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Dominion

July 8, 2004

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D.C. 20555

Serial No. 04-270
ESP/JDH
Docket No. 52-008

DOMINION NUCLEAR NORTH ANNA, LLC
NORTH ANNA EARLY SITE PERMIT APPLICATION
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION NO. 3

In its April 15, 2004 letter titled "Request for Additional Information Letter No. 3," the NRC requested additional information regarding certain aspects of Dominion Nuclear North Anna, LLC's (Dominion) Early Site Permit application. This letter contains our responses to the following requests for additional information:

2.5.1-1, 2.5.1-2, 2.5.1-3, 2.5.1-4, 2.5.2-2, 2.5.2-3, 2.5.2-4, 2.5.3-1

It is our intent to revise the North Anna ESP application to reflect our responses to these and other RAIs to support issuance of the NRC staff's draft safety and environmental evaluations scheduled for later this year. Planned changes to the application are identified following the response to each RAI.

If you have any questions or require additional information, please contact us.

Very truly yours,

Eugene S. Grecheck
Vice President-Nuclear Support Services

Enclosures:

1. Response to NRC RAI Letter No. 3

2. CD containing the following 2 references in response to RAI 2.5.2-2 Part b):
   a. Silva, W., N. Abrahamson, G. Toro, and C. Costantino (1996). Description and Validation of the Stochastic Ground Motion Model, Pacific Engineering and Analysis report, prepared for the Engineering Research and Applications Division, Department of Nuclear Energy, Brookhaven National Laboratory, Associated Universities, Inc., Upton, New York.
   b. Silva, W., N. Gregor, and R. Darragh (2002). Development of regional hard rock attenuation relations for central and eastern North America. Pacific Engineering and Analysis report, http://www.pacificengineering.org/CEUS/Development%20of%20Regional%20Hard_ABC.pdf

Commitments made in this letter:

1. Revise North Anna ESP application to reflect RAI responses.

cc: (with enclosures)

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COMMONWEALTH OF VIRGINIA

COUNTY OF HENRICO

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Eugene S. Grecheck, who is Vice President, Nuclear Support Services, of Dominion Nuclear North Anna, LLC. He has affirmed before me that he is duly authorized to execute and file the foregoing document on behalf of Dominion Nuclear North Anna, LLC, and that the statements in the document are true to the best of his knowledge and belief.

Acknowledged before me this 8th day of July, 2004.

My Commission expires: 3/31/08

Maggie McClure
Notary Public

(SEAL)

Enclosure 1

Response to NRC RAI Letter No. 3

RAI 2.5.1-1 (NRC 4/15/04 Letter)

Section 2.5.2 of the site safety analysis report (SSAR) concludes that the Central Virginia seismic zone (CVSZ) is the largest contributor to the seismic hazard for the ESP site. SSAR Section 2.5.1.1.4 (pg 2-2-194 and 195) summarizes the findings of Obermeier and McNulty (Reference 71), who conducted reconnaissance studies in search of paleoliquefaction features associated with the CVSZ.

<u>RAI 2.5.1-1 Part a)</u>

a) The Obermeier and McNulty study (Reference 71) regarding paleoliquefaction was limited in time interval (mid- to late-Holocene) and geographic coverage. Therefore, please provide additional justification for the SSAR statement:

> "The near-total lack of widespread paleoliquefaction features in the 300 km of stream exposures searched within the Piedmont, has led some researchers (Reference 71) to conclude that it is unlikely that any earthquakes have occurred in central Virginia in excess of **M**~7."

<u>Response to Part a)</u>

The SSAR statement cited in the RAI is a summary statement paraphrased directly from Obermeier and McNulty (1998). As indicated in the RAI, however, the statement as written is ambiguous in terms of time interval and geographic coverage of the liquefaction study. This wording of this statement will be clarified.

Further information on the area of geographic coverage and age of the liquefaction features is provided in the responses to Parts b) and c).

<u>RAI 2.5.1-1, Part b)</u>

b) The findings of Obermeier and McNulty (Reference 71) indicate the presence of two Holocene paleoliquefaction features in the CVSZ. According to SSAR Section 2.5.1.1.4, these two paleoliquefaction features are located along the James and Rivanna Rivers, about 25-30 miles from the ESP site. Please provide justification for concluding that, in spite of the occurrence of recent earthquake(s) that produced paleoliquefaction features in the CVSZ, such earthquakes are not abundant in the seismic zone, and for concluding that the earthquakes that produced these liquefaction features are "local shallow moderate magnitude earthquakes of **M** 5 to 6." In addition, please describe the impact of these liquefaction-producing earthquake events on the recurrence model used for the CVSZ.

Response to Part b)

Our interpretation of the liquefaction features identified in the CVSZ by Obermeier and McNulty (1998) in terms of the frequency and size of earthquakes that produced these features is based primarily on the experience and judgment of Dr. Steve Obermeier and related published literature that relates the size and geographic distribution of liquefaction features to earthquake size (e.g., Olson et al., 2003, revised 2004, Obermeier, 1996, Ambrayses, 1988). Dr. Obermeier's approach for relating the size and distribution of liquefaction features to earthquake magnitude is described in his most recent paper (Obermeier et al., 2004). Based on this information, the liquefaction features identified by Obermeier and McNulty (1998) are interpreted to represent at least one and possibly two moderate magnitude earthquakes in the CVSZ in the middle to late Holocene. Because of the absence of liquefaction features in otherwise susceptible middle to late Holocene deposits elsewhere in the study area, Obermeier interprets these liquefaction features to be the result of localized moderate sized earthquakes. In the SSAR, these magnitudes are estimated to be in the range of **M** 5 to 6. In further discussions with Dr. Obermeier during the preparation of this RAI response, the magnitude range that likely produced the liquefaction features is more likely **M** ~5.5 to 6.5. The SSAR will be revised to reflect this estimate. Larger earthquakes on the order of **M** ~7 would have produced a more widespread liquefaction field with more numerous, larger liquefaction features. As concluded by Obermeier and McNulty (1998):

> The paucity of liquefaction features in central Virginia makes it seem unlikely that any earthquakes in excess of **M**~7 have struck there. Smaller earthquakes could have struck but not be recorded in the paleoseismic record of our study area, but even if **M**6-7 earthquakes had been relatively abundant, then many more liquefaction effects would have been expected.

Dr. Obermeier confirmed this initial interpretation in recent discussions with him. On the basis of the large amounts of outcrop of liquefiable deposits of mid-Holocene age along the Pamunkey River near Ashland, and along the Robinson and Rapidan Rivers located farther to the northwest, Dr. Obermeier informed us that his comments about a **M**~7 earthquake are very probably valid. Dr. Obermeier also stated that there is a lot of outcrop of likely mid-Holocene age deposits near site SA-3 [see description of this site below], likely containing liquefiable sands, in which there is no evidence of liquefaction. So, even if the features at SA-3 are seismic dikes, the overall effects do not indicate very strong seismic shaking, stronger than MMI ~ VII to VIII.

Thus, the liquefaction features identified by Obermeier and McNulty are best interpreted to be the result of at least one and possibly two moderate magnitude earthquakes occurring in the CVSZ. In Obermeier's opinion, he canvassed thousands of meters of exposure of liquefiable deposits in his search area, and the absence of liquefaction in these deposits and restricted nature of the observed liquefaction features indicates that a magnitude **M**~7 earthquake has not occurred in the Holocene and that abundant magnitude **M**~6-7 earthquakes have not occurred in the Holocene within the CVSZ. It should be noted, however, that Obermeier did not perform any subsurface geotechnical investigations to confirm the liquefaction susceptibility of deposits along the rivers searched in the CVSZ. The interpretation that the riverine deposits are susceptible to liquefaction is based on the judgment of Obermeier from his years of experience investigating similar riverine deposits along rivers in other parts of the eastern and central United States.

The occurrence of two moderate magnitude earthquakes in the CVSZ during the Holocene as recognized from the liquefaction data is consistent with the earthquake recurrence estimates for the CVSZ provided in the EPRI seismic source model. The mean recurrence interval for earthquakes exceeding different magnitudes can be computed from the EPRI team models using each team's parameters for modeling the CVSZ. Table 1 shows this computation for five of the six EPRI teams. (The Law Engineering team did not delineate a specific CVSZ geometry but relied instead on larger zones with "local smoothing" of seismicity parameters to capture the higher rate of earthquake activity in the central Virginia region.)

Table 1. Summary of Recurrence Intervals for the CVSZ

		Recurrence interval (yrs) for				
		m_{Lg}>5.43	m_{Lg}>5.87	m_{Lg}>6.26	m_{Lg}>6.6	m_{Lg}>6.91
Team	**Source**	**M**>5.0	**M**>5.5	**M**>6.0	**M**>6.5	**M**>7.0
Bechtel	E	596	5155	43,054	Infinity	Infinity
Dames & Moore	40	608	1,977	6,970	66,350	214,327
Law Engineering	---					
Rondout	29	311	888	2,683	13,510	401,337
Woodward-Clyde	27	522	2,016	8,668	31,864	Infinity
Weston Geophysical	22	407	2,243	18,557	Infinity	Infinity
	Average*:	458	1,806	7,055	41,503	698,574
	No. of events per 10,000 yrs:	22	6	1	<1	<<1

* average recurrence interval calculated as inverse of average frequency of exceedance.

Table 1 shows for example that the average recurrence interval for **M**>6 specifically associated with the CVSZ by the EPRI teams is 7055 years, meaning that, on average, about 1 event of this size would be expected over a period of 10,000 years. Similarly, approximately 6 events of **M**>5.5 would be expected over a period of 10,000 years. Thus, the evidence of liquefaction features described by Obermeier and McNulty (1998) is consistent with both the size and recurrence of magnitude ~**M5.5 to** 6.5 earthquakes in the CVSZ.

2.5.1-1 Part c)

c) Considering that the CVSZ is the major contributor to the hazard at the ESP site, please provide the following additional information:

i) a map showing the locations of the paleoliquefaction features relative to the ESP site,

ii) evidence that supports the stated ages of the liquefied sediments,

iii) specific locations, dimensions, and characteristics of the liquefaction features, and

iv) extent of the CVSZ covered by the study.

Response to Part c)

Given the importance of the CVSZ as a major contributor to hazard at the North Anna ESP site, the RAI requests additional information on the detailed location and characterization of the liquefaction features and the location of the liquefaction study area relative to the CVSZ.

Location. A map showing the general area covered by the Obermeier and McNulty, 1998 study relative to the location of the North Anna site and the Central Virginia Source Zone as identified by the EPRI teams is shown on Figure 1. [Figures are located at the end of the RAI response.] A detailed map showing the locations of rivers canvassed by Obermeier and McNulty (1998) in relation to the North Anna ESP site is shown in Figure 2. This figure is modified from a figure produced by Obermeier for presentations, but never published. Figure 2 shows the locations of the liquefaction features identified during the study, as well as the locations of exposures of middle to late Holocene liquefiable deposits along rivers that did not contain liquefaction features. In general, more than 300 kilometers of rivers were examined by canoe in the summer of 1997 following a severe drought that revealed extensive exposures of stream banks that are rarely exposed. In recent discussions however, Dr. Obermeier indicated that parts of the North Anna River were surveyed following a rainstorm, such that high water submerged many exposures along the river and prevented continuous evaluation. As shown on the map, the liquefaction study area included many river segments over a broad regional area encompassing a large part of the CVSZ as identified by the EPRI teams.

Age. The age of the liquefaction features are based, in part, on the age of the host sediment and the degree of weathering of the observed liquefaction feature relative to the host sediment. Obermeier and McNulty, 1998 surveyed over 300 kilometers of riverbank. They calibrated the age of the riverbank deposits by obtaining 17 radiocarbon dates. The radiocarbon dates were from fragile seeds, leaves and twigs, and thus the dates closely approximate the age of the sediments. No detrital charcoal samples were analyzed to avoid reworked charcoal fragments that have the potential to yield dates that would be older than the host sediment. The dates range in age from 190 years to 21,000 years, with most dates from the middle Holocene (2,000 to 5,000 years old). The samples were selected to avoid sediments that were obviously young (e.g., historic). The sample ages were used to calibrate the approximate age of map units along each river. Obermeier and McNulty (1998) generally recognized deposits in two age ranges within which they focused their observations: (1) ~ 5,000 years old or older, and (2) 2,000 to 3,000 years old. A liquefaction feature observed within deposits 2,000 to 3,000 years old must be that age or younger. A liquefaction feature observed within deposits 5,000 years old or older must be that age or younger. If the liquefaction feature is weathered along with the surrounding sediment, the age of the liquefaction feature is interpreted to more closely approximate the older age.

Specific Liquefaction Features. Obermeier and McNulty (1998) cite one probable late Holocene liquefaction feature (Site JAR-1) and one possible early to mid Holocene liquefaction feature (Site Cedar Branch-1). In recent discussions with Dr. Obermeier, he also indicated a third possible Holocene feature at site SA-3. Each of these locations is shown on Figure 2 and described in greater detail below.

(1) Probable late Holocene liquefaction feature along the James River (Locality JAR-1, Perkinsville 7.5 minute quadrangle). Several liquefaction dikes were observed at this location on the James River in deposits 2,000 to 3,000 years old (Figures 3, 4 and 5). The dikes are concentrated in a zone about 10 feet wide. The dikes are sand-filled tabular intrusions within a clay-rich cap. The dikes are generally less than 1 centimeter wide, although one dike is up to 10 centimeters wide. The dikes extend below river level so their vertical continuity and length is not known. A sand bed is present about 4 feet below the water level (at that time) and may be the source bed for the sand dikes. A radiocarbon date from the host sediment yields a date of 190 years, although Obermeier is skeptical of such a young age. Figures 3, 4 and 5 show photos taken by Obermeier and McNulty of two of the liquefaction dikes observed at the James River locality.

(2) Possible early to middle Holocene liquefaction feature along the Rivanna River (Locality Cedar Branch – 1, Boyd Ranch 7.5 minute quadrangle). Three possible liquefaction dikes were observed near the confluence of the Rivanna River with Cedar Branch. Two of the dikes were near the confluence of the two streams; the third dike is located several hundred

feet upstream on Cedar Branch. The dikes are less than 1 centimeter wide and a little more than 0.5 meters in length, although their vertical continuity is not known with certainty. The dikes consist of clean sand, but the potential source bed could not be identified because water level in the river prevented hand excavation of the dike to depth. The dikes are estimated to be mid Holocene based on the age of the host sediment and weathering. No radiocarbon samples were available for dating at the locality; age of the host sediment was estimated through calibration of the map unit from dated radiocarbon samples collected elsewhere along the river. Obermeier photographed the features at Cedar Branch; but the dikes were not photogenic and are not distinct on the photos.

(3) Possible early to mid-Holocene liquefaction feature along the South Anna River (Locality SAR-3, Dabneys 7.5 minute quadrangle). In addition to the two liquefaction features described by Obermeier and McNulty (1998) and summarized above, Obermeier indicated in a recent conversation that a third liquefaction feature may be present along the South Anna River (Figure 3). At this site, a single tabular clastic dike extends across the river on both banks. The feature is highly weathered and Obermeier originally interpreted the feature to be an infilled weathered fracture or crack in the host sediment. Upon reviewing his notes and slides, however, he suggests that the feature may be a liquefaction dike. Age of the dike is estimated to be early to mid Holocene based on the age of the host sediment and degree of weathering. It is not known if this possible liquefaction feature is the same age as the possible liquefaction feature observed along the Rivanna River given the broad uncertainty in age control (i.e., early to mid Holocene). Thus, the two features may be the result of one earthquake or two earthquakes. If the possible liquefaction feature at SAR-3 is from a separate earthquake, the results of the Obermeier and McNulty (1998) study would indicate one probable and two possible earthquakes in the study area during the Holocene. Figures 6 and 7 are photos taken by Obermeier and McNulty of the possible liquefaction dike along the South Anna River at location SAR-3.

<u>References</u>

Ambrayses, N. N., 1988, Engineering Seismology: Earthquake Engineering and Structural Dynamics, Volume 16, pp. 985-1006.

Obermeier, S. F., 1996, Use of Liquefaction-Induced Features for Paleoseismic Analysis – An Overview of How Seismic Liquefaction Features can be Distinguished From Other Features and How Their Regional Distribution and Properties can be Used To Infer the Location and Strength of Holocene Paleo-Earthquakes: Engineering Geology, Elsevier Science, Volume 44, pp. 1-76.

Obermeier, S. F., and W. E. McNulty, 1998, Paleoliquefaction Evidence for Seismic Quiescence in Central Virginia During the Late and Middle Holocene Time [abs], Eos Transactions of the American Geophysical Union, Volume 79, No. 17, p S342, (Reference 71 of SSAR Section 2.5).

Obermeier, S. F., S. M. Olson, R. A. Green, 2004, in press, Field Occurrences of Liquefaction-Induced Features: A Primer For Engineering Geologic Analysis of Paleoseismic Shaking; Engineering Geology, Elsevier.

Olson, S. M., R. A. Green, and S. F. Obermeier, 2003 (revised 2004), Geotechnical Analysis of Paleoseismic Shaking Using Liquefaction Features: Part 1. Major Updating of Techniques for Analysis, U. S. Geological Survey Open-File Report 03-307.

Application Revision

SSAR Section 2.5.1.1.3.c.4, under the heading “Paleoliquefaction Features within the Central Virginia Seismic Zone,” will be revised to read as follows:

Paleo-Liquefaction Features within the Central Virginia Seismic Zone

Two sites of Holocene liquefaction have been reported within the CVSZ (References 59 and 71). These sites include an area of probable late Holocene (2,000 to 3,000 years old) liquefaction along the James River and a possible area of early- to mid-Holocene (~5,000 years old) liquefaction along the Rivanna River (Reference 71). In an April 2004 discussion, Dr. Obermeier suggested that a third site of possible early- to mid-Holocene liquefaction may also be present along the South Anna River.

The presence of these probable or possible paleo-liquefaction features along the James, Rivanna and South Anna Rivers, about 25–30 miles from the site, shows that the Central Virginia seismic zone reflects both an area of paleo-seismicity as well as observed historical seismicity. Based on the absence of widespread paleo-liquefaction, however, Obermeier and McNulty (Reference 71) conclude that an earthquake of Magnitude 7 or larger has not occurred within the seismic zone in the last 2,000–3,000 years, or in the eastern portion of the seismic zone for the last 5,000 years. They also conclude that the geologic record of one or more magnitude 6 or 7 earthquakes might be concealed between streams, but that such events could not have been abundant in the seismic zone. In addition, these isolated locations of paleo-liquefaction may have been produced by local shallow moderate magnitude earthquakes of **M** 5.5 to 6.5. Thus, the presence of these liquefaction features does not indicate a change in the smallest maximum magnitude level assigned to the Central Virginia seismic zone in the 1986 EPRI study. Because the causative faults remain unidentified, the Central Virginia seismic zone is best characterized as a seismogenic source and not a capable tectonic source, as defined by RG 1.165.

The last paragraph of SSAR Section 2.5.2.2.8 will be revised to read as follows:

> Since the EPRI study, one probable and two possible liquefaction features have been found within the Central Virginia seismic zone. As described in Section 2.5.1.1.4, these new observations are consistent with the Mmax values and recurrence parameters assigned by the EPRI teams. The lack of widespread liquefaction features in the 300 km of stream exposures searched within the CVSZ despite the presence of mid- to late-Holocene potentially liquefiable deposits, has led some researchers (Reference 71) to conclude that it is unlikely that any earthquakes have occurred in the area investigated in excess of **M**~7 during the Holocene.

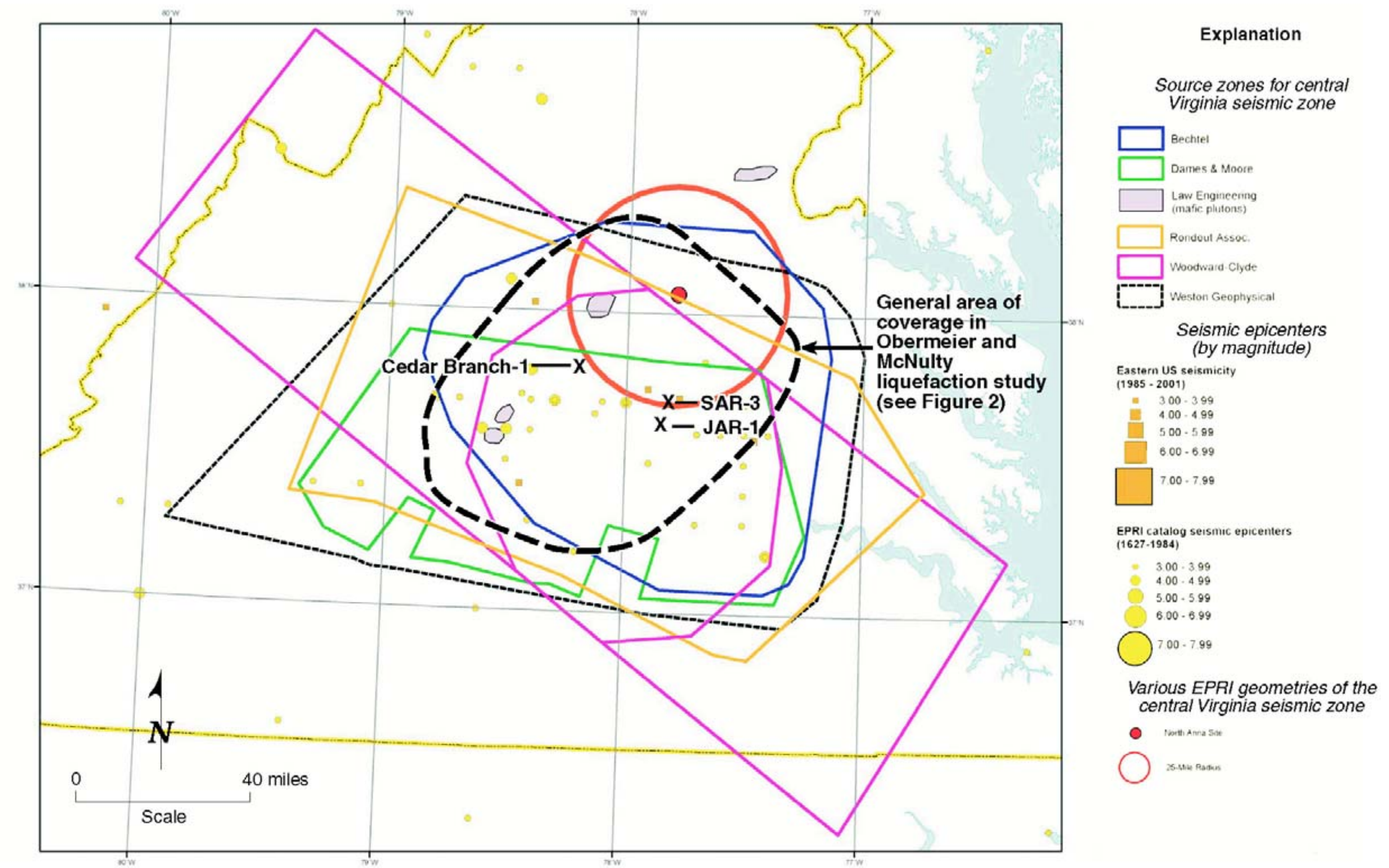

Figure 1. Map showing general area of coverage of Obermeier and McNulty (1998) liquefaction study relative to interpretations of the Central Virginia Seismic Zone.

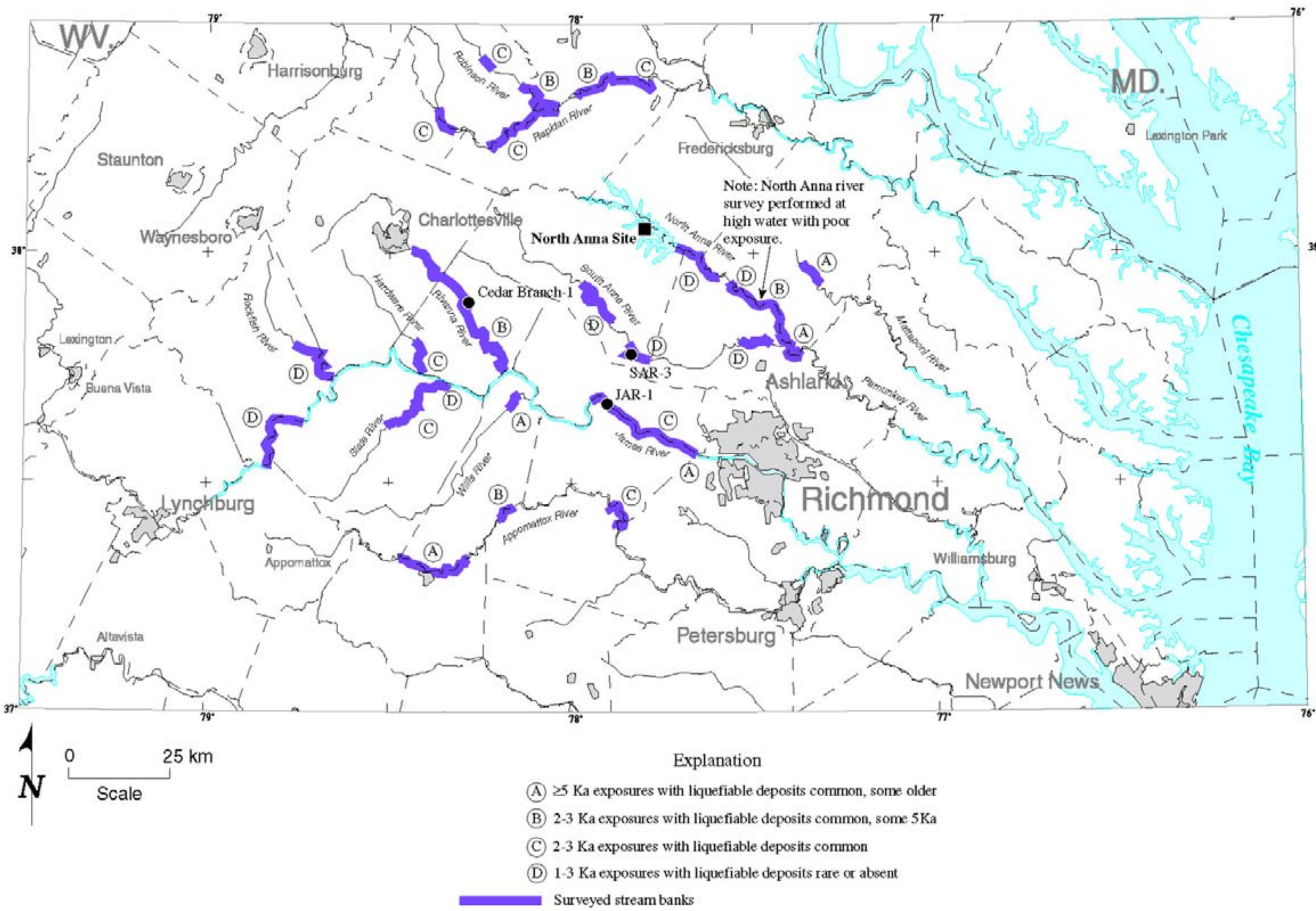

Figure 2. Map of Central Virginia Seismic Zone liquefaction features. This figure is modified from a figure produced by Obermeier for presentations, but never published.

Figure 3. Late Holocene liquefaction dikes along the James River, Perkinsville 7.5-minute quadrangle. (JAR-1).

Figure 4. Late Holocene liquefaction dike along the James River (location JAR-1).

Figure 5. Late Holocene liquefaction dike (10 cm wide) along the James River (Location JAR-1).

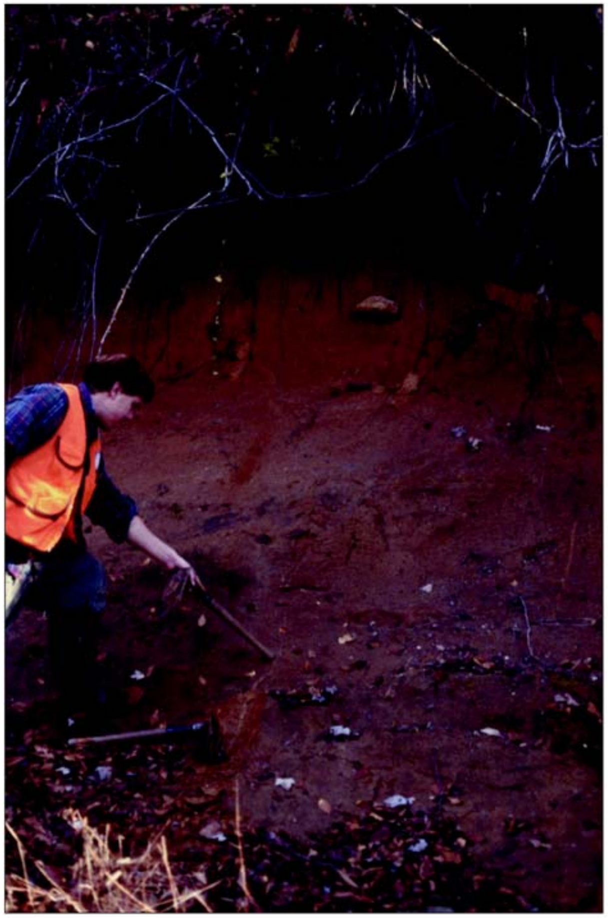

Figure 6. Possible mid Holocene liquefaction dike along the South Anna River (Location SAR-3)

Figure 7. Close-up view of possible mid-Holocene liquefaction dike along the South Anna River, 7.5-minute quadrangle (location SAR-3).

RAI 2.5.1-2 (NRC 4/15/04 Letter)

> In SSAR Section 2.5.1.1.4, Dominion concludes on the basis of several lines of evidence, including aerial reconnaissance, that the northern segment of the East Coast Fault System (ECFS) “probably does not exist or has a very low probability of activity if it does exist.” Please provide additional information on the nature of the aerial reconnaissance for the ECFS, including the area covered and the type of evidence used to conclude that the northern segment of the ECFS does not exist or has low probability of activity. Please explain how information gathered during the aerial reconnaissance and from other sources supports conclusions in the SSAR that appear to be inconsistent with those made in the detailed geomorphic analysis of Marple and Talwani (Reference 74).

Response

Our conclusion, presented in SSAR Section 2.5.1.1.4, that the northern segment of the ECFS (Marple and Talwani, 2000) has a low probability of existence and a low probability of activity is based on critical evaluation of the evidence presented by Marple and Talwani (2000), aerial reconnaissance, and professional judgment.

The RAI states that the conclusions regarding the northern segment of the ECFS in the SSAR “appear to be inconsistent with the detailed geomorphic analysis of Marple and Talwani.” In our view, Marple and Talwani (2000) did not perform a very detailed or rigorous geomorphic analysis to conclude that an active fault is present beneath the coastal plain of North Carolina and Virginia. As discussed in this response, critical evaluation of the evidence by Marple and Talwani (2000) strongly shows that the northern segment of the ECFS probably does not exist or, if it does exist, has a very low probability of being active during the late Cenozoic.

The SSAR conclusions regarding the northern segment of the ECFS were developed primarily from a critical evaluation of the geomorphic observations and interpretations presented by Marple and Talwani (2000) in the Coastal Plain of Virginia and northern North Carolina. The aerial reconnaissance, which was performed only on the northernmost portion of the northern segment of the ECFS, played an important but less significant role in developing our conclusions. The response to this RAI is organized into the following sections:

- *Description of evidence presented by Marple and Talwani (2000) to conclude that a buried fault system (i.e., the ECFS) is present beneath the Coastal Plain of the southeastern United States.* In this discussion, we distinguish between the evidence cited by Marple and Talwani (2000) for the southern and central segments of the ECFS and evidence cited for the northern segment of the ECFS;

- *Validity and independent evaluation of the evidence presented by Marple and Talwani (2000) for the northern segment of the ECFS.* This section evaluates the geological, geophysical and geomorphic evidence cited by Marple and Talwani (2000), and presents an alternative, non-tectonic explanation for each of the features identified by Marple and Talwani (2000);

- *Aerial Reconnaissance*. This section presents information from the aerial reconnaissance performed on March 10, 2003.

1. <u>Evidence Presented by Marple and Talwani (2000)</u>

Marple and Talwani (2000) draw on geological, geophysical, seismological and geomorphic evidence to support their interpretation of the presence, location and activity of the ECFS. The location of the ECFS as described by Marple and Talwani (2000) is shown in Figure 1. [Figures are located at the end of the RAI response.] A detailed map of the northern segment of the ECFS is shown in Figure 2.

The types of evidence for the entire ECFS (southern, central, and northern segments) are described below:

(a) Geologic evidence for the ECFS cited by Marple and Talwani (2000) includes:

- Westward termination of the Cape Fear and Norfolk arches along the NE-SW trend of the ECFS
- Quaternary uplift and arching across the ECFS, inferred from structure contours on Pliocene-Quaternary stratigraphic units and contacts.
- Association of Plio-Pleistocene surface faults with the ECFS trend

(b) Geophysical and seismological evidence for the ECFS cited by Marple and Talwani (2000) includes:

- Small earthquakes clustered along the southern end of the ECFS
- Discontinuities imaged on reflection seismic data along the ECFS, interpreted as subvertical faults
- Spatial association of linear aeromagnetic anomalies with the ECFS

(c) Geomorphic evidence for the ECFS cited by Marple and Talwani (2000) generally consists of a NE-SW alignment of “river anomalies”; i.e., variations in the character of streams and their valleys across the ECFS that Marple and Talwani (2000) interpret as evidence for neotectonic activity of blind or buried faults. Specific geomorphic features cited as anomalies by Marple and Talwani (2003) include:

- Local incision of streams into their floodplains, and formation of flights of fluvial terraces

- Abrupt changes in valley morphology, such as broad floodplains giving way to incised, V-shaped valleys.

- Systematic variations in stream sinuousity

- Local fluvial aggradation and anastomosing stream patterns

- Local convexities in the longitudinal profiles of “fluvial surfaces”, which are not explicitly defined, but presumably include channels and floodplains

- Formation of incised channel meanders with a preferred convex-to-the-northeast morphology

It is important to note that most of the data used by Marple and Talwani (2000) to support their interpretation of the ECFS apply exclusively to the southern and central segment of the fault system (i.e., the “southern zone of river anomalies”, or “ZRA-S”, and “central zone of river anomalies”, or “ZRA-C”). The actual number and quality of the data used to infer the presence of the northern segment of the fault system (i.e., “ZRA-N”) is significantly less than that for the ZRA-S and ZRA-C segments. Marple and Talwani (2000) note that:

> Evidence of uplift from stratigraphic and elevation data is sparse, but supports the location of the ZRA-S and ZRA-C and uplift along them. The best evidence for uplift along the zones is along the ZRA-S near Summerville.

Marple and Talwani (2000) further acknowledge that there is a greater preponderance of evidence in support of the southern ECFS in the introduction to the “Discussion” section of their paper:

> The following discussion deals largely with the ZRA-S because more corroborative data are available along its trend than for the ZRA-C and ZRA-N.

Thus, much of the data and observations reported by Marple and Talwani (2000) apply only to the southern segment, or to the southern and central segments of the postulated ECFS, and do not apply to the northern segment of the fault system. Table 1 summarizes the information presented by Marple and Talwani (2000) that specifically applies to the northern segment of the ECFS (ZRA-N).

Table 1. Evidence Used by Marple and Talwani (2000) to Define the ZRA-N (from north to south)

River/Location	River Anomaly/Line of Evidence	Type	Presented in Marple and Talwani (2000): Text	Table	Figure	Argument Against Tectonic Interpretation
Interstate 64	high angle crustal boundary in I-64 seismic line	Geophysical	p. 213		7	low angle, E-dipping, crustal boundary identified as Paleozoic Spotsylvania thrust fault
Blackwater	uplifted fluvial surface (2 m)	Geomorphic		1, 2	11	no uplift demonstrated by M&T; only convexity of river profile
Near Nottoway R.	western termination of the Norfolk Arch	Geological	p. 213		7	Pazzaglia (1993) shows NFA terminating against Fall Line, which is west of ECFS
Nottoway	cross-valley change and tilting to NE	Geomorphic	p. 215	1	DR6	Pliocene Coastal Plain units not tilted; geomorphology explained by fluvial processes in river meander bend
Three Creek	uplifted fluvial surface (2 m)	Geomorphic		1, 2	11	profile of Plio-Pleistocene river terraces reveals no uplift
Fountains	uplifted fluvial surface (1 m)	Geomorphic		1, 2	11	no uplift demonstrated by M&T; only convexity of river profile
Roanoke	cross-valley change and tilting to SW	Geomorphic	p. 201, 210	1	15	geomorphology explained by fluvial processes in river meander bend
Roanoke	anastomosing stream pattern u/s	Geomorphic		1	15	anastomosing reach located downstream of Fall Zone and dam
Roanoke	deflection to SW	Geomorphic		1	7	no evidence for tectonic control of deflection presented by M&T
Marsh Swamp	uplifted fluvial surface (2 m)	Geomorphic		1, 2	11	no uplift demonstrated by M&T; only convexity of river profile
Marsh Swamp	deflection to SW	Geomorphic	p. 211	1	7	no evidence for tectonic control of deflection presented by M&T

Table 1. Evidence Used by Marple and Talwani (2000) to Define the ZRA-N (from north to south)

River/Location	River Anomaly/Line of Evidence	Type	Presented in Marple and Talwani (2000): Text	Table	Figure	Argument Against Tectonic Interpretation
Fishing Creek	incision (3 m)	Geomorphic		1	7	not reproducible on 7.5' quadrangle topography
Fishing Creek	uplifted fluvial surface (1.5 m)	Geomorphic		1, 2	11	no uplift demonstrated by M&T; only convexity of river profile
Fishing Creek	sinuosity change (low u/s; increase immed. d/s)	Geomorphic		1	DR3	reported variations in sinuosity not consistent with experimental results of Ouchi (1985)
Swift Creek	uplifted fluvial surface (2 m)	Geomorphic		1, 2	11	no uplift demonstrated by M&T; only convexity of river profile
Swift Creek	deflection (C-NNE)	Geomorphic		1	7	no evidence for tectonic control of deflection presented by M&T
Tar	incision (3 m)	Geomorphic		1	7	not reproducible on 7.5' quadrangle topography
Tar	deflection to NE	Geomorphic		1	7	no evidence for tectonic control of deflection presented by M&T

2. Validity and Independent Evaluation of Evidence Presented by Marple and Talwani (2000)

This section explicitly evaluates the geologic, geophysical, seismological and geomorphic data used by Marple and Talwani (2000) to infer the presence of the ZRA-N (Figure 2; also, Table 1).

2.1 Geological Data

The majority of geological data cited by Marple and Talwani (2000) in support of the postulated ECFS apply only to the ZRA-S and ZRA-C segments. Structure contour maps used by Marple and Talwani (2000) to interpret local Quaternary uplift and arching over the ECFS are presented for the ZRA-S only. Pliocene-Pleistocene surface faults associated with the ECFS are noted along the ZRA-C only (Figure DR7 in Marple and Talwani, 2000). There are no Pliocene-Pleistocene faults or structure contour maps indicating uplift along the ZRA-N segment of the ECFS.

The only geologic data that Marple and Talwani (2000) cite in support of the ZRA-N is the coincidence of the ZRA-N with the westward termination of the Norfolk arch axis (Figures 1 and 2; Table 1). Marple and Talwani (2000) note that their depiction of the Norfolk arch axis is “modified” from a small-scale map in Pazzaglia (1993), which shows the arch axis terminating westward against the Fall Zone. Specifically, Marple and Talwani (2000) have modified Pazzaglia’s map by showing the Norfolk arch axis as terminating about 25 km east of the Fall Zone, on trend with their inferred location of the ZRA-N. Marple and Talwani (2000) provide no additional references, interpretations or original data to justify their changes to Pazzaglia’s map of the Norfolk arch axis. Thus, it is not possible to determine if their modification of the Norfolk arch axis is based on independent data, or simply a re-interpretation of the Norfolk arch location that is compatible with their model of the ZRA-N. We conclude that the location of the Norfolk arch axis, as presented in Marple and Talwani (2000), does not provide independent geologic evidence in support of the ZRA-N. Therefore, there is no known geologic evidence to support the existence of the ZRA-N.

2.2 Geophysical and Seismological Data

The only geophysical or seismological data presented by Marple and Talwani (2000) in support of the ZRA-N is an east-west-trending seismic reflection profile along Interstate 64 (I-64) through central Virginia (Table 1). Marple and Talwani (2000) do not associate any seismicity with the ZRA-N (this observation is confined to the ZRA-S segment only).

On the I-64 reflection profile (see Figure 2 for location), Marple and Talwani (2000) assert that the reflector geometries “reveal a steep, deep-crustal boundary beneath the ZRA-N’s northern projection” (Marple and Talwani, 2000, p. 213), near shotpoint 3000. However, the two references cited by Marple and Talwani that present the original seismic reflection data (Çoruh et al., 1988; Pratt et al., 1988) do not interpret the presence of a “steep, deep crustal boundary” on trend with the ZRA-N at shotpoint 3000. The segment of the I-64 seismic line presented in Çoruh et al. (1988) actually terminates eastward at shotpoint 3000, and there is no steeply dipping discontinuity in the reflectors in the vicinity of shotpoint 3000.

The version of the I-64 profile presented by Pratt et al. (1988) extends approximately 80 km east of shotpoint 3000, and also does not image a steeply dipping structure in the vicinity of the postulated ZRA-N. On the contrary, the major crustal-scale feature in this region interpreted by Pratt et al. (1988) is an east-dipping shear zone beneath the Goochland terrain in the central Piedmont and Coastal Plain regions. This shear zone probably is equivalent to the east-dipping Spotsylvania thrust fault, which underlies the Goochland-equivalent rocks in the vicinity of the ZRA-N (Glover et al., 1995). In the structural model of Glover et al. (1995), which is based in part on the data and interpretations of Çoruh et al. (1988) and Pratt et al. (1988), the shear zone associated with the Spotsylvania thrust fault dips about 25° to 30° east and is present at a depth of about 30 km beneath the inferred ZRA-N. Glover et al. (1995) do not interpret a steeply dipping, crustal-scale shear zone in the vicinity of the ZRA-N.

To summarize, Marple and Talwani (2000) appears to us to inaccurately characterize the I-64 seismic reflection profile and interpretations of Çoruh et al. (1988) and Pratt et al. (1988) in stating that the data indicate the presence of a steeply dipping, crustal-scale shear zone in the vicinity of the ZRA-N. Çoruh et al. (1988) and Pratt et al. (1988) do not interpret a steeply dipping crustal shear zone in the vicinity of the ZRA-N. The only crustal-scale structure in this region interpreted by these workers in the reflection data is an east-dipping shear zone that underlies the Goochland terrain, and which is probably equivalent to the Spotsylvania thrust fault at the latitude of central Virginia. The SSAR summarized work by Glover et al. (1995) that presents and documents this structural model. We conclude that the I-64 reflection profile does not support the interpretation by Marple and Talwani (2000) of the presence or the geometry of a blind, steeply dipping fault zone coincident with the ZRA-N in Virginia, and that, there is no geophysical or seismological evidence to support the existence of the ZRA-N.

2.3 Geomorphic Data

2.3.1 Comparison of River Anomalies Among ZRA-S, ZRA-C and ZRA-N

Without substantiated geophysical, seismological or geological data, Marple and Talwani (2000) rely primarily on the presence of inferred “river anomalies” to postulate the existence of the ZRA-N and to define its extent and orientation. The geomorphic data presented by Marple and Talwani (2000), however, do not appear to provide a compelling case for the presence of the ZRA-N. In Table 1 of their paper, Marple and Talwani (2000) summarize their interpretation of geomorphic anomalies along streams that cross the three main segments of the ECFS. There are six categories of anomalies assessed for each stream. As summarized in Table 1 of Marple and Talwani (2000), these anomalies include channel incision, upward-displaced fluvial surfaces, cross-valley change, sinuosity change, anastomosing stream patterns, and "river deflections" (i.e., formation of pronounced, incised meanders).

For the ZRA-S, Marple and Talwani (2000) report a total of 23 anomalies along a total of five streams. Out of a total of 30 possible anomalies for these five streams (six anomaly categories times five streams), this represents an approximately 77% positive assessment of the presence of river anomalies. For the ZRA-C, Table 1 in Marple and Talwani (2000) reports 19 total anomalies along six rivers, indicating an approximately 53% positive assessment. For the ZRA-N, Marple and Talwani (2000) interpret 17 total anomalies along a total of ten streams. Out of a total of 60 possible anomalies, this represents an approximately 28% positive assessment.

These relations indicate that the expression of the ZRA-N, as characterized by the density of river anomalies selected by Marple and Talwani (2000), is significantly less than that of the ZRA-S and ZRA-C. Marple and Talwani (2000) also assessed fluvial anomalies in a "non-tectonic" region as a control. They report five total anomalies along four streams across the control region. Out of a total of 24 possible anomalies, the four streams in the control area exhibit an approximately 21% positive assessment. The percentage of anomalies along the ZRA-N is only slightly higher than that of the non-tectonic control region.

2.3.2 Critical Assessment of Geomorphic Anomalies Along the ZRA-N

As described above, Marple and Talwani (2000) use six categories of river anomalies to identify potential uplift and deformation along the ECFS. Of these six categories of anomalies, only "upward displaced fluvial surfaces" *require* a tectonic interpretation. The other five anomalies are examples of channel pattern change that can be and typically are produced by non-tectonic processes. As noted by Schumm (1986), "channel pattern change alone is not sufficient evidence for active tectonics, rather it is one bit of evidence that must be supported with other morphological evidence of aggradation, degradation or survey data."

In the following sections, we critically evaluate each of these geomorphic anomalies used by Marple and Talwani (2000) to define the ZRA-N (see summary in Table 1).

2.3.2.1 Channel Incision

As shown in their Table 1, "channel incision" is noted by Marple and Talwani (2000) along only two of the ten streams crossing the ZRA-N: the Tar River and Fishing Creek, both of which are located at the extreme southern end of the ZRA-N. If the observed channel incision along Tar River and Fishing Creek is driven by uplift, then we may expect to see consistent evidence along both streams for deformation of the adjacent floodplain and/or fluvial terrace. Of these two incised streams, however, only Fishing Creek is cited as having "upward displaced fluvial surfaces". Conversely, Swift Creek, Marsh Swamp River, Fountains River, Three River, and the Blackwater River are cited by Marple and Talwani as having "upward displaced fluvial surfaces", but the streams themselves are not incised. Marple and Talwani (2000) provide no explanation for this inconsistent fluvial response to what they interpret to be active uplift along the entire length of the ZRA-N.

Using 7.5-minute topographic maps, we examined the reaches of Fishing Creek and Tar River that are interpreted to be incised by Marple and Talwani (2000). The eastward limit of the incised reach of Fishing Creek shown in Figure 7 of Marple and Talwani (2000) is approximately located near the small town of Bricks, about 2 to 3 km south-southwest of Enfield. Inspection of these streams on the Ringwood and Enfield 7.5-minute quadrangles, however, shows that there are no changes in stream incision in this region, and specifically no obvious reduction in incision east of Bricks. In the case of the Tar River, the incised reach is shown by Marple and Talwani (2000) to terminate eastward at the town of Rocky Mount. Inspection of the Rocky Mount and Hartsease 7.5-minute quadrangle maps of this region indicate that the Tar River continues to be incised about 6 m below its adjacent terrace/floodplain for many kilometers downstream of Rocky Mount, and the incision is not a unique feature limited to the location of the postulated ZRA-N.

To summarize, local stream incision is reported only at the southern end of the ZRA-N, and is not systematically associated with "upward displaced fluvial surfaces" noted by Marple and Talwani (2000) along other streams that cross the ZRA-N. Also, we are unable to duplicate their observations of incision of Fishing Creek and the Tar River across the inferred location of the ZRA-N. In fact, inspection of available 7.5-minute topographic maps shows that distinct stream incision either is not present (e.g., Fishing Creek) or is not unique along the river channel at the location of the ZRA-N (e.g., Tar River). We conclude that Marple and Talwani's river anomaly of channel incision provides no evidence to support the existence, location or activity of the ZRA-N.

2.3.2.2 "Upward Displaced" Fluvial Surfaces

Marple and Talwani (2000) interpret the presence of "upward displaced fluvial surfaces" along six of the ten streams that cross the ZRA-N, and cite them as evidence for uplift spatially associated with the ZRA-N. If Marple and Talwani (2000) documented evidence of upward displaced fluvial surfaces, then tectonic deformation would be required to explain this anomaly. However, they did not observe or document upward displacement. Strictly speaking the features described by Marple and Talwani (2000) are not "upward displaced fluvial surfaces", but rather convexities in the longitudinal profiles of these river floodplains. Marple and Talwani (2000) incorrectly interpret convexity as a proxy for tectonic uplift. Because streams at grade typically exhibit smooth, concave longitudinal profiles, local convexities in the profiles indicate a departure from equilibrium. Although a convexity can be produced by local uplift of the channel and adjacent floodplain, several non-tectonic processes also can locally perturb a stream from an equilibrium condition and produce a convexity in its longitudinal profile (Schumm, 1986).

Apparent convexities in longitudinal stream and valley profiles may occur at the confluence of two streams. For example, the eastern limit of the convexity along Three Creek noted by Marple and Talwani (2000) coincides with the confluence of Three Creek and the Roanoke River. When two rivers merge, the gradient of the natural concave profile will change due to increased discharge and sediment load downstream of the confluence, commonly producing a steeper gradient. Hence, two concave profiles will “intersect” at the confluence, basically producing a “peak” or “cusp” in the longitudinal profile. When “smoothed”, this peak looks like a convexity in the profile. The convexity in the Three Creek longitudinal profile appears to simply reflect its confluence with the Roanoke River, and not tectonic uplift.

The convexities interpreted as “upward displaced fluvial surfaces” by Marple and Talwani (2000) along six of the ten streams crossing the ZRA-N are shown in Figure 3. For the Blackwater River, Three Creek and Fountains Creek, Marple and Talwani (2000) sketched a smooth concave profile joining the reaches of these streams upstream and downstream of the convexity. They measured the vertical distance between their hypothetical, sketched concave profile and the peak of the convexity and reported it as “upward displacement” in their Table 1. Strictly speaking, however, what Marple and Talwani (2000) have reported as “uplift” is only the vertical distance between the observed fluvial surface and a hypothetical concave profile. They have not demonstrated that the convexities are due to uplift, and they use no rigorous method to derive the concave profile. As discussed above, there is no reported stream incision along five of the six streams that exhibit “upward displaced fluvial surfaces”, so the interpretation of tectonic uplift includes the implicit assumption that uplift (reported to range between 1 and 2 m in Table 1 of Marple and Talwani, 2003) occurred so recently that the streams have not yet begun to incise their channels.

Marple and Talwani’s (2000) interpretation of the convexities along three other rivers that cross the ZRA-N (i.e., Marsh Swamp River, Fishing Creek and Swift Creek) are not consistent with the actual shapes of the respective longitudinal stream profiles presented in their paper. In each of these cases, Marple and Talwani do not extend their model of the presumed original concave reach of the stream to the eastern end of the convexity in the profile. Alternative interpretations of graded concave profiles that encompass the entire length of the convexities on these streams are shown in red on Figure 3. These alternative interpretations are arguably more valid than those of Marple and Talwani (2000) because they show a hypothetical graded profile along the entire reach of the stream.

The alternative models of the graded profiles for the Marsh Swamp River, Fishing Creek and Swift Creek in Figure 3 are significant because they demonstrate that qualitative interpretations of anomalies in the longitudinal profiles are not unique. If the alternative interpretations are correct, it implies that the ZRA-N is more diffuse, less linear, and perhaps not on trend with the ZRA-S and ZRA-C as shown in Figure 7 of Marple and Talwani (2000). Also, the east-west extent of the expanded convexities ranges from about 17 km (Swift Creek) to 27 km (Marsh Swamp River). If these anomalies are due to tectonic uplift, then the implied width of the active ZRA-N along these drainages is 17 km to 27 km. This width is much greater than the zone of distributed surface deformation associated with typical active oblique strike-slip faults, which is the style of faulting suggested by Marple and Talwani (2000) for the ECFS. In fact, the east-west extent of the convexities is comparable to the *length* of many fault segments and seismic sources. In our view, the width of the ZRA-N inferred by Marple and Talwani (2000) is not consistent with observations of deformation associated with active faults in other regions. Finally, the greater east-west extent of the convexity on Fishing Creek than originally interpreted by Marple and Talwani (2000) has implications for their interpretation that variations in sinuosity along Fishing Creek are associated with the ZRA-N (this is discussed in greater detail below).

Finally, the uplift rate that Marple and Talwani (2000) derive by comparing their models of concave profiles with the observed longitudinal profiles is not consistent with the height of fluvial terraces above the modern channels. For example, Marple and Talwani (2000) estimate an uplift rate of 0.2 mm/yr for the ZRA-N at Three Creek, based on their conclusion that the Holocene channel of Three Creek is displaced 2 m above the inferred original concave profile. Based on regional geologic and geomorphic relations, Marple and Talwani (2000) infer that the onset of activity of the ECFS occurred between 200 ka and 1.25 Ma. This implies that geomorphic surfaces that are older than 1.25 Ma in age should have experienced the full magnitude of late Cenozoic uplift along the ECFS. At Three Creek, Mixon et al. (1989) have mapped remnants of late Pliocene-early Pleistocene terraces called the Windsor Formation; the elevations of these terrace remnants are plotted above the longitudinal profile of Three Creek in Figure 4. If it is assumed that the Windsor Formation terraces are about 2 million years old, and if they have been uplifted above Three Creek at a rate of 0.2 mm/yr since 200 ka to 1.25 Ma, then we would expect them to currently lie 40 m to 250 m above Three Creek. The profile in Figure 4 shows, however, that the Windsor Formation terraces are only about 10 m to 20 m above Three Creek. As discussed in the following section on cross-valley change, the Windsor Formation terraces along Three Creek also demonstrate that there has been no folding or arching across the axis of the ZRA-N, which is a key prediction of the kinematic model Marple and Talwani (2000) propose for deformation along the ECFS (Figure 5). We conclude that interpretations of uplift and uplift rate by Marple and Talwani (2000) based on their method for evaluating convexities in longitudinal profiles are not consistent with other geologic data.

To summarize, the “upward displaced fluvial surfaces” cited in Table 1 of Marple and Talwani (2000) are more objectively characterized as convexities, or local increases in the gradient of the longitudinal profiles of floodplains due to the intersection of concave profiles at river confluences. The change in gradient at the confluence of two rivers may reflect increased discharge, sediment load, and stream power (Schumm, 1986), and thus does not unequivocally indicate tectonism. We find that the interpretations of the convexities and the magnitude of uplift associated with them that are reported by Marple and Talwani (2000) are subjective and non-unique. Finally, the great east-west extent of the anomalies (17 km to 27 km) strongly implies that they are not associated with discrete uplift above a single fault or active fault zone.

2.3.2.3 Cross-Valley Change

Marple and Talwani (2000) cite cross-valley changes in the morphology of the Roanoke and Nottoway River valleys across the ZRA-N as evidence for Quaternary tectonic tilting and folding. Specifically, they observe that the Roanoke and Nottoway rivers west of the ZRA-N have relatively straight WNW-ESE-trending courses, but are deflected and form prominent incised meanders across the ZRA-N. The Roanoke River is deflected southward and forms a convex-southward meander bend, and the Nottoway River is deflected northward, forming a convex northward meander bend. In both cases the rivers have progressively widened their meanders during incision, such that there are a series of slip-off terraces on the inner bends of the meanders that step progressively downward to the river. Topographic profiles across the meander bends presented by Marple and Talwani (2000) reveal that the valleys of the Roanoke and Nottoway Rivers are distinctly asymmetric, with the steeper valley wall associated with the outer bend of the meander loop, consistent with the pattern of downcutting recorded by the slip-off terraces. Marple and Talwani (2000) explicitly attribute the valley asymmetry to tectonic tilting in the direction of the steeper valley wall (Figure 5). In their interpretation, tilting (down to the SW for the Roanoke River; down to the NE for the Nottoway River) has forced the rivers to preferentially erode the outer bend of the meander loops during the incision, producing the observed valley asymmetry.

Marple and Talwani (2000) repeatedly state that the asymmetric valleys represent "cross-valley tilt," but they do not acknowledge that this is an interpretation of the valley morphology, not a direct observation of deformation. The geomorphology they describe is typical for meanders or bends in streams and rivers in tectonically quiescent regions. No tectonic uplift is required to produce these observations. If tectonic deformation were, in part, responsible for producing this geomorphology (i.e., Figure 5), then there should be additional geomorphic and geologic evidence in support of tilting, such as:

- Tilt of individual terraces; i.e., older surfaces should be tilted more than younger surfaces.

- Folded/tilted strata; i.e., systematic tilting of Pliocene and older Tertiary stratigraphic contacts should be visible in longitudinal cross sections drawn parallel to the trend of the ZRA-N.

- Drainage patterns of 2nd and 3rd order streams should be influenced by tilting. For example, streams should flow northeast into the large Nottoway meander, not directly toward the coast as observed.

Marple and Talwani (2000) do not present any direct stratigraphic or geologic evidence of tilting of the kinds listed above. For example, none of the cross-valley profiles presented by Marple and Talwani (2000) document progressive down-to-the-valley tilting of older terraces, as would be expected for tectonic tilting.

We independently evaluated geologic and geomorphic relations along Three Creek (Figure 4) to test the kinematic model proposed by Marple and Talwani (2000) for uplift, tilting and folding across the ECFS (Figure 5). Remnants of the Pliocene-Pleistocene Windsor Formation terraces along Three Creek extend from the western margin of the ZRA-N shown by Marple and Talwani in Figure 2, to a point located several kilometers east of the axis of the ZRA-N (Figure 4). If uplift is occurring across the ZRA-N, and if the ZRA-N is being arched into a broad, north-plunging anticline that has caused the formation of the large meander bend in the Nottoway River, then we would expect to see remnants of the Windsor terrace along Three Creek at the west end of the ZRA-N not uplifted at all or uplifted only slightly, and the terrace remnants near the axis of the ZRA-N should be elevated to the maximum extent as dictated by the uplift rate and length of time that deformation has been active (i.e., 40 m to 250 m above Three Creek; see discussion in previous section on “upward displaced” fluvial surfaces). In other words, we should see 40 m to 250 m of structural relief on the Windsor terrace remnants across the ZRA-N, and in fact the terraces on the western limb of the ZRA-N arch should be backtilted to the west. The Windsor terraces along Three Creek, however, are not deformed in this manner. As shown in Figure 4, the Windsor terraces maintain a constant height of about 10 m to 20 m above Three Creek from the west end of the ZRA-N to a point east of the ZRA-N axis, and the gradient of the Windsor terrace remnants is toward the east, similar to the gradient of the modern Three Creek channel. We conclude that these data provide strong, direct evidence for no tilting or arching across the ZRA-N of the type inferred by Marple and Talwani (2000; Figure 5) to explain the formation of the large meander bend in the Nottoway River. In our opinion, the observed river meander is a natural geomorphic fluvial response that balances river incision, sediment load and discharge and is not a response to tectonic uplift or tilting.

As another direct test of the tilting hypothesis, we evaluated the contact between the Pliocene Upper Bacons Castle Formation and the Chesapeake Group, which is mapped by Mixon et al. (1989) in and around the large convex-northward meander loop in the Nottoway River that is associated by Marple and Talwani (2000) with the ZRA-N (Figure 6). Mixon et al. (1989) consistently map the Bacons Castle-Chesapeake Group contact at an elevation of about 100 feet throughout this region. In the vicinity of the town of Emporia, approximately 25 km south of the Nottoway River, the contact generally falls slightly below the 100 ft elevation contour (Points “B” on Figure 6). Directly south of the large meander in the Nottoway River, the contact is generally coincident with the 100 ft contour (Points “C” on Figure 6). North of the Nottoway River, the Bacons Castle-Chesapeake Group contact generally lies slightly above the 100-foot elevation contour (Points “A” on Figure 6). These relations imply that there is negligible structural relief on the contact across the area of assumed down-to-the-northeast tilting, and that the contact may actually *increase* slightly in elevation from south to north, rather than *decrease* in elevation as would be expected if down-to-the-north tilting has occurred to produce the large meander in the Nottoway River.

To summarize, we conclude that Marple and Talwani (2000) have not demonstrated that the observed valley asymmetry, which is a common characteristic of non-tectonic meander growth in fluvial systems, is due to tectonic tilting. Map-scale geologic and stratigraphic relationships documented by Mixon et al. (1989) provide direct, positive evidence for no Quaternary antiformal folding and NE-directed tilting in the vicinity of the Nottoway River, as required by the kinematic model of Marple and Talwani (Figure 5). Therefore, the “river anomalies of cross-valley change” provide no evidence for the existence of the ZRA-N.

2.3.2.4 Sinuosity Change

Out of ten streams that cross the inferred ZRA-N, Marple and Talwani (2000) cite only Fishing Creek as exhibiting an anomalous change in stream sinuosity associated with the ZRA-N. Specifically, Marple and Talwani (2003; Figure DR3) show an increase in stream sinuosity directly downstream of a 4-km-long incised reach of the stream. In their interpretation, localized uplift of the ZRA-N is centered on the incised reach of the stream, and the sinuosity increases downstream as a response to an increase in the gradient of the valley floor west of the uplift axis (see discussions in Schumm, 1986, and Ouchi, 1985).

However, the full extent of the convexity in the longitudinal profile along Fishing Creek that Marple and Talwani (2000) attribute to uplift is approximately 20 km in length. The increase in sinuosity cited by Marple and Talwani (2000) is associated with the western margin of the convexity only. To the east, there are multiple variations in sinuosity along the presumably uplifted reach of Fishing Creek that occur over distances of 4 to 6 km; given the short-wavelength character of these sinuosity variations relative to the dimensions of the convexity in the longitudinal profile, we infer that they are due to variations in fluvial parameters like discharge and sediment load rather than tectonics. There is no systematic increase in sinuosity across the convexity as would be expected for a systematic response of the stream to an increase in gradient downstream of the uplift axis (Ouchi, 1985; Schumm, 1986).

To summarize, anomalous changes in stream sinuosity are not reported by Marple and Talwani (2000) along nine of the ten streams that cross the inferred ZRA-N. We find that the single example of an anomalous change in sinuosity along Fishing Creek is not consistent with other features Marple and Talwani (2000) cite as evidence for uplift of the ZRA-N, nor is it consistent with variations in sinuosity due to uplift as described by Ouchi (1985) and Schumm (1986). Therefore, the “sinuosity change” reported by Marple and Talwani (2000) does not provide evidence for the existence of the ZRA-N.

2.3.2.5 Anastomosing Stream Pattern

Out of ten streams that cross the ZRA-N, Marple and Talwani (2000) cite only the Roanoke River as exhibiting an anastomosing pattern upstream of the inferred ZRA-N uplift. However, Marple and Talwani (2000) note in their Table 1 that the Roanoke River is not incised across the ZRA-N, nor do they observe an “upward displaced fluvial surface” associated with the ZRA-N at this latitude. Apparently, Marple and Talwani (2000) do not observe complementary geomorphic evidence of uplift downstream of the anastomosing reach of the river, as may be expected if the channel pattern change is associated with tectonism. Conversely, Marple and Talwani (2000) interpret that six other streams have “upward displaced fluvial surfaces” across the ZRA-N, but none of these streams have an anastomosing reach directly upstream of the inferred uplift. These observations provide additional evidence that there is no consistent fluvial response by streams crossing the inferred ZRA-N.

If there is no discernable uplift or deformation downstream of the anastomosing reach of the Roanoke River, then it is probable that the observed channel pattern change is produced by some process other than tectonism. To assess this, we examined the anastomosing reach of the Roanoke River on the Roanoke Rapids and Weldon 7.5-minute topographic maps, and observed that it is directly downstream of: (1) a dam built on the Fall Line; and (2) Roanoke Rapids Lake. Marple and Talwani (2000) do not discuss the possible influence of these geomorphic and cultural features on the development of the observed anastomosing stream pattern. It is possible that the anastomosing reach of the Roanoke River simply reflects a relative increase in sediment load to discharge related either to the Fall Line producing increased sediment bedload or to the dam and reservoir which would reduce flood flows during which time sediment bedload typically is transported. The ultimate cause of the anastomosing reach of the Roanoke River cannot be determined without a careful detailed geomorphic analysis of the fluvial system at this location, which has not been performed.

2.3.2.6 Stream Deflection

Marple and Talwani (2000) infer that five of the ten streams that cross the ZRA-N are anomalously deflected. Two of these deflections (on the Roanoke and Nottoway Rivers) are interpreted to be associated with cross-valley tilting. As discussed above, Marple and Talwani (2000) have not demonstrated that these particular deflections are due to tectonic tilting, and in the case of the Nottoway River, map-scale geologic relations provide evidence for no tilting or deformation to produce the deflections. The deflection along the Tar River is coincident with both the inferred ZRA-N and the Fall Zone; it is possible that the deflection of the Tar River is associated with the Fall Zone and not the ZRA-N (Marple and Talwani, 2000, show these two features diverging north of the Tar River). The other two noted deflections, on Swift Creek and Marsh Swamp, are associated with convexities in the longitudinal valley profiles. It is possible that the observed stream deflections are genetically associated with the convexities, but as noted above, these features likely are produced by non-tectonic processes.

3. Aerial Reconnaissance

Aerial reconnaissance of the northern portion of the northern segment of the ECFS (ZRA-N) was performed as part of the ESP studies. The March 10, 2003 reconnaissance flight, which is described in more detail in the response to RAI 2.5.3-1, provided limited coverage of the ECFS, as mapped by Marple and Talwani (2000), in the area between the Nottoway and James Rivers. This portion of the flight is shown in Figure 7. Near the location of the ECFS trace, the Coastal Plain is characterized by very low relief, and no geomorphic features indicative of potentially active faulting were observed. However, the nearby, northeast trending Surry scarp, which represents a Pliocene shoreline, was observed during the reconnaissance flight. Given the amounts of Holocene and Pleistocene uplift and the rates of deformation proposed by Marple and Talwani (2000), there should be geomorphic expression of the ECFS in the relatively flat topography of the Coastal Plain. Although the aerial reconnaissance of the ECFS was limited in coverage and not comprehensive, the lack of geomorphic expression supports the SSAR conclusions that the northern segment of the ECFS (ZRA-N) has both a low probability of existence and activity. These conclusions were based not on the aerial reconnaissance alone, but primarily on the independent evaluation described above of the geomorphic “evidence” presented by Marple and Talwani (2000).

4. Summary

Based on our review and assessment of the geophysical, geological, seismological and geomorphic evidence cited by Marple and Talwani (2000), we reiterate the conclusion in SSAR Section 2.5.1.1.4 that the ZRA-N “probably does not exist or has a very low probability of activity if it does exist.” Our conclusions are based specifically on the following observations:

1) Marple and Talwani (2000) cite the westward termination of the Norfolk arch along the trend of the ZRA-N as geologic evidence for the presence of the ZRA-N. The basic source of geologic data on the location of the Norfolk arch cited by Marple and Talwani (2000) is a small-scale map in Pazzaglia (1993), which shows the arch terminating westward at the Fall Line. However, Marple and Talwani (2000) have “modified” Pazzaglia’s map to show that the westward termination of the Norfolk arch is about 25 km east of the Fall Line, where it lies on trend with the ZRA-N. Marple and Talwani (2000) provide no references to detailed mapping of the Norfolk arch or other evidence in support of their modification of Pazzaglia’s map. In the absence of such data, we conclude that Marple and Talwani’s modification of Pazzaglia’s depiction of the Norfolk arch is unsubstantiated, and does not provide independent evidence for the presence of the ZRA-N.

2) Marple and Talwani (2000) mischaracterize an east-dipping structure imaged at about 30 km depth beneath the inferred location of the ZRA-N by the I-64 deep

seismic reflection profile as "steeply dipping", and they erroneously associate it with the postulated ZRA-N. As interpreted by Glover et al. (1995), this reflective feature probably is associated with the east-dipping Spotsylvania thrust fault that crops out 60 km west of the ZRA-N as they map it. The east-dipping structure imaged on the I-64 profile does not support the interpretation of the ZRA-N.

3) Based on a quantitative comparison of the density of "river anomalies" attributed to three segments of the ECFS, the ZRA-N is much less well expressed than the ZRA-S and ZRA-C. As characterized by Marple and Talwani (2000), the ZRA-N has only a slightly higher percentage of anomalies than a non-tectonic control region. We find that there is no consistent co-occurrence of two or more anomalies along each of the drainages, as may be expected if they have developed in response to uplift of the ZRA-N. Also, we find that there is no consistent pattern of anomalies along the trend of the ZRA-N, as expected if the structure was active along its entire length.

4) Based on our independent assessment of "river anomalies" on the ZRA-N, we find (1) no evidence for the existence of a fault and (2) direct stratigraphic evidence against the types of deformation postulated by Marple and Talwani (2000). In some cases, we could not verify or duplicate geomorphic observations, such as channel incision, cited by Marple and Talwani (2000). The "upward displaced fluvial surfaces" cited in their paper are inferred only from qualitative analysis of convexities of river profiles and, therefore, this type of "anomaly" does not provide evidence for tectonic uplift and is inconsistent with other geomorphic observations. And finally, we documented direct stratigraphic evidence for no Quaternary deformation in the vicinity of a large meander of the Nottoway River that Marple and Talwani (2000) interpreted to have formed in response to systematic folding and northeastward tilting. We conclude that the fluvial geomorphic features cited by Marple and Talwani (2000) are likely produced by non-tectonic fluvial processes, are not anomalous, and, thus do not support their interpretation of the presence and activity of the ZRA-N (northern segment of the ECFS).

5) No geomorphic features indicative of potential Quaternary faulting or folding were observed along the northern trace of the ZRA-N during aerial reconnaissance performed as part of the ESP study.

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Application Revision

The last two paragraphs of SSAR Section 2.5.1.1.4.c.4, under the heading "East Coast Fault System," will be revised to read as follows:

> Although the postulated ECFS represents a potentially new tectonic feature in the Coastal Plain of Virginia and North Carolina (Reference 74), aerial reconnaissance and independent analyses of the evidence presented by Marple and Talwani (Reference 74) for the northern segment indicate that this segment of the fault zone probably does not exist and, if it exists, is not a capable tectonic source. Current compilations of seismic sources also suggest that others interpret a low confidence that the northern segment of the ECFS exists. For example, Crone and Wheeler (Reference 59) do not include the northern and central segments of the fault in their compilation of potentially active Quaternary

faults. In addition, workshops convened for the 2002 USGS seismic hazard model (Reference 77) and for the TIP project (Reference 78) do not identify the northern and central segments of the fault system as a Quaternary active fault. As a member of both the USGS and TIP workshops, Talwani did not propose the northern and central segments of the fault system for consideration as a potential source of seismic activity. In addition, Marple and Talwani (Reference 74) do not argue that the northern and central segments of the fault system are associated with any seismicity.

In summary, the northern segment of the ECFS, as postulated by Marple and Talwani (Reference 74), is located approximately 70 miles southeast of the site. Marple and Talwani (Reference 74) further suggest that the southern segment of the fault system may be the source of the 1886 Charleston earthquake, implying that the northern and central segments may produce earthquakes of similar size. Although geomorphic analyses and aerial reconnaissance performed for this ESP application indicate that the northern segment of the fault zone probably does not exist and has a very low probability of activity if it does exist, given the proximity of the fault to the site and uncertainty regarding the existence and activity of the fault, a sensitivity analysis was performed to evaluate the fault's potential contribution to hazard at the ESP site. The results of this sensitivity analysis are described in Section 2.2.2.6.2.

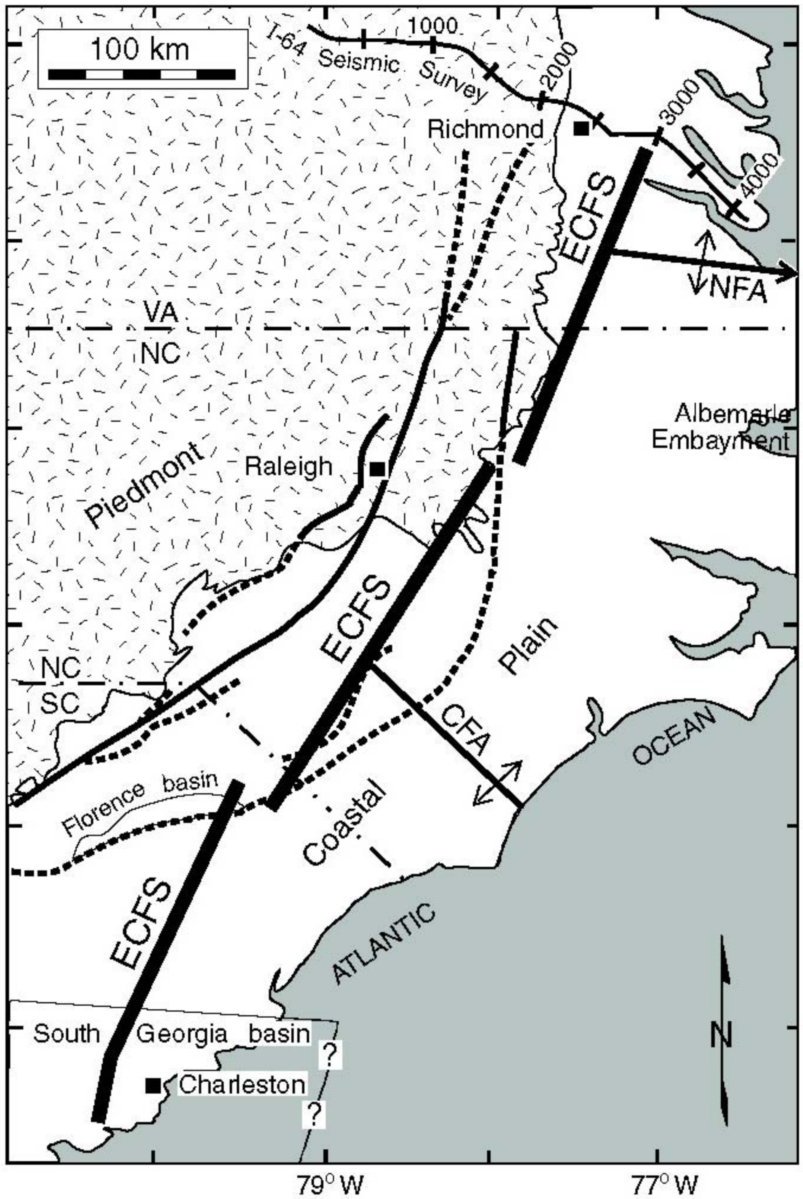

Figure 1. Map of the East Coast fault system (ECFS, thick black lines), taken from Marple and Talwani (2000). CFA = Cape Fear arch; NFA = Norfolk Arch.

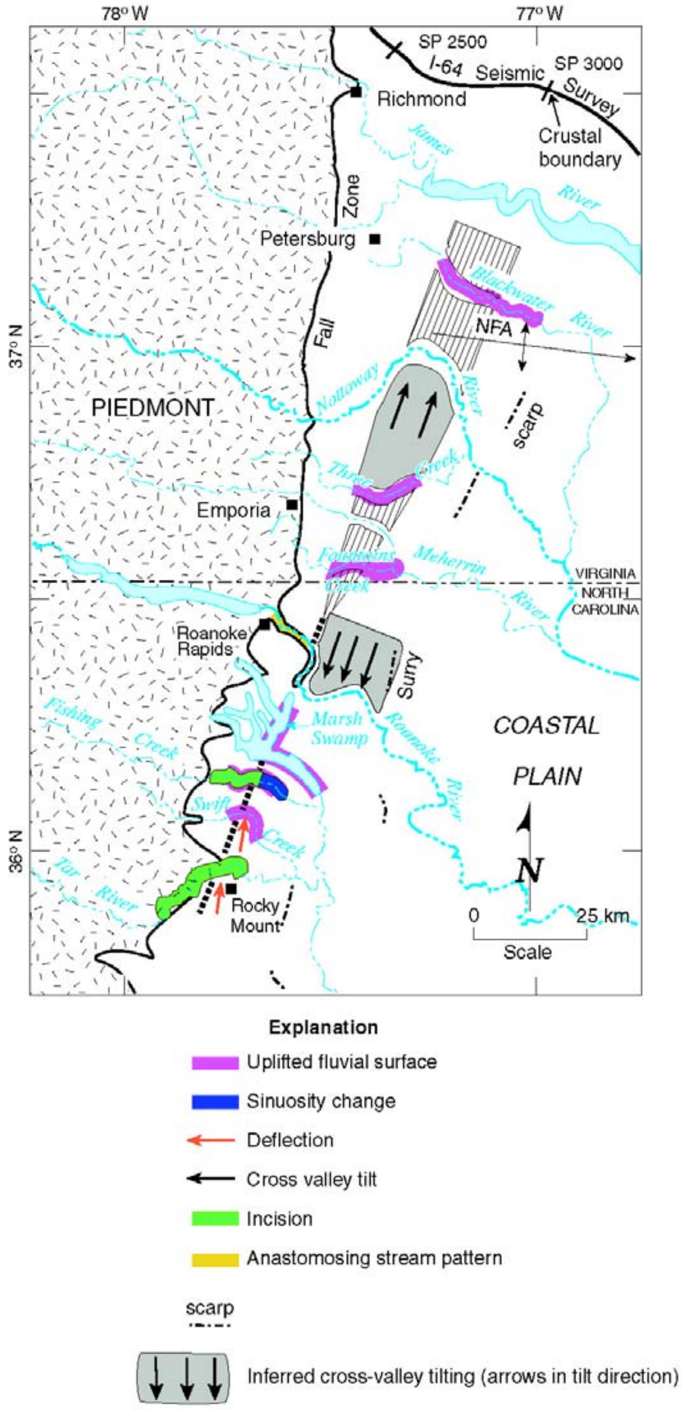

Figure 2. Map of ZRA-N (modified from Marple and Talwani, 2000). Locations of geomorphic river anamolies inferred by Marple and Talwani are highlighted as shown in the explanation. NFA = Norfolk Arch. ZRA-N shown as thick dotted line and zone of thin parallel lines.

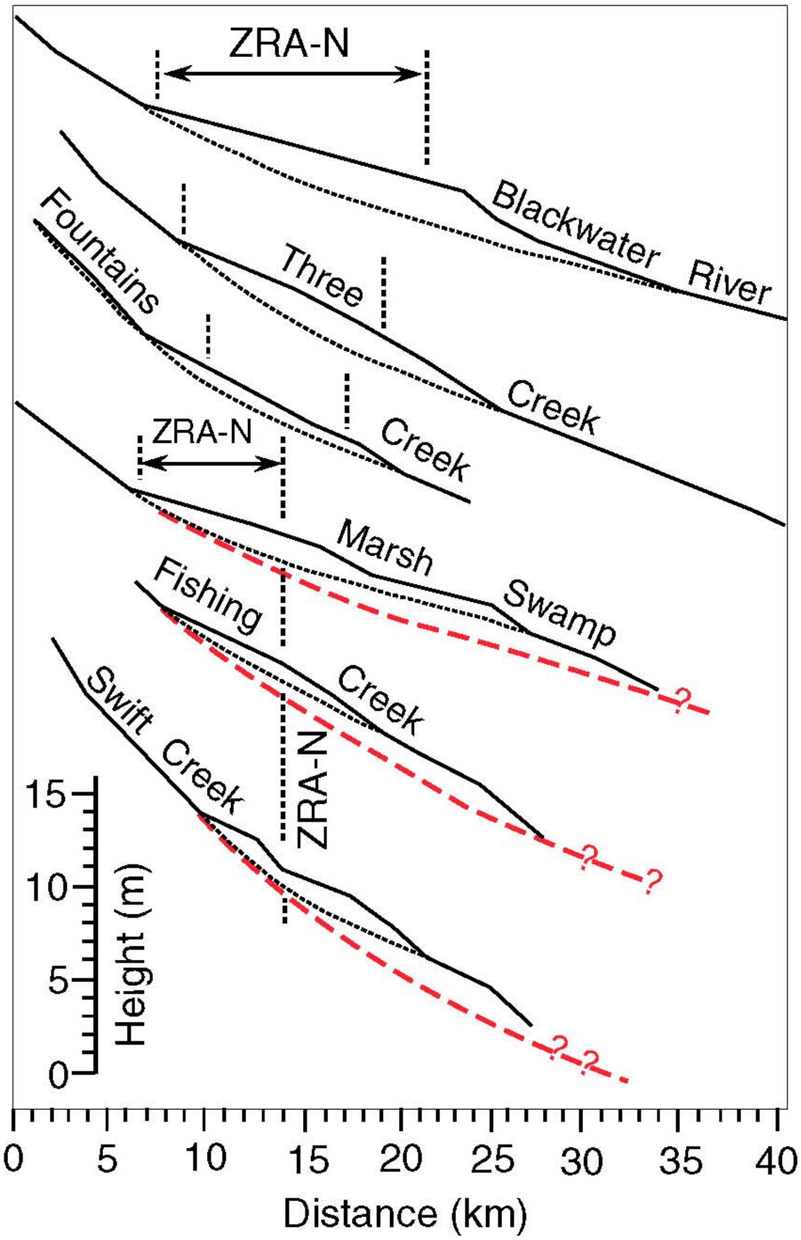

Figure 3. Longitudinal profiles of rivers showing convexity at ZRA-N. Inferred smooth, concave profiles shown as dashed lines. Black lines are interpretations of Marple and Talwani (2000); red lines are interpretations by WLA. Modified from Marple and Talwani (2000).

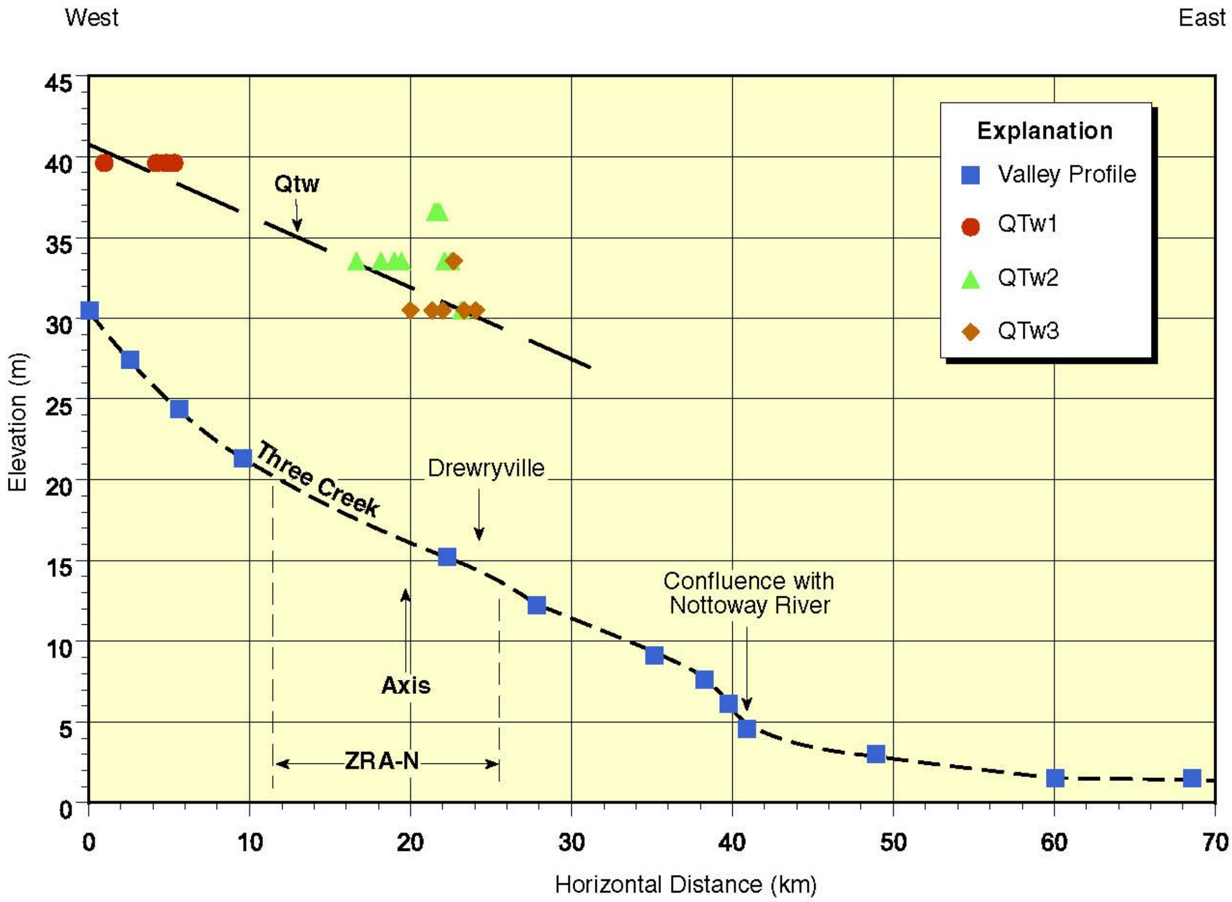

Figure 4. Longitudinal valley profile along Three Creek across the ZRA-N of Marple and Talwani, 2000. Also shown are elevations of remnants of the Pliocene-Pleistocene Windsor Formation terraces (Qtw; from mapping by Mixon, et al., 1989). Elevations taken from three separate terrace remnants (QTw1, QTw2, QTw3) indicate the Windsor terrace lies 10 meters to 20 meters above Three Creek, and has a similar gradient to the modern floodplain.

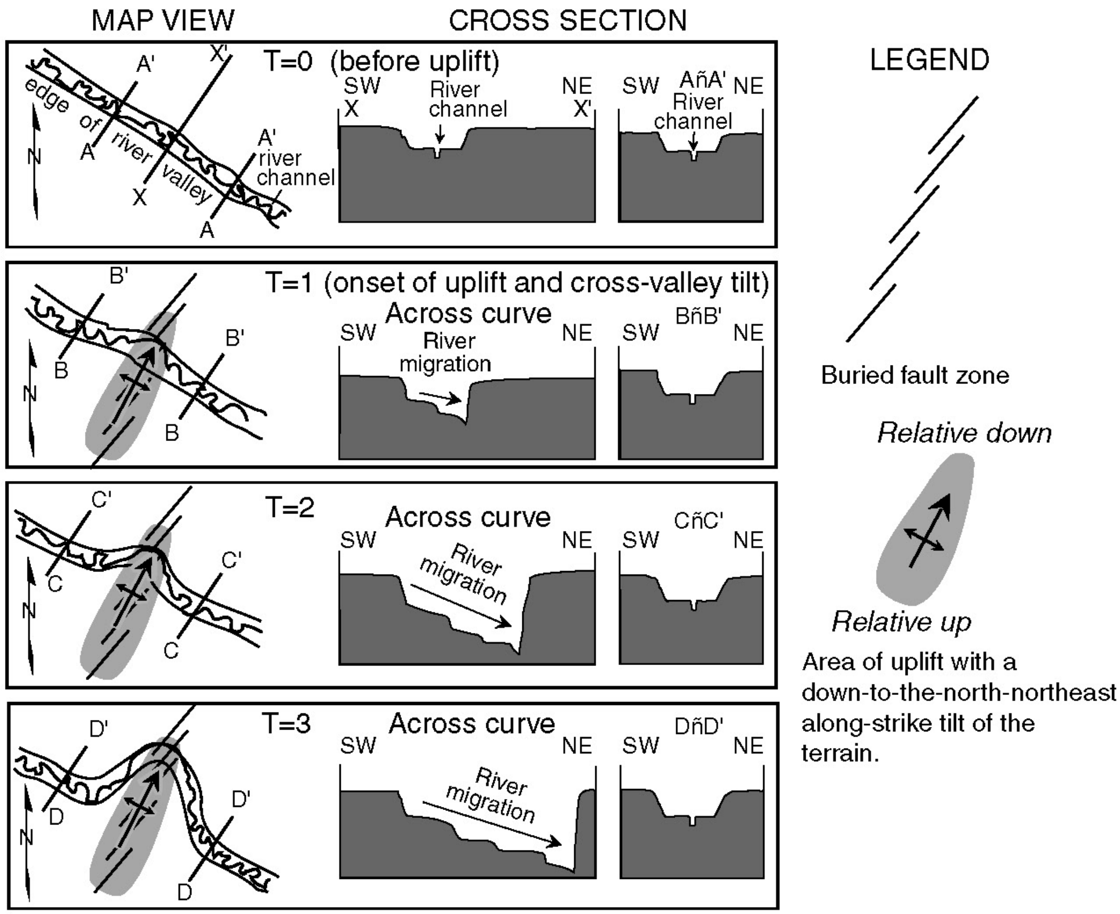

Figure 5. Model for development of large meander bends and asymmetric river valleys due to tectonic uplift and tilting along the ECFS (from Marple and Talwani, 2000).

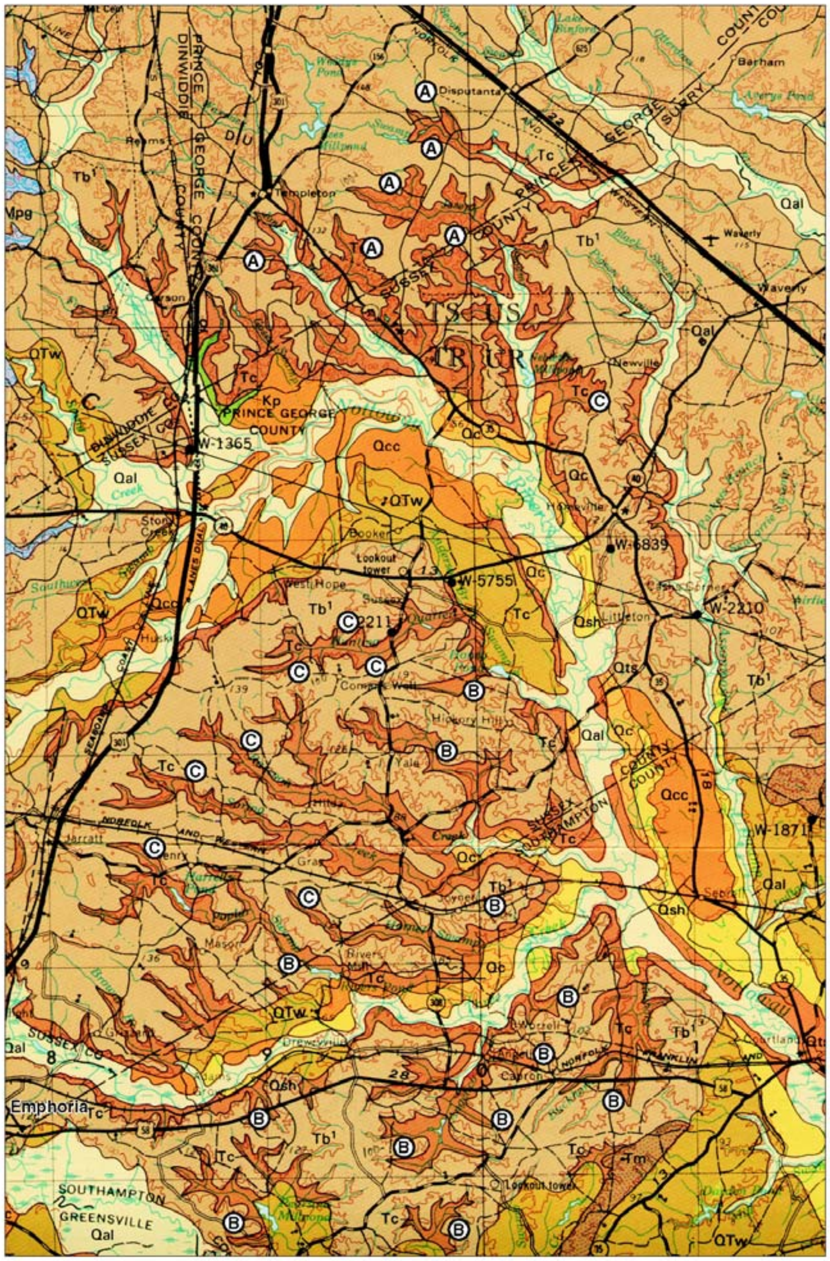

Figure 6. Geologic map of the area between Three Creek and Nottoway River (taken from Mixon et al., 1989). The contact between the Pliocene Upper Bacons Castle Formation (Tb[1], light brown) and the Chesapeake Group (Tc, orange-brown) occurs at about 100 ft elevation throughout this area. In general, the Bacons Castle/Chesapeake Group contact lies slightly below the 100 ft contour directly east of Emporia (sites labeled "B"). Just south of the Nottoway River, the contact is approximately coincident with the 100 ft elevation contour (sites labeled "C"). North of the Nottoway River, the contact lies slightly above the 100 ft contour (sites labeled "A"). These relations suggest that the contact dips slightly toward the south.

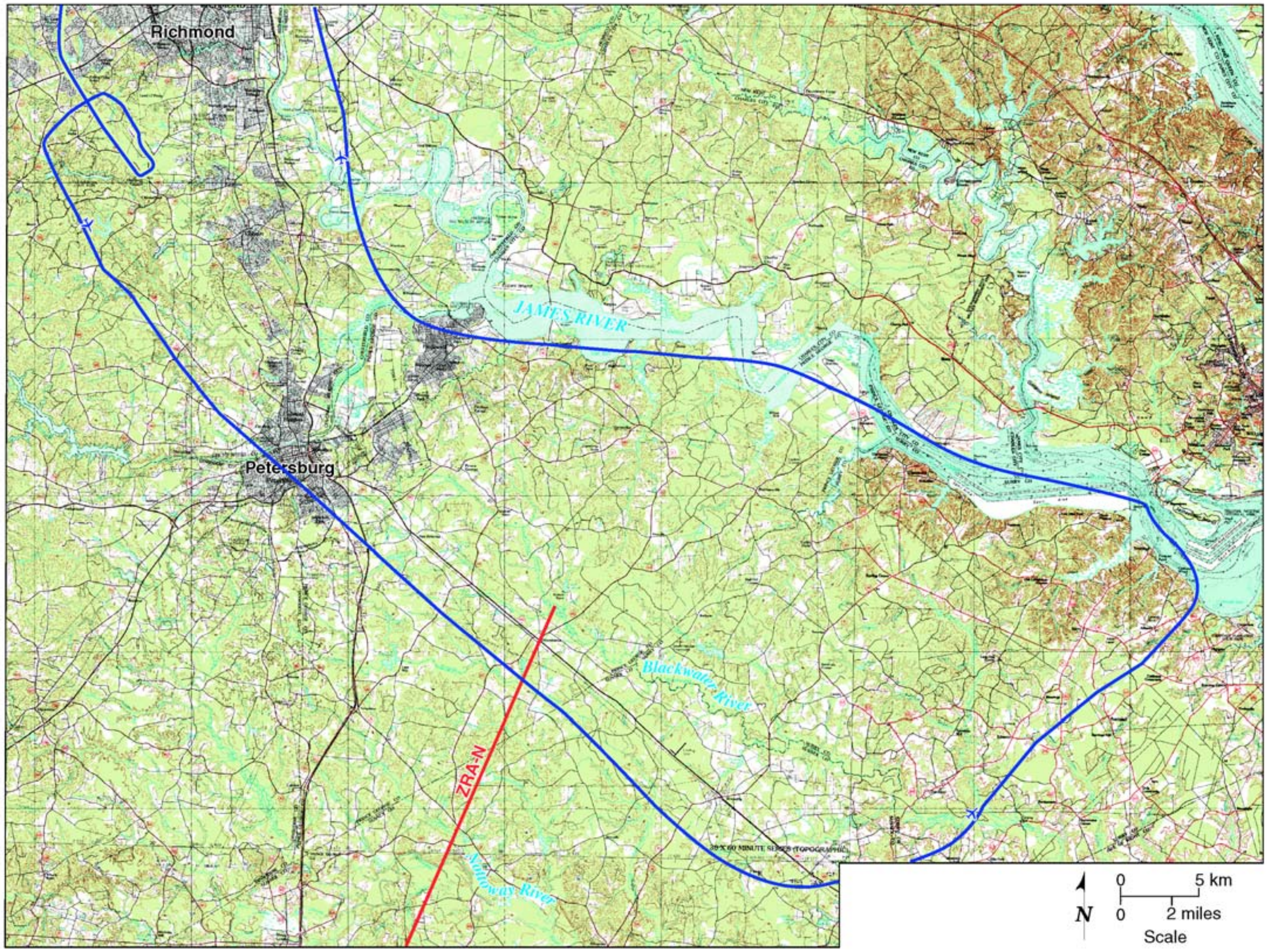

Figure 7. Portions of the March 2002 aerial reconnaissance over the northern extent of the ZRA-N.

RAI 2.5.1-3 (NRC 4/15/04 Letter)

> In SSAR Section 2.5.1.1.4, Dominion concludes that the seven fall lines defined by Weems (Reference 70) do not "represent a capable tectonic source." Weems (Reference 70) favors a neotectonic origin for the seven fall lines. Please provide additional justification to confirm or disprove the seven fall lines defined by Weems (Reference 70) as a capable tectonic source. Also, please explain how the absence of these features in the compilation of Crone and Wheeler (Reference 59) demonstrates that the fall lines are not capable tectonic sources.

Response

The conclusion, presented in SSAR Section 2.5.1.1.4, that the seven fall lines defined by Weems (Reference 70) do not represent a capable tectonic source is based on critical evaluation of the evidence presented by Weems (1998) and professional judgment.

Specifically, the "fall lines" described by Weems (1998) (Figure 1) are not defined by formal, consistently applied criteria, and thus are not as well defined and laterally continuous as depicted. [Figures are located at the end of the RAI response.] For example, different features are sometimes correlated to form a laterally continuous fall line while in other cases similar features are not correlated. Weems (1998) also argued for a neotectonic origin for the fall lines primarily because he concluded that the competing hypotheses (Quaternary climatic variations; differential bedrock erodability) are less compelling. However, Weems (1998) does not present direct credible evidence for a tectonic origin of the fall lines. Based on our evaluation of stratigraphic, structural and geomorphic relations across and adjacent to the fall zones described by Weems (1998), we conclude that differential erosion due to variable bedrock hardness is a viable and more plausible explanation than Quaternary tectonism. Furthermore, there is no complementary geomorphic expression of tectonism, such as the presence of tectonic escarpments, along the trend of the fall lines between drainages where one would expect to find better preservation of tectonic geomorphic features.

This response presents additional detailed analysis of geologic and geomorphic data to support the conclusion in the SSAR that the fall lines are not tectonic features, and thus do not represent capable tectonic sources. This response is organized into the following sections:

- Summary of the analytical approach used by Weems (1998) to identify fall lines and fall zones

- Validity and independent evaluation of Weems' methodology

- Evaluation of evidence presented by Weems for deformation of Nottoway River terraces

- Independent geomorphic analysis of the Tidewater and Central Piedmont Fall Lines

- Explanation of reference in the SSAR to Crone and Wheeler (2000)

1. <u>Summary of Analytical Approach Used by Weems (1998)</u>

Weems (1998) analyzed longitudinal profiles of rivers in the Piedmont and Blue Ridge provinces of North Carolina and Virginia, and identified discrete reaches along individual streams commonly marked by the presence of rapids and/or falls, that have locally steeper gradients than adjacent upstream and downstream reaches. Weems (1998) described these reaches of steeper gradient, falls and rapids as *fall zones*. Some of these fall zones are more than 16 km (10 miles) long, and in some cases Weems (1998) has combined multiple steep reaches of rivers into a single fall zone with widths up to 32 km (20 miles). Weems (1998) further observed that fall zones along individual rivers in the Piedmont and Blue Ridge provinces regionally form curvilinear arrays or alignments parallel to the NE-SW-trending Appalachian structural grain (Figure 1). Weems (1998) defined these apparent alignments of fall zones to be *fall lines*.

Weems (1998) notes in the introduction to his paper that the "Fall Line" of common usage, generally understood to be the farthest point that Colonial era ocean-going ships were able to navigate upstream before encountering falls and rapids, is a discrete fall line at or near the western margin of the Atlantic Coastal Plain province. Weems (1998) named this feature the "Tidewater Fall Line". Based on his analysis of longitudinal stream profiles, Weems (1998) interpreted that six other laterally continuous fall lines also are present west of the Tidewater Fall Line in the Piedmont and Blue Ridge provinces (Figure 1). From east to west, these additional fall lines are:

- Nutbush fall line
- Durham fall line
- Central Piedmont fall line
- Western Piedmont fall line
- Blue Ridge fall line
- Great Smokey fall line

Of these six fall lines, the Nutbush, Durham, Western Piedmont, and Great Smokey fall lines all terminate well to the south of the North Anna Site Vicinity. The Blue Ridge fall line lies approximately 67 km (42 mi) west of the North Anna site. As shown in Figure 1, only the Tidewater and Central Piedmont fall lines approach to within 25 miles of the North Anna site (i.e., lie within the Site Vicinity).

Weems (1998) discussed three hypotheses for the origins of the fall lines in the Blue Ridge and Piedmont provinces:

- Variable erosion across linear belts of rocks of varying hardness;
- Late Cenozoic climatic and sea level fluctuations, producing “waves” of headward-retreating nick points that are expressed as fall zones and fall lines; and
- Localized neotectonic uplift along fall lines.

Weems (1998) rejected the first two hypotheses. He argued that control of fall zones and fall lines by rock hardness “is true only locally and occurs as a consequence of uplift”. He further argued that climatic control “does not adequately explain the observed patterns” of fall lines. Weems (1998) concluded that tectonic uplift “is the dominant cause of the existing Piedmont fall lines” because neither differential rock erosion, nor regional creation of nickpoints by climate-driven changes in fluvial parameters, could “adequately explain the observed patterns”. In other words, Weems (1998) adopted a tectonic interpretation primarily because the alternative interpretations he considered were less compelling, and not because of direct evidence supporting a tectonic origin.

Weems (1998) cited two specific examples in support of a neotectonic origin for the fall lines he identified. Weems (1998) noted that the coincidence of the Nutbush fall line with the Nutbush fault zone is an “association so intimate that it would appear to be causal rather than coincidental”. However, a spatial association is not evidence for late Cenozoic tectonic movement on the fault zone, because juxtaposition of different rock types with different hardness characteristics by an ancestral fault also would produce such an “intimate” spatial association. Weems (1998) also interpreted that late Cenozoic terraces of the Roanoke River are deformed by east-down flexure or faulting, but based on our evaluation of these terraces (described in Section 3 of this response), we conclude that changes in the gradient of the terrace surfaces can be more plausibly explained by differential erodability of the underlying bedrock than by tectonism.

2. Validity and Independent Evaluation of Weems (1998) Methodology

2.1 Lack of Formal, Consistent Criteria

Although Weems’ analytical approach allowed him to identify and document changes in gradient along streams in the Blue Ridge and Piedmont provinces, he did not establish specific criteria for defining fall zones and fall lines. As described in detail below, the lack of such criteria make it impossible to reproduce Weems’ delineation of individual fall zones, or his correlations of fall zones as laterally continuous fall lines. In particular, his model for the lateral continuity of fall lines for hundreds of kilometers along trend in the Blue Ridge and Piedmont provinces is based on subjective assessments of some steep stream reaches as "anomalous" fall zones.

2.1.1 Lack of Formal, Consistent Criteria For Defining Individual Fall Zones.

Although most of the stream reaches identified as fall zones by Weems (1998) clearly have steeper gradients than adjacent upstream and downstream reaches, many other reaches with a locally steeper gradient were not identified by Weems (1998) as fall zones. Examples include:

- <u>Jackson/James Rivers (Weems 1998, Figure 2, Profile 4A)</u>. The Blue Ridge fall line is identified at horizontal distance 170 miles, but two other locally steeper reaches at horizontal distance 292 miles and 300 miles are not defined as fall zones.

- <u>Staunton River (Weems 1998, Figure 2, Profile 6A)</u>. The Blue Ridge fall line is identified in the each between horizontal distances 220-235 miles, but an apparently steeper reach at horizontal distance 272 miles is not defined as a fall zone.

- <u>Rapidan River (Weems 1998, Figure 3, Profile 2)</u>. The Central Piedmont fall line is identified at horizontal distance 40 miles, but a more prominent, locally steepened reach at horizontal distance 62 miles is not defined as a fall zone.

- <u>South Anna River (Weems 1998, Figure 3, Profile 3)</u>. Three locally steepened reaches occur between the Tidewater fall line and Central Piedmont fall line, at horizontal distances 38 miles, 48 miles and 65 miles. These features are not identified as fall zones, but they appear to have relief and expression comparable to that of the Central Piedmont fall line on the Potomac River (Figure 3, Profile 1), as identified by Weems (1998).

- <u>James River (Weems 1998, Figure 3, Profile 4)</u>. Two locally steepened reaches occur between the Central Piedmont fall line and the Blue Ridge fall line, at horizontal distances 127 miles and 140 miles. These steep reaches are not identified as fall zones, but they have relief and expression comparable to that of the Central Piedmont fall line on the Potomac River (Figure 3, Profile 1).

- <u>Shenandoah River (Weems 1998, Figure 7, Profile 17)</u>. A locally steepened reach, which occurs at horizontal distance 130 miles, has relief comparable to that of fall zones identified by Weems on several other river profiles; however, this particular steepened reach is not identified by Weems (1998) as a fall zone.

In addition to not providing criteria for what distinguishes a "fall zone" from a stream reach with a steeper gradient, Weems (1998) does not provide his rational for defining long reaches of streams with multiple cusps or convexities as a single fall zone. For example, Weems (1998) associates a 16-km-long (10-mi-long) reach of the Broad River with the Blue Ridge fall line (horizontal distance 87 mi to 97 mi on Profile 14 in Weems, 1998). This reach of the Broad River is characterized by a uniformly steeper gradient than the reaches directly upstream and downstream. Weems (1998) also associates an approximately 32-km-long (20-mi-long) reach of the adjacent Green River with the Blue Ridge fall line (Profile 14 on Figure 2 of Weems, 1998); however, the fall zone here is shown as consisting of two discrete steeper reaches separated by a reach with a lower gradient.

Other examples of multiple steepened reaches being grouped into a single fall zone include the Nutbush fall line on the Meherrin River (Weems, 1998, Figure 4, Profile 7), and the Durham fall line on the Tar and Neuse Rivers (Profiles 9 and 10, respectively, on Figure 4 of Weems, 1998). On the other hand, the Central Piedmont fall line is shown as two completely distinct fall zones along County Line Creek separated by a distance of about 19 km (12 miles; Profile 6 on Figure 4 of Weems, 1998). In addition, the multiple steep gradient reaches that have been defined as single fall zones by Weems (1998) can have significant widths. For example, the Tidewater fall line on the Rappahannock and South Anna Rivers (Profiles 2 and 3 on Figure 3 of Weems, 1998), and the Blue Ridge fall line on the Green River (Profile 14 on Figure 2 of Weems, 1998) have widths between 24 and 32 km (15 and 20 miles).

To summarize, there is inconsistency in Weems' (1998) methodology for distinguishing "fall zones" from relatively steep reaches of streams that are not otherwise "anomalous". Also, some of the individual fall zones are relatively long reaches of streams with multiple steep reaches. Therefore, we conclude that the "fall lines" are not as well defined and laterally continuous as depicted by Weems (1998).

2.1.2 Lack of Formal, Consistent Criteria for Correlating Individual Fall Zones as Fall Lines

Weems (1998) provides no criteria for connecting individual fall zones into laterally continuous fall lines. Without such criteria, it is difficult to evaluate the existence of regional fall lines against the alternative hypothesis that the fall zones on individual rivers are not connected or genetically linked.

For example, relief across the Blue Ridge fall line along streams in North Carolina and southern Virginia ranges from about 245 m to 610 m (800 ft to 2000 ft). Relief across the Blue Ridge fall line diminishes dramatically north of the Dan and Smith rivers. From the Staunton River northward, relief across the Blue Ridge fall line shown on Figure 9 of Weems (1998) is 61 m (200 ft) or less, and the steepened reaches interpreted to be fall zones associated with the Blue Ridge fall line are very poorly expressed, even at the extreme vertical exaggeration of Weems' profiles, which ranges from 260:1 (Figure 7 in Weems, 1998), 560:1 (Figures 2, 3 and 4 in Weems, 1998), to about 730:1 (Figure 5 in Weems, 1998).

In particular, the steepened reaches on the Staunton and Jackson/James Rivers (Figure 2 in Weems, 1998) associated with the Blue Ridge fall line are very poorly expressed, and there is a steepened reach along the Staunton River approximately 80 km (50 miles) west of the "Blue Ridge fall line" that is arguably more persuasive as a fall zone than the one chosen by Weems (1998) on his Profile 6A. Aside from lying generally along trend, it is not clear why Weems (1998) chose to correlate one steepened reach of the Staunton River with the Blue Ridge fall line and not the other. Similar arguments can be made about Weems' correlations of very modest increases in gradient along the Dan, Smith, and Catawba Rivers to define a laterally continuous Western Piedmont fall line in North Carolina, and correlations of modest gradient increases along the Appomattox and Rapidan Rivers with the Central Piedmont fall line.

The Tidewater fall line of Weems (1998), which has long been recognized as one of the region's more prominent geomorphic features, is depicted on most geologic maps as a highly irregular and sinuous trace along the western margin of the Coastal Plain (e.g., Horton et al., 1991). Weems (1998), however, depicts the Tidewater fall line and all other fall lines as fairly linear features with very low sinuosity in map view. There is clearly some inconsistency in the criteria used by Weems and other workers to define the Tidewater fall line.

To summarize, there is inconsistency and ambiguity in the correlations of steep or "anomalous" reaches of streams to define regionally extensive, laterally continuous fall lines. This implies that the individual fall zones may not be laterally connected as interpreted by Weems (1998), and thus do not share a common genetic relationship.

2.2 Erroneous Interpretations of Fall Zones and Fall Lines

2.2.1 Misinterpretation of Steep Headwater Reaches as Fall Zones

In several cases, Weems (1998) identifies abrupt increases in gradient in the headwater reach of a stream as a fall zone. Examples include:

- South Anna River (Weems 1998, Figure 3, Profile 3). The abrupt increase in gradient at the eastern margin of the headwaters reach (horizontal distance 96 miles) is identified as a fall zone, and correlated with the Central Piedmont fall line.

- Tar River (Weems 1998, Figure 4, Profile 9). An abrupt increase in gradient in the headwaters reach west of the Triassic Durham basin (horizontal distance 145 miles) is identified as a fall zone, and correlated with the Durham fall line.

- Green and Broad Rivers (Weems 1998, Figure 2, Profile 14). The abrupt increase in gradient at the eastern margin of the headwaters reach (horizontal distance 90 miles) is identified as a fall zone, and correlated with the Blue Ridge fall line.

- Smith River (Weems 1998, Figure 2, Profile 6B). The abrupt increase in gradient of the headwaters reach (horizontal distance 253 miles) is identified as a fall zone, and correlated with the Blue Ridge fall line.

- Meherrin River (Weems 1998, Figure 4, Profile 7). The abrupt increase in gradient at the eastern margin of the headwaters reach (horizontal distance 60 miles) is identified as a fall zone, and correlated with the Nutbush fall line.

These particular steep river reaches are not anomalous because the gradients of all streams typically steepen dramatically in the upstream third of their profiles, especially with proximity to the headwaters. The upstream increase in gradient is a logarithmic function, and is characteristic of the typical concave longitudinal profile of a stream. The logarithmic increase in gradient with proximity to the headwaters is especially pronounced by the vertical exaggeration in Weems' profiles, contributing to the appearance of a "fall zone". Weems (1998) does not explain why these particular headwater reaches should be considered anomalous, and thus characterized as fall zones. In addition, Weems (1998) does not explain why steep headwater reaches of the majority of other rivers in the study area are not considered fall zones.

2.2.2 Steepened Reaches Possibly Created by a Confluence of Rivers

Local increases in the gradient of longitudinal stream and valley profiles may occur at the confluence of two streams. When two rivers merge, the gradient of the natural concave profile will change due to increased discharge downstream of the confluence, commonly producing a steeper gradient. Hence, two concave profiles will "intersect" at the confluence, basically producing a "peak" or "cusp" in the longitudinal profile, and a locally steeper reach of the stream. In this case, the steep reach is directly related to an increase in stream power below the confluence, not climate or tectonics.

Several examples of "cusps" in the longitudinal profiles that are identified as "fall zones" by Weems (1998) have been noted, including

- The steep reach at horizontal distance 57 miles on the Nottoway River (Figure 4, Profile 8 in Weems, 1998), correlates with the Nutbush fall line.

- The steep reach at horizontal distance 105 miles on the Tar River (Figure 4, Profile 9 in Weems, 1998), correlates with the Nutbush fall line.

- The steep reach at horizontal distance 140 miles on the Cape Fear River (Figure 4, Profile 11 in Weems, 1998), correlates with the Central Piedmont fall line.

Weems (1998) provides no description or analyses of these reaches that would refute their relationship to river confluences and support his contention that they are the result of tectonic movement.

2.3 Summary

Based on a critical evaluation of the longitudinal stream profiles presented by Weems (1998), it appears that there is:

Inconsistent identification of fall zones among various steep reaches of streams;
Inconsistent correlation of individual fall zones to define laterally continuous fall lines;
Erroneous interpretations of steep headwater reaches as "anomalous"; and
Possibly erroneous interpretation of steep stream reaches associated with the confluence of two or more rivers as anomalous "fall zones".

Although we acknowledge that Weems (1998) has documented numerous reaches with locally steeper gradients along streams in the Piedmont and Blue Ridge provinces, we conclude that he has not convincingly established the presence and lateral continuity of numerous "fall lines" west of the well-known "Tidewater fall line" in the Coastal Plain.

3. Evaluation of Evidence Presented by Weems for Deformation of Nottoway River Terraces

The only evidence in support of late Cenozoic tectonism cited by Weems (1998) consists of locally steepened reaches in the longitudinal profiles of Pliocene terraces along the Roanoke/Staunton Rivers (Figure 2, taken from Figure 10 in Weems, 1998). Weems (1998) presents profiles of three Pliocene fluvial terraces along the Roanoke/Staunton Rivers that he interprets to show down-to-the-east warping across the Central Piedmont and Nutbush fall lines. From youngest to oldest, the terraces are located at heights of about 60 ft, 140 ft, and 200 ft above the modern stream channel (Figure 2). As depicted by Weems (1998), there is about 60 ft of structural relief in the terraces across the fall zones. It should be noted, however, that the 60 ft of relief occurs across a horizontal distance of about 17 miles. Given the extreme vertical exaggeration of Figure 2 (over 500:1), this relief appears to define a distinct east-facing warp or scarp in the terraces. However, 60 ft of relief in 17 miles is equivalent to an approximately 0.04° change in the gradient of the terrace surfaces, which is probably not visually perceptible. Localized displacement on a fault will not produce a sustained 0.04° increase in gradient across a horizontal distance of 17 miles.

Weems (1998) did not consider alternative hypotheses to account for the variations in the terrace gradients. For example, the fall zone along the Roanoke River correlated by Weems (1998) with the Central Piedmont fall line crosses the northern end of the Triassic Danville basin, and generally straddles structural boundaries between several tectonostratigraphic terranes delineated by Horton et al. (1991). From inspection of Weems' 1:100,000-scale map of the fall zones and fall lines in North Carolina and Virginia, the western margin of the Central Piedmont fall line on the Roanoke River is the western edge of the Danville basin. Rocks underlying the less steep reach of the stream west of the fall zone are gneiss, amphibolite and metabasalt of the Smith River terrane (Horton et al., 1991). The lower-gradient reach of the Roanoke River east of the fall zone is underlain by gneisses and minor pelitic schists of the Milton terrane. A thin sliver of the Potomoc terrane, consisting of metamorphosed mélange and deformed-arc oceanic island rocks, lies between the eastern margin of the Danville basin and the Milton terrane. Thus, the 12-mile-wide fall zone correlated by Weems (1998) with the Central Piedmont fall line is associated with Triassic basin sediments and metamorphosed accretionary complex rocks, and is bounded by metamorphosed crystalline rocks on the east and west. In our opinion, the variable erodability of the rocks spatially associated with the fall zone provides a tenable and more likely alternative hypothesis to tectonism. Similarly, the Nutbush fault, which is coincident with the Nutbash fall line, forms the tectonic boundary between the Albemarle volcanic arc terrane to the west, and the Goochland terrane rocks to the east (Horton et al., 1991). This suggests that the variable erodability of rocks juxtaposed along this ancient tectonic boundary, rather than tectonism, could explain the geomorphic observations.

If the changes in gradient along the Nottoway River are primarily due to variations in rock type, then such variations may be expected to be relatively stable and persistent during progressive fluvial incision. This expectation is consistent with the relationships shown in Figure 2. The changes in gradient are identical for all three terraces, and equivalent to the modern gradients of the two fall zones in the stream profile. If the gradient changes in the profiles were due to tectonism, then the parallel gradients in terraces of different ages would indicate that the deformation post-dates the youngest terrace (2.0 million years old) and is, therefore, quite young. However, such youthful deformation would be expected to produce a sharper topographic relief than the 0.04° gradient change and would be more clearly expressed geomorphically across interfluve areas. Given the long-term stability (post-Mesozoic) of the regional stress field along the passive margin of eastern North America (Dahlen, 1981; Richardson and Reding, 1991), it seems unlikely that new styles or locations of tectonic deformation would begin in the Quaternary.

If the deflections in the Roanoke River and Pliocene terraces represent tectonic deformation and the fall lines represent previously unrecognized active fault zones deforming the earth’s surface, as suggested by Weems (1998), then this interpretation implies an east-side-down sense of slip on the causative faults. Given the NE-SW orientation of the principle compressive stress in the CEUS (Zoback and Zoback, 1989), it is considered highly unlikely that any of the abundant east-dipping thrust faults within the Appalachian crust have been reactivated to form the fall lines of Weems (1998). East-dipping Appalachian thrust faults would most likely reactivate with dextral and reverse components of slip in the current stress regime, rather than a normal sense of slip that would be needed to form the down-to-the-east warping interpreted from the terrace profiles.

To summarize, the tectonic explanation presented by Weems (1998) for changes in gradient of the Nottoway River terraces is not valid because the deformation would be characterized by uniform, presumably monoclinal tilting of 0.04° over a horizontal distance of 17 miles, and this is not consistent with localized deformation on a reactivated Paleozoic fault associated with the Central Piedmont and Nutbush fall lines. A non-tectonic hypothesis of formation for the terraces with varying gradients is more plausible, and consistent with the modern stream profile. Thus, we conclude that Weems (1998) has not presented credible stratigraphic or geomorphic evidence for late Cenozoic tectonic activity along any of the fall lines.

4. Independent Geomorphic Analysis

We conducted independent geomorphic analyses of the Tidewater and Central Piedmont fall lines because these two features lie within the North Anna site vicinity (Figure 1). The goals of the analyses were to: (1) confirm the presence and exact location of the fall lines as fall zones on major rivers; and (2) evaluate geologic and geomorphic relationships to determine whether late Cenozoic deformation has occurred along the fall lines, as postulated by Weems (1998). Similar analyses of the other fall lines identified by Weems (1998) were not performed because these features lie outside the 25-mile-radius of the ESP site vicinity (Figure 1).

4.1 Tidewater Fall Line

To assess the presence or absence of Quaternary tectonic activity along the Tidewater fall line, a detailed longitudinal profile of the Rappahannock River was prepared across the fall zone at Fredericksburg (Figure 3). In addition, elevations were plotted of remnants of a regressive late Pliocene marine sand (Unit Tps of Mixon et al., 2000), which cap upland surfaces of the inner Coastal Plain in northern Virginia, and specifically underlie the flattish, accordant summit surfaces north and south of the Rappahannock River, upstream and downstream of Fredericksburg (Figure 3). Although there is some scatter in the elevations of the Tps remnants on the profile, they generally define an east-sloping surface with a constant gradient that crosses the Tidewater fall zone on the Rappahannock River without obvious east-down deflection. Therefore, the Tps unit does not appear to be deformed across the Tidewater fall line at Fredericksburg. The gradient of the Tps surface is similar to that of the modern Rappahannock River upstream of the fall zone. If this interpretation that the Tps unit is not deformed is correct, then development of the fall zone in the river, which clearly postdates deposition of the Tps unit, must be due to non-tectonic geomorphic processes.

While acknowledging that there is uncertainty in the elevations of the Tps unit (as represented in a qualitative manner by the scatter in the points plotted on Figure 3), the total vertical scatter in the Tps elevations on Figure 3 of about 12 m (40 ft) is similar to the total relief on the Holocene channel of the Rappahannock River across the fall zone of about 15 m (50 ft). Although it is difficult to estimate original topographic relief across the fall zone with precision because a dam has been built at the top of the fall zone (Figure 3), the height of the fall zone appears to be comparable to or greater than the maximum scatter in the Tps elevations. If the fall zone is a scarp formed by east-side-down displacement along a fault, the height of the fall zone would be expected to be a minimum bound on the vertical separation, because fluvial erosion would act to lower the escarpment. The river flows at a high angle to the fall zone, and thus it is not plausible that fluvial erosion would enhance or increase the relief across the scarp. The present location of the river channel below the Tps unit indicates that the magnitude of total incision and downcutting since deposition of the Tps unit is about 60 m (200 ft), which is about four times the present height of the fall zone. These relations strongly imply that, if tectonic, then the fall zone escarpment must have been formed by significantly more than 15 m of vertical tectonic separation. Based on the profile of the Tps remnants, however, it is not credible that 15 m or more of post-Pliocene, east-down vertical separation has occurred, even within the uncertainty (about 30 ft) of the elevations of the Tps remnants.

We also profiled the South Anna River to better understand the significant width of the Tidewater fall line depicted by Weems (1998) and the location of lithologic changes along the profile (Figure 4). The Tidewater fall line defined by Weems (1998) extends nearly 18 miles and includes a prominent steep fall zone east of the Taylorsville basin and a more subtle gradient change near the eastern margin of the basin. It is not clear why Weems (1998) interpreted these multiple gradient changes as a single fall zone and not two distinct and different fall zones. A strong correlation between bedrock lithology and gradient can be observed on this profile (Figure 4). The steepest reach of the river corresponds to the portion flowing across the Petersburg granite (Mpg). Directly upstream, the river gradient across the mylonitic rocks of the Hylas shear zone (PzHy) is steeper than the portion of the stream underlain by undifferentiated metasedimentary and metaigneous rocks (PzZu). The Coastal Plain portion of the river (downstream of the confluence with the North Anna River) exhibits the gentlest gradient and is underlain by Potomac Formation (Ky) and alluvium (Qal). The river gradient is demonstrably different on either side of the rocks of the Taylorsville basin. The strong correlation between gradient changes across five reaches of the river and contrasting rock types appears to support a non-tectonic interpretation for the formation of the Tidewater fall line. Near the eastern margin of the Taylorsville basin, the gradient change or fall zone is likely a function of two additional factors: (1) the increase in stream power at the confluence with the North Anna River and (2) Pliocene coastal processes.

To summarize, a profile of the Pliocene Tps unit shows no deformation across the Tidewater fall line at the Rappahannock River (Figure 3). There is also a very strong correlation between variations in rock type and gradient changes in the South Anna River profile (Figure 4) that strongly suggests the Tidewater fall line formed as a result of variable erosion across rocks of varying hardness. We conclude, therefore, that the fall zone formed by non-tectonic geomorphic processes.

4.2 Central Piedmont Fall Line

Weems (1998) cites "anomalous gradient-to-bedrock-hardness" relationships in the Triassic Culpeper Basin along the Rappahannock and Rapidan Rivers as evidence that the Central Piedmont fall zone and fall line are not controlled by differential bedrock erosion. Specifically, Weems (1998) states:

> …the toe of the Central Piedmont fall line is anchored along the eastern edge of the Culpeper basin, so that the basin rocks support the steepened gradient.

Based on analysis of geologic and topographic maps, as well as detailed profiling of the Rappahannock and Rapidan Rivers in this region, this assertion appears to be incorrect. The fall zones along the rivers occur in Jurassic igneous and Paleozoic metamorphic rocks east of the basin, and not within the Triassic basin sediments. The relevant geologic and geomorphic relations are described in detail, in the following paragraphs.

On the Rappahannock River, the fall zone that Weems (1998) associates with the Central Piedmont fall line occurs about 1 km west of the eastern Culpeper basin boundary, just upstream of Kellys Ford (Germana Bridge 7.5-minute quadrangle). The western two-thirds of the fall zone is underlain by Jurassic diabase intrusive rocks (Figure 5), which crop out extensively in the eastern Culpeper basin (Figure 6). As noted by Weems (1998), the diabase rocks "can be very resistant to erosion where they are not pervasively fractured."

Based on these relations, the diabase is interpreted to be more resistant to erosion than the basin sediments, and is acting as a bedrock "sill", which controls the base level of erosion in the basin to the west. Because rivers erode headward, the Rappahannock is only able to incise its channel in the basin as rapidly as it can erode through the diabase along its eastern (downstream) margin. If the Triassic basin sediments are softer and less resistant to erosion than the diabase, then the river will tend to cut laterally back and forth in the basin upstream of the diabase, producing an area of low relief and low gradient upstream of the fall zone.

Similarly, a detailed longitudinal profile of the Rapidan River (Figure 7) shows that the fall zone associated by Weems (1998) with the Central Piedmont fall line occurs entirely within Paleozoic metamorphic rocks that are juxtaposed against the Triassic basin sediments by the Mountain Run fault zone. This is contrary to Weems (1998) assertion that "the rocks at and upstream of the anomaly are softer than the rocks below the anomaly" (i.e., the locally steeper reach of the stream). As with the Rappahannock River, the Paleozoic rocks that support the steeper gradient appear to control the local base level and are the limiting factor in the rate at which the Rapidan River can erode headward and incise its channel in the Triassic basin sediments. The lower gradient in the basin upstream of the Paleozoic rocks (Figure 7) may reflect lateral planation by the Rapidan River. Thus the observed changes in gradient along the Rapidan River do not require a tectonic explanation, and in fact, contrary to Weems (1998) assertion, appear to be related to differences in bedrock lithology.

Other geomorphic relations along the eastern margin of the Culpeper Basin are contrary to the interpretation of late Cenozoic east-side-down tectonic deformation along the Central Piedmont fall line. The eastern Culpeper basin is bordered by higher ridgelines and hills that form a broad, northeast-trending northwest-facing escarpment along the Mountain Run fault zone (Figure 8). Parts of this escarpment are recognized as “Kellys Ford scarp” and the “Mountain Run scarp”. Elevations of the floor of the Culpeper basin, estimated from 1:24,000-scale topographic maps, range from about 290 ft to 320 ft. The elevations of the summit ridges and hills comprising the top of the escarpment range from about 380 ft to 410 ft, indicating about 100 ft of down-to-the-west topographic relief across the Central Piedmont fall line. This is opposite to the east-side-down sense of tectonic displacement inferred by Weems (1998) to create the fall lines, or gradient increases along the Rapidan and Rappahannock Rivers as they exit the basin.

To summarize, the increased gradients along the Rapidan and Rappahannock Rivers as they exit the Culpeper Basin are associated with Jurassic igneous rocks and Paleozoic metamorphic rocks, not Triassic basin sediments as stated by Weems (1998). The crystalline rocks appear to act as “sills” to control the local base level of the rivers and promote lateral planation in the basin upstream. The observed increase in gradient as the streams leave the basin, therefore, is explained by differential erosion of bedrock without invoking down-to-the-east tectonic deformation along the Central Piedmont fall line, and such deformation is not consistent with the presence of the broad northwest-facing escarpment that borders the eastern margin of the Culpeper basin.

5. <u>Explanation of Reference in SSAR to Crone and Wheeler (2000)</u>

In the SSAR, it was assumed that the fall lines from the Weems (1998) study were included in the later compilation of suspect Quaternary tectonic features by Crone and Wheeler (2000). The absence of the fall line features from the Crone and Wheeler (2000) compilation was interpreted to mean that the features were evaluated, but not considered to represent suspect Quaternary features, and thus did not represent capable tectonic sources.

At the March 2004 meetings with the NRC, however, Drs. Crone and Wheeler pointed out that they had not reviewed the Weems (1998) study during their compilation effort. Therefore, no inference should be drawn from the absence of the fall lines in the Crone and Wheeler (2000) report. The SSAR will be revised to clarify that the Crone and Wheeler (2000) reference cannot be used to characterize the fall lines defined by Weems (1998).

6. Summary

Based on a critical evaluation of Weems (1998) work, as well as an independent analysis of the Central Piedmont and Tidewater fall lines within the Site Vicinity, the "fall lines" described by Weems (1998) are not as well defined and laterally continuous as he depicts, and in fact lack geomorphic expression typical of laterally continuous, tectonically active faults and folds. For example, if individual fall zones are created by down-to-the-east warping or fault displacement, then better expression of warping or faulting in the interfluves would be evident because fluvial erosion by streams would tend to eradicate evidence of faulting. In general, however, this is not observed in the Piedmont and Blue Ridge provinces. In the specific example of eastern Culpeper basin evaluated for this study, the existing topographic escarpment faces west, opposite the direction predicted by Weems (1998) tectonic model for formation of the fall zones. Although the escarpment is inconsistent with Weems (1998) tectonic model, it is consistent with the differential erosion of the Triassic Culpeper Basin strata relative to the metamorphic Paleozoic rocks to the east. Similarly, there is no east-facing escarpment expressed in the remnants of the Pliocene Tps unit along the Tidewater fall line, which would be expected if the fall zones on rivers like the Rappahannock are formed by localized east-side-down folding or faulting.

Based on our evaluation of stratigraphic, structural and geomorphic relations across and adjacent to the fall zones described by Weems (1998), therefore, we conclude that:

- There is no positive evidence for a neotectonic origin of individual fall zones;
- There is positive evidence for no Quaternary deformation across the "Tidewater fall zone"; and
- Regional geomorphic relations provide indirect evidence for no east-side-down deformation along the "Central Piedmont fall line" adjacent to Culpeper Basin.

Therefore, differential erosion due to variable bedrock hardness appears to be a more plausible explanation for the formation of individual fall zones than Quaternary tectonism.

References

Crone A. J. and R. L. Wheeler, 2000, Data for Quaternary faults, liquefaction features, and possible tectonic features in the Central and Eastern United States, east of the Rocky Mountain front, U.S. Geological Survey Open-File Report 00-260, (Reference 59 of SSAR Section 2.5).

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Application Revision

The third paragraph of SSAR Section 2.5.1.1.4.c.4, “Quarternary Tectonic Features,” will be revised to read as follows:

> In 1998, Weems defined and named seven fall lines across the Piedmont and Blue Ridge Provinces of North Carolina and Virginia. These fall lines are based on the alignment of short stream segments with anomalously steep gradients. Weems (Reference 70) explores possible ages and origins (rock hardness, climatic, and tectonic) of the fall lines and “based on limited available evidence favors a neo-tectonic origin” for these geomorphic features during the Quaternary. A review of Weems' study (Reference 70) reveals that no direct evidence is presented for a neo-tectonic origin, no formal, consistent criteria are

used to define the fall lines, and geologic and geomorphic observations along some of the fall lines actually demonstrate either a lack of tectonic activity or a strong correlation to changes in bedrock lithology. Therefore, these features postulated by Weems (Reference 70) are not considered to represent capable tectonic sources.

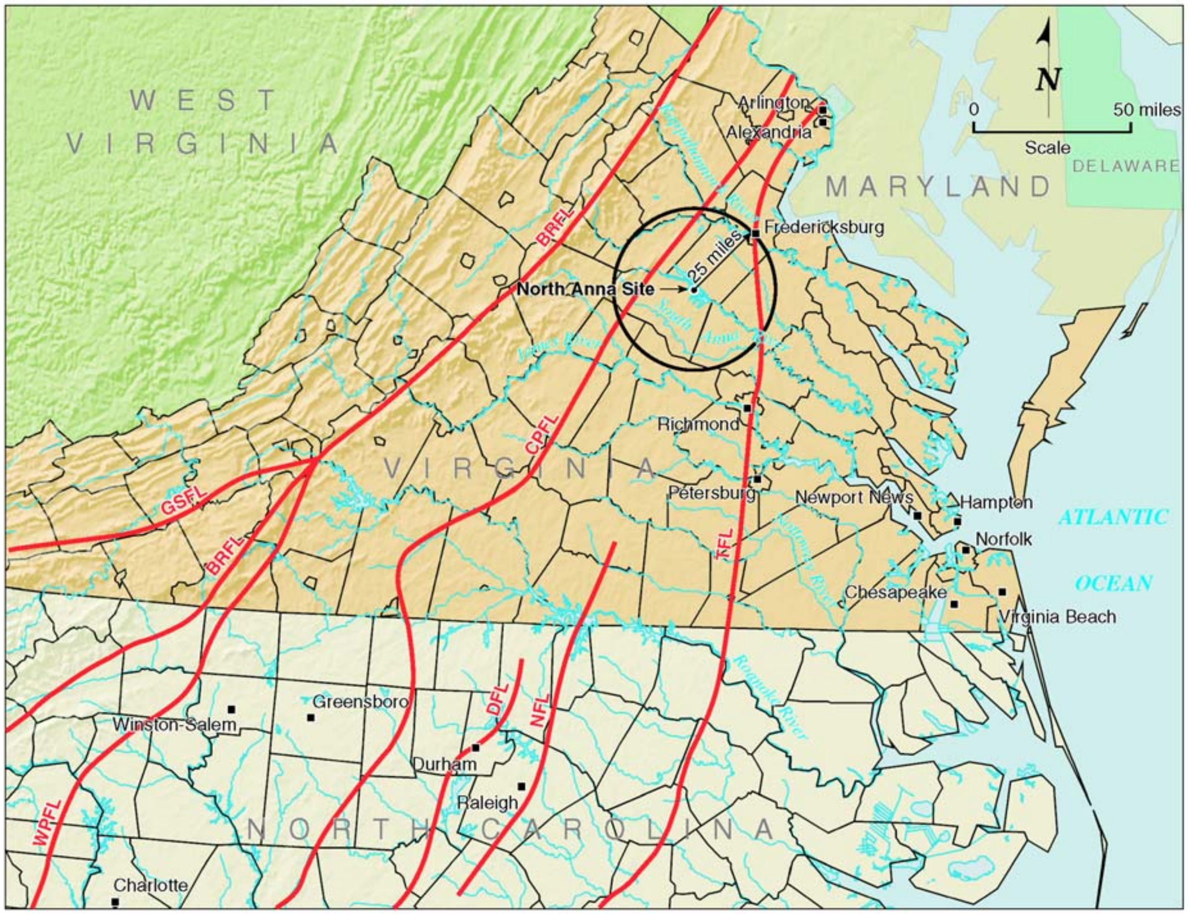


Figure 1. Approximate locations of fall lines proposed by Weems (1998). From east to west the fall lines include the Tidewater Fall Line (TFL), Nutbush Fall Line (NFL), Durham Fall Line (DFL), Central Piedmont Fall Line (CPFL), Western Piedmont Fall Line (WPFL), Blue Ridge Fall Line (BRFL), and the Great Smokey Fall Line (GSFL).

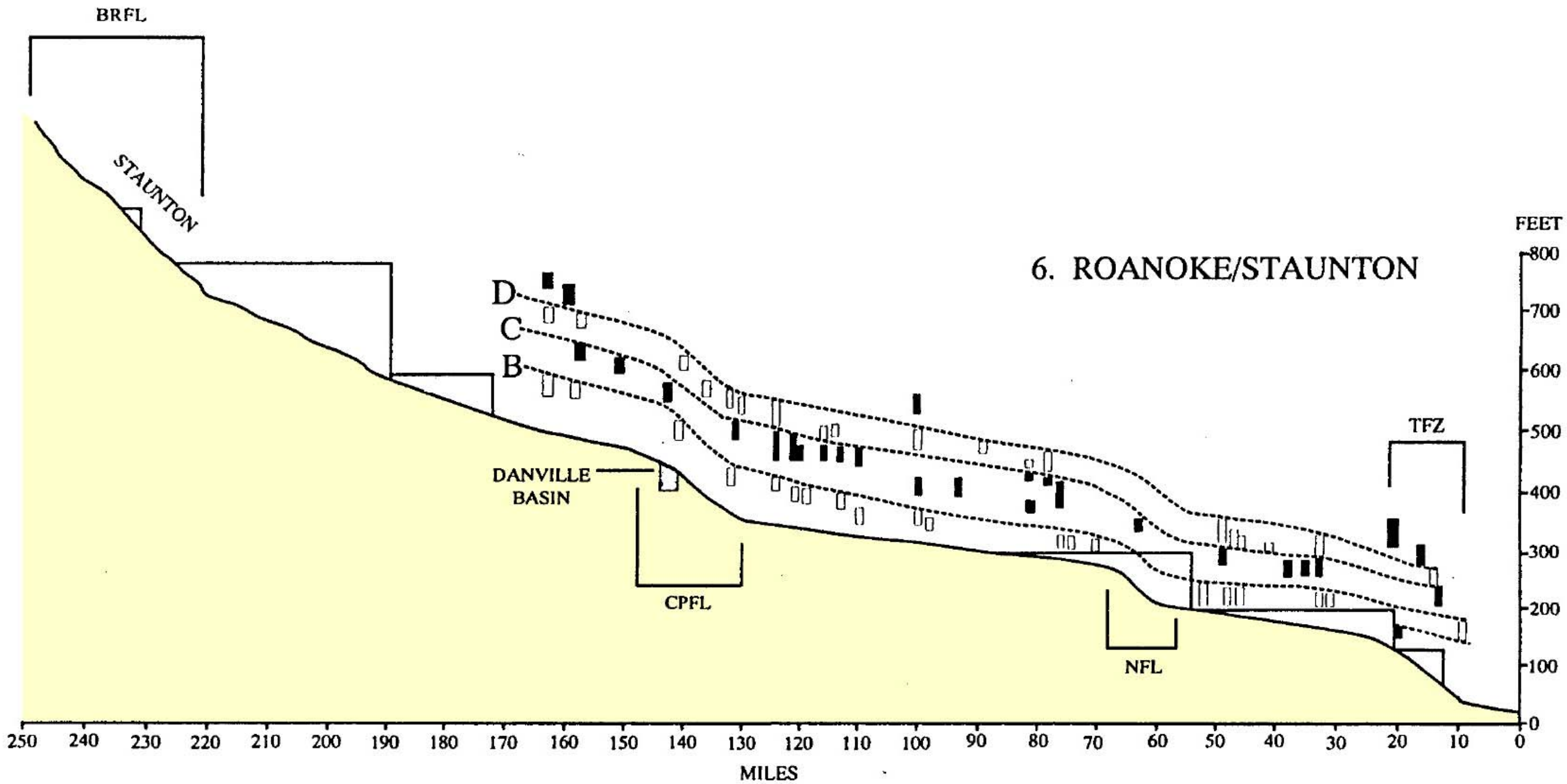


Figure 2. Profiles of three late Cenozoic terraces (B, C, and D) of the Roanoke River (from Weems, 1998), BRFL = Blue Ridge fall line; CPFL = Central Piedmont fall line; NFL = Nutbush fall line; TFZ = Tidal Fall Zone.

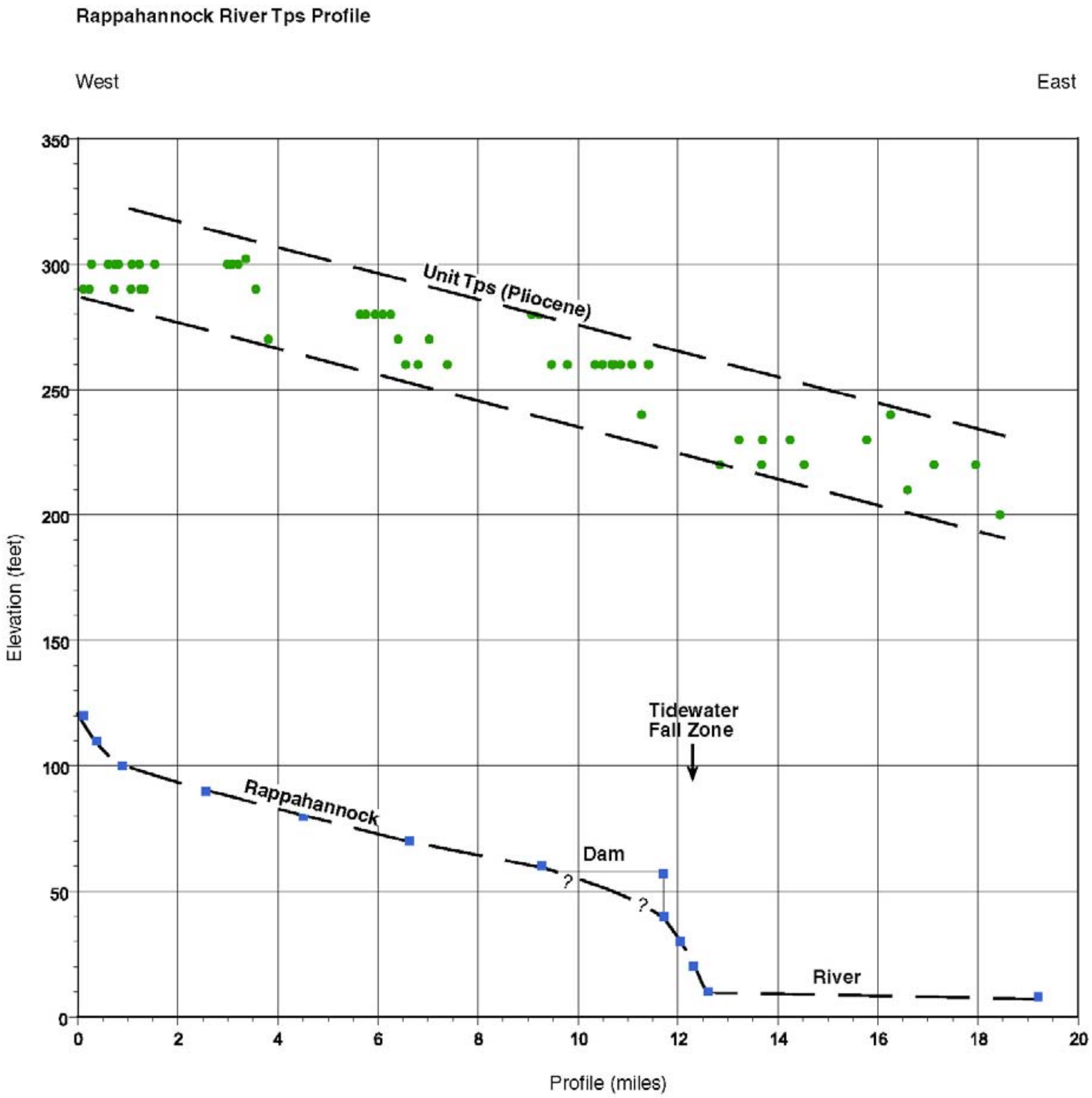
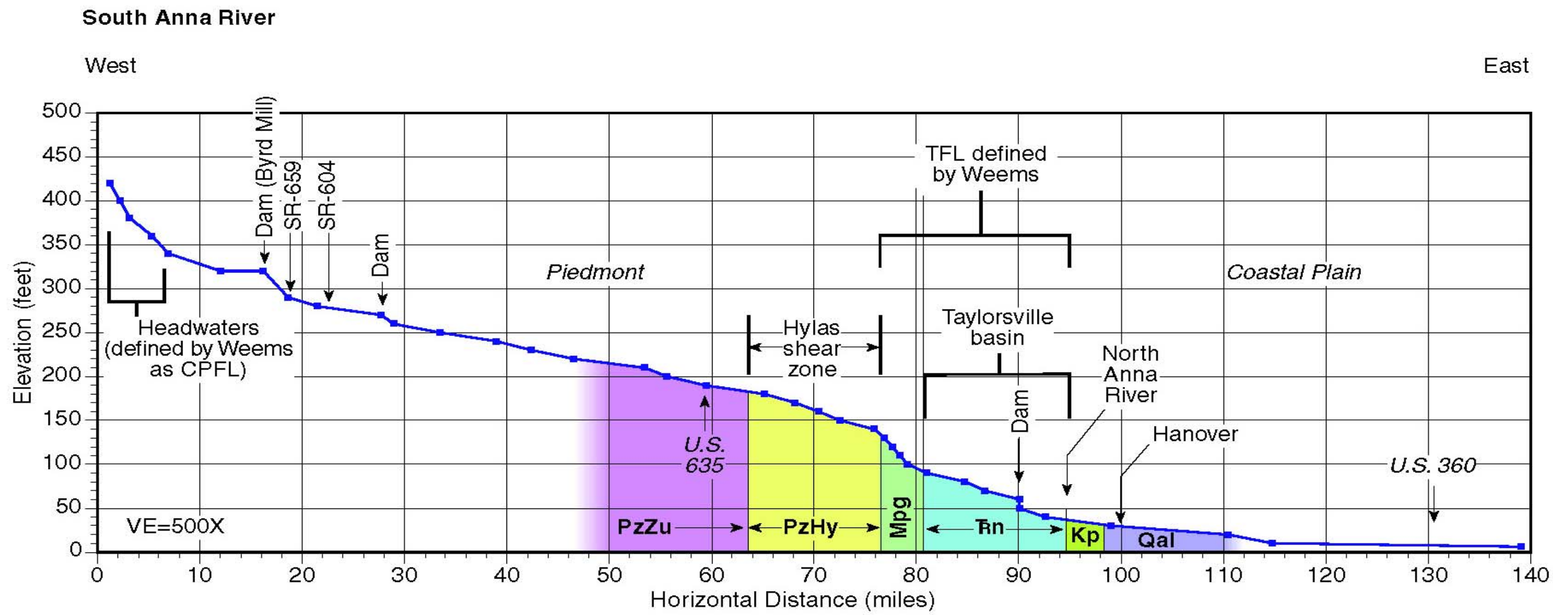


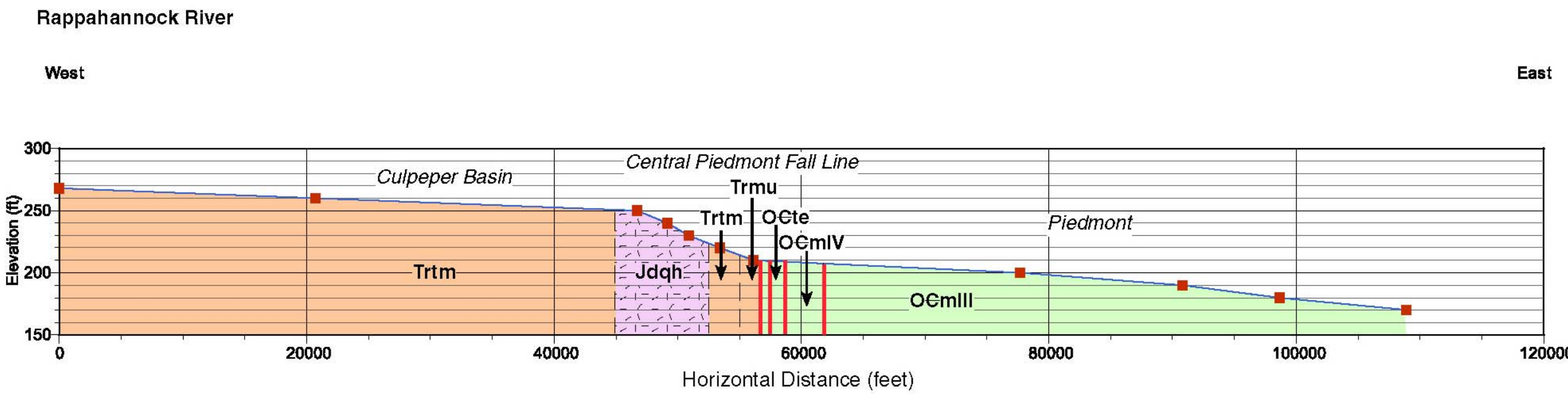
Figure 3. Longitudinal profiles of the Rappahannock River and the Pliocene Tps unit across the Tidewater fall line at Fredericksburg. The Tps surface has a constant gradient and extends across the fall zone in the river without obvious east-down deflection.



Explanation

Qal	Pleistocene terrace deposits and Holocene alluvium
Kp	Potomac formation (Cretaceous)
Ћn	Newark supergroup, undivided; deposits of the Taylorsville Basin (Triassic)
PzHy	Petersburg Granite (Mesozoic)
Mpg	Hylas Zone Clastic Rock (Paleozoic)
PzZu	Metasedimentary and metaigneous rocks, undifferentiated (Paleozoic)

Figure 4. Longitudinal profile of the South Anna River across the Central Piedmont Fall Line (CPFL) and Tidewater Fall Line (TFL) of Weems (1998), Geology from Mixon et al. (1989).



Explanation

Jdqh Diabase (Jurassic)
Trtm Mountain Run member, Tibbstown formation (Triassic)
Culpeper Basin strata
Trmu Manassas Sandstone (Triassic)
OЄte True Blue formation (Ordovician -Cambrian)
OЄmIV, OЄmIII Mine Run Complex (Ordovician-Cambrian)

Figure 5. Longitudinal profile of Rappahannock River across eastern Culpepper Basin margin showing faults in red. Geology from Mixon et al. (2000).

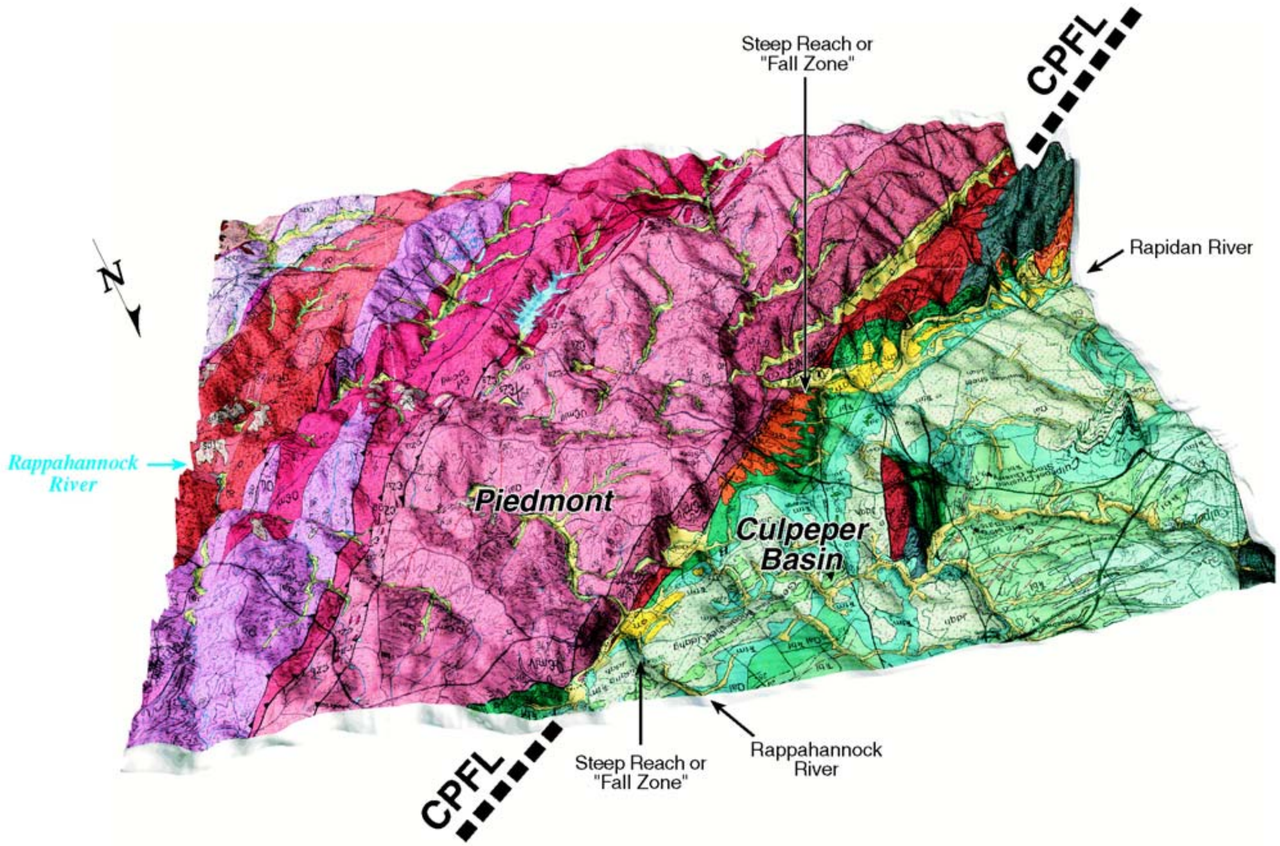
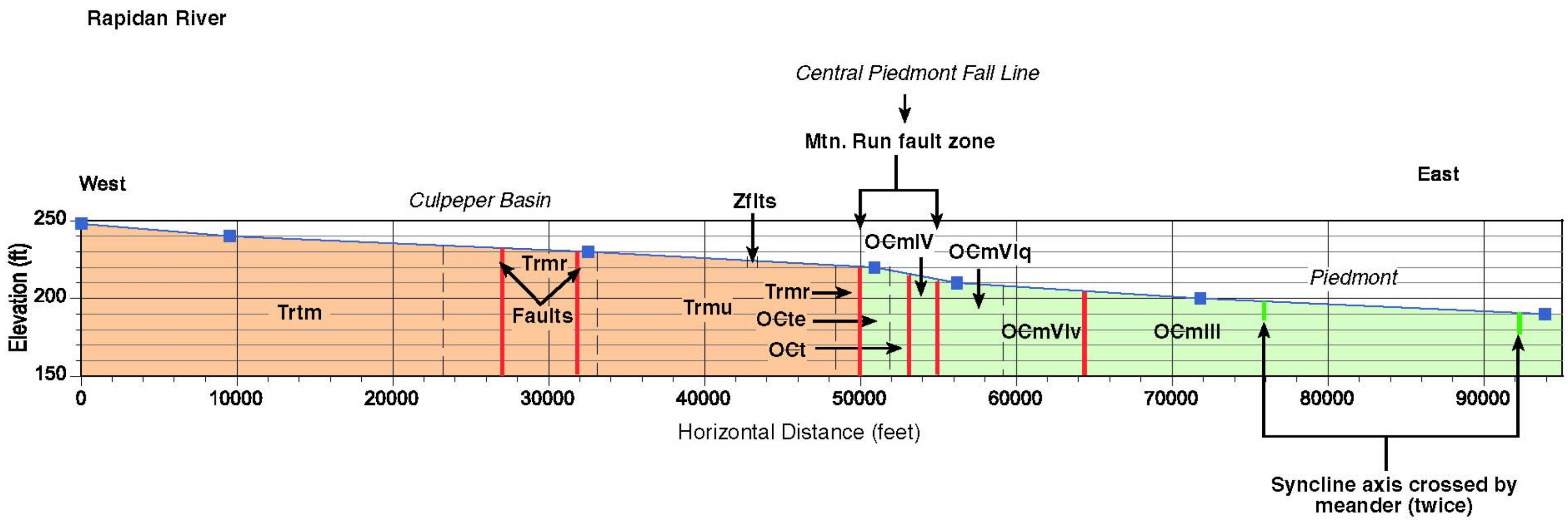


Figure 6. Part of the geologic map of Mixon et al. (2000) covering the eastern Culpepper Basin, draped over topography (USGS DEM with 30x vertical exaggeration). Triassic Culpepper Basin rocks in blue and green; Jurassic diabase is light bluish gray with red pattern. Paleozoic rock of the Piedmont in shades or red and purple. Note northwest-facing escarpment along the Central Piedmont fall line of Weems (1998), underlain by Paleozoic rocks.



Explanation

Trtm	Mountain Run member, Tibbstown Formation (Triassic)	Culpeper Basin strata
Trmr, Trmu	Manassaas Sandstone (Triassic)	
OꞒt, OꞒte	True Blue formation (Cambrian-Ordovician)	
OꞒmVIv, OꞒmIII, OꞒmVIq, OꞒmIV	Mine Run complex (Ordovician-Cambrian)	

Figure 7. Longitudinal profile of Rapidan River across eastern Culpepper Basin margin showing faults in rad and fold axes in green. Geology from Mixon et al. (2000).

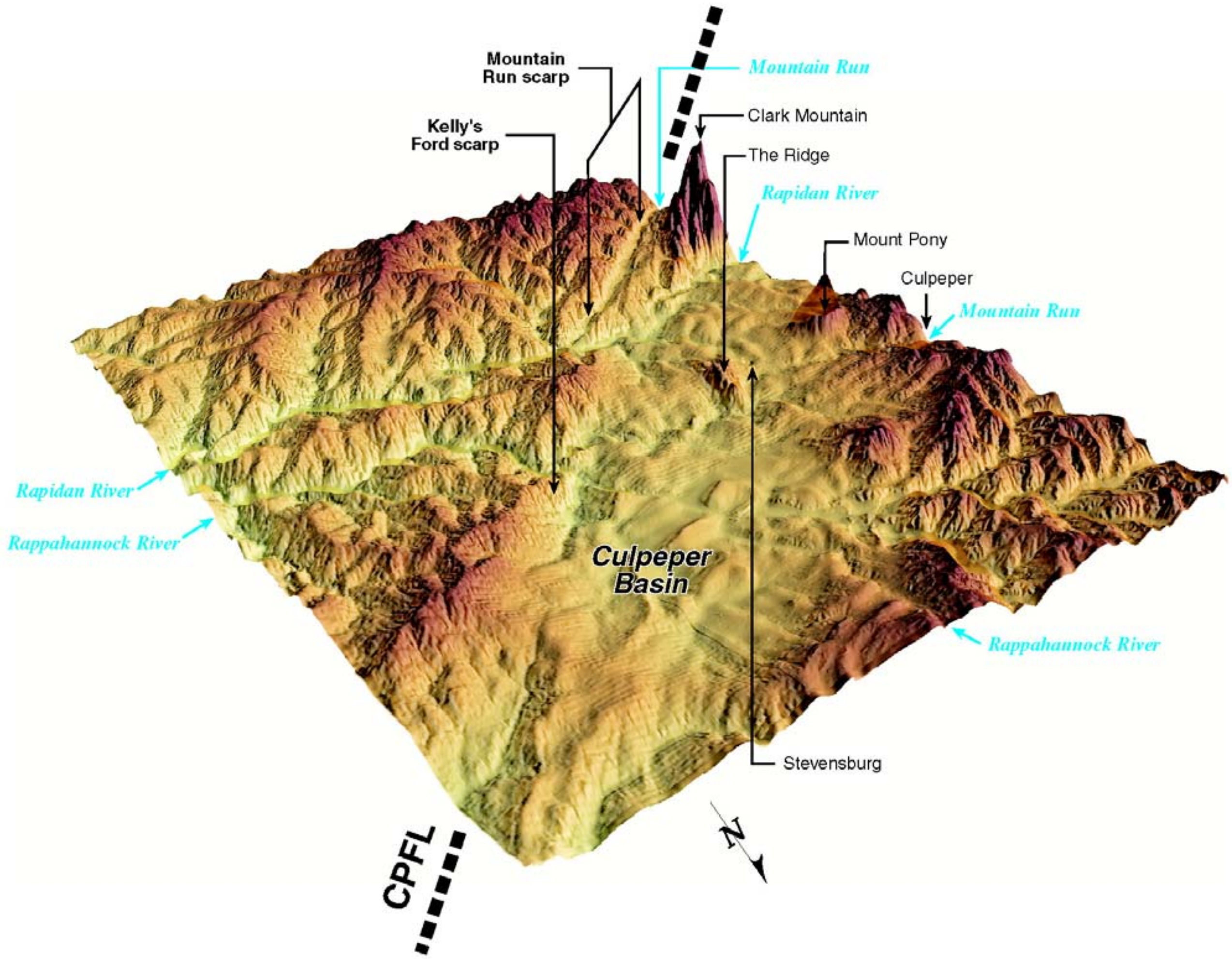


Figure 8. Oblique view to the southeast of topography (USGS DEM with 30x vertical exaggeration) along the Central Piedmont Fall Line (CPFL) of Weems (1998), at the latitude of Culpepper Basin. Note the broad, northwest-facing topographic escarpment along the fall line.

RAI 2.5.1-4 (NRC 4/15/04 Letter)

> In SSAR Section 2.5.1.1.4, Dominion concludes, citing Crone and Wheeler (Reference 59), that neither the Hylas shear zone nor the Lake of the Woods thrust fault are capable tectonic sources stating, "there is no geomorphic expression, historical seismicity, or Quaternary deformation along either the Hylas shear zone or Lake of the Woods thrust fault (Reference 59)." Please provide an explanation of how the information in Crone and Wheeler (Reference 59) forms a basis for this conclusion.

Response

Crone and Wheeler (2000) provide a compilation and evaluation of Quaternary faults, liquefaction features, and possible tectonic features in the Central and Eastern United States. They do not list the Hylas shear zone or the Lake of the Woods thrust fault as suspect Quaternary features, nor do they explicitly describe either of these two structures.

Our conclusion that there is no concentration or alignment of historical seismicity, geomorphic expression, or Quaternary deformation on these faults is based on review of published literature and historical seismicity performed during this investigation. Our review of the literature did not reveal any information published since 1986 that would indicate potential Quaternary activity of the faults. The published literature describes the faults as Paleozoic structures with mylonitic shear textures implying that the faults formed at deep crustal levels and that their current surface exposure is the result of exhumation. As reported in the SSAR, the Hylas shear zone also borders, in part, a Mesozoic basin suggesting that the fault may have been reactivated in the Mesozoic.

There is no reported seismicity attributed to the Hylas shear zone or the Lake of the Woods thrust fault in the published literature. Based on the review of EPRI and post-EPRI seismicity performed for the ESP, there is also no alignment or concentration of seismicity associated with either of these two faults. However, the presence of diffuse, scattered seismicity within the CVSZ makes it difficult to preclude with certainty that a few small, individual events are not spatially associated with any of the several east-dipping thrust faults and shear zones within the Appalachian crust, such as the Hylas shear zone and Lake of the Woods thrust fault.

References

Crone A. J. and R. L. Wheeler, 2000, Data for Quaternary faults, liquefaction features, and possible tectonic features in the Central and Eastern United States, east of the Rocky Mountain front, U.S. Geological Survey Open-File Report 00-260, (Reference 59 of SSAR Section 2.5).

Application Revision

The second to last paragraph of SSAR Section 2.5.1.1.4.c.1 will be revised to read as follows:

> Between 5 and 25 miles from the site, the Hylas shear zone, Mountain Run fault zone, and Lake of the Woods thrust fault are prominent structural features. These structures exhibit mylonitic textures, indicative of the ductile conditions in which they formed during the Paleozoic Era. The Hylas shear zone, for example, comprises a 1.5-mile wide zone of ductile shear fabric and mylonites, and was active between 330 and 220 million years ago based on the presence of mylonitized and unmylonitized intrusive rocks across the fault zone (Reference 60). The Hylas shear zone and Mountain Run fault zone also locally border Mesozoic basins and appear to have been locally reactivated during Mesozoic extension to accommodate growth of the basins. The Mountain Run fault zone exhibits geomorphic expression suggestive of potential Tertiary or Quaternary reactivation. The Mountain Run fault zone is discussed in greater detail in this section under Quaternary Tectonic Features. Based on review of published literature and historical seismicity, there is no reported geomorphic expression, historical seismicity, or Quaternary deformation along either the Hylas shear zone or Lake of the Woods thrust fault. Diffuse, scattered seismicity occurs throughout the CVSZ, but is not spatially concentrated or aligned with either of these two structures. Crone and Wheeler (Reference 59) provide a compilation and evaluation of Quaternary fault, liquefaction features, and possible tectonic features in the Central and Eastern United States. They do not show the Hylas shear zone or the Lake of the Woods thrust fault as suspect Quaternary features. These structures are not considered to be capable tectonic sources.

2.5.2-2 (NRC 4/15/04 Letter)

SSAR Section 2.5.2.6.6 states that new ground motion models were used to characterize the seismic hazard and determine the Safe Shutdown Earthquake (SSE) spectrum for the ESP site. According to the SAR, the new ground motions are based on the 2003 EPRI-sponsored study (Reference 116), which considers 13 different ground motion relations. As stated in SSAR Section 2.5.2.6.6, differences between the ground motions from the 2003 EPRI study and the 1989 EPRI report are substantial, with the new ground motions as much as 55% higher for spectral accelerations at 10 Hz. To allow the NRC staff to fully assess the new ground motion modeling presented in the 2003 EPRI study, the following information is needed.

2.5.2-2 Part a)

a) Please provide hazard curves for 2.5 and 5 Hz spectral acceleration similar to those provided in the SSAR for 1 Hz (Figure 2.5-45) and 10 Hz (Figure 2.5-44).

Response to Part a)

The requested hazard curves are provided in Figures 1 and 2 on the next 2 pages. These curves were calculated just as were the 1 Hz (Figure 2.5-45) and 10 Hz (Figure 2.5-44) curves of the SSAR except that attenuation relationships appropriate for 2.5 Hz and 5 Hz ground motions were used.

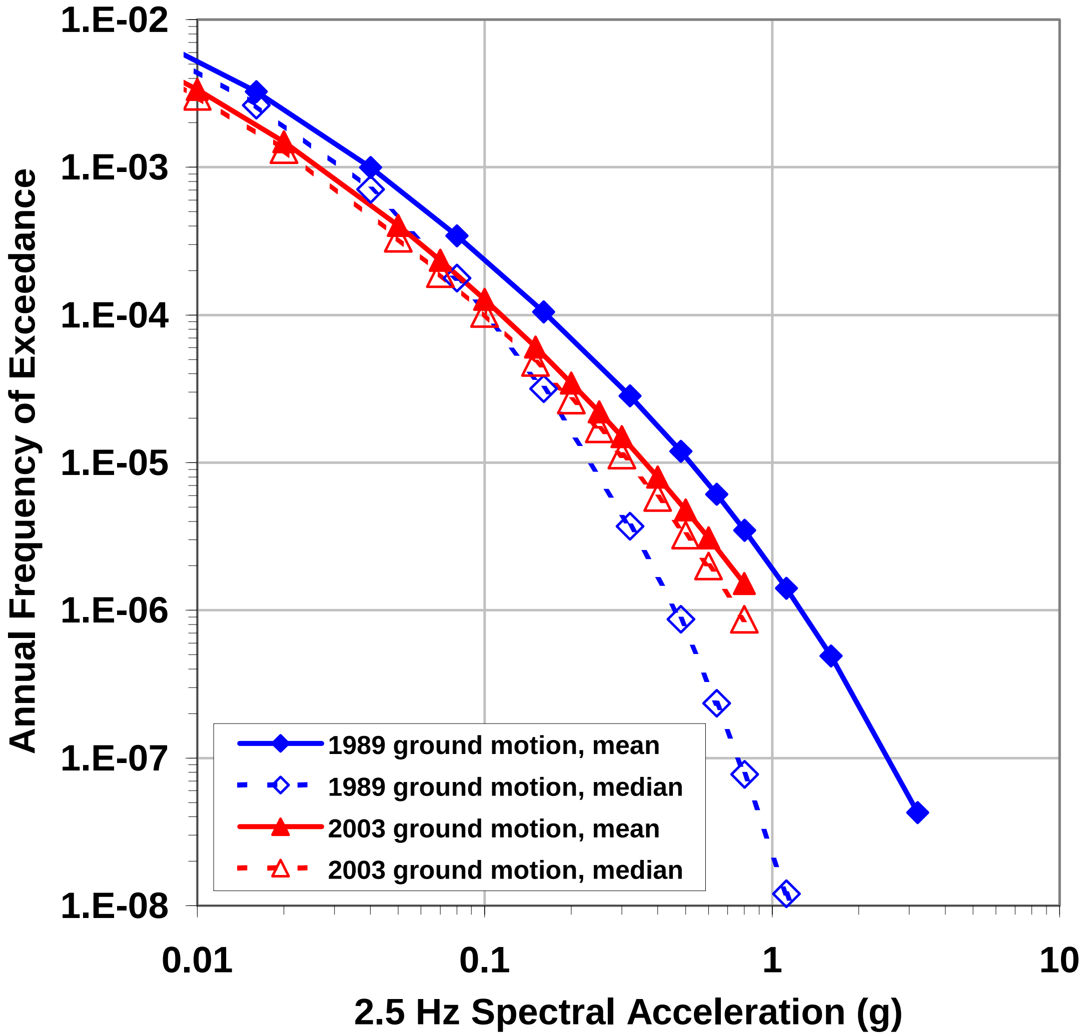


Figure 1. Sensitivity to ground motion model, 2.5 Hz

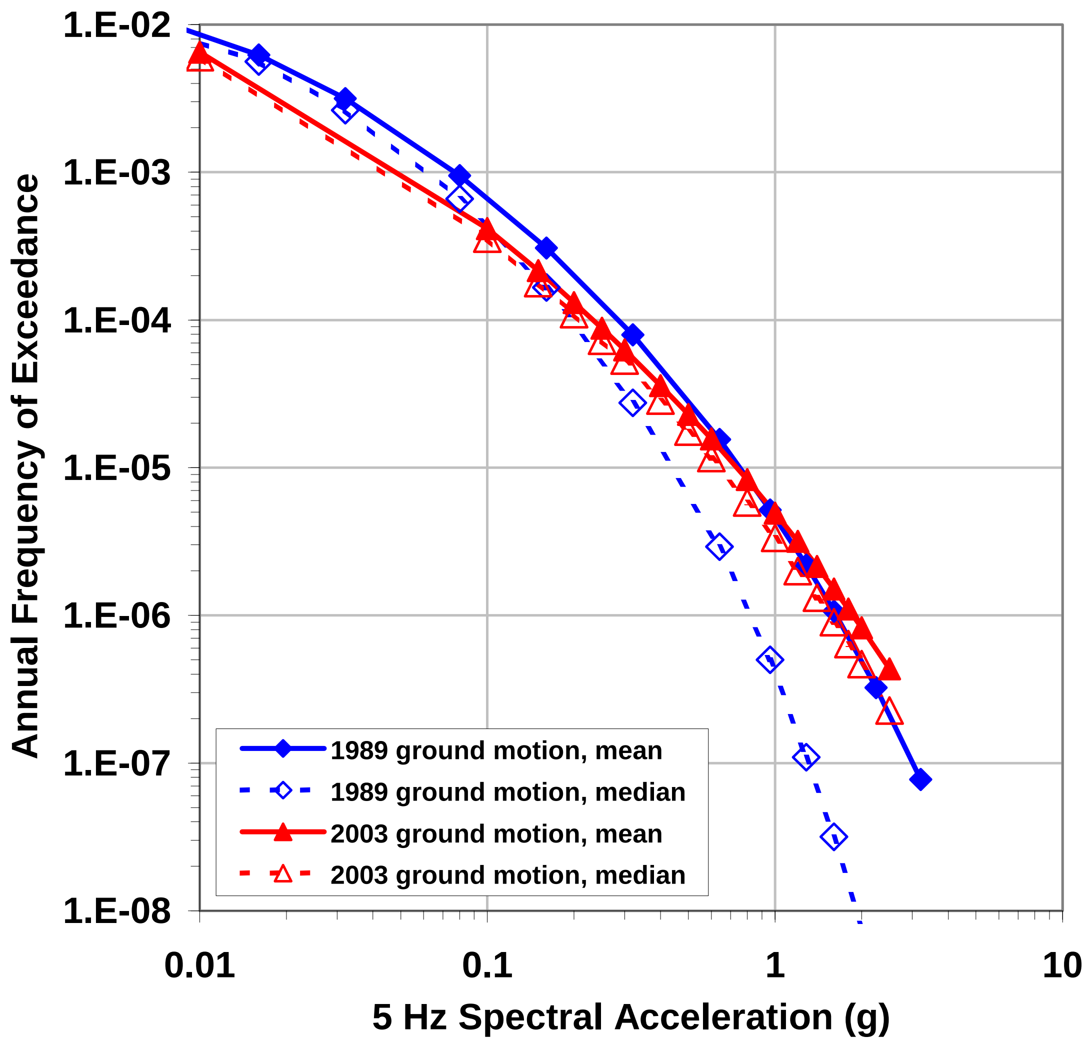


Figure 2. Sensitivity to ground motion model, 5 Hz

RAI 2.5.2-2 Part b)

b) Please provide a copy of the following two documents: Silva et al. (1997) “Description and validation of the stochastic ground motion model”, submitted to Brookhaven National Laboratory (BNL) and Silva et al. (2002) “Development of regional hard rock attenuation relations for Central and Eastern North America.”

Response to Part b)

Copies of the following documents are enclosed in the attached compact disc (CD):

- Silva, W., N. Abrahamson, G. Toro, and C. Costantino (1996). Description and Validation of the Stochastic Ground Motion Model, Pacific Engineering and Analysis report, prepared for the Engineering Research and Applications Division, Department of Nuclear Energy, Brookhaven National Laboratory, Associated Universities, Inc., Upton, New York.

- Silva, W., N. Gregor, and R. Darragh (2002). Development of regional hard rock attenuation relations for central and eastern North America. Pacific Engineering and Analysis report, http://www.pacificengineering.org/CEUS/Development%20of%20Regional%20Hard_ABC.pdf

2.5.2-2 Part c)

c) Chapter 2, “Ground Motion Model Development,” of the 2003 EPRI study (Reference 116) describes the development of the ground motion models, and Table 2-2 in Chapter 2 shows the placement of each of the 13 ground motion relationships into 4 groups. Page 2-6 of the 2003 EPRI study states that “the model weight was based on the variance between a model’s predictions and the available ground motion database.” Please describe the data (i.e., earthquake dates, magnitudes, source-receiver distances, frequencies, site conditions) used to determine the weighting of the models within each group or cluster. Also, please provide the weight assigned to each of the 13 ground-motion relationships within their respective group or cluster.

Response to Part c)

Table 1 describes the data used to determine the model weighting. Table 2 shows the weights assigned to each of the 13 ground motion relationships. The information in these tables was provided by M. McCann, a principal investigator for the EPRI (2003) ground motion report.

Table 1. Eastern North America Rock PSA

Event		EQ #	Mag. M	Rhypo km	Frequency (Hz)					PGA
Date	Name				1	5	10	20	25	
3/1/1925	Charlevoix, Quebec, CAN	1	6.4	862	*					
3/1/1925	"	1	6.4	960	*					
11/1/1935	Timiskaming, CAN	2	6.2	428	*					
11/1/1935	"	2	6.2	616	*					
11/1/1935	"	2	6.2	783	*					
11/1/1935	"	2	6.2	861	*					
11/1/1935	"	2	6.2	869	*					
9/5/1944	Cornwall (CAN) - Massena, NY	3	5.8	389	*					
9/5/1944	"	3	5.8	599	*					
9/5/1944	"	3	5.8	698	*					
3/25/1976	New Madrid, MO	4	4.6	150.48	*	*	*		*	*
1/19/1982	Franklin Falls, NH	5	4.3	62.69	*	*	*		*	*
1/19/1982	"	5	4.3	76.05	*	*	*		*	*
1/19/1982	"	5	4.3	275.4	*	*	*			
1/19/1982	"	5	4.3	323.6	*	*	*			
1/19/1982	"	5	4.3	389	*	*	*			
1/19/1982	"	5	4.3	537	*	*	*			
1/19/1982	"	5	4.3	724.4	*	*	*			
3/31/1982	New Brunswick (A13)	6	4.0	4.08	*	*	*		*	*
3/31/1982	"	6	4.0	5.66	*	*	*		*	*
3/31/1982	"	6	4.0	5.72	*	*	*		*	*
10/7/1983	Goodnow, NY	7	5.0	143.4	*	*	*			
10/7/1983	"	7	5.0	180.4	*	*	*			
10/7/1983	"	7	5.0	198.7	*	*	*			
10/7/1983	"	7	5.0	245.5	*	*	*			
10/7/1983	"	7	5.0	257	*	*	*			
10/7/1983	"	7	5.0	309	*	*	*			
10/7/1983	"	7	5.0	323.6	*	*	*			
10/7/1983	"	7	5.0	338.8	*	*	*			
10/7/1983	"	7	5.0	501.2	*	*	*			
10/7/1983	"	7	5.0	562.3	*	*	*			
10/7/1983	"	7	5.0	602.6	*	*	*			
10/7/1983	"	7	5.0	616.6	*	*	*			
10/7/1983	"	7	5.0	691.8	*	*	*			
10/7/1983	"	7	5.0	741.3	*	*	*			
10/7/1983	"	7	5.0	776.2	*	*	*			
10/7/1983	"	7	5.0	831.8	*	*	*			
11/9/1985	Nahani, CAN (F1)	8	4.6	18.82	*	*	*		*	*

Table 1. Eastern North America Rock PSA

Event		EQ #	Mag. M	Rhypo km	Frequency (Hz)					PGA
Date	Name				1	5	10	20	25	
12/23/1985	Nahani, CAN	9	6.7	9.53	*	*	*		*	*
12/23/1985	"	9	6.7	9.68	*	*	*		*	*
12/23/1985	"	9	6.7	23.38	*	*	*		*	*
12/25/1985	Nahani, CAN (A1)	10	5.0	18.88	*	*	*		*	*
1/31/1986	Painesville, OH	11	4.8	20.9	*	*	*			
1/31/1986	"	11	4.8	524.8	*	*	*			
1/31/1986	"	11	4.8	588.8	*	*	*			
1/31/1986	"	11	4.8	602.6	*	*	*			
1/31/1986	"	11	4.8	741.3	*	*	*			
1/31/1986	"	11	4.8	776.2	*	*				
1/31/1986	"	11	4.8	851.1	*	*	*			
1/31/1986	"	11	4.8	871	*	*	*			
7/12/1986	St. Marys, OH	12	4.5	794	*	*	*			
7/12/1986	"	12	4.5	832	*	*	*			
7/12/1986	"	12	4.5	884	*	*	*			
7/12/1986	"	12	4.5	891	*	*	*			
7/12/1986	"	12	4.5	959	*	*	*			
11/23/1988	Saguenay, CAN (F1)	13	4.5	100.33	*	*	*			*
11/23/1988	"	13	4.5	106.98	*	*	*			*
11/23/1988	"	13	4.5	118.78	*	*	*			*
11/23/1988	"	13	4.5	125.58	*	*	*			*
11/23/1988	"	13	4.5	127.34	*	*	*			*
11/23/1988	"	13	4.2	128.3	*	*	*			
11/23/1988	"	13	4.5	198.58	*	*	*		*	*
11/23/1988	"	13	4.2	202.3	*	*	*			
11/23/1988	"	13	4.2	232.1	*	*	*			
11/23/1988	"	13	4.2	314.6	*	*	*			
11/23/1988	"	13	4.2	346.6	*	*	*			
11/23/1988	"	13	4.2	390.3	*	*	*			
11/23/1988	"	13	4.2	460.2	*	*	*			
11/23/1988	"	13	4.2	467.8	*	*	*			
11/23/1988	"	13	4.2	473.6	*	*	*			
11/25/1988	Saguenay, CAN	14	5.9	70.35	*	*	*		*	*
11/25/1988	"	14	5.9	97.5	*	*	*		*	*
11/25/1988	"	14	5.9	101.34	*	*	*		*	*
11/25/1988	"	14	5.9	113.08	*	*	*		*	*
11/25/1988	"	14	5.9	117.56	*	*	*		*	*
11/25/1988	"	14	5.9	118.11	*	*	*		*	*
11/25/1988	"	14	5.9	132.53	*	*	*		*	*

Table 1. Eastern North America Rock PSA

Event					Frequency (Hz)					
Date	Name	EQ #	Mag. M	Rhypo km	1	5	10	20	25	PGA
11/25/1988	"	14	5.9	196.95	*	*	*		*	*
11/25/1988	"	14	5.9	325.79	*	*	*		*	*
11/25/1988	"	14	5.9	360.77	*	*	*		*	*
11/25/1988	"	14	5.9	472.29	*	*	*		*	*
11/25/1988	"	14	5.8	51.3	*	*	*			
11/25/1988	"	14	5.8	70.8	*	*	*			
11/25/1988	"	14	5.9	94.97	*	*	*		*	*
11/25/1988	"	14	5.8	97.7	*	*	*			
11/25/1988	"	14	5.8	112.2	*	*				
11/25/1988	"	14	5.8	117.5	*	*	*			
11/25/1988	"	14	5.8	117.5	*	*	*			
11/25/1988	"	14	5.8	125.9	*	*	*			
11/25/1988	"	14	5.8	151.4	*	*	*			
11/25/1988	"	14	5.8	177.8	*	*	*			
11/25/1988	"	14	5.8	313.5	*	*	*			
11/25/1988	"	14	5.8	332.5	*	*	*			
11/25/1988	"	14	5.8	389.2	*	*	*			
11/25/1988	"	14	5.8	391.2	*	*	*			
11/25/1988	"	14	5.8	468	*	*	*			
11/25/1988	"	14	5.8	471.8	*	*	*			
11/25/1988	"	14	5.8	537	*	*	*			
11/25/1988	"	14	5.8	549.5	*	*	*			
11/25/1988	"	14	5.8	707.9	*	*	*			
4/27/1989	New Madrid, MO	15	4.7	174.19	*	*	*		*	*
9/26/1990	Cape Girardeau	16	4.7	47.73	*	*	*		*	*
10/19/1990	Mount-Laurier Quebec, CAN	17	4.5	26.9	*	*	*			
10/19/1990	"	17	4.5	87.1	*	*	*			
10/19/1990	"	17	4.5	123	*	*	*			
10/19/1990	"	17	4.5	169.8	*	*	*			
10/19/1990	"	17	4.5	190.5	*	*	*			
10/19/1990	"	17	4.5	218.8	*	*	*			
10/19/1990	"	17	4.6	407.87	*	*	*			*
10/19/1990	"	17	4.6	418.59	*	*	*			*
10/19/1990	"	17	4.6	437.43	*	*	*			*
10/19/1990	"	17	4.6	437.49	*	*	*			*
10/19/1990	"	17	4.6	456.18	*	*	*			*
10/19/1990	"	17	4.6	466.68	*	*	*			*
10/19/1990	"	17	4.5	467.7	*	*	*			
5/4/1991	New Madrid, MO	18	4.4	114.22	*	*	*		*	*

Table 1. Eastern North America Rock PSA

Event		EQ #	Mag. M	Rhypo km	Frequency (Hz)					PGA
Date	Name				1	5	10	20	25	
1/1/2000	Temiscamingue Region, Quebec, CAN	19	4.7	22.7	*	*	*	*		
1/1/2000	"	19	4.7	147.2	*	*	*	*		
1/1/2000	"	19	4.7	228.5	*	*	*	*		
1/1/2000	"	19	4.7	235.1	*	*	*	*		
1/1/2000	"	19	4.7	292.8	*	*	*	*		
1/1/2000	"	19	4.7	293.9	*	*	*	*		
1/1/2000	"	19	4.7	340.9	*	*	*	*		
1/1/2000	"	19	4.7	394.7	*	*	*	*		
1/1/2000	"	19	4.7	433.8	*	*	*	*		
1/1/2000	"	19	4.7	468.6	*	*	*	*		
1/1/2000	"	19	4.7	541.1	*	*	*	*		
1/1/2000	"	19	4.7	591.8	*	*	*	*		
1/1/2000	"	19	4.7	647.4	*	*	*	*		
1/1/2000	"	19	4.7	654.4	*	*	*	*		
1/1/2000	"	19	4.7	662.7	*	*	*	*		
1/1/2000	"	19	4.7	673.4	*	*	*	*		
1/1/2000	"	19	4.7	678	*	*	*	*		
1/1/2000	"	19	4.7	689.5	*	*	*	*		
1/1/2000	"	19	4.7	703.3	*	*	*	*		
1/1/2000	"	19	4.7	808.3	*	*	*	*		
1/1/2000	"	19	4.7	830.3	*	*	*	*		
1/1/2000	"	19	4.7	850.8	*	*	*	*		
1/1/2000	"	19	4.7	851.2	*	*	*	*		
1/1/2000	"	19	4.7	910.2	*	*	*	*		
1/1/2000	"	19	4.7	913.5	*	*	*	*		
1/1/2000	"	19	4.7	974.7	*	*	*	*		
4/20/2002	Au Sable Forks, NY	20	5.0	73	*	*	*	*		
4/20/2002	"	20	5.0	110	*	*	*	*		
4/20/2002	"	20	5.0	144	*	*	*	*		
4/20/2002	"	20	5.0	192	*	*	*	*		
4/20/2002	"	20	5.0	280	*	*	*	*		
4/20/2002	"	20	5.0	317	*	*	*	*		
4/20/2002	"	20	5.0	840	*	*	*	*		
4/20/2002	"	20	5.0	897	*	*	*	*		
4/20/2002	"	20	5.0	988	*	*	*	*		

Table 2. Ground Motion Attenuation Model Weights in Each Cluster

Cluster No.	Model Type	Models	Weights[1]
1	Spectral, Single Corner	Hwang & Huo [1997]	0.037
		Silva et al. [2002] – SC-CS	0.192
		Silva et al. [2002] – SC-CS-S	0.148
		Silva et al. [2002] – SC-VS	0.560
		Toro et al. [1997]	0.029
		Frankel et al. [1996]	0.034
2	Spectral, Double Corner	*Atkinson & Boore [1995]*	0.714
		Silva et al. [2002] DC	0.154
		Silva et al. [2002] DC-S	0.132
3	Hybrid	Abrahamson & Silva [2002]	0.336
		Atkinson [2001] & Sadigh et al. [1997]	0.363
		Campbell [2003])	0.301
4	Finite Source/Greens Function	*Somerville et al.* [2001]	1.0

[1]The model weights have been rounded to three decimal places.

2.5.2-2 Part d)

d) Table 2-7 in Chapter 2 shows the relative weights for each of the 4 groupings of ground motion models. Please describe the seismological principles used to determine the importance weights given for each of the model clusters.

Response to Part d)

Expert Panel members were asked to subjectively evaluate how well the alternative ground motion attenuation models relied on seismological principles. This attribute considered the degree to which the methodology that is the basis for the ground motion attenuation model incorporates seismological modeling principles, including seismic source modeling and/or scaling, crustal wave propagation, and near-surface crustal effects. The experts were further asked to provide the technical basis for their ratings. Consistency with data as well as adherence to seismological principles was considered. Experts were asked to evaluate each model in terms of a rating of Low, Moderate, or High. Opinions on the relative importance of consistency with data versus seismological principles varied. One view was that consistency with existing CEUS data should be paramount, while conformance with seismological principles was subjective, since those principles were open to disagreement and debate. The other, more dominant, view was that the existing CEUS data was not only sparse, but could be misleading due to issues regarding site conditions, recording methods, data processing, and V/H (vertical to horizontal) conversions. Furthermore, because data were sparse, it would be relatively easy to make a model fit them well, even if they were unrepresentative. In this view, a fit to existing data should not be done if it entailed a compromise of physical principles of wave generation and propagation.

The responses of the Expert Panel members indicated that the model class (Hybrid, Spectral, and Finite Source) was quite important in establishing the degree to which a model either did or did not have a strong basis in seismological principles. The following order of model preference (from strong to less strong) was selected:

- Finite source – This type of model is able to use scaling relations for fault dimensions and rise time that have a clear basis in the physical space-time properties of a fault rupture process. It is, therefore, able to better represent ground motion with low frequencies emanating from large nearby earthquakes. Somerville et al. (2001) is the only example of this type of model among all those considered.

- Hybrid – These models incorporate the host region empirical data, and can also be relatively consistent with seismological principles including representation of nearby large magnitude earthquakes. The Campbell (2003) model was judged relatively strong and the Abrahamson & Silva (2002) model, if it were better documented and peer-reviewed, could also be favorably assessed.

- Spectral – These models tend to be governed by their mathematical form which is most compatible with a point source event. Thus they are weak for large nearby earthquakes although techniques for overcoming this, such as “double corner”, “variable stress drop”, and “saturation,” are used. Atkinson & Boore (1995), Silva et al. (2002, double corner saturation), and Toro et al. (1997) were considered the stronger contenders.

2.5.2-2 Part e)

e) Chapter 3, “Ground Motion Model Results,” of the 2003 EPRI study (Reference 116) describes the ground motion attenuation model for sites located in the Central and Eastern U.S. Table 3-2 in Chapter 3 provides the ground motion attenuation model functional forms for 5 groups or clusters. Please explain why some of the attenuation relationships in cluster 1 contain terms accounting for Moho reflections or losses from the effective Q in the crust, whereas the functional form for cluster 1 does not contain either of these two terms.

Response to Part e)

In developing their models, Silva et al. (2002) – the proponents for the reference model form for Cluster 1 – explicitly considered Moho reflections and losses from the effective Q in the crust. For their model development and generation of synthetic ground motion data they considered an epistemic range of Q values and a change of geometrical spreading at 80 km distance that would accommodate Moho reflection effects.

In trying different regression forms to best fit the synthetic ground motion data, Silva et al. did not find sufficient ground motion attenuation trends to warrant retention of model terms for Moho reflection – that is, an explicit change in the model coefficients at a specified distance – or the term typically associated with Q – that is, a term linear with distance for log ground motion.

The following Silva et al. ground motion model term

$$(C_3 + C_4 m) \times \boldsymbol{ln}(d_{JB} + e^{C_5})$$

was intended to capture magnitude-dependent changes in attenuation with distance, including the contribution of Moho reflections.

In considering an explicit Q term in the final model form, Silva et al. did not find the coefficient of this term to be significant.

Similarly in their initial ground motion model development for the western United States, Boore et al. (1997) did not find this term significant, and, in fact, found the coefficient of this term trending to a physically unreasonable positive value. This term was subsequently dropped.

In summary, when considering reasonable epistemic ranges in source, path, and shallow crustal parameters, the central or average tendency of ground motion smeared out the Moho reflection behavior or, due to interaction of coefficients of complex attenuation algorithms, gave rise to insignificant or even unphysical regression coefficients, such as the Q term coefficient. The simpler form of the attenuation model adopted for Cluster 1 was found to fit the synthetic data generated by Silva et al. as well and it was adopted.

<u>References</u>

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Application Revision

None.

RAI 2.5.2-3 (NRC 4/15/04 Letter)

Regarding new seismic source characterizations, SSAR Section 2.5.2.6.3 states that, for the Charleston seismic source, the USGS source parameters (Reference 127) were adopted. SSAR Section 2.5.2.2.9 states that "the most significant impact of the 2002 USGS model (Reference 127) on seismic hazard for the ESP site is the updated Charleston sources parameters." Figures 2.5-40 and 2.5-41 show 1 Hz spectral acceleration seismic hazard curves (median and mean, respectively) at the ESP site for the northern and southern segments of the East Coast Fault System (ECFS). As shown in both of these figures, the southern segment of the ECFS (ECFS-S), which includes the Charleston seismic source, makes a significant contribution to the overall hazard at the 1 Hz spectral acceleration. In spite of the significant contribution of the ECFS-S for low frequency ground motion, the controlling earthquake for the 1 and 2.5 Hz frequency range is a magnitude 5.5 earthquake at a distance of 30 km from the ESP site (Table 2.5-26). Neither this magnitude nor this distance correspond to an event occurring in the ECFS-S (i.e., Charleston source zone). Please explain this result in view of the statement quoted above and Figures 2.5-40 and 41 in the application.

Response

SSAR Section 2.5.2.2.9 states that the most significant impact of the 2002 USGS seismic hazard model, Frankel, et al. (2002), is on the Charleston source parameters. This is in the context of evaluating the EPRI seismic hazard study to determine if seismic sources and parameters should be updated, as recommended by RG 1.165, Appendix E. As stated in Appendix E, "If new information identified by the site-specific investigations would result in a significant increase in the hazard estimate for a site, and this new information is validated by a strong technical basis, the PSHA may have to be modified to incorporate the new technical information." This is the procedure that was followed to prepare SSAR Section 2.5.

As illustrated in SSAR Figures 2.5-40 and 2.5-41, the contribution to seismic hazard at 1 Hz frequency of the ECFS-S source (representing the updated Charleston source parameters) depends on the ground motion amplitude of interest and on whether the median or mean hazard is examined. Based on the comparisons in these figures, the ECFS-S source was included in the seismic hazard calculations for the SSAR.

To develop the selected ground motion spectrum, the procedure in Appendix C of RG 1.165 was followed, deaggregating the seismic hazard at 1, 2.5, 5, and 10 Hz. The ground motion amplitude used to deaggregate the seismic hazard at each frequency was that corresponding to the mean 5×10^{-5} annual frequency of exceedance (see SSAR Section 2.5.2.6.8 and Table 2.5-25). For 1 Hz, this amplitude is 0.0652g, as shown in SSAR Table 2.5-25. At this amplitude, SSAR Figure 2.5-40 shows that the *median* hazard from the ECFS-S fault (representing the updated Charleston source) is about four percent of the *median* hazard of all other sources, including the nearby Central Virginia seismic zone. Also at this amplitude, SSAR Figure 2.5-41 shows that the *mean* hazard from the ECFS-S fault is about one-half the *mean* hazard from all other sources, including the nearby Central Virginia seismic zone.

RG 1.165, Appendix C, describes a procedure to determine the magnitude and distance of controlling earthquakes, based on deaggregation of the *median* seismic hazard at 1, 2.5, 5, and 10 Hz. At 1 and 2.5 Hz, the combined relative contribution from sources at distances greater than 100 km to the *median* hazard is quantified. If this relative contribution exceeds 5%, a separate controlling earthquake is determined from these distant sources. For the SSAR, the contribution of sources with distances greater than 100 km is an average of the contributions for 1 Hz (which is about 4%) and 2.5 Hz (which is close to zero), for an overall contribution of about 2%. Because of this low contribution, RG 1.165, Appendix C, did not require a separate controlling earthquake for distant sources. Thus, the controlling earthquake for 1 and 2.5 Hz corresponded to a magnitude and distance consistent with the Central Virginia seismic zone.

It is worth noting that, at higher ground motion amplitudes, deaggregation of the hazard would indicate an even smaller contribution from distant sources than that just discussed. This follows because, from SSAR Figure 2.5.2-40, the relative contribution of the ECFS-S median hazard decreases at higher ground motion amplitudes. Thus the recommendation of higher amplitudes would not result in a separate large magnitude, long-distance controlling earthquake.

If a large-magnitude, distant earthquake were to be adopted as a controlling earthquake for low frequencies, the primary effect would be a small increase below the 1-to-2.5 Hz control frequency point in the SSE spectrum. This is illustrated in Figure 1. This plot shows a low-frequency spectrum scaled to the average of the 1 and 2.5 Hz amplitudes for a mean hazard of $5x10^{-5}$, using **M**=7.5 and R=500 km (the green triangles). The low-frequency spectrum developed in the SSAR used **M**=5.6 and R=37 km (the red diamonds in Figure 1), representing the dominant contribution of the central Virginia seismic zone. The selected performance-based spectrum is also shown as orange circles. The **M**=7.5 spectrum lies below the **M**=5.6 spectrum at frequencies higher than 2 Hz, and lies below the selected performance-based spectrum at frequencies between 1 Hz and 0.2 Hz (few, if any, plant components are sensitive to these low frequencies). The high-frequency spectrum developed in the SSAR, which used **M**=5.3 and R=23 km (the blue squares in Figure 1), does not affect the SSE in the low-frequency range.

There is significant additional margin above the selected performance-based spectrum provided by the RG1.60 spectrum anchored at 0.3g (see, for example, SSAR Figure 2.5.2-51). Thus, the adoption of a large-magnitude, distant earthquake as a controlling earthquake would not change the seismic design requirements above the selected performance-based spectrum.

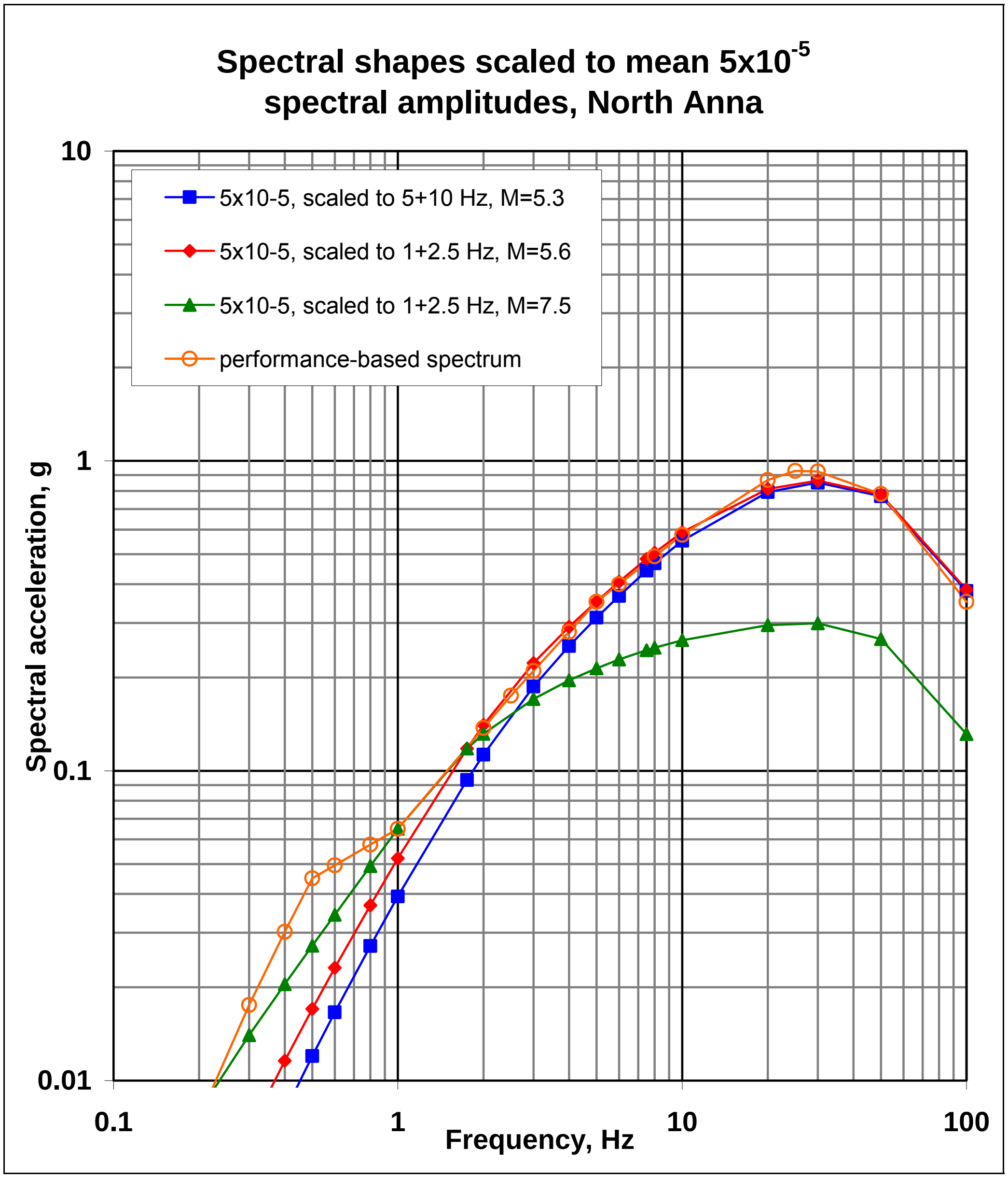

Figure 1. Spectrum scaled to 1 and 2.5 Hz using M=7.5, R= 500 km, compared to similar spectrum using M=5.6, R=37 km, to spectrum scaled to 5 and 10 Hz using M=5.3, R=23 km, and to performance-based spectrum.

References

Frankel, A. D., M. D. Petersen, C. S. Mueller, K. M. Haller, R. L. Wheeler, E. V. Leyendecker, R. L. Wesson, S. C. Harmsen, C. H. Cramer, D. M. Perkins, and K. S. Rukstales. *Documentation for the 2002 Update of the National Seismic Hazard Maps*, U.S. Geological Survey Open-File Report 02-420, 2002, (Reference 127 of SSAR Section 2.5).

Application Revision

None.

2.5.2-4 (NRC 4/15/04 Letter)

SSAR Tables 2.5-5 through 2.5-11 summarize the parameters developed by the six EPRI teams as part of the 1989 EPRI Project (Reference 115) for the seismic source zones surrounding the ESP site. The source parameters shown in Tables 2.5-5 through 2.5-11 are maximum magnitudes, distances from the ESP site, activity probabilities, and smoothing options. In addition, Tables 2.5-5 through 2.5-10 provide information on whether the source parameters have been updated for the probabilistic seismic hazard analysis (PSHA) presented in the ESP application.

2.5.2-4 Part a)

a) Please provide the actual *a* and *b* values for the recurrence model used for each of the seismic source zones and the weights assigned to these values. In addition, please provide the recurrence intervals and their weights associated with the $\mathbf{M}_{\mathbf{max}}$ values for each seismic source.

Response to Part a)

Seismicity parameters for the recurrence models used in each of the seismic sources defined by the EPRI teams vary in space within each seismic source. The EPRI methodology allowed teams to choose smoothing options that smoothed the seismicity rates and *b*-values within each source. The *a*-value used in the EPRI project was defined as the base-10 logarithm of the annual number of earthquakes with magnitude (m_b) between 3.3 and 3.9 per equatorial square degree. A more relevant parameter for seismic hazard assessment is the annual *rate* of earthquakes above the minimum magnitude (which was m_b=5 in the EPRI study). Multiple values of *a* and *b* were computed during the EPRI project for each partial or complete degree cell (longitude and latitude) covered by each source, using the multiple smoothing options selected by each EPRI team for that source. The smoothing options and weights are listed in SSAR Tables 2.5-5 through 2.5-10.

The complete enumeration of *a* and *b* values for each source would be quite voluminous. For example, Bechtel source BZ5 covers parts of 83 degree cells, and the Bechtel team specified three smoothing options for this source, so there are 249 sets of *a* and *b* values for this source. Given that the ground motion hazard is dominated at this site by local seismicity, it is most relevant to concentrate on the seismicity parameters for the degree cell centered on longitude 77.5^{o}W, latitude 38.5^{o}N, which is the degree cell encompassing the ESP site. Table 1 lists the rates and *b*-values for this degree cell for the four Bechtel sources used in the PSHA. Bechtel specified three smoothing options for each source, resulting in three sets of *rates* and *b*-values for each degree cell. Table 1 shows the annual *rate* of m_b>5.0 as calculated from the EPRI *a*-value, rather than the *a*-value itself. Table 1 also shows the total rates and weighted average *b*-values for all cells within that source and for the three smoothing options, using weights proportional to the fraction of each degree cell that is covered by the source. (By this weighting, whole degree cells have higher weight than partial degree cells in calculating the *b*-value).

Tables 2 through 6 provide similar rates and *b*-values for the other five EPRI teams, for the sources used in the seismic hazard calculations (other sources listed in SSAR Tables 2.5.2-5 through 2.5.2-10 did not contribute to the seismic hazard and were not used in calculations).

Epistemic uncertainty in the maximum magnitude (m_{bmax}) assigned to each source by the EPRI teams was represented by a range of alternative values and associated weights. The values and weights for each source are shown in SSAR Tables 2.5-5 through 2.5-10. Recurrence intervals for all but the highest value of m_{bmax} can be calculated assuming that the highest value of m_{bmax} applies. Table 7 shows values of these recurrence intervals, calculated using the averaged rates and *b*-values for each source and each team, weighted over all smoothing options.

Table 1. Rates and b-values for Bechtel team sources

Source	Cell	Weight	Rate	b-value
E	77.5, 38.5	0.33	8.30E-4	0.92
		0.34	5.55E-4	0.94
		0.33	4.27E-4	1.01
	All	0.33	7.04E-3	0.92
		0.34	6.93E-3	0.93
		0.33	5.93E-3	0.98
24	77.5, 38.5	0.33	4.08E-5	0.85
		0.34	2.41E-5	0.90
		0.33	1.38E-5	1.05
	All	0.33	1.01E-2	0.84
		0.34	1.17E-2	0.84
		0.33	7.40E-3	0.99
BZ4*	All	0.33	9.17E-3	1.06
		0.34	1.06E-2	1.08
		0.33	1.15E-2	1.10
BZ5	77.5, 38.5	0.33	1.04E-3	0.92
		0.34	4.92E-4	0.96
		0.33	3.97E-4	1.02
	All	0.33	6.18E-2	0.91
		0.34	6.78E-2	0.92
		0.33	6.94E-2	0.93

*source does not overlie degree cell 77.5, 38.5

Table 2. Rates and b-values for Dames & Moore team sources

Source	Cell	Weight	Rate	b-value
04	77.5, 38.5	0.75	4.91E-6	1.04
		0.25	4.89E-6	1.04
	All	0.75	2.04E-2	1.04
		0.25	2.08E-2	1.04
4B*	All	0.75	2.86E-3	1.02
		0.25	3.39E-3	0.95
40*	All	0.75	4.95E-3	1.05
		0.25	4.58E-3	1.09
41	77.5, 38.5	0.75	1.54E-4	1.05
		0.25	1.50E-4	1.06
	All	0.75	2.30E-2	1.04
		0.25	2.67E-2	1.03
42	77.5, 38.5	0.75	2.74E-4	1.02
		0.25	3.31E-4	0.95
	All	0.75	2.31E-3	1.02
		0.25	2.78E-3	0.95
47	77.5, 38.5	0.75	3.35E-5	1.05
		0.25	3.17E-5	1.06
	All	0.75	1.55E-3	1.05
		0.25	1.47E-3	1.06
53	77.5, 38.5	0.75	3.35E-5	1.04
		0.25	3.26E-5	1.06
	All	0.75	1.92E-2	1.04
		0.25	2.06E-2	1.05

*source does not overlie degree cell 77.5, 38.5

Table 3. Rates and b-values for Law Engineering team sources

Source	Cell	Weight	Rate	b-value
17	77.5, 38.5	1.0	4.22E-4	0.99
	All	1.0	3.21E-2	0.99
22	77.5, 38.5	1.0	1.98E-4	1.06
	All	1.0	5.58E-2	1.05
107	77.5, 38.5	1.0	1.27E-4	1.04
	All	1.0	4.86E-3	1.04
217	77.5, 38.5	1.0	1.22E-4	0.99
	All	1.0	9.32E-3	0.99
C09	77.5, 38.5	1.0	4.45E-5	1.05
	All	1.0	1.12E-2	1.05
C10	77.5, 38.5	1.0	2.04E-5	1.05
	All	1.0	5.02E-3	1.05
C11	77.5, 38.5	1.0	1.87E-4	1.06
	All	1.0	5.03E-2	1.05
M19*	All	1.0	4.62E-4	0.99
M20*	All	1.0	6.72E-4	0.99
M21*	All	1.0	6.33E-4	0.99
M22**	All	1.0	7.39E-4	0.99
M23*	All	1.0	1.21E-3	0.99
M24*	All	1.0	1.44E-3	0.99
M27*	All	1.0	4.86E-4	1.04

*mafic pluton encompasses part of one degree cell
**mafic pluton encompasses parts of two degree cells

Table 4. Rates and b-values for Rondout team sources

Source	Cell	Weight	Rate	b-value
28	All	1.0	3.00E-3	0.90
29	All	1.0	8.37E-3	0.93
30	All	1.0	1.71E-3	1.01

*rates and b-values specified for entire source, not by degree cell

Table 5. Rates and b-values for Weston Geophysical team sources

Source	Cell	Weight	Rate	b-value
22	77.5, 38.5	1.0	5.05E-4	0.92
	All	1.0	9.12E-3	0.92
C19	77.5, 38.5	1.0	5.28E-5	1.00
	All	1.0	1.51E-2	1.00
C21	77.5, 38.5	0.3	3.78E-4	0.99
		0.7	5.51E-4	1.01
	All	0.3	2.32E-2	0.99
		0.7	2.17E-2	1.00
C22	77.5, 38.5	0.3	3.61E-4	0.99
		0.7	5.54E-4	1.00
	All	0.3	1.88E-2	0.99
		0.7	1.71E-2	1.00
C23	77.5, 38.5	0.5	1.53E-4	1.00
		0.5	1.49E-4	1.01
	All	0.5	9.64E-3	1.00
		0.5	9.43E-3	1.00
C34	77.5, 38.5	0.2	2.47E-4	0.98
		0.8	4.55E-4	1.00
	All	0.2	1.75E-2	0.99
		0.8	1.56E-2	0.99
C35	77.5, 38.5	0.2	2.53E-4	0.98
		0.8	4.55E-4	1.00
	All	0.2	2.20E-2	0.99
		0.8	2.00E-2	0.99

Table 6. Rates and b-values for Woodward-Clyde team sources

Source	Cell	Weight	Rate	b-value
26	77.5, 38.5	0.25	3.16E-5	0.93
		0.25	2.62E-5	0.98
		0.25	3.45E-5	0.91
		0.25	4.44E-5	0.83
	All	0.25	8.62E-3	0.93
		0.25	7.12E-3	0.98
		0.25	9.28E-3	0.91
		0.25	1.20E-2	0.84
27	77.5, 38.5	0.25	5.47E-5	0.99
		0.25	5.31E-5	1.00
		0.25	6.37E-5	0.94
		0.25	7.57E-5	0.90
	All	0.25	5.57E-3	0.99
		0.25	5.43E-3	0.99
		0.25	6.57E-3	0.94
		0.25	7.90E-3	0.89
29*	All	0.25	1.68E-2	0.99
		0.25	1.62E-2	1.00
		0.25	2.19E-2	0.91
		0.25	2.96E-2	0.83
29A*	All	0.25	1.25E-2	0.95
		0.25	1.07E-2	0.99
		0.25	1.38E-2	0.91
		0.25	1.76E-2	0.83
B22	77.5, 38.5	0.25	3.13E-4	0.95
		0.25	2.67E-4	1.00
		0.25	3.70E-4	0.91
		0.25	5.11E-4	0.82
	All	0.25	1.37E-2	0.95
		0.25	1.10E-2	0.99
		0.25	1.52E-2	0.90
		0.25	2.07E-2	0.81

*source does not overlie degree cell 77.5, 38.5

Table 7. Recurrence intervals for maximum magnitude values

Team	Source	m_{max} value	weight	Recur. Interval, yrs
Bechtel	24	5.7	0.1	485
		6.0	0.4	1,059
		6.3	0.4	2,996
		6.6	0.1	Infinity
Bechtel	E	5.4	0.1	376
		5.7	0.4	777
		6.0	0.4	1,756
		6.6	0.1	Infinity
Bechtel	BZ4	6.6	0.1	5,984
		6.8	0.1	10,978
		7.1	0.4	34,141
		7.4	0.4	Infinity
Bechtel	BZ5	5.7	0.1	76
		6.0	0.4	169
		6.3	0.4	488
		6.6	0.1	Infinity
Dames & Moore	04	6.0	0.8	563
		7.2	0.2	Infinity
Dames & Moore	4b	6.2	0.75	5,795
		7.2	0.25	Infinity
Dames & Moore	40	6.6	0.8	13,270
		7.2	0.2	Infinity
Dames & Moore	41	6.1	0.8	614
		7.2	0.2	Infinity
Dames & Moore	42	6.3	0.75	9,213
		7.2	0.25	Infinity
Dames & Moore	47	6.0	0.75	7,709
		7.2	0.25	Infinity
Dames & Moore	53	5.6	0.8	220
		7.2	0.2	Infinity
Law Engineering	17	5.7	0.2	165
		6.8	0.8	Infinity
	22	6.8	1.0	Infinity
	107	5.0	0.3	212
		5.5	0.4	1,460
		5.7	0.3	Infinity
	217	5.0	0.5	110
		5.7	0.5	Infinity
	C09	6.8	1.0	Infinity
	C10	6.8	1.0	Infinity
	C11	6.8	1.0	Infinity
	mafic sources	6.8	1.0	Infinity

Table 7. Recurrence intervals for maximum magnitude values

Team	Source	m_{max} value	weight	Recur. Interval, yrs
Rondout	28	6.6	0.3	34,534
		6.8	0.6	403,040
		7.0	0.1	Infinity
Rondout	29	6.6	0.3	13,517
		6.8	0.6	159,660
		7.0	0.1	Infinity
Rondout	30	5.2	0.3	1,368
		6.3	0.55	208,912
		6.5	0.15	Infinity
Weston Geophysical	22	5.4	0.19	268
		6.0	0.66	1,222
		6.6	0.16	∞
Weston Geophysical	C19	5.4	0.26	173
		6.0	0.58	863
		6.6	0.16	∞
Weston Geophysical	C21	5.4	0.24	117
		6.0	0.61	582
		6.6	0.15	∞
Weston Geophysical	C22	5.4	0.24	148
		6.0	0.61	732
		6.6	0.15	∞
Weston Geophysical	C23	5.4	0.8	273
		6.0	0.14	1,354
		6.6	0.06	∞
Weston Geophysical	C34	5.4	0.24	163
		6.0	0.61	805
		6.6	0.15	∞
Weston Geophysical	C35	5.4	0.24	127
		6.0	0.61	627
		6.6	0.15	∞
Woodward-Clyde	26	5.4	0.33	253
		6.5	0.34	3,687
		7.0	0.33	∞
Woodward-Clyde	27	5.6	0.33	608
		6.3	0.34	3,602
		6.9	0.33	∞
Woodward-Clyde	29	6.7	0.33	2,119
		7.0	0.34	5,349
		7.4	0.33	∞
Woodward-Clyde	29A	6.7	0.33	3,241
		7.0	0.34	8,181

Table 7. Recurrence intervals for maximum magnitude values

Team	Source	m_{max} value	weight	Recur. Interval, yrs
		7.4	0.33	∞

2.5.2-4 Part b)

b) With regard to the seismic source zones surrounding the ESP site, in particular the Central Virginia Seismic Zone (CVSZ), and considering the 1994 EPRI study of Arch Johnston, "Seismotectonic Interpretation and Conclusion from the Stable Continental Region Seismicity Database," please provide updated information on the following or explain why updated information is not needed: 1) maximum magnitudes and weights, 2) probabilities of activity, 3) recurrence model values and weights, and 4) source zone geometries for the PSHA recently completed for the ESP site.

Response to Part b)

In 1994, the Electric Power Research Institute (EPRI) published a five-volume study on "The Earthquakes of Stable Continental Regions" (Johnston et al., 1994). Volume 1 of the study, "Assessment of Large Earthquake Potential", presents results from a worldwide database of earthquakes within stable continental regions (SCRs) to assess the relationship, if any, between maximum magnitude and specific tectonic environments. As stated in the introduction to this volume: "*Part of the focus of the early phase of this work was the evaluation of existing methods for assessing maximum earthquakes and preliminary development of new methods for use by the earth science teams in the EPRI-SOG seismic hazard analysis for the Central and Eastern United States (CEUS)"* (Johnston et al, 1994, page 1-1).

Part b) of the RAI requests additional information on the Johnston et al. (1994) study and whether or not the results of this study would require an update or modification to the 1989 EPRI SOG characterization of seismic source parameters (maximum magnitude, probability of activity, recurrence models, source zone geometry) used in the SSAR. RG 1.165, Appendix E, specifies that the EPRI study is an acceptable methodology for the evaluation of seismic hazard with the caveat "*If new information identified by the site-specific investigations would result in a significant increase in the hazard estimate for a site, and this new information is validated by a strong technical basis, the PSHA may have to be modified to incorporate the new technical information."*

The Johnston et al. (1994) EPRI study was initiated in the mid 1980s to examine the assessment of maximum magnitudes in SCRs for specific use in the EPRI SOG seismic hazard analysis for the CEUS. The study did not explicitly address the probability of activity, recurrence models or source zone geometry, other than the observation that the largest SCR earthquakes appear to be associated with tectonic domains of Mesozoic and younger extended crust. Initial results of the study (Coppersmith et al, 1987), "Methods for assessing maximum earthquakes in the central and eastern United

States," were provided to the EPRI teams for the EPRI SOG PSHA. Thus, the fundamental observation of the Johnston et al. (1994) worldwide database associating the largest SCR earthquakes with Mesozoic and younger extended crust was known to the EPRI teams at the time of the EPRI SOG study. However, given the preliminary nature of the database at that time, the teams generally used a variety of approaches (and philosophies) to estimate maximum magnitude, and incorporated a large degree of uncertainty in their estimates. Several of the EPRI earth science teams explicitly refer to the preliminary worldwide database in their estimate of maximum magnitudes for seismic sources in the central and eastern United States.

The uncertainty in maximum magnitude for each EPRI team seismic source zone generally encompasses the maximum magnitude estimate for extended and non-extended tectonic domains described by Johnston et al. (1994) (i.e., moment magnitude 7.7 for passive margin extended crust of Mesozoic and younger age, and of 6.4 for non-extended Paleozoic fold crust). It is important to note that fold crust of Paleozoic age, similar to much of the Piedmont and Blue Ridge provinces of eastern North America, is specifically categorized as non-extended crust by Johnston et al. (1994). Johnston et al (1994) include only the Coastal Plain province in their characterization of extended crust in the North Anna site region, although in detail it is likely that Johnston et al. (1994) would include all of the Mesozoic basins along the eastern seaboard within their definition of "extended crust" including those basins occurring within the Piedmont and Blue Ridge provinces.

In our opinion, therefore, the final results of the Johnston et al. (1994) study do not provide new information that would significantly change the maximum magnitude estimates, probability of occurrence, recurrence models or source zone geometries of the 1989 EPRI SOG seismic source model for the following reasons: (1) the Johnston et al. (1994) study was initiated specifically for use by the EPRI teams in their development of the EPRI SOG seismic source model; (2) preliminary results of the study were available to the teams, in particular the fundamental observation associating large magnitude earthquakes with extended crust of Mesozoic or younger age; and (3) all of the estimates of maximum magnitude and source zone geometry drawn from the Johnston et al. (1994) are generally enveloped by one or more of the EPRI team source models.

The following sections provide supporting information on the use of the Johnston et al. (1994) study for assessing (1) maximum magnitude, (2) probability of activity, (3) recurrence model, and (4) source zone geometry.

1. <u>Maximum Magnitude and Source Zone Geometry</u>

Johnston et al. (1994) developed a comprehensive database of earthquakes in stable continental regions (SCRs) of the world and statistically examined the database to assess the spatial correlation of large SCR earthquakes with specific tectonic domains within SCRs. SCR crust is distinguished from "Active" crust by (a) age since the last major tectonic activity, (b) absence of prominent faulting, (c) absence of post early

Cretaceous orogenic, magmatic or intrusive activity, and (d) absence of rifting, or major extension/transtension younger than Paleogene. Because the occurrence of moderate to large magnitude earthquakes (≥ **M** 6.5) in SCRs is rare, the principal premise of the Johnston et al. (1994) study was to substitute space for time by aggregating the geologic and seismic information from all SCR's of the world considered to have a similar geologic history to the CEUS, and thus to identify regions of the CEUS having the potential to produce a specified maximum magnitude.

Four principal tectonic domains were recognized in SCRs by Johnston et al. (1994): (1) intracontinental rifts (extended crust) of Mesozoic and younger age; (2) passive margin extended crust of Mesozoic and younger age; (3) non-extended crust of the craton; and (4) non-extended crust of Paleozoic and Mesozoic fold belts. The primary observation from the database published by Johnston et al. (1994) is that the majority of seismic energy release and the largest historical earthquakes in SCRs have occurred in extended crust of Mesozoic or younger age (both intracontinental rifts and passive margin extended crust). The maximum observed earthquakes in SCR crust are: **M** 8.3± 0.5 in Mesozoic and younger intracontinental rifts, **M** 7.7±0.2 in Mesozoic or younger extended passive margins, **M** 6.8±0.3 in non-extended cratonic crust, and **M** 6.4±0.2 in non-extended Paleozoic and Mesozoic fold belts.

Figure 2-14 of the Johnston et al. (1994) study shows crustal domains for North America. The North Anna ESP site region includes both Mesozoic passive margin extended crust (maximum magnitude of **M** 7.7) and Paleozoic fold belt non-extended crust (maximum magnitude of **M** 6.4). These maximum magnitudes would convert to m_b estimates of 7.3 and 6.5, respectively. The passive margin extended crust as defined by Johnston et al. (1994) includes the Coastal Plain Province in the North Anna site region. All other regions of the Piedmont, Valley and Ridge, and Blue Ridge provinces are included in the Paleozoic non-extended crust. Five of the six EPRI teams incorporate the Mesozoic extended crust either into specific Mesozoic Basins (e.g., Dames and Moore, Law Engineering, Weston and Woodward Clyde) or into a regional source (e.g., Bechtel). As shown in SSAR Tables 2.5-5 to 2.5-10, maximum magnitudes assigned to these sources range from m_b 7.4 (Bechtel, Atlantic Coastal Region and Law Engineering, Mesozoic Basins), to m_b 7.2 (Dames and Moore, exposed and buried Triassic Basins), to m_b 7.1 to 7.2, Woodward Clyde, Newark and Richmond Basins), to m_b 6.6 (Weston, various sources in Coastal Plain). The sixth team, Rondout, chose not to identify extended crust as a potential seismic source. In addition, all six EPRI teams recognize the Charleston source zone within the extended crust as defined by Johnston et al. (1994) and assign maximum magnitudes of m_b 7.4 (Bechtel), 7.2 (Dames and Moore), 6.8 (Law Engineering), 7.0 (Rondout), 7.2 (Weston), and 7.5 (Woodward Clyde). As described in SSAR Sections 2.5.2.6.2 and 2.5.2.6.3, a sensitivity analysis also was performed for the Charleston source zone using an updated maximum magnitude distribution, recurrence model and source zone geometry. In this analysis, an upper bound maximum magnitude of **M** 7.5 was used.

The Central Virginia Source Zone (CVSZ) is recognized by all six EPRI teams. SSAR Figure 2.5-25 shows the geometry of the CVSZ for each team. In general, the CVSZ lies within the non-extended Paleozoic crust of the Piedmont, Valley and Ridge, and Blue Ridge provinces, and only locally extends into the extended Mesozoic crust of the Coastal Plain Province. Johnston et al. (1994) would assign a maximum magnitude of **M** 6.4 for this source in non-extended crust. All five teams that explicitly recognize the CVSZ (the Law Engineering Team identified mafic plutons as the source of seismicity in the CVSZ region), assign a larger maximum magnitude than that suggested by the Johnston et al. (1994) study.

Johnston et al. (1994) also conclude that "The results of this study lend support to preliminary indications from this work (e.g. Coppersmith, 1991, Coppersmith et al., 1987) that were used in the assessments of maximum magnitude for seismic source zones in the EPRI SOG seismic hazard methodology", Thus, in a general sense, results from the Johnston et al. (1994) study were incorporated into the thought process and analysis of the initial EPRI team's source characterizations.

An important result of the Johnston et al. (1994) study is that even while trading "space for time", the database still contains too few data on maximum earthquakes and/or tectonic features to draw statistically significant results on the correlation of tectonic domains to maximum earthquakes. As described above, the database compiled by Johnston et al. (1994) clearly shows that all SCR earthquakes of **M**≥7 have occurred within extended crust of Mesozoic age. A statistical analysis performed by Cornell (Chapter 5 of Volume 1), however, also shows that many extended crustal domains have maximum observed magnitudes smaller than **M** 7, such that the mean maximum magnitude is not significantly different than for non-extended crust. A conclusion from this analysis may be that extended crust in some areas has maximum magnitudes less than **M** 7, or that the "observed" historical data in the database are still too few to draw statistically significant results, despite the underlying premise of the Johnston et al. (1994) study to substitute "space for time". Altogether, the statistical analysis performed by Cornell (Johnston et al., 1994, Chapter 5) shows that none of the descriptor variables for the tectonic domains are a strong predictor or determinant of maximum magnitude.

Johnston et al. (1994) also included a formal Bayesian procedure that can be used to assess a maximum magnitude (Mmax) distribution for a seismic source. For a seismic source located in a defined tectonic regime, this procedure uses information on worldwide earthquakes in similar tectonic regimes as the basis for a Bayesian prior distribution on $\mathbf{M}_{max}$. Local earthquakes within the seismic source are used to derive a statistical likelihood function for $\mathbf{M}_{max}$, and the two distributions are combined to obtain a posterior distribution on $\mathbf{M}_{max}$.

Geometries used by EPRI teams to represent the Central Virginia Seismic Zone (CVSZ) encompass primarily Paleozoic fold belt non-extended crust (of the Piedmont, Valley and Ridge, and Blue Ridge provinces) and locally some Mesozoic passive margin extended crust (of the Coastal Plain Province). As noted above, the majority of seismic energy release and the largest historical earthquakes in SCRs have occurred in extended crust of Mesozoic age or younger. Applying the Bayesian procedure to the CVSZ using worldwide data from Mesozoic or younger extended crust would lead to a broad $\mathbf{M}_{max}$ prior distribution that ranges from **M** 5.0 to 7.9, with low (but not zero) probability from **M** 5.0 to 5.5, and a virtually flat distribution from **M** 5.5 to 7.9. Application of the statistical procedure to the CVSZ, with an observed $\mathbf{M}_{max}$ less than 5, would yield a mildly decaying likelihood function above **M** 5, meaning that the observation of small events is not very diagnostic in defining an $\mathbf{M}_{max}$ distribution. Combining the prior distribution and likelihood function would yield a very broad distribution on $\mathbf{M}_{max}$. The six EPRI teams assessed $\mathbf{M}_{max}$to be in a broad range from m_{blg} (equivalent to m_b) 5.4 to 7.2 (**M** 5 to 7.5). Thus, application of the statistical procedure described in Johnston et al. (1994) would likely yield a distribution similar to the composite $\mathbf{M}_{max}$ distribution of the EPRI teams. This is not surprising, given that the EPRI teams acted in effect as "Bayesian processors" by considering both worldwide observations and local data to express an informally integrated distribution on $\mathbf{M}_{max}$ for the CVSZ.

In addition, a cautionary note must be acknowledged when using the Johnston et al. (1994) study. An important part of the Johnston et al. (1994) study was to convert and/or re-calibrate all intensity data and magnitude estimates of historical earthquakes to moment magnitude. The conversion of intensity and/or early magnitude estimates to moment magnitude, however, has undergone continued revision since 1994 for many SCR earthquakes. For example, Johnston (1996) assigned moment magnitude estimates of **M** 8.1, 8.0 and 7.8 for the three 1811-1812 New Madrid earthquakes, and **M** 7.3 for the 1886 Charleston earthquake. These moment magnitude estimates have more recently been estimated to be **M** 7.2 to 7.3, 7.4 to 7.5, and 7.1 for the New Madrid sequence (Bakun and Hopper, 2003; and Hough et al., 2000), and **M** 6.8 for the Charleston earthquake. These and other magnitude revisions may influence the statistical results of the Johnston et al. (1994) study. This uncertainty must be taken into consideration when using the Johnston et al. (1994) study to evaluate whether or not there has been a significant change to the EPRI SOG source characterization.

In summary, the Johnston et al. (1994) database, while providing important new data on the nature of SCRs worldwide and the distribution of observed maximum magnitudes associated with these SCRs, does not provide new constraints on maximum magnitude range provided by the EPRI teams for their seismic source model in the North Anna site region. Given the uncertainty associated with estimating moment magnitudes for SCR earthquakes from intensity data and early magnitude estimates of historical earthquakes, the EPRI source model was not updated because:

- Initial results of the Johnston et al. (1994) study were available to the EPRI teams and explicitly referenced by several of the teams in the EPRI (1986) study.

- Final results of the Johnston et al. (1994) study generally support the initial findings of the study.

- Statistical analysis of the database performed by Johnston et al. (1994) shows that there is no significant difference between average maximum magnitude for various tectonic domains.

- Recent updates in the estimate of moment magnitude from intensity data for large SCR earthquakes indicates significant uncertainty in the estimate of maximum magnitude, and generally, has decreased magnitude estimates from that used in the Johnston et al. (1994) study.

- The 1989 EPRI SOG source model conservatively assigns a larger maximum magnitude to the CVSZ than would be suggested by the Johnston et al. (1994) study.

- Our review of the Johnston et al. (1994) worldwide database suggests that a Bayesian analysis of the CVSZ would not lead to a significant revision of the maximum magnitude estimates for this source zone.

- The 1989 EPRI SOG source model provides maximum magnitudes of up to m_b 7.2 to 7.4 for extended crust in the North Anna region, and of m_b 7.4 to 7.5 for the Charleston source zone in the extended crust of the Coastal Plain.

2. Probability of Activity

The Johnston et al. (1994) study does not comment explicitly regarding the probability of activity of tectonic domains in SCR crust. However, SCR earthquakes have occurred in all four of the principal tectonic domains identified by Johnston et al. (1994). Thus, the study cannot be used to argue that certain tectonic domains are not active. The Johnston et al. (1994) study does not provide empirical or statistical data that would require an update or modification to the EPRI SOG source model.

3. Recurrence Model

The Johnston et al. (1994) study does not comment explicitly regarding recurrence models for tectonic domains in SCR crust. The study shows that roughly 2/3 of all large magnitude SCR earthquakes occurred in regions of prior seismicity. This would suggest that potential future large earthquakes in the CEUS are more likely to occur in regions with currently recognized elevated rates of seismicity such as the Charleston, New Madrid, Giles County and Central Virginia source zones. The Johnston et al. (1994) study, however, does not provide recurrence information that would require an update or modification to the current EPRI SOG source model.

4. Source Zone Geometry

Chapter 2 of Johnston et al. (1994) defines tectonic “Domains” of North America, and divides these domains into extended crust and non-extended crust. The North Anna site lies within the Piedmont Domain of “non-extended” crust (Figure 2-14 of Johnston et al., 1994). Each of the domains identified by Johnston et al. (1994) are represented by one or more source zones from the six EPRI teams. In general, the EPRI source zone models are more detailed than the more regional, generalized domains recognized by

Johnston et al. (1994). In addition, the Johnston et al. (1994) domains are not based on, and thus do not represent nor reflect areas with, distinct patterns or rates of seismicity. For example, the CVSZ is not identified by Johnston et al. (1994) despite the prominent spatial pattern of historical and instrumental seismicity. The CVSZ is contained within the Piedmont and Valley and Ridge domains of Johnston et al. (1994). Thus, the domain map presented in Johnston et al. (1994) does not provide an improvement over the more detailed source zonation model of the EPRI teams.

The principal benefit offered by the Johnston et al. (1994) tectonic domain map is the differentiation of tectonic domains containing extended crust from those containing non-extended crust, and the recognition that large magnitude earthquakes (**M**>7) in SCRs worldwide have all occurred within extended crust of Mesozoic age. This observation would suggest that extended crust beneath the Eastern Seaboard domain of Johnston et al. (1994), which contains the Charleston source zone and ECFS, may produce larger magnitude earthquakes that the non-extended crust of the Piedmont and Valley Ridge Domains, which contains the CVSZ and the North Anna ESP site area.

References

Bakun, W. H. and M. G. Hopper. Magnitudes and Locations of the 1811 - 1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes, Bulletin of the Seismological Society of America, 2004. (Reference 93 of SSAR Section 2.5 as “in press, 2003, with the title *The 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes*.”)

Hough, S. E., J. G. Armbruster, L. Seeber, and J. F. Hough. On the Modified Mercalli intensities and magnitudes of the 1811-12 New Madrid earthquakes, Journal of Geophysical Research, Volume 105, 23,839–23,864, 2000. (Reference 95 of SSAR Section 2.5)

Johnston, A. C., Seismic moment assessment of earthquake in stable continental regions - III. New Madrid 1811-1812, Charleston 1886 and Lisbon 1755, Geophysical Journal International, Volume 126, 314–344, 1996. (Reference 90 of SSAR Section 2.5)

Johnston, A.C., Coppersmith, K.J., Kanter, L.R., and Cornell, C.A., 1994, The Earthquakes of Stable Continental Regions: Volume 1 – Assessment of Large Earthquake Potential; Electric Power Research Institute, TR- 102261-V1.

Coppersmith, K.J., Johnston, A.C., Metzger, A.G., and Arabasz, W.J., 1987, Methods for assessing maximum earthquakes in the central and eastern United States; Electric Power Research Institute Research Project 2556-12.

Coppersmith, K.J., 1991, Seismic source characterization for engineering seismic hazard analyses; Proceedings, Fourth International Conference on Seismic Zonation, v. 1, p. 1-60.

Application Revision

The following new paragraph will be added at the end of Section 2.5.2.6.2:

> In 1994, the Electric Power Research Institute (EPRI) published a five-volume study on "The Earthquakes of Stable Continental Regions" (Johnston et al., Reference 195). Volume 1 of the study, "Assessment of Large Earthquake Potential", presents results from a worldwide database of earthquakes within stable continental regions (SCRs) to assess the relationship, if any, between maximum magnitude and specific tectonic environments. Initial results of the study were provided to the EPRI teams for the EPRI SOG PSHA. Thus, the fundamental observation of the Johnston et al. (Reference 195) worldwide database associating the largest SCR earthquakes with Mesozoic and younger extended crust was known to the EPRI teams at the time of the EPRI SOG study. Results of the Johnston et al. study (Reference 195) do not provide new information that would significantly change the maximum magnitude estimates or source zone geometries of the 1989 EPRI SOG seismic source model for the following reasons: (1) the Johnston et al. study (Reference 195) was initiated in the mid-1980s specifically for use by the teams in their development of the EPRI SOG seismic source model; (2) preliminary results of the study were available to the EPRI teams; and (3) all of the estimates of maximum magnitude and source zone geometry drawn from the Johnston et al. study (Reference 195) are generally enveloped by one or more of the EPRI teams.

The following new reference will be added to SSAR Section 2.5 References:

195. Johnston, A.C., Coppersmith, K.J., Kanter, L.R., and Cornell, C.A., 1994, The Earthquakes of Stable Continental Regions: Volume 1 – Assessment of Large Earthquake Potential; Electric Power Research Institute, TR- 102261-V1.

RAI 2.5.3-1 (NRC 4/15/04 Letter)

SSAR Section 2.5.3 states that, in addition to compiling and reviewing existing data, Dominion interpreted aerial photography and conducted field and aerial reconnaissance of all faults within a five-mile radius of the site to assess the potential for surface fault rupture. Dominion focused on seven bedrock faults, as listed in Section 2.5.3.2, and concluded that “the Chopawamsic and Spotsylvania thrust faults are not associated with seismicity and do not exhibit geomorphic evidence of potential Quaternary activity.” The SSAR indicates that Dominion conducted similar aerial photographic and reconnaissance studies for the other faults within five miles of the site, and draws similar conclusions. Please provide the following details about each of the reconnaissance studies:

2.5.3-1 Part a)

a) A general description of the flight conditions (i.e., weather, lighting conditions and the time of year).

Response to Part a)

Aerial reconnaissance was performed in the North Anna site area on Monday, March 10, 2003 between approximately 12:30 and 4:00 pm. The flight originated and ended at the Chesterfield County Airport, located about 10 miles south of downtown Richmond. The plane used for the reconnaissance flight was a Cessna 172 Skyhawk piloted by Mr. Chike Foster from Dominion Aviation (not affiliated with Dominion Energy). Messrs. William Lettis and Scott Lindvall of William Lettis & Associates (WLA) performed the aerial reconnaissance. The reconnaissance flight focused on the following faults:

- Northern portion of the north segment of the East Coast Fault System (ECFS)
- Hazel Run and Fall Hill faults of the Stafford fault system
- Kellys Ford and Mountain Run scarps along the Mountain Run fault zone
- Faults within 5-mile radius of the site, including the Spotsylvania, Chopawamsic, Long Branch, Sturgeon Creek, and faults “a”, “b”, and “c”, with emphasis on the Sturgeon Creek fault and fault “a”.

Weather conditions during the flight were clear and sunny. The lighting conditions were slightly hazy (scattered high thin clouds) over the Coastal Plain south of Richmond during the initial portion of the flight. Lighting improved to excellent conditions for the remainder of the flight in all areas north and west of Richmond, including the 5-mile radius area around the site

The entire flight path is shown in Figure 1. [Figures are located at the end of the RAI response.] A more detailed portion of the flight within the site area (5-mile radius) is shown along with the geologic base from Mixon et al. (2000) in Figure 2. Photographs of selected features along the flight, which also illustrate the weather and lighting conditions, are included in Photographs 1-5.

2.5.3-1 Part b)

b) The extent of the coverage for each fault and the criteria for the locations chosen along the fault.

Response to Part b)

Aerial and field reconnaissance was performed along faults within a 5-mile radius of the plant. Reconnaissance emphasized fault "a" and the Sturgeon Creek fault because of their proximity to the site. Field reconnaissance was performed along the entire length of fault "a" south of Lake Anna and accessible portions of the Sturgeon Creek fault. Aerial reconnaissance was performed along nearly the entire length of both faults (Figure 2). Aerial and field reconnaissance was performed along selected portions of the Spotsylvania, Chopawamsic, Long Branch, fault "b", and fault "c", in particular where these faults were accessible by road and/or where the faults were mapped as offsetting a plutonic or metamorphic stratigraphic contact. Given the low relief and deeply weathered nature of the Piedmont, there are very few exposures of bedrock, either natural or in road cuts. Therefore, none of the seven faults that traverse the site area (5-mile radius) were observed in outcrop. As noted by Pavlides (2000), the Spotsylvania fault is not exposed within the Fredericksburg 30' x 60' quadrangle, but rather defined based on geophysical data and contrasting bedrock lithologies.

Previously mapped stratigraphic offsets of pluton margins or metamorphic contacts could not be confirmed along any of the faults. Geomorphic expression indicative of potential Quaternary deformation was not observed along any fault, in field reconnaissance, aerial reconnaissance, or analysis of aerial photography.

Fault "a" is mapped over a distance 5 miles south from the southern shore of Lake Anna, southward across the North Anna site, to within about 1 mile of the southern edge of the Fredericksburg 30' x 60' quadrangle (Mixon et al., 2000). As shown on the compilation map of Mixon et al. (2000), the fault locally offsets the margin of the Paleozoic Elk Creek pluton about 2 miles south of the North Anna site. WLA performed field reconnaissance of fault "a" along the shore of Lake Anna, at the North Anna site, along the entry road to North Anna, and along State Route 700 south of the site. No structural, stratigraphic, or geomorphic evidence of fault "a" was observed. In particular, WLA performed field reconnaissance along the margin of the Elk Creek pluton to confirm the presence or absence of offset of the pluton margin (further information will be provided in the response to RAI Letter No. 5, specifically, RAI 2.5.3-2). In addition, the presence of the Elk Creek pluton could not be confirmed. There is no evidence that the pluton is present as a discrete mappable lithologic unit, certainly not to the level of accuracy and precision to conclude that the margin of the pluton has been offset by fault "a". In WLA's opinion, the pluton does not exist, and the mapped offset shown on Mixon et al. (2000) is primarily interpreter's license, and also does not exist. This is also supported by the mapping of Marr (2002) on the adjacent Richmond sheet, which does not show the Elk Creek pluton (Figure 2).

The Sturgeon Creek fault follows, in part, the valley of Freshwater Creek. Locally, Freshwater Creek exhibits multiple, long linear reaches within the alluvial-covered valley floor. These straight portions of Freshwater Creek suggest that the stream was channelized, probably in the late 1800s or early 1900s prior to the availability of topographic maps or aerial photography. WLA performed field reconnaissance along the straight segments of Freshwater Creek to assess the presence or absence of the Sturgeon Creek fault. The straight stream segments are located within the valley, and are not associated with any scarps, vegetation lineaments, or bedrock contacts that would imply a tectonic origin. The straight stream segments appear to be the result of channelization by man. The Sturgeon Creek fault is not shown on the adjacent Richmond map sheet by Marr (2002), indicating that he did not find any evidence for this fault (Figure 2).

In addition, a Miocene pediment surface extends across the site area. Remnants of the pediment surface are preserved as fluvial/marine gravel and sand deposits and scattered lag gravels above saprolitic weathered bedrock. Remnants of the pediment locally extend across fault "a" without apparent vertical separation. In addition, the pediment surface extends regionally across the Sturgeon Creek fault, Spotslyvania fault, Long Branch fault, and faults "b" and "c". Based on WLA's field reconnaissance, WLA did not observe any significant elevation differences of the pediment gravels across any of the faults that would suggest post-Miocene vertical separation. However, WLA's limited reconnaissance observations do not allow WLA to provide a quantitative assessment of the limit of resolution or threshold of detection for any vertical deformation.

2.5.3-1, Part c)

c) The geomorphic setting (i.e., valleys, hills, bedrock exposures, ...) for each of the sites visited along the faults.

Response to Part c)

All faults in the site area (5-mile radius) cross gently rolling topography with relief on the order of 200 feet. The rolling topography formed through dissection and erosion of a once broad, continuous Miocene pediment that extended across the region. The pediment was produced by one or more marine transgressions during the Miocene that beveled Paleozoic bedrock in the Piedmont, probably as a series of one or more wave-cut platforms. Remnants of the pediment are preserved today as deposits of rounded marine gravel and sand capping many of the low hills and ridges in the site area.

Deep saprolitic weathering has left the hills in the site area with gentle slopes and low relief. Natural outcrops of bedrock are rare, even along stream cuts. Bedrock is exposed in the site area only in a few roadcuts. Most of the faults, such as fault “a”, are mapped across broad, gentle ridges that more closely approximate the elevation of the Miocene pediment surface (south of the North Anna site). The Sturgeon Creek fault is mapped largely within an incised stream valley. No bedrock exposures of any faults were found during the field reconnaissance.

Field reconnaissance was performed by driving available roads that cross faults, examining road and natural cuts across and in the vicinity of mapped faults, and walking parts of fault “a” and the Sturgeon Creek fault. No geomorphic expression of the seven faults or any other geomorphic features indicative of potential Quaternary activity were observed during WLA’s aerial and field reconnaissance of the site area.

2.5.3-1, Part d)

d) A description of the criteria used for concluding that there is no evidence of Quaternary activity on the fault.

Response to Part d)

The seven faults within the site area (5-mile radius) are all mapped in Paleozoic bedrock. The larger structures (Spotsylvania, Chopawamsic, and Long Branch faults) have been demonstrated to have originated during the multiple Paleozoic Appalachian orogenies. Studies of fault “a” at the site by Dames & Moore (1973) concluded that this minor fault initially formed during a ductile phase of deformation in the Paleozoic.

Criteria used during WLA’s site investigation to evaluate whether there is any evidence to suggest Quaternary activity included:

- Published and unpublished reports
- Geomorphic expression
- Alignment of seismicity
- Offset Cenozoic deposits
- Paleoseismic features

For all seven faults within the site area, there is no evidence or criteria that would suggest Quaternary activity on these structures (Table 1). The only potential geomorphic feature was found along the Sturgeon Creek fault, where the fault is aligned with linear reaches of the channel. However, the linear channel likely represents channelization of the creek by man. It is, therefore, concluded that there is no geomorphic expression of the Sturgeon Creek fault suggestive of Quaternary activity.

Table 1. Criteria for Evaluating Quaternary Activity

Fault	Reports of Quaternary Activity?	Geomorphic Expression?	Alignment of Seismicity?	Offset Cenozoic Strata?	Paleo-seismic Features
Spotsylvania	No	No	No	No	No
Fault “a”	No	No	No	No	No
Fault “b”	No	No	No	No	No
Fault “c”	No	No	No	No	No
Sturgeon Creek	No	No	No	No	No
Long Branch	No	No	No	No	No
Chopawamsic	No	No	No	No	No

2.5.3-1, Part e)

e) The vintage and scale of the photographs used for the aerial photographic study.

Response to Part e)

Stereo-paired aerial photographs were studied to evaluate the geomorphic expression of faults within the site area (5-mile radius). The photography consisted of USGS black and white (B&W) imagery at a scale of 1:19,000 (Table 2) and B&W and color infrared (CIR) imagery at a scale of 1:40,000 (Table 3). The coverage of the different sets of photography is shown on Figure 3.

The 1:19,000 scale photography was flown in 1963 and 1966 and predates the filling of Lake Anna and the construction of the North Anna Power Station. These photos cover the entirety of the Lake Anna West 7.5 minute quadrangle and significant portions of the adjacent Lake Anna East, Belmont, Brokenburg, and Beaverdam quadrangles (Table 1).

The 1:40,000 scale NAPP photography included both B&W and CIR imagery flown in 2000 and 1989, respectively, and was centered on the North Anna site. In addition to 9x9 inch stereo-paired prints of the 2000 NAPP photos, a single frame centered on the Site (frame 43) was enlarged by 300% to produce a 36x36 inch print in order to provide a more detailed image of the ground surface surrounding the site.

Table 2. USGS Aerial Photography Reviewed (1:19,000 Scale)

Date	Quadrangle	Type	Project	Frames
3/4/63	Belmont	B&W	GS-VAQV	4-3 to 4-5 4-21 to 4-25 4-29 to 4-31 4-50 to 4-52
3/3/63	Brokenburg	B&W	GS-VAQV	3-228 to 3-229 3-264 to 3-266
3/29/66	Lake Anna West	B&W	GS-VBKG	1-83 to 1-90 1-148 to 1-154 2-35 to 2-42 2-97 to 2-106 2-158 to 2-166
3/3/63	Lake Anna East	B&W	GS-VAQV	3-215 to 3-217 3-221 to 3-223 3-272 to 3-274
3/17/66	Beaverdam	B&W	GS-VBIZ	2-226 to 2-229 2-261 to 2-262 3-40 to 3-42

Table 3. NAPP Aerial Photography Reviewed (1:40,000 Scale)

Date	Type	Flight No.	Frames
3/16/89	CIR	NAPP 1635	160
3/24/00	B&W	NAPP 12115	42, 43, 44

<u>References</u>

Crone, A. J. and R. L. Wheeler, 2000, Data for Quaternary faults, liquefaction features, and possible tectonic features in the Central and Eastern United States, east of the Rocky Mountain front, U.S. Geological Survey Open-File Report 00-260, (Reference 59 of SSAR Section 2.5).

Dames & Moore, 1973, Supplemental Geologic Data, North Anna Power Station, Louisa County, Virginia, Virginia Electric Power Company Report, August 17, 1973, (Reference 9 of SSAR Section 2.5).

Mixon, R. B., L. Pavlides, D. S. Powars, A. J. Froelich, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards, and L. W. Ward, 2000, Geologic Map of the Fredericksburg 30’ x 60’ Quadrangle, Virginia and Maryland, U.S. Geological Survey, Geologic Investigations Series Map I-2607, (Reference 66 of SSAR Section 2.5).

Marr, J. D, Jr., 2002, Geologic Map of the Western Portion of the Richmond 30 x 60 minute Quadrangle, Virginia, Virginia Division of Mineral Resources, Publication 165, (Reference 105 of SSAR Section 2.5).

Pavlides, L., 2000, Geology of the Piedmont and Blue Ridge Provinces, Geologic Map of the Fredericksburg 30’ x 60’ Quadrangle, Virginia and Maryland, U.S. Geological Survey, Geologic Investigations Series Map I-2607. (Reference 40 of SSAR Section 2.5)

Application Revision

None.

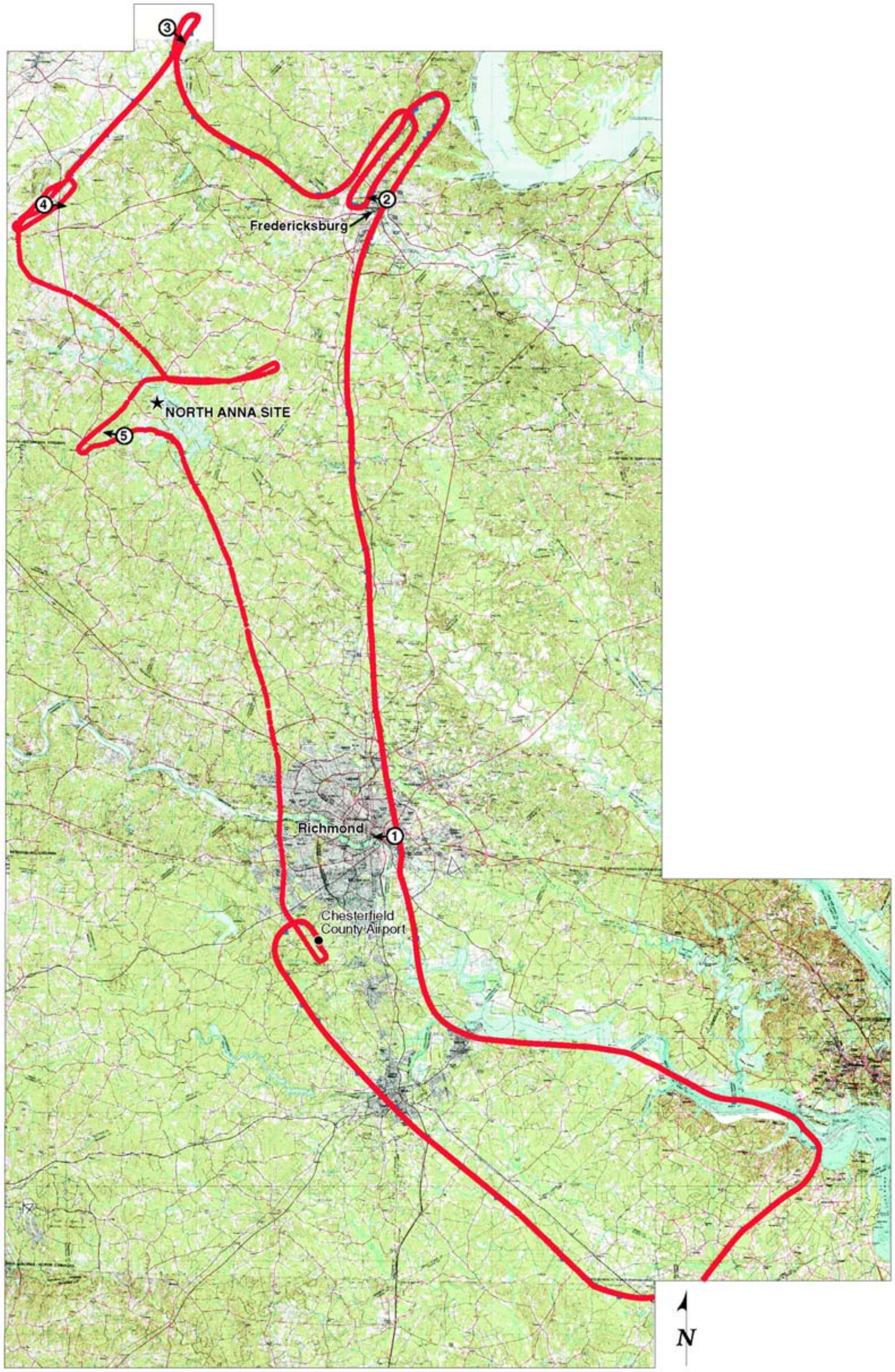

Figure 1. March 10, 2003 aerial reconnaissance flight path. Photographs shown as number with arrow denoting direction of view.

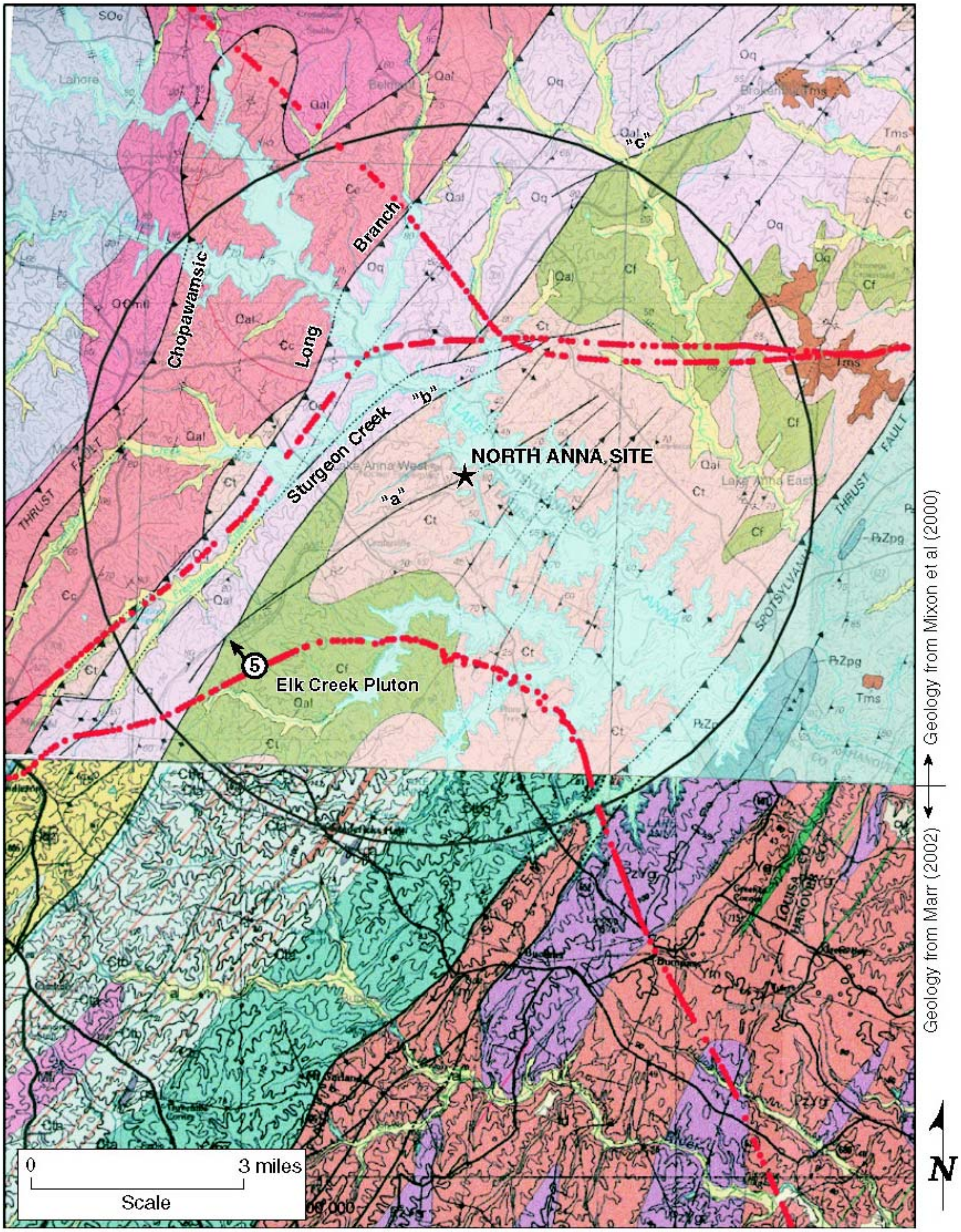

Figure 2. Aerial reconnaissance flight over site area. Photograph shown as number with arrow denoting direction of view.

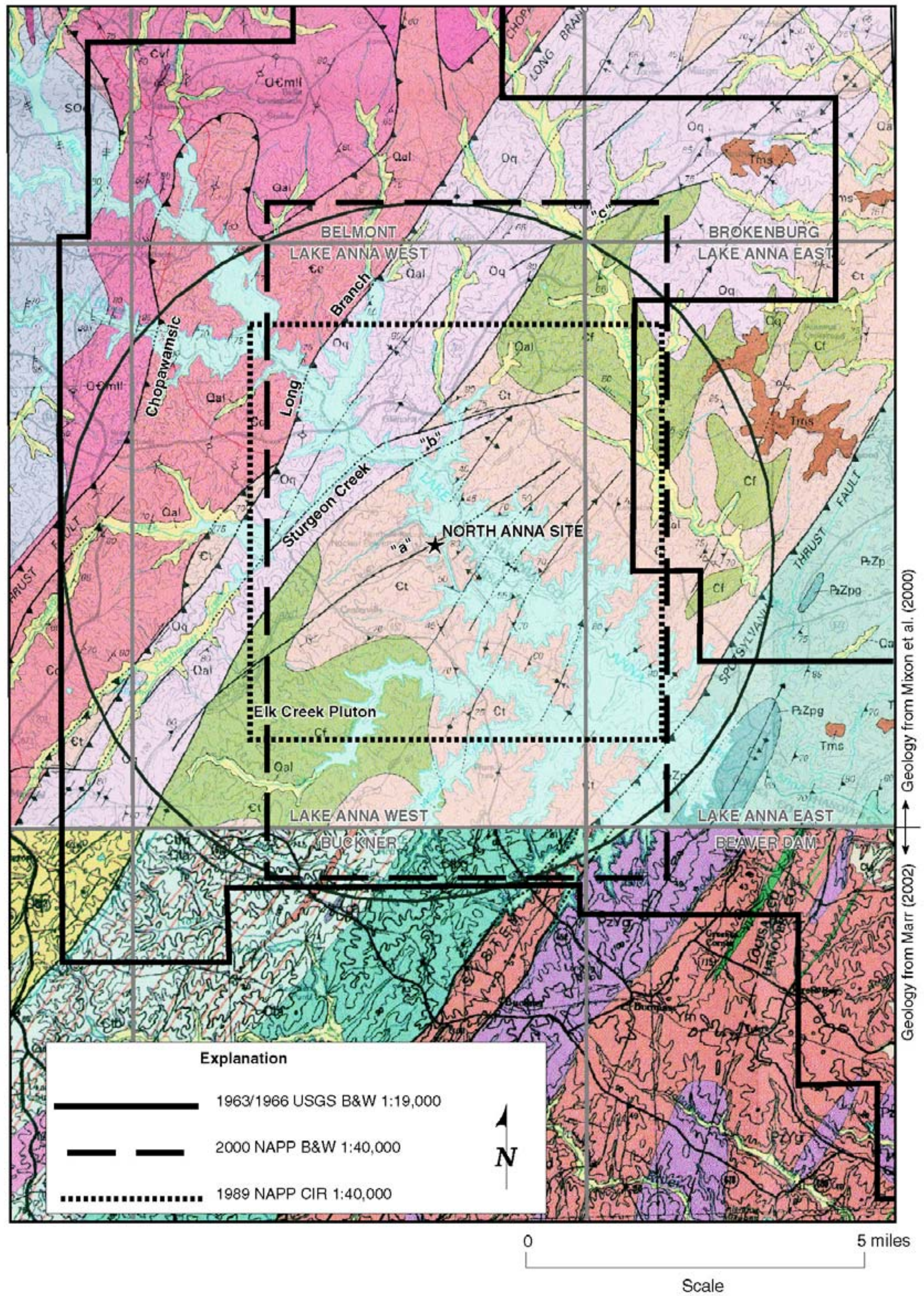

Figure 3. Aerial photography coverage of the site area. Quadrangles (7.5 minute) shown in gray.

Photograph 1. Fall Line on the James River at Richmond (view west).

Photograph 2. Fall Line on the Rappahannock River at Fredericksburg (view west).

Photograph 3. Kellys Ford Scarp (arrows) along the Mountain Run fault zone (view southeast).

Photograph 4. Mountain Run scarp (arrows) along the Mountain Run fault zone (view east).

Photograph 5. Mapped trace of fault “a” (arrows) across broad pediment surface (view northwest).