Ronald B. Clary
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SCE&G®
A SCANA COMPANY

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U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, DC 20555

ATTN: Document Control Desk

Subject: Virgil C. Summer Nuclear Station (VCSNS) Units 2 and 3 Combined License Application (COLA) - Docket Numbers 52-027 and 52-028 Response to NRC Request for Additional Information (RAI) Letter No. 033

Reference:
1. Letter from Ravindra G. Joshi (NRC) to Alfred M. Paglia (SCE&G), Request for Additional Information Letter No. 033 Related to SRP Section 2.5.1 for the Virgil C. Summer Nuclear Station Units 2 and 3 Combined License Application, dated February 12, 2009.
2. Letter from Ronald B. Clary (SCE&G) to Document Control Desk (NRC), Response to NRC Request for Additional Information (RAI) Letter No. 033, dated March 16, 2009.

The enclosure to this letter provides the South Carolina Electric & Gas Company (SCE&G) response to RAIs 02.05.01-4, 02.05.01-6, 02.05.01-7, 02.05.01-8, 02.05.01-21, 02.05.01-24, 02.05.01-25, 02.05.01-29, 02.05.01-32, 02.05.01-34, 02.05.01-35, 02.05.01-36, 02.05.01-37, 02.05.01-38, 02.05.01-39, and 02.05.01-49 included in Reference 1 of this letter. The enclosure also identifies any associated changes that will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA.

The responses to NRC RAI Numbers 02.05.01-5, 02.05.01-12, 02.05.01-19, 02.05.01-20, 02.05.01-26-28, 02.05.01-30, 02.05.01-31, 02.05.01-33, 02.05.01-40, and 02.05.01-41 were submitted in a letter dated March 16, 2009 (Reference 2).

The responses to NRC RAI Numbers 02.05.01-1-3, 02.05.01-9-11, 02.05.01-13-18, 02.05.01-22-23, and 02.05.01-42-48 are still under development and review by SCE&G. The final responses to those RAIs are expected be provided to the NRC by May 6, 2009.

Should you have any questions, please contact Mr. Al Paglia by telephone at (803) 345-4191, or by email at apaglia@scana.com.

D083
NRO

I declare under penalty of perjury that the foregoing is true and correct.

Executed on this 15th day of April, 2009.

Sincerely,

Ronald B Clary

Ronald B. Clary
General Manager
New Nuclear Deployment

JMG/RBC/jg

Enclosure

c:

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NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-4

FSAR Sections 2.5.1.1.2.1 (pgs 2.5.1-11 and 2.5.1-12) and 2.5.1.1.2.4.2 (pgs 2.5.1-24 and 2.5.1-25) state that normal faults which bound Triassic basins may be listric into Paleozoic detachment faults, or may penetrate the crust as high-angle faults, but no definitive correlation of seismicity with Mesozoic normal faults has been demonstrated conclusively. FSAR Section 2.5.1.1.2.4.2 (pg 2.5.1-25) also states that Mesozoic basins have long been considered potential sources of earthquakes along the eastern seaboard, and were captured by most of the EPRI science teams in the definition of seismic sources. If these faults do penetrate the crust as high-angle structures, there may be increased potential for future seismicity, and no information is directly presented in the FSAR which precludes Mesozoic basin-bounding faults in the site region from extending deep into the crust.

In order for the staff to assess the hazard potential of Mesozoic basin-bounding normal faults in the site region, please summarize any published information which provides evidence to support an inference that these faults are either steep and deep or shallow listric structures.

VCSNS RESPONSE:

Data constraining the down-dip geometry of faults that bound Mesozoic basins are equivocal. Seismic reflection data, borehole studies, gravity and magnetic signatures, and geologic mapping have all been used to characterize these faults, but different studies have depicted these faults as listric (e.g., Crespi 1988 [Reference 1]; Manspeizer and Cousminer 1988 [Reference 2]; Dennis et al. 2004 [FSAR Reference 2.5.1-246]) and as high-angle features (e.g., Wentworth and Mergner-Keefer 1983 [FSAR Reference 2.5.1-402]; Schlische 2003 [FSAR Reference 2.5.1-359]).
The on-going debate over the down-dip geometry of these features pre-dates the seismic source characterizations of the original EPRI ESTs (EPRI 1986) (FSAR Reference 2.5.2-234). No new information has been published since 1986 on these features that would cause a significant change in the EPRI seismic source model, therefore the distinction between listric and high-angle geometries is not explicitly treated in the PSHA. If the basin-bounding faults are seismogenic structures, the effects of the two possible geometries on hazard at the site are highly uncertain, but both geometries may be able to produce moderate- to large-magnitude earthquakes. High-angle faults that extend through the crust potentially are the loci of moderate to large earthquakes because they penetrate to seismogenic depths. Earthquake magnitude is primarily a function of fault plane area. Listric features potentially have far greater fault

plane area than high-angle features, especially if they sole into a regional detachment that extends to seismogenic crustal depths. However, if listric structures are thin-skinned and limited to the upper few km of crust, they may have no seismogenic potential. Because of the uncertainty regarding their geometry, the EPRI ESTs used area sources instead of individual fault sources to represent these basin-bounding faults in the PSHA (EPRI 1986) (FSAR Reference 2.5.2-234).

References:

1. Crespi, J.M., *Using Balanced Cross Sections to Understand Early Mesozoic Extensional Faulting*, in A.J. Froelich and G.R. Robinson Jr. (eds.), Studies of the Early Mesozoic Basins of the Eastern United States, U.S. Geological Survey Bulletin no. 1776, p. 220-229, 1988.
2. Manspeizer, W. and Cousminer, H.L., *Late Triassic-Early Jurassic Synrift Basins of the U.S. Atlantic Margin*, in R.E. Sheridan and J.A. Grow (eds.), The Atlantic Continental Margin, vol. 1-2 of The Geology of North America, Geological Society of America, Boulder CO, p. 197-216, 1988.
3. Schlische, R.W., *Progress in Understanding the Structural Geology, Basin Evolution, and Tectonic History of the Eastern North America Rift System*, in P.M. LeTourneau and P.E. Olsen (eds.), The Great Rift Valleys of Pangea in Eastern North America--Volume 1--Tectonics, Structure, and Volcanism, Columbia University Press, New York, p. 21-64, 2003.

ASSOCIATED VCSNS COLA REVISIONS:

No COLA changes have been identified as a result of this response.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-6

FSAR Section 2.5.1.1.2.3.1 (pg 2.5.1-16) states that regional gravity data acquisition and modeling studies performed to date show no evidence for Cenozoic tectonic activity or specific Cenozoic structures. Similarly, FSAR Section 2.5.1.1.2.3.2 (page 2.5.1-18) states that regional magnetic data show no evidence for Cenozoic structures in the site region. However, no explanation is provided in regard to how regional gravity or magnetic data can be used to determine that a given tectonic feature is Cenozoic in age. Furthermore, FSAR Sections 2.5.1.1.2.3.1 (pg 2.5.1-16) and 2.5.1.1.2.3.2 (pg 2.5.1-18) state that, in general, most regional anomalies at both first-order and superimposed second-order scales equate to lithologic variations rather than regional structures.

In order for the staff to determine the adequacy of the geologic interpretations based on regional gravity and magnetics data provided in the FSAR, please discuss the criteria applied for determining the presence of Cenozoic tectonic structures based on regional gravity and magnetic data.

VCSNS RESPONSE:

Potential field data alone cannot be used to make explicit age determinations of geologic features. However, when used in concert with other geologic datasets that include quantitative and/or relative dating information, potential field data can be used to help determine the timing of geologic events in an area. A large part of the discussion in FSAR Subsection 2.5.1.1.2.3.1 "Gravity Data of the Site Region and Site Vicinity" and FSAR Subsection 2.5.1.1.2.3.2 "Magnetic Data of the Site Region and Site Vicinity" is devoted to explaining the regional gravity and magnetic anomalous fields in terms of pre-Cenozoic crustal processes. The last paragraphs of FSAR Subsections 2.5.1.1.2.3.1 and 2.5.1.1.2.3.2 describe, in part, the East Coast Fault System, which is assessed to be likely Cenozoic in age based on geologic data. The East Coast Fault System exhibits a lack of expression in potential field data. The discussion of the East Coast Fault System in FSAR Subsections 2.5.1.1.2.3.1 and 2.5.1.1.2.3.2 is in no way intended to imply that the potential field data are used to explicitly date these, or other, geologic features.

FSAR Subsections 2.5.1.1.2.3.1 and 2.5.1.1.2.3.2 will be modified such that the potentially misleading text seemingly implying that potential field data can be used to date geologic features will be deleted.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

FSAR Subsection 2.5.1.1.2.3.1, seventh paragraph, page 2.5.1-16, will be revised as follows:

~~The gravity data acquisition and modeling studies performed to date do not show any evidence for Cenozoic tectonic activity or specific Cenozoic structures.~~ In general, there is better spatial correlation in the VCSNS study region among gravity anomalies and igneous intrusions than faults. The exception is the Paleozoic Modoc shear zone, which appears to separate higher density rocks to the northwest from lower density rocks to the southeast. The juxtaposition of basement terranes with varying densities across this fault occurred during the Paleozoic Alleghanian orogeny (Reference 279), and does not reflect Cenozoic activity. The mapped trace of the southern segment of the East Coast Fault System has no expression in the gravity field and cuts across anomalies with wavelengths on the order of tens of kilometers without noticeably perturbing or affecting them. This implies that the southern segment of the East Coast F~~f~~ault S~~s~~ystem, if present, has not accumulated sufficient displacement to systematically juxtapose rocks of differing density, and thus produce an observable gravity anomaly at the scale of Figure 2.5.1-205.

FSAR Subsection 2.5.1.1.2.3.2, fourth paragraph, page 2.5.1-18, will be revised as follows:

The magnetic data ~~do not show evidence for any Cenozoic structures in the site region and does~~ do not have sufficient resolution to identify or map discrete faults, such as border faults along the Triassic basins. In particular, the southern segment of the East Coast Fault System has no expression in the magnetic field and cuts across anomalies with wavelengths on the order of tens of kilometers without noticeably perturbing or affecting them. If the fault exists as mapped, then it has not accumulated sufficient displacement to juxtapose rocks of varying magnetic susceptibility, and thus does not produce an observable magnetic anomaly at the scale of Figures 2.5.1-205 and 2.5.1-206.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-7

According to FSAR Section 2.5.1.1.2.3.2 (pg 2.5.1-16) and FSAR Figure 2.5.1-207 (northeast of the Summer site), the Western Piedmont between the Brevard Zone and the Central Piedmont shear zone (CPSZ) is characterized by a relatively uniformly varying magnetic field around a background of approximately -500 nT. However, Figure 2.5.1-208 (southeast of the Summer site) appears to indicate a varying magnetic field about a background closer to 0 nT for this same area.

In order for the staff to determine the adequacy of the geologic interpretations based on regional magnetics data provided in the FSAR, please discuss the importance of this apparent difference in magnetic signature between these two profiles.

VCSNS RESPONSE:

The two magnetic profiles shown in FSAR Figures 2.5.1-207 and 2.5.1-208 are located more than 300 kilometers apart. The profile in FSAR Figure 2.5.1-207 cuts across central and southern North Carolina, whereas the profile in FSAR Figure 2.5.1-208 runs along the South Carolina-Georgia border. These two areas correspond to two different terranes mapped within the Western Piedmont, the Tugaloo in the southwest and the Cat Square in the northeast (Merschat and Hatcher 2008) (Reference 1). These two terranes include different rock types and exhibit different magnetic signatures.

References:

1. Merschat, A.J. and Hatcher, R.D. Jr., The Cat Square Terrane: Possible Siluro-Devonian Remnant Ocean Basin in the Inner Piedmont, Southern Appalachians, USA, in R.D. Hatcher, Jr., M.P. Carlson, J.H. McBride, and J.R. Martinez Catalan (eds), 4-D Framework of Continental Crust, Geological Society of America Memoir 200, p. 553-565, 2007.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

No COLA changes have been identified as a result of this response.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-8

FSAR Figure 2.5.1-209 illustrates site vicinity gravity and magnetic profiles and discusses the information reflected in these profiles in Sections 2.5.1.1.2.3.1 (pg 2.5.1-15) and 2.5.1.1.2.3.2 (pg 2.5.1-17) with reference to the Central Piedmont and Modoc shear zones. However, neither the Central Piedmont shear zone (CPSZ) nor the Summer site is located in the profiles to enable correlation of gravity and magnetic anomalies in the site vicinity with regional geologic structures. Furthermore, as illustrated in the profiles of Figure 2.5.1-209, the relatively short wavelength magnetic high near 20 km (12.43 mi), which appears to correspond with a gravity high, and the magnetic low from about 50-70 km (31.07-43.5 mi), which corresponds with a gravity high, are not explained in relation to regional features which may cause these anomalies.

It is also not clearly stated in FSAR Sections 2.5.1.1.2.3.1 (pg 2.5.1-15) and 2.5.1.1.2.3.2 (pg 2.5.1-17) whether the site vicinity gravity and magnetic profiles represent data collected at that scale or are extrapolated from regional gravity and magnetics data. However, the reference cited in Figure 2.5.1-209 (Daniels, 2005) would seem to indicate that these site vicinity data are extracted from gravity and magnetic maps produced for the State of South Carolina and, therefore, the data is at a scale less than the regional scale but greater than the site vicinity scale.

In order for the staff to determine the adequacy of the geologic interpretations based on site vicinity gravity and magnetics data provided in the FSAR, please locate the site and the CPSZ on Figure 2.5.1-209 and discuss the significance of these two magnetic anomalies as they may relate to the gravity anomalies and geologic structures or lithlologies in the site vicinity. Please also clarify whether the site vicinity gravity and magnetic profiles represent data collected at that scale or are extrapolated from regional gravity and magnetics data or a statewide database. Finally, please summarize any pertinent points discussed by Daniels (2005) related to the anomalies as they may bear on geologic structures in the site vicinity.

VCSNS RESPONSE:

The Central Piedmont shear zone in the site vicinity marks the boundary between the rocks of the Inner Piedmont and those of the Carolina Zone, and includes faults that define the Whitmire Reentrant (FSAR Figure 2.5.1-212). The map pattern of the Whitmire Reentrant indicates that the thrust fault that defines the boundary is a relatively flat-lying feature that exposes Inner Piedmont rocks (Cat Square terrane) in a window through the Carolina Zone (Charlotte terrane). These relationships imply that the Carolina Zone, at least in the vicinity of the Whitmire Reentrant, is thin and underlain at relatively shallow depths by Inner Piedmont rocks. The location of the magnetic and gravity profiles illustrated in FSAR Figure 2.5.1-209 transects the Whitmire Reentrant in a small portion of its northeastern extent so that the bounding fault is intersected in two locations a relatively short distance apart. FSAR Figure 2.5.1-209 (Site Vicinity Gravity and Magnetic Profiles) will be revised to show the location of the Central Piedmont shear zone, as defined by the boundaries of the Whitmire Reentrant. In addition, the location of the site and site area boundaries will also be annotated.

The RAI refers to a short wavelength magnetic high coincident with a gravity high at location "20 kilometers" on the gravity and magnetic profiles. The short wavelength magnetic high referred to in the RAI is accompanied by a magnetic low that exhibits smaller gradients to the northwest. The relatively short wavelength high – low pair is consistent with an induced dipole source at relatively shallow levels and probably originates from a magnetic source in the metaigneous Charlotte terrane. The gravity anomaly at the same location on the profile exhibits lower spatial frequencies that suggest a deeper source. The gravity anomaly also occurs on both sides of the Whitmire Reentrant boundary (see FSAR Figure 2.5.1-205). These observations indicate that this gravity anomaly likely originates from a higher density source in the underlying Inner Piedmont rocks. However, the spatial density of the gravity data are significantly less than those of the magnetic data with consequent lower resolution and ability to capture higher gradients associated with shallow sources. The differences in spatial resolution between the two potential field data sets make detailed correlation between magnetic and gravity anomalies in this setting uncertain.

The RAI also refers to a gravity high and magnetic low from locations "50 to 70 kilometers" on the potential field profiles. This region corresponds to metasediments of the Asbill Pond, Richtex, and Persimmon Fork Formations. These formations comprise metamudstone and metasiltstone sequences interbedded with metavolcanics. These formations are relatively nonmagnetic, resulting in a subdued magnetic field in this region. However, based on their composition, these units should be of relatively low density, inconsistent with the observed elevated gravity field. Therefore, it is likely that this gravity anomaly also arises from a deeper source. In fact, the profile appears to be located on and subparallel to an anomalous gravity high that extends from, and is continuous with, the anomaly described in the previous paragraph.

Daniels (2005) (FSAR Reference 2.5.1-245) does not provide specific interpretations of potential field data in South Carolina. Instead, this source is a state-wide database of gravity and magnetic data compiled as an online U.S. Geological Survey Open-File Report (http://pubs.usgs.gov/of/2005/1022/). The webpage includes interactive tools with which to view and download gravity and magnetic data and metadata.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The FSAR Figure 2.5.1-209 will be replaced with the attached revised Figure 2.5.1-209 (Attachment 1 to this response).

ASSOCIATED ATTACHMENTS:

Attachment 1 – Revised Figure 2.5.1-209

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-21

FSAR Section 2.5.1.1.2.4.2 (pg 2.5.1-24) discusses the Mulberry Creek fault, indicating it is Mesozoic in age based on an association with other similar silicified breccias described by West (1998), although the legend symbol shown in FSAR Figure 2.5.1-212 indicates it is Paleozoic in age. However, Nystrom (2006) discussed field occurrence of silicified breccias in the site region and suggested that they may occur along faults exhibiting late Cenozoic movement in the Eastern Piedmont fault zone. In addition, there is no explanation in the figure legend for the "diagonal line" symbol shown on the map which appears to designate shear zones in some cases (e.g., the Modoc shear zone) but not in others (e.g., the Kings Mountain and Boogertown shear zones).

In order for the staff to completely understand the geologic setting of the Summer site in relation to regional tectonic structures, please qualify the age of the Mulberry Creek fault and summarize the logic presented by West (1998) that silicified breccias are indicative of Mesozoic age fault displacements in light of the interpretation by Nystrom (2006) that late Cenozoic movement may have occurred along some structures in the site region which are marked by silicified breccias. Please also explain the meaning and use of the "diagonal line" symbol in Figure 2.5.1-212.

VCSNS RESPONSE:

The Mulberry Creek fault is a sub-vertical fault approximately 45 miles west of the VCSNS site. According to West (1998) (FSAR Reference 2.5.1-403), the Mulberry Creek fault contains silicified breccia, microbreccia, and cataclasite. The age of the Mulberry Creek fault is poorly constrained but, based on 180 ± 3 Ma whole rock dates (Fullagar and Butler 1980) (Reference 1) from similar silicified breccias and cataclasites elsewhere in the Carolinas, West (1998) (FSAR Reference 2.5.1-403) suggests a Late Triassic to Early Jurassic age for the Mulberry Creek fault. More recent work by Hatcher (2006) (Reference 2) corroborates Fullagar and Butler's (1980) (Reference 1) ages. Hatcher (2006) (Reference 2) indicates these silicified cataclasite fault zones formed coevally with Mesozoic (170-190 Ma) diabase dikes.

In a 2006 abstract, Nystrom (Reference 3) suggests potential minor localized Cenozoic brittle reactivation of the Augusta and Davis Pond faults, two components of the Eastern Piedmont fault system (EPFS) in South Carolina, west and west-southwest of Columbia. Nystrom (2006) (Reference 3) notes the presence of silicified breccias associated with portions of the Augusta and Davis Pond faults. Nystrom's (2006) (Reference 3) proposed Late Cretaceous to Cenozoic movement on portions of the EPFS is based on map patterns and inferred offsets of Eocene and Miocene geologic formations, however, and not on the presence of silicified breccias. Silicified breccias are characteristic of Mesozoic faults in the Piedmont (Secor et al. 1998) (FSAR Reference 2.5.1-368), and likely reflect hydrothermal activity indicative of a Mesozoic age and not a Cenozoic age. Moreover, whereas Nystrom (2006) (Reference 3) suggests potential minor localized Cenozoic brittle reactivation of the EPFS, the Mulberry Creek fault is not a part of the EPFS.

Based on available data, the Mulberry Creek fault is assessed to be Mesozoic in age. As such, FSAR Figure 2.5.1-212 will be revised to show the Mulberry Creek fault as a Mesozoic structure. The use of the "plain line" symbol in FSAR Figure 2.5.1-212 indicates shear zones, fault zones, and faults that are mapped in their original source reference with width equal to or less than the plain line width shown in FSAR Figure 2.5.1-212. The use of the "diagonal line" symbol in FSAR Figure 2.5.1-212 indicates shear zones, fault zones, or faults that are mapped in their original source reference as having width greater than the plain line width in FSAR Figure 2.5.1-212.

References:

1. Fullagar P.D. and Butler, J.R., *Radiometric Dating in the Sauratown Mountains Area, North Carolina*, in Geological Investigations of Piedmont and Triassic Rocks, Central North Carolina and Virginia, Carolina Geological Society Field Trip Guidebook, V. Price, P.A. Thayer, and W.A. Ranson (eds), p. 1-11, Virginia of Division Mineral Resources, 1980.
2. Hatcher, R.D. Jr., Juxtaposed Mesozoic Diabase Dikes and Siliceous Cataclasite Fault Zones in the Carolinas and the Mechanics of Dike Emplacement, Geological Society of America, Southeastern Section Abstracts with Programs, v. 38, no. 3, p. 8, 2006.
3. Nystrom, P.G. Jr., Late Cretaceous-Cenozoic Brittle Faulting Beneath the Western South Carolina Coastal Plain: Reactivation of the Eastern Piedmont Fault System, Geological Society of America, Southeastern Section Abstracts with Programs, v. 38, no. 3, p. 74, 2006.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

1. The FSAR Figure 2.5.1-212 will be replaced with the attached revised Figure 2.5.1-212 (Attachment 2 to this response) to show the Mulberry Creek fault as a Mesozoic structure.

ASSOCIATED ATTACHMENTS:

Attachment 2 – Revised Figure 2.5.1-212

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-24

FSAR Section 2.5.1.1.2.4.3 (pg 2.5.1-26) discusses arches and embayments but does not show the location of the Yamacraw Arch on Figure 2.5.1-211 on which the Cape Fear Arch is located. This section states that late Cretaceous through Pleistocene (i.e., as young as 1.8 my to 10,000 yrs in age) differential tectonic movement is indicated by these features, although Crone and Wheeler (2000) label them as Class C features. Furthermore, FSAR Section 2.5.1.1.2.4.4 (pg 2.5.1-29), mentions the Cape Fear Arch, but not the Yamacraw, in relation to potential regional Quaternary tectonic structures.

In order for the staff to assess the hazard potential for these two arches, please locate the Yamacraw Arch on Figure 2.5.1-211 and include a discussion of this arch in FSAR Section 2.5.1.1.2.4.4, as was done for the Cape Fear Arch. Please also refer to primary sources of data which render the conclusions about these features plausible rather than relying on the compiled information presented by Crone and Wheeler (2000).

VCSNS RESPONSE:

The basement surface on which Coastal Plain sediments were deposited is not a simple planar platform. Instead, it is characterized by broad structural upwarps (arches) that separate depositional basins (embayments) (Horton and Zullo 1991) (FSAR Reference 2.5.1-261). The hinge lines of these upwarps are aligned roughly perpendicular to the coastline. Two of these upwarps, the Cape Fear and Yamacraw arches, are located within the site region. The Cape Fear arch is located near the South Carolina-North Carolina border (FSAR Figure 2.5.1-211). The Yamacraw Arch is located near the South Carolina-Georgia border and will be added to FSAR Figure 2.5.1-211.

Evidence constraining the timing of most-recent movement on the Cape Fear and Yamacraw arches is limited. Gohn (1998) (Reference 1) indicates that the Cape Fear arch has affected the thickness and distribution of Late Cretaceous to late Tertiary strata. Prowell and Obermeier (1991) (Reference 2) suggest that upwarping on the Cape Fear arch may have continued through the Pleistocene Epoch. Data constraining the timing of most-recent movement on the Yamacraw arch are unavailable. However, due to the roughly parallel orientations and similar structural styles of the Cape Fear and Yamacraw arches, it is assessed that the tectonic history of the Yamacraw arch likely is analogous to that of the Cape Fear arch; the timing of most-recent movement on these two arches is assessed to be similar.

References:
1. Gohn, G.S., Late Mesozoic and early Cenozoic geology of the Atlantic Coastal Plain: North Carolina to Florida," in *The Geology of North America vol. 1-2, The Atlantic Continental Margin*, The Geological Society of America, 1988.
2. Prowell, D.C. and Obermeier, S.F., "Evidence of Cenozoic Tectonism," in *The Geology of the Carolinas – Carolina Geological Society 50th Anniversary Volume*, University of Tennessee Press, 1991.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

1. COLA Part 2, FSAR. Chapter 2, Subsection 2.5.1.1.2.4.3, fifth paragraph, page 2.5.1-26, will be revised as follows:

Arches and Embayments

The basement surface on which Coastal Plain sediments were deposited is not a simple planar platform. Instead, it is characterized by broad structural upwarps (arches) that separate depositional basins (embayments) (Horton and Zullo 1991) (Reference 261). The hinge lines of these upwarps are aligned roughly perpendicular to the coastline. Two of these upwarps, the Cape Fear and Yamacraw arches, are located within the site region. The Cape Fear arch is located near the South Carolina-North Carolina border and the Yamacraw Arch is located near the South Carolina-Georgia border (Figure 2.5.1-211).

Evidence constraining the timing of most-recent movement on the Cape Fear and Yamacraw arches is limited. Based on subsurface structure contour maps, Gohn (1988) (Reference 418) indicates that the Cape Fear arch has affected the thickness and distribution of Late Cretaceous to late Tertiary strata. Prowell and Obermeier (1991) (Reference 419) suggest that upwarping on the Cape Fear arch may have continued through the Pleistocene Epoch. Data constraining the timing of most-recent movement on the Yamacraw arch are unavailable. However, due to the roughly parallel orientations and similar structural styles of the Cape Fear and Yamacraw arches, the timing of the most-recent movement on these two arches is assessed to be similar. Crone and Wheeler (2000) (Reference 232) classify the Cape Fear Arch as a Class C feature based on lack of evidence for Quaternary faulting and do not include the Yamacraw Arch in their assessment. ~~A series of topographic highs and lows in the crust (arches and embayments, respectively) oriented perpendicular to the hinge zone have exerted control over Coastal Plain sedimentation from late Cretaceous through Pleistocene time and are indicative of episodic, differential tectonic movement. The arches are broad anticlinal upwarps, whereas the embayments are broad, sediment-filled basement flexures. The most prominent arches in the VCSNS site region include the Cape Fear Arch on the South Carolina-North Carolina border and the Yamacraw~~

~~Arch on the Georgia-South Carolina border. The Cape Fear Arch is bordered by the Salisbury embayment to the northeast and the Georgia embayment to the southeast. There is no evidence that these structures are active, and Crone and Wheeler (Reference 232) classify the Cape Fear Arch as a Class C feature (Table 2.5.1-201), based on lack of evidence for Quaternary faulting.~~

2. Add the following new references to FSAR Section 2.5.1:

418. Gohn, G.S., Late Mesozoic and early Cenozoic geology of the Atlantic Coastal Plain: North Carolina to Florida," in *The Geology of North America vol. 1-2, The Atlantic Continental Margin*, The Geological Society of America, 1988.

419. Prowell, D.C. and Obermeier, S.F., "Evidence of Cenozoic Tectonism," in *The Geology of the Carolinas – Carolina Geological Society 50th Anniversary Volume*, University of Tennessee Press, 1991.

3. The FSAR Figure 2.5.1-211 will be replaced with the attached revised Figure 2.5.1-211 to show the location of the Yamacraw Arch.

ASSOCIATED ATTACHMENTS:

Attachment 3 – Revised Figure 2.5.1-211

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-25

FSAR Section 2.5.1.1.2.4.4 (pg 2.5.1-27) states that, based on a review of published literature, field reconnaissance, and work performed as part of the North Anna ESP application, the Fall Lines of Weems (1998) are interpreted to be erosional features related to contrasting erosional resistances of adjacent rock types and are not tectonic in origin.

In order for the staff to assess the basis for the conclusion that the Fall Lines of Weems (1998) are erosional in nature, please summarize the pertinent information which leads to this conclusion by presenting pertinent data from primary sources which render this conclusion plausible.

VCSNS RESPONSE:

The Fall Lines of Weems (1998) (FSAR 2.5.1 Reference 398) were studied in detail as part of the North Anna ESP Application. The pertinent information that supports the conclusion that these features are erosional in nature and do not represent tectonic features was summarized in the response to North Anna ESP Application RAI 2.5.1-3 (Dominion Letter dated 7/8/2004, Serial No. 04-270, Docket No. 52-008; ML042800292) (Reference 1). The evidence and conclusions presented in the North Anna RAI response regarding the erosional nature of the fall lines was reviewed and accepted by the NRC staff. As stated on page 2-164 of the North Anna ESP SER (NUREG-1835), "the staff concludes that the applicant has accurately characterized the seven fall lines as non-tectonic features." The following discussion summarizes pertinent information from the North Anna RAI 2.5.1-3 response (Reference 1) in order to support the non-tectonic explanation for the fall lines.

In addition to the traditional Fall Line (termed "Tidewater Fall Line" by Weems) that separates the Piedmont from the Coastal Plain, Weems (1998) (FSAR 2.5.1 Reference 398) interpreted that six other laterally continuous fall lines also are present west of the Tidewater Fall Line in the Piedmont and Blue Ridge provinces. From east to west, these include the Nutbush, Durham, Central Piedmont, Western Piedmont, Blue Ridge, and Great Smokey fall lines.

Weems (1998) (FSAR 2.5.1 Reference 398) 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) (FSAR 2.5.1 Reference 398) rejected the first two hypotheses and instead 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) (FSAR 2.5.1 Reference 398) adopted a tectonic interpretation primarily because he considered the alternative interpretations to be less compelling, and not because of direct evidence supporting a tectonic origin. The following discussion summarizes three primary topics that provide the evidence and rationale to support a non-tectonic interpretation for the proposed fall lines:

- Lack of formal, consistent criteria for proposed fall lines,
- Evaluation of river terraces across Central Piedmont and Nutbush fall lines, and
- Independent geomorphic analyses.

The following sections describe each of these three primary topics.

Lack of Formal, Consistent Criteria for Proposed Fall Lines

The lack of formal, consistent criteria make it very difficult to independently reproduce Weems' (1998) (FSAR 2.5.1 Reference 398) delineation of individual fall zones, or the correlations of fall zones on individual streams as laterally continuous fall lines. In particular, the proposed model for the lateral continuity of fall lines for hundreds of miles along trend in the Blue Ridge and Piedmont provinces is based on subjective assessments of some steep stream reaches as "anomalous" fall zones. Because the fall lines proposed by Weems (1998) (FSAR 2.5.1 Reference 398) are not demonstrably reproducible, Wheeler (2005) (FSAR 2.5.1 Reference 406) concluded that tectonic faulting is not yet demonstrated.

Evaluation of River Terraces Across Central Piedmont and Nutbush Fall Lines

The only evidence in support of late Cenozoic tectonism cited by Weems (1998) (FSAR 2.5.1 Reference 398) consists of locally steepened reaches in the longitudinal profiles of Pliocene terraces along the Roanoke and Staunton Rivers in southern Virginia (Figure 10 in Weems (1998)). Weems (1998) presents profiles of three Pliocene fluvial terraces along the Roanoke and 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, 140, and 200 feet above the modern stream channel. As depicted by Weems (1998) (FSAR 2.5.1 Reference 398), there is about 60 feet of structural relief in the terraces across the fall zones. It should be noted, however, that the 60 feet of relief occurs across a horizontal distance of about 17 miles.

This relief in Weems' terrace profiles is presented at ~500x vertical exaggeration and appears to define a distinct east-facing warp or scarp in the terraces. However, 60 feet of relief in 17 miles is equivalent to an approximately 0.04° change in the gradient of the terrace surfaces. Localized displacement on a fault is not a plausible explanation for producing a sustained 0.04° increase in gradient across a horizontal distance of 17 miles.

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) (FSAR 2.5.1 Reference 398), then this interpretation implies an east-side-down sense of slip on the causative faults. Given the northeast-southwest orientation of the principle horizontal compressive stress in the Central and Eastern United States (Zoback and Zoback 1989) (FSAR 2.5.1 Reference 416), 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) (FSAR 2.5.1 Reference 398). 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.

Independent Geomorphic Analyses

Independent geomorphic analyses of the Tidewater fall line and Central Piedmont fall line were evaluated in northern Virginia. The analyses were designed 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) (FSAR 2.5.1 Reference 398).

To assess the presence or absence of Quaternary tectonic activity along the Tidewater fall line, a detailed longitudinal profile of the Rappahannock River was constructed across the fall zone at Fredericksburg, Virginia as part of work performed for the North Anna ESP application. Also plotted were elevations of remnants of a regressive late Pliocene marine sand, which caps upland surfaces of the inner Coastal Plain in northern Virginia, and specifically underlies the relatively flat, accordant summit surfaces north and south of the Rappahannock River, upstream and downstream of Fredericksburg. Despite some scatter in the elevations of the late Pliocene marine sand remnants on the profile, these elevations 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. The gradient of the late Pliocene marine sand surface is similar to that of the modern Rappahannock River upstream of the fall zone. If this interpretation that the Pliocene marine sand is not deformed is correct, then development of the fall zone in the river, which clearly postdates deposition of the late Pliocene marine sand, must be due to non-tectonic geomorphic processes.

Weems (1998) (FSAR 2.5.1 Reference 398) 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 line is not controlled by differential bedrock erosion. However, based on analysis of geologic and topographic maps, as well as detailed profiling of the Rappahannock and Rapidan Rivers in this region, it is concluded that the gradient location is not anomalous with respect to bedrock hardness. 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.

On the Rappahannock River, the fall zone that Weems (1998) associates with the Central Piedmont fall line occurs about 1 kilometer west of the eastern Culpeper basin boundary. Detailed profiles indicate that the western two-thirds of the fall zone is underlain by Jurassic diabase intrusive rocks, which crop out extensively in the eastern Culpeper basin. Based on these relations, the diabase is interpreted to be more resistant to erosion than the basin sediments, and that it acts 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.

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, northwest-facing escarpment along the Mountain Run fault zone. Parts of this escarpment are recognized as the "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 to 320 feet above sea level. The elevations of the summit ridges and hills comprising the top of the escarpment directly east of the basin range from about 380 to 410 feet, indicating about 100 feet 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) (FSAR 2.5.1 Reference 398) to create the fall lines or gradient increases along Rapidan and Rappahannock Rivers as they exit the basin.

Detailed topographic and geologic profiles reveal that 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) (FSAR 2.5.1 Reference 398). It appears that the crystalline rocks 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 can be explained 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.

Summary

Based on a critical evaluation of Weems (1998) (FSAR 2.5.1 Reference 398), as well as an independent analysis of the Central Piedmont and Tidewater fall lines in northern Virginia, the "fall lines" described by Weems (1998) (FSAR 2.5.1 Reference 398) are not as well defined and laterally continuous as originally proposed, 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 a more pronounced expression of warping or faulting should be preserved in the interfluves because continued incision along rivers would tend to eradicate the evidence of deformation. However, in general, down-to-the-east topographic escarpments are not observed along the proposed fall lines between rivers in the Piedmont and Blue Ridge provinces. In the specific example of the eastern Culpeper Basin, the topographic escarpment faces west, opposite the direction predicted by Weems' (1998) (FSAR 2.5.1 Reference 398) tectonic model for formation of the fall zones. Although the local Culpeper Basin escarpment is inconsistent with Weems' (1998) (FSAR 2.5.1 Reference 398) tectonic model, it is consistent with the differential erosion of the Triassic Culpeper Basin strata relative to the Paleozoic metamorphic and Jurassic igneous rocks to the east. Similarly, there is no east-facing escarpment expressed in the remnants of the late Pliocene marine sand 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 the evaluation of stratigraphic, structural, and geomorphic relations across and adjacent to the fall zones described by Weems (1998) (FSAR 2.5.1 Reference 398), it is concluded that:

- Positive evidence is lacking for a neotectonic origin of individual fall zones,
- Positive evidence exists for no Quaternary deformation across the "Tidewater fall zone,"
- Regional geomorphic relations provide indirect evidence for a lack of east-side-down deformation along the "Central Piedmont fall line" adjacent to Culpeper Basin, and
- Differential erosion due to variable bedrock hardness appears to be a more plausible explanation for the formation of individual fall zones than Quaternary tectonism.

This RAI response summarizes information presented in response to North Anna ESP Application RAI 2.5.1-3 (Reference 1). Reference 1 provides additional detail, including maps and figures, describing the preferred interpretation of an erosional origin for the fall lines of Weems (1998) (FSAR 2.5.1 Reference 398).

References:

1. North Anna ESP Application RAI 2.5.1-3; Dominion Letter dated 7/8/2004, Serial No. 04-270, Docket No. 52-008; ML042800292.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

No COLA changes have been identified as a result of this response.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-29

FSAR Section 2.5.1.1.2.4.4 (pg 2.5.1-29) discusses the postulated Hares Crossroads and Stanleytown-Villa Heights faults, interpreting them to be the result of landsliding, and therefore of non-tectonic origin. This FSAR section cites the data compilation paper by Crone and Wheeler (2000), who classified these faults as Class C features, but does not summarize information from original data sources to document the conclusion that these faults are non-tectonic in origin.

In order for the staff to assess the hazard potential for these faults, please summarize the evidence from primary data sources used to conclude that the faults formed in response to a non-tectonic, landslide mechanism, rather than referring only to the compiled data presented by Crone and Wheeler (2000).

VCSNS RESPONSE:

This response is divided into two sections. The first section addresses the Stanleytown and Villa Heights faults. The second section addresses the Hares Crossroads fault.

Stanleytown and Villa Heights faults:

Conley and Toewe's (1968) (Reference 1) 1:24,000-scale geologic mapping of the Martinsville West quadrangle in southern Virginia shows two small, unnamed faults. These proposed faults are located approximately 200 miles north-northeast of the VCSNS site near the communities of Stanleytown and Villa Heights, Virginia. As such, Crone and Wheeler (2000) (FSAR Reference 2.5.1-232) informally name these the Stanleytown and Villa Heights faults, respectively.

The proposed Stanleytown fault strikes N12°E, dips 62° east, and cuts nearly perpendicularly across the nose of an east-plunging hill (Conley and Toewe 1968) (Reference 1), parallel to local drainage direction. Conley and Toewe (1968, p. 25) (Reference 1) describe this fault as approximately 900 feet long, but their map shows the fault length closer to 600 or 700 feet. No geomorphic expression is reported for this fault. The proposed Stanleytown fault juxtaposes Paleozoic Rich Acres Norite on the west against Quaternary alluvial terrace deposits on the east, with apparent down-to-the-east separation of approximately 15 to 20 feet (Conley and Toewe 1968) (Reference 1). The bedrock in the footwall of the proposed Stanleytown fault is highly weathered, landslide-prone saprolite (Crone and Wheeler 2000) (FSAR Reference 2.5.1-232).

The following observations suggest a non-tectonic origin for the proposed Stanleytown fault:

- Conley and Toewe (1968) (Reference 1) do not report any shear fabrics, kinematic indicators, or piercing lines displaced by faulting;
- Conley and Toewe's (1968) (Reference 1) Figure 12 shows a black-and-white photograph of the proposed Stanleytown fault exposed in a roadcut. This photograph could be interpreted as showing a depositional contact between alluvial deposits and crystalline bedrock. The supposed fault does not appear to continue downward into the crystalline rock, nor are shear fabrics evident along the fault. Without a description of shear fabric or piercing lines, the reported 15 to 20 feet of separation may simply reflect the height of the depositional contact juxtaposing terrace and bedrock.
- The limited lateral extent of the proposed Stanleytown fault;
- The apparent absence of publications subsequent to Conley and Toewe (1968) (Reference 1) addressing these features suggests a lack of scientific interest in these potential Quaternary faults. Most potential Quaternary features compiled by Crone and Wheeler (2000) (FSAR Reference 2.5.1-232) and Wheeler (2005) (FSAR Reference 2.5.1-406) are the subject of multiple publications; and
- Crone and Wheeler (2000) (FSAR Reference 2.5.1-310) classify the proposed Stanleytown fault as a Class C structure.

The proposed near-vertical Villa Heights fault strikes N17°E across the northeast-plunging nose of a hill (Conley and Toewe 1968) (Reference 1). Conley and Toewe (1968, p. 25) (Reference 1) describe this fault as approximately 100 feet long, but their map shows the fault length between 600 and 800 feet. No geomorphic expression is reported for this fault. The proposed Villa Heights fault juxtaposes Paleozoic biotite gneiss on the west against Quaternary colluvium on the east (Conley and Toewe 1968) (Reference 1). Apparent down-to-the-east separation is roughly 5 feet across the fault. The gneiss bedrock west of the proposed Villa Heights fault is highly weathered and good outcrops are rare in the vicinity (Conley and Toewe 1968) (Reference 1).

The following observations call into question a tectonic origin for the proposed Villa Heights fault:

- Conley and Toewe (1968) (Reference 1) do not report any shear fabrics, kinematic indicators, or piercing lines displaced by faulting;
- Bedrock contacts along the north and south projections of the proposed Villa Heights fault appear unfaulted, at least on Conley and Toewe's (1968) (Reference 1) 1:24,000-scale mapping;
- The limited lateral extent of the proposed Villa Heights fault;
- No other faults are mapped within the Martinsville West quadrangle (Conley and Toewe 1968) (Reference 1);
- The apparent absence of publications subsequent to Conley and Toewe (1968) (Reference 1) addressing these features suggests a lack of scientific interest in these potential Quaternary faults. Most potential Quaternary features compiled by

Crone and Wheeler (2000) (FSAR Reference 2.5.1-232) and Wheeler (2005) (FSAR Reference 2.5.1-406) are the subject of multiple publications; and

- Crone and Wheeler (2000) (FSAR Reference 2.5.1-310) classify the proposed Villa Heights fault as a Class C structure.

The preponderance of evidence suggests that the Stanleytown and Villa Heights faults likely are non-tectonic in origin. Crone and Wheeler (2000) (FSAR Reference 2.5.1-310) indicate these features likely are landslide-related, based on their limited lateral extent and spatial association with hillsides and landslide-prone bedrock. Critical analysis of Conley and Toewe's (1968) (Reference 1) Figure 12 photograph suggests the proposed Stanleytown fault may be a depositional contact between alluvium and bedrock.

Hares Crossroads fault:

Based on a single roadcut exposure, Daniels et al. (1972) (Reference 2) map an unnamed fault near Hares Crossroads, North Carolina, approximately 200 miles northeast of the VCSNS site. Prowell (1983) (FSAR Reference 2.5.1-346) refers to this proposed fault as "feature 46" in his compilation of potential faults of Cretaceous and Cenozoic age in the eastern US. Crone and Wheeler (2000) (FSAR Reference 2.5.1-232) name this feature the Hares Crossroads fault.

Daniels et al.'s (1972) (Reference 2) field trip guidebook provides minimal description of the proposed Hares Crossroads fault. According to their rough sketch, the roadcut exposes deeply weathered, saprolitic Paleozoic crystalline rocks overlain by unconsolidated Coastal Plain sediments of the Coharie Formation of Pliocene to Pleistocene age. As sketched, this contact is highly irregular and undulatory. In this roadcut, Daniels et al. (1972) (Reference 2) describe a fault that strikes N7°E and dips 63°E with an unidentified amount of north-side-up reverse displacement, but provide no further discussion of this feature. Prowell (1983) (FSAR Reference 2.5.1-346) estimates 9 feet of vertical separation at the base of the Coastal plain sediments and at least 6 feet of lateral slip, but provides no description of the piercing lines used for these slip estimates. No shear fabrics are described in association with this feature and the geometry of the roadcut is such that assessment of whether faulting extends downward into saprolite and crystalline rocks is not possible. Crone and Wheeler (2000) (FSAR Reference 2.5.1-232) note that geomorphic expression associated with the proposed Hares Crossroads fault is "negligible at most."

The apparent absence of publications subsequent to Daniels et al. (1972) (Reference 2) and Prowell (1983) (FSAR Reference 2.5.1-346) addressing this feature suggests a lack of scientific interest in this potential Quaternary fault. Crone and Wheeler (2000) (FSAR Reference 2.5.1-232) describe two unpublished personal communications that suggest a non-tectonic origin for this feature. According to the first personal communication, C.H. Gardner indicates that the offsets measured by Daniels et al. (1972) (Reference 2) and Prowell (1983) (FSAR Reference 2.5.1-346) are localized, thereby suggesting a landslide origin. According to the second personal communication, R.T. Marple's trench atop the roadcut failed to expose a fault trace. Based on available data, the proposed Hares Crossroads fault is assessed to be likely non-tectonic in origin.

References:

1. Conley, J.F. and Toewe, E.C., *Geology of the Martinsville West Quadrangle, Virginia*: Virginia Division of Mineral Resources Report of Investigations 16, 44 p. with 1:24,000-scale plate, 1968.
2. Daniels, R.B., Gamble, E.E., Wheeler, W.H., and Holzhey, C.S., *Field Trip Guidebook 13: Raleigh,* Carolina Geological Society and Atlantic Coastal Plain Geological Association, Annual Meetings and Field Trip, October 7-8, 1972, 68p., 1972.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

No COLA changes have been identified as a result of this response.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-32

FSAR Section 2.5.1.1.2.4.5 (pgs 2.5.1-32 and 2.5.1-33) discusses the Appalachian thrust front and states that it is interpreted to be a major fault splay off the regional Appalachian detachment. However, no details of this structural relationship are presented. In addition, the importance of the Appalachian detachment in the site region, the age of this regional structure, and the pertinence of the detachment surface for constraining seismicity in the site region are not discussed.

In order for the staff to assess the adequacy of the regional geologic characterization provided in the FSAR, please provide details regarding the suggested relationship between the Appalachian thrust front and the Appalachian detachment. Please also discuss the importance of the Appalachian detachment in the site region, including how it may constrain seismicity, and the age of this regional structure.

VCSNS RESPONSE:

As shown in FSAR Figure 2.5.1-211, the Appalachian thrust front is located beyond the site region and, as such, FSAR Subsection 2.5.1.1.2.4.5 provides minimal description of this feature. This RAI response provides a more thorough description of the Appalachian thrust front, including: (1) the structural relationship between the Appalachian thrust front and the Appalachian detachment; and (2) the relationship between the Appalachian detachment and seismicity within the site region.

The Appalachian orogen represents a series of collision events that spanned most of the Paleozoic Era in eastern North America. To accommodate this convergence, a slab of metamorphosed Paleozoic rocks and slivers of basement was transported hundreds of kilometers northwest and was thrust over the Precambrian cratonic basement of North America. The fundamental structural feature responsible for transport of this slab is the shallowly southeast-dipping Appalachian detachment (or decollement), located at mid-crustal depths below the Blue Ridge and Piedmont (Cook et al. 1979; 1981) (FSAR References 2.5.1-228 and 2.5.12-229) (FSAR Figure 2.5.1-207). The northwest limit of the crystalline slab is a sharply defined boundary that coincides with a major splay of the Appalachian detachment. In other words, this boundary represents the northwestern limit of allocthonous crystalline Appalachian crust. Seeber and Armbruster (1988) (FSAR Reference 2.5.1-370) name this boundary the "Appalachian Front." Wheeler (1995) (FSAR Reference 2.5.1-404) refers to this same boundary as the "Appalachian thrust front." For the purposes of the VCSNS Units 2 and 3 FSAR, Wheeler's more descriptive term is adopted.

The role of the Appalachian thrust front and the Appalachian detachment in regional seismicity is the focus of numerous studies. For example, Seeber and Armbruster (1988) (FSAR Reference 2.5.1-370) suggest:

> "The Appalachian [thrust front]...appears to control the spatial distribution of seismicity on a large scale. Hypocenters are concentrated in the autochthounous basement below the sedimentary wedge and in the allocthonous crystalline slab above this wedge. The sedimentary wedge and the detachment are relatively aseismic" [p. 578].

Wheeler (1995) (FSAR Reference 2.5.1-404) observes that most of the Appalachians and Coastal Plain of eastern North America are more seismically active than the adjacent craton to the northwest. Moreover, as described in FSAR Subsection 2.5.1.1.2.4.1, Wheeler observes that much of the sparse seismicity in eastern North America occurs within the North American basement below the basal decollement. Therefore, seismicity within the Appalachians may be unrelated to the abundant, shallow thrust sheets mapped at the surface (FSAR Reference 2.5.1-404). For example, seismicity in the Giles County seismic zone is occurring at depths ranging from 3 to 16 miles (5 to 25 kilometers) (Chapman and Krimgold 1994) (FSAR Reference 2.5.1-222), which is generally below the Appalachian thrust sheets and basal decollement (Bollinger and Wheeler 1988) (FSAR Reference 2.5.1-217).

In summary, the Appalachian thrust front is a Paleozoic feature that approximates the surface projection of the Appalachian detachment and, thus, the northwestern limit of allocthonous crystalline Appalachian crust. As defined above by Seeber and Armbruster (1988) (FSAR Reference 2.5.1-370), the Appalachian detachment is an important structural element that exerts some control over the distribution of seismicity within the site region and beyond.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

No COLA changes have been identified as a result of this response.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-34

FSAR Section 2.5.1.1.3.2.1 describes potential source faults in the Charleston area, including the postulated Sawmill Branch fault (pg 2.5.1-37). FSAR Section 2.5.1.1.3.2.1 (page 2.5.1-37) states that the Sawmill Branch fault trends northwest, but the fault is shown with two different strike directions: a northwest strike on Figure 2.5.1-219 and a northeast strike on Figure 2.5.1-218. Furthermore, FSAR Section 2.5.1.1.3.2.1 indicates it is a segment of the Ashley River fault and offsets the Woodstock fault. However, Figure 2.5.1-219 shows it crossing the Ashley River fault while Figure 2.5.1-218 shows that it intersects, but does not cross or offset, the Woodstock fault.

In addition, based on their interpretation that conjugate normal faults occur in the walls of Colonial Fort Dorchester, Bartholomew and Rich (2007) proposed the Dorchester fault in the area south of the Ashley River fault zone, seemingly near the vicinity of the Sawmill Branch fault. Under the discussion of the Sawmill Branch fault in FSAR Section 2.5.1.1.3.2.1 (pg 2.5.1-37), observed displacements in the walls of Fort Dorchester are equated with seismic shaking and not fault rupture, and there is no indication that information presented by Bartholomew and Rich (2007) was taken into account. Talwani and others (2008) proposed that displacement along the Sawmill Branch fault is the cause of the suggested conjugate faults in the walls of Fort Dorchester, and they reported a previously undiscovered paleoliquefaction feature as well. The Dorchester fault and its possible relationship to the Sawmill Branch fault are not described in FSAR Section 2.5.1.1.3.2.1, and the Dorchester fault is not located in a figure illustrating potential Charleston tectonic features (e.g., Figures 2.5.1-218 and 2.5.1-219).

In order for the staff to assess the hazard potential of the Sawmill Branch fault, please provide a corrected figure to illustrate location, orientation, and cross-cutting character of this fault. Please also discuss the proposed Dorchester fault, locate this structure on the appropriate map, and clarify the interpreted relationships between the Sawmill Branch, Ashley River, Woodstock, and Dorchester faults taking into account information presented in the recent literature.

VCSNS RESPONSE:

The depictions of faults near Charleston, South Carolina shown in FSAR Figures 2.5.1-218 and 2.5.1-219 are identical, with the exception that the latter figure shows a close-up view of the 1886 meizoseismal area. The apparent discrepancy in the strike of the proposed Sawmill Branch fault between these two figures is the result of misleading cartography. In FSAR Figure 2.5.1-218, the reviewer has misinterpreted a leader-line pointing to the Sawmill Branch fault for the map depiction of the fault itself. FSAR Figure 2.5.1-218 will be modified to correct this potentially confusing leader-line.

The Dorchester fault is proposed by Bartholomew and Rich (2007) (Reference 1) as a near-vertical, northwest-striking, reverse-oblique (right-lateral) fault located in the general vicinity of the Ashley River and Sawmill Branch faults (Figure 1). This proposed fault is shown in Figure 1, but is not shown on FSAR Figures 2.5.1-218 and 2.5.1-219 because of its highly speculative nature. As proposed, the Dorchester fault is a subsurface feature that extends from a depth of about 8 kilometers below the ground surface downward to a depth between 13 and 25 kilometers. The existence of this proposed fault is not based on direct evidence, but rather is inferred based on the analysis of: (1) cracks in the walls of colonial Fort Dorchester, (2) local and regional stress orientations including borehole breakouts, and (3) fault plane solutions from local microseismicity. There is no direct geologic or geomorphic evidence for the Dorchester fault. However, Bartholomew and Rich (2007) (Reference 1) suggest that local geomorphology is consistent with the location of the proposed Dorchester fault and a fault length of approximately 43 kilometers. Based on the lack of direct evidence presented by Bartholomew and Rich (2007) (Reference 1), the existence of the Dorchester fault is assessed to be questionable.

FSAR Figures 2.5.1-218 and 2.5.1-219 show the Sawmill Branch and Ashley River faults intersecting at a low angle in an apparent crosscutting relationship. Likewise, Figure 1 shows the Dorchester fault intersecting the Ashley River and Woodstock faults. The locations of proposed faults in the Charleston 1886 meizoseismal area, however, are poorly constrained by available data. Moreover, the locations of the Ashley River, Sawmill Branch, Woodstock, and Dorchester faults are based on coarse-scale location maps from publications authored by separate research groups. The Ashley River fault is based on mapping presented at roughly 1:700,000-scale in Weems and Lewis's (2002) (FSAR Reference 2.5.1-399) Figure 14. The Sawmill Branch and Woodstock faults are based on mapping presented at roughly 1:400,000-scale in Talwani and Katuna's (2004) (FSAR Reference 2.5.1-385) Figure 2. The Dorchester fault is based on mapping presented at roughly 1:500,000-scale in Bartholomew and Rich's (2007) (Reference 1) Figure 2. Based on the highly speculative nature of these faults, interpreting relationships between them is questionable. As mapped, however, the proposed Sawmill Branch, Ashley River, and Dorchester faults are located in the apparent left-stepover separating the southern and northern Woodstock faults (Attachment 4).

The proposed Ashley River, Sawmill Branch, Woodstock, and Dorchester faults are wholly included within Geometries A, B, and B' of the Updated Charleston Seismic Source (UCSS) model. FSAR Subsection 2.5.2.2.2.4.1 describes in detail UCSS model and these areal source geometries. The Charleston seismic source is best modeled as areal source zones, as opposed to individual fault sources, due to the speculative nature of proposed faults in the Charleston area.

References:

1. Bartholomew, M.J. and Rich, F.J., *The Walls of Colonial Fort Dorchester: A Record of Structures Caused by the August 31, 1886 Charleston, South Carolina, Earthquake and its Subsequent Earthquake History*, Southeastern Geology, v. 44, no. 4, p. 147-169, 2007.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

FSAR Figure 2.5.1-218 will be replaced with the attached revised Figure 2.5.1-218 (Attachment 5) to correct a potentially confusing leader-line pointing to the Sawmill Branch fault.

ASSOCIATED ATTACHMENTS:

Attachment 4 - Figure 1. Local Charleston faults and seismicity.

Attachment 5 – Revised Figure 2.5.1-218

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-35

FSAR Section 2.5.1.1.3.2.1 (page 2.5.1-38) discusses the Middleton Place-Summerville seismic zone which includes the Sawmill Branch fault which FSAR Figure 2.5.1-218 shows as striking northeast. This seismic zone is not defined on the cited figure (i.e., Figure 2.5.1-219), but only on Figure 2.5.1-218. Based on recent data, Dura-Gomez and Talwani (2008) propose that the Sawmill Branch fault strikes northwest parallel to the Ashley River fault, is the most active fault in the Summerville area, and offsets the Woodstock fault. Furthermore, Chapman and Beale (2008) present data which they interpret as showing Cenozoic compressional reactivation of a Mesozoic extensional fault near the intersection of the inferred Sawmill Branch and Woodstock faults. However, these two new information sources are not discussed in regard to faulting within the Middleton Place-Summerville seismic zone.

In order for the staff to assess the most recent geologic literature and determine if the information presented in the FSAR represents an up-to-date characterization of the Sawmill Branch fault and the Middleton-Summerville seismic zone, please incorporate recent data from the two 2008 published sources which discuss faulting in the Middleton-Summerville seismic zone.

VCSNS RESPONSE:

In an abstract published after preparation and submittal of the VCSNS Units 2 and 3 COL FSAR, Dura-Gomez and Talwani (2008) (Reference 2) propose a slightly revised depiction of faults spatially associated with the Middleton Place-Summerville seismic zone (MPSSZ) and the roughly 6-km-wide stepover zone of the Woodstock fault. Dura-Gomez and Talwani (2008) (Reference 2) describe three northwest-striking faults that accommodate this stepover, the Sawmill Branch, Lincolnville, and Charleston faults. The Dura-Gomez and Talwani (2008) (Reference 2) depiction of the Sawmill Branch fault is similar to that proposed by Talwani and Katuna (2004) (FSAR Reference 2.5.1-385), who first postulated the existence of this fault. The Lincolnville fault, and possibly the Charleston fault, are newly proposed structures.

Based on their abstract, it appears that Dura-Gomez and Talwani (2008) (Reference 2) may be defining a new Charleston fault that does not correspond to the Charleston fault described in FSAR Subsection 2.5.1.1.3.2.1. The Charleston fault described in the FSAR was originally defined by Lennon (1986) (FSAR Reference 2.5.1-315) and later shown by Weems and Lewis (2002) (FSAR Reference 2.5.1-399) as a northeast-dipping reverse fault extending from the MPSSZ to slightly offshore (FSAR Figure 2.5.1-218). Dura-Gomez and Talwani (2008) (Reference 2) describe their Charleston fault as a shallowly southwest-dipping fault confined to the Woodstock fault stepover zone.

The exact number and locations of faults proposed to be spatially associated with the MPSSZ and the stepover zone of the Woodstock fault remains somewhat ambiguous. As described in FSAR Subsection 2.5.2.2.2.4.1, however, the MPSSZ and proposed faults within the 1886 meizoseismal area were used, in part, to define Geometry A of the Updated Charleston Seismic Source (UCSS) model. Geometry A completely envelops the Sawmill Branch, Lincolnville, and Charleston faults of Dura-Gomez and Talwani (2008) (Reference 2.) Likewise, these three faults are completely contained within Geometries B and B', and partially contained within Geometry C, of the UCSS model. Therefore, the exact locations of Dura-Gomez and Talwani's (2008) (Reference 2) Sawmill Branch, Lincolnville, and Charleston faults within the Woodstock fault stepover zone would not alter the UCSS model, nor impact the seismic hazard at the site.

In a paper published after preparation and submittal of the VCSNS Units 2 and 3 COL FSAR, Chapman and Beale (2008) (Reference 1) present reprocessed seismic reflection data showing two minor unnamed faults they refer to as faults A and B, and one larger fault they refer to as fault C. Faults A, B, and C are located within the MPSSZ and in the vicinity of Dura-Gomez and Talwani's (2008) (Reference 2) faults discussed above.

Fault C is imaged as a steeply dipping, down-to-the-east fault with approximately 200 m of vertical offset displacing lower Mesozoic rocks (Chapman and Beale 2008) (Reference 1). Overlying Coastal Plain sediments of Cretaceous and Tertiary age show approximately 10 m of reverse up-to-the-east displacement, suggesting Cenozoic reactivation of fault C. Neither the strike nor the extent of fault C is constrained by the single seismic line in which fault C is identified. Based on spatial coincidence with modern seismicity and the documented effects of the 1886 earthquake, Chapman and Beale (2008) (Reference 1) conclude that fault C "was very likely associated with [the 1886 Charleston earthquake]" [p. 2533].

As with Dura-Gomez and Talwani's (2008) (Reference 2) faults discussed above, Chapman and Beale's (2008) (Reference 1) faults A, B, and C are contained within Geometry A of the UCSS model. Likewise, these three faults are contained within UCSS model Geometries B, B', and C. Therefore, the exact locations of Chapman and Beale's (2008) (Reference 1) faults A, B, and C within the MPSSZ would not alter the UCSS model, nor impact the seismic hazard at the site. To date, no faults mapped or postulated within the 1886 Charleston meizoseismal area are defined as capable tectonic sources (RG 1.208) and, thus, uncertainty in the geometry of the Charleston seismogenic source is best modeled as an areal source zone.

FSAR Subsection 2.5.1.1.3.2.1 will be revised to indicate the Middleton Place-Summerville seismic zone is shown on FSAR Figure 2.5.1-218 rather than FSAR Figure 2.5.1-219.

References:

1. Chapman, M.C. and Beale, J.N., *Mesozoic and Cenozoic Faulting Imaged at the Epicenter of the 1886 Charleston, South Carolina, Earthquake*, Bulletin of the Seismological Society of America, v. 98, no. 5, p. 2533-2542, 2008.
2. Dura-Gomez, I. and Talwani, P., *A Revised Seismotectonic Framework for the Charleston, South Carolina Earthquakes*, Abstracts with Programs, American Geophysical Union Annual Fall Meeting, S42A-06, 2008.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

FSAR Subsection 2.5.1.1.3.2.1, page 2.5.1-38 will be revised as follows:

Charleston Area Seismic Zones

Three zones of concentrated microseismic activity have been identified in the greater Charleston area. These include the Middleton Place-Summerville, Bowman, and Adams Run seismic zones. Each of these features is described in detail below, and the specifics of the seismicity catalog are discussed in Subsection 2.5.2.

- *Middleton Place–Summerville Seismic Zone*. The Middleton Place–Summerville seismic zone is an area of elevated microseismic activity located about 12 miles northwest of Charleston (References 387, 218, 319, and 385) (Figure 2.5.1-218~~219~~). Between 1980 and 1991, 58 events with m_b 0.8 to 3.3 were recorded in an 11 x 14 kilometer area, with hypocentral depths ranging from about 1 to 7 miles (2 to 11 kilometers) (Reference 319). The elevated seismic activity of the Middleton Place-Summerville seismic zone has been attributed to stress concentrations associated with the intersection of the Ashley River and Woodstock faults (References 382, 319, 385, and 260). Persistent foreshock activity was reported in the Middleton Place-Summerville seismic zone area (Reference 249), and it has been speculated that the 1886 Charleston earthquake occurred within this zone (*e.g.,* References 382, 387, and 206).

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-36

FSAR Section 2.5.1.1.3.2.1 (page 2.5.1-38) discusses the Adams Run seismic zone and cites Figure 2.5.1-219 as showing the location of this zone. The Adams Run seismic zone is not labeled in Figure 2.5.1-219, although the Adams Run fault, which is separately discussed in FSAR Section 2.5.1.1.3.2.1 (page 2.5.1-33), is located on that figure. Neither discussion directly relates the seismic zone to the fault, although they appear to be the same feature.

In order for the staff to assess the hazard potential of the Adams Run seismic zone and understand the specific relationship of this zone to the Adams Run fault, please clearly define the relationship between these two features which are currently discussed separately and locate the seismic zone relative to the fault on the appropriate figure(s).

VCSNS RESPONSE:

Very low rates of seismicity and small earthquakes characterize the Adams Run seismic zone. Tarr et al. (1981) (FSAR Reference 2.5.1-388) and Tarr and Rhea (1983) (FSAR Reference 2.5.1-387) defined the Adams Run seismic zone on the basis of four small earthquakes (coda magnitudes < 2.3) that occurred between December 1977 and October 1979. Bollinger et al. (1991) (FSAR Reference 2.5.1-218) downplayed the significance of the Adams Run seismic zone, noting that, in spite of increased instrumentation, no additional events were recorded after October 1979. Between October 1979 and December 2002, only one additional earthquake occurred in the zone, a coda magnitude 2 event in May 1994 (SCSN 2002) (Reference 2). FSAR Figure 2.5.1-219 shows the earthquakes of the Adams Run seismic zone, all five of which are within three miles west and northwest of Hollywood, South Carolina.

Weems and Lewis (2002) (FSAR Reference 2.5.1-399) used the microseismicty of the Adams Run seismic zone to help define the southern end of their postulated Adams Run fault (FSAR Figure 2.5.1-219). As described by Marple and Miller 2006) (Reference 1), however, the existence of the Adams Run fault is questionable.

FSAR Subsection 2.5.1.1.3.2.1 will be revised to describe in greater detail the earthquakes of the Adams Run seismic zone. FSAR Figure 2.5.1-219 will be revised to show the location of the Adams Run seismic zone.

References:

1. Marple, R. and Miller, R., *Association of the 1886 Charleston, South Carolina, Earthquake and Seismicity Near Summerville with a 12° Bend in the East Coast Fault System and Triple-Fault Junctions*, Southeastern Geology, v. 44, no. 3, p. 101-127, 2006.
2. South Carolina Seismic Network (SCSN), *List of Earthquakes in Charleston Between 1974 and 2002*, Available at http://scsn.seis.sc.edu/, accessed 9/13/2005.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

1. COLA Part 2, FSAR. Chapter 2, Subsection 2.5.1.1.3.2.1, twenty-fourth paragraph, page 2.5.1-38, will be revised as follows:

Adams Run Seismic Zone. The Adams Run seismic zone is~~,~~ located within the meizoseismal area of the 1886 Charleston earthquake, approximately 115 miles southeast of the VCSNS site (Figure 2.5.1-219). The Adams Run seismic zone was~~is~~ originally identified on the basis of four **M**<2.5 earthquakes, three of which occurred in a two-day period in December 1977 (References 387 and 388). ~~The Adams Run seismic zone is located about 115 miles southeast of the VCSNS site (Figure 2.5.1-219).~~ Bollinger et al. (Reference 218) downplay the significance of the Adams Run seismic zone, noting that, in spite of increased instrumentation, no additional events were detected after October 1979. Between October 1979 and December 2002, only one additional earthquake occurred in the zone, a coda magnitude 2 event in May 1994 (SCSN 2002) (Reference 420). Weems and Lewis (2002) (Reference 399) used the microseismicty of the Adams Run seismic zone to help define the southern end of their postulated Adams Run fault (Figure 2.5.1-219). More recently, however, Marple and Miller (2006) (Reference 421) question the existence of the Adams Run fault based on their assessment of seismic reflection data.

2. Add the following new references to FSAR Section 2.5.1:

420 Marple, R. and Miller, R., *Association of the 1886 Charleston, South Carolina, Earthquake and Seismicity Near Summerville with a 12° Bend in the East Coast Fault System and Triple-Fault Junctions*, Southeastern Geology, v. 44, no. 3, p. 101-127, 2006.

421 South Carolina Seismic Network (SCSN), *List of Earthquakes in Charleston Between 1974 and 2002*, Available at http://scsn.seis.sc.edu/, accessed 9/13/2005.

3. FSAR Chapter 2, Figure 2.5.1-219 will be replaced with revised Figure 2.5.1-219 (Attachment 6) to show the location of the Adams Run seismic zone.

ASSOCIATED ATTACHMENTS:

Attachment 6 – Revised Figure 2.5.1-219

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-37

FSAR Section 2.5.1.1.3.2.1 (page 2.5.1-39) discusses paleoliquefaction features in coastal South Carolina. Talwani and others (2008) have reported discovery of another paleoliquefaction feature associated with the Sawmill Branch fault well, and it is not clear whether this feature is considered in this discussion.

In order for the staff to assess seismic hazard potential for the Summer site as inferred from paleoliquefaction features, please discuss the paleoliquefaction feature associated with the Sawmill Branch, as was reported by Talwani and others (2008), and any bearing this feature may have on magnitude and recurrence interval for earthquakes in the site region.

VCSNS RESPONSE:

In an abstract published after preparation and submittal of the VCSNS FSAR, Talwani et al. (2008) (Reference 1) describe a previously undiscovered paleoliquefaction feature near Fort Dorchester in the meizoseismal area of the 1886 Charleston, South Carolina, earthquake. Talwani et al. (2008) (Reference 1) describe this feature as a 1-m-wide sandblow at a depth of approximately 0.5 m below the ground surface. There are no radiocarbon or other quantitative age constraints on this feature. Talwani et al. (2008) (Reference 1), however, indicate a pre-1886 age for this sandblow, presumably on the basis of burial depth and degree of soil formation. Based on unspecified back calculation techniques, Talwani et al. (2008) (Reference 1) estimate a magnitude of ~6.9 (magnitude scale unspecified) for the causative earthquake.

The recent discovery of this paleoliquefaction feature has no bearing on parameter estimates for the Charleston seismic source as defined by the Updated Charleston Seismic Source (UCSS) model. FSAR Subsection 2.5.2.2.2.4 describes in detail the UCSS. Very little is known about the earthquake that produced Talwani et al.'s (2008) (Reference 1) recently discovered paleoliquefaction feature, thus the discovery of this feature does not provide any reliable constraints on the timing, magnitude, or location of paleoearthquakes.

The newly discovered paleoliquefaction feature is located within UCSS Geometry A. As described in FSAR Subsection 2.5.2.2.2.4.1, Geometry A is completely contained within Geometries B and B', and is partially contained within Geometry C. Geometry A is centered on the area containing the greatest density of 1886 and prehistoric liquefaction features, as well as the preponderance of local tectonic features (FSAR Figure 2.5.2-213). Geometry A represents a localized source area that generally confines the Charleston source to the 1886 meizoseismal area and is assigned a weight of 0.70 in the UCSS model. The fact that the newly discovered paleoliquefaction feature is located within Geometry A is consistent with the UCSS model.

Talwani et al.'s (2008) (Reference 1) magnitude estimate of ~6.9 for the causative earthquake falls within the range of Mmax magnitudes of the UCSS model. The Mmax distribution for the UCSS is moment magnitude (Mw) 6.7 – 7.5. Talwani et al.'s (2008) (Reference 1) estimated magnitude is, therefore, consistent with the UCSS model. However, this magnitude is estimated from a single paleoliquefaction feature and is therefore not well constrained, given the large number of assumptions and uncertainties inherent in any of the methods used to estimate paleoearthquake magnitude.

The timing of formation of the newly discovered paleoliquefaction feature is not yet constrained by radiocarbon or other quantitative means. As such, it cannot be determined if this feature is the result of a previously recognized prehistoric event (FSAR Subsection 2.5.2.2.2.4.3), or if this feature is the result of an unrecognized event. Without an age estimate for this paleoliquefaction feature, it cannot be evaluated against the recurrence parameters of the UCSS model.

Very little is known about the earthquake that produced Talwani et al.'s (2008) (Reference 1) recently discovered paleoliquefaction feature. As such, the discovery of this paleoliquefaction feature does not provide any reliable constraints on the timing, magnitude, or location of paleoearthquakes. Therefore, no modifications to the UCSS model are required.

References:

1. Talwani, P., Dura-Gomez, I., Gassman, S., Hasek, M., and Chapman, A., Studies related to the discovery of a prehistoric sandblow in the epicentral area of the 1886 Charleston SC earthquake: trenching and geotechnical investigations, Program and Abstracts, Eastern Section of the Seismological Society of America, p. 50, 2008.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

No COLA changes have been identified as a result of this response.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-38

FSAR Section 2.5.1.1.3.2.2 (pgs 2.5.1-40 and 2.5.1-41) discusses the six EPRI/SOG team source zones and corresponding Mmax values for the Eastern Tennessee Seismic Zone (ETSZ). The FSAR (pg 2.5.1-41) specifies the upper-bound maximum range of the EPRI/SOG teams Mmax values as **M** 6.3 to 7.5 (converted from mb values 5.2 to 7.2). Although the FSAR (pg 2.5.1-41) states that more recent estimates of Mmax are captured in the range of Mmax values used by the EPRI/SOG teams, the FSAR cites post-EPRI/SOG Mmax estimates of **M** 6.3 (Bollinger, 1992) and **M** 7.5 (Frankel and others, 2002) but not the alternate higher estimate of **M** 7.8 by Bollinger (1992) which is presented in FSAR Section 2.5.2.2.2.5 (pg 2.5.2-33).

In order for the staff to assess the information presented in the FSAR on the ETSZ, please clarify why FSAR Section 2.5.1.1.3.2.2 does not include the Bollinger (1992) Mmax estimate of **M** 7.8 since this value is not captured in the range of Mmax values used by the EPRI/SOG teams as claimed.

VCSNS RESPONSE:

In order to clarify the two discussions of Eastern Tennessee seismic zone M_{max} values from the Bollinger (1992) (FSAR Reference 2.5.1-215) study in FSAR Subsections 2.5.1.1.3.2.2 and 2.5.2.2.2.5, the text of FSAR Subsection 2.5.1.1.3.2.2 will be modified to: (1) more clearly state that the EPRI-SOG M_{max} distributions nearly encompasses all of the more recent characterizations; and (2) point the reader to the more complete discussion of the larger M_{max} value of **M** 7.8 from the Bollinger (1992) (FSAR Reference 2.5.1-215) study. These modifications to the FSAR have no downstream impact on the PSHA described in FSAR Subsection 2.5.2.4.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

Subsequent hazard studies have used Mmax values within the range of maximum magnitudes used by the six EPRI models. Collectively, upper-bound maximum values of Mmax used by the EPRI ESTs range from **M** 6.3 to 7.5 (conversion from m_b to **M** by arithmetic mean of three equally weighted relations: Atkinson and Boore (Reference 204), Frankel et al. (Reference 254), and EPRI (Reference 251). <u>Subsection 2.5.2.2.2.5</u>

describes Mmax values used for the ETSZ in hazard studies subsequent to the EPRI models. ~~Using three different methods specific to the eastern Tennessee seismic source, Bollinger (Reference 215) estimates an Mmax of **M** 6.3. The U.S. Geological Survey (USGS) source model assigns a single Mmax value of **M** 7.5 for the Eastern Tennessee Seismic Zone (Reference 255). Both of these more recent estimates of Mmax for the Eastern Tennessee Seismic Zone are captured by the range of Mmax values used in EPRI (Reference 250).~~

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-39

FSAR Section 2.5.1.1.3.2.2 (pg 2.5.1-40) states that a lack of seismicity in the relatively shallow Appalachian thrust sheets implies that seismogenic structures in the ETSZ are unrelated to surficial geology of the Appalachian orogen. The FSAR also states (pg 2.5.1-44) that the lack of seismicity in the shallow Appalachian thrust sheets, estimated to be about 3.2-5.6 km (2-3.5 mi) thick, implies that seismogenic structures in the Giles County seismic zone are also unrelated to surficial geology of the Appalachian orogen.

In order for the staff to assess the interpretation that seismogenic structures in the ETSZ and the Giles County seismic zone are unrelated to surficial geology, please provide the following information:

(a) Document any direct evidence available from seismograms for constraining earthquakes in the ETSZ to depths between 4.8-25.7 km (3-16 mi), precluding a possible association with known shallow faults.

(b) Summarize the available evidence supporting the statement that the basal Appalachian detachment, into which thrust faults in the ETSZ sole out, has a maximum depth of 4.8 km (3 mi).

(c) Given the degree of uncertainty in [1] phase identification present in most seismic network data (particularly for distances corresponding to stations in the ETSZ), [2] distance to the nearest station, [3] seismograph station density, and [4] velocity structure and its relationship to models used in routine hypocenter determination, please discuss what modifications to some or all of these uncertainties would be necessary to enable location of some of the earthquake hypocenters on one of the mapped faults shown in Figure 2.5.1-212 and whether this modification is in the zero to one sigma uncertainty bound.

VCSNS RESPONSE:

The Eastern Tennessee Seismic Zone (ETSZ) is located in the Valley and Ridge geologic province of eastern Tennessee, beyond the area shown in FSAR Figure 2.5.1-212. Earthquake location uncertainties are large in the region spanned by FSAR Figure 2.5.1-212 due to sparse and widely separated seismographic station installations. The overall earthquake location uncertainties in the area shown in FSAR Figure 2.5.1-212 are sufficiently large such that: (1) the definite association of seismicity with particular fault structures is precluded; and (2) the possibility that some earthquakes located to date are located on faults mapped at the surface cannot be entirely precluded. Specific responses to parts a through c follow.

(a) In the ETSZ, the only direct information used from seismograms to constrain earthquake locations are body-wave first-arrival time picks from analog and digital seismographic network records (Vlahovic et al. 1998 [Reference 4]; Dunn and Chapman 2006 [Reference 2]). In the ETSZ, earthquake location capabilities are such that more than 95% of the earthquakes have horizontal uncertainties < 2 kilometers, while more than 90% have vertical uncertainties < 4.4 kilometers (Vlahovic et al. 1998) (Reference 4). The arrival time picks for P- and S-wave were obtained from 1 Hz vertical component recordings (Dunn and Chapman 2006) (Reference 2). Picking S-wave arrival times from vertical component stations can result in a bias toward picking arrival times earlier than the actual S-wave first arrival due to S-P converted phases produced in the upper crust. The result of such a systematic bias would be to bias hypocenter depth estimates toward shallower depths, since S minus P times would be reduced. Additional detail regarding depth constraints on ETSZ earthquakes is presented in part (c) of this response, below.

(b) The Appalachian detachment in the Valley and Ridge in eastern Tennessee is located in the upper part of the Lower Cambrian clastic sequence consisting of the Rome Formation and Conasauga Groups (Hatcher et al. 1989) (Reference 3). This interval occurs above the base of the Paleozoic section located at approximately 4.5 kilometers depth based on seismic reflection information presented in Dunn and Chapman (2006) (Reference 2). The evidence from these sources supports the statement that the basal detachment in the ETSZ occurs above 4.8 kilometers.

(c) Several investigations provide a means to evaluate earthquake location uncertainties in the ETSZ. Vlahovic et al. (1998) (Reference 4) performed one-dimensional (1D) and three-dimensional (3D) velocity-hypocenter inversions with ETSZ P- and S-wave arrival time picks to reduce earthquake location biases associated with velocity model errors. Their 1D P-wave velocities in the top 12 kilometers of the crust increased relative to previous velocity models used to locate ETSZ earthquakes (Bollinger et al. 1980) (Reference 1). This results in a decrease in shallow earthquake hypocenter depths. Vlahovic et al. (1998) (Reference 4) found a small increase in the number of earthquakes that located in the shallowest layer after relocation, but most earthquakes (37 out of 45) located below 3 kilometers depth.

A reasonable assumption is that the final 1D and 3D velocity models and corresponding earthquake locations of Vlahovic et al. (1998) (Reference 4) minimize earthquake location biases associated with velocity model biases. Thus, the remaining source of potentially large earthquake depth estimation bias is S-wave arrival time picking bias associated with S-to-P converted phases. The relatively homogenous shallow crustal P- and S-wave is not conducive to producing pronounced S-to-P conversions for earthquakes occurring at < 4 kilometers depth (Figure 3 of Vlahovic et al. 1998) (Reference 4).

After relocation of ETSZ earthquakes using the final 3D velocity model, Vlahovic et al. (1998) (Reference 1) found that most earthquakes were located in the 4 to 20 kilometers depth range. Dunn and Chapman's (2006) (Reference 2) analysis of the best constrained ETSZ locations using double-difference relocation and the unbiased 1D velocity model of Vlahovic et al. (1998) (Reference 4) did not produce a single earthquake location shallower than 5 kilometers out of the 80 earthquakes relocated. Noise-related picking uncertainties between separate events mostly are uncorrelated. Consequently, the aggregate uncertainty from a large group of locations is reduced on the order of 1/sqrt(N), where N is the total number of earthquakes in a particular depth range of interest. Thus, while individual earthquake depth location uncertainties within the ETSZ might exceed several kilometers (Vlahovic et al. 1998) (Reference 4), the small number of earthquakes located at depths < 4 kilometers out of N=45 shallowest relocated earthquakes by Vlahovic et al. (1998) (Reference 4) and N=9 shallowest relocated earthquakes by Dunn and Chapman (2006) (Reference 2) strongly suggests that very few earthquakes are occurring at depths < 4 kilometers in the ETSZ. Thus, even if S-to-P conversions are producing systematic errors in S-wave arrival time picks, the net effect is a systematic bias to underestimating earthquake depths, which only increases the probability that little seismicity is occurring at depths < 4 kilometers in Paleozoic sediments in the ETSZ. Based on the results of Vlahovic et al. (1998) (Reference 4) and Dunn and Chapman (2006) (Reference 2), it appears that ETSZ earthquakes mostly are located in basement rocks, below the deepest extent of Paleozoic sediments. There may be a stronger correlation of earthquake depths with the maximum depth of Paleozoic sediments than the slightly shallower depth of the Appalachian detachment.

Seismic deformation is driven from below, not from the free surface. Surficial fault orientations are not likely to determine rupture initiated at seismogenic depths in the ETSZ, which the ETSZ earthquake depth distributions (Vlahovic et al. 1998 [Reference 4]; Dunn and Chapman 2006 [Reference 2]) suggest will occur at depths > 4 kilometers in basement. Consequently, Dunn and Chapman (2006) (Reference 2) used seismicity at depth and focal mechanisms to infer the orientation of basement faults responsible for the observed seismicity. However, in the region encompassed by FSAR Figure 2.5.1-212, earthquake location uncertainties are substantially larger than in the ETSZ and there is no statistically significant way to associate or preclude association of earthquakes in FSAR Figure 2.5.1-212 with the mapped faults shown in FSAR Figure 2.5.1-212. Additionally, there is no documented evidence for recent surface faulting in the area shown in FSAR Figure 2.5.1-212.

References:

1. Bollinger, G.A., Chapman, M.C., and Moore, T.P., *Central Virginia Regional Seismic Network: Crustal Velocity Structure in Central and Southwestern Virginia*, U.S. NRC Report, NUREG/CR-1217, 187p., 1980.

2. Dunn, M.M. and Chapman, M.C., *Fault Orientation in the Eastern Tennessee Seismic Zone: A study Using Double-Difference Earthquake Location Algorithm*, Seismological Research Letters, v. 77, p. 494-504, 2006.

3. Hatcher, R.D. Jr., Thomas, W.A., Geiser, P.A., Snoke, A.W., Misher, S., and Wiltschko, D.V., *Alleghanian Orogen*, in The Geology of North America, The Appalachian-Ouachita Orogen in the United States, The Geological Society of America, Volume F-2, p. 233-318, 1989.

4. Vlahovic, G.C., Powell, C.A., Chapman, M.C., and Sibol, M.S., *Joint Hypocenter-Velocity Inversion for the Eastern Tennessee Seismic Zone*, Journal of Geophysical Research, v. 103, p. 4,879-4,896, 1998.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

No COLA changes have been identified as a result of this response.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

QUESTIONS from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-49

FSAR Section 2.5.1.2.6 (pg 2.5.1-54) states that no published reports indicate the presence of paleoseismic features in the site area, and that extensive studies of outcrops in the site area showed no evidence for post-Miocene earthquake activity. However, whether these studies were performed specifically for Units 2 and 3 is not clear. Furthermore, there is no indication of the types of materials examined during these studies and no information indicating where the studies were performed to document the area in which no paleoliquefaction features were found.

In order for the staff to assess seismic hazard potential for the site as inferred from a lack of paleoliquefaction features, please clarify whether or not the new studies were conducted specifically for Units 2 and 3. Please also indicate the types of materials examined and provide information regarding where the studies were performed to document the area in which no paleoliquefaction features were discovered.

VCSNS RESPONSE:

New geologic studies performed for the VCSNS Units 2 and 3 COL application revealed a general lack of liquefaction-susceptible deposits and, therefore, no paleoliquefaction features were found within the site area. These studies included:

- Field Geologic Reconnaissance. A search for liquefaction-susceptible deposits and liquefaction features preserved in the geologic record was performed as part of geologic field reconnaissance of the site area and beyond. This reconnaissance included an investigation of roadcut exposures, outcrops, and creek banks in the site area. Additionally, the banks of the Broad River were investigated by canoe for roughly four miles between Hellers Creek and State Route 213. While minor amounts of alluvium exist in the site area, geologic field reconnaissance was unable to document any significant cross-sectional exposures of alluvium or liquefaction-susceptible deposits. Rocks within the site area predominantly are Carboniferous and older in age (FSAR Figure 2.5.1-224), commonly weathered to saprolite. As such, no paleoliquefaction features are known to exist in the site area.
- Aerial Geologic Reconnaissance and Aerial Photograph Interpretation. Assessment of stereo aerial photography and low altitude overflights revealed no evidence for surface expression of liquefaction features in the site area. However, this assessment also revealed minimal alluvial deposits within stream valleys in the site area.

- Literature Review and Interviews with Experts. A comprehensive review of published literature and interviews with experts in the geology of the site area revealed no known paleoliquefaction features within the site area.

These studies indicate the absence of paleoliquefaction features in the site area. These studies also indicate, however, the lack of liquefaction-susceptible deposits in the site area. As such, the lack of paleoliquefaction features in the site area is consistent with, but not definitive proof of, the lack of strong ground shaking within the site area.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

FSAR Subsection 2.5.1.2.6, sixth paragraph, page 2.5.1-55, will be revised as follows:

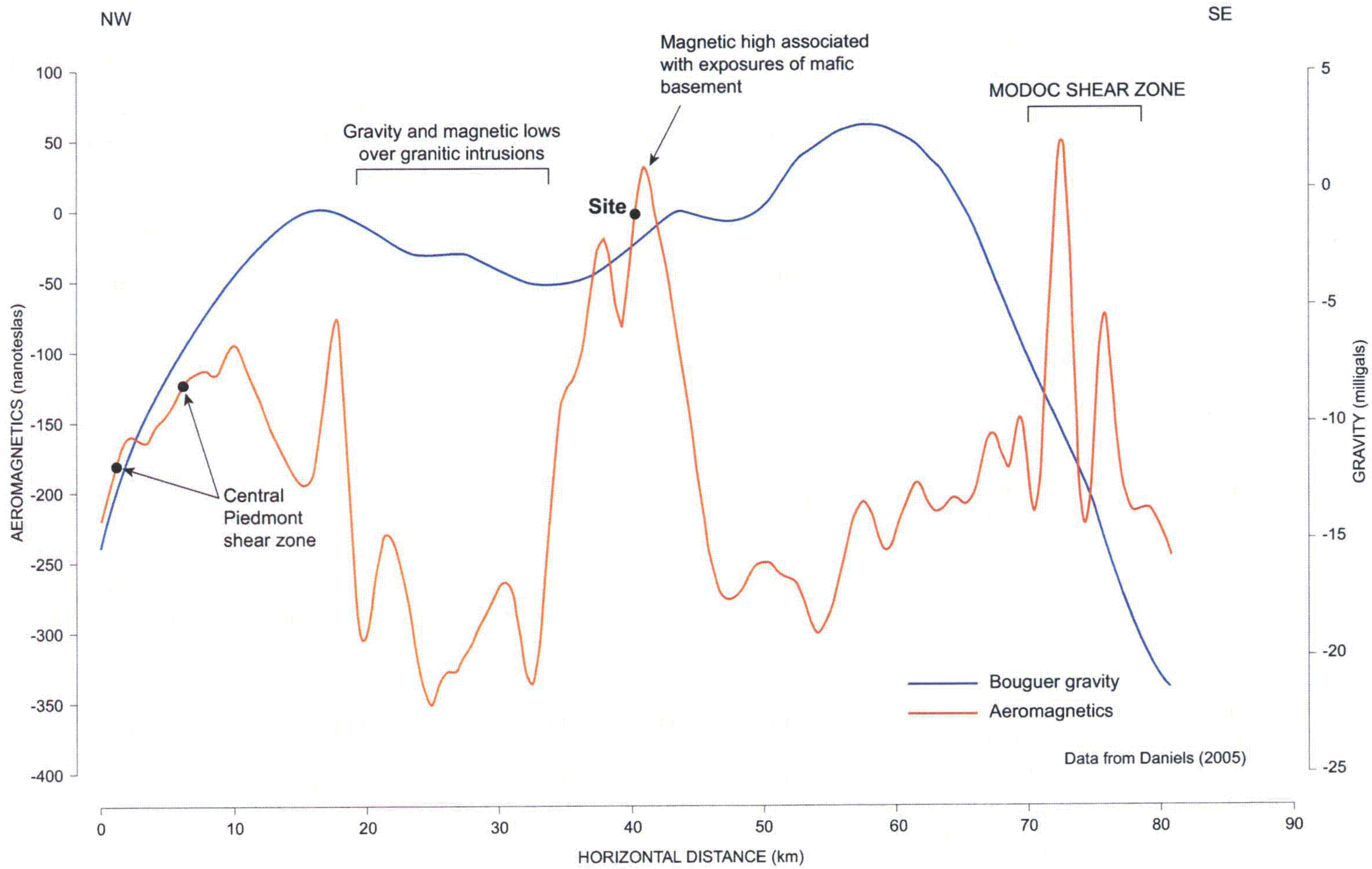
There are no published reports of paleoseismologic studies within the site area. ~~Extensive~~ Geologic reconnaissance studies of outcrops and exposures performed for the VCSNS Units 2 and 3 COL application reveal a general lack of liquefaction-susceptible deposits within the site area and, therefore, no paleoliquefaction features were found ~~do not indicate any evidence for post-Miocene earthquake activity~~ within the site area.

ASSOCIATED ATTACHMENTS:

None

Attachment 1

Revised Figure 2.5.1-209



See Regional Gravity and Magnetic Maps (Figures 2.5.1-205 and 2.5.1-206) for location of profiles.

Figure 2.5.1-209 Site Vicinity Gravity and Magnetic Profiles

Attachment 2

Revised Figure 2.5.1-212

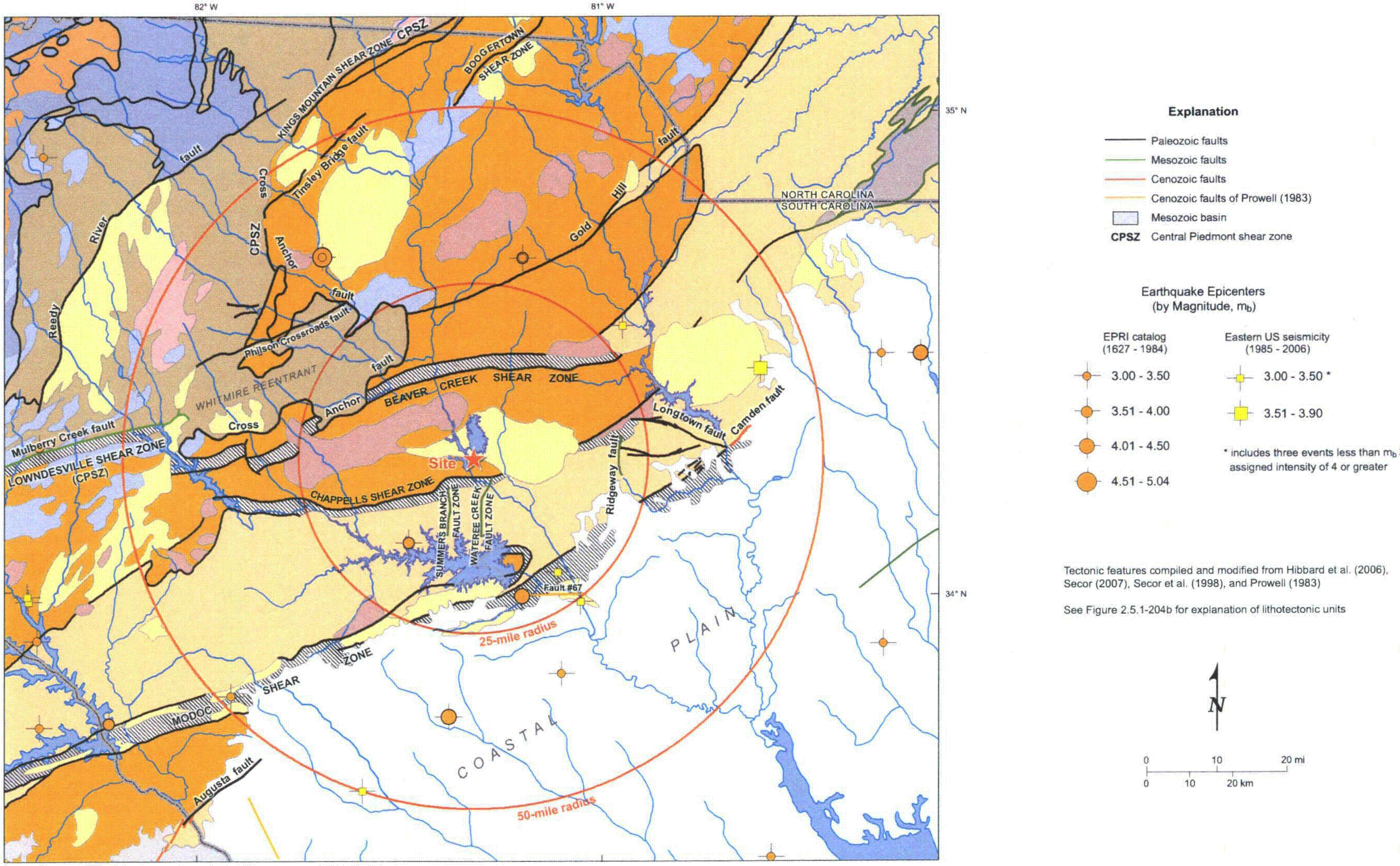


Figure 2.5.1-212 50-Mile Tectonic Features Map

Attachment 3

Revised Figure 2.5.1-211

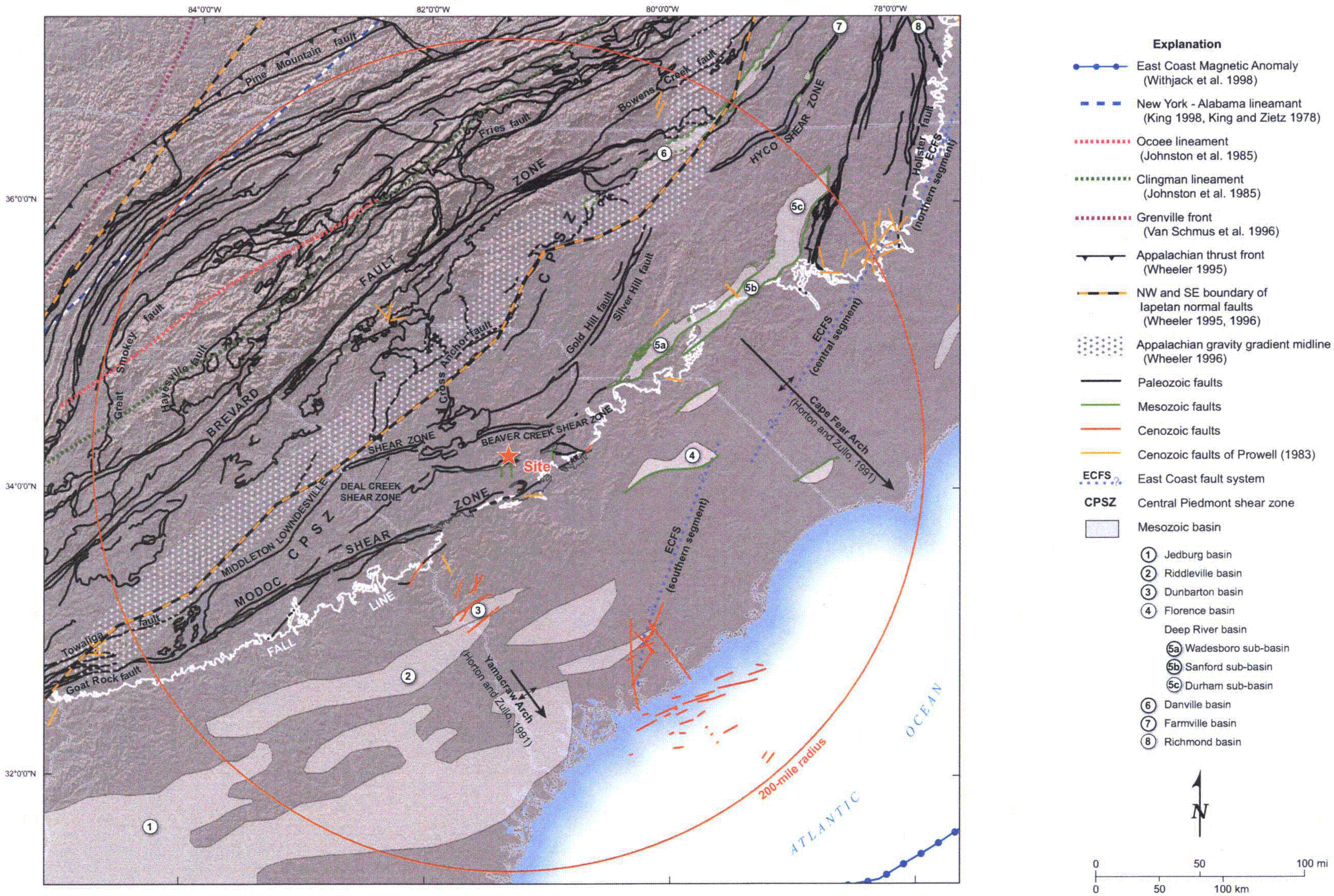


Figure 2.5.1-211 Site Region Tectonic Features

Attachment 4

Figure 1 – Local Charleston Faults and Seismicity

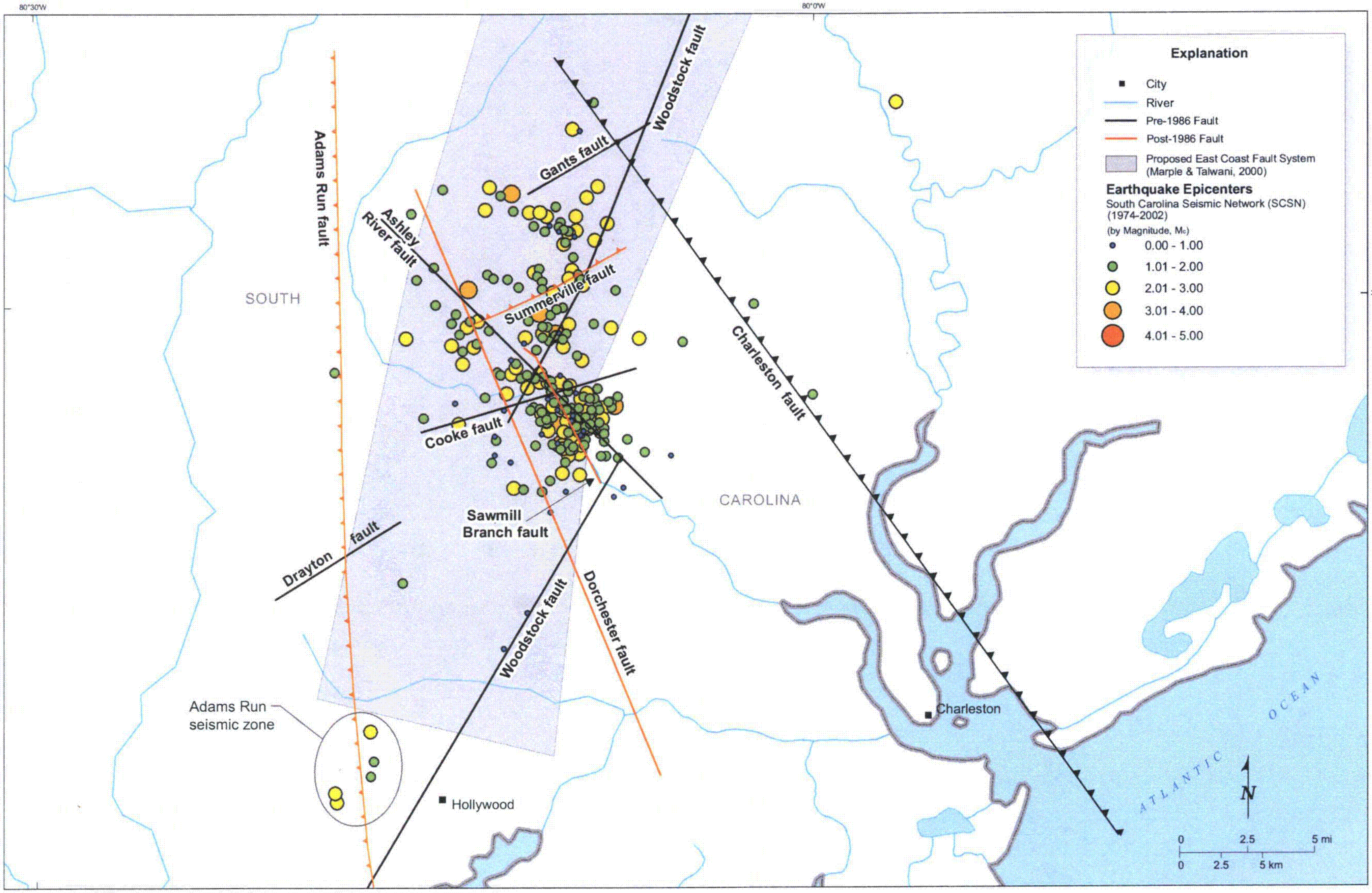


Figure 1. Local Charleston Faults and Seismicity

Attachment 5

Revised Figure 2.5.1-218

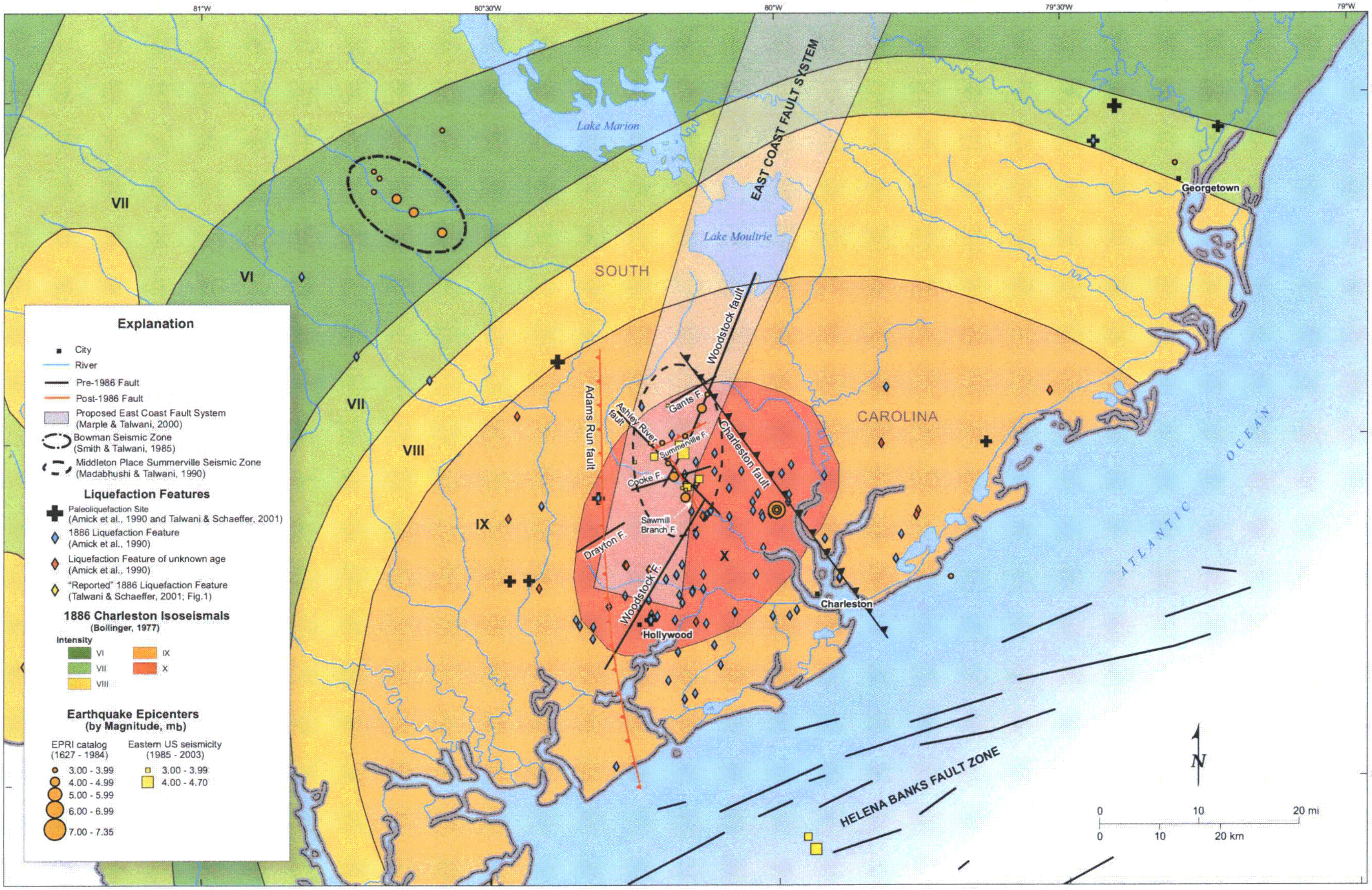


Figure 2.5.1-218 Local Charleston Tectonic Features

Attachment 6

Revised Figure 2.5.1-219

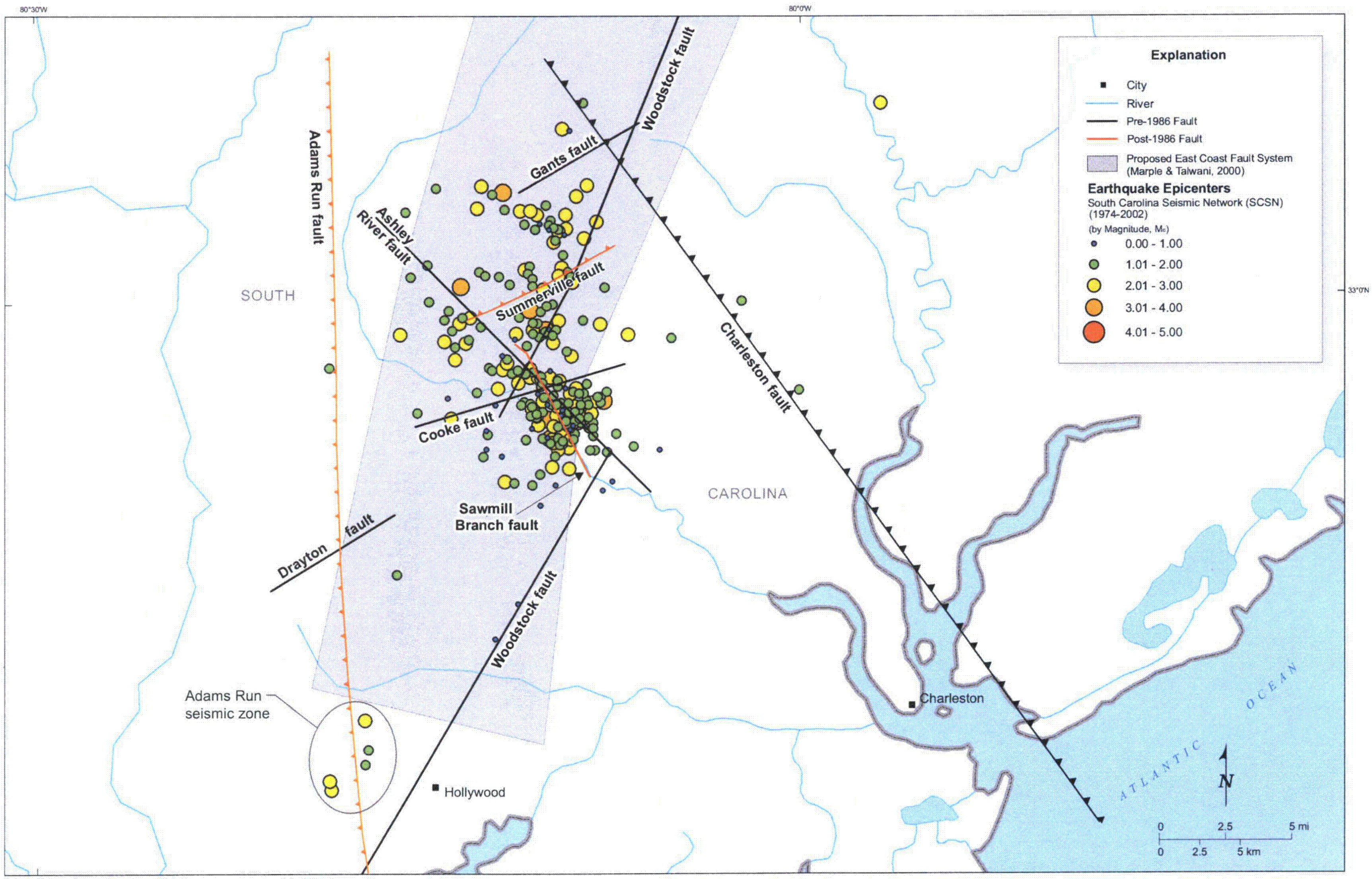


Figure 2.5.1-219 Charleston Area Seismicity