Ronald B. Clary
General Manager
New Nuclear Deployment

SCE&G®
A SCANA COMPANY

May 6, 2009
NND-09-0113

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 Supplemental Response No. 2 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.
3. Letter from Ronald B. Clary (SCE&G) to Document Control Desk (NRC), Response to NRC Request for Additional Information (RAI) Letter No. 033, dated April 15, 2009.

The enclosure to this letter provides the South Carolina Electric & Gas Company (SCE&G) 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 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 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 were submitted in a letter dated April 15, 2009 (Reference 3).

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 6th day of May, 2009.

Sincerely,

Ronald B. Clary
General Manager
New Nuclear Deployment

AMM/RBC/am

Enclosure

c (w/o enclosure):
Luis A. Reyes
John Zeiler
Stephen A. Byrne
Ronald B. Clary
Bill McCall
Kenneth J. Browne
Randolph R. Mahan
Kathryn M. Sutton

c (with enclosure)
Chandu Patel
Courtney W. Smyth
John J. DeBlasio
Grayson Young
Bob Whorton
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NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-1

FSAR Section 2.5.1.1.1 (pg. 2.5.1-2) references Figure 2.5.1-202 and states that the Blue Ridge and Piedmont physiographic provinces are further divided into different lithotectonic terranes. However, the cited figure does not include Blue Ridge lithotectonic sub-divisions, but only sub-divisions for a part of the Piedmont (i.e., the Carolina Zone of the Central Piedmont in which the site is located and the geologic/lithotectonic terranes therein). FSAR Sections 2.5.1.1.1.3 (pgs. 2.5.1-3 & 2.5.1-4) and 2.5.1.1.1.4 (pgs. 2.5.1-4ff) also reference Figure 2.5.1-202, but regional relationships between the adjacent geologic/lithotectonic terranes, the regional faults which separate them, and the Carolina Zone are not clearly distinguished in a single figure.

In order for the staff to completely understand the geologic setting of the Summer site in relation to regional geology and lithotectonic elements, please prepare a single figure that illustrates the geologic/lithotectonic subdivisions (including the Valley and Ridge, Blue Ridge, Western Piedmont, and Central Piedmont relative to the Coastal Plain physiographic province), the regional fault zones which separate them, and the Carolina Zone of the Central Piedmont in which the site is located. The aim should be to place them in the regional geologic/tectonic context before finer details of these subdivisions are presented in existing FSAR Figure 2.5.1-202 and discussed in the text.

VCSNS RESPONSE:

FSAR Figure 2.5.1-202 will be revised to provide the information requested in RAIs 02.05.01-1, 02.05.01-2, 02.05.01-13 and 02.05.01-31. This revised figure will show the lithotectonic classification of Hibbard et al. (2006; 2007) (FSAR Reference 2.5.1-284 and Reference 2). In addition, a new figure will be added to the FSAR (FSAR Figure 2.5.1-232) that illustrates the relationships between: (1) the physiographic subdivisions of the site region; (2) regional fault zones; and (3) the lithotectonic divisions presented by Hibbard et al. (2006; 2007) (FSAR Reference 2.5.1-284 and Reference 2) and Hatcher et al. 2007 (Reference 1).

References:

1. Hatcher, R.D. Jr., Bream, B.R., Merschat, A. J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in 4-

D Framework of Continental Crust, Geological Society of America Memoir 200, p. 595-625, 2007.

2. Hibbard, J.P., van Staal, C.R., Rankin, D.W., *The Comparative Analysis of Pre-Silurian Crustal Building Blocks of the Northern and the Southern Appalachian Orogen*, American Journal of Science, v. 307, p. 23-45, 2007.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Figure 2.5.1-202 (sheets 1 and 2) will be revised to show the lithotectonic classification of Hibbard et al. 2006 (FSAR Reference 2.5.1-284).

New Figure 2.5.1-232 will be added to the FSAR.

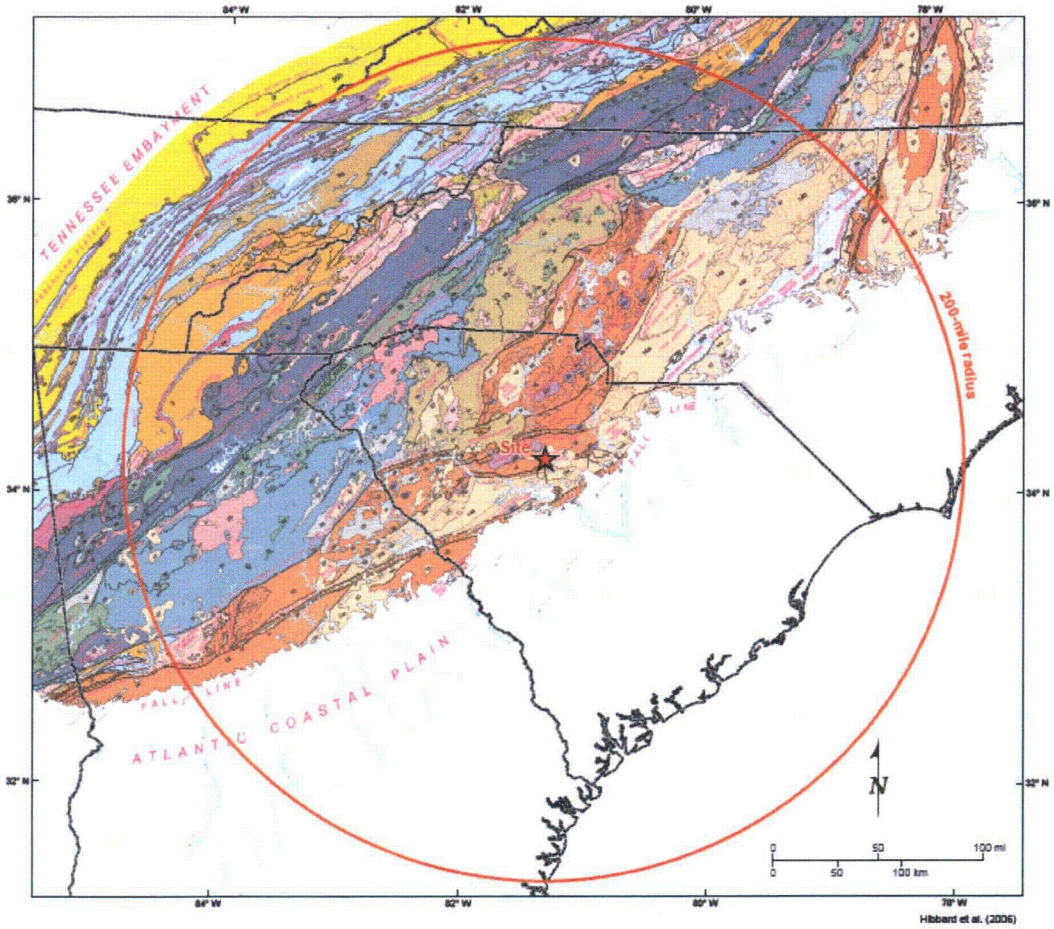
Add the following references to FSAR Section 2.5.1:

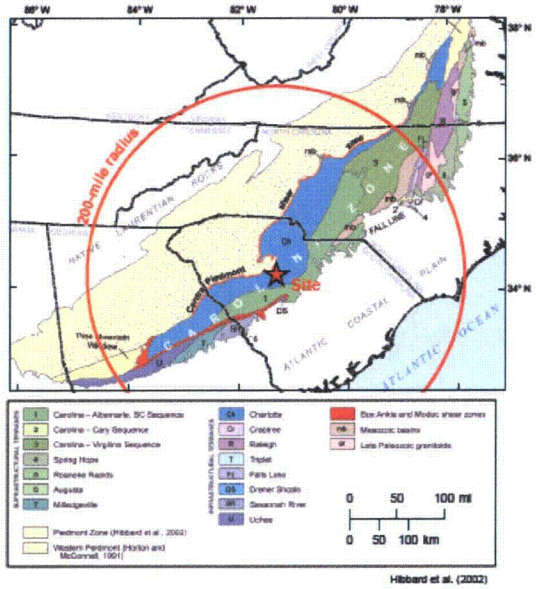
423. Hatcher, R.D., Bream, B.R., and Merschat, A.J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in R.D. Hatcher, M.P. Carlson, J.H. McBride, and J.R. Martinez Catalan (eds.), 4-D Framework of Continental Crust, Geological Society of America Memoir 200, p. 595-632, 2007.

427. Hibbard, J.P., van Staal, C.R., Rankin, D.W., *The Comparative Analysis of Pre-Silurian Crustal Building Blocks of the Northern and the Southern Appalachian Orogen*, American Journal of Science, v. 307, p. 23-45, 2007.

ASSOCIATED ATTACHMENTS:

FSAR Figure 2.5.1-202 (sheets 1 and 2)
Figure 2.5.1-232





See Sheet 2 of 2 for explanation

Figure 2.5.1-202 Lithotectonic Map of the Site Region (Sheet 1 of 2)

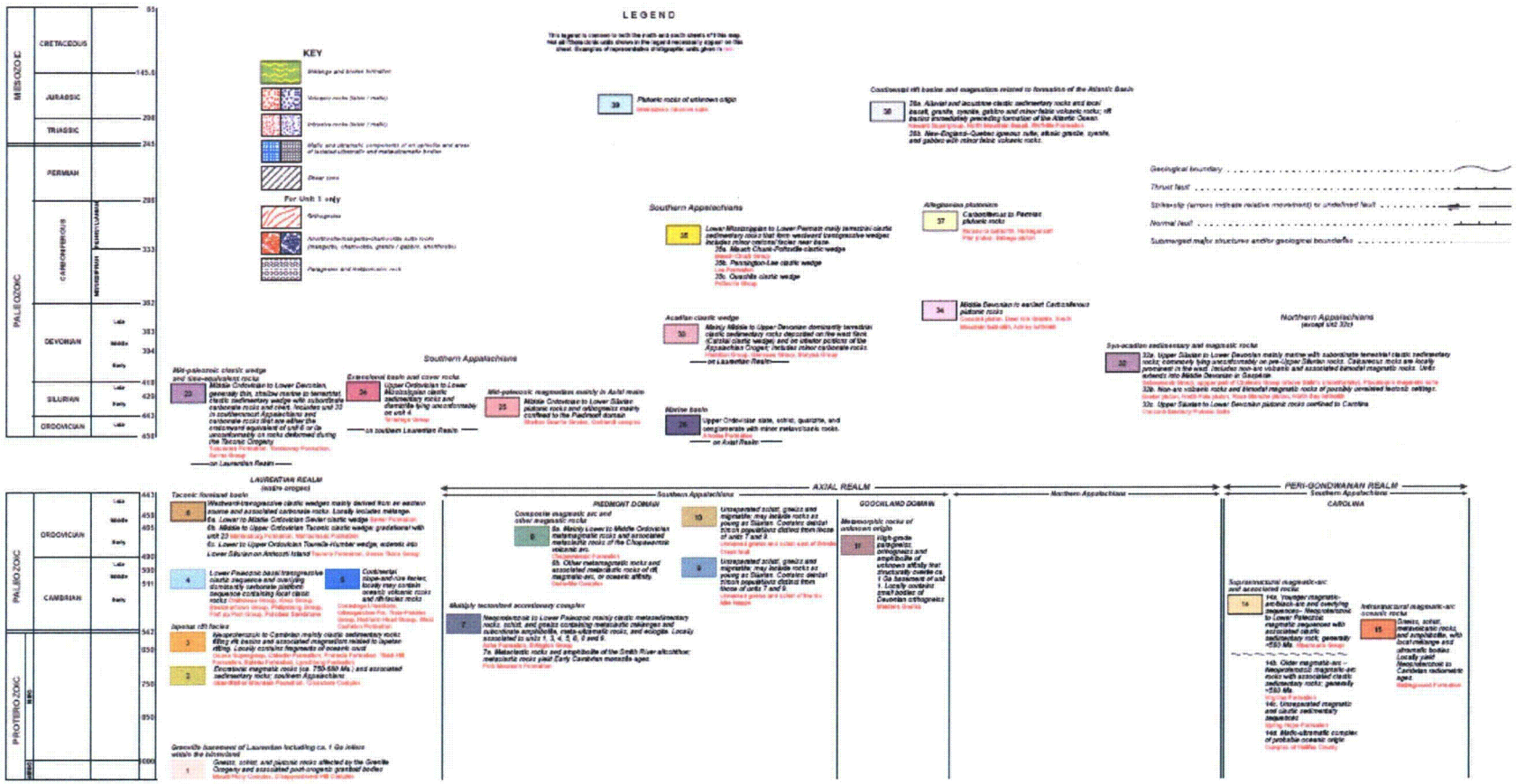


Figure 2.5.1-202 Explanation of Lithotectonic Map of the Site Region (Sheet 2 of 2)

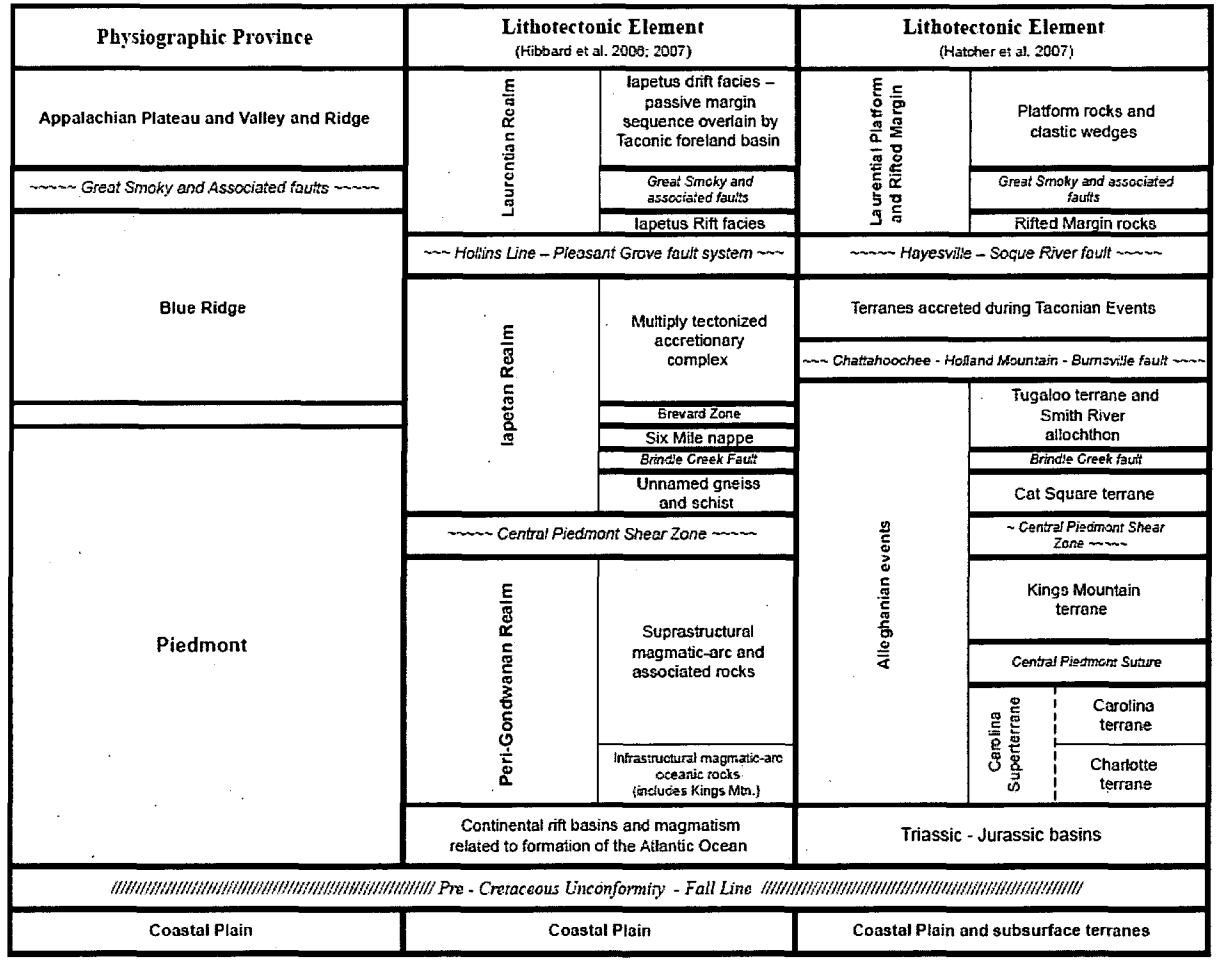


Figure 2.5.1-232 Correlations between Physiographic Provinces and Recent Lithotectonic Classifications

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-2

FSAR Section 2.5.1.1.1.4 (pg 2.5.1-6) uses Carolina "Zone" and Carolina "Terrane" interchangeably in the first paragraph discussing the Carolina Zone, while stating and illustrating in FSAR Figure 2.5.1-202 (Sheet 1) that specific individual terranes make up this zone, including the infrastructural Charlotte Terrane in which the site is located.

In order for the staff to clearly understand the geologic setting of the Summer site in relation to regional geology and lithotectonic elements, please correctly distinguish the area which contains the infrastructural Charlotte Terrane and other suprastructural terranes.

VCSNS RESPONSE:

FSAR Figure 2.5.1-202 will be revised to provide the information requested in RAIs 02.05.01-1, 02.05.01-2, 02.05.01-13 and 02.05.01-31. This revised figure will show the lithotectonic classification of Hibbard et al. (2006; 2007) (FSAR Reference 2.5.1-284 and FSAR Reference 2.5.1-427) and will delineate the Charlotte Terrane and other terranes in the Carolina Zone. FSAR Subsection 2.5.1.1.1.4 will be revised to clearly distinguish the terms "Carolina Zone" and "Carolina Terrane."

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

See revised FSAR Figure 2.5.1-202 provided with the response to RAI 02.05.01-1.

FSAR Subsection 2.5.1.1.1.4 revisions are provided with the response to RAI 02.05.01-3.

Add the following reference to FSAR Section 2.5.1:

427. Hibbard, J.P., van Staal, C.R., Rankin, D.W., *The Comparative Analysis of Pre-Silurian Crustal Building Blocks of the Northern and the Southern Appalachian Orogen*, American Journal of Science, v. 307, p. 23-45, 2007.

ASSOCIATED ATTACHMENTS:

See FSAR Figure 2.5.1-202 attachments to RAI 02.05.01-1

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-3

FSAR Section 2.5.1.1.1.4 (pgs 2.5.1-6 and 2.5.1-7) describes the Carolina Zone of the Central Piedmont, including the Charlotte terrane of the Carolina Zone in which the Summer site is located. The most recent reference cited is Hibbard et al (2002), while other references cited are substantially older. More recently-published references (e.g., from 2007) exist in which the lithologic, stratigraphic, and structural geologic characteristics of the site region, including the Carolina Zone, are discussed.

In order for the staff to assess whether or not information presented in the FSAR represents an up-to-date characterization of regional geology, please incorporate pertinent information from more recently-published references for description of the lithologic, stratigraphic, and structural geologic characteristics of the Carolina Zone of the Piedmont physiographic province in which the site is located.

VCSNS RESPONSE:

Hatcher et al. (2007) (Reference 1) and Hibbard et al. (2006; 2007) (FSAR Reference 2.5.1-284 and Reference 2) present up-to-date discussions of lithotectonic divisions of the southern Appalachians. There is some disagreement between these researchers' interpretations regarding, for example, the polarity of subduction and the timing of docking of Carolinia or the Carolina Superterrane with Laurentia. However, these researchers provide no significant revisions to Hibbard et al.'s (2002) (FSAR Reference 2.5.1-283) interpretation of the Charlotte Terrane, the terrane in which the VCSNS site is located.

FSAR Subsection 2.5.1.1.1 will be modified to include a discussion of the lithotectonic divisions of Hibbard et al. (2006; 2007) (FSAR Reference 2.5.1-284 and Reference 2) and Hatcher et al. 2007 (Reference 1), as they pertain to the site region. FSAR Figure 2.5.1-202 will be revised to show the lithotectonic classification of Hibbard et al. 2006 (FSAR Reference 2.5.1-284). In addition, a new figure will be added to the FSAR (FSAR Figure 2.5.1-232) that illustrates the relationships between: (1) the physiographic subdivisions of the site region; (2) regional fault zones; and (3) the lithotectonic divisions presented by Hibbard et al. 2006 (FSAR Reference 2.5.1-284) and Hatcher et al. 2007 (Reference 1). The revised figure and the new figure are provided with the response to RAI 02.05.01-1.

References:

1. Hatcher, R.D. Jr., Bream, B.R., and Merschat, A.J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in 4-D Framework of Continental Crust, Geological Society of America Memoir 200, p. 595-625, 2007.
2. Hibbard, J.P., van Stall, C.R., and Rankin, D.W., *The Comparative Analysis of Pre-Silurian Crustal Building Blocks of the Northern and the Southern Appalachian Orogen*, American Journal of Science, v. 307, p. 23-45, 2007.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Subsection 2.5.1.1.1, pages 2.5.1-1 through 2.5.1-2, will be revised as follows:

2.5.1.1.1 Regional Physiography, Geomorphology, and Stratigraphy

The VCSNS site is located in the Central Piedmont province, about 20 miles (32 kilometers) northwest of the Fall Line that separates the Piedmont and Coastal Plain provinces (Figure 2.5.1-201). From northwest to southeast, the VCSNS site region includes portions of five physiographic provinces: the Appalachian Plateau (the "Cumberland Plateau" at the latitude of the site region), Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain.

Each of these five physiographic provinces is described below, from northwest to southeast, in terms of their physiography, geomorphology, and stratigraphy. A more detailed discussion is provided for the Piedmont physiographic province in which the VCSNS site is located. Although they do not technically constitute a physiographic province, Mesozoic rift basins are also discussed in this subsection since they contain a distinct assemblage of non-metamorphosed sedimentary rocks and are distributed across both the Piedmont and Coastal Plain provinces.

Depending on the focus of a given study, the Appalachian orogenic belt is subdivided in a variety of ways by various researchers. These subdivisions, in the past, included provinces, belts, and terranes. More recent syntheses are organized around lithotectonic associations based on common tectonic or depositional origins, mainly relative to the Iapetus Ocean and its marginal continental masses, Laurentia and Gondwana (Hibbard et al. 2002) (Reference 283); (Hibbard et al. 2006) (Reference 284); (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423). Physiographic provinces ~~Provinces~~ are defined based on both physiography (landforms) and geology (Figure 2.5.1 201). However, with the modern emphasis on lithotectonic association, the influence of physiography has become subordinate and the "belt" concept has been abandoned. ~~The Blue Ridge and Piedmont physiographic provinces~~

~~are further divided into different lithotectonic terranes of similar rock type and/or tectonic origin (Figure 2.5.1-202). Some geologists further divide the lithotectonic belts into individual fault-bounded terranes (*e.g.*, [References 292, 291, 279]). The various classification schemes, which continue to evolve, have focused on grouping rocks by their stratigraphic, structural, or metamorphic characteristics. The most recent revision to this terminology in the site region is by Hibbard et al. (Reference 283), who subdivide the Piedmont into the Piedmont Zone to the west and Carolina Zone to the east. The Carolina Zone is further subdivided into terranes. Based on synthesis of available data, Hibbard et al. (Reference 283) revamp the archaic~~

~~'belt' terminology of the southern Appalachians, and modify older terrane and belt boundaries (for example, Hibbard et al. Reference 283) revise the old Charlotte and Carolina belts to the Charlotte and Carolina terranes, and, in the process, shifted this boundary eastward at the latitude of the VCSNS site.~~

Figure 2.5.1-232 diagrams how the modern lithotectonic classification schemes of Hibbard et al. 2006 (Reference 284; Figure 2.5.1-202) and Hibbard et al. 2007 (Reference 427) relate and compare to Hatcher et al. 2007 (Reference 423) and to the nomenclature for the physiographic provinces. Note for instance that the Tugaloo Terrane (Hatcher et al. 2007) (Reference 423) falls on both sides of the Brevard fault zone, which roughly coincides with the boundary of the Blue Ridge and Piedmont physiographic provinces. Similarly, this same fundamental physiographic boundary also transects the Hibbard et al. 2006 (Reference 284) Piedmont Domain. Also, note that the Piedmont physiographic province, in the scheme of Hibbard et al. 2006 (Reference 284), is divided by the Central Piedmont shear zone into the Piedmont Domain to the west and Carolinia (previously termed the "Carolina Zone" in Hibbard et al. 2002 (Reference 283)) to the east. These examples serve to illustrate the decreased role of physiography in modern lithotectonic classifications.

FSAR Subsection 2.5.1.1.1.4, pages 2.5.1-4 through 2.5.1-7, will be revised as follows:

2.5.1.1.1.4 The Piedmont Physiographic Province

The VCSNS site is located in the Piedmont physiographic province. The Piedmont physiographic province extends southwest from New York to Alabama and lies west of and adjacent to the Atlantic Coastal Plain. It is the easternmost physiographic ~~and structural~~ province of the Appalachian Mountains. The Piedmont is a seaward-sloping plateau varying in width from about 10 miles (16 kilometers) in southeastern New York to almost 125 miles (200 kilometers) in South Carolina and is the least rugged of the Appalachian provinces. Elevation of the inland boundary ranges from about 200 feet (60 meters) MSL in New Jersey to over 1,800 feet (550 meters) MSL in South Carolina.

Within the VCSNS site region, the area of the Piedmont physiographic province is also divided on the basis of its geologic history and lithology into different lithotectonic associations that include:

The Piedmont Zone, also referred to as the Piedmont Domain in more recent publications (Hibbard et al. 2006) (Reference 284), comprises the Inner Piedmont and the terranes that make up the Eastern Blue Ridge. The terranes that compose the Piedmont Zone generally are considered to represent depositional and tectonic environments closely associated with Iapetus and its margins (Figure 2.5.1-202). The terranes of the Eastern Blue Ridge possibly represent a distal Laurentian accretionary wedge subducted beneath Taconic volcanic arcs during the Middle Ordovician. However, the terranes of the Inner Piedmont show both Laurentian and peri-Gondwanan associations (Hibbard et al. 2006) (Reference 284); (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423). The term "peri-Gondwanan" is used to refer to terranes that formed the periphery of Gondwana itself or that broke away from the main Gondwanan supercontinent.

The Carolina Zone is referred to in more recent literature as "Carolinia" (Hibbard et al. 2007) (Reference 427) or "Carolina Superterrane" (Hatcher et al. 2007) (Reference 423). The terranes that compose the Carolina Zone are considered to be of peri-Gondwanan association and represent volcanic arcs resulting from subduction in the Gondwanan Realm of Iapetus (Hibbard et al. 2006) (Reference 284); (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423).

These two lithotectonic elements, the Piedmont Zone and the Carolina Zone, are separated by a series of faults collectively called the Central Piedmont shear zone. West of the Central Piedmont shear zone, the Piedmont Zone contains the Inner Piedmont block, the Smith River Allochthon in Virginia and North Carolina, and the Sauratown Mountains anticlinorium of north central North Carolina (Reference 290) (Figure 2.5.1-202). The province is a composite stack of thrust sheets containing a variety of gneisses, schists, amphibolites, sparse ultramafic bodies, and intrusive granitoids (References 333 and 262). The protoliths are immature quartzo-feldspathic sandstone, pelitic sediments, and mafic lavas.

The Inner Piedmont block is a fault-bounded, composite thrust sheet with metamorphic complexes of different tectonic affinities (Reference 290). Rocks within the Inner Piedmont block include gneisses, schists, amphibolites, sparse ultramafic bodies, and intrusive granitoids (References 333 and 262). There is some continental basement within the block (Reference 262) and scattered mafic and ultramafic bodies and complexes (Reference 330), suggesting the presence of oceanic crustal material (Reference 290). The rest of the block contains a coherent sequence of metasedimentary rock, metavolcanic gneisses, and schists (Reference 290).

The Smith River Allochthon is a completely fault-bounded terrane that contains two predominantly metasedimentary units and a suite of plutonic rocks (Figure 2.5.1-202). The Sauratown Mountains anticlinorium is a complex structural window of four stacked thrust sheets that has been exposed in eroded structural domes (Figure 2.5.1-202). Each sheet contains Precambrian basement with an overlying sequence of younger Precambrian to Cambrian metasedimentary and metaigneous rocks (Reference 290).

The stratigraphic and structural geologic data in the Western Piedmont reflect a complex tectonic history from the Precambrian Grenville through Late Paleozoic

Alleghanian orogenies. Metamorphism affected the basement rocks of the Sauratown Mountains anticlinorium at least twice: during the Precambrian Grenville orogeny and later during the Paleozoic. The metasedimentary cover sequence, the Smith River allochthon, and the Inner Piedmont block were affected by one metamorphic event in the Paleozoic (Reference 290). The Alleghanian continental collision is reflected in the thrust and dextral strike-slip fault systems, including the Brevard and Bowens Creek fault zones. A few late Paleozoic granites were emplaced in the Inner Piedmont block; however, most lie further east in the Carolina Zone. Early Mesozoic extension resulted in the formation of rift basins.

The Central Piedmont shear zone (Reference 283) (Figure 2.5.1-202) includes: the Ocmulgee, Middleton-Lowdensville, Cross Anchor, Kings Mountain, Eufola, and Hyco fault zones (Reference 290). Since the Central Piedmont shear zone marks the boundary between rocks on both sides of Iapetus, it is associated with a "suture" (Hatcher et al. 2007) (Reference 423) although the polarity and timing of the suturing event are under debate (Hibbard et al. 2007) (Reference 427); (Hatcher et al. 2007) (Reference 423). The detailed relationship of the Central Piedmont shear zone to the original structure associated with the suture is obscured by the fact that the original structure has been tectonically modified and overprinted by the final orogenic effects of the interactions of the Gondwanan and Laurentian continents during the Carboniferous (late Alleghanian orogeny). Hibbard et al. 2002 (Reference 283) and Hibbard et al. 2007 (Reference 427) consider the Central Piedmont shear zone to be a Late Alleghanian thrust that cut the original suture off in the subsurface and that the portion of the hanging wall containing the cut-off suture has been eroded away (Hibbard et al. 1998) (Reference 282). Hatcher et al. 1989 (Reference 420) also consider that the Central Piedmont shear zone has been tectonically modified in the late Alleghanian orogeny, in large part by folding. This allows infolding of rocks with Laurentian affinities and rocks of peri-Gondwanan affinities to explain terranes considered to have mixed associations, including the Kings Mountain Terrane (Hatcher et al. 2007) (Reference 423).

~~The Piedmont province in northwestern South Carolina consists of variably deformed and metamorphosed igneous and sedimentary rocks ranging in age from Middle Proterozoic to Permian (1,100 to 265 Ma). The Piedmont comprises the Western Piedmont and the Carolina Zone (Figure 2.5.1-202 Sheets 1 and 2). This distinction of the western and eastern parts of the province is based on tectonic history and distinct protolithic differences (Reference 283).~~

~~The rocks of the Piedmont are deformed into isoclinal recumbent and upright folds that have been refolded and are contained in several thrust sheets or nappes. These metamorphic rocks extend beneath the Coastal Plain sediments in South Carolina and Georgia. The southeastern extent of the Piedmont province underneath the Coastal Plain is unknown but is thought to extend to the East Coast Magnetic Anomaly (Reference 292). Subsection 2.5.1.1.2.4.5 presents additional discussion of the East Coast Magnetic Anomaly. Within the site region, the Piedmont physiographic province is divided into the Piedmont Zone on the west and Carolina Zone on the east based on the tectonothermal history (Reference 283) (Figure 2.5.1-202, Sheet 1 of 2). The Piedmont~~

~~Zone defined by Hibbard et al. (Reference 283) is roughly equivalent to the Western Piedmont defined by Horton and McConnell (Reference 290) (Figure 2.5.1-202, Sheet 2 of 2). Horton and McConnell's (Reference 290) discussion of the Western Piedmont provides more detail than Hibbard et al.'s (Reference 283) discussion of the Piedmont Zone; accordingly, the discussion below focuses on Horton and McConnell's (Reference 290) Western Piedmont and Hibbard et al.'s (Reference 283) Carolina Zone.~~

~~Western Piedmont~~

~~The Western Piedmont is separated from the Blue Ridge province on the northwest by the Brevard fault zone. The Western Piedmont is separated from the Carolina Zone by a complex series of fault zones that define the Central Piedmont shear zone (Reference 283) (Figure 2.5.1-202, Sheets 1 and 2). These faults include, among others, the Lowdensville, Kings Mountain, and Eufola fault zones (Reference 290). The Western Piedmont encompasses the Inner Piedmont block, the Smith River Allochthon in Virginia and North Carolina, and the Sauratown Mountains Anticlinorium in north central North Carolina (Reference 290) (Figure 2.5.1-202, Sheet 2 of 2).~~

~~The Inner Piedmont block is a fault-bounded, composite thrust sheet with metamorphic complexes of different tectonic affinities (Reference 290). Rocks within the Inner Piedmont block include gneisses, schists, amphibolites, sparse ultramafic bodies, and intrusive granitoids (References 333 and 262). There is some continental basement within the block (Reference 262) and scattered mafic and ultramafic bodies and complexes (Reference 330), suggesting the presence of oceanic crustal material (Reference 290). The rest of the block contains a coherent, though poorly understood, sequence of metasedimentary rock, metavolcanic gneisses, and schists (Reference 290). The eastern Blue Ridge and Inner Piedmont contain some stratigraphically equivalent rocks (Reference 277).~~

~~The Smith River Allochthon is a completely fault-bounded terrane that contains two predominantly metasedimentary units and a suite of plutonic rocks (Figure 2.5.1-202, Sheet 2 of 2). The Sauratown Mountains anticlinorium is a complex structural window of four stacked thrust sheets that have been exposed in eroded structural domes (Figure 2.5.1-202, Sheet 2 of 2). Each sheet contains Precambrian basement with an overlying sequence of younger Precambrian-to- Cambrian metasedimentary and metaigneous rocks (Reference 290).~~

~~The stratigraphy and structural geologic data in the Western Piedmont reflect a complex tectonic history from the Precambrian Grenville through Late Paleozoic Alleghanian orogenies. Metamorphism affected the basement rocks of the Sauratown Mountains anticlinorium at least twice: during the Precambrian Grenville orogeny and later during~~

~~the Paleozoic. The metasedimentary cover sequence as well as the Smith River allochthon and the Inner Piedmont block were affected by one metamorphic event (prograde and retrograde) in the Paleozoic (Reference 290). The Alleghanian continental collision is reflected in the thrust and dextral strike-slip fault systems such as the Brevard and Bowens Creek fault zones. A few late Paleozoic granites were emplaced in the Inner Piedmont block; however, most lie further east in the Carolina Zone. Early Mesozoic extension resulted in the formation of rift basins.~~

~~Carolina Zone~~

The VCSNS site is located east of the Central Piedmont shear zone in the Carolina Zone (Hibbard et al 2007) (Reference 427) (Carolina Superterrane of Hatcher et al. 2007 (Reference 423)). The Carolina Zone represents an amalgamation of metaigneous dominated terranes along the eastern flank of the southern Appalachians (Figure 2.5.1 202~~, Sheet 1 of 2~~) (Reference 283). The Carolina terrane of the Carolina Zone extends for more than 300 miles from central Virginia to eastern Georgia and is characterized by generally low-grade metaigneous and associated metasedimentary rocks. The original definition of the Carolina Terrane (Reference 365) included higher-grade metamorphic rocks along its western margin, but the more recent classification of Hibbard et al. (Reference 283) includes these rocks in the Charlotte Terrane to the west. Hibbard et al.'s (Reference 283) more recent classification results in a southeastward shift in the boundary between these two terranes.

The VCSNS site lies within the Charlotte Terrane, the westernmost terrane of the Carolina Zone (Figure 2.5.1-202~~, Sheet 1 of 2~~). The Charlotte terrane is dominated by Neoproterozoic to Early Paleozoic plutonic rocks that intrude a suite of mainly metaigneous rocks (Reference 283). The western limit of the Charlotte Terrane and Carolina Zone is the Central Piedmont shear zone, a late Paleozoic ductile thrust, located approximately 15 miles northwest of the VCSNS site.

~~The northwestern boundary of the Carolina Zone is formed by a complex set of faults that constitute the Central Piedmont shear zone (Figures 2.5.1-205 and 2.5.1-206) and separate exotic accreted terranes from rocks of North American affinity (References 278, 285, 379, 354, 288, 281, 329, 283). The Carolina Zone extends southeastward to the East Coast Magnetic Anomaly (Reference 292, Subsection 2.5.1.1.2.4.5 presents a detailed discussion of the East Coast Magnetic Anomaly).~~ The rocks of the Carolina Zone are unconformably overlain by the sediments of the Carolina Coastal Plain southeast of the Fall Line (Figure 2.5.1-202~~, Sheet 1 of 2~~).

The Carolina Zone is part of a late Precambrian-Cambrian composite arc terrane, exotic to North America (References 365 and 357), that accreted ~~sometime during the Ordovician to Devonian (References 396 and 335)~~ either during the late Ordovician to

Silurian (Hibbard et al. 2002) (Reference 283) or during the middle Devonian to early Mississippian (Hatcher et al. 2007) (Reference 423). It consists of felsic to mafic metaigneous and metasedimentary rock. Middle Cambrian fossil ~~fauna indicate a European or African affinity~~ trilobite assemblages preserved in metasedimentary rocks near Batesburg, South Carolina indicate these rocks constitute an exotic terrane that was accreted to North America (Reference 365).

Hibbard et al. (Reference 283) propose updated nomenclature for the Carolina Zone ("Carolinia" in Hibbard et al. 2007 (Reference 427)) based on the tectonothermal overprint of units. ~~and abandoned the term "belts."~~ Suprastructural terranes (i.e., the upper structural layer in an orogenic belt subjected to relatively shallow or near-surface processes) comprise rocks of lower grade metamorphism where original rock fabric is preserved. Infrastructural terranes (produced at relatively deep crustal levels at elevated temperature and pressure, located beneath suprastructural terranes) comprise higher-grade metamorphic units where original rock fabric has been completely destroyed.

The western part of the Carolina Zone in Georgia, South Carolina, and North Carolina consists of the infrastructural Charlotte Terrane and to a lesser extent the Savannah River Terrane. The easternmost portion of the Carolina Zone in South Carolina and portions in ~~on~~ North Carolina contain the Suprastructural Albemarle and South Carolina Sequence. Metamorphic grade increases to the northwest from lower greenschist facies to upper amphibolite facies. ~~Lithologies~~ Rock types include amphibolite, biotite gneiss, hornblende gneiss, and schist ~~and~~ that probably were derived from volcanic, ~~volcanoclastic~~ volcaniclastic, or sedimentary protoliths. Pre-Alleghanian structure is dominated by large northeast-trending folds with steeply dipping axial surfaces. All country rock of the Charlotte Terrane was penetratively deformed during the Late Proterozoic to Early Cambrian (Hibbard et al. 2002) (Reference 283)~~Ordovician Taconic orogeny (Reference 220)~~, thereby producing axial plane cleavage and foliation ~~(Reference 279)~~. The Charlotte Terrane also contains numerous granitic and gabbroic intrusions dating to about 300 Ma.

Add the following references to FSAR Section 2.5.1:

423. Hatcher, R.D., Bream, B.R., and Merschat, A.J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in R.D. Hatcher, 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. 595-632, 2007.

427. Hibbard, J.P., van Staal, C.R., Rankin, D.W., *The Comparative Analysis of Pre-Silurian Crustal Building Blocks of the Northern and the Southern Appalachian Orogen*, American Journal of Science, v. 307, p. 23-45, 2007.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-9

FSAR Section 2.5.1.1.2.3.2 (pg 2.5.1-17) discusses magnetic anomalies in the site vicinity which are associated with the Modoc shear zone and are shown in FSAR Figure 2.5.1-209. This section equates these high-amplitude, short wavelength anomalies with both (a) "a susceptibility contrast across a dipping structural contact" and (b) "sub-vertical interleaved tabular bodies of varying magnetic susceptibility". The FSAR cites the same reference (i.e., Cumbest and others, 1992) for both seemingly different interpretations. However, no explanation is offered to indicate how these two interpretations are related or which may be preferred.

In order for the staff to determine the adequacy of the geologic interpretations based on site vicinity magnetics data provided in the FSAR, please discuss these two interpretations relative to their apparent differences and specify which interpretation is preferred.

VCSNS RESPONSE:

The Modoc shear zone was one of the original faults assigned to the Eastern Piedmont fault system by Hatcher et al. (1977) (FSAR Reference 2.5.1-275) primarily based on its association with prominent linear magnetic anomalies. These magnetic anomalies are characterized by laterally continuous linear segments whose ends sometimes overlap to form parallel linear features. Based on detailed mapping of the Modoc shear zone in the vicinity of Clarks Hill Reservoir (northwest of Augusta on the Georgia-South Carolina border), Maher et al. (1991) (Reference 1) attribute these linear magnetic anomalies to northwest-dipping orthogneiss sheets within the fault zone. Based on seismic reflection profiling, they also indicate these orthogneiss sheets can be traced in the subsurface 10 kilometers down-dip to the northwest. As such, the orthogneiss sheets that give rise to the anomalous magnetic field associated with the Modoc shear zone represent both dipping structural contacts and interleaved tabular bodies. In this configuration, the surface and near-surface up-dip edges of the orthogneiss sheets would be the main contributor to the short spatial wavelength components of the magnetic response that characterizes the Modoc shear zone.

Cumbest et al. (1992) (FSAR Reference 2.5.1-233) do not describe the Modoc shear zone. Instead, this study describes magnetic anomalies located in the Dunbarton Basin that are analogous to those described by Maher et al. (1991) (Reference 1) for the Modoc shear zone. However, the Dunbarton Basin anomalies result from tabular bodies

that dip to the southeast, as opposed to the northwest-dipping tabular bodies within the Modoc shear zone.

FSAR Subsection 2.5.1.1.2.3.2 will be modified for clarity. Description of the Modoc shear zone will be revised to cite Maher et al. (1991) (Reference 1), who indicate the tabular bodies dip to the northwest (and are not "sub-vertical"). In addition, the portions of FSAR Subsection 2.5.1.1.2.3.2 that describe the Modoc shear zone will be modified such that references to Cumbest et al. (1992) (FSAR Reference 2.5.1-233) will be deleted, as this reference describes the Dunbarton Basin and not the Modoc shear zone.

References:

1. Maher, H.D. Jr., Sacks, P.E., and Secor, D.T. Jr., *The Eastern Piedmont in South Carolina*, in The Geology of the Carolinas, Carolina Geological Society fiftieth anniversary volume, J.W. Horton, Jr. and V.A. Zullo (eds.), p. 93-108, 1991.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Subsection 2.5.1.1.2.3.2, page 2.5.1-17, will be revised as follows:

- The Modoc shear zone is clearly associated with elongate, east-northeast trending high and low magnetic anomalies. ~~The very short-wavelengths and linear trends of the anomalies are characteristic of those produced by a susceptibility contrast across a dipping structural contact (*e.g.*, Reference 233).~~ These magnetic anomalies are characterized by laterally continuous linear segments whose ends sometimes overlap to form parallel linear features. Based on detailed mapping of the Modoc shear zone in the vicinity of Clarks Hill Reservoir (northwest of Augusta on the Georgia-South Carolina border), Maher et al. (1991) (Reference 426) attribute these linear magnetic anomalies to northwest-dipping orthogneiss sheets within the fault zone. Based on seismic reflection profiling, they also indicate these orthogneiss sheets can be traced in the subsurface 10 kilometers down-dip to the northwest. As such, the orthogneiss sheets that give rise to the anomalous magnetic field associated with the Modoc shear zone represent both dipping structural contacts and interleaved tabular bodies. In this configuration, the surface and near-surface up-dip edges of the orthogneiss sheets would be the main contributor to the short spatial wavelength components of the magnetic response that characterizes the Modoc shear zone.

- The most regionally extensive magnetic anomalies occur beneath the Coastal Plain east of the Modoc shear zone. In general, the magnetic anomalies are relatively high, indicating the presence of rocks with higher magnetic susceptibility at depth, and they are paired with high-gravity anomalies (Figures 2.5.1-205, 2.5.1-206, 2.5.1-207, and 2.5.1-208), indicating that the rocks are also relatively dense. Detailed modeling of magnetic data from the Savannah River Site south-southwest of the VCSNS site indicates that these anomalies may be associated with mafic intrusions (Reference 233). Felsic plutons in this region, which are inferred to exist from borehole data and gravity modeling, have modest susceptibility contrasts with the country rock they intrude and thus do not generate high-amplitude magnetic anomalies (Reference 233). Similarly, Mesozoic basin sediments are inferred to have relatively low susceptibility contrasts with the pre-intrusive basement rock, and modeling by Cumbest et al. (Reference 233) suggests that the anomaly associated with the sediments and margins of the Dunbarton basin is a second-order feature of the magnetic field relative to the amplitudes of the anomalies produced by the intrusive mafic rocks.

Several of the characteristics of the regional magnetic field are illustrated in a northwest-southeast trending profile that passes through the VCSNS site (Figure 2.5.1-209). The magnetic intensities between horizontal distances 20 ~~kilometers~~ and 33 kilometers are relatively low and ~~probably because of~~ likely result from the presence of felsic plutons that have lower magnetic susceptibilities than the intermediate country rocks. The high magnetic anomaly approximately between horizontal distances 33 ~~kilometers~~ and 46 kilometers is associated with exposures of mafic basement rocks ~~of the Carolina-Avalon terrane~~. The high-amplitude, short-wavelength anomalies around horizontal distance 70 kilometers are associated with the Modoc shear zone, and are characteristic of ~~sub-vertical~~dipping, interleaved tabular bodies of varying magnetic susceptibility (Reference 426~~e.g., Reference 233~~).

Add the following reference to FSAR Section 2.5.1:

426. Maher, H.D. Jr., Sacks, P.E., and Secor, D.T. Jr., *The Eastern Piedmont in South Carolina*, in The Geology of the Carolinas, Carolina Geological Society fiftieth anniversary volume, J.W. Horton, Jr. and V.A. Zullo (eds.), p. 93-108, 1991.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-10

FSAR Figure 2.5.1-206 shows prominent regional aeromagnetic lows within the Summer site vicinity; Figure 2.5.1-207 illustrates these lows in a regional profile; and Figure 2.5.1-209 shows magnetic lows and highs in a profile drawn at the site vicinity scale. The low regional magnetic anomalies are not discussed in the FSAR even though the magnetic highs are discussed (pg 2.5.1-17).

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 significance of the regional magnetic lows as they may relate to geologic structures or lithologies in the site vicinity.

VCSNS RESPONSE:

This response is divided into two parts. The first part describes the dipolar nature of the earth's magnetic field in general. The second part describes the specifics of magnetic lows in the site region and their relations to geologic structure and rock types.

Part 1:

The earth's magnetic field is dipolar in nature. In other words, magnetic monopoles (isolated magnetic highs or lows) do not exist in nature but come in pairs that compose dipole anomalies. Except for the case of unmetamorphosed volcanic rocks that may contain a relatively large remnant magnetization, the dominant source of the anomalous magnetic field generally results from the induced magnetization produced by interaction of the earth's magnetic field with the mineral magnetite and, to a lesser degree, with magnetite - ulvospinel solid solution phases (Blakely 1996; p. 90) (Reference 1).

The detailed expression of the dipole pair in the induced anomalous field depends on the inclination and declination of the earth's magnetic field at the location of the dipole source. The practical result of the dipole expression in the induced anomalous magnetic field for the northern hemisphere is that dipole anomalies will be expressed by a magnetic high on the southeast and a magnetic low directly adjacent to and northwest of the high (Telford et al. 1976; p.186) (Reference 2). This high-low pair constitutes the dipole pair. Because of the steep inclination of the field at mid and high latitudes, the induced dipole moment is also steeply dipping. This results in one end of the dipole being closer to the surface than the other, making the dipolar high exhibit higher relative amplitude and steeper gradients than the magnetic low pole. For this reason, the magnetic highs associated with the dipole are more visible and noticeable than the

lows. As such, the dipole anomaly commonly is referred to in the geophysical literature as a magnetic high only in order to avoid cumbersome language. In the site vicinity, the consistent occurrence of the magnetic lows to the northwest of higher amplitude magnetic highs attests to the induced dipolar nature of these anomalies consistent with the magnetic declination at this location.

It should be noted that the above discussion does not apply to the situation in which the response from magnetic sources is attenuated due to burial beneath nonmagnetic material such as sedimentary basins or nonmagnetic intrusions. In this case a "low" magnetic field is sometimes discussed. However, this is not a reference to a magnetic source but to the attenuated nature of the anomalies.

Part 2:

The above discussion notwithstanding, magnetic lows in the site region can be explained in part by association with geologic structure and rock types. For example, a short wavelength magnetic high coincident with a gravity high occurs at location 20 kilometers on the gravity and magnetic profiles (FSAR Figure 2.5.1-209). The short wavelength magnetic high is accompanied by a magnetic low that exhibits smaller gradients to the northwest. This 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 meta-igneous Charlotte terrane. The gravity anomaly at the same location on the profile appears to exhibit lower spatial frequencies, indicating 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 suggest this anomaly 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 potential field profiles shown in FSAR Figure 2.5.1-209 indicate a gravity high coincident with a magnetic low between 50 and 70 kilometers. This location corresponds to the Asbill Pond, Richtex, and Persimmon Fork Formations. These formations comprise meta-mudstone and meta-siltstone sequences interbedded with meta-volcanics. These rocks, as a whole, are relatively nonmagnetic, resulting in the observed subdued magnetic field. However, based on their composition, these rocks likely are of relatively low density, inconsistent with the observed elevated gravity field. As such, the gravity anomaly likely arises from a deeper source.

In summary, magnetic lows in the site region can be explained in part by association with geologic structure and rock types. These magnetic data alone, however, provide limited information regarding the geology of the site region and are most useful in interpreting geologic structures and rock types when used in combination with other geophysical and geologic data.

References:

1. Blakely, R.J., Potential Theory in Gravity and Magnetic Applications, Cambridge University Press, 441p., 1996.

2. Telford, W.M., Geldart, L.P., Sheriff, R.E., and Keys, D.A., Applied Geophysics, Cambridge University Press, 860p., 1976.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Subsection 2.5.1.1.2.3.1, pages 2.5.1-14 through 2.5.1-16, will be revised as follows:

2.5.1.1.2.3.1 Regional Gravity Data

The 1987 DNAG gravity map, and the gravity profile along the DNAG E-4 crustal transect (Figure 2.5.1-207), document a long-wavelength anomaly east of the Brevard fault zone, which marks the tectonic boundary between the Blue Ridge province to the west and the Piedmont province to the east (Figure 2.5.1-201). Bouguer gravity values increase by about 80 to 120 mGal across an approximately 200- to 250-kilometer reach of the Piedmont east of the Blue Ridge (Figure 2.5.1-207). As documented by the DNAG gravity map, this gradient is present across the Piedmont physiographic province along much of the length of the Appalachian belt.

Previous researchers refer to this long-wavelength feature in the gravity field as the "Piedmont gradient" or the "Appalachian gravity gradient" (References 269, 237, and 405~~References 269 and 237~~). For the purposes of the VCSNS FSAR, the term "Appalachian gravity gradient" is adopted for this feature. At the latitude of Virginia, north of the VCSNS site region, Harris et al. (Reference 269) interpret the Appalachian gravity gradient~~Piedmont gradient~~ to reflect the eastward thinning of the North American continental crust and associated positive relief on the Moho with proximity to the Atlantic margin. Gravity models by Iverson and Smithson (Reference 296) along the southern Appalachian COCORP seismic reflection profile, and by Dainty and Frazier (Reference 237) in northeastern Georgia, suggest that the gradient probably arises from both eastward thinning of continental crust and the obduction of the Inner Piedmont and Carolina Zone~~Carolina-Avalon terranes~~, which have higher average densities than the underlying Precambrian basement of North America.

Superimposed on the long-wavelength Appalachian gravity gradient~~Piedmont gradient~~ are numerous high and low-gravity anomalies that have wavelengths of about 10 to 20 kilometers, and which are elliptical to irregular in plan view. These anomalies are especially well expressed in the Carolina Zone~~Carolina-Avalon terrane~~ (in accordance with Reference 279) between the Central Piedmont shear zone and the Modoc shear zone (Figure 2.5.1-205). Based on comparison of the gravity maps with geologic maps, many of these anomalies are spatially associated with Paleozoic igneous intrusions and plutons. The basement of the Carolina Zone at this latitude is interpreted to be crust of an oceanic island arc terrane or terranes~~ that were accreted to the Appalachian orogen during the Taconic orogeny (References 292 and 279)~~. The composition of this crust generally is intermediate between felsic and mafic (Reference 350). The intrusions and plutons in the Carolina Zone with associated gravity anomalies fall more toward the extremes in felsic and mafic compositional ranges for igneous rocks, which give rise to density contrasts with the country rock they intrude. In general, gravity highs are associated with mafic intrusions and mafic basement rocks, and gravity lows are associated with granitic plutons. Detailed gravity modeling by Cumbest et al. (Reference 233) in the vicinity of the Dunbarton Basin south-southwest of the VCSNS site supports the general association of 10- to 20-kilometer-high and -low anomalies in the Piedmont gravity field with mafic and felsic intrusions, respectively.

A northwest-southeast trending profile of the gravity field that passes through the VCSNS site (Figure 2.5.1-209) highlights the fact that the gravity is about 20 to 25 mGal higher between the Central Piedmont shear zone and the Modoc shear zone than in adjacent regions to the northwest and southeast. This local gravity high probably arises from relatively dense basement of the accreted Carolina Zone~~Carolina-Avalon terrane~~ bounded by the two faults. Superimposed on this positive anomaly is a 5 to 10 mGal low gravity anomaly located approximately between horizontal distances of 15 and 60 kilometers on the profile. This gravity low is spatially associated with granitic plutons that intrude the intermediate basement of the Carolina Zone~~Carolina-Avalon terrane~~, and probably reflects the relatively lower density of the intrusive rocks.

The origin of the high- and low-gravity anomalies beneath the Coastal Plain southeast of the VCSNS site (Figure 2.5.1-209) is uncertain because of the lack of data on basement rock composition. There are several high-gravity anomalies that appear to be associated with Triassic basin structures approximately 100 to 150 kilometers east of the VCSNS site. A possible analogue for interpreting these anomalies is the well-studied Triassic Dunbarton basin beneath the Savannah River Site south-southwest of the VCSNS site. Figure 2.5.1-205 shows a pronounced gravity high along the southern margin of the Dunbarton basin. From a synthesis of borehole data and gravity modeling, Cumbest et al. (Reference 233) demonstrate that the extremes in the local gravity field at the Savannah River Site are highs associated with Triassic-Jurassic mafic intrusive complexes southeast of the Dunbarton basin, and lows associated with granitic plutons mapped to the north-northeast and east-northeast of the basin. Cumbest et al. (Reference 233) show that the predicted anomaly associated with the Mesozoic Dunbarton basin fill is a subordinate feature of the gravity field compared to the

anomalies associated with the plutons and mafic intrusions. If similar geologic relations apply for the Triassic basins east of the VCSNS site, it is likely that the high-gravity anomalies are associated with Triassic mafic intrusions. Gravity lows associated with the basin fill strata may be obscured by the relatively high amplitude of the anomalies associated with the mafic rocks.

To summarize, gravity data published since the mid-1980s documents that long wavelength anomalies in the vicinity of the VCSNS site are characteristic of large parts of the Appalachian belt, and reflect first-order features of the various provinces and accreted Paleozoic terranes, as well as west-to-east thinning of the ancestral North American continental crust. The dominant short-wavelength characteristics of the gravity field in the vicinity of the VCSNS site are gravity highs and lows associated with mafic and granitic intrusions, respectively.

~~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 fault system, 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, pages 2.5.1-16 – 2.5.1-18, will be revised as follows:

2.5.1.1.2.3.2 Regional Magnetic Data

Regional aeromagnetic data from the eastern United States reveal numerous regional northeast-southwest trending magnetic anomalies that are generally parallel to the structural grain of the Paleozoic Appalachian orogenic belt (References 226 and 331) (Figures 2.5.1-206 and 2.5.1-210). In contrast to the gravity data, the magnetic field does not exhibit a long-wavelength anomaly east of the Brevard fault zone ~~coincident with the accreted Taconic terranes of the Piedmont~~. As shown on the magnetic profile for the DNAG E-4 transect (Figure 2.5.1-207), the magnetic field across the Piedmont generally is characterized by high and low anomalies with wavelengths on the order of about 5 to 10 kilometers. Key features of the regional magnetic field (Figure 2.5.1-206) include:

• The Western Piedmont between the Brevard fault zone and Central Piedmont shear zone is characterized by a relatively uniform to smoothly varying magnetic field about a background value of approximately –500 nT (Figure 2.5.1-206 and 2.5.1-207).

• The Carolina Zone east of the Central Piedmont shear zone is characterized by numerous circular, elliptical, and irregular anomalies with plan dimensions on the order of about 5 to 20 kilometers. The change in character between the magnetic field of the Western Piedmont and Carolina Zone is very distinct across the Central Piedmont shear zone. Comparison of the magnetic data to geologic mapping indicates that nearly all of these anomalies are associated with mafic and felsic intrusions, which are generally characterized by relatively higher and lower magnetic susceptibility than the country rock they intrude.

• The Modoc shear zone is clearly associated with elongate, east-northeast trending high and low magnetic anomalies. The very short-wavelengths and linear trends of the anomalies are characteristic of those produced by a susceptibility contrast across a dipping structural contact produced by tabular bodies (*e.g.,* Reference 233).

• The most regionally extensive magnetic anomalies occur beneath the Coastal Plain east of the Modoc shear zone. In general, the magnetic anomalies are relatively high, indicating the presence of rocks with higher magnetic susceptibility at depth, and they are paired with high-gravity anomalies (Figures 2.5.1-205, 2.5.1-206, 2.5.1-207, and 2.5.1-208), indicating that the rocks are also relatively dense. Detailed modeling of magnetic data from the Savannah River Site south-southwest of the VCSNS site indicates that these anomalies may be associated with mafic intrusions (Reference 233). Felsic plutons in this region, which are inferred to exist from borehole data and gravity modeling, have modest susceptibility contrasts with the country rock they intrude and thus do not generate high-amplitude magnetic anomalies (Reference 233). Similarly, Mesozoic basin sediments are inferred to have relatively low susceptibility contrasts with the pre-intrusive basement rock, and modeling by Cumbest et al. (Reference 233) suggests that the anomaly associated with the sediments and margins of the Dunbarton basin is a second-order feature of the magnetic field relative to the amplitudes of the anomalies produced by the intrusive mafic rocks.

Several of the characteristics of the regional magnetic field are illustrated in a northwest-southeast trending profile that passes through the VCSNS site (Figure 2.5.1-209). The magnetic intensities between horizontal distances 20 kilometers and 33 kilometers are relatively low and probably because of the presence of felsic plutons that have lower magnetic susceptibilities than the intermediate country rocks. The high magnetic anomaly approximately between horizontal distances 33 kilometers and 46 kilometers is associated with exposures of mafic basement rocks of the Carolina Zone~~Carolina-Avalon terrane~~. The high-amplitude, short-wavelength anomalies around horizontal distance 70 kilometers are associated with the Modoc shear zone, and are characteristic of sub-vertical, interleaved tabular bodies of varying magnetic susceptibility (e.g., Reference 233).

To summarize, magnetic data published since the mid-1980s provide additional characterization of the magnetic field in the VCSNS site region. The first-order magnetic anomalies are associated primarily with northeast-southwest trending Paleozoic terranes of the Paleozoic Appalachian orogen. Superimposed on this regional magnetic field are anomalies with wavelengths on the order of 5 to 20 kilometers that are associated with intrusive bodies and plutons.

The magnetic data ~~do not show evidence for any Cenozoic structures~~ in the site region ~~and~~ does 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

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-11

FSAR Section 2.5.1.1.2.3.2 (pg 2.5.1-18) states that regional magnetic data do not have sufficient resolution to identify border faults along Triassic basins, while Section 2.5.1.1.2.4 (pg 2.5.1-18) states that most Mesozoic structures are both geophysically and geologically recognizable. These two statements do not appear to be compatible.

In order for the staff to determine the adequacy of the geologic interpretations based on regional magnetics data provided in the FSAR, please clarify whether or not Mesozoic structures can be identified using geophysical data, including regional magnetic data.

VCSNS RESPONSE:

The usefulness of magnetic data in identifying faults and other geologic structures largely is a scale-dependent issue. Relatively coarse, regional-scale magnetic data can be used to help identify faults and intrusions that juxtapose rocks with relatively high contrasts in magnetic susceptibility. For example, the regional-scale magnetic data shown in FSAR Figure 2.5.1-206 highlight the approximate locations of the Central Piedmont shear zone and site region plutons (including the Winnsboro Plutonic complex and the Bald Rock pluton.) Additionally, subtle northwest-trending lineations on FSAR Figure 2.5.1-206 suggest the approximate locations of northwest-trending Mesozoic dikes. However, as a result of the relatively coarse, regional-scale of these data, these features cannot be located with a high degree of precision. On the other hand, Simpson (1981) (Reference 3) used high-resolution, local magnetic surveys to map in detail the location of a narrow (roughly a few to tens of meters wide) diabase dike crossing the Wateree Creek fault. These high-resolution surveys enabled Simpson (1981) (Reference 3) to preclude offset of the dike within a resolution of roughly 10 meters.

With the above scale-dependent issues in mind, the seemingly incompatible FSAR statements are, in fact, compatible. The statement that discrete faults cannot necessarily be identified from regional-scale magnetic data is not inconsistent with the statement that most Mesozoic structures can be identified by a combination of geophysical and geologic means. The regional magnetic data described in FSAR Section 2.5.1.1.2.3.2 can be used in concert with other geologic data to identify Mesozoic structures. Other geologic and geophysical datasets, such as boring, gravity, and seismic data, have been used to identify, for example, a single border fault (e.g., the Pen Branch fault.) The regional magnetic dataset is best used to identify structures associated with magnetic anomalies, such as large mafic intrusions. In fact, the magnetic signature of a fault is not associated with the fault plane itself, but rather the

contrast in magnetic susceptibility of materials on either side of the fault (e.g., Hudson et al. 2008) (Reference 2). This is related to the fact that sedimentary rocks generally have low magnetic susceptibility relative to igneous and metamorphic units. Consequently, one would expect the rift basins to have anomalously low magnetic susceptibility compared to the surrounding basement. This generality is complicated by the occurrence of mafic rocks with high magnetic susceptibility intruded into basin-fill sediments. Nevertheless, Mesozoic rift basins in the region generally are identifiable by the presence of magnetic susceptibility lows centered over the basin, rather than associated with the basin-bounding faults themselves (e.g., Daniels et al. 1983) (Reference 1).

References:

1. Daniels, D. L., Zietz, I., Popenoe, P., *Distrubution of Subsurface Lower Mesozoic Rocks in the Southeastern United States, as Interpreted from Regional Aeromagnetic and Gravity Maps*, in Gohn, G. S., (ed.) Studies Related to the Charleston, South Carolina, Earthquake of 1886—Tectonics and Seismicity, US Geological Survey Professional Paper 1313-K, 1983.
2. Hudson, M.R., Grauch, V.J.S., Minor, S.A., *Rock Magnetic Characterization of Faulted Sediments with Associated Magnetic Anomalies in the Albuquerque Basin, Rio Grande Rift, New Mexico*, Geological Society of America Bulletin, v. 120, p. 641-658, 2008.
3. Simpson, D.H., *The Wateree Creek Fault Zone*, unpub. M.S. thesis, University of South Carolina, 38p., 1981.

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

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-13

FSAR Section 2.5.1.1.2.4.1 (pgs 2.5.1-19 and 2.5.1-20) discusses the Paleozoic Central Piedmont shear zone (CPSZ) which forms the western boundary of the Carolina Zone in which the site is located. FSAR Section 2.5.1.1.1.4 (pg 2.5.1-5) describes the CPSZ as a complex series of fault zones, including at least the Lowdensville, Kings Mountain, and Eufola fault zones. FSAR Figure 2.5.1-202 (Sheet 2) labels more faults northward along strike which may also be a part of the CPSZ. It is not clear whether the Paleozoic Beaver Creek shear zone, discussed in FSAR Section 2.5.1.1.2.4.1 (pg 2.5.1-20), or the Deal Creek shear zone shown in FSAR Figure 2.5.1-211, may be part of the CPSZ or lie south of that zone. Finally, FSAR Section 2.5.1.1.2.4.1 (pg 2.5.1-20) describes the CPSZ as "a late Paleozoic thrust" based on Hibbard and others (1998 and 2002), a description that would appear not to reconcile with the interpretation that this zone is comprised of a complex series of multiple faults.

In order for the staff to completely understand the geologic setting of the Summer site in relation to regional tectonic structures, please define the faults which comprise the CPSZ, include these faults in a single figure (such as that requested in RAI 2.5.1-1), and discuss interpretations related to the complexity of the zone in regard to hazard potential for the site.

VCSNS RESPONSE:

The Central Piedmont shear zone (CPSZ) in the site region comprises several faults that together make up the boundary between the Piedmont Zone and Carolina Zone (Hibbard et al. 2006) (FSAR Reference 2.5.1-284). The CPSZ was first identified on the basis of gravity and magnetic data (Hatcher and Zietz 1980) (FSAR Reference 2.5.1-274) and is considered a suture between (1) the Charlotte terrane, part of the Gondwana-affinity arcs of the Carolina Zone, and (2) the Laurentia-affinity Piedmont Zone or Inner Piedmont (Hatcher et al. 2007) (Reference 3). Others consider the CPSZ a late Paleozoic thrust that 'beheaded' the suture (Hibbard et al. 1998) (FSAR Reference 2.5.1-282). Assessments of which faults compose the CPSZ have changed over time. For example, whereas some older studies consider the Shacktown fault as the northeastern-most extent of the CPSZ (Horton and McConnell 1991) (FSAR Reference 2.5.1-290), more recent studies conclude the CPSZ is located farther east along the Hyco shear zone in Virginia and northern North Carolina (Wortman et al. 1998; Hibbard et al. 1998) (FSAR References 2.5.1-413 and 2.5.1-282). Similarly, although some geologists trace the southernmost extent of the CPSZ along the Towaliga fault (Hooper and Hatcher 1988) (FSAR Reference 2.5.1-285), others suggest the Ocmulgee fault likely represents the CPSZ in South Carolina and Georgia (Hooper

and Hatcher 1990; Hatcher et al. 2007) (References 4 and 3). Fortunately, nearest to the VCSNS site, there is consensus that the CPSZ can be traced along the Eufola and Kings Mountain shear zones across central and southern North Carolina (Horton 1981; Horton and McConnell 1991) (FSAR References 2.5.1-288 and 2.5.1-290) and the Kings Mountain shear zone, Cross Anchor fault, and Middleton-Lowndesville shear zone in South Carolina (West 1998) (FSAR Reference 2.5.1-403). FSAR Figure 2.5.1-202 will be revised to show the most up-to-date regional depiction of faults of the CPSZ.

Neither the Beaver Creek nor the Deal Creek shear zone is part of the CPSZ. The Beaver Creek shear zone lies to the east of, and is truncated by, the Cross Anchor fault section of the CPSZ (West 1998) (FSAR Reference 2.5.1-403). The Deal Creek shear zone is a 300-meter-wide zone of dextral shear bands in muscovite- and chlorite-bearing phyllonite that lies completely within and overprints the deformed rocks of the Lowndesville shear zone section of the CPSZ (West 1998) (FSAR Reference 2.5.1-403). Orthogneiss sheets of the Lowndesville shear zone are truncated by the dextral shear bands of the Deal Creek shear zone along a 50 kilometer segment of the Lowndesville shear zone. However, both the Lowndesville and Deal Creek shear zones are folded about shallow northeast- and southwest-plunging fold axes (West 1998) (FSAR Reference 2.5.1-403). Both the Deal Creek and Lowndesville shear zones are truncated by both the Mulberry Creek fault, a brittle fault that defines the northwestern edge of the Lowndesville shear zone, and the Cross Anchor fault (West 1998) (FSAR Reference 2.5.1-403). As such, any deformation on the Lowndesville shear zone or the younger Deal Creek shear zone is older than the Paleozoic Cross Anchor fault (West 1998).

The Hyco shear zone in northern North Carolina and southern Virginia is part of the CPSZ. This fault dips eastward and juxtaposes Carolina terrane rocks over Milton terrane rocks that are correlative with the Inner Piedmont or Piedmont zone (Hibbard et al. 1998) (FSAR Reference 2.5.1-282). Mylonitic fabrics and mineral stretching lineations are consistent with west-directed transport on this structure (Hibbard et al. 1998) (FSAR Reference 2.5.1-282). Ages on granitoids interpreted as syn-kinematic to deformation on this structure range from ca. 320 to 335 Ma, indicating a Mississippian age for deformation (Wortman et al.1998) (FSAR Reference 2.5.1-413).

The Eufola fault is part of the CPSZ and separates rocks of the Inner Piedmont from the Charlotte terrane (Milton 1981; Horton and McConnell 1991) (Reference 6 and FSAR Reference 2.5.1-290). However, Milton (1981) (Reference 6) indicates that the Eufola fault is not continuous with the Kings Mountain shear zone. Wortman et al. (1998) (FSAR Reference 2.5.1-413) report a Rb/Sr mica date of 321 Ma on dikes that crosscut and are not deformed by mylonites associated with the Eufola fault. Based on sparse occurrences of silicified cataclasites, Milton (1981) (Reference 6) suggests possible localized minor brittle Mesozoic reactivation along portions of the Eufola fault.

The Kings Mountain shear zone is part of the CPSZ and separates rocks of the Charlotte terrane from the Piedmont near the North Carolina-South Carolina state line. Mylonitic deformation in the Kings Mountain shear zone is overprinted by semi-brittle cleavage (Horton 1981) (Reference 5). Pegmatite dikes in North Carolina intruded

parallel to the semi-brittle cleavage and some have been ductilely deformed. Hence, the dikes are interpreted as syn- to post-kinematic and their Rb-Sr whole rock isochron age of 340 ± 5 Ma indicates that the late-stage semi-brittle deformation occurred in the Mississippian Epoch (Horton 1981) (Reference 5).

The Cross Anchor fault is part of the CPSZ. This fault is a low-angle, west-vergent thrust juxtaposing the Carolina and Inner Piedmont terranes. The Cross Anchor fault includes ductile mylonites and cataclastic fabrics (West 1998) (FSAR Reference 2.5.1-403). An unnamed granite with a 326 ± 3 Ma U-Pb upper-intercept age cuts the Cross Anchor fault. As such, the Cross Anchor fault was last active before 326 Ma (Dennis and Wright 1995) (Reference 1). However, West (1998) (FSAR Reference 2.5.1-403) interprets the same granite as pre- to syn-kinematic and suggests the Cross Anchor fault was active at approximately 325 Ma.

The Middleton-Lowndesville shear zone is part of the CPSZ. This shear zone predominately comprises mylonitic gneisses, localized muscovite phyllonites, and localized silicified breccias (West 1998) (FSAR Reference 2.5.1-403). The Middleton-Lowndesville shear zone coincides with the sharply defined southeastern boundary of the Inner Piedmont terrane and is characterized by amphibolite-facies to migmatitic rocks (Griffin 1981) (Reference 2). Where it extends south into Georgia, this shear zone is mapped by geophysical data and described as a northeast-striking cataclastic zone (Rozen 1981) (FSAR Reference 2.5.1-354). The ductile deformation features associated with the Middleton-Lowndesville shear zone formed at greenschist-facies or higher conditions and the brittle features formed near the brittle-ductile transition (Nelson 1981) (Reference 7). In South Carolina, the Cross Anchor fault truncates the Lowndesville shear zone. As such, the Middleton-Lowndesville shear zone was active prior to 325 Ma (West 1998) (FSAR Reference 2.5.1-403).

The Ocmulgee fault in Georgia is part of the CPSZ. The Ocmulgee fault separates sillimanite-bearing meta-sedimentary schists and gneisses of the Piedmont from greenschist-facies meta-igneous rocks of the Charlotte terrane. Based on the interpretation that deformation occurred after peak metamorphism, Hooper and Hatcher (1990) (Reference 4) estimate a ca. 350 Ma age for deformation on this structure. Hooper and Hatcher (1990) (Reference 4) project the northeast end of the Ocmulgee fault such that it connects with the Middleton-Lowndesville shear zone.

In summary, at least six structures in the site region are interpreted as part of the CPSZ. These include the Hyco shear zone, the Eufola fault, the Kings Mountain shear zone, the Cross Anchor fault, the Middleton-Lowndesville shear zone, and the Ocmulgee fault. CPSZ history includes formation at relatively deep crustal levels (below the brittle-ductile transition) with localized brittle overprinting during reactivation at mid to upper crustal levels, possibly as recent as Mesozoic. To date there is no evidence demonstrating Quaternary activity on faults of the CPSZ, and none of these faults is designated a capable tectonic structure.

References:

1. Dennis, A.J. and Wright, J.E., *Mississippian (ca. 326-323 Ma) U-Pb Crystallization for Two Granitoids in Spartanburg and Union Counties, South Carolina*, Carolina Geological Society Guidebook, p. 43-47, 1995.
2. Griffin, V.S., *The Lowndesville Belt North of the South Carolina-Georgia Border*, in J.W. Horton, J.R. Butler, and D.J. Milton, (eds.), Geological Investigations in the Kings Mountain Belt and Adjacent Areas, Carolina Geological Society Field Trip Guidebook, p. 166-173, 1981 .
3. Hatcher, R.D., Bream, B.R., and Merschat, A.J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in R.D. Hatcher, 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. 595-632, 2007.
4. Hooper, R.J. and Hatcher, R.D., *Ocmulgee Fault: The Piedmont-Avalon Terrane Boundary in Central Georgia*, Geology v. 18, p. 708-711, 1990.
5. Horton, J.W., *Shear Zone Between the Inner Piedmont and Kings Mountain Belts in the Carolinas*, Geology, v. 9, p. 28-33, 1981.
6. Milton, D.J., *The Northern Termination of the Kings Mountain Belt,* in J.W. Horton, J.R. Butler, and D.J. Milton (eds.), Geological Investigations of the Kings Mountain Belt and Adjacent Areas in the Carolinas, Carolina Geological Society Field Trip Guidebook, p. 1-5, 1981.
7. Nelson, A.E., *Polydeformed Rocks of the Lowndesville Shear Zone in the Greenville 2 Degree Quadrangle, South Carolina and Georgia*, in J.W. Horton, J.R. Butler, and D.J. Milton (eds.), Geological Investigations in the Kings Mountain Belt and Adjacent Areas, Carolina Geological Society Field Trip Guidebook, p. 181-193, 1981.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Figure 2.5.1-202 will be revised to show the most up-to-date regional depiction of faults of the CPSZ. Revised FSAR Figure 2.5.1-202 is provided in the response to RAI 02.05.01-1.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-14

FSAR Section 2.5.1.1.2.4.1 (pg 2.5.1-20) discusses a postulated unnamed fault near Parr which, if it exists, occurs about 4.8 km (3 mi) south-southwest of the Summer site. A trace length of about 9.7 km (6 mi) is shown for this fault on the site area geologic map of FSAR Figure 2.5.1-224, although the FSAR states that evidence for the fault included shear fabrics in only a single exposure and it probably does not extend to the northeast. This FSAR section further states that the boundary of the Winnsboro pluton is not offset along the projected northeast trace of this unnamed fault as proof that it does not extend northeastward to the site location. Physical characteristics of the fault are not discussed (e.g., dip of the fault; whether the feature may exhibit a mylonitic fabric indicative of deep-seated, older ductile deformation or is clearly a later-stage brittle shear zone; amount and type of displacement), although its strike appears to generally parallel that of the three northeast-trending shear zones mapped in the Unit 1 excavation.

In order for the staff to assess the hazard potential of this unnamed fault which has been postulated to occur within the site area, please provide information on characteristics of this fault which may bear on age of faulting, including whether the boundary of the Winnsboro pluton has been mapped accurately enough to preclude any offset along the fault. Please also provide information on fault characteristics and discuss whether the fault could be related to the northeast-trending system of minor faults represented by the dated shear zones mapped in the Unit 1 excavation. Finally, please provide the logic for illustrating the fault with a trace length of 9.7 km (6 mi) in Figure 2.5.1-224 if it was only mapped in a single exposure.

VCSNS RESPONSE:

This response provides a description of the unnamed fault near Parr based on the original geologic and seismic report for the Parr Hydroelectric Project by Dames & Moore (1972) (FSAR Reference 2.5.1-239), which first postulated the existence of this structure. The evidence for a continuous through-going fault is speculative and relies on connecting exposures exhibiting minor faults and "discordance in foliation and beds." This response first describes the characteristics of these exposures, then addresses the reviewer's comments regarding the possible similarity with minor faults exposed in the VC Summer Unit 1 foundation and whether the Winnsboro plutonic complex boundary is mapped accurately enough to constrain the timing of slip on this postulated fault. The reviewer correctly questions whether the postulated fault was based on only a single exposure, as is currently stated in FSAR Subsection 2.5.1.1.2.4.1. The FSAR text will

be revised to provide further clarification that the original mapping of the postulated unnamed fault near Parr was based on multiple exposures, only one of which included a measurement of strike.

Dames & Moore (1972) (FSAR Reference 2.5.1-239) describe the postulated fault near Parr as follows:

> Field evidence suggests a fault in the Parr area, passing approximately through Parr Dam, as shown on Figure 5. Discordance in foliation and beds exist at Parr and 3¼ miles southwest on State Route 29. The faulted rock at the Route 29 exposure exhibits intense shearing in thin section and strikes N50E toward the faulted exposure at Parr. Similar rock, also exhibiting shear features, may be traced, on strike, approximately two miles southwest of the Route 29 exposure. The similarity of the strike to those proposed by others (McCauley, Secor, Wagener) suggests that the structure is part of a general fault zone. An approximate 90 degree dip reversal across a narrow disrupted zone exists on the fault strike along Route 213 one mile northeast of the Route 29 exposure. A thin section from this exposure also exhibits shearing. Slickensides are present in the core of one boring drilled on the Parr Dam. Displacement at the Parr exposure seems to be small, and could not be determined at other exposures due to the lack of evidence. It is improbable that the fault (if it exists) can be traced to the northeast due to disruptive effects of plutons.
>
> Since conclusive evidence of the fault penetrating the igneous plutons was not found, it is probable that the plutons were intruded subsequent to faulting. This hypothesis dates the fault as older than 200 million years. No evidence of recent movement was found during the investigation [pp. 19-20].

Based on the above passage, there appear to be five locations that may have been used to infer the existence and location of the unnamed fault near Parr. These are listed in the table below in order from northeast to southwest.

Exposure	Location	Description
1. Parr	No description of location provided	"discordance in foliation and beds"; "displacement at the Parr exposure seems to be small"
2. Parr Dam	Parr Dam boring	"slickensides in core of one boring"
3. Route 213	1 mi NE of SR 29 exposure	"approximate 90 degree dip reversal across narrow disrupted zone"
4. Route 29	3 ¼ mi SW from Parr	"discordance in foliation and beds"; "faulted rock … exhibits intense shearing in thin section and strikes N50E toward the faulted exposure at Parr"
5. Two mi. SW of Route 29 exposure	2 mi SW of SR 29 Exposure	Similar rock to SR 29 exposure exhibiting shear features

The Dames & Moore (1972) report does not show these locations on a map. However, the report does include the fault on Figure 5 (Bedrock Geologic Map of Site Area) as a dashed line, which is described as "trace of inferred fault" in the explanation. Based on the descriptions from the report text, the total distance between exposures 1 and 5 is about 5¼ miles. The mapped length of the postulated fault shown in Figure 5 in Dames & Moore (1972) (FSAR Reference 2.5.1-239) is about 5 miles. The length of this feature shown in FSAR Figure 2.5.1-224 is about 5 miles.

This same postulated fault is shown on Figure 2.5-13 (Aerial Geologic Map) of the V. C. Summer Unit 1 UFSAR (Reference 1), which displays a total of eight "exposures containing minor displacement features" within 10 miles of the site. Two of these features are located on the fault: one in Parr and one on State Route 213. We presume these two locations represent exposures 1 and 4 listed in the table above. However, the other six "exposures containing minor displacement features" on Figure 2.5-13 of the V. C. Summer Unit 1 UFSAR (Reference 1) are not located along the postulated fault, and suggest that minor faults are common in the site vicinity bedrock.

The Dames & Moore (1972) report provides very few details regarding the characteristics of the deformation or faulting observed in the exposures. Other than the noted slickensides encountered in a single boring at Parr Dam, it is not clear whether the observed features represent ductile or brittle deformation. A strike (N50°E) is provided for only a single location and no dip information is given for any of the exposures.

The log of Parr Hydroelectric Project Boring C-14, located on the axis of Parr Dam, encountered two zones of slickensides in predominantly "migmatite of amphibole-quartz-plagioclase gneissic composition" (plate 37 of FSAR Reference 2.5.1-239). At a depth of about 51 feet, a "6 to 8 in. shear zone with slickensides mineralized with epidote" was described. At a depth of about 60 feet, the boring log provides the following description: "20 in. shear zone with well developed slickensides. Dark green amphibole gneiss vertically displaced by pink coarse-grained granodiorite." It is not clear whether the reported widths of the shear zones are true widths measured orthogonal to the boundaries of the shear zone or whether they are simply measured as the vertical length of core containing the shear zone.

If the slickensides were mineralized with epidote either before or during the formation of the slickensides, these would be considered evidence of ancient deformation since epidote growth requires minimum pressures and temperatures of at least 1-6 kbar and about 220 ± 50 °C (Liou 1977) (Reference 2), conditions that likely last occurred during the late Paleozoic or Mesozoic based on fission track ages (e.g., Naeser et al. 2001 (Reference 3); 2006 (Reference 4)). However, without a more complete description of the mineral growth (e.g., epidote fibers growing along striations), the relationship between the age of epidote mineral growth and slickenside formation cannot be firmly established.

Ductile and brittle deformation features are abundant throughout the Piedmont. For example, the excavation for nearby VC Summer Unit 1 revealed similar ancient brittle deformational features in the form of bedrock joints, shears, and minor faults. Detailed studies of these features suggest a Mesozoic age based on the presence of undeformed zeolite minerals coating shear surfaces that precipitated out of solution during Mesozoic hydrothermal activity.

The VC Summer Unit 1 excavation exposed near-vertical, northeast- and northwest-striking sets of shears that appear to follow the joint system (FSAR Reference 2.5.1-240). The dominant sets of shears are northeast-striking, oblique-slip faults with left-lateral and south-side-down normal components of slip. The largest faults are divided into Zones 1, 2, and 3 (FSAR Figure 2.5.1-230). Zone 3 faults are the most significant and exhibit a maximum displacement of about 7 feet. Individual shears range in thickness from a fraction of an inch to less than 2 feet and exhibit an en echelon map pattern with several of the smaller shears terminating within the exposure. The shears do not penetrate the overlying soil profile to the ground surface. Many shears exhibit growth of a mineral assemblage indicative of hydrothermal origin. The presence of undeformed, euhedral laumontite (zeolite) crystals on many of the shear surfaces indicates that these minor faults have not slipped since the hydrothermal activity. Rb-Sr and K-Ar age dating of the hydrothermal laumontite and surrounding rock, along with other lines of evidence, are reported to constrain the hydrothermal event to some time before 45 Ma, with a likely Mesozoic age (FSAR References 2.5.1-240 and 2.5.1-392). Regional studies also support a Mesozoic or earlier age for temperature conditions

suitable for the formation of hydrothermal minerals (Naeser et al. 2001 (Reference 3); 2006 (Reference 4)).

The few characteristics available for the postulated Parr fault exposures suggest similarities with the minor faults exposed in the VC Summer Unit 1 excavation. These include mainly the northeast orientation, the width of shears, and relatively minor amount of deformation based on the general lack of detailed descriptions of the exposures for the postulated fault near Parr. Given that many of the minor bedrock shears exposed in the VC Summer Unit 1 foundation have finite lengths that are less than the width of the exposure (a few hundred feet), it is highly speculative and likely very improbable to assume that outcrops located miles apart and exhibiting minor deformation represent a single, continuous fault in the Piedmont. A later study of the VC Summer Unit 1 excavation by Dames & Moore (1974) (FSAR Reference 2.5.1-240) describes the Parr Road cut exposure of this postulated fault as exhibiting less than 1-foot displacement of pegmatite and aplite veins. This very small displacement measured in the Parr Road cut, would suggest a small localized bedrock shear rather than a fault with a length of 5 miles.

The unfaulted boundary of the Winnsboro plutonic complex is mapped at a 1:24,000 scale as a dashed line indicating the contact is approximately located (FSAR References 2.5.1-363 and 2.5.1-364). Dames & Moore (1972) (FSAR Reference 2.5.1-239) imply this unfaulted contact precludes movement on the unnamed fault near Parr after the intrusion of the pluton. While the plutonic complex boundary may preclude the presence of a major fault with offset on the order of thousands of feet or more, the lack of continuous bedrock exposures along this boundary does not preclude minor displacements along small faults. Therefore, the rationale used by Dames & Moore (1972) (FSAR Reference 2.5.1-239) to suggest that the age of faulting predates the intrusion of the pluton is not well supported. Based on the abundance of minor Paleozoic and Mesozoic deformational features throughout the Piedmont, the minor features observed in outcrop along the postulated unnamed fault near Parr are assigned a Paleozoic age, but could be as young as Mesozoic.

In summary, the postulated unnamed fault near Parr is based on a limited number of exposures and the assumption that these exposures all represent the same structure. With the exception of the outcrop in Parr and the boring on Parr Dam, the exposures are separated by distances greater than 1 mile. In addition, none of these exposures provide kinematic indicators and only one of the exposures yields information on orientation. More recent mapping of the area at 1:24,000 scale (FSAR References 2.5.1-363 and 2.5.1-364) does not include this postulated fault. For completeness, the inferred fault was conservatively included on FSAR Figures 2.5.1-224 and 2.5.1-225, even though the existence of a single fault connecting each of the exposures is highly speculative.

References:

1. V. C. Summer Unit 1 UFSAR, accessed 2009.

2. Liou, J.G., *Synthesis and Stability Relations of Epidote*, Ca2Al2FeSi3O12(OH): Journal of Petrology, v. 14, p. 381-413, 1973.

3. Naeser, C.W., Naeser, N.D., Kunk, M.J., Morgan, B.A., Schultz, A.P., Southworth, C.S., Weems, R.E., *Paleozoic through Cenozoic Uplift, Erosion, Stream Capture and Deposition History in the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain Provinces of Tennessee, North Carolina, Virginia, Maryland, and District of Columbia*: USGS Open-file Report 01-406, 129p., 2001.

4. Naeser, C.W., Naeser, N.D., Southworth, S., *Tracking Across the Southern Appalachians; Eastern Tennessee and Western Carolinas*: Geological Society of America Southeastern Section Abstracts, v. 38, p. 67, 2006.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Subsection 2.5.1.1.2.4.1, page 2.5.1-20, paragraph 1, will be revised as follows:

Unnamed Fault Near Parr, South Carolina

As part of an investigation performed for the Parr ~~hydroelectric~~ Hydroelectric ~~project~~Project, Dames & Moore (Reference 239) describes a postulated fault 3 miles south-southwest of the VCSNS site, as shown in Figures 2.5.1-224 and 2.5.1-225. Evidence for this fault includes slickensides observed in a boring at Parr Dam and four bedrock exposures described as "faulted rock", "dip reversal across narrow disrupted zone", "discordance in foliation and beds", and "shear ~~fabrics~~features." ~~recognized in a single roadcut exposure.~~ The postulated unnamed fault near Parr is based on a limited number of exposures and the assumption that these exposures all represent the same structure. With the exception of the outcrop in Parr and the boring on Parr Dam, the exposures are separated by distances greater than 1 mile. In addition, none of these exposures provide kinematic indicators and only one of the exposures yields information on orientation. ~~Dames & Moore (Reference 239) notes, however, "it is improbable that the fault (if it exists) can be traced to the northeast." Dames & Moore (Reference 239) concludes that, if it exists, the unnamed fault near Parr, South Carolina does not offset local pluton boundaries of the Winnsboro plutonic complex. Secor et al. (Reference 364) assign a Carboniferous (late Paleozoic) age to the rocks of the Winnsboro plutonic complex. Therefore, the unfaulted pluton margin precludes post- Paleozoic activity of this fault, if this fault extends northeast to the pluton margin.~~ Alternatively, the ~~shear~~

~~fabrics~~exposures observed by Dames & Moore (Reference 239) ~~in the roadcut~~ could represent ~~be a~~individual local features of limited extent, similar to the minor faults and shears studied in the VC Summer Unit 1 exposure. More recent mapping of the area at 1:24,000 scale (References 363 and 364) does not include this postulated fault. For completeness, the inferred fault was conservatively included on Figures 2.5.1-224 and 2.5.1-225, even though the existence of a single fault connecting each of the Dames & Moore (Reference 239) exposures is highly speculative. ~~The~~ This ~~unnamed~~ postulated fault ~~near Parr, South Carolina~~, if it exists, is assigned a Paleozoic age, however, there are no data to constrain timing at any of the exposures. It is permissible that some could be as young as Mesozoic in age if they are similar to the bedrock shears mapped in the VC Summer Unit 1 excavation. The brief descriptions of the exposures by Dames & Moore (Reference 239) do not provide sufficient information to even classify the minor deformational features as having formed under ductile or brittle conditions. Field reconnaissance performed as part of this license application did not recognize evidence for faulting in the vicinity of Dames & Moore's (Reference 239) postulated fault near Parr, South Carolina (Reference 363).

FSAR Subsection 2.5.1.2.4, page 2.5.1-52, paragraph 2, will be revised as follows:

The Unit 1 excavation exposed near-vertical, northeast, and northwest striking sets of shears that appear to follow the joint system (Reference 240). Additional excavations for the staging area, control building, intermediate building wall, and north dam of the service water pond were mapped to document these features (References 241, 242, 243, and 244) (Figures 2.5.1-230 and 2.5.1-231). The dominant set of shears are northeast striking, oblique-slip faults with left-lateral and south-side-down normal components of slip. The dominant faults are divided into Zones 1, 2, and 3 (Figure 2.5.1-230). Zone 3 faults are the most significant and exhibit a maximum displacement of about 7 feet. Individual shears range in thickness from a fraction of an inch to less than ~~1~~ 2 ~~foot~~ feet and exhibit an en echelon map pattern with several of the smaller shears terminating within the exposure. The shears do not penetrate the overlying soil profile to the ground surface. Many shears exhibit growth of a mineral assemblage indicative of hydrothermal origin. The presence of undeformed, euhedral laumontite (zeolite) crystals on many of the shear surfaces indicates that these minor faults have not slipped since the hydrothermal activity. Rb-Sr and K-Ar age dating of the hydrothermal laumonite and surrounding rock, along with other lines of evidence, constrain the hydrothermal event to some time before 45 Ma, with a likely Mesozoic age (References 240 and 392). The Cenozoic or Mesozoic timing of last movement on the bedrock shears demonstrates that these features are not capable tectonic sources and represent neither a ground motion hazard nor a surface rupture hazard to the site.

FSAR Subsection 2.5.3.2, page 2.5.3-9, paragraph 2, will be revised as follows:

- Unnamed Fault near Parr, South Carolina. As part of an investigation performed for the Parr Hydroelectric Project, Dames & Moore (Reference 207) describes a postulated fault 3 miles south-southwest of the VCSNS site (Figures 2.5.1-224 and 2.5.1-225). Evidence for this fault includes slickensides observed in a boring at Parr Dam and four bedrock exposures described as "faulted rock", "dip reversal across narrow disrupted zone", "discordance in foliation and beds", and "shear features." The postulated unnamed fault near Parr is based on a limited number of exposures and the assumption that these exposures all represent the same structure. With the exception of the outcrop in Parr and the boring on Parr Dam, the exposures are separated by distances greater than 1 mile. In addition, none of these exposures provide kinematic indicators and only one of the exposures yields information on orientation. Alternatively, the exposures observed by Dames & Moore (Reference 239) could represent individual local features of limited extent, similar to the minor faults and shears studied in the VC Summer Unit 1 exposure. More recent mapping of the area at 1:24,000 scale (References 363 and 364) does not include this postulated fault. For completeness, the inferred fault was conservatively included on Figures 2.5.1-224 and 2.5.1-225, even though the existence of a single fault connecting each of the Dames & Moore (Reference 239) exposures is highly speculative. This postulated fault, if it exists, is assigned a Paleozoic age, however, there are no data to constrain timing at any of the exposures. It is permissible that some could be as young as Mesozoic in age if they are similar to the bedrock shears mapped in the VC Summer Unit 1 excavation. The brief descriptions of the exposures by Dames & Moore (Reference 239) do not provide sufficient information to even classify the minor deformational features as having formed under ductile or brittle conditions. ~~Evidence for this fault includes shear fabrics recognized in a single roadcut exposure. Dames & Moore (Reference 207) notes, however, "it is improbable that the fault (if it exists) can be traced to the northeast." Dames & Moore (Reference 207) concludes that, if it exists, the unnamed fault near Parr, South Carolina does not offset local pluton boundaries of the Winnsboro plutonic complex. Secor et al. (Reference 219) assign a Carboniferous (Late Paleozoic) age to the rocks of the Winnsboro plutonic complex. Therefore, the unfaulted pluton margin precludes post-Paleozoic displacement on this fault, if it extends northeast to the pluton margin. Alternatively, the shear fabrics observed by Dames & Moore (Reference 207) in the roadcut could be a local feature of limited extent. The unnamed fault near Parr, South Carolina, if it exists, is assigned a Paleozoic age.~~ Field reconnaissance performed for Units 2 and 3 did not recognize evidence for faulting in the vicinity of Dames & Moore's (Reference 207) postulated fault near Parr, South Carolina (Reference 221).

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-15

FSAR Section 2.5.1.1.2.4.1 (pgs 2.5.1-20 and 2.5.1-21) discusses the Cross Anchor fault and states that the fault is assigned a Paleozoic age based on cross-cutting and structural relationships. However, these relationships are not summarized to document the conclusion that this fault is Paleozoic in age.

In order for the staff to completely understand the geologic setting of the Summer site in relation to regional tectonic structures, please provide a summary of the information to document a Paleozoic age for the Cross Anchor fault.

VCSNS RESPONSE:

The Cross Anchor fault strikes north-northeast and its trace extends from the southern end of the King's Mountain shear zone, around the Whitmire reentrant, to the southwest (FSAR Figure 2.5.1-211). Dennis and Wright (1995) (Reference 1) interpret an unnamed granitic pluton, dated at 326 ± 3 Ma, to cut and post-date the Cross Anchor fault. However, West (1998) (FSAR Reference 2.5.1-403) interprets the timing of emplacement of this same pluton as syn- to pre-faulting. As such, West (1998) (FSAR Reference 2.5.1-403) interprets movement on the fault to be ca. 325 Ma.

The unnamed granitic pluton intersects the Cross Anchor fault north of the Whitmire reentrant, just south of the intersection of the Tinsley Bridge and Cross Anchor faults (FSAR Figure 2.5.1-212). Mapped relationships indicate that the fault is truncated at the north and south ends of the granitic pluton. The 2-kilometer-diameter pluton is described by Dennis and Wright (1995) (Reference 1) as bearing a weak magmatic to submagmatic fabric defined by compositional layering. This fabric strikes N30°E, with eastward dips varying from 30° to vertical, and is locally accompanied by a south plunging lineation. They note the possibility of some solid-state deformation related to Alleghanian folding, but conclude that the unnamed granite crosscuts the central Piedmont suture (i.e., the Cross Anchor fault) (Dennis and Wright, 1995) (Reference 1). West (1998) (FSAR Reference 2.5.1-403), however, interprets the same foliation and lineation as similar to the fabric in the adjacent Inner Piedmont and concludes that the pluton was pre- to syn-kinematic with fault-related deformation. In either case, the Cross Anchor fault was possibly active as recently as ca. 325 Ma, and is a Paleozoic structure, as described in FSAR Subsection 2.5.1.1.2.4.1.

<u>References</u>:

1. Dennis, A.J. and Wright, J.E., *Mississippian (ca. 326-323 Ma) U-Pb Crystallization for Two Granitoids in Spartanburg and Union Counties, South Carolina*, Carolina Geological Society Guidebook, p. 43-47, 1995.

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

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-16

FSAR Section 2.5.1.1.2.4.1 (pgs 2.5.1-21 and 2.5.1-22) discusses the Modoc shear zone and the Augusta fault, indicating that both these structural features show ductile and later-stage brittle deformation fabrics. This FSAR section (pg 2.5.1-21) further states that the Modoc shear zone may have experienced movement in Mesozoic (i.e., Triassic) time. While age relationships for the two fabrics are discussed, this FSAR section does not summarize the salient logic used for clearly documenting that both fabrics are old and the brittle fabric does not represent late-stage faulting which may pose a hazard for the site. In addition, Nystrom (2006) indicates that the Modoc shear zone and the Augusta fault are part of the Eastern Piedmont fault system which may exhibit movement extending into the late Cenozoic.

In order for the staff to assess the hazard potential for these two regional structures, please summarize the logic used to document that both fabrics are old and the brittle fabric does not represent late-stage faulting. Please include an assessment of the interpretation by Nystrom (2006) that faults in the Eastern Piedmont fault system, which includes the Augusta fault and Modoc shear zone, may exhibit late Cenozoic movement.

VCSNS RESPONSE:

Both the Augusta fault and the Modoc shear zone are elements of the Eastern Piedmont fault system and both exhibit characteristics similar to other Eastern Piedmont fault system faults (Hatcher et al. 1977; Nystrom 2006) (FSAR Reference 2.5.1-275; Reference 5). These characteristics include: (1) an early kinematic phase associated with the creation of a ductile fabric defined by dynamic recrystallization and recovery mechanisms; followed by (2) a brittle overprint manifested as cataclasites, silica-cemented cataclasites, locally intense jointing, and normal faulting (Bobyarchick 1981; Maher 1987) (FSAR References 2.5.1-213 and 2.5.1-320).

The pressure and temperature conditions necessary to activate dynamic recrystallization and recovery mechanisms in quartz and feldspar indicate that the ductile fabric recorded in the Eastern Piedmont fault system formed at relatively deep levels in the crust, below the brittle-ductile transition, thus constraining the ductile phase of displacement to Late Paleozoic time. Based on 40Ar/39Ar ages on recrystallized biotite, Maher et al. (1991) (Reference 4) indicate that Modoc fault ductile fabrics formed prior to 268 Ma. Similarly, based on 40Ar/39Ar ages on a fine-grained muscovite schist, Maher et al. (1994) (FSAR Reference 2.5.1-321) indicate that Augusta fault ductile

fabrics formed at about 274 Ma. Moreover, based on textural relationships including similar directions and shear sense between striae and minor brittle faults and ductile structures, Maher et al. (1994) (FSAR Reference 2.5.1-321) conclude that the Augusta fault synkinematically cooled through the ductile-brittle transition during the Late Paleozoic. As such, at least some portion of the brittle fabric associated with the Augusta fault and other Eastern Piedmont fault system faults can be attributed to Late Paleozoic slip.

Several faults of the Eastern Piedmont fault system experienced localized Mesozoic reactivation associated with rifting of the Atlantic margin (Bobyarchick 1981; Garihan et al. 1993) (FSAR Reference 2.5.1-213; Reference 2). This association with Mesozoic deformation at high structural levels within the crust is largely responsible for the localized brittle overprint of the Eastern Piedmont fault system and the occurrence of silicified cataclasites. Silicified cataclasites (or "silicified breccias") are characteristic of Mesozoic faults in the Piedmont, and likely reflect hydrothermal activity indicative of a Mesozoic age and not a Cenozoic age (Garihan et al. 1993; Secor et al. 1998; Hatcher 2006) (Reference 2, FSAR Reference 2.5.1-368, Reference 3). This age estimate is consistent with (1) the elevated temperatures necessary for the hydrothermal activity associated with the deposition of quartz and observed silicification (Coombs et al. 1959) (Reference 1); and (2) the fact that the current surface of the Piedmont and the pre-Cretaceous unconformity has been at relatively low temperatures for approximately the last 100 million years (Spotila et al. 2004) (FSAR Reference 2.5.1-377).

In a 2006 abstract, Nystrom (Reference 5) suggests potential minor localized Cenozoic brittle reactivation of the Augusta and Davis Pond faults, two components of the Eastern Piedmont fault system in South Carolina, west and west-southwest of Columbia. Nystrom (2006) (Reference 5) notes the presence of silicified breccias associated with portions of the Augusta and Davis Pond faults. Nystrom's (2006) (Reference 5) proposed Late Cretaceous to Cenozoic movement on portions of the Eastern Piedmont fault system is based on map patterns and inferred 20- to 30-foot offsets of Eocene and Miocene geologic formations, however, and not on the presence of silicified breccias. Nystrom (2006) (Reference 5) suggests a spatial correlation between silicified breccias and Cenozoic faulting for portions of the Augusta and Davis Pond faults. Available data do not support a temporal association between Nystrom's (2006) (Reference 5) proposed Cenozoic faulting and silicified breccias.

In summary, the faults that make up the Eastern Piedmont fault system, including the Modoc shear zone and the Augusta fault, have experienced an extended polyphase history that began in the Late Paleozoic and continued, at least locally, into the Mesozoic and possibly into the Cenozoic. This history includes formation at relatively deep crustal levels (below the brittle-ductile transition) with localized brittle overprinting during reactivation at mid to upper crustal levels. To date there is no evidence demonstrating Quaternary activity on faults of the Eastern Piedmont fault system, and none of these faults are designated capable tectonic structures.

References:

1. Coombs, D.S., Ellis, A.J., Fyfe, W.S., Taylor, A.M., *The Zeolite Facies, With Comments on the Interpretation of Hydrothermal Syntheses*, Geochimica et Cosmochimica Acta, v. 17, p. 53-107, 1959.

2. Garihan, J.M., Preddy, M.S., and Ranson, W.A., *Summary of Mid-Mesozoic Brittle Faulting in the Inner Piedmont and Nearby Charlotte Belt of the Carolinas,* in Carolina Geological Society Field Trip Guidebook – Studies of Inner Piedmont Geology with a Focus on the Columbus Promontory, p. 55-66, 1993.

3. 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 Abstracts with Programs, Southeastern Section 55th annual meeting, 2006.

4. Maher, H.D. Jr., *The Eastern Piedmont in South Carolina*, in J.W. Horton Jr. and V.A. Zullo (eds.) The Geology of the Carolinas: Carolina Geological Society Fiftieth Anniversary Volume, 1st edition, p. 93-108, 1991.

5. 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 Abstracts with Programs, Southeastern Section 55th annual meeting, 2006.

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

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-17

FSAR Section 2.5.1.1.2.4.1 (pg 2.5.1-22) discusses the Augusta fault and lists the observations made by Maher (1987) used to document a hanging-wall-down, oblique sense of displacement along this fault. However, other researchers have interpreted different types of displacement along the fault, including possible normal displacement during the Mesozoic. FSAR Section 2.5.1.1.2.4.1 does not explain how these observations prove the type of displacement suggested by Maher (1987). This FSAR section (pg 2.5.1-22) also states that Maher (1994) interprets some extension to have occurred in pre-Mesozoic time during late stages of the collisional Alleghanian orogeny.

In order for the staff to completely understand the hazard potential for the Augusta fault and whether extension along the fault occurred in Mesozoic or pre-Mesozoic time, please provide a summary of the details behind the list of observations made by Maher (1987) that document a hanging-wall-down, oblique sense of displacement for the fault, as well as the details to document his interpretation (Maher, 1994) of late stage Alleghanian, rather than Mesozoic, extension.

VCSNS RESPONSE:

The Augusta fault has experienced an extended polyphase history that began in the Late Paleozoic and continued, at least locally, into the Mesozoic and possibly into the Cenozoic (Nystrom 2006) (Reference 3). This history includes: (1) an early kinematic phase associated with the creation of ductile fabrics; followed by (2) localized brittle overprinting. The ductile fabrics formed at relatively deep crustal levels (below the brittle-ductile transition), whereas the later brittle overprinting formed at mid to upper crustal levels, possibly during reactivation. Although observations presented by Maher (1987) (FSAR Reference 2.5.1-320) and Maher et al. (1994) (FSAR Reference 2.5.1-321) indicate the Augusta fault principally is a Paleozoic structure, these observations do not preclude subsequent localized brittle reactivation.

Maher (1987) (FSAR Reference 2.5.1-320) describes evidence for two sub-perpendicular, hanging-wall-down movement directions preserved in ductile features on the southeast-dipping Augusta fault. These include: (1) a movement direction that plunges south-southwest to south, primarily based on the direction of a variably developed stretching lineation defined by elongate grain aggregates; and (2) a movement direction roughly perpendicular to that recorded by the mineral aggregate lineation, based on the orientation of fold axes developed in late-kinematic granitic veins present in the mylonitic foliation. Maher (1987) (FSAR Reference 2.5.1-320) concludes

the overall direction of movement is somewhere between the above two interpretations, but likely closer to the lineation direction. In either case, data indicate a significant hanging-wall-down component for movement on the Augusta fault.

Maher (1987) (FSAR Reference 2.5.1-320) establishes one movement direction that plunges south-southwest to south, primarily based on the direction of a variably developed stretching lineation defined by elongate grain aggregates. Maher (1987) (FSAR Reference 2.5.1-320) concludes that this lineation records a movement direction because, in thin sections cut parallel to the lineation, the internal fabric of quartz ribbons defined by the elongate shapes of individual grains is oblique to the ribbon boundaries and the mylonitic foliation. Furthermore, Maher (1987) (FSAR Reference 2.5.1-320) notes that, in thin sections cut perpendicular to the lineation direction, these relationships are no longer evident.

Maher's (1987) (FSAR Reference 320) second movement direction is roughly perpendicular to that recorded by the mineral aggregate lineation and is based on the orientation of fold axes developed in late-kinematic granitic veins present in the mylonitic foliation. These fold axes are subparallel to the mineral aggregate stretching lineation. In his model of the vein deformation, Maher (1987) (FSAR Reference 2.5.1-320) assumes that vein folding initiated with fold axes perpendicular to the transport direction and that the veins have not experienced enough strain to reorient the fold axes. Based on this model, he interprets the fold axis orientations as indicating oblique slip, with approximately equal components of down-dip and sinistral movement, perpendicular to the direction established by the elongated mineral aggregates. In other words, Maher's (1987) (FSAR Reference 320) second movement direction plunges roughly eastward.

The sense of movement on the Augusta fault established by Maher (1987) (FSAR Reference 320) is based on: (1) several sense-of-shear indicators routinely used for this purpose; and (2) hanging wall/foot wall metamorphic relationships. The most common microstructural feature is the presence of S and C surfaces defined by the mylonitic fabric. The C surfaces are loci of accumulated strain that consist of narrow bands of finer-grained recrystallized material that generally form sub-parallel to the shear zone boundaries. Maher (1987) (FSAR Reference 2.5.1-320) describes the C surfaces in thin section as discontinuous and anastomosing. The S surfaces record the last finite strain increment in the kinematic history, and form at an oblique angle to the C surfaces. Maher (1987) (FSAR Reference 2.5.1-320) describes S surfaces defined by mineral shape preferred orientations, as indicated by flattened quartz, feldspar, mica, and opaque aggregates. The sense of shear may be determined by the sense of obliquity between the C and S surfaces. Maher (1987) (FSAR Reference 2.5.1-320) also notes that the obliquity recorded in the S and C relationship is also mirrored by the obliquity between the internal fabric of quartz ribbons and the external ribbon boundaries. Although Maher (1987) (FSAR Reference 2.5.1-320) notes that mesoscopic S and C fabric is not distinguishable in most Augusta fault zone rocks, it can be discerned in the coarser-grained phases.

Maher (1987) (FSAR Reference 2.5.1-320) also reports the presence of "mica fish" as a shear sense indicator. Mica fish are books of porphryoclastic phyllosilicates that have been rotated into the plane of finite flattening, parallel to the phyllosilicate basal layers. Recrystallized material forms tails at each end of the porphyroclasts that are incorporated into the C fabric subparallel to the shear zone boundaries. This system expresses an asymmetry by which the shear sense may be determined. A similar relationship is recorded in aggregates of opaque material that show "tails" of recrystallized material that extend into the C surfaces along the direction of shear. Although the fabric analysis discussed above resulted in two movement directions, all of the sense-of-shear indicators indicate a significant down-dip component indicating a hanging-wall-down kinematic history. This conclusion is supported by the fact that the Augusta fault places rocks formed at upper crustal levels, at greenschist facies conditions, over those formed at deeper levels characterized by partial melting. These relationships are typical of extensional environments.

The presence of granitic intrusions and evidence for high-temperature crystal plastic processes, such as strain recoverey in quartz and extensive feldspar recrystallization, in association with the mylonitic fabric of the Augusta fault, indicate that this component of the ductile fabric in the fault zone was developed at amphibolite facies conditions. Maher et al. (1994) (FSAR Reference 2.5.1-321) interpret an 40Ar/39Ar age of approximately 274 Ma obtained from muscovite in the shear zone to indicate cooling through argon retention temperature in muscovite (about 350°C to 400°C), thereby constraining the approximate age of movement on the Augusta fault. However, Maher (1987) (FSAR Reference 320) also note that strain in the Augusta fault zone is heterogeneously developed and that upper portions contain lower temperature intracrystalline strain features, including undulose extinction in quartz, feldspar cataclasis, and limited recrystallization. These relatively low temperature features also are associated with striae and minor brittle faults. Maher (1987) (FSAR Reference 2.5.1-320) interpret these features as indicating the Augusta fault experienced a late kinematic history that included transition from ductile to brittle fabric development. He based this conclusion on the observation that the striae and brittle faults record the same sense of movement as the ductile features discussed above (i.e., roughly southward to eastward). However, the muscovite cooling age that Maher et al. (1994) cite as evidence for constraining the Augusta fault zone kinematic history to Late Paleozoic (ca. 274 Ma) only constrains the age for the development of the high temperature ductile fabric elements. The 274 Ma age does not preclude that the lower temperature brittle features may have resulted from Mesozoic extension at mid to upper crustal levels, only that this reactivation be in the same movement sense as the earlier Paleozoic phase. In fact, at least some component of Mesozoic activity on the Augusta fault is indicated by Maher's (1987) (FSAR Reference 2.5.1-320) observation that silicified cataclasites exist along the Augusta fault east of the Savannah River.

In a 2006 abstract, Nystrom (2006) (Reference 3) notes the presence of silicified breccias associated with portions of the Augusta fault. These silicified breccias suggest localized Mesozoic brittle reactivation of portions of the Augusta fault. Based on equivocal 20- to 30-foot offsets of Eocene and Miocene geologic formations, Nystrom

(Reference 3) suggests potential minor localized Cenozoic brittle reactivation of the Augusta fault. However, silicified breccias are characteristic of Mesozoic faults in the Piedmont, and likely reflect hydrothermal activity indicative of a Mesozoic age and not a Cenozoic age (Garihan et al. 1993; Secor et al. 1998; Hatcher 2006) (Reference 1, FSAR Reference 2.5.1-368, Reference 2).

In summary, although evidence presented in Maher (1987) (FSAR Reference 2.5.1-320) and Maher et al. (1994) (FSAR Reference 2.5.1-321) documents a Late Paleozoic kinematic phase for the Augusta fault, it does not preclude localized Mesozoic, and possibly Cenozoic, brittle reactivation. To date there is no evidence demonstrating Quaternary activity on the Augusta fault and this fault is not designated a capable tectonic structure.

References:

1. Garihan, J.M., Preddy, M.S., and Ranson, W.A., *Summary of Mid-Mesozoic Brittle Faulting in the Inner Piedmont and Nearby Charlotte Belt of the Carolinas,* in Carolina Geological Society Field Trip Guidebook – Studies of Inner Piedmont Geology with a Focus on the Columbus Promontory, p. 55-66, 1993.

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 Abstracts with Programs, Southeastern Section 55th annual meeting, 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 Abstracts with Programs, Southeastern Section 55th annual meeting, 2006.

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

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-18

FSAR Section 2.5.1.1.2.4.1 (pg 2.5.1-22) discusses "other Paleozoic faults" in the site region, but includes only a partial list of the named Paleozoic geologic structures found in the region and shown in FSAR Figure 2.5.1-211. For example, the Deal Creek shear zone, Bowens Creek fault, Fries fault, Great Smokey fault, Hyco shear zone, and Silver Hill fault are labeled in Figure 2.5.1-211 but are not listed or discussed on pg 2.5.1-22. Consequently, all named faults are not qualified as Paleozoic in age based on field data.

In order for the staff to completely understand the geologic setting of the Summer site in relation to regional tectonic structures, please include named faults found in the site region in the discussion of other Paleozoic faults and qualify them as Paleozoic in age.

VCSNS RESPONSE:

The site region contains numerous faults and shear zones, a limited number of which have a well-determined kinematic history and/or direct timing evidence available. Hence, the goal of FSAR Subsection 2.5.1.1.2.4.1 is to provide detailed information about the faults that are most important, either because of their regional tectonic significance, or because of their proximity to the site. The text of FSAR Subsection 2.5.1.1.2.4.2 will be revised to: (1) provide more detailed information regarding specific faults, including more complete constraints on fault age, where available; and (2) to clarify the rationale for assigning a Paleozoic age to the majority of the faults shown in FSAR Figure 2.5.1-211. As requested, the remainder of this response provides more detailed information on specific faults.

<u>Deal Creek shear zone</u>

The Deal Creek shear zone is a 300-meter-wide zone of dextral shear bands in phyllonite that lies completely within, and overprints, the Lowndesville shear zone portion of the Central Piedmont shear zone (CPSZ) (West 1998) (FSAR Reference 2.5.1-403). Both the Deal Creek shear zone and the Lowndesville shear zone are truncated by: (1) the Mulberry Creek fault, a brittle fault that defines the northwestern edge of the Lowndesville shear zone; and (2) the Cross Anchor fault, a ductile thrust that is part of the CPSZ. Crosscutting relationships indicate the Cross Anchor fault was active at approximately 325 Ma (West 1998) (FSAR Reference 2.5.1-403). As such, the age of the Deal Creek shear zone is constrained to some time before 325 Ma and the fault therefore is assessed to be a Paleozoic structure.

Bowens Creek fault

The Bowens Creek fault is considered a northern extension of the Brevard fault (e.g., Bobyarchick 1988; Hatcher et al. 2007) (References 2 and 5). This steeply dipping reverse dextral fault was active in the Carboniferous, based on Rb-Sr biotite-whole rock isochron ages on nearby schists (Carter et al. 2006) (Reference 3).

Fries fault

The Fries fault is a greenschist-grade shear zone with top-to-the-northwest mylonites (Trupe et al. 2004) (Reference 9). Based on $^{40}Ar/^{39}Ar$ muscovite ages of mylonites (323 to 336 Ma), crosscutting relationships, and retrogression of metamorphic assemblages, Trupe et al. (2004) (Reference 9) conclude that Fries fault thrusting was associated with the Alleghanian orogeny, and therefore assign this fault a Late Paleozoic age.

Great Smoky fault

The Great Smoky fault is a west-directed thrust that coincides with the boundary between the Valley-and-Ridge and Blue Ridge physiographic provinces. The Great Smoky fault placed unmetamorphosed Cambrian sedimentary rocks over Mississippian strata during the Alleghanian orogeny (Hatcher et al. 1989) (Reference 6). There is no evidence for post-Paleozoic motion on the Great Smoky fault.

Hyco shear zone

In northern North Carolina and southern Virginia, the Hyco shear zone dips shallowly to steeply to the east and juxtaposes Carolina terrane rocks over Milton terrane rocks correlated with the Inner Piedmont or Piedmont zone (Hibbard et al. 1998) (FSAR Reference 2.5.1-282). Mylonitic fabrics and mineral stretching lineations are consistent with west-directed transport on this structure (Hibbard et al. 1998) (FSAR Reference 2.5.1-282). Ages on granitoids interpreted as syn-kinematic to deformation on this structure range approximately from 320 Ma to 335 Ma, and indicate a Mississippian age for deformation (Wortman et al. 1998) (FSAR Reference 2.5.1-413).

Silver Hill fault

The Silver Hill fault is part of the Gold Hill-Silver Hill shear zone (GHSZ), a northeast-striking shear zone. The age estimate of the GHSZ is based upon the interpretations that the GHSZ: (1) cuts gabbroic plutons northeast of the Whitmire reentrant that are interpreted to be part of the ca. 400 Ma Concorde plutonic suite (West 1998) (FSAR Reference 2.5.1-403); and (2) is cut by the Cross Anchor fault (West 1998) (FSAR Reference 2.5.1-403), which was active either pre-326 Ma (Dennis and Wright 1995) (Reference 4) or ca. 325 Ma (West 1998) (FSAR Reference 2.5.1-403).

More recently, several abstracts and a fieldtrip guidebook provide additional data that suggest a more complex tectonic history for the GHSZ in North Carolina. A ca. 539 Ma pluton is interpreted as late- to syn-kinematic to the dextral-reverse deformation, indicating earliest Cambrian deformation for the GHSZ (Allen et al. 2007) (Reference 1). Elsewhere, sinistral and southeast-vergent thrusting is interpreted as synchronous with

a series of Late Ordovician folds (Hibbard et al. 2008) (Reference 8). However, $^{40}Ar/^{39}Ar$ mica ages of ca. 377, 338, and 335 Ma from the fault zone may indicate subsequent localized reactivation of deformation in the Devonian and/or Mississippian (Hibbard et al. 2007; Hibbard et al. 2008) (References 7 and 8).

In summary, nearest the site in South Carolina, the best estimates for kinematics and timing of the GHFZ indicate dextral deformation occurred approximately between 400 and 325 Ma (Dennis and Wright 1995; West 1998) (Reference 4, FSAR Reference 2.5.1-297). To the northeast, in southern North Carolina, dextral deformation occurred in the earliest Cambrian and was possibly over by approximately 400 Ma (Allen et al. 2007) (Reference 1). Farther to the northeast, in central North Carolina, deformation was sinistral in the Late Ordovician, although evidence exists for potential Devonian and/or Mississippian deformation as well (Hibbard et al. 2008) (Reference 8). Hence, these studies indicate that the tectonic history for this structure is unresolved and potentially complex. The best evidence for the latest movement on the GHSZ, however, is based on its crosscutting relationship with the Cross Anchor fault that constrains latest motion to sometime prior to about 325 Ma (West 1998) (FSAR Reference 2.5.1-403).

References:

1. Allen, J.S., Miller, B., Hibbard, J., and Boland, I., *Significance of Intrusive Rocks Along the Charlotte-Carolina Terrane Boundary: Evidence for the Timing of Deformation in the Gold Hill fault Zone Near Waxhaw, NC*, Geological Society of America Southeast Section Abstracts with Programs, v. 39, p. 12, 2007.
2. Bobyarchick, A.R., *Location and Geometry of Alleghanian Dispersal-Related Strike-Slip Faults in the Southern Appalachians*, Geology, v. 16, p. 915-919, 1988.
3. Carter, B.T., Hibbard, J.P., Tubrett, M., and Sylvester, P., *Detrital Zircon Geochronology of the Smith River Allochthon and Lynchburg Group, Southern Appalachians: Implications for Neoproterozoic-Early Cambrian Paleogeography*, Precambrian Research, v. 147, p. 279-304, 2006.
4. Dennis, A.J. and Wright, J.E., *Mississippian (ca. 326-323 Ma) U-Pb Crystallization for Two Granitoids in Spartanburg and Union Counties, South Carolina*, Carolina Geological Society Guidebook, p. 43-47, 1995.
5. Hatcher, R.D., Bream, B.R., and Merschat, A.J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in R.D. Hatcher, 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. 595-632, 2007.
6. Hatcher, R.D., Thomas, W.A., Geiser, P.A., Snoke, A.W., Mosher, S., and Wiltschko, D.V., *Alleghanian Orogen*, in R.D. Hatcher, W.A. Thomas, G.W. and Viele (eds.), The Appalachian-Ouachita Orogen in the United States, Boulder, Colorado, Geological Society of America, the Geology of North America, v. F-2, 1989.

7. Hibbard, J., Miller, B., Hames, W., Allen, J., and Sandard, I., *Carolinia; Definition and Recent Findings in Central North Carolina*, Geological Society of America, Southeastern Section Abstracts with Programs, v. 39, p. 11-12, 2007.
8. Hibbard, J., Pollock, J., Allen, J., and Brennan, M., *The Heart of Carolinia: Stratigraphic and Tectonic Studies in the Carolina Terrane of Central North Carolina*, Geological Society of America Southeast Section Fieldtrip Guidebook, 54 p., 2008.
9. Trupe, C.H., Stewart, K.G., Adams, M.G., and Foudy, J.P., *Deciphering the Grenville of the Southern Appalachians Through Evaluation of the Post-Grenville Tectonic History in Northwestern North Carolina*, in R.P. Tollo, L. Corriveau, J. McLelland, and M.J. Bartholomew (eds.), Proterozoic Tectonic Evolution of the Grenville Orogen in North America, Boulder, Colorado, Geological Society of America Memoir 197, p. 679-695, 2004.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Subsection 2.5.1.1.2.4.2, page 2.5.1-20, 3rd full paragraph, will be revised as follows:

Gold Hill Fault Extension

Horton and Dicken (Reference 289) and Hibbard et al. (Reference 284) map an unnamed fault north of the Beaver Creek shear zone that is considered the southwest extension of the Gold Hill-Silver Hill ~~fault~~ shear zone (Figures 2.5.1-211 and 2.5.1-212). At its nearest point, this fault is located approximately 20 miles north of the VCSNS site. The southwest extension of the Gold Hill fault is truncated by, and therefore predates, the Cross Anchor fault. Based upon crosscutting relationships with intrusive igneous bodies ~~structural correlations with~~ and the ~~Deal Creek shear zone~~ Cross Anchor fault (Figure 2.5.1-211), ~~and crosscutting relationships with intrusive igneous bodies,~~ West (Reference 403) constrains motion on the Gold Hill fault to between approximately 400 and 325 Ma. Work along the Gold Hill-Silver Hill shear zone to the northeast has variably indicated deformation events of earliest Cambrian dextral-reverse faulting (Allen et al. 2007) (Reference 422), Late Ordovician sinistral deformation (Hibbard et al 2007) (Reference 424), and Devonian to Mississippian remobilization (Hibbard et al 2007; Hibbard et al 2008) (References 424 and 425). The best evidence for the latest movement on the GHSZ, however, is based on its crosscutting relationship with the Cross Anchor fault that indicate latest motion was sometime prior to 325 Ma (West 1998) (Reference 403).

FSAR Subsection 2.5.1.1.2.4.2, page 2.5.1-21, 3rd full paragraph, 2nd sentence will be revised as follows:

The Augusta fault ~~trends~~ strikes east-northeast and dips moderately to the southeast.

FSAR Subsection 2.5.1.1.2.4.2, pages 2.5.1-22 through 2.5.1-23, 2nd full paragraph, will be revised as follows:

Other Paleozoic Faults

Other Paleozoic faults within the site region include the Brevard fault zone, the Hayesville fault, the Towaliga fault, and the Central Piedmont ~~suture~~ shear zone, Middleton-Lowndesville shear zone, Philson Crossroads fault, Tinsley Bridge fault, and others (Figures 2.5.1-211 and 2.5.1-212). While direct timing evidence does not exist for many of these faults, they can be assigned a Paleozoic age based on the following types of indirect evidence:

- Mapping that indicates that these faults only deform rocks of Paleozoic or older age,
- Geometries and kinematics similar to other faults with established Paleozoic ages in the region (e.g., west-directed thrusts); and/or
- Textural fabrics or mineral assemblages consistent with deformation at ductile high-temperature metamorphic conditions, the latest of which generally occurred during the late Paleozoic collision with Gondwana (e.g. Hatcher et al. 2007) (Reference 423).

Furthermore, ~~No~~ no seismicity is attributed to the~~se~~ Paleozoic faults in the site region, and published literature does not indicate that any of these faults offset late Cenozoic deposits or exhibit a geomorphic expression indicative of Quaternary deformation. In addition, Crone and Wheeler (Reference 232) and Wheeler (Reference 406) do not show any of these faults to be potentially active Quaternary faults. Therefore, these Paleozoic structures in the site region are not considered to be capable tectonic sources, as defined in Regulatory Guide 1.208.

No new information has been published since 1986 on any Paleozoic fault in the site region that would cause a significant change in the EPRI seismic source model.

The following references will be added to FSAR Section 2.5.1:

422. Allen, J.S., Miller, B., Hibbard, J., and Boland, I., *Significance of Intrusive Rocks Along the Charlotte-Carolina Terrane Boundary: Evidence for the Timing of*

Deformation in the Gold Hill fault Zone Near Waxhaw, NC, Geological Society of America Southeast Section Abstracts with Programs, v. 39, p. 12, 2007.

423. Hatcher, R.D., Bream, B.R., and Merschat, A.J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in R.D. Hatcher, 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. 595-632, 2007.

424. Hibbard, J., Miller, B., Hames, W., Allen, J., and Sandard, I., *Carolinia; Definition and Recent Findings in Central North Carolina*, Geological Society of America, Southeastern Section Abstracts with Programs, v. 39, p. 11-12, 2007.

425. Hibbard, J., Pollock, J., Allen, J., and Brennan, M., *The Heart of Carolinia: Stratigraphic and Tectonic Studies in the Carolina Terrane of Central North Carolina*, Geological Society of America Southeast Section Fieldtrip Guidebook, 54 p., 2008.

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-22

FSAR Section 2.5.1.1.2.4.2 (pgs 2.5.1-24 and 2.5.1-25) states that Mesozoic rift basins are areas of extended crust that potentially contain the largest earthquakes, but there is no definitive correlation of seismicity with Mesozoic normal faults. However, although FSAR Section 2.5.1.1.2.4.2 makes this statement, FSAR Section 2.5.3.1.5 (pgs 2.5.1-4 and 2.5.1-5) indicates that two September 2006 earthquakes, which occurred near Bennettsville, SC, more than 144.84 km (90 mi) east-northeast of the Summer site, were spatially associated with a small Mesozoic extensional basin lying beneath the Coastal Plain as mapped by Benson (1992). If the September 2006 earthquakes are best explained as having occurred on faults related to a buried Mesozoic rift basin, the presence of such basins in the site region may have implications for the existence of potentially capable tectonic structures. 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 which occur within the currently seismic meizoseismal area of the 1886 Charleston earthquake (i.e., within the Middleton Place-Summerville seismic zone).

In order for the staff to assess the hazard potential of Mesozoic rift basins in the site region, please include earthquake epicenters on an appropriate figure to show their locations relative to areas of Mesozoic extended crust. Also, in light of information presented in FSAR Section 2.5.3.1.5 regarding spatial association of two earthquakes with a small Mesozoic basin and the recent data presented by Chapman and Beale (2008) for the Middleton Place-Summerville seismic zone, please summarize the logic for not interpreting Mesozoic structures in the site region as potential capable tectonic sources.

VCSNS RESPONSE:

RAI Figure 02.05.01-22.1 and FSAR Figure 2.5.1-212 show the general lack of spatial correlation between Mesozoic basins and seismicity in the site region and within 50 miles of the site, respectively. To date, there is no positive correlation between earthquakes in the site region and Mesozoic basin-bounding faults. Furthermore, no studies have demonstrated Quaternary reactivation of Mesozoic basin-bounding faults in the site region.

FSAR Subsection 2.5.3.1.5 describes two minor earthquakes that occurred near Bennettsville, South Carolina on September 22 and 25, 2006 (RAI Figure 02.05.01-

22.1). These minor earthquakes are given specific mention in the FSAR only because they post-date compilation of the seismicity catalog update performed for this COLA project, and not because they provide significant new information regarding the seismic potential of the region. Given the lack of focal mechanisms for these small magnitude events, the large positional uncertainties associated with these two earthquakes, and uncertainty in the locations of geologic structures mapped beneath the Coastal Plain, positive correlation of these earthquakes with a specific tectonic feature is not established. Furthermore, the small magnitudes of these earthquakes (magnitudes 3.5 and 3.7) indicate small rupture areas, on the order of <0.5 km^2 (Brune 1970 [Reference 1], Brune 1971 [Reference 2], Mahdyiar 1987 [Reference 4]). A small fault with limited dimensions could serve as the source of these events, and thus these minor earthquakes need not have occurred on a relatively large structure such as a Mesozoic basin-bounding fault. Whereas available data do not preclude the possibility that these earthquakes occurred on a fault or faults associated the extensional basin, there are no data (such as focal mechanisms or alignment of aftershocks) demonstrating that basin-related structures produced these minor earthquakes.

The Pen Branch fault is the most extensively studied Mesozoic basin-bounding fault within the site region. The northeast-striking Pen Branch fault bounds the northwest side of the Dunbarton Basin, about 30 miles south of the VCSNS site (FSAR Figure 2.5.1-211). Approximately two decades of extensive studies at the Savannah River Site in South Carolina and studies performed for the Vogtle site in Georgia have failed to demonstrate deformation associated with the Pen Branch fault in strata younger than late Eocene age (Reference 5). These studies include seismic reflection and refraction, drilling programs, and geomorphic analyses. Studies of the Pen Branch fault also demonstrate an absence of deformation in Quaternary Savannah River alluvial terraces (Reference 5).

In a paper published after preparation and submittal of the VCSNS Units 2 and 3 COL FSAR, Chapman and Beale (2008) (Reference 3) present reprocessed seismic reflection data from the Charleston meizoseismal area 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 Middleton Place-Summerville seismic zone. Fault C is imaged as a steeply dipping, down-to-the-east fault with approximately 200 meters of vertical offset displacing lower Mesozoic rocks (Chapman and Beale 2008) (Reference 3). Overlying Coastal Plain sediments of Cretaceous and Tertiary age show approximately 10 meters 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 the documented effects of the 1886 earthquake, Chapman and Beale (2008) (Reference 3) suggest that fault C may have caused the 1886 earthquake. However, definitive correlation between fault C and the 1886 earthquake is not compelling based on available data and more work is needed to demonstrate whether or not this structure represents the causative fault for the 1886 Charleston earthquake. The shallowest observed deformation associated with fault C is at roughly 100 meters below the ground surface, likely within Eocene deposits of the Santee formation (Reference 3). Chapman

and Beale's (2008) (Reference 3) fault C deforms Eocene deposits, but deformation in younger deposits is not yet demonstrated by available data.

In Summary, available data support the assessment that the bounding faults of Mesozoic basins in the site region are not capable tectonic sources. This assessment is supported by: (1) the lack of spatial correlation between seismicity and Mesozoic basin-bounding faults, as shown in RAI Figure 02.05.01-22.1; and (2) the absence of Quaternary deformation associated with the Pen Branch fault, the most extensively studied Mesozoic basin-bounding fault within the site region.

FSAR Subsection 2.5.1.1.2.4.2 will be revised to provide clarification regarding the general lack of spatial correlation between Mesozoic basins and seismicity in the site region.

References:

1. Brune, J.N., *Tectonic Stress and the Spectra of Seismic Shear Waves from Earthquakes*, Journal of Geophysical Research 75 (26):4,997-5,009, 1970.
2. Brune, J.N., *Correction to Brune (1970)*, Journal of Geophysical Research 76(20):5,002, 1971.
3. 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.
4. Mahdyiar, M. *A Nomograph to Calculate Source Radius and Stress Drop from Corner Frequency, Shear Velocity, and Seismic Moment*, Bulletin of the Seismological Society of America 77 (1):264-265, 1987.
5. Vogtle ESP Final Safety Evaluation Report - Chapter 2.0, Section 2.5 Geology, Seismology, and Geotechnical Engineering, ADAMS Accession ML090130404, dated February 4, 2009.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

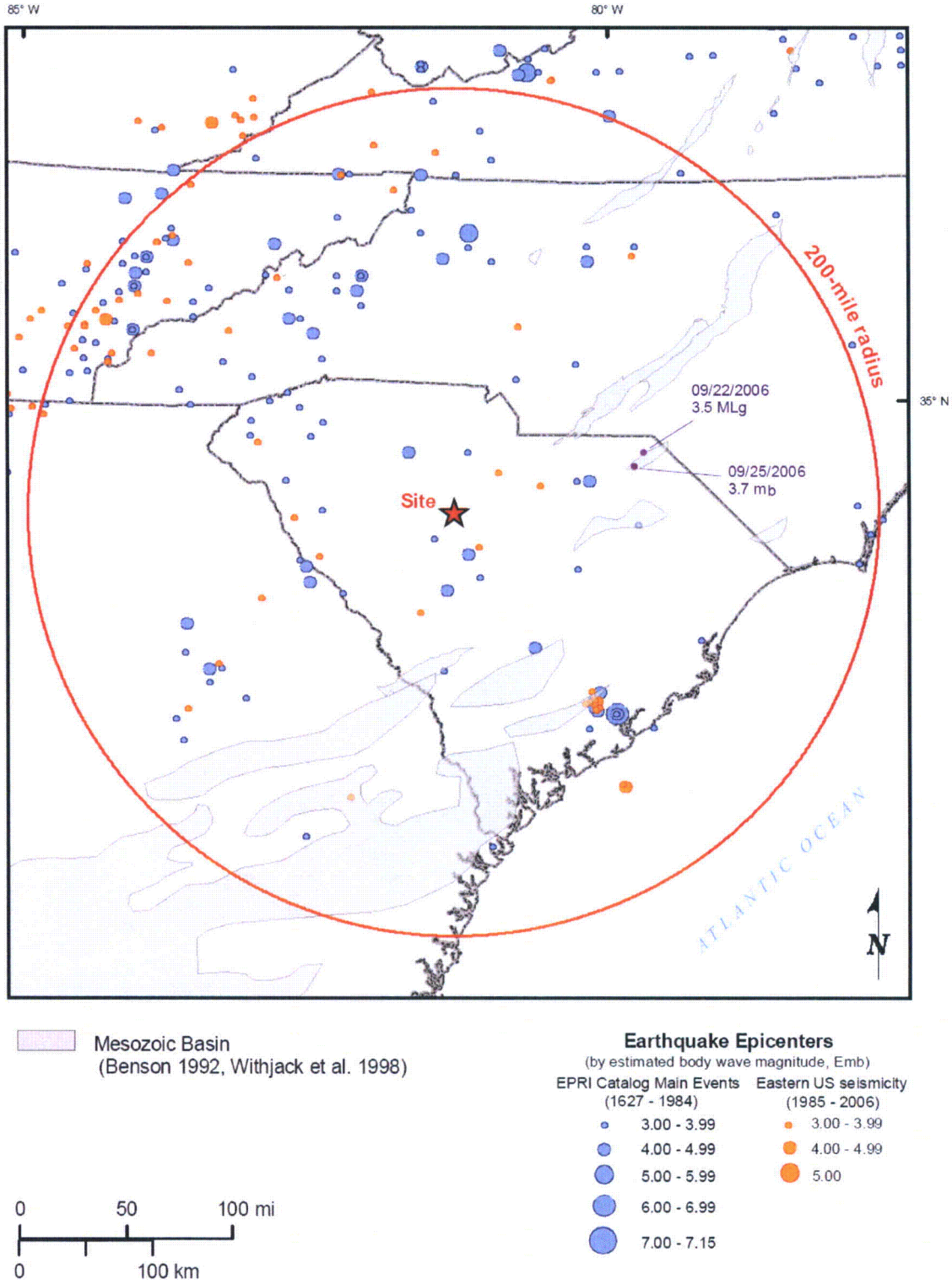
FSAR Subsection 2.5.1.1.2.4.2, pages 2.5.1-24 through 2.5.1-25, will be revised as follows:

Mesozoic Rift Basins

A broad zone of fault-bounded, elongate depositional basins associated with crustal extension and rifting formed during the opening of the Atlantic Ocean in early Mesozoic time. These rift basins are common features along the eastern coast of North America from Florida to Newfoundland. Wheeler (Reference 404) suggests that many earthquakes in the eastern part of the Piedmont province and beneath the Coastal Plain province may be associated spatially with buried normal faults related to rifting that occurred during the Mesozoic Era. However, no definitive correlation of seismicity with Mesozoic normal faults has been conclusively demonstrated. Figure 2.5.1-212 shows the lack of spatial correlation between Mesozoic basins and seismicity within 50 miles of the site. To date, there is no positive correlation between earthquakes in the site region and Mesozoic basins. Normal faults in this region that bound Triassic basins may be listric into the Paleozoic detachment faults, or may penetrate through the crust as high-angle faults (*e.g.,* Reference 359). Within regions of stable continental cratons, areas of extended crust potentially contain the largest earthquakes (Reference 301) (Figure 2.5.1-214). Mesozoic basins have long been considered potential sources for earthquakes along the eastern seaboard (Reference 402) and were considered by most EPRI ESTs in their definition of seismic sources (Reference 250).

ASSOCIATED ATTACHMENTS:

RAI Figure 02.05.01-22.1



RAI Figure 02.05.01-22.1 Mesozoic Basins and Seismicity in the Site Region.

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-23

FSAR Section 2.5.1.1.2.4.3 (pgs 2.5.1-25 and 2.5.1-26) discusses the Camden fault under Cenozoic age regional structures, stating in one sentence that age of most recent slip is uncertain and, in another, that age of displacement along the Camden fault is constrained because overlying Tertiary deposits are not offset. There is no indication which interpretation is preferred, and pertinent information from the original cited source (Knapp and others, 2001) related to the constrained age interpretation is not summarized to document a pre-Quaternary age for this fault.

In order for the staff to assess the hazard potential for the Camden fault, please clarify whether the age of this fault is considered to be constrained or is uncertain, and summarize the information used by Knapp and others (2001) to suggest the fault is pre-Quaternary in age.

VCSNS RESPONSE:

Recent interpretations indicate the Camden fault is Oligocene or older in age, based on: (1) up-to-the-north vertical separation of the basal Late Cretaceous unconformity of about 65 to 120 feet; and (2) undeformed and unfaulted deposits of the Oligocene Upland formation (Balinsky 1994; Secor et al. 1998; Knapp et al. 2001; Barker and Secor 2005) (FSAR References 2.5.1-207, 2.5.1-368, 2.5.1-312 and 2.5.1-208). These interpretations are based on geologic mapping and geophysical data, as described below.

Geologic mapping by Balinsky (1994) (FSAR Reference 2.5.1-207) in the Rabon Crossroads quadrangle suggests that the Camden fault is a reactivated Late Paleozoic ductile structure, with roughly 120 feet of brittle slip during the Late Mesozoic to Cenozoic. This estimate of 120 feet of brittle slip is based on the apparent offset of the basal Late Cretaceous unconformity beneath Atlantic Coastal Plain sediments. Balinsky (1994) (FSAR Reference 2.5.1-207) maps silicified breccias in the fault zone and speculates these may indicate possible early Mesozoic age for reactivation. Based on field relations, Balinsky (1994) (FSAR Reference 2.5.1-207) suggests the latest movement on the Camden fault likely predates deposition of the Oligocene Upland formation gravels, which appear unfaulted and undeformed.

Geologic mapping by Barker and Secor (2005) (FSAR Reference 2.5.1-208) in the Longtown quadrangle suggests that the basal Late Cretaceous unconformity is not offset by the Camden fault, at least in this quadrangle. However, geologic mapping by

Secor et al. (1998) (FSAR Reference 2.5.1-368) in the adjacent Rabon Crossroads quadrangle, indicates greater than 65 feet of up-to-the-north vertical separation of the basal Late Cretaceous unconformity. Based on this inconsistency, Barker and Secor (2005) (FSAR Reference 2.5.1-208) state that the age of most recent movement on the Camden fault is uncertain.

Shallow seismic reflection data and a 2-D gravity survey collected and interpreted by Knapp et al. (FSAR Reference 2.5.1-312) provide evidence for approximately 80 to 100 feet of up-to-the-north vertical separation of the basal Late Cretaceous unconformity across the Camden fault. Moreover, these data suggest that undeformed and unfaulted deposits of the Oligocene Upland formation cover the southwest projection of the Camden fault. As such, Knapp et al. (FSAR Reference 2.5.1-312) conclude that slip on the Camden fault predates deposition of the Oligocene Upland formation gravels.

Taken together, these geologic and geophysical data suggest that the Camden fault is Oligocene or older in age. FSAR Subsection 2.5.1.1.2.4.3 will be modified to indicate more clearly the age constraints on the Camden fault.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

COLA Part 2, FSAR. Chapter 2, Subsection 2.5.1.1.2.4.3, second through fourth paragraphs, pages 2.5.1-25 – 2.5.1-26, will be revised as follows:

Camden Fault

The northeast striking Camden fault is located in the eastern part of the Ridgeway-Camden area (Figure 2.5.1-213), about 40 miles from the VCSNS site. Along much of its length, the Camden fault juxtaposes crystalline rocks of the Carolina terrane on the northwest against crystalline rocks interpreted to be part of the Alleghanian Modoc shear zone on the southeast (Reference 368). Total slip on the Camden fault is uncertain, although, based on geologic mapping; Secor et al. (Reference 368) suggest total displacement on the order of kilometers is likely in order to explain the apparent disruption of crystalline rocks across the fault.

Up-to-the-north vertical separation of the basal Late Cretaceous unconformity of about 50 to ~~80~~120 feet ~~suggests~~ indicates Late Mesozoic and possibly Cenozoic ~~(pre-Oligocene)~~ reactivation of the Camden fault (References 207, 312, and 368). ~~Map relationships in the northeastern Rabon Crossroads quadrangle suggest a northwest-side up vertical separation of the unconformity at the base of the sand unit of about 80 feet. However, more recent mapping~~ Mapping by Barker and Secor (Reference 208) in the southeast corner of the Longtown quadrangle suggests that the base of the

unconformity is not offset by the Camden fault, at least in this quadrangle. Balinsky (1994) suggests latest movement on the Camden fault predates deposition of the Oligocene Upland formation gravels (Reference 207). Likewise, ~~Therefore, based on map relationships, the age of most recent slip on the Camden fault is uncertain.~~

~~Knapp et al. (Reference 312) describe seismic reflection and gravity data that they interpret as suggesting an 80 to 100 feet offset of the base of the Coastal Plain section.~~ Knapp et al. (Reference 312) suggest that undeformed and unfaulted deposits of the Oligocene Upland formation cover the southwest projection of the Camden fault. ~~is covered by deposits of the Tertiary Upland formation,~~ Taken together, these data suggest that the Camden fault is Oligocene or older in age (References 207, 312, and 208). ~~providing a potential upper age limit on the Cenozoic movement of the fault.~~

ASSOCIATED ATTACHMENTS:

None

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-42

FSAR Section 2.5.1.1.3.2.2 (pgs 2.5.1-44 and 2.5.1-45) discusses the Pembroke faults of probable Quaternary age which occur within the Giles County seismic zone, and concludes that these shallow faults are unrelated to seismicity within the seismic zone. There is no discussion regarding whether the Pembroke faults could represent shallow tectonic structures which were triggered by deeper faulting within the Giles County seismic zone.

In order for the staff to assess the hazard potential for the shallow Pembroke faults, please discuss whether they could have been triggered by deeper faulting within the Giles County seismic zone.

VCSNS RESPONSE:

As described in detail in the response to RAI 2.5.1-30, the Pembroke faults are mapped in early Quaternary to latest Pliocene alluvial deposits exposed in a roadcut in the general vicinity of the Giles County seismic zone. These alluvial deposits overlie faulted and folded Ordovician carbonate rocks that are susceptible to dissolution. It is unclear whether the faults in alluvium can be traced continuously downward and connected with faults in the underlying carbonate rocks. Moreover, it is unclear whether these surficial faults are related to tectonic processes or result from collapse related to dissolution of the carbonate rocks (e.g., Williams and Callis 1996; Law et al. 1997; Crone and Wheeler 2000) (References 2; 1; FSAR Reference 2.5.1-232).

FSAR Subsection 2.5.1.1.3.2.3 states, "The shallow Pembroke faults do not appear to be related to the seismicity within the Giles County seismic zone, which is occurring beneath the Appalachian basal decollement in the North American basement" [pp. 2.5.1-44 – 45]. The role of the Appalachian basal decollement in regional seismicity is the focus of numerous studies. For example, as described in FSAR Subsection 2.5.1.1.2.4.1, Wheeler (1995) (FSAR Reference 2.5.1-404) observes that much of the sparse seismicity in eastern North America occurs within the North American basement below the basal decollement. Bollinger and Wheeler (1988) (FSAR Reference 2.5.1-217) observe that, in the Giles County region, the basal decollement occurs at approximately 4 to 7 kilometers below the ground surface and, accordingly, structures in rocks shallower than 4 to 7 kilometers are unrelated to deeper structures. Bollinger and Wheeler's (1988) (FSAR Reference 2.5.1-217) Table 4 indicates that seismicity in the Giles County seismic zone occurs at depths greater than about 4.5 kilometers. Likewise, Chapman and Krimgold (1994) (FSAR Reference 2.5.1-222) observe that seismicity in the Giles County seismic zone is occurring at depths ranging from 5 to 25

kilometers. As such, there is no apparent direct connection between seismicity at depth and structures observed at and near the surface. According to Chapman and Krimgold (1994) (FSAR Reference 2.5.1-222):

> Earthquakes in the [Giles County seismic] zone occur well below the Valley and Ridge thrust sheets. This detachment separation implies that any correlation between the surface features and seismogenic structures at depth may be tenuous or completely lacking [pp. 8-9].

Similarly, Bollinger and Wheeler (1988) (FSAR Reference 2.5.1-217) state:

> [Earthquakes in the Giles County seismic zone] lie below the deepest likely thrust fault, indicating that Giles County seismicity probably has no simple relationship to surface geology...whatever structures cause the earthquakes have nothing obvious to do with exposed structures or stratigraphic units" [pp. 1 and 7].

There is no demonstrable association between Giles County seismicity at depth and any structures within the overlying Appalachian thrust sheets, including the Pembroke faults, which may not even be tectonic in origin. Even if the Pembroke faults are seismogenic structures, their fault plane area, and therefore their seismic potential, is limited by the basal decollement at approximately 4 to 7 kilometers depth. The possibility that the Pembroke faults represent "triggered" slip from earthquakes at depth is not supported by available data. It is possible that the Pembroke faults represent dissolution collapse triggered by strong ground shaking from earthquakes below the basal decollement. In the absence of data suggesting a temporal relationship between Giles County seismicity at depth and slip on the Pembroke faults at the surface, however, this inference remains highly speculative.

References:

1. Law, R.D., Robinson, E.S., Cyrnak, J.S., Sayer, S., Williams, R.T., Callis, J., and Pope, M., *Geologically Recent Faulting and Folding of Alluvial Sediments Near Pearisburg, Giles, County, Virginia- Tectonic Faulting or Karst Subsidence in Origin?* Eos- Transactions of the American Geophysical Union, v. 78, no. 17 supplement, p. S316, 1997.
2. Williams, R.T. and Callis, J.G., *Collocated Seismic Reflection and Radar Profiles Over Quaternary Normal Faults in Southwestern Virginia*, Eos- Transactions of the American Geophysical Union, v. 77, no. 46 supplement, p. F497-F498, 1996.

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

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-43

FSAR Section 2.5.1.2.2 (pg 2.5.1-46) states that the Central Piedmont shear zone (CPSZ) is located about 24.14 km (15 mi) northwest of the Summer site. However, this regional shear zone is not shown on the site vicinity geologic map presented in FSAR Figure 2.5.1-220, and locating it would help to define the northwestern extent of the Charlotte Terrane in which the site is located. In addition, other faults mapped in the site vicinity (e.g., the Cross Anchor, Summers Branch, Wateree, and #67 faults and the unnamed fault near Parr) are not labeled in Figure 2.5.1-220. Furthermore, the along-strike length of the Chappells shear zone appears to be inaccurate based on how this feature is represented as extending west-southwestward from the site in FSAR Figure 2.5.1-212.

In order for the staff to completely understand the geologic setting of the Summer site in relation to regional tectonic structures, please locate the CPSZ on the site vicinity geologic map presented in Figure 2.5.1-220. Please also label other faults mapped in the site vicinity, and define the northwestern boundary of the Charlotte Terrane on Figure 2.5.1-220. Please indicate the along-strike extent of the Chappells shear zone west of the site.

VCSNS RESPONSE:

FSAR Figure 2.5.1-220 will be revised to show the following:

- Location of the Central Piedmont shear zone (CPSZ). In the site vicinity, the Cross Anchor fault represents the CPSZ and the northwestern boundary of the Charlotte Terrane.
- Location of the postulated unnamed fault near Parr.
- Location of Prowell's (1983) (FSAR Reference 2.5.1-346) fault #67.
- Labels for the Cross Anchor fault, Wateree Creek fault, the postulated Summers Branch fault.
- Label for the southwestern extent of the Chappells shear zone. As shown on revised FSAR Figure 2.5.1-220 and FSAR Table 2.5.3-201, the Chappells shear zone is approximately 60 miles long.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

COLA Part 2, FSAR. Chapter 2, Figure 2.5.1-220 will be revised as described in response to RAI 02.05.01-43.

ASSOCIATED ATTACHMENTS:

FSAR. Figure 2.5.1-220 (Sheets 1 and 2)

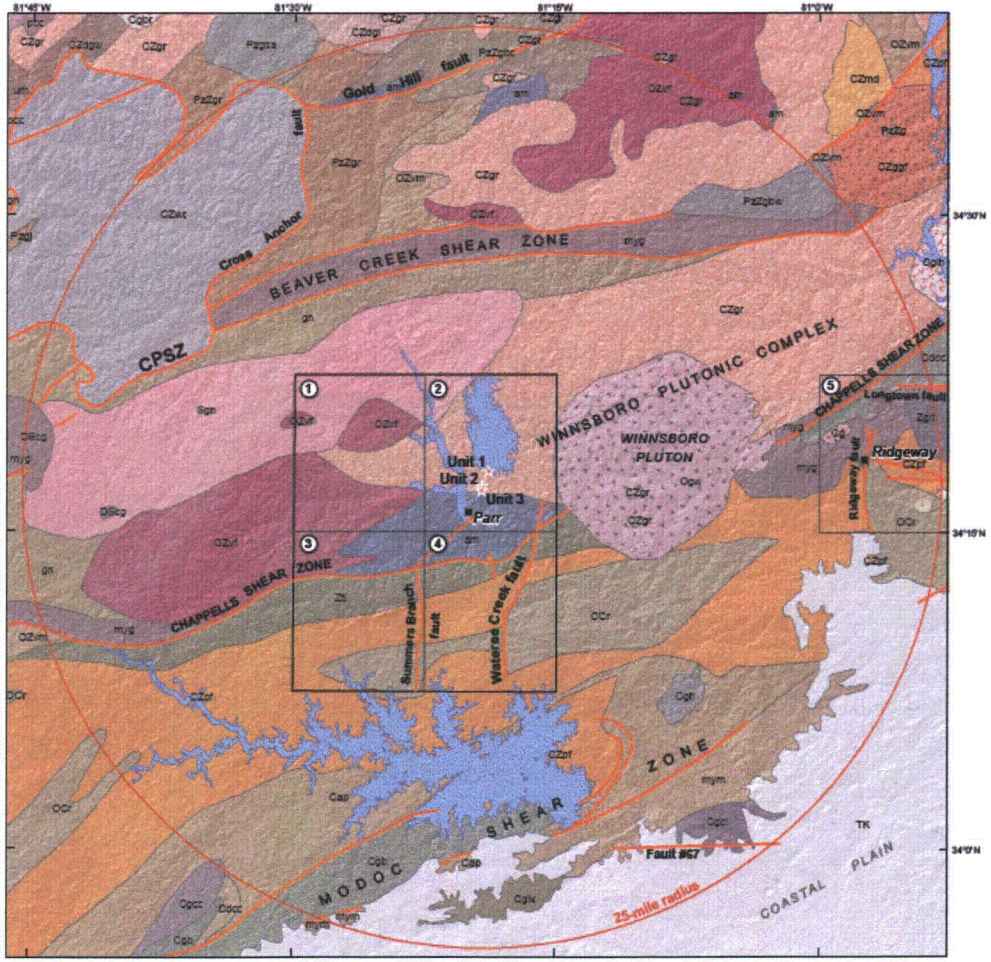


Figure 2.5.1-220. Site Vicinity Geologic Map (Sheet 1 of 2)

Explanation

Horton and Dicken (2001)

LATE PALEOZOIC

- mylg — Mylonitic gneiss
- mylm — Mylonitic rocks of Modoc fault zone

CARBONIFEROUS TO PERMIAN

- Cpb — Granite, Balesman pluton
- Cpbr — Granite, Bald Rock pluton
- Cpcc — Granite, Clouds Creek pluton
- Cpcl — Granite, Columbia pluton
- Cph — Granite, Hartolson pluton
- Cplh — Granite, Liberty Hill pluton
- Cpw — Granite, Winnsboro pluton
- Cpln — Granite, Lexington pluton

CARBONIFEROUS

- Cdcc — Gabbro and diorite, Clouds Creek pluton
- Cdpc — Gabbro and diorite, Dutchmans Creek pluton

DEVONIAN TO SILURIAN

- Dsbg — Gabbro

SILURIAN

- Sgn — Newberry granite and similar, possibly related granites

ORDOVICIAN TO MIDDLE CAMBRIAN

- OCr — Richtex Formation - metamudstone

MIDDLE CAMBRIAN

- Cap — Asbill Pond Formation - metamorphosed siltstone and sandstone with interbedded metavolcanic rocks

PALEOZOIC

- Pzg — Granite sheets near Joanna
- Pzgss — Santuck granite

MIDDLE PALEOZOIC TO MIDDLE PROTEROZOIC

- Pz2g — Metagabbro and minor metadiorite
- Pz2gbc — Metagabbro and minor metadiorite - Chester
- Pz2gbw — Metagabbro and minor metadiorite - Big Wateree Creek

ORDOVICIAN TO MIDDLE PROTEROZOIC

- O2vf — Felsic metavolcanic rocks and layered felsic gneiss
- O2vm — Mafic to intermediate metavolcanic rocks including hornblende gneiss and amphibolite

PALEOZOIC TO MIDDLE PROTEROZOIC

- Pz2gr — Metamorphosed granitoids
- am — Amphibolite and amphibole gneiss
- gn — Biotite-quartz-plagioclase gneiss
- um — Ultramafic rock - metamorphosed

EARLY PALEOZOIC MIDDLE PROTEROZOIC

- C2dgl — Metadiorite and minor metagabbro - Lockhart metadiorite
- C2dgw — Metadiorite and minor metagabbro - Wildcat Branch complex

CAMBRIAN OR MIDDLE PROTEROZOIC

- C2gsf — Great Falls metagranite - metamorphosed muscovite-biotite granite
- C2gr — Metamorphosed granite to granodiorite
- C2md — Metadiorite
- C2pf — Persimmon Fork Formation - mainly metatuff
- C2wr — Biotite-quartz-feldspar gneiss of Whitmire reentrant

MID PROTEROZOIC

- Z3 — Metatolanite

UNDIFFERENTIATED

- pcc — Philson Crossroads complex - biotite-quartz-feldspar gneiss having layers of amphibolite and metagranite

Other Mapped Quandrangles, not shown

1. Pomaria 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
2. Jenkinsville 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
3. Little Mountain 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
4. Chapin 7.5-minute quandrangle, Secor (2007); See Figure 2.5.1-225
5. Ridgeway 7.5-minute quandrangle, Secor et al. (1996); See Figure 2.5.1-213

Faults modified from Hibbard et al. (2006) and Secor (2007); dashed where postulated and likely non-existent

Figure 2.5.1-220b. Explanation of Site Vicinity Geologic Map (Sheet 2 of 2)

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-44

FSAR Section 2.5.1.2.2 (pgs 2.5.1-46 and 2.5.1-47) lists 10 geologic events that affected rocks in the site area. This FSAR section states that definition of these 10 events was based on results of radiometric age dating analyses performed for Unit 1, which implies that these events are arranged in a chronologic sequence. However, although absolute age dates are presented for three other geologic events in a separate list, those three events are not keyed to the longer list of 10 events. Therefore, the radiometric age dates alluded to in FSAR Section 2.5.1.2.2 (pg 2.5.1.46) are not provided for the 10 geologic events to clarify event chronology and constrain the timing of faulting and folding for the site area. In addition, no references are cited to document the sources of the radiometric age data. Finally, the amount of displacement related to "minor" and "very minor" movement along northeast and northwest-trending joints is not specified.

In order for the staff to understand the geologic setting of the Summer site in relation to geologic events which occurred within the site area, including complex faulting and folding of the Charlotte Terrane, please add the radiometric age dates to the list of events. Please combine the two separate lists, if they are related, to present the information concisely. Please also summarize the specific age dating information used to constrain faulting in the site area; provide references to document the sources of the radiometric age data; and quantify the amount of displacement related to "minor" and "very minor" movement along the two joint systems.

VCSNS RESPONSE:

The relative ordering of the ten geologic events described in FSAR Subsection 2.5.1.2.2 that affected rocks in the site area is based on crosscutting relationships between structures, between intrusive phases and structures (or structural fabrics), and/or by textural relationships exhibited by post-kinematic mineralization. Of these ten events, there are four for which absolute or limiting ages can be established based on thermochronlogic data from previous site investigations (Dames & Moore 1974) (FSAR Reference 2.5.1-240), or that can be inferred based on regional correlations within the Charlotte terrane (Hibbard et al. 2002) (FSAR Reference 2.5.1-283). These four events provide chronologic reference points that may used to calibrate the geochronologic history expressed in the list of ten events. RAI Table 02.05.01-44.1 tabulates the geochronologic evidence constraining the timing of geologic events in the site area.

The earliest geologic event for which relatively well-defined geochronologic data are available is the development of regional penetrative structural fabric and metamorphism in the Charlotte terrane country rocks of the site area. This event occurred prior to 535 Ma based on crosscutting relationships with an undeformed dike (Dennis and Wright 1997; Hibbard et al. 2002) (Reference 2; FSAR Reference 2.5.1-283.)

The second geologic event for which an absolute age may be established is the intrusion and solidification of the Winnsboro plutonic complex. Crystallization of the Winnsboro pluton is estimated at 295±2 Ma based on a whole rock Rb-Sr isochron reported in McSween et al. (1991) (Reference 5). This result is consistent with the occurrence of xenoliths of foliated country rock (Charlotte terrane) within the Winnsboro plutonic complex.

The third geologic event for which an absolute age may be established is the intrusion of aplite and pegmatite into the Winnsboro plutonic complex. The cooling to aplite and pegmatite subsolidus temperatures is indicated by Rb-Sr and K-Ar biotite ages, as presented in Dames & Moore's (1974) (FSAR Reference 2.5.1-240) Table 1 (Summary of Results of Radiometric Ages Determinations). Several of these ages are from samples that are mixed phases (whole-rock), weathered, or from phases that are not well characterized in terms of their isotopic thermal behavior, therefore their thermochronologic interpretation is uncertain. However, sample NK2.1 from unweathered granodiorite yields a Rb-Sr isochron age of 292±10 Ma. Footnote 1 to Table 1 indicates that this is a two-point, whole-rock – biotite isochron. As such, this age effectively reflects the biotite mineral cooling age for this sample. Sample NK2.1 also yields a biotite K-Ar age of 292±17 Ma. Several other samples on biotite from unweathered material (samples SC2.1, SC2.3, SD3.3, NJ1.1, and SH1) yield K-Ar ages ranging from 289 to 297 Ma. This age range is well within the analytical uncertainty reported for each age (about ±16 Ma). The good agreement between ages from multiple samples indicates that the Winnsboro plutonic complex cooled to below the temperature necessary to homogenize strontium isotopes between biotite and whole rock and for retention of argon within biotite (about 300^{0}C; McDougall and Harrison 1999) (Reference 4) at about 292 Ma, shortly after crystallization of the Winnsboro plutonic complex at 295 Ma. The thermal conditions expressed by isotopic closure of biotite to argon (approximately 300^{0}C) represent subsolidus conditions (<700^{0}C) for both aplite and pegmatite (Krauskoft 1979, pp. 324-330) (Reference 3) and constrain their formation to this relatively short time interval. This is consistent with the conventional interpretation of aplite and pegmatite as late-stage residual, uncrystalized components of the magma that are the final phases to crystallize and that typically occur in association with fractures (Williams et al. 1982) (Reference 8).

The fourth absolute age determination that provides geochronologic calibration to the site area geologic history is the crystallization of post-kinematic laumontite in association with some fractures and healing of microbreccias. Dames & Moore (1974) (FSAR Reference 2.5.1-240) describes K-Ar dating of hand-picked laumonite crystals collected from a vug associated with a minor shear exposed in the VC Summer Unit 1 foundation. As described by Dames & Moore (1974) (FSAR Reference 2.5.1-240), the 45±5 Ma age for these laumonite crystals likely represents a minimum. Pressure and

temperature conditions necessary for stability of laumontite (Coombs et al. 1959; Thompson 1971) (References 1 and 7) have not been present in the Piedmont since the occurrence of hydrothermal activity associated with Mesozoic rifting of the Atlantic margin (Naeser et al. 2001) (Reference 6). The occurrence of undeformed laumontite crystals in association with fractures and microbreccias associated with jointing effectively constrains the displacement associated with these structures as Mesozoic or earlier.

FSAR Section 2.5.1.2.2 uses the qualitative terms "minor" and "very minor" to describe movement along northeast- and northwest-striking joints. As indicated in RAI Table 02.05.01-44.1, the offsets along northeast- and northwest-striking joints measured in the VC Summer Unit 1 foundation are roughly 7 feet and <2 feet, respectively (Dames & Moore 1974) (FSAR Reference 2.5.1-240).

References:

1. Coombs, D.S, Ellis, A.J., Fyfe, W.S., and Taylor, A.M., *The Zeolite Facies, with Comments on the Interpretation of Hydrothermal Synthesis*, Geochimica et Cosmochemica Acta, v.17, p.53-107, 1959.

2. Dennis, A.J. and Wright, J.E., *The Carolina Terrane in Northwestern South Carolina, USA: Age of Deformation and Metamorphism in an Exotic Arc*, Tectonics, v.16, p. 460-473, 1997.

3. Krauskoft, K.B., *Introduction to Geochemistry*, Second Edition McGraw Hill Book Co., 1979.

4. McDougall, I. and Harrison, T.M., *Geochronology and Thermochronology by the 40Ar/39Ar Method*, 2nd edition, Oxford University Press, New York, 1999.

5. McSween, H.Y. Jr., Speer, J.A., and Fullagar, P.D., *Plutonic Rocks*, in J.W. Horton and V. A. Zullo (eds.), The Geology of the Carolinas: Carolina Geological Society Fiftieth Anniversary Volume, p.109-126, 1991.

6. Naeser, C.W., Naeser, N.D., Kunk, M.J., Morgan, B.A., Schultz, A.P., Southworth, C.S., and Weems, R.E., *Paleozoic Through Cenozoic Uplift, Erosion, Stream Capture, and Deposition History in the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain Provinces of Tennessee, North Carolina, Virginia, Maryland, and District of Columbia*, U.S. Geological Survey Open-File Report 01-406, p.129, 2001.

7. Thompson, A.B., *P CO_2 in Low-Grade Metamorphism: Zeolite, Carbonate, Clay Mineral, Prehnite Relations in the System CaO-Al_2O_3-SiO_2-CO_2-H_2O*, Contributions to Mineralogy and Petrology, v.33, p.145-161, 1971.

8. Williams, H., Turner, F.J., and Gilbert, C.M., *Petrography, An Introduction to the Study of Rocks in Thin Sections*, 2nd edition, W.H. Freeman Co., 1982.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

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

ASSOCIATED ATTACHMENTS:

RAI Table 02.05.01-44.1

RAI Table 02.05.01-44.1. Summary of Geologic Events Affecting the Site Area

Event	Result	Age	Control	References
1. Volcanic and clastic sedimentation associated with subduction-related volcanic arc	Formation of Charlotte Terrane protolith rocks	Late Proterozoic to Early Cambrian	Correlation with regional relationships expressed in the Charlotte Terrane	Hibbard et al. (2002)
2 & 3. Regional metamorphism and deformation	Amphibolite facies metamorphism, complex folding and fabric development in Charlotte Terrane	550 to 535 Ma	Correlation with regional relationships expressed in the Charlotte Terrane (Crosscutting relationships between metamorphic fabric and undeformed dike)	Dennis and Wright (1997); Hibbard et al. (2002)
4. Intrusion of granodiorite into Charlotte Terrane	Crystallization of Winnsboro pluton; inclusion of foliated country rock as xenoliths	295±2 Ma	Rb-Sr Whole Rock Isochron	Fullagar (1983) as reported in McSween et al. (1991)
5. Response to regional stresses	Production of joints	Pre- to syn-aplite and pegmatite intrusion (see below)	Aplite and pegmatite intrudes along and is cut by joints	Dames & Moore (1974)
6. Intrusion of aplite and pegmatite	Aplite and pegmatite dikes	295 to 292 Ma	Cooling to aplite and pegmatite subsolidus tempertures as indicated by Rb-Sr and K-Ar biotite ages	Dames & Moore (1974)
7. Activation of northeast-striking joints	Minor (6 to 7 ft) displacement along northeast-striking joints	Post aplite and pegmetite; pre-northwest-striking joint displacement (see below)	Northwest-striking joint displacement offsets northeast-striking joints	Dames & Moore (1974)
8. Activation of northwest-striking joints	Very minor (< 2 ft) displacement along northwest-striking joints	Mesozoic (see below)	Fractures and associated microbreccias healed with post-kinematic mineralization of laumontite	Dames & Moore (1974)
9. Hydrothermal metamorphism	Mineralization along joints and within microbreccia	45±5 Ma (minimum), likely Mesozoic	Latest age for pressure and temperature conditions necessary for laumontite stability	Coombs et al. (1959); Thompson (1971); Dames & Moore (1974); Naeser et al. (2001)
10. Stable continental margin	Epeirogenic uplift, weathering, and erosion	Mesozoic to present	Coastal Plain sedimentation	Dames & Moore (1974)

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SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-45

FSAR Section 2.5.1.2.3 (pg 2.5.1-49) refers to amphibolite-grade meta-igneous and meta-sedimentary rocks of the Carolina Zone which occur within the site area, but does not clarify whether these units specifically occur in the Charlotte Terrane of the Carolina Zone.

In order for the staff to completely understand the geologic setting of the Summer site and site area in relation to regional geology and lithotectonic elements, please clarify whether the specific units being discussed under FSAR Section 2.5.1.2.3, page 2.5.1-49 (as well as other rock units discussed under this FSAR section), occur within the Charlotte Terrane of the Carolina Zone.

VCSNS RESPONSE:

Hibbard et al. (2002) (FSAR Reference 2.5.1-283) define the Carolina Zone as an amalgamation of mainly Neoproterozoic to Early Paleozoic metaigneous-dominated terranes along the eastern flank of the southern Appalachians. As described in response to RAI 02.05.01-3, Hibbard et al. (2007) (Reference 2) refer to the Carolina Zone as "Carolinia" and Hatcher et al. (2007) (Reference 1) use the term "Carolina Superterrane."

The VCSNS site area is located within the westernmost terrane of the Carolina Zone, the Charlotte Terrane, as shown in Hibbard et al.'s (2002) (FSAR Reference 2.5.1-283) Figure 2. The Charlotte Terrane is dominated by Neoproterozoic to late Paleozoic plutonic rocks that intrude a suite of mainly metaigneous rocks (Hibbard et al. 2002) (FSAR Reference 2.5.1-283).

References:

1. Hatcher, R.D. Jr., Bream, B.R., and Merschat, A.J., *Tectonic Map of the Southern and Central Appalachians: A Tale of Three Orogens and a Complete Wilson Cycle*, in 4-D Framework of Continental Crust, Geological Society of America Memoir 200, p. 595-625, 2007.
2. Hibbard, J.P., van Stall, C.R., Rankin, D.W., *The Comparative Analysis of Pre-Silurian Crustal Building Blocks of the Northern and the Southern Appalachian Orogen*, American Journal of Science, v. 307, p. 23-45, 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

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-46

FSAR Section 2.5.1.2.4 (pgs 2.5.1-51 and 2.5.1-52) discusses three minor shear zones which were mapped in the Unit 1 excavation and constrained by radiometric age dating results to be likely no younger than Mesozoic or Early Cenozoic in age. However, there is no discussion of sample controls for the unsheared minerals extracted from the shear zones to ensure that they were collected in the part of the shear zone which experienced the last movement. This FSAR section (pg 2.5.1-51) states that minor shears of this type are common in rocks of the Piedmont, but no reference is cited to document this statement. This FSAR section (pg 2.5.1-52) also indicates, based on investigations performed for Unit 1, that an evaluation was performed regarding the potential for movement along the shear zones due to filling of the Monticello Reservoir. The conclusion drawn is that reservoir impoundment would not adversely affect the shears; that both northwest and northeast-striking shears existed although the dominant set trends northeast; and that these shears were not observed to penetrate the soil profile. No details, however, are provided to document either of these three additional statements.

In order for the staff to assess the adequacy of the information presented in the FSAR related to faults mapped in the Unit 1 excavation (which may also be expected to occur at Units 2 and 3), please do the following:

(a) Please discuss sample controls which were implemented for collecting the unsheared minerals to ensure that they were collected in the part of the shear zone which experienced the last movement, and add the sampling location(s) to the map shown in FSAR Figure 2.5.1-230.

(b) Please provide references to document the statement that minor shears of the type mapped in the Unit 1 excavation are common in rocks of the Piedmont.

(c) Please summarize information used to conclude that impoundment of the Monticello Reservoir would not adversely affect the shear zones based on evaluation results.

(d) Please clarify the statement that shears trending both northeast and northwest occur in the Unit 1 excavation in light of the fact that only three northeast-trending shear zones with offsets are shown in the map of FSAR Figure 2.5.1-230.

(e) Please clarify the statement that shears did not penetrate the soil profile, when it is likely that they may have penetrated saprolite overlying hard rock due to the interpreted timing of formation.

VCSNS RESPONSE:

(a) As described by Dames & Moore (1974) (FSAR Reference 2.5.1-240), a careful strategy was used to collect and analyze samples for characterizing V. C. Summer Unit 1 foundation shears and joints. As requested, the map in FSAR Figure 2.5.1-230 will be revised to display sample locations. Samples were collected from the cleaned Unit 1 excavation rock surface as well as core from a 45° angle boring in order to obtain the least-weathered shear zone material. Samples were obtained to perform age dating, thin-section analyses, and x-ray diffraction. Potassium-argon (K-Ar) and rubidium-strontium (Rb-Sr) radiometric age dating techniques were used to obtain whole rock and biotite ages from samples of granodiorite (unweathered and hydrothermally altered), aplite (sheared and unsheared), and microbreccia within shears. K-Ar ages were also obtained for hydrothermal laumontite crystals growing in vugs along one of the shears. Two thin sections were prepared and evaluated for each dating specimen and analyses were also performed on thin sections oriented perpendicular to shears as well as grain mounts obtained from microbreccia to evaluate the nature and mineralogy of the shear zones. X-ray diffraction analyses were also performed to identify the mineralogy within the shear zones.

The following discussion summarizes the sampling and analyses presented in Dames & Moore (1974) (FSAR Reference 2.5.1-240), as well as key observations and results that demonstrate the analyses were performed for those parts of the shear zones that experienced the last movement, and that the last movement is constrained as no younger than Mesozoic in age.

Samples for age dating were collected from the least-weathered microbreccia in each of the widest shears from shear Zones 1 and 3. Control samples were also collected from unfractured and unweathered rock, approximately 5 to 15 feet on either side of the primary sample locations. Based on crosscutting field relationships, the microbreccia and hydrothermal mineral growth along shear zones post-date formation of the younger rock units (granodiorite and aplite dikes), and thus were the focus of additional sampling. From shear Zone 3, specimens were collected for X-ray diffraction to identify minerals and fracture-filling material related to hydrothermal activity. Hand picking of individual crystals using needle and tweezers isolated a pure mineral concentrate for X-ray diffraction analysis. This analysis identified the predominant hydrothermal mineral as laumonite, occurring as both vein filling in the microbreccias and as euhedral and subhedral crystals in vugs along shears. Euhedral crystals of laumontite were also sampled in this same manner for K-Ar age dating. X-ray diffraction identified lesser amounts of alpha quartz and kaolin within the microbreccias.

Both mesoscopically and microsopically, the microbreccias appear to be produced by brittle failure, exhibiting angular rock and crystal fragments suspended in a matrix of

compositionally similar, but finer, material. Under 200x and 400x magnification, the matrix has a distinct interlocking crystal mosaic and there is no evidence of un-recrystallized rock powder. The microbreccias, which typically exhibit a thickness of one to two inches but locally widen to a maximum width of less than two feet, are thoroughly permeated by hydrothermal laumontite, which occurs as both vein filling and crystals and crystal groups in microbreccia. The following mesoscopic and microscopic observations indicate the hydrothermal activity post-dates brittle displacement along the Unit 1 foundation shears and that no additional displacement has occurred since the hydrothermal activity:

- Crosscutting relationships in the Unit 1 excavation reveal the latest movement occurred on the northwest-striking set of shears (maximum slip of 4 inches) as opposed to the more common northeast-striking shears (maximum slip of 7 feet). Hydrothermal mineralization appears along both sets of shears and also, to a lesser extent, other joint surfaces that exhibit no displacement within the Unit 1 excavation. This demonstrates that the hydrothermal event post-dates the formation of joints and shears.
- "Vugs up to about 18 inches long lined with euhedral pink laumontite crystals up to about 10 mm long (Photographs #10 and 11) were observed in all shear orientations. At least two points (Plate 14) along a principal shear in shear zone 3, and elsewhere, laumontite crystals completely fill the shear, having grown inward from both walls." The lack of deformation of these crystals indicates that no displacement has occurred on these minor shears following crystal growth.
- In thin-section, "delicate microscopic overgrowths on microcline crystals project into laumontite vein filling or micorbreccia and have not been disturbed by shearing or crushing."

Given that unsheared hydrothermal mineralization occurs in both sets of shears (northwest- and northeast-striking), no movement has occurred along these surfaces since the hydrothermal event. Radiometric dating of rock and mineral specimens from the V. C. Summer Unit 1 excavation (Dames & Moore 1974) (FSAR Reference 2.5.1-240) constrain the timing of slip on the shears to have occurred: (1) after the cooling of the granodiorite approximately 300 Ma and emplacement of aplite dikes no later than 227 Ma; and (2) before the hydrothermal mineralization prior to 45 Ma, based on the K-Ar age of the laumontite crystals. The 45 Ma age for the formation of laumontite is considered a minimum, and since there are no known occurrences of hydrothermal activity within the stability field of laumontite in the Piedmont since Triassic and Jurassic time, the likely age of the laumontite is late Paleozoic to Mesozoic (300-150 Ma) (Dames & Moore 1974) (FSAR Reference 2.5.1-240). Therefore, the minor shears exposed in the V. C. Summer Unit 1 excavation are assessed to be Mesozoic or older in age.

(b) Garihan et al. (1993) (Reference 1) observe that N30° to 80°W, N30° to 70°E, and E-W striking joints are common in the Piedmont, and associate this with mid-Mesozoic crustal extension. Dames & Moore (1974) (FSAR Reference 2.5.1-240) describe

lineaments and drainage patterns in the site vicinity that they interpret as the expression of northwest- and northeast-striking regional joint patterns. Additionally, Dames & Moore describe a survey of joints orientations within a 10-mile radius of the site. The regional characterization of joints within the Piedmont and areas surrounding the site all include joint sets oriented northeast and northwest, similar to those observed in the Unit 1 exposure.

(c) As described in FSAR Subsection 2.5.2.1.3, the impoundment of Monticello Reservoir in the late 1970s triggered a short-lived and expected increase in shallow microseismicty (Secor et al. 1982; Chen and Talwani 2001) (FSAR References 2.5.3-219 and 2.5.2-222). This induced seismic activity reached a peak in 1978, decaying to background levels in the early 1990s. These reservoir-induced earthquakes occurred above 5 kilometers depth, with most events above 3 kilometers. The largest of these earthquakes had a magnitude M_L 2.8, with most being much smaller (Whorton 1988) (FSAR Reference 2.5.2-295). In 1995, the NRC noted that reservoir-induced seismicity had decreased to the point that its continued monitoring was no longer necessary (FSAR Reference 2.5.2-287).

The reservoir-induced earthquakes are scattered across most of the reservoir, indicating that these earthquakes are not related to a single fault, but instead are located on small fractures that pervade the rock (Secor et al. 1982) (FSAR Reference 2.5.3-219). As described in FSAR Subsection 2.5.1.3, the maximum size reservoir-induced earthquakes and their frequency content have already been considered with respect to their potential impact on Unit 1 (FSAR References 2.5.2-264 and 2.5.2-265). Furthermore, reservoir-induced seismicity has diminished to background rates. As such, reservoir-induced seismicity would not adversely affect the shear zones in the original V. C. Summer Unit 1 excavation area. The fact that shear zones have not slipped since Mesozoic hydrothermal mineralization supports the conclusion that background seismicity, or any other mechanism, has not produced slip on these minor shears since the Mesozoic Era and will be unlikely to do so in the future.

(d) The map presented in FSAR Figure 2.5.1-230 was recreated from previous mapping by Dames & Moore (1974; 1975) (FSAR References 2.5.1-240 and 2.5.1-241) and is intended to replicate the information shown on Plate 13A from Dames & Moore (1975) (FSAR Reference 2.5.1-241). Based on the text descriptions in these Dames & Moore reports, FSAR Figure 2.5.1-230 shows both joints and shears that are greater than 25 feet in length for the eastern two-thirds of the map based on initial mapping of the Unit 1 area (Dames & Moore 1974) (FSAR Reference 2.5.1-240) and greater than 20 feet in length for the western one-third of the map based on additional exposure of the staging area (Dames & Moore 1975) (FSAR Reference 2.5.1-241). As described in FSAR Reference 2.5.1-240, pink-filled fractures indicating hydrothermal alteration (solid red lines on FSAR Figure 2.5.1-230) are identified separately from other fractures (dashed red lines on FSAR Figure 2.5.1-230). The sense of slip is shown where movement was determined. Joints and shears less than 20 to 25 feet in length are not shown on FSAR

Figure 2.5.1-230. The most common shear zones strike northeast and the three most prominent shear zones are labeled as Zones 1, 2, and 3. Other shears are simply indicated by arrows showing relative movement. Northeast-striking shears exhibit the largest displacements with a maximum net slip of 7 feet documented for Zone 3. At all other locations where displacements were observed, displacements were less than two feet and commonly less than a foot. Northwest-striking shears are less common and exhibit slip of 4 inches or less. FSAR Figure 2.5.1-230 shows both northeast- and northwest-striking shears, as indicated by arrows depicting relative movement. Fractures where no slip was observed or slip was precluded are much more abundant than fractures exhibiting displacement.

(e) Dames & Moore (1974) (FSAR Reference 2.5.1-240) state Zone 3 shears "were traced away from the excavation and through the saprolite, becoming increasingly indistinct with higher elevation. At approximately 10 to 20 feet beneath the original ground surface visible manifestation of these features disappeared." [p.30]. This description is consistent with a Mesozoic or older shear in the bedrock mass that was later subjected to deep weathering of the bedrock to saprolite resulting in a weathering profile with increasing weathering and obliteration of bedrock structure towards the surficial soil, where the shear is no longer visible.

References:

1. Garihan, J.M., Preddy, M.S., and Ranson, W.A., *Summary of Mid-Mesozoic Brittle Faulting in the Inner Piedmont and Nearby Charlotte Belt of the Carolinas,* in Carolina Geological Society Field Trip Guidebook – Studies of Inner Piedmont Geology with a Focus on the Columbus Promontory, p. 55-66, 1993.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Figure 2.5.1-230 will be revised to show sample locations.

FSAR Subsection 2.5.1.2.4 will be revised to modify the 2nd paragraph on page 2.5.1-52 and to add significant text following that paragraph, as shown below.

The Unit 1 excavation exposed near-vertical, northeast, and northwest striking sets of shears that appear to follow the joint system (Reference 240). Additional excavations for the staging area, control building, intermediate building wall, and north dam of the

service water pond were mapped to document these features (References 241, 242, 243, and 244) (Figures 2.5.1-230 and 2.5.1-231). The dominant set of shears are northeast striking, oblique-slip faults with left-lateral and south-side-down normal components of slip. The dominant faults are divided into Zones 1, 2, and 3 (Figure 2.5.1-230). Zone 3 faults are the most significant and exhibit a maximum displacement of about 7 feet. Individual shears range in thickness from a fraction of an inch to less than 1 foot and exhibit an en echelon map pattern with several of the smaller shears terminating within the exposure. The shears do not penetrate the overlying soil profile to the ground surface. Many shears exhibit growth of a mineral assemblage indicative of hydrothermal origin. The presence of undeformed, euhedral laumontite (zeolite) crystals on many of the shear surfaces indicates that these minor faults have not slipped since the hydrothermal activity. Rb-Sr and K-Ar age dating of the hydrothermal laumonite and surrounding rock, along with other lines of evidence, constrain the hydrothermal event to some time before 45 Ma, with a likely Mesozoic age (References 240 and 392). The ~~Cenozoic or~~ Mesozoic timing of last movement on the bedrock shears demonstrates that these features are not capable tectonic sources and represent neither a ground motion hazard nor a surface rupture hazard to the site.

The following discussion summarizes the sampling and analyses presented in Dames & Moore (1974) (Reference 240), as well as key observations and results that demonstrate the analyses were performed for those parts of the shear zones that experienced the last movement, and that the last movement is constrained as no younger than Mesozoic in age.

Samples for age dating were collected from the least-weathered microbreccia in each of the widest shears from shear Zones 1 and 3. Control samples were also collected from unfractured and unweathered rock, approximately 5 to 15 feet on either side of the primary sample locations. Based on crosscutting field relationships, the microbreccia and hydrothermal mineral growth along shear zones post-date formation of the younger rock units (granodiorite and aplite dikes), and thus were the focus of additional sampling. From shear Zone 3, specimens were collected for X-ray diffraction to identify minerals and fracture-filling material related to hydrothermal activity. Hand picking of individual crystals using needle and tweezers isolated a pure mineral concentrate for X-ray diffraction analysis. This analysis identified the predominant hydrothermal mineral as laumonite, occurring as both vein filling in the microbreccias and as euhedral and subhedral crystals in vugs along shears. Euhedral crystals of laumontite were also sampled in this same manner for K-Ar age dating. X-ray diffraction identified lesser amounts of alpha quartz and kaolin within the microbreccias.

Both mesoscopically and microsopically, the microbreccias appear to be produced by brittle failure, exhibiting angular rock and crystal fragments suspended in a matrix of compositionally similar, but finer, material. Under 200x and 400x magnification, the matrix has a distinct interlocking crystal mosaic and there is no evidence of un-recrystallized rock powder. The microbreccias, which typically exhibit a thickness of one to two inches but locally widen to a maximum width of less than two feet, are thoroughly permeated by hydrothermal laumontite, which occurs as both vein filling and crystals and crystal groups in microbreccia. The following mesoscopic and microscopic

observations indicate the hydrothermal activity post-dates brittle displacement along the Unit 1 foundation shears and that no additional displacement has occurred since the hydrothermal activity:

- Crosscutting relationships in the Unit 1 excavation reveal the latest movement occurred on the northwest-striking set of shears (maximum slip of 4 inches) as opposed to the more common northeast-striking shears (maximum slip of 7 feet). Hydrothermal mineralization appears along both sets of shears and also, to a lesser extent, other joint surfaces that exhibit no displacement within the Unit 1 excavation. This demonstrates that the hydrothermal event post-dates the formation of joints and shears.
- "Vugs up to about 18 inches long lined with euhedral pink laumontite crystals up to about 10 mm long (Photographs #10 and 11) were observed in all shear orientations. At least two points (Plate 14) along a principal shear in shear zone 3, and elsewhere, laumontite crystals completely fill the shear, having grown inward from both walls." The lack of deformation of these crystals indicates that no displacement has occurred on these minor shears following crystal growth.
- In thin-section, "delicate microscopic overgrowths on microcline crystals project into laumontite vein filling or micorbreccia and have not been disturbed by shearing or crushing."

Given that unsheared hydrothermal mineralization occurs in both sets of shears (northwest- and northeast-striking), no movement has occurred along these surfaces since the hydrothermal event. Radiometric dating of rock and mineral specimens from the VC Summer Unit 1 excavation (Dames & Moore 1974) (Reference 240) constrain the timing of slip on the shears to have occurred: (1) after the cooling of the granodiorite approximately 300 Ma and emplacement of aplite dikes no later than 227 Ma; and (2) before the hydrothermal mineralization prior to 45 Ma, based on the K-Ar age of the laumontite crystals. The 45 Ma age for the formation of laumontite is considered a minimum, and since there are no known occurrences of hydrothermal activity within the stability field of laumontite in the Piedmont since Triassic and Jurassic time, the likely age of the laumontite is late Paleozoic to Mesozoic (300-150 Ma) (Dames & Moore 1974) (Reference 240). Therefore, the minor shears exposed in the VC Summer Unit 1 excavation are assessed to be Mesozoic or older in age.

ASSOCIATED ATTACHMENTS:

FSAR Figure 2.5.1-230

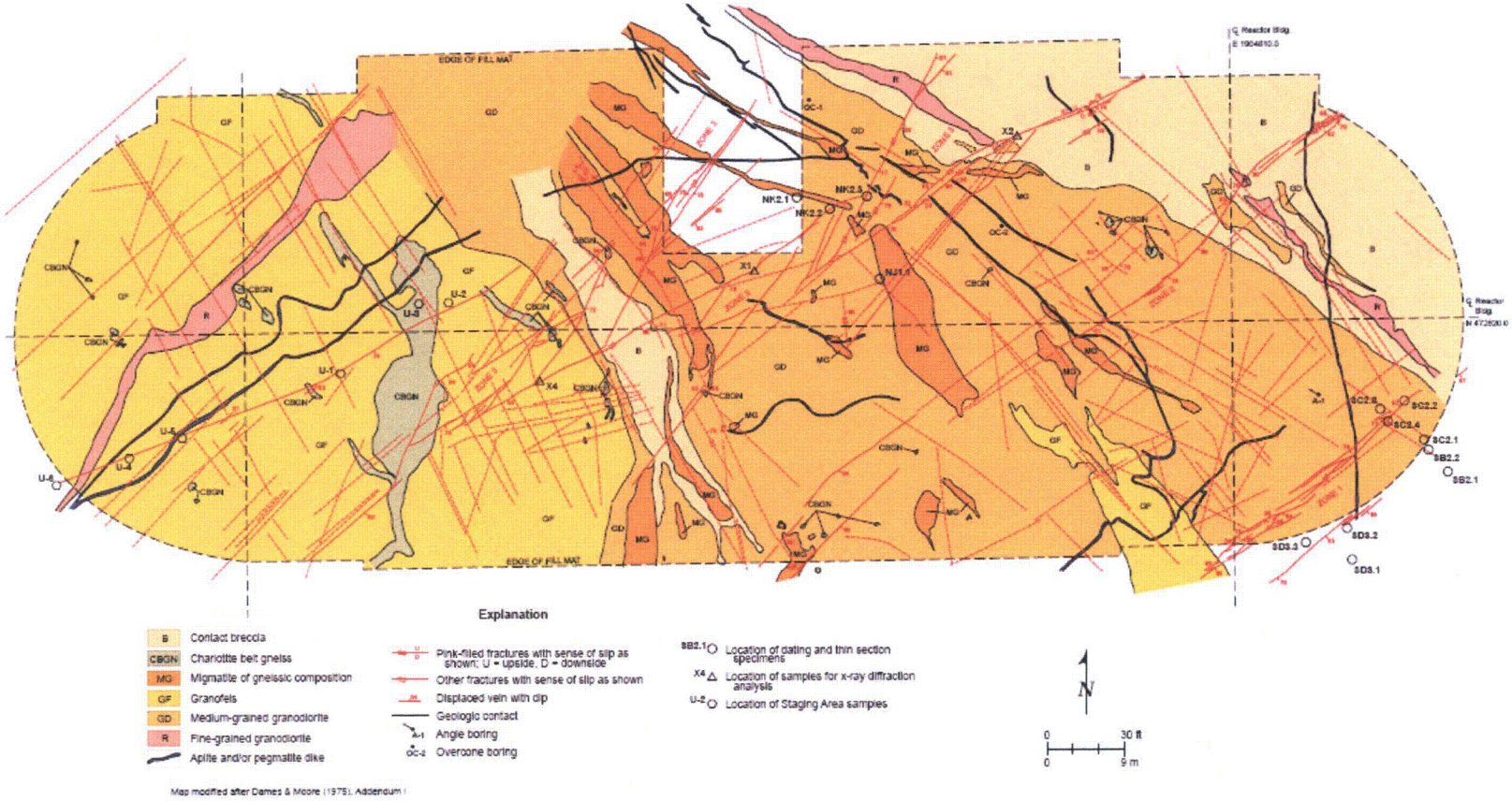


Figure 2.5.1-230 Structure Map of Unit 1 Excavation

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-47

FSAR Section 2.5.1.2.4 (pgs 2.5.1-52 and 2.5.1.53) discusses three faults mapped within the site area (the Wateree Creek fault, Summers Branch fault, an unnamed fault near Parr, and the Chappels shear zone) and cites FSAR Figure 2.5.1-225. This figure does not show the site area as inscribed by an 8-km (5-mi) radius circle around the site for reference, but FSAR Figure 2.5.1-224 does. FSAR Figure 2.5.1-224 also shows several unnamed faults within the site area that are not discussed in FSAR Section 2.5.1.2.4, some of which are apparently silicified. Neither FSAR Figure 2.5.1-224 nor FSAR Figure 2.5.1-225 locates the Chappels shear zone, although it is shown on Figure 2.5.1-212.

In addition, the contact for the Winnsboro plutonic complex shown on FSAR Figure 2.5.1-224 is different between the two maps combined in that figure (i.e., Horton and Dicken, 2001 and Secor, 2007). Since this contact is used to constrain fault ages in some cases (e.g., for the proposed unnamed fault near Parr which, if it exists, occurs in the site area), it should be represented correctly.

In order for the staff to completely understand the geologic setting of the Summer site in relation to faults mapped in the site area, locate all four structures discussed in FSAR Section 2.5.1.2.4 on the site area geologic map of Figure 2.5.1-224, and include a circle defining the site area on Figure 2.5.1-225. Please also discuss the other faults shown within the site area on both Figures 2.5.1-224 and 2.5.1-225, and address the pertinence of the fact that some fault zones are apparently silicified while some are not in relation to any potential age implications for the silicified faults. Finally, please explain why the contact of the Winnsboro plutonic complex is different between the maps produced by different workers and represent it correctly in FSAR Figure 2.5.1-224.

VCSNS RESPONSE:

FSAR Figure 2.5.1-224 will be revised to show the location of the Chappells shear zone. FSAR Figure 2.5.1-225 will be revised to show the 5-mile radius circle that defines the site area. FSAR Subsection 2.5.1.2.4 will be revised to indicate that the Summers Branch fault is located beyond the site area.

Faults and shear zones within the site area include the Wateree Creek fault (Secor et al. 1982; Secor 2007) (FSAR References 2.5.1-364 and 2.5.1-363), the Chappells shear zone (Hibbard et al. 2006) (FSAR Reference 2.5.1-284), a postulated unnamed fault of Dames & Moore (1972) (FSAR Reference 2.5.1-239), and eight minor unnamed faults

of Secor (2007) (FSAR Reference 2.5.1-363). None of Secor's minor faults exceeds 1½ miles in length and most are much shorter (FSAR Figure 2.5.1-224). Six of Secor's (2007) (FSAR Reference 2.5.1-363) minor unnamed faults are silicified, two are unsilicified.

The fact that some of Secor's (2007) (FSAR Reference 2.5.1-363) minor unnamed faults are silicified allows for estimation of their age. These silicified faults likely reflect hydrothermal activity indicative of a Mesozoic age (Garihan et al. 1993; Secor et al. 1998; Hatcher 2006) (Reference 2, FSAR Reference 2.5.1-368, Reference 3). This age estimate is consistent with: (1) the elevated temperatures necessary for the hydrothermal activity associated with the recrystallization of quartz and observed silicification (Coombs et al. 1959) (Reference 1); and (2) the fact that the current surface of the Piedmont and the pre-Cretaceous unconformity has been at relatively low temperatures for approximately the last 100 million years (Spotila et al. 2004) (FSAR Reference 2.5.1-377). As such, Secor's minor unnamed silicified faults likely are Mesozoic or older in age. Moreover, the southwestern-most silicified fault is crossed by, but does not displace, a diabase dike of Triassic or Jurassic age Secor (2007) (FSAR Reference 2.5.1-363).

Direct age constraints are not available for Secor's (2007) (FSAR Reference 2.5.1-363) two unsilicified, unnamed minor faults. However, based on their limited lengths, minor displacements, and similarity to other minor features found throughout the Piedmont, these minor features are not considered capable tectonic sources.

The apparent differences in the mapped location of the southern contact of the Carboniferous Winnsboro plutonic complex shown in FSAR Figure 2.5.1-224 largely result from the different scales at which this contact was mapped by different researchers. Specifically, Secor et al. (1982) (FSAR References 2.5.1-364) and Secor's (2007) (FSAR Reference 2.5.1-363) depictions are based on mapping performed at 1:24,000-scale, whereas Horton and Dicken's (2001) (FSAR Reference 2.5.1-289) mapping is presented at 1:500,000-scale. Secor's mapping is assessed to be the most accurate depiction of this contact, but, since Secor's mapping does not cover the entire site area, the easternmost edge of Figure 2.5.1-224 is supplemented by data from Horton and Dicken (2001) (FSAR Reference 2.5.1-289).

References:

1. Coombs, D.S., Ellis, A.J., Fyfe, W.S., Taylor, A.M., *The Zeolite Facies, With Comments on the Interpretation of Hydrothermal Syntheses*, Geochimica et Cosmochimica Acta, v. 17, p. 53-107, 1959.
2. Garihan, J.M., Preddy, M.S., and Ranson, W.A., *Summary of Mid-Mesozoic Brittle Faulting in the Inner Piedmont and Nearby Charlotte Belt of the Carolinas,* in Carolina Geological Society Field Trip Guidebook – Studies of Inner Piedmont Geology with a Focus on the Columbus Promontory, p. 55-66, 1993.
3. 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 Abstracts with Programs, Southeastern Section 55th annual meeting, 2006.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

The following changes to the FSAR will be incorporated in a future revision of the VCSNS Units 2 and 3 COLA:

FSAR Subsection 2.5.1.2.4, page 2.5.1-52, paragraphs 3 and 4, will be revised as follows:

~~Three faults and one shear zone are mapped within the site area. These include the Wateree Creek fault, the Summers Branch fault, the Chappells shear zone, and a postulated, unnamed fault near Parr, South Carolina. These features are described briefly below, and in more detail in Subsection 2.5.1.1.2.4 and 2.5.3.2.~~ Faults and shear zones within the site area include the Wateree Creek fault (References 363 and 364), the Chappells shear zone (Reference 284), and a postulated unnamed fault of Dames & Moore (Reference 239). These features are described briefly below, and in more detail in Subsections 2.5.1.1.2.4 and 2.5.3.2.

Secor et al. (Reference 364) mapped the more than 8-mile-long Wateree Creek fault as an approximately north striking, unsilicified fault zone. At its nearest point, the Wateree Creek fault is located approximately 2 miles south of the VCSNS site (Figure 2.5.1-225). Based on crosscutting relationships with Triassic or Jurassic diabase dikes, Secor et al. (Reference 364) estimate a minimum age of Triassic for the Wateree Creek fault.

~~Secor et al. (Reference 364) mapped the approximately 8-mile-long Summers Branch fault as an approximately north striking, unsilicified fault zone. At its nearest point, the Summers Branch fault is located approximately 5 miles southwest of the VCSNS site (Figure 2.5.1-225). By association with the Wateree Creek fault, Secor et al. (Reference 364) estimate a minimum age of Triassic for the Summers Branch fault.~~

FSAR Figure 2.5.1-224 will be revised to show the location of the Chappells shear zone after Horton and Dicken (2001) (FSAR Reference 2.5.1-289).

FSAR Figure 2.5.1-225 will be revised to show the site area radius.

ASSOCIATED ATTACHMENTS:

FSAR Figure 2.5.1-224

FSAR Figure 2.5.1-225

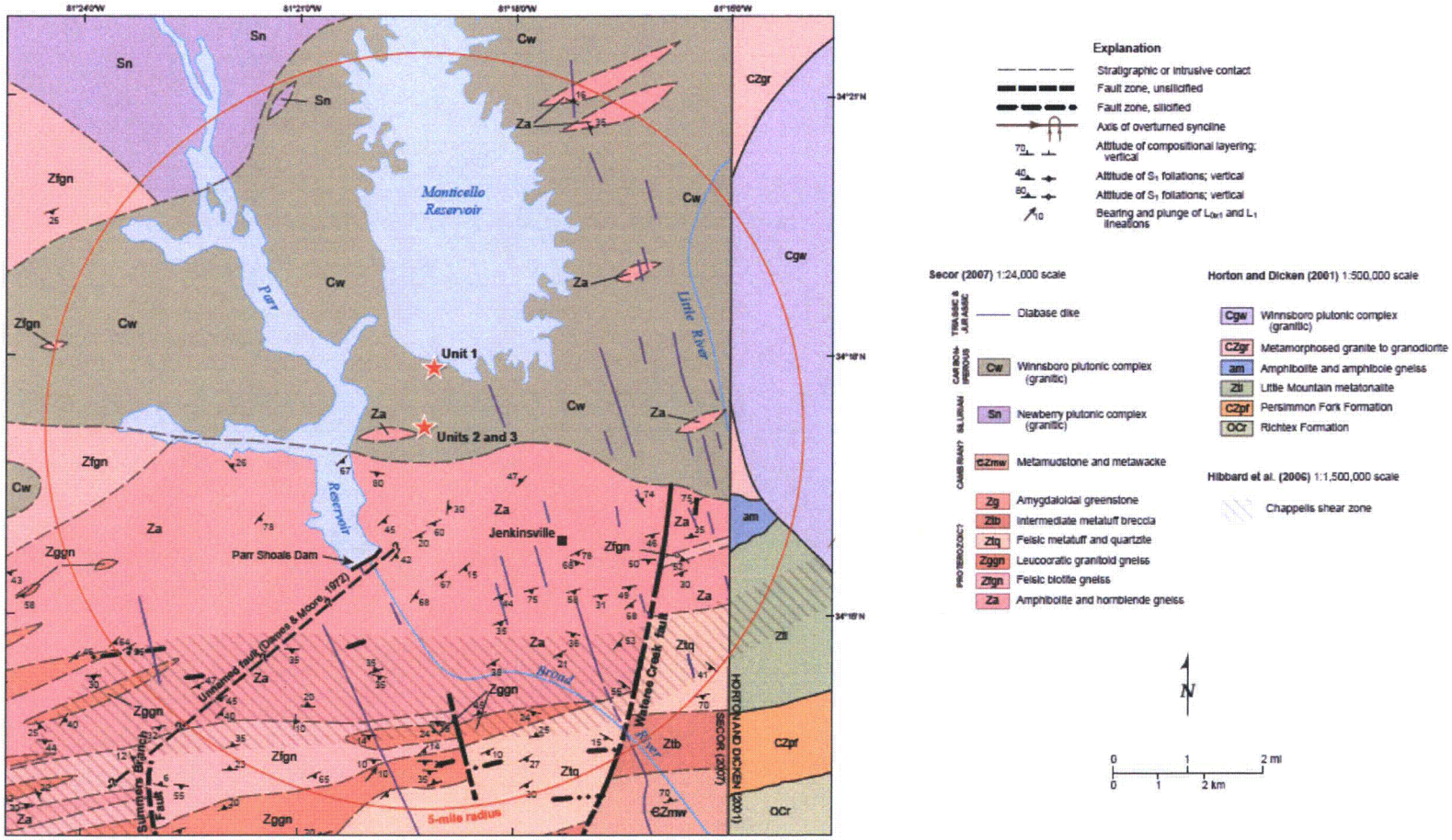
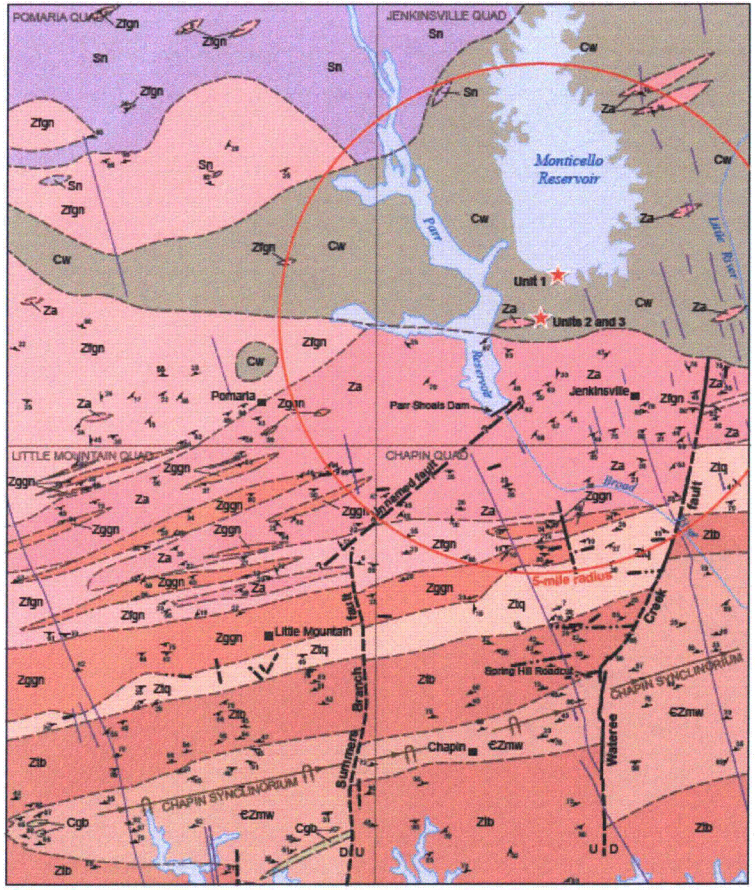


Figure 2.5.1-224 Site Area Geologic Map



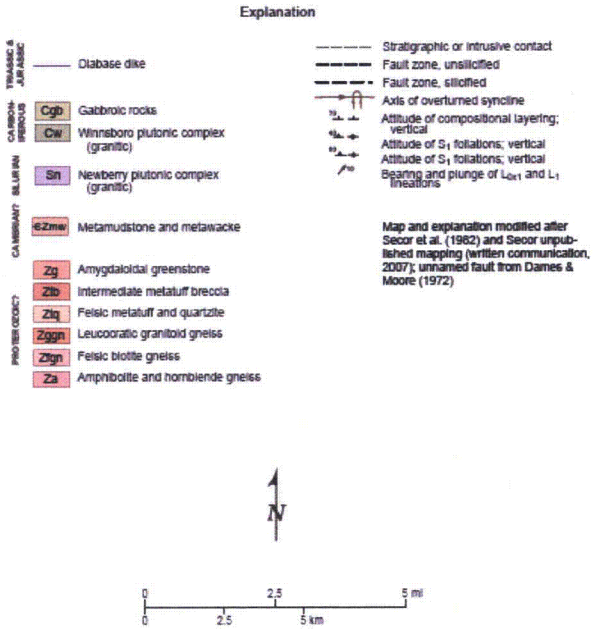


Figure 2.5.1-225 Geologic Map of the Jenkensville, Pomaria, Little Mountain and Chapin 7.5-Minute Quadrangles

NRC RAI Letter No. 033 Dated February 12, 2009

SRP Section: 2.5.1 – Basic Geologic and Seismic Information

Question from Geosciences and Geotechnical Engineering Branch 1 (RGS2)

NRC RAI Number: 02.05.01-48

FSAR Section 2.5.1.2.5 (pg 2.5.1-53) states that northeast and northwest-striking, near-vertical shear zones mapped in Unit 1 excavations parallel joint systems which occur in the area and region. However, no summary of regional or local joint orientations (e.g., as could be presented in stereonet plots) is included to document that the shear zones parallel trends of joints which exhibit no offset.

In order for the staff to assess the adequacy of the structural interpretation of shear zones which occur in Unit 1 excavations, please provide information on orientations of regional and local joint systems to document that the shear zones reflect regional orientations of joints along which no displacement has occurred.

VCSNS RESPONSE:

Maps of minor shear zones and joints with lengths greater than 20 to 25 feet in the VC Summer Unit 1 excavation (Dames & Moore 1974; 1975)(FSAR References 2.5.1-240 and 2.5.1-241) reveal nearly orthogonal sets striking northeast and northwest (FSAR Figure 2.5.1-230). The northeast-striking set of discontinuities contains the majority of the minor shear zones, including the three most prominent shear zones (Zones 1, 2, and 3). As shown on FSAR Figure 2.5.1-230, faults and shears that exhibit displacement are oriented subparallel to northeast- and northwest-striking joints that exhibit no displacement. This local observation of the largest discontinuities supports the interpretation that the shear zones developed along previously existing joint sets.

Stereonet plots comparing joints that exhibit displacement and/or contain hydrothermal minerals to joints that exhibit no displacement are provided in Plates 15 and 16 of Dames & Moore 1974 (FSAR Reference 2.5.1-240). These plots contain all joints measured in the Unit 1 excavation (not just those over 20 to 25 feet in length shown on FSAR Figure 2.5.1-230) and document that the minor shear zones exhibit local orientations of some of the joint sets along which no displacement has occurred.

Based on a stereonet plot of poles to joint surfaces exhibiting displacement and/or mineralization, the following average orientations of planes are interpreted (Plate 16 of Dames & Moore 1974) (FSAR Reference 2.5.1-240):

- N35°E, dipping greater than 75°SE;
- N58°E, dipping greater than 70°SE;
- N38 to 50°E, dipping greater than 65°NW; and

- N15 to 40°W, dipping greater than 60°NE.

A wider range of orientations and greater number of joint sets was obtained for surfaces that exhibited no displacement within the Unit 1 excavation, as listed below (Plate 15 of Dames & Moore 1974) (FSAR Reference 2.5.1-240). Three of the four orientations of surfaces exhibiting displacement and mineralization listed above are included with two of the interpreted joint sets listed below (shown in bold) that exhibit no displacement:

- **N35 to 75°E, dipping greater than 60°SE**;
- N30 to 60°E, dipping less than 40°NW;
- N10 to 10°E, dipping about 30°W;
- N20 to 40°W, dipping greater than 70°SW;
- **N20 to 40°W, dipping greater than 60°NE**; and
- N55 to 85°W, dipping greater than 70°NE or 70°SW.

The Dames & Moore study (FSAR Reference 2.5.1-240) also notes that northeast- and northwest-striking joints are reflected on more regional scales based on topographic lineaments within the Jenkinsville 7.5-minute quadrangle and attitudes of joints surveyed from outcrops within a 10-mile radius of Unit 1. Stream drainage patterns within the Jenkinsville quadrangle exhibit linear segments with orientations of N20 to 30°W and N40°E. Steeply dipping joint sets from outcrops within 10 miles of Unit 1 are reported with average strikes of N30°W, N67°E, and N45°E (FSAR Reference 2.5.1-240).

Secor et al. (1982) (FSAR Reference 2.5.1-364) presents geologic mapping of four 7.5-minute quadrangles including and surrounding Unit 1. These include the Chapin, Little Mountain, Jenkinsville, and Pomaria quadrangles. In most outcrops of their study area, "rocks are cut by one or more joint sets in which individual fractures have little or no lateral displacement." The joint sets typically are continuous for 10 to 200 cm in length and shorter joints are in echelon patterns near the termination of longer joints. Approximately 100 joint orientation measurements were made at each of the 50 study localities. Secor et al. (1982) (FSAR Reference 2.5.1-364) conclude that the orientation and frequency of joint sets varies between localities. However, the wide range of joint orientations does include a range of northwest and northeast orientations as mapped in the Unit 1 excavation.

A more regional study of brittle faulting and cataclasite zones associated with mid-Mesozoic crustal extension within the Inner Piedmont and Charlotte belt of the Carolinas by Garihan et al. (1993) (Reference 1) provides additional information on regional joint sets. Their study area lies east of the VCSNS site, is about 20 to 100 km wide by 350 km long, and is located between Westminster, South Carolina and the Sauratown Mountains, North Carolina. The following statements from this study summarize regional joint patterns and that brittle faulting has developed along existing joint sets:

- "N30-80°W, N30-70°E, and E-W-trending joints are common in the Piedmont."

- "We interpret the consistent regional N50-70°E trend of brittle faults to have developed by left-oblique shearing along the most widespread, steep joint set at N60°E, accompanying oblique (~S40°E) mid-Mesozoic crustal extension."

The Mesozoic age and northeast orientation of brittle faulting noted in the regional Garihan et al. (1993) study (Reference 1) are similar to the age and orientation of shears exposed in the Unit 1 excavation. This regional study also interprets that brittle faulting has developed along pre-existing joint sets similar to those in the Unit 1 excavation.

References:

1. Garihan, J.M., Preddy, M.S., and Ranson, W.A., *Summary of Mid-Mesozoic Brittle Faulting in the Inner Piedmont and Nearby Charlotte Belt of the Carolinas,* in Carolina Geological Society Field Trip Guidebook – Studies of Inner Piedmont Geology with a Focus on the Columbus Promontory, p. 55-66, 1993.

This response is PLANT SPECIFIC.

ASSOCIATED VCSNS COLA REVISIONS:

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

ASSOCIATED ATTACHMENTS:

None