.8 Earthquake indicating reverse faulting (USGS, 2011b). The shaded areas show quadrants of the focal sphere in which the first P-wave motions were away from the source. The black and white dots represent the maximum and compressive and extensional strain, respectively.

Individual earthquakes within the CVSZ occur as the result of slip on faults that are much smaller than the overall dimensions of the zone (USGS, 2011a). The dimensions of the fault that produced the M5.8 August 2011 earthquake will not be known until longer-term studies (ongoing) are completed; however, the spatial distribution of recorded aftershocks suggest a fault rupture plane approximately 10 km long by 6 - 7 km wide (USGS, 2011a; M. Chapman, personal communication).

A block diagram showing the main geologic structures within the CVSZ is shown in Figure 2-8. A detailed discussion of epicentral-area geologic structure, especially as it pertains to the M5.8 event and other recent earthquakes, is provided by Harrison et al. (2011), Bailey (2004), and Spears et al. (2004), among others. A description of the bedrock geology of the epicentral region (Ferncliff, VA 7.5-minute Quadrangle) is also presented in Appendix A of this report.



Schematic block diagram showing relationship of major structural elements in the central Virginia Piedmont.

Figure 2-8 Geologic structures within the CVSZ (adapted from Spears at DMME 2011).

In previous efforts to better understand the underlying faulting structure, a deep seismic profile was run along Interstate 64 from the Valley and Ridge to the Coastal Plain (Harris et al., 1986). As shown in Figure 2-9, the I-64 seismic profile is only about 5.5 km southwest along strike of the M5.8 hypocentral area and provides at least some insight into the faulting structure. The highlighted box in Figure 2-10 indicates the approximate position of the M5.8 hypocenter within the profile 5.5 km southwest along strike from the event.

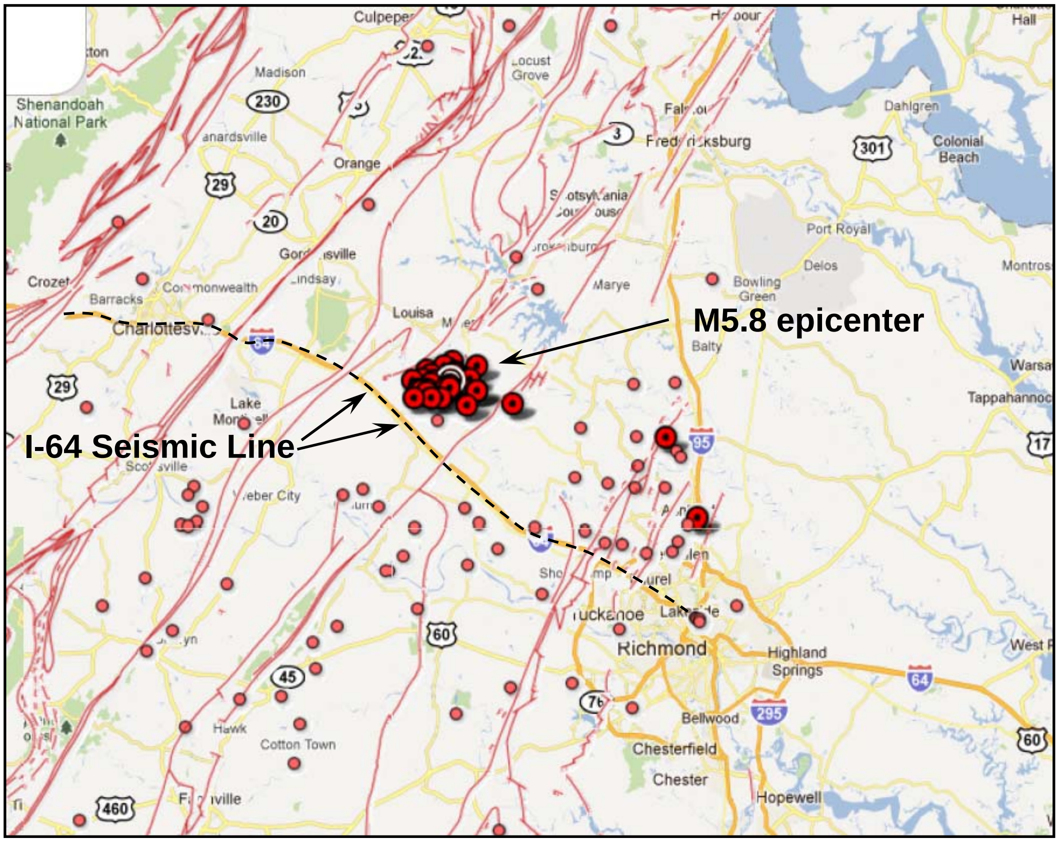


Figure 2-9 - Location of 1986 seismic line run along I-64 ~ 5.5 km SW of the M5.8 EQ (adapted from VDMR, 1993).

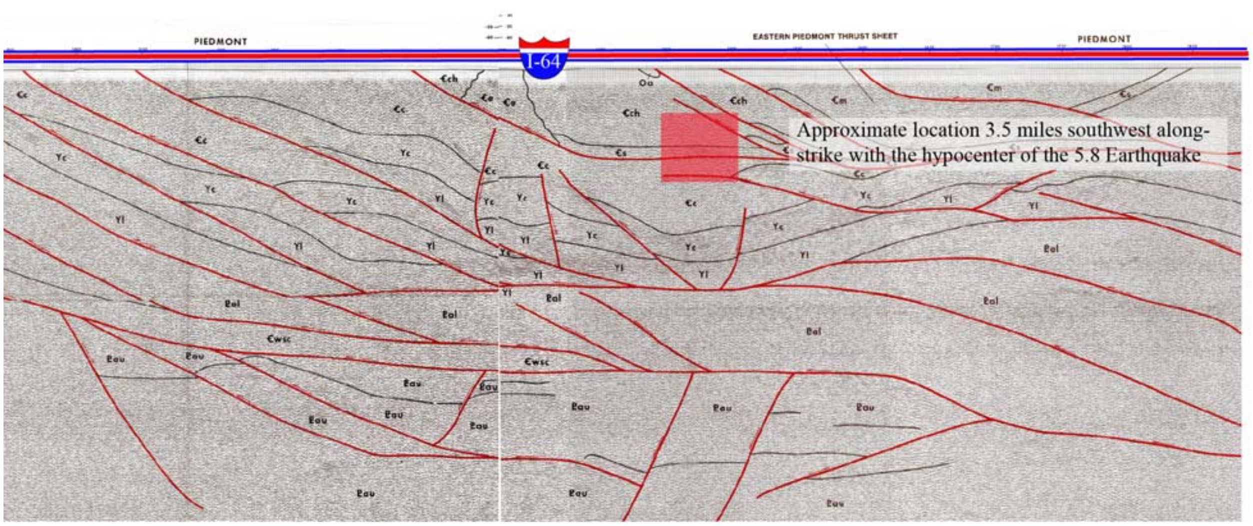


Figure 2-10 Seismic profile along I-64 showing structure beneath the CVSZ 5.5 km (3.5 mi.) SW of the M5.8 Earthquake (adapted from Harris et al., 1986 and VA DMME, 2011).

Surface Geology of the Epicentral Region (from M. Carter, personal communication)

The epicentral area is drained by the South Anna River and its major, secondary, and tertiary tributaries. Alluvium in the form of unconsolidated clay, silt, sand, and gravel of Tertiary to Quaternary age, occurs along portions of these streams, typically at leeward-side point bars and horseshoe bend cut-offs. Alluvium thickness in these areas ranges from a few meters to tens of meters.

Topographic sideslopes and hilltops are typically underlain by saprolite (decomposed bedrock chemically weathered in-place) beneath soil horizons. Saprolite typically ranges from a few meters to tens of meters thick.

These topographic settings are also typically mantled by thin deposits (typically less than a 0.5-meter thick) of gravel-, cobble- and boulder-size polycrystalline vein quartz. (Thin veins of quartz, in this region locally gold-bearing, are likely Paleozoic in age, and cross-cut metavolcanic, metaplutonic, and metavolcaniclastic rocks throughout the region). These vein quartz deposits may have accumulated in-situ from weathering of surrounding bedrock, but more likely are colluvial, having been transported and concentrated down-slope, albeit locally, via Cenozoic erosional processes.

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Spears, D.B., Owens, B.E., and Bailey, C.M., (2004), The Goochland-Chopawamsic Terrane Boundary, Central Virginia Piedmont: *US Geological Survey Circular 1264,* pp. 223-231.

USGS (2011a) U.S. Geological Survey (2011); viewed 21 September 2011 http://earthquake.usgs.gov/earthquakes/eqarchives/fm/neic_c0005ild_wmt.php

USGS (2011b) U.S Geological Survey (2011); viewed 21 September 2011 http://earthquake.usgs.gov/earthquakes/recenteqsww/Quakes/se082311a.php#summary

VA DMME (2011) Virginia Department of Mines, Minerals, and Energy, viewed 21 Sept. 2011 http://www.dmme.virginia.gov/DMR3/va_5.8_earthquake.shtml

VDMR (1993) - Virginia Division of Mineral Resources (1993), *Geologic Map of Virginia*, Department of Mines, Minerals, and Energy, Division of Mineral Resources, Charlottesville, VA.

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