

2.5.5 Stability of Slopes

This section presents information on the stability of permanent slopes at the NAPS site. The information has been developed in accordance with Review Standard RS-002, "Processing Applications for Early Site Permits" (Reference 145), following the guidance presented in RG 1.70, Section 2.5.5 (Reference 3). The geological, geophysical, geotechnical and seismological information presented in this section is used as a basis to evaluate the stability of specific slopes at the site.

The information presented in this section was developed from a review of reports prepared for the existing units and the abandoned Units 3 and 4, geotechnical literature, and a subsurface investigation conducted for preparation of this ESP application. The review included the site-specific reports from the UFSAR (Reference 5), and reports prepared by Dames and Moore regarding the design and construction of the existing units (Reference 7) and the abandoned Units 3 and 4 (Reference 8).

A 55-foot high, 2-horizontal to 1-vertical (2h:1v) slope descends from north of the SWR down to south of the existing excavation made for abandoned Units 3 and 4. This slope was excavated during construction of the existing units, and is almost entirely in cut material. The top of this slope is 200 feet from the top of the SWR embankment, and thus any potential instability of the slope would have no impact on the stability of the SWR embankment.

The only new permanent slope that may be created in association with the new units would be to the west of the SWR to accommodate the buried UHSs for certain new unit designs. The amount (if any) of this cut depends on the design that would be selected. The maximum slope height envisioned is about 55 feet, cut at a 2h:1v slope. The top of the slope would be at least 200 feet from the top of the SWR embankment, the same distance as for the existing slope to the north of the SWR. Thus, any instability of the new slope would not impact the SWR.

Although instability of the existing and possible new 2h:1v slopes would not impact the SWR, sloughing or collapse of these slopes could impact the new units, depending on their final location. The stability of these slopes is addressed in the following sections. The new slopes of the non-safety-related, deepened intake channel, which would be used for the normal cooling water system supply of the new units, would be analyzed during detailed design, if required. Such analysis is not part of the ESP SSAR.

2.5.5.1 Existing Slope Characteristics

The location and direction of the existing 2h:1v slope to the north of the SWR is shown in plan view in Figure 2.5-65; the location is also shown in the photograph in Figure 2.5-66. The photograph in Figure 2.5-67 shows the existing slope clearly, descending from the SWR to close to the excavation for the now abandoned Unit 3 and 4 containment buildings. The structure behind the slope on the SWR embankment is the Unit 1 and 2 valve house, which was originally designed to be the now

abandoned Unit 3 and 4 pump house. A cross-section through the existing slope is shown on Figure 2.5-68.

2.5.5.1.1 Slope Borings

As shown in Figure 2.5-65, two borings (B-15 and B-18) were performed previously on or close to the area of the slope. These borings were conducted for the Unit 1 and 2 investigation. The profiles of these borings are included in Figure 2.5-68. The boring logs are presented in Section 2.5.5.3. No additional exploration for the slope was made during the ESP exploration program.

2.5.5.1.2 Slope Subsurface Conditions

The ESP site soils and bedrock are described in detail in Section 2.5.4.2.2. As can be seen from Figure 2.5-68, the soils in the slope consist almost entirely of Zone IIA saprolites. Saprolites are a further stage of weathering beyond weathered rock. They have been derived by in-place disintegration and decomposition and have not been transported. Saprolites are classified as soils but still contain the relict structure of the parent rock, and they also typically still contain some core stone of the parent rock. The North Anna saprolites in many instances maintain the foliation characteristics of the parent rock. They are mainly classified as silty sands, although there are also sands, clayey sands, sandy silts, clayey silts and clays, depending very much on their degree of weathering. The fabric is strongly anisotropic. The texture shows angular geometrically interlocking grains with a lack of void network, very unlike the well-pronounced voids found in marine or alluvial sands and silts. The Zone IIA saprolites comprise, on average, about 80 percent of the saprolitic materials onsite. About 75 percent of the Zone IIA saprolites are classified as coarse-grained (sands, silty sands) while the remainder are fine-grained (clayey sands, sandy and clayey silts, and clays). The majority of the saprolites obtained from the borings in the slope area are dense silty sands.

The bedrock beneath the Zone IIA saprolite ranges from moderately to severely weathered (Zone III), to fresh to slightly weathered (Zone IV). The bedrock throughout the North Anna site is classified as a gneiss, which is a metamorphic rock that exhibits a banded texture (foliation) in which light and dark bands alternate. It is composed of feldspar, quartz, and one or more other minerals such as mica and hornblende. The majority of the bedrock obtained from the borings in the slope area is a dark green or gray to black biotite hornblende gneiss.

The engineering properties of the site soils and bedrock are described in Section 2.5.4.2.5 and are tabulated in Table 2.5-45. These properties are based on extensive field and laboratory testing described in Section 2.5.4.3 and Section 2.5.4.2, respectively.

The liquefaction characteristics of all of the Zone IIA saprolite are thoroughly examined in Section 2.5.4.8. That section concludes that there would be no liquefaction of the Zone IIA saprolitic soils at the ESP site, except possibly in isolated near-surface zones.

2.5.5.1.3 Slope Phreatic Surface

The postulated phreatic surface is shown in Figure 2.5-68 for the existing slope. This surface has been developed from the water table levels derived in Section 2.4.12. The depth of this phreatic surface precludes any potential for liquefaction of the near-surface soils in the slope.

2.5.5.2 Design Criteria and Analyses

2.5.5.2.1 Required Factor of Safety

The following factors of safety are proposed by the Department of the Army (Reference 183):

Condition	Minimum Factor of Safety
End of Construction	1.4
Long-Term Static (non-seismic)	1.5
Long-Term Seismic	1.1

2.5.5.2.2 Stability of Existing Slope

The photograph in Figure 2.5-67 of the existing 2h:1v slope to the north of the SWR was taken about 20 years ago. The condition of the slope is essentially the same today. It was thoroughly inspected during the ESP site investigation. The slope shows no signs of distress.

2.5.5.2.3 Analysis of Modified Slope

The static and dynamic stability of the existing slope to the north of the SWR was analyzed using the computer program SLOPE/W (Reference 184).

a. Long-Term Static Analysis

The SLOPE/W Program used the Bishop method of slices (Reference 185) for analysis of the long-term static condition. The analysis assumed the saprolite was predominantly coarse grained (as shown in borings B-15 and B-18 close to the slope). The effective strength parameters given in Table 2.5-45 were an angle of internal friction $\phi' = 30$ degrees and effective cohesion $c' = 0.25$ ksf for the coarse-grained saprolite.

The input to the analysis and the results are shown in Figure 2.5-69. The computed factor of safety is about 1.75. This value is above the minimum 1.5 factor of safety required.

b. Seismic Slope Stability Analysis

The pseudo-static approach is used as a first approximation for the seismic analysis of slopes. In this approach, the horizontal and vertical seismic forces are assumed to act on the slope in a static manner; that is, as a constant static force. This is an obviously conservative approach, since an actual seismic event occurs for only a short period of time, and during that time, the forces alternate their direction at a relatively high frequency. Also, the pseudo-static analysis tends to be run using the peak seismic acceleration; the mean acceleration during the

design seismic event is significantly less than the peak value. A pseudo-static analysis using peak acceleration values can be a useful tool in a limit analysis where the peak acceleration is relatively low. In such analyses, the computed factor of safety may well exceed the minimum of 1.1, thus requiring no further analysis. However, where the peak seismic acceleration values are high, the pseudo-static analysis produces unreasonably low safety factor values.

The pseudo-static analysis was run using SLOPE/W. The peak horizontal acceleration used was 0.33g. This is the average peak acceleration in the top 55 feet of unimproved soil shown in Table 2.5-46, which shows the amplification of the acceleration values up through the unimproved soil column. The vertical acceleration used was 0.165g. The computed factor of safety was 0.91.

Seed (Reference 186), in the 19th Rankine Lecture, addressed the over-conservatism intrinsic in the pseudo-static analysis. He looked at the more rational approach proposed by Newmark (Reference 187), where the effective acceleration time-history is integrated to determine velocities and displacements of the slope. He also examined dams in California that had been subjected to seismic forces, including several dams that survived the 1906 San Francisco earthquake. Based on his studies, he concluded that for embankments that consist of materials that do not tend to build up large pore pressures or lose significant percentages of their shear strength during seismic shaking, seismic coefficients of only 0.15g are adequate to ensure acceptable embankment performance for earthquakes up to Magnitude $M = 8.25$ with peak ground accelerations of 0.75g. For earthquakes in the range of $M = 6.5$, Seed recommends a horizontal seismic coefficient of only 0.1g with a vertical seismic coefficient of zero.

The fabric and interlocking angular grain structure of the Zone IIA saprolite, along with the significant portion of low plasticity clay minerals present in the material, have been demonstrated to give the grain structure of the saprolite a low susceptibility to pore pressure build-up or liquefaction (Section 2.5.4.8). This material would not lose a significant proportion of its shear strength during shaking. Thus, with a design Magnitude $M = 5.5$, the pseudo-static analysis should be limited to a horizontal acceleration of only 0.1g. The pseudo-static analysis was again run using SLOPE/W. This time the horizontal acceleration used was 0.1g, with zero vertical acceleration. The computed factor of safety was about 1.41. The input to the analysis and the results are shown in Figure 2.5-70.

Other researchers have also recommended substantially reducing the peak acceleration when applying the pseudo-static analysis. Kramer (Reference 188) recommends using an acceleration of 50 percent of the peak acceleration. Using the average peak acceleration in the top 55 feet of 0.33g, the horizontal input using Kramer's recommendation would be 0.165g. This level of input provides a factor of safety against slope failure in excess of 1.1.

2.5.5.3 Logs of Borings

As noted in Section 2.5.5.1, two sample borings were drilled on or close to the existing 2h:1v slope to the north of the SWR. The logs of borings B-15 and B-18 are reproduced in Figure 2.5-71 and Figure 2.5-72, respectively.

2.5.5.4 Compacted Fill

The existing 2h:1v slope described and analyzed in the previous sections is a cut slope and does not contain fill materials in any significant quantity.

2.5.5.5 Proposed New Slope

As noted at the beginning of Section 2.5.5, a new slope may be excavated to the west of the SWR to accommodate UHSs for the new units. The new slope would be approximately the same height and would have the same 2h:1v slope as the existing slope discussed in Section 2.5.5.1 through Section 2.5.5.4. It would also be a cut slope like the existing slope, and would comprise similar materials to those in the existing slope. Therefore, the analytical conclusions for the existing slope would apply to the new slope, namely the new slope would be stable under seismic and long-term static conditions.

If the selected design for the new units requires that the new slope be constructed, and it is deemed that any failure of the slope could impact the new units, then investigation and analysis of the slope would be performed as part of detailed engineering and described in the COL application. If the analysis, based on the subsurface investigation results, showed an inadequate factor of safety against slope failure, then the design would be modified to eliminate any risk of slope failure. Such modification would include measures such as reducing the slope steepness, removing and replacing materials that could lose significant strength during the design earthquake, and/or ground improvement measures such as soil nailing.

2.5.5.6 Conclusions

Existing slopes and embankments that are not impacted by the new units (such as the SWR embankments) are not analyzed. New slopes of the non-safety-related, deepened intake channel, which would be used for the normal cooling water system supply of the new units, would be analyzed during detailed design, if required. Such analysis is not part of the ESP SSAR.

The only existing slope whose failure could adversely affect the safety of the new units because of its proximity to the ESP site is a 55-foot high, 2h:1v slope that descends from north of the SWR down to south of the existing excavation made for abandoned Units 3 and 4. The slope is made almost entirely in cut material. Static long-term analyses of the existing slope using the computer program SLOPE/W gave values of factor of safety in excess of the minimum 1.5 required. Pseudo-static analyses using ESP design values of horizontal and vertical seismic acceleration gave safety factor values less than the minimum acceptable value of 1.1. However, when the

seismic input was modified to conform to the reductions given by Seed (Reference 186), the computed safety factors against slope failure were well in excess of 1.1. The Seed reductions are considered reasonable and valid, and it is concluded that the SWR slope has an adequate factor of safety against failure.

A new slope may be excavated to the west of the SWR to accommodate UHSs for the new units. The new slope would be approximately the same height, would have the same 2h:1v slope, and would have the same soil and rock characteristics as the existing slope that was analyzed. The analytical conclusions for the existing slope would apply to the new slope, namely the new slope would be stable under seismic and long-term static conditions. If analysis during the design stage of this slope indicates unacceptable factors of safety against slope failure, modifications would be employed to ensure adequate slope stability, including measures such as reducing the slope steepness, removing and replacing materials that could lose significant strength during the design earthquake, and/or ground improvement measures such as soil nailing.

2.5.6 Embankments and Dams

Because Lake Anna would only be used for normal plant cooling of the new units, the North Anna Dam, which is designed and constructed to meet requirements for a seismic Category I structure in support of the existing units, was not re-analyzed as part of this application. Analysis of the new non-safety-related deepened intake channel slopes for the new units would be performed during detailed design.

Construction of the new units would not adversely affect the slopes of the SWR for the existing units. There is an existing 55-foot high embankment to the north of the SWR and to the south of the new units. A similar embankment may be constructed to the west of the SWR to accommodate the buried UHS of certain reactor designs that might be constructed on the ESP site. Instability of these slopes could affect the new units. This is described and discussed in Section 2.5.5.

In summary, there are no embankments and dams to be addressed in this section.

Section 2.5 References

1. *Seismic Hazard Methodology for the Central and Eastern United States*, Electric Power Research Institute (EPRI), Volumes 5–10, Tectonic Interpretations, July 1986.
2. Regulatory Guide 1.165, Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion, U.S. Nuclear Regulatory Commission, March 1997.
3. Regulatory Guide 1.70, *Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants*, LWR Edition, Revision 3, U.S. Nuclear Regulatory Commission, November 1978.
4. Code of Federal Regulations, Title 10, Section 100.23, *Geologic and Seismic Siting Criteria*, U.S. Nuclear Regulatory Commission, December 03, 2002.
5. *Updated Final Safety Analysis Report, North Anna Power Station Units No. 1 and 2* Revision 38.
6. Independent Spent Fuel Storage Installation Safety Analysis Report, North Anna Power Station Units 1 and 2, Revision 3.
7. Site Environmental Studies, Proposed North Anna Power Station, Louisa County, Virginia, Virginia Electric and Power Company Report, (Included in Units 1 and 2 PSAR as Appendix A), Dames & Moore, January 13, 1969.
8. Site Environmental Studies, North Anna Nuclear Power Station, Proposed Units 3 and 4, Louisa County, Virginia, Virginia Electric Power Company Report, Dames and Moore, August 18, 1971.
9. Supplemental Geologic Data, North Anna Power Station, Louisa County, Virginia, Virginia Electric and Power Company Report, Dames & Moore, August 17, 1973.
10. Thelin, G. P., and R. J. Pike, *Landforms of the Conterminous United States—A Digital Shaded-Relief Portrayal*, U.S. Geological Survey, pamphlet to accompany Geological Investigation Series Map I-2206, April 17 1991.
11. Vigil, J. F., R. J. Pike, and D. G. Howell. *A Tapestry of Time and Terrain*, U.S. Geological Survey, pamphlet to accompany U.S. Geological Survey, Geological Investigation Series Map I-2720, February 24, 2000.
12. Lane, C. F., *Physiographic Provinces of Virginia*, Virginia Geographer, Volume XV, Fall-Winter 1983.

13. *Hope Creek Generating Station, Updated Final Safety Analysis Report*, Public Service Electrical and Gas Company, Revision 0, April 11, 1988.
14. College of William and Mary, *The Geology of Virginia: Piedmont Province*, Department of Geology Web Source, 1998: www.wm.edu/geology/virginia/piedmont.html.
15. Clark, G. M., R. E. Behling, D. D. Braun, E. J. Ciolkosz, J. S. Kite, and B. Marsh. *Central Appalachian Periglacial Geomorphology, A Field Excursion Guidebook* under the auspices of the 27th International Geographical Congress, Commission on Frost Action Environments, Agronomy Series Number 120, August 1992, Reprinted January 1993.
16. Trapp, H., Jr. and M. A. Horn. *Ground Water Atlas of the United States, Segment 11, Delaware, Maryland, New Jersey, North Carolina, Pennsylvania, Virginia, West Virginia*, U.S. Geological Survey, Hydrologic Investigations Atlas, 730-L, 1997.
17. Edwards, J. E., Jr. *A Brief Description of the Geology of Maryland, Maryland Geological Survey*, Pamphlet Series, Web Source, 1981:
www.mgs.md.gov/esic/brochures/mdgeology.html.
18. Bingham, E. *The Physiographic Provinces of Virginia*, Virginia Geographer, Volume 23 (2), Fall-Winter 1991.
19. Bates, R. L. and J. A. Jackson. *Glossary of Geology*, Third Edition, The American Geological Institute, 1995.
20. Bailey, C. M. *The Geology of Virginia: Physiographic Map of Virginia*, College of William and Mary, Department of Geology Web Source, 1999:
www.wm.edu/geology/virginia/phys_regions.html.
21. Hack, J. T. *Geomorphology of the Appalachian Highlands*, in R. D. Hatcher, Jr., W. A. Thomas, and G. W. Viele, eds., *The Geology of North America*, Volume F-2, The Appalachian-Ouachita Orogen in the United States, Geological Society of America, 1989.
22. Faill, R. T. A Geologic History of the North-Central Appalachians. Part 1. Orogenesis from the Mesoproterozoic through the Taconic Orogeny, American Journal of Science, June 1997, Volume 297, 551–619.
23. Fichter, L. S. and S. J. Baedke. *The Geological Evolution of Virginia and the Mid-Atlantic Region: Chronology of Events in the Geologic History of Virginia*, Stages A through M, James Madison University Web source, Last Update September 2000:
geollab.jmu.edu/vageol/vahist.html.

24. Colton, G. W. *The Appalachian Basin – Its Depositional Sequences and Their Geologic Relationships*, Chapter 2 in *Studies of Appalachian Geology: Central and Southern* by G. W. Fisher, F. J. Pettijohn, J. C. Reed, Jr., and K. N. Weaver, Interscience Publishers, 1970.
25. Faill, R. T. *A Geologic History of the North-Central Appalachians, Part 2: The Appalachian Basin from Silurian through the Carboniferous*, *American Journal of Science*, Volume 297, 729–761, Summer 1997.
26. Faill, R. T. *A Geologic History of the North-Central Appalachians, Part 3. The Allegheny Orogeny*, *American Journal of Science*, Volume 298, 131–179, February 1998.
27. Conners, J. A. *Quaternary Geomorphic Processes in Virginia*, in *The Quaternary of Virginia – A Symposium Volume*, edited by J. N. McDonald and S. O. Bird, Virginia Division of Mineral Resources, Publication 75, 1986.
28. Cleaves, E. T. *Regoliths of the Middle-Atlantic Piedmont and Evolution of a Polymorphic Landscape*, *Southeastern Geology*, Volume 39, Nos. 3 and 4, 199–122, October 2000.
29. King, P. B. and H. M. Beikman. *Geologic Map of the United States*, U.S. Geological Survey, 1974.
30. Fichter, L. S. and S. J. Baedke. *The Geological Evolution of Virginia and the Mid-Atlantic Region: A Description of the Geology of Virginia*, James Madison University Web Source, Last Update September 2000: gsmres.jmu.edu/geollab/vageol/vahist/PhysProv.html.
31. Markewich, H. W., M. J. Pavich, and G. R. Buell. *Contrasting Soils and Landscapes of the Piedmont and Coastal Plain, Eastern United States*, *Geomorphology*, Volume 3, 417–447, 1990.
32. Bledsoe, H. W., Jr. and I. W. Marine. *Executive Summary, Review of Potential Host Rocks for Radioactive Waste Disposal in the Southeastern United States*, prepared by E.I. du Pont de Nemours and Company for the U.S. Department of the Energy, DP-1559, October 1980.
33. Pavlides, L., J. G. Arth, J. F. Sutter, T. W. Stern, and H. Cortesini, Jr. *Early Paleozoic Alkalic and Calc-Alkalic Plutonism and Associated Contact Metamorphism, Central Virginia Piedmont*, U.S. Geological Survey Professional Paper 1529, 1994.
34. Frye, K. *Roadside Geology of Virginia*, Mountain Press Publishing Company, 1986.
35. Spears, D. B., and C. M. Bailey. *Geology of the central Virginia Piedmont between the Arvonian syncline and the Spotsylvania high-strain zone*, Thirty-Second Annual Virginia Geological Conference, Charlottesville, Virginia, October 11-13, 2002.

36. Pavlides, L. *Early Paleozoic Composite Melange Terrane, Central Appalachian Piedmont, Virginia and Maryland: Its Origin and Tectonic History*, Geological Society of America Special Paper 228, 135–193, 1989.
37. Pavlides, L. *Revised Nomenclature and Stratigraphic Relationships of the Fredericksburg Complex and Quantico Formation of the Virginia Piedmont*, U.S. Geological Survey Professional Paper 1146, 1980.
38. Bailey, C. M. *The Geology of Virginia: Generalized Geologic Terrane Map of the Virginia Piedmont and Blue Ridge*, College of William and Mary, Department of Geology Web Source, 1999: www.wm.edu/geology/virginia/phys_regions.html.
39. Rader, E. K., and N. H. Evans, editors. *Geologic map of the Virginia – expanded explanation*: Virginia Division of Mineral Resources, 1993.
40. Pavlides, L. *Geology of the Piedmont and Blue Ridge Provinces*, Chapter II of the pamphlet to accompany the U.S. Geological Survey, Geologic Investigations Series Map I-2607, 2000.
41. Carter, J. B. *Soil Survey of Louisa County, Virginia*, United States Department of Agriculture, Soil Conservation Service, March 1976.
42. Sevon, W. D. *Regolith in the Piedmont Upland section, Piedmont Province, York, Lancaster, and Chester Counties, Southeastern Pennsylvania*, Southeastern Geology, Volume 39, No. 3 and 4, 223–241, October 2000.
43. Mixon, R. B. *Overview of the Fredericksburg 30' x 60' Quadrangle, Virginia and Maryland*, Chapter I of the pamphlet that accompanies the U.S. Geologic Investigations Series Map I-2607, 2000.
44. Conley, J. F. *Geology of the Piedmont of Virginia – Interpretations and Problems*, in Contributions to Virginia Geology – III: Virginia Division of Mineral Resources Publication 7, 115–149, 1978.
45. Hatcher, R. D., Jr. *Tectonics of the southern and central Appalachian internides*, Annual Reviews of Earth and Planetary Science, Volume 15, 337–362, 1987.
46. Horton, J. W., A. A. Drake, D. W. Rankin, and R. D. Dallmeyer. *Preliminary Tectonostratigraphic Terrane Map of the Central and Southern Appalachians*, U.S. Geological Survey Miscellaneous Investigations Series Map I-2163, 1991.

47. Glover, L., III, J. K. Costain, and C. Coruh. Chapter 1. *Tectonics of the central Appalachian orogen in the vicinity of corridor E-3, with implications for tectonics of the southern Appalachians*, in L. Glover III, and K. D. Klitgord, Chief Compilers, E-3 Southwestern Pennsylvania to Baltimore Canyon Trough, Geological Society of America Continent/Ocean Transect #19, Explanatory Pamphlet, 2–49, 1995.
48. Williams, H., and R. D. Hatcher, Jr. *Appalachian Suspect Terranes*, in R. D. Hatcher, Jr., H. Williams, and I. Zeitz, eds., *Contributions to the Tectonics and Geophysics of Mountain Chains*, Geological Society of America Memoir 158, 33–53, 1983.
49. Wheeler, R. L. *Earthquakes and the Cratonward Limit of Iapetan Faulting in Eastern North America*, *Geology*, Volume 23, 105–108, 1995.
50. Zoback, M. L., and M. D. Zoback. *Tectonic Stress Field of the Coterminous United States*, in L. C. Pakiser and M. D. Mooney, eds., *Geophysical Framework of the Continental United States*, Geological Society of America Memoir 172, 523–539, 1989.
51. Zoback, M. L., et al. *Global Patterns of Tectonic Stress*, *Nature*, Volume 341, 291–298, 1989.
52. Zoback, M. L. *Stress Field Constraints on Intraplate Seismicity in Eastern North America*, *Journal of Geophysical Research*, Volume 97, 11,761–11,782, 1992.
53. Coblenz, D. D., and R. M. Richardson. *Statistical Trends in the Intraplate Stress Field*, *Journal of Geophysical Research*, Volume 100, 20,245–20,255, 1995.
54. Richardson, R. M., and L. M. Reding. *North American plate dynamics*, *Journal of Geophysical Research*, Volume 96, 12,201–12,223, 1991.
55. Turcotte, D. L., and G. Schubert. *Geodynamics*, Cambridge University Press, Cambridge, UK, 456 p., 2002.
56. Dahlen, F. A. *Isostasy and Ambient State of Stress in the Oceanic Lithosphere*, *Journal of Geophysical Research*, Volume 86, 7801–7807, 1981.
57. Chapman, M. C., and F. Krimgold. *Seismic Hazard Assessment for Virginia*, Virginia Tech Seismological Observatory, Department of Geological Sciences, February 1994.
58. Bollinger, G. A., and R. L. Wheeler. *The Giles County, Virginia, Seismic Zone – Seismological Results and Geological Interpretations*, U.S. Geological Survey Professional Paper 1355, 1988.

59. Crone, A. J. and R. L. Wheeler. *Data for Quaternary Faults, Liquefaction Features, and Possible Tectonic Features in the Central and Eastern United States, east of the Rocky Mountain front*, U.S. Geological Survey Open-File Report 00-260, 2000.
60. Bobyarchick, A. R., and L. Glover. *Deformation and Metamorphism in the Hylas Zone and Adjacent Parts of the Eastern Piedmont in Virginia*, Geological Society of America Bulletin, Volume 90, 739–752, 1979.
61. Ratcliffe, N. M., W. C. Burton, R. M. D' Angelo, and J. K. Costain. *Seismic Reflection Geometry of the Newark Basin Margin in Eastern Pennsylvania*, NUREG/CR-4676, 1986.
62. Manspeizer, W., J. DeBoer, J. K. Costain, A. J. Froelich, C. Coruh, P. E. Olsen, G. J. McHone, J. H. Puffer, and D. C. Prowell. *Post-Paleozoic Activity*, Geology of North America, v. F-2, The Appalachian-Ouachita Orogen in the United States, Geological Society of America, 1989.
63. Benson, R. N. *Map of Exposed and Buried Early Mesozoic Rift Basins/Synrift Rocks of the U.S. Middle Atlantic Continental Margin*, Delaware Geological Survey Miscellaneous Map Series No. 5, 1992.
64. Prowell, D. C. *Index of Faults of Cretaceous and Cenozoic Age in the Eastern United States*, U.S. Geological Survey Miscellaneous Field Studies Map MF-1269, 1983.
65. Newell, W. L., D. C. Prowell, and R. B. Mixon. *Detailed Investigation of a Coastal Plain-Piedmont Fault Contact in Northeastern Virginia*, U.S. Geological Survey Open-File Report 76-329, 1976.
66. Mixon, R. B., L. Pavlides, D. S. Powars, A. J. Froelich, R. E. Weems, J. S. Schindler, W. L. Newell, L. E. Edwards, and L. W. Ward. *Geologic Map of the Fredericksburg 30' x 60' Quadrangle, Virginia and Maryland*, U.S. Geological Survey, Geologic Investigations Series Map I-2607, 2000.
67. Mixon, R. B., and W. L. Newell. *Stafford Fault System: Structures Documenting Cretaceous and Tertiary Deformation Along the Fall Line in Northeastern Virginia*, Geology, Volume 5, 437–440, 1977.
68. Mixon, R. B., and W. L. Newell. *The Faulted Coastal Plain Margin at Fredericksburg, Virginia*, Tenth Annual Virginia Geology Field Conference, October 1978.
69. Mixon, R. B., D. S. Powars, S. David, R. E. Weems, J. S. Schindler, and W. Newell. *Upper Mesozoic and Cenozoic Deposits of the Atlantic Coastal Plain*, in Mixon and others, 2000, U.S. Geological Survey, Geologic Investigations Series I-2607, 17–28, 2000.

70. Weems, R. E. *Newly Recognized En Echelon Fall Lines in the Piedmont and Blue Ridge Provinces of North Carolina and Virginia, With a Discussion of Their Possible Ages and Origins*, U.S. Geological Survey Open-File Report 98-374, 1998.
71. Obermeier, S. F., and W. E. McNulty. *Paleoliquefaction Evidence for Seismic Quiescence in Central Virginia During the Late and Middle Holocene Time* [abs], Eos Transactions of the American Geophysical Union, Volume 79, No. 17, p S342, 1998.
72. Pavlides, L. *Mountain Run Fault Zone of Virginia*, U.S. Geological Survey Open-File Report 87-93, 93–94, 1986
73. Pavlides, L., A. R. Bobyarchick, W. L. Newell, and M. Pavish. *Late Cenozoic faulting along the Mountain Run Fault Zone, central Virginia Piedmont*, GSA Abstracts with Programs, Volume. 15, No. 2, 1983.
74. Marple, R. T., and P. Talwani. *Evidence for a Buried Fault System in the Coastal Plain of the Carolinas and Virginia - Implications for Neotectonics in the Southeastern United States*, Geological Society of America Bulletin, Volume 112, No. 2., 200–220, February 2000.
75. Marple, R. T., and P. Talwani. *Evidence for Possible Tectonic Upwarping Along the South Carolina Coastal Plain from an Examination of River Morphology and Elevation Data*, Geology, Volume 21, 651–654, 1993.
76. Frankel, A. D., M. D. Petersen, C. S. Mueller, K. M. Haller, R. L. Wheeler, E. V. Leyendecker, R. L. Wesson, S. C. Harmsen, C. H. Cramer, D. M. Perkins, and K. S. Rukstales. *Documentation for the 2002 Update of the National Seismic Hazard Maps*: U.S. Geological Survey Open-File Report 02-420, 2002.
77. Wheeler, R. L. and D. M. Perkins. *Research, Methodology, and Applications of Probabilistic Seismic-hazard Mapping of the Central and Eastern United States*, Minutes of a workshop on June 13-14, 2000 at Saint Louis University: U.S. Geological Survey Open-File Report 00-0390, 2000.
78. Savy, J. B., W. Foxall, N. Abrahamson, and D. Bernreuter. *Guidance for Performing Probabilistic Seismic Hazard Analysis for a Nuclear Plant Site: Example Application to the Southeastern United States*, U.S. Nuclear Regulatory Commission, NUREG-CR/6607, 2002.
79. Bollinger, G. A. *Specification of Source Zones, Recurrence Rates, Focal Depths, and Maximum Magnitudes for Earthquakes Affecting the Savannah River Site in South Carolina*, U.S. Geological Survey Bulletin 2017, 1992.

80. Bollinger, G. A., and M. S. Sibol. *Seismicity, Seismic Reflection Studies, Gravity and Geology of the Central Virginia Seismic Zone: Part I. Seismicity*, Geological Society of America Bulletin, Volume 96, 49–57, January 1985.
81. Bollinger, G. A., and M. G. Hopper. *Virginia's Two Largest Earthquakes - December 22, 1875 and May 31, 1897*, Bulletin of the Seismological Society of America, Volume 61, No. 4, 1033–1039, 1971.
82. Wheeler, R. L., and A. C. Johnston. *Geologic Implications of Earthquake Source Parameters in Central and Eastern North America*, Seismological Research Letters, Volume 63, No. 4, 491–505, 1992.
83. Coruh, C., G. A. Bollinger, and J. K. Costain. *Seismogenic structures in the central Virginia seismic zone*, Geology, Volume 16, 748–751, August 1988.
84. Bollinger, G. A., M. S. Sibol, and M. C. Chapman. *Maximum magnitude estimation for an intraplate setting - Example: The Giles County, Virginia, Seismic Zone*, Seismological Research Letters, Volume 63, No. 2, p. 139, 1992.
85. Law, R. D., E. S. Robinson, M. Pope, and R. T. Williams. *Folding and Faulting of Plio-Pleistocene Sediments in Giles County, SW Virginia: 1) Surface Data and Interpretation*, Geological Society of America, Southeastern Section Meeting, Abstracts with Programs, Volume 32, No. 2, p. A-57, 2000.
86. Bollinger, G. A., R. D. Law, M. C. Pope, R. H. Wirgart, and R. S. Whitmarsh. *Geologically Recent Near-surface Faulting in the Valley and Ridge Province: New exposures of extensional faults in alluvial deposits, Giles County, SW Virginia*, Geological Society of America, Abstracts with Programs 1992 Annual Meeting, October 26-29, 1992.
87. Powell, C. A., G. A. Bollinger, M. C. Chapman, M. S. Sibol, and A. R. Johnston. *A Seismotectonic Model for the 300 Kilometer-Long Eastern Tennessee Seismic Zone*, Science, Volume 264, 686–688, April 1994.
88. Chapman, M. C., C. A. Powell, G. Vlahovic, and M. S. Sibol. *A Statistical Analysis of Earthquake Focal Mechanisms and Epicenter Locations in the Eastern Tennessee Seismic Zone*, Bulletin of the Seismological Society of America, Volume 87, No. 6, 1522–1536, 1997.
89. Johnston, A. C., D. J. Reinbold, and S. I. Brewer. *Seismotectonics of the Southern Appalachians*, Bulletin of the Seismological Society of America, Volume 75, No. 1, 291–312, February 1985.

90. Johnston, A. C., *Seismic moment assessment of earthquake in stable continental regions - III. New Madrid 1811-1812, Charleston 1886 and Lisbon 1755*, Geophysical Journal International, Volume 126, 314–344, 1996.
91. Talwani, P. and W. T. Schaeffer. *Recurrence Rates of Large Earthquakes in the South Carolina Coastal Plain Based on Paleoliquefaction Data*, Journal of Geophysical Research, Volume 106, No. B4, 6621–6642, 2001.
92. Talwani, P. *An internally consistent pattern of seismicity near Charleston, South Carolina*, Geology, Volume 10, 655–658, 1982.
93. Bakun, W. H., and M. G. Hopper. *The 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes*, Bulletin of the Seismological Society of America, 2003, in press.
94. Wheeler, C. M., and A. J. Crone. *Known and Suggested Quaternary Faulting in the Mid-continent United States*, Engineering Geology, Volume 62, 51–78, 2001.
95. Hough, S. E., J. G. Armbruster, L. Seeber, and J. F. Hough. *On the Modified Mercalli intensities and magnitudes of the 1811-12 New Madrid earthquakes*, Journal of Geophysical Research, Volume 105, 23,839–23,864, 2000.
96. Johnston, A. C., and G. D. Schweig. *The enigma of the New Madrid earthquakes of 1811-181*, Annual Review of Earth and Planetary Sciences, Volume 24, 339–384, 1996.
97. Van Arsdale, R. B., K. I. Kelson, and C. H. Lumsden. *Northern Extension of the Tennessee Reelfoot Scarp into Kentucky and Missouri*: Seismological Research Letters, Volume 66, No. 5., 57–62, 1995.
98. Kelson, K. I., G. D. Simpson, R. B. Van Arsdale, C. C. Haraden, and W. R. Lettis. *Multiple late Holocene earthquakes along the Reelfoot fault, central New Madrid seismic zone*, Journal of Geophysical Research, Volume 101, No. B3, 6151–6170, 1996.
99. Mueller, K., J. Champion, M. Buccione, and K. Kelson. *Fault slip rates in the modern New Madrid seismic zone*, Science, Volume 286, 1135–1138, 1999.
100. Van Arsdale, R. B. *Displacement History and Slip Rate on the Reelfoot Fault of the New Madrid Seismic Zone*, Engineering Geology, Volume 55, 219–226, 2000.
101. Tuttle, M. P., and E. S. Schweig. *Earthquake potential of the New Madrid seismic zone (ads.)*, EOS, Transactions of the American Geophysical Union, Volume 81, S308-309, 2000.

102. Glover, L., III, and K. D. Klitgord. *E-3 Southwestern Pennsylvania to Baltimore Canyon Trough*, Geological Society of America Centennial Continent/Ocean Transect #19, 1995.
103. Harris, L. D., W. deWitt, Jr., and K. C. Bayer. *Interpretive seismic profile along Interstate I-64 from the Valley and Ridge to the Coastal Plain in central Virginia*, United States Geological Survey Oil and Gas Investigations Chart OC-123, 1982.
104. Committee for the Gravity Anomaly Map of North America, *Gravity Anomaly Map of North America*, Geological Society of America, Continent-Scale Map-002, scale 1:5,000,000, 1987.
105. Marr, J. D., Jr. *Geologic Map of the Western Portion of the Richmond 30 x 60 Minute Quadrangle, Virginia*, Virginia Division of Mineral Resources, Publication 165, 2002.
106. *North Anna Power Station, Units 3 and 4, Supplement Volume 2, Appendix E – Applicants Correspondence to the Atomic Energy Commission Relevant to the Geological Fault Investigation in Connection with the Construction of North Anna Power Station Units 3 and 4, Dockets Nos. 50-404 and 50-405*, Virginia Electric Power Company, Preliminary Safety Analysis Report, February 20, 1974.
107. *Geotechnical Report on Excavation, Reinforcement, and Final Conditions of Foundation Rock, North Anna Power Station – Units 3 and 4*, report for Virginia Electric and Power Company, Stone & Webster Engineering Corporation, 1975.
108. *Safety Evaluation Report of the North Anna Power Station, Units 3 and 4, Supplement No. 3*, Docket Nos. 50-404 and 50-405, U.S. Atomic Energy Commission, Directorate of Licensing, February 28, 1974.
109. ASTM D-6032-96, *Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Core*, American Society for Testing and Materials (ASTM).
110. Poole, J. L. *Notes on Some Abandoned Copper, Lead, and Zinc Mines in the Piedmont of Virginia*, Virginia Minerals, Volume 20, No. 2, May 1974.
111. Hickman, R. C. *Pyrites, Mineral, Louisa county, Virginia*, United States Department of the Interior - Bureau of Mines, Report of Investigations, R.I. 4116, August 1947.
112. Miller, J. W., and J. R. Craig. *Ore Minerals of the Cofer Volcanogenic Massive Sulfide Deposit, Louisa County, Virginia*, The Canadian Mineralogist, Volume 35, part 6, 1465–1483, December 1997.

113. Pavlides, L., J. E. Gair, and S. L. Cranford. *Massive Sulfide Deposits of the Southern Appalachians: Central Virginia Volcanic-Plutonic Belt as a Host for Massive Sulfide Deposits*, Economic Geology and the Bulletin of the Society of Economic Geologists, Volume 77, No. 2, March-April 1982.
114. NUREG-0800, *Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, Section 2.5.2, Revision 3, March 1997.
115. Rept. NP-6395-D, *Probabilistic seismic hazard evaluations at nuclear plant sites in the central and eastern United States: resolution of the Charleston earthquake issue*. EPRI, April 1989.
116. EPRI 1008910, *CEUS ground motion project—model development and results*, EPRI, August 2003.
117. USDOE. *Natural phenomena hazards design and evaluation criteria for Department of Energy facilities*, U.S. Department of Energy, Washington, D.C., Rept. DOE-STD-1020-2002, January 2002.
118. American Society of Civil Engineers, *Seismic design criteria for structures, systems, and components in nuclear facilities and commentary*, ASCE draft standard, July 25, 2003.
119. Risk Engineering, Inc. *Technical basis for revision of regulatory guidance on design ground motions: hazard- and risk-consistent ground motion spectra guidelines*, USNRC, Report NUREG/CR-6728, October 2001.
120. EPRI. *Seismic Hazard Methodology for the Central and Eastern United States*, EPRI Report NP-4726, July 1986.
121. Risk Engineering, Inc. *EQHAZARD Primer*, EPRI, Report NP-6452-D, July 1989.
122. Atkinson, G. M. and D. M. Boore (1995). Ground-motion relations for eastern North America. *Bull. Seism. Soc. Am.*, v. 85, n. 1, 17-30.
123. Frankel, A., C. Mueller, T. Barnhard, D. Perkins, E. V. Leyendecker, N. Dickman, S. Hanson, and M. Hopper. 1996, National seismic-hazard maps; documentation: U.S. Geological Survey Open-File Report 96-532.
124. EPRI (1993). Guidelines for determining design basis ground motions. Volume 5: Quantification of seismic source effects. EPRI Report TR-102293, Project 3302, Final Report, November 1993.

125. Bollinger, G. A., *Specification of Source Zones, Recurrence Rates, Focal Depths, and Maximum Magnitudes for Earthquakes Affecting the Savannah River Site in South Carolina*, U.S. Geological Survey, Bulletin 2017, 1992.
126. Chapman, M. C., and F. Krimgold. *Seismic Hazard Assessment for Virginia*, Virginia Tech Seismological Observatory, Department of Geological Sciences, February 1994.
127. Frankel, A. D., M. D. Petersen, C. S. Mueller, K. M. Haller, R. L. Wheeler, E. V. Leyendecker, R. L. Wesson, S. C. Harmsen, C. H. Cramer, D. M. Perkins, and K. S. Rukstales. *Documentation for the 2002 Update of the National Seismic Hazard Maps*, U.S. Geological Survey Open-File Report 02-420, 2002.
128. Kennedy, Robert C., and Stephen A. Short. *Basis for seismic provisions of DOE-STD-1020*, LLNL Rept. to U.S. Department of Energy, Report UCRL-CR-111478, April 1994.
R. C. Kennedy and S. A. Short (1994). *Basis for seismic provisions of DOE-STD-1020*, Lawrence Livermore Nat. Lab Rept. UCRL-CR-111478, Brookhaven Nat. Lab. Rept. BNL-52418.
129. Sobel, P. *Revised Livermore seismic hazard estimates for sixty-nine nuclear power plant sites east of the Rocky Mountains*, USNRC, Rept. NUREG-1488, April 1994.
130. Jack R. Benjamin and Associates, Inc. *Lower-bound magnitude for probabilistic seismic hazard assessment*, EPRI, Rept. NP-6496, Oct. 1989. Also published as Reference 115, Appendix B.
131. Abrahamson, N. N., and W. J. Silva. "Empirical response spectral attenuation relations for shallow crustal earthquakes," *Bull. Seism. Soc. Am.*, 68, 1, 94-127, Jan/Feb 1997.
132. Sadigh, K., C.-Y. Chang, J. A. Egan, F. Makdisi, and R. R. Youngs. "Attenuation relationships for shallow crustal earthquakes based on California strong motion data," *Bull. Seism. Soc. Am.*, 68,1, 180-189, Jan/Feb 1997.
133. Campbell, K. W. "Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra, *Bull. Seism. Soc. Am.*, 68,1, 154-179, Jan/Feb 1997.
134. Boore, D. M., W. B. Joyer, and T. E. Fumal. "Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes," a summary of recent work," *Bull. Seism. Soc. Am.*, 68, 1, 128-153, Jan/Feb 1997.
135. Chang, C. Y., et al. "Engineering Characterization of Ground Motion – Task II: Observational Data on Spatial Variations of Earthquake Ground Motion," NUREG/CR-3805, Vol. 3, Prepared for the Nuclear Regulatory Commission, February 1986.

136. Jack R. Benjamin and Associates, Inc. and RPK Structural Mechanics Consulting. "Analysis of High-Frequency Seismic Effects," Report EPRI TR-102470, prepared for EPRI, October 1993.
137. ASCE. "Seismic Analysis of Safety-Related Nuclear Structures and Commentary," ASCE 4-98, published by the American Society of Civil Engineers.
138. Neuschel, S. K. *Correlation of aeromagnetism and aeroradioactivity with lithology in the Spotsylvania area, Virginia*, Geological Society of America Bulletin, vol. 81, no. 12, 3573–3582, 1970.
139. *Lateral Continuity of a Pre- or Early Cretaceous Erosion Surface Across Neuschel's Lineament Northern Virginia*, for Virginia Electric and Power Company, Dames & Moore, April 1977.
140. *Safety Evaluation Report Related to Operation of North Anna Power Station Units 1 and 2, Supplement No. 5, Virginia Electric and Power Company*, Docket Nos. 50-338 and 50-339, USNRC, Office of Nuclear Reactor Regulation, December 1976.
141. Pavlides, L. *Geology of part of the northern Virginia Piedmont*, U.S. Geological Survey Open-File Report 90-548, 1:100,000 scale, 1990.
142. *A Seismic Monitoring Program at the North Anna Site in Central Virginia, January 24, 1974 Through August 1, 1977*, for Virginia Electric and Power Company, Dames & Moore, September 13, 1977.
143. *Safety Evaluation Report Related to Operation of North Anna Power Station Units 1 and 2, Virginia Electric and Power Company*, Docket Nos. 50-338 and 50-339, USNRC, Office of Nuclear Reactor Regulation, June 1976.
144. *Safety Evaluation Report Related to Operation of North Anna Power Station Units 1 and 2, Supplement No. 2, Virginia Electric and Power Company*, Docket Nos. 50-338 and 50-339, USNRC, Office of Nuclear Reactor Regulation, August 1976.
145. Review Standard RS-002, Processing Applications for Early Site Permits, Draft for Interim Use and Public Comment, U.S. Nuclear Regulatory Commission.
146. Dames and Moore, Site Environmental Studies, Proposed North Anna Power Station, Louisa County, Virginia, Virginia Electric Power Company, Report, January 13, 1969.
147. Results of Geotechnical Exploration and Testing, North Anna ESP Project, Louisa County, Virginia, MACTEC Engineering and Consulting, Inc., for Bechtel Power Corporation, February 11, 2003.

148. Regulatory Guide 1.138, Laboratory Investigation of Soils for Engineering Analysis and Design of Nuclear Power Plants, U.S. Nuclear Regulatory Commission, April 1978.
149. Draft Regulatory Guide DG-1109, Laboratory Investigation of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants, U.S. Nuclear Regulatory Commission, August 2001.
150. Bowles, J. E. *Foundation Analysis and Design*, Third Edition, McGraw-Hill Book Company, New York, 1982.
151. Davie, J. R., and M. R. Lewis. *Settlement of Two Tall Chimney Foundations*, Proceedings, Second International Conference on Case Histories in Geotechnical Engineering, St. Louis, MO, June 1988.
152. Terzaghi, K. Evaluation of Coefficients of Subgrade Reaction, *Geotechnique*, Volume 5, 1955.
153. Regulatory Guide 1.132, *Site Investigations for Foundations of Nuclear Power Plants*, Revision 1, U.S. Nuclear Regulatory Commission, March 1979.
154. Draft Regulatory Guide DG-1101, *Site Investigations for Foundations of Nuclear Power Plants*, U.S. Nuclear Regulatory Commission, February 2001.
155. ASTM D 1586 – 99, *Test Method for Penetration Test and Split-Barrel Sampling of Soils*, American Society for Testing and Materials (ASTM).
156. ASTM D 2113 – 99, *Practice for Rock Core Drilling and Sampling of Rock for Site Investigation*, American Society for Testing and Materials (ASTM).
157. ASTM D 4044 – 96, *Test Method for Instantaneous Change in Head (Slug Tests) for Determining Hydraulic Properties of Aquifers*, American Society for Testing and Materials (ASTM).
158. ASTM D 5778 – 95(2000), *Test Method for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils*, American Society for Testing and Materials (ASTM).
159. *Seismic Survey of the North Anna Power Station*, Virginia Electric and Power Company, Weston Geophysical Research, Inc., for Stone and Webster Engineering Corporation, February 1969. (Appendix 2B of the Unit 1 and 2 UFSAR).
160. *Velocity Measurements, North Anna Power Station*, Virginia Electric and Power Company, Weston Geophysical Research, Inc., for Stone and Webster Engineering Corporation, January 1970.

161. ASTM D 4428/D 4428M – 00, *Test Methods for Crosshole Seismic Testing*, American Society for Testing and Materials (ASTM).
162. OSHA 29 CFR Part 1926, *Safety and Health Regulations for Construction*.
163. *Geotechnical Report on Excavation, Reinforcement, and Final Conditions of Foundation Rock, North Anna Power Station – Units 3 and 4*, Stone and Webster Engineering Corporation for Virginia Electric and Power Company, July 1, 1975.
164. Preliminary Safety Analysis Report, North Anna Power Station, Units 3 and 4, Supplement Volume 2, Appendix E – Applicants Correspondence to the Atomic Energy Commission Relevant to the Geological Fault Investigation in Connection with the Construction of North Anna Power Station Units 3 and 4, Dockets Nos. 50-404 and 50-405, Virginia Electric Power Company, February 20, 1974.
165. ASTM D 1557 – 00, *Laboratory Compaction Characteristics of Soil Using Modified Effort*, American Society for Testing and Materials (ASTM).
166. *Road and Bridge Specifications*, Virginia Department of Transportation, Richmond, VA, 2002.
167. Seed, H. B., and I. M. Idriss. *Soil Moduli and Damping Factors for Dynamic Response Analyses*, Report No. UCB/EERC-70/10, University of California, Berkeley, December 1970.
168. Seed, H. B., R. T. Wong, I. M. Idriss, and K. Tokimatsu. *Moduli and Damping Factors for Dynamic Analyses of Cohesionless Soils*, Report No. UCB/EERC-84/14, University of California, Berkeley, September 1984.
169. Sun, J. I., R. Golesorkhi, and H. B. Seed. *Dynamic Moduli and Damping Ratios for Cohesive Soils*, Report No. UCB/EERC-88/15, University of California, Berkeley, August 1988.
170. *Guidelines for Determining Design Basis Ground Motions*, Electric Power Research Institute (EPRI), Volumes 1-5, EPRI TR-102293, Palo Alto, CA, 1993.
171. McGuire, R. K., W. J. Silva, and C. J. Constantino. *Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard and Risk-Consistent Ground Motion Spectra Guidelines*, NUREG/CR6728, October, 2001.
172. Draft Regulatory Guide DG-1105, Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites, U.S. Nuclear Regulatory Commission, March 2001.
173. *Liquefaction of Soils During Earthquakes*, Committee on Earthquake Engineering, National Research Council, National academy Press, Washington, D.C. 1985.

174. *Soil Failure/Liquefaction Susceptibility Analysis for North Anna Power station Seismic Margin Assessment*, Geotechnics for Virginia Power Company, December 1994.
175. Seed, H. B., and I. M. Idriss. *Ground Motions and Soil Liquefaction During Earthquakes*, Earthquake Engineering Research Institute Monograph, Oakland, CA, 1982.
176. Pavich, M. J., L. Brown, J. N. Valette-Silver, J. Klein, and R. Middleton. *¹⁰Be Analysis of a Quaternary Weathering Profile in the Virginia Piedmont*, Geology, Volume 13, January 1985.
177. Bierschwale, J. G., and K. H. Stokoe. *Analytical Evaluation of Liquefaction Potential of Sands Subjected to the 1981 Westmoreland Earthquake*, Geotechnical Engineering Report GR-84-15, Civil Engineering Department, University of Texas, Austin, Texas, 1984.
178. Youd, T. L. et al. Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction of Soils, ASCE Journal of Geotechnical and Environmental Engineering, Volume 127, No. 10, October 2001.
179. Tokimatsu, K. and H.B. Sneed. *Evaluation of Settlements on Sands Due to Earthquake Shaking*, ASCE Journal of Geotechnical Engineering, Volume 113, No. 8, August 1997.
180. Vesic, A. S. *Bearing Capacity of Shallow Foundations*, in Foundation Engineering Handbook, H. F. Winterkorn and H-Y Fang, Editors, Van Nostrand Reinhold Company, New York, 1975.
181. D'Appolonia, E., D. J. D'Appolonia, and R. D. Ellison. *Drilled Piers*, in Foundation Engineering Handbook, H. F. Winterkorn and H-Y Fang, Editors, Van Nostrand Reinhold Company, New York, 1975.
182. Peck, R. B., W. E. Hanson, and T. H. Thornburn. *Foundation Engineering*, Second Edition, John Wiley and Sons, Inc., New York, 1974.
183. Engineering and Design, Stability of Earth and Rock-Fill Dams, Department of the Army, April 1970.
184. *SLOPE/W for Slope Stability Analysis*, Version 4, GEO-SLOPE International Ltd., 1998.
185. Fang, H.-Y. *Stability of Earth Slopes*, in Foundation Engineering Handbook, H. F. Winterkorn and H-Y Fang, Editors, Van Nostrand Reinhold Company, New York, 1975.
186. Seed, H. B. *Considerations in the Earthquake-Resistant Design of Earth and Rockfill Dams*, Geotechnique, Volume 29, No. 3, 1979.
187. Newmark, N. M. *Effects of Earthquakes on Dams and Embankments*, Geotechnique, Volume 15, No. 2, 1965.

188. Kramer, S. L. Geotechnical Earthquake Engineering, Prentice-Hall, Inc., Upper Saddle River, NJ, 1996.
189. McGuire, R. K., G. R. Toro, and W. J Silva, *Engineering model of earthquake ground motion for eastern North America*, EPRI Rept. NP-6074, October 1988.
190. Boore, D. M., and G. M. Atkinson, "Stochastic prediction of ground motion and spectral response parameters at hard-rock sites in eastern North America, *Bull. Seism. Soc. Am*, 77, 2, 1987.
191. Nuttli, O. W. Letter dated September 19, 1986, to J. B. Savy, in D. Bernreuter et al. *Seismic hazard characterization of 69 nuclear plant sites east of the Rocky Mountains: questionnaires*, USNRC, Rept NUREG/CR-5250, Vol. 7, 1989.
192. Newmark, N. M, and W. J. Hall. *Earthquake spectra and design*, Earthquake Engineering Research Institute, Berkeley, CA, 1982.
193. Priebe, H. J. *Design Criteria for Ground Improvement by Stone Columns*, Fourth National Conference on Ground Improvement, Lahore, Pakistan, January 1993.
194. Clemente, J. L. M., and J. R. Davie. Stone Columns for Settlement Reduction, Proceedings, GeoEng 2000, Melbourne, Australia, November 2000.

Table 2.5-1 Definitions of Classes Used in the Compilation of Quaternary Faults, Liquefaction Features, and Deformation in the Central and Eastern United States (After Crone and Wheeler, 2000)

Class Category	Definition
Class A	Geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed for mapping or inferred from liquefaction to other deformational features.
Class B	Geologic evidence demonstrates the existence of a fault or suggests Quaternary deformation, but either: 1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or 2) the currently available geologic evidence is too strong to confidently assign the feature to Class C but not strong enough to assign it to Class A.
Class C	Geologic evidence is insufficient to demonstrate: 1) the existence of tectonic fault, or 2) Quaternary slip or deformation associated with the feature.
Class D	Geologic evidence demonstrates that the feature is not a tectonic fault or feature; this category includes features such as demonstrated joints or joint zones, landslides, erosional or fluvial scarps, or landforms resembling fault scarps, but of demonstrable non-tectonic origin.

Table 2.5-2 Quaternary Faults, Liquefaction Features, and Possible Tectonic Features Within the Site Region (200-Mile Radius) (Modified from Crone)

Feature	State	County	Physiographic Province	Distance from Site (mi.)	Class	Post-EPRI Info. (1986)	Fault Length (mi.)
Central VA Seismic zone	VA	14 counties	Piedmont	0	A	No	NA ^a
Mountain Run/Everona fault zone	VA	Orange, Culpeper, Fauquier	Piedmont	19	C	No	60–90
Lebanon Church fault	VA	Albemarle	Blue Ridge	45	C	No	NR ^b
Upper Marlboro faults	MD	Prince Georges	Coastal Plain	75	C	No	NA ^a
Old Hickory faults	VA	Dinwiddie, Sussex	Coastal Plain	78	C	Yes	0.6–0.09
Stanleytown-Villa Heights fault	VA	Henry	Piedmont	144	C	No	~0.1
Lancaster fault zone	PA	Lancaster	Piedmont	157	C	No	NA ^a
Lindside fault zone	VA, WV	Giles (VA)	Appalachian Plateaus	162	C	Yes	>30
Pembroke faults	VA	Giles	Valley and Ridge	163	B	Yes	NA ^a
Hares Crossroads fault	NC	Johnston	Coastal Plain	165	C	No	NR ^b
Cacoosing Valley earthquake	PA	Berks	Valley and Ridge	186	C	Yes	NA ^a

a. NA: Not Applicable

b. NR: Not Reported

Table 2.5-3 Site Area Stratigraphic Column (5-Mile Radius)

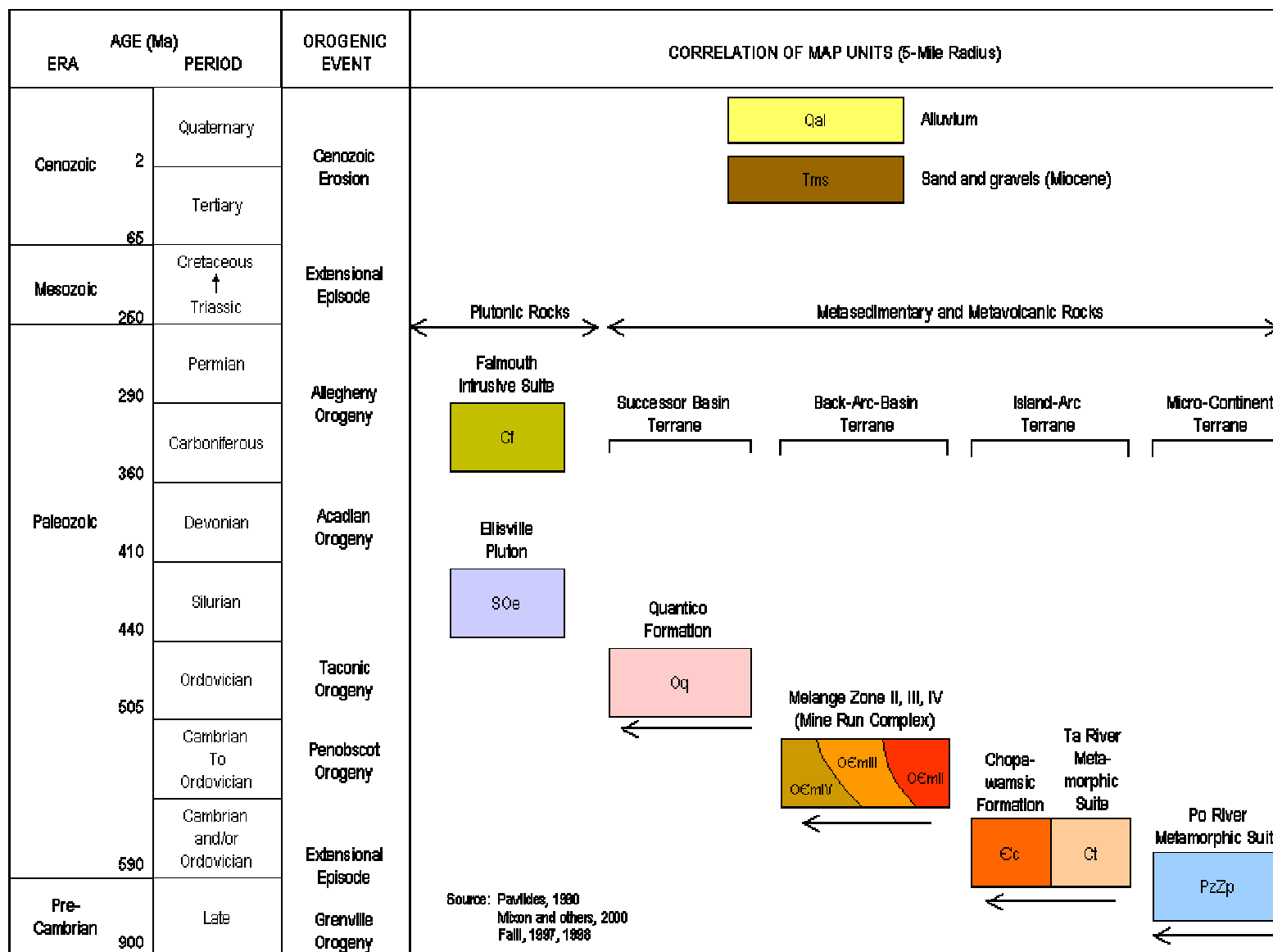


Table 2.5-4 Earthquakes 1985-2001, $m \geq 3.0$, within 35°N–41°N and 74°W–82°W

Year	Month	Day	Latitude North	Longitude West	Depth km	m_b	$m(\text{coda})$	$m(\text{int})$	ML	$m(\text{unk})$	Source
1985	6	10	37.248	80.485	11.1	3.2	2.8	3.3			VT
1986	3	26	37.245	80.494	11.9		2.9	3.3			VT
1986	12	3	37.58	77.458	1.6		1.5	3.3			VT
1986	12	10	37.585	77.468	1.2	2.5	2.2	3.5			VT
1986	12	24	37.583	77.458	1		1.6	3.3			VT
1987	1	13	37.584	77.465	2.5		1.9	3.3			VT
1988	5	28	39.753	81.613	0					3.4	ANSS
1988	8	27	37.718	77.775	14.3		2.7	3.3			VT
1990	1	13	39.366	76.851	4.1	2.5	2.6	3.5			VT
1991	3	15	37.746	77.909	15.5	3.8	3.3	3.5			VT
1991	4	22	37.942	80.205	14.8	3.5	3.5	3.3			VT
1991	6	28	38.231	81.335	7	3.0					VT
1991	8	15	40.786	77.657	1					3.0	ANSS
1992	1	9	40.363	74.341	7.9					3.1	ANSS
1993	3	10	39.233	76.882	5		2.5	3.3			VT
1993	3	15	39.197	76.87	0.9	2.7	2.1	3.5			VT
1993	7	12	36.035	79.823	5	2.7		3.3			VT
1993	10	28	39.25	76.77			2.1	3.3			VT
1993	10	28	39.25	76.77			1.8	3.3			VT
1994	1	16	40.327	76.007	5	4.2					ANSS
1994	1	16	40.33	76.037	5	4.6					ANSS
1994	8	6	35.101	76.786	0	3.6	3.8	3.5			VT
1995	6	26	36.752	81.481	1.8	3.4	3.3				VT
1995	7	7	36.493	81.833	10	3.0	3.1				VT
1997	11	14	40.146	76.252	5				3.0		ANSS
1997	11	14	40.741	76.549	0		3.0				VT
1998	6	5	35.554	80.785	9.4	3.2	3.4				VT
1998	10	21	37.422	78.439	12.6	3.8	3.4				VT
2001	9	22	38.026	78.396	0.4	3.2	2.5				VT
2001	12	4	37.726	80.752	8.5	3.1					VT

Table 2.5-5 Summary of Bechtel Seismic Sources

Source	Description	Distance ^a			M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)	Pa ^b				Geometry? ^f	M _{max} ? ^g	RI? ^h
Sources within 200 mi (320 km)										
E	Central Virginia	0	0	0.35	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	Yes	No	No	No
BZ5	S. Appalachians	0	0	1.00	5.7 [0.10] 6.0 [0.40] 6.3 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 3 [0.33]	Yes	No	No	No
24	Bristol Trends	61	38	0.25	5.7 [0.10] 6.0 [0.40] 6.3 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	Yes	No	No	No
BZ4	Atlantic Coastal Region	144	90	1.00	6.6 [0.10] 6.8 [0.40] 7.1 [0.40] 7.4 [0.10]	1 [0.33] 2 [0.34] 3 [0.33]	Yes	No	No	No
17	Stafford fault zone	0	0	0.10	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	No	No	No	No
13	Eastern Mesozoic Basins	5	3	0.10	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	No	No	No	No
25	NY-Alabama Lineament	189	118	0.30	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	No	No	No	No
23	Lebanon Trend	211	131	0.05	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	No	No	No	No
19	Giles County	221	137	0.35	5.7 [0.10] 6.0 [0.40] 6.3 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	No	No	No	No

Table 2.5-5 Summary of Bechtel Seismic Sources

Source	Description	Distance ^a		Pa ^b	M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)					Geometry? ^f	M _{max} ? ^g	RI? ^h
BZ6	SE. Craton Region	229	142	1.00	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 3 [0.33]	No	No	No	No
F	SE. Appalachians	274	170	0.35	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	1 [0.33] 2 [0.34] 4 [0.33]	No	No	No	No
Selected Sources Beyond 200 mi (320 km)										
H	Charleston Area	545	339	0.50	6.8 [0.20] 7.1 [0.40] 7.4 [0.40]	1 [0.33] 2 [0.34] 4 [0.33]	No	Yes; ECFS Southern Section	No	Yes; RI of 550 yrs
N3	Charleston Faults	579	359	0.53	6.8 [0.20] 7.1 [0.40] 7.4 [0.40]	1 [0.33] 2 [0.34] 4 [0.33]	No	Yes; ECFS Southern Section	No	Yes; RI of 550 yrs

a. Closest Distance between site and source measured in Bechtel GIS system using EPRI source files.

b. Pa = probability of activity; from Reference 121

c. Maximum Magnitude (M_{max}) and weights (wts.); from Reference 121

d. Smoothing options are defined as follows (from Reference 121):

1 = constant a, constant b (no prior b);

2 = low smoothing on a, high smoothing on b (no prior b);

3 = low smoothing on a, low smoothing on b (no prior b);

4 = low smoothing on a, low smoothing on b (weak prior of 1.05).

Weights on magnitude intervals are [1.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0].

e. Did the source contribute to 99% of EPRI hazard calculated at NAPS?; from Table 2.5-18.

f. No, unless new geometry proposed in literature.

g. No, unless EPRI M_{max} exceeded in literature. For Charleston, M_{max} from Reference 127 and weights even though new magnitude estimates do not generally exceed majority of EPRI M_{max} values.

h. RI = recurrence interval; assumed no change if no new paleoseismic data or rate of seismicity has not significantly changed per Section 2.5.2.6.5.

Table 2.5-6 Summary of Dames & Moore Seismic Sources

Source	Description	Distance ^a			M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)	Pa ^b				Geometry? ^f	M _{max} ? ^g	RI? ^h
Sources within 200 mi (320 km)										
41	S. Cratonic Margin (Default Zone)	0	0	0.12	6.1[0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	Yes	No	No	No
53	S. Appalachian Mobile Belt (Default Zone)	6	4	0.26	5.6[0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	Yes	No	No	No
40	Central VA Seismic Zone	24	15	1.00	6.6[0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	Yes	No	No	No
42	Newark- Gettysburg Basin	32	20	0.40	6.3[0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	Yes	No	No	No
47	Connecticut Basin	41	25	0.28	6.0[0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	Yes	No	No	No
4	Appalachian Fold Belts	74	46	0.35	6.0[0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	Yes	No	No	No
4B	Kink in Fold Belt (Giles Co. Area)	145	90	0.65	6.2[0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	Yes	No	No	No
44	Stafford Fault Zone	34	21	1.00	5.0[0.80] 7.2 [0.20]	1 [0.69] 2 [0.23] 3 [0.06] 4 [0.02]	No	No	No	No
C01	Combination zone 4-4A-4B-4C-4D	74	46	NA	6.0[0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	No	No	No	No
45	Hopewell Fault Zone	87	54	1.00	5.0[0.80] 7.2 [0.20]	1 [0.69] 2 [0.23] 3 [0.06] 4 [0.02]	No	No	No	No
46	Dan River Basin	118	74	0.28	6.0[0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	No	No	No	No
4C	Kink in Fold Belt	173	108	0.65	5.0[0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	No	No	No	No
48	Buried Triassic Basins	175	108	0.28	6.0[0.75] 7.2 [0.25]	3 [0.75] 4 [0.25]	No	No	No	No

Table 2.5-6 Summary of Dames & Moore Seismic Sources

Source	Description	Distance ^a		Pa ^b	M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)					Geometry? ^f	M _{max} ? ^g	RI? ^h
8	E. Marginal Basin	188	117	0.08	5.6[0.80] 7.2 [0.20]	1 [0.75] 2 [0.25]	No	No	No	No
C02	Combination zone 8-9	188	117	NA	5.6[0.80] 7.2 [0.20]	1 [0.75] 2[0.25]	No	No	No	No
49	Jonesboro Basin	204	127	0.28	6.0[0.75] 7.2 [0.25]	3[0.75] 4 [0.25]	No	No	No	No
6	Rome Trough	218	135	0.24	5.0[0.75] 7.2 [0.25]	3[0.75] 4 [0.25]	No	No	No	No
7	Dunkard Basin	281	175	0.38	5.7[0.75] 7.2 [0.25]	3[0.75] 4 [0.25]	No	No	No	No
50	Buried Triassic Basins	290	180	0.28	6.0[0.75] 7.2 [0.25]	3[0.75] 4 [0.25]	No	No	No	No
Selected Sources Beyond 200 mi (320 km)										
54	Charleston Seismic Zone	533	331	1.00	6.6[0.75] 7.2 [0.25]	1 [0.22] 2[0.08] 3[0.52] 4 [0.18]	No	Yes; ECFS Southern Section	No	Yes; RI of 550 yrs

- a. Closest Distance between site and source measured in Bechtel GIS system using EPRI source files.
- b. Pa = probability of activity; from Reference 121
- c. Maximum Magnitude (M_{max}) and weights (wts.); from Reference 121
- d. Smoothing options are defined as follows (from Reference 121):
 1 = No smoothing on a, no smoothing on b (strong prior of 1.04);
 2 = No smoothing on a, no smoothing on b (weak prior of 1.04);
 3 = Constant a, constant b (strong prior of 1.04);
 4 = Constant a, constant b (weak prior of 1.04).
 Weights on magnitude intervals are [0.1, 0.2, 0.4, 1.0, 1.0, 1.0, 1.0]
- e. Did the source contribute to 99% of EPRI hazard calculated at NAPS?; from Table 2.5-18.
- f. No, unless new geometry proposed in literature.
- g. No, unless EPRI M_{max} exceeded in literature. For Charleston, M_{max} from Reference 127 and weights even though new magnitude estimates do not generally exceed majority of EPRI M_{max} values.
- h. RI = recurrence interval; assumed no change if no new paleoseismic data or rate of seismicity has not significantly changed per Section 2.5.2.6.5.

Table 2.5-7 Summary of Law Engineering Seismic Sources

Source	Description	Distance ^a			M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)	Pa ^b				Geometry? ^f	M _{max} ? ^g	RI? ^h
Sources within 200 mi (320 km)										
17	Eastern Basement	0	0	0.62	5.7 [0.20] 6.8 [0.80]	1b [1.00]	Yes	No	No	No
217	Eastern Basement Background	0	0	1.00	4.9 [0.50] 5.7 [0.50]	1b [1.00]	Yes	No	No	No
GC011	22 - 35	7	4	NA	6.8 [1.00]	2a [1.00]	Yes	No	No	No
107	Eastern Piedmont	7	4	1.00	4.9 [0.30] 5.5 [0.40] 5.7 [0.30]	1a [1.00]	Yes	No	No	No
22	Reactivated E. Seaboard Normal	7	4	0.27	6.8 [1.00]	2a [1.00]	Yes	No	No	No
M22	Mafic Pluton	23	14	0.43	6.8 [1.00]	5 [1.00]	Yes	No	No	No
GC09	Mesozoic Basins (8 - Bridged)	28	18	NA	5.0 [0.20] 5.8 [0.50] 7.4 [0.30]	1c [1.00]	Yes	No	No	No
C10	Combination Zone 8-35	28	18	NA	6.8 [1.00]	2a [1.00]	Yes	No	No	No
M21	Mafic Pluton	47	29	0.43	6.8 [1.00]	5 [1.00]	Yes	No	No	No
M23	Mafic Pluton	73	45	0.43	6.8 [1.00]	5 [1.00]	Yes	No	No	No
M20	Mafic Pluton	79	49	0.43	6.8 [1.00]	5 [1.00]	Yes	No	No	No
M24	Mafic Pluton	81	50	0.43	6.8 [1.00]	5 [1.00]	Yes	No	No	No
M27	Mafic Pluton	152	94	0.43	6.8 [1.00]	5 [1.00]	Yes	No	No	No
M19	Mafic Pluton	159	98	0.43	6.8 [1.00]	5 [1.00]	Yes	No	No	No
GC13	22 - 24 - 35	7	4	NA	6.8 [1.00]	2a [1.00]	No	No	No	No
GC12	22 - 24	7	4	NA	6.8 [1.00]	2a [1.00]	No	No	No	No
105	Northern Coastal Plain	60	37	1.00	4.6 [0.90] 4.9 [0.10]	1a [1.00]	No	No	No	No
M25	Mafic Pluton	84	52	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
M26	Mafic Pluton	112	70	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No

Table 2.5-7 Summary of Law Engineering Seismic Sources

Source	Description	Distance ^a		Pa ^b	M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)					Geometry? ^f	M _{max} ? ^g	RI? ^h
8	Mesozoic Basins	194	120	0.27	6.8 [1.00]	a and b values calculated for C09	No	No	No	No
M28	Mafic Pluton	200	124	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
M18	Mafic Pluton	211	131	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
M29	Mafic Pluton	220	136	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
112	Ohio-Pennsylvania Block	223	138	1.00	4.6 [0.20] 5.1 [0.50] 5.5 [0.30]	1a [1.00]	No	No	No	No
M30	Mafic Pluton	240	149	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
M17	Mafic Pluton	272	169	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
M16	Mafic Pluton	281	175	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
101	Western New England	313	194	1.00	4.5 [0.15] 5.5 [0.85]	1c [1.00]	No	No	No	No
M31	Mafic Pluton	321	199	0.43	6.8 [1.00]	5 [1.00]	No	No	No	No
Selected Sources Beyond 200 mi (320 km)										
35	Charleston Seismic Zone	560	348	0.45	6.8 [1.00]	2a [1.00]	No	Yes; ECFS Southern Section	No	Yes; RI of 550 yrs

a. Closest Distance between site and source measured in Bechtel GIS system using EPRI source files.

b. Pa = probability of activity; from Reference 121

c. Maximum Magnitude (M_{max}) and weights (wts.); from Reference 121

d. Smoothing options are defined as follows (from Reference 121):

1a = High smoothing on a, constant b (strong prior of 1.05);

1b = High smoothing on b, constant b (strong prior of 1.00);

1c = High smoothing on a, constant b (strong prior of 0.95);

1d = High smoothing on a, constant b (strong prior of 0.90);

1e = High smoothing on a, constant b (strong prior of 0.70);

2a = Constant a, constant b (strong prior of 1.05);

2c = Constant a, constant b (strong prior of 0.95);

2d = Constant a, constant b (strong prior of 0.90).

Weights on magnitude intervals are all 1.0 for above options.

3a = High smoothing on a, constant b (strong prior of 1.05).

Weights on magnitude intervals are [0.0, 1.0, 1.0, 1.0, 1.0, 1.0, 1.0] for option 3a.

e. Did the source contribute to 99% of EPRI hazard calculated at NAPS?; from Table 2.5-18.

f. No, unless new geometry proposed in literature.

- g. No, unless EPRI M_{\max} exceeded in literature. For Charleston, M_{\max} from Reference 127 and weights even though new magnitude estimates do not generally exceed majority of EPRI M_{\max} values.
- h. RI = recurrence interval; assumed no change if no new paleoseismic data or rate of seismicity has not significantly changed per Section 2.5.2.6.5.

Table 2.5-8 Summary of Rondout Seismic Sources

Source	Description	Distance ^a			M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)	Pa ^b				Geometry? ^f	M _{max} ? ^g	RI? ^h
Sources within 200 mi (320 km)										
29	Central VA	0	0	1.00	6.6 [0.30] 6.8 [0.60] 7.0 [0.10]	1 [1.00] (a=-0.900, b=0.930)	Yes	No	No	No
30	Shenandoah	0	0	0.96	5.2 [0.30] 6.3 [0.55] 6.5 [0.15]	1 [1.00] (a=-1.710, b=1.010)	Yes	No	No	No
28	Giles County	188. 4	117	1.00	6.6 [0.30] 6.8 [0.60] 7.0 [0.10]	1 [1.00] (a=-1.130, b=0.900)	Yes	No	No	No
49	Appalachian	66.9	42	1.00	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	2 [1.00]	No	No	No	No
C01	Background 49	67	42	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	No	No	No	No
C09	49+32	67	42	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	No	No	No	No
50	Grenville	106. 9	66	1.00	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	2 [1.00]	No	No	No	No
C07	50 (02) + 12	107	66	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	No	No	No	No
C02	Background 50	107	66	NA	4.8 [0.20] 5.5 [0.60] 5.8 [0.20]	3 [1.00]	No	No	No	No
32	Norfolk Fracture Zone	114.1	71	0.67	5.8 [0.15] 6.5 [0.60] 6.8 [0.25]	1 [1.00] (a=-2.110, b=1.040)	No	No	No	No
31	Quakers	210. 3	131	1.00	5.8 [0.15] 6.5 [0.60] 6.8 [0.25]	1 [1.00] (a=-1.200, b=0.960)	No	No	No	No
Selected Sources Beyond 200 mi (320 km)										
24	Charleston	526	327	1.00	6.6 [0.20] 6.8 [0.60] 7.0 [0.20]	1 [1.00] (a=-0.710, b=1.020)	No	Yes; ECFS Southern Section	No	Yes; RI of 550 yrs

- a. Closest Distance between site and source measured in Bechtel GIS system using EPRI source files.
- b. P_a = probability of activity; from Reference 121
- c. Maximum Magnitude (M_{\max}) and weights (wts.); from Reference 121
- d. Smoothing options are defined as follows (from Reference 121):
 - 1, 6, 7, 8 = a, b values as listed above, with weights shown;
 - 3 = Low smoothing on a, constant b (strong prior of 1.0);
 - 5 = a, b values as listed above, with weights shown.
- e. Did the source contribute to 99% of EPRI hazard calculated at NAPS?; from Table 2.5-18.
- f. No, unless new geometry proposed in literature.
- g. No, unless EPRI M_{\max} exceeded in literature. For Charleston, M_{\max} from Reference 127 and weights even though new magnitude estimates do not generally exceed majority of EPRI M_{\max} values.
- h. RI = recurrence interval; assumed no change if no new paleoseismic data or rate of seismicity has not significantly changed per Section 2.5.2.6.5.

Table 2.5-9 Summary of Weston Seismic Sources

Source	Description	Distance ^a			M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)	Pa ^b				Geometry? ^f	M _{max} ? ^g	RI? ^h
Sources within 200 mi (320 km)										
22	Central VA Seismic Zone	0	0	0.82	5.4 [0.19] 6.0 [0.65] 6.6 [0.16]	1b [1.00]	Yes	No	No	No
C21	104-25	0	0	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.30] 2a [0.70]	Yes	No	No	No
C22	104-26	0	0	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.30] 1b [0.70]	Yes	No	No	No
C34	104-28BE-26	0	0	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.20] 1b [0.80]	Yes	No	No	No
C35	104-28BE-25	0	0	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.20] 1b [0.80]	Yes	No	No	No
C23	104-22-26	17	10	NA	5.4 [0.80] 6.0 [0.14] 6.6 [0.06]	1a [0.50] 2a [0.50]	Yes	No	No	No
C19	103-23-24	43	27	NA	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [1.00]	Yes	No	No	No
104	Southern Coastal Plain	0	0	1.00	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.20] 2a [0.80]	No	No	No	No
C25	104-28BCDE	0	0	NA	5.4 [0.24] 6.6 [0.61] 6.6 [0.15]	1a [0.30] 2a [0.70]	No	No	No	No
C20	104-22	17	10	NA	6.0 [0.85] 6.6 [0.15]	1a [0.30] 2a [0.70]	No	No	No	No
C24	104-22-25	17	10	NA	5.4 [0.80] 6.0 [0.14] 6.6 [0.06]	1a [0.50] 2a [0.50]	No	No	No	No
C26	104-28BCDE-22	17	11	NA	5.4 [0.24] 6.0 [0.61] 6.6 [0.15]	1a [0.30] 2a [0.70]	No	No	No	No
C27	104-28BCDE-22-2 5	17	11	NA	5.4 [0.30] 6.0 [0.70]	1a [0.70] 2a [0.30]	No	No	No	No
C28	104-28BCDE-22-2 6	17	11	NA	5.4 [0.30] 6.0 [0.70]	1a [0.70] 2a [0.30]	No	No	No	No

Table 2.5-9 Summary of Weston Seismic Sources

Source	Description	Distance ^a		Pa ^b	M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)					Geometry? ^f	M _{max} ? ^g	RI? ^h
28B	Zone of Mesozoic Basin	24	15	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	No	No	No	No
C01	28A thru E	24	15	NA	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	No	No	No	No
28E	Zone of Mesozoic Basin	41	25	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	No	No	No	No
103	Southern Appalachians	43	27	1.00	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [0.20] 2a [0.80]	No	No	No	No
C17	103-23	43	27	NA	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [0.70] 2a [0.30]	No	No	No	No
C18	103-24	43	27	NA	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1a [0.70] 1b [0.30]	No	No	No	No
28D	Zone of Mesozoic Basin	116	72	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	No	No	No	No
28C	Zone of Mesozoic Basin	142	88	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	No	No	No	No
23	Giles County Seismic Zone	213	132	0.90	6.0 [0.81] 6.6 [0.19]	1b [1.00]	No	No	No	No
102	Appalachian Plateau	234	145	1.00	5.4 [0.62] 6.0 [0.29] 6.6 [0.09]	1a [0.20] 2a [0.80]	No	No	No	No
101	S. Ontario-Ohio-Indiana	236	147	1.00	5.4 [0.19] 6.0 [0.68] 6.6 [0.13]	1a [0.20] 2a [0.80]	No	No	No	No
C12	101-7	236	147	NA	5.4 [0.19] 6.0 [0.68] 6.6 [0.13]	1a [0.70] 2a [0.30]	No	No	No	No
C13	101-8	236	147	NA	5.4 [0.19] 6.0 [0.68] 6.6 [0.13]	1a [0.70] 2a [0.30]	No	No	No	No
C14	101-29	236	147	NA	5.4 [0.19] 6.0 [0.68] 6.6 [0.13]	1a [0.70] 2a [0.30]	No	No	No	No

Table 2.5-9 Summary of Weston Seismic Sources

Source	Description	Distance ^a		Pa ^b	M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)					Geometry? ^f	M _{max} ? ^g	RI? ^h
C15	101-7-8	236	147	NA	5.4 [0.19] 6.0 [0.68] 6.6 [0.13]	1a [0.70] 2a [0.30]	No	No	No	No
C16	101-7-8-29	236	147	NA	5.4 [0.19] 6.0 [0.68] 6.6 [0.13]	1a [1.00]	No	No	No	No
24	New York-Alabama- Clingman	255	159	0.90	5.4 [0.26] 6.0 [0.58] 6.6 [0.16]	1b [1.00]	No	No	No	No
21	New York Nexus	296	184	1.00	5.4 [0.62] 6.0 [0.29] 6.6 [0.09]	1b [1.00]	No	No	No	No
28A	Mesozoic Basin	296	184	0.26	5.4 [0.65] 6.0 [0.25] 6.6 [0.10]	1b [1.00]	No	No	No	No
C07	21-19	296	184	NA	5.4 [0.62] 6.0 [0.29] 6.6 [0.09]	1b [0.70] 2b [0.30]	No	No	No	No
C08	21-19-10A	296	184	NA	5.4 [0.62] 6.0 [0.29] 6.6 [0.09]	1b [0.70] 2b [0.30]	No	No	No	No
C09	21-19-10A-28A	320	199	NA	5.4 [0.62] 6.0 [0.29] 6.6 [0.09]	1b [1.00]	No	No	No	No
C10	21-19-28A	320	199	NA	5.4 [0.62] 6.0 [0.29] 6.6 [0.09]	1b [1.00]	No	No	No	No

Selected Sources Beyond 200 mi (320 km)

25	Charleston Seismic Zone	532	330	0.99	6.6 [0.90] 7.2 [0.10]	1b [1.00]	No	Yes; ECFS Southern Section	No	Yes; RI of 550 yrs
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a. Closest Distance between site and source measured in Bechtel GIS system using EPRI source files.

b. Pa = probability of activity; from Reference 121

c. Maximum Magnitude (M_{max}) and weights (wts.); from Reference 121

- d. Smoothing options are defined as follows (from Reference 121):
 - 1a = Constant a, constant b (medium prior of 1.0);
 - 1b = Constant a, constant b (medium prior of 0.9);
 - 1c = Constant a, constant b (medium prior of 0.7);
 - 2a = Medium smoothing on a, medium smoothing on b (medium prior of 1.0);
 - 2b = Medium smoothing on a, medium smoothing on b (medium prior of 0.9);
 - 2c = Medium smoothing on a, medium smoothing on b (medium prior of 0.7).
- e. Did the source contribute to 99% of EPRI hazard calculated at NAPS?; from Table 2.5-18.
- f. No, unless new geometry proposed in literature.
- g. No, unless EPRI M_{\max} exceeded in literature. For Charleston, M_{\max} from Reference 127 and weights even though new magnitude estimates do not generally exceed majority of EPRI M_{\max} values.
- h. RI = recurrence interval; assumed no change if no new paleoseismic data or rate of seismicity has not significantly changed per Section 2.5.2.6.2.

Table 2.5-10 Summary of Woodward-Clyde Seismic Sources

		Distance ^a			M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
Source	Description	(km)	(mi)	Pa ^b				Geometry? ^f	M _{max} ? ^g	RI? ^h
Sources within 200 mi (320 km)										
B22	North Anna Background	0	0	1.00	5.8 [0.33] 6.2 [0.34] 6.6 [0.33]	1 [0.25] 6 [0.25] 7 [0.25] 8 [0.25]	Yes	No	No	No
26	Central VA Gravity Saddle	4	3	0.434	5.4 [0.33] 6.5 [0.34] 7.0 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	Yes	No	No	No
27	State Farm Complex	5	3	0.474	5.6 [0.33] 6.3 [0.34] 6.9 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	Yes	No	No	No
28	Richmond Basin	41	26	0.092	5.3 [0.33] 6.0 [0.34] 7.2 [0.33]	3 [0.33] 4 [0.34] 5 [0.33]	No	No	No	No
61	Tyrone-Mt. Union Lineament	76	47	0.048	5.4 [0.33] 6.5 [0.34] 7.1 [0.33]	3 [0.33] 4 [0.34] 5 [0.33]	No	No	No	No
63	Pittsburg- Washington Lineament	186	116	0.050	5.4 [0.33] 6.3 [0.34] 7.1 [0.33]	3 [0.33] 4 [0.34] 5 [0.33]	No	No	No	No
21	New Jersey Isostatic Gravity Saddle	192	120	0.135	5.3 [0.33] 6.5 [0.34] 6.9 [0.33]	2 [0.10] 3 [0.10] 4 [0.10] 5 [0.10] 9 [0.60] (a=-1.406, b=1.020)	No	No	No	No
21A	New Jersey Isostatic Gravity Saddle No. 2 (Combo C2)	192	120	0.045	5.5 [0.33] 6.3 [0.34] 7.1 [0.33]	2 [0.10] 3 [0.10] 4 [0.10] 5 [0.10] 9 [0.60] (a=-1.406, b=1.020)	No	No	No	No
31A	Blue Ridge Combination - Alternate Configuration	209	130	0.211	5.9 [0.33] 6.3 [0.34] 7.0 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	No	No	No	No

Table 2.5-10 Summary of Woodward-Clyde Seismic Sources

Source	Description	Distance ^a		Pa ^b	M _{max} (m _b) and Wts. ^c	Smoothing Options and Wts. ^d	Contributed to 99% of EPRI Hazard ^e	New Information to Suggest Change in Source:		
		(km)	(mi)					Geometry? ^f	M _{max} ? ^g	RI? ^h
53	SE NY/NJ/PA NOTA Zone	247	153	0.100	5.5 [0.33] 6.3 [0.34] 6.8 [0.33]	2 [0.10] 3 [0.10] 4 [0.10] 5 [0.10] 9 [0.60] (a=-1.406, b=1.020)	No	No	No	No
22	Newark Basin	259	161	0.078	5.5 [0.33] 6.5 [0.34] 7.1 [0.33]	2 [0.10] 3 [0.10] 4 [0.10] 5 [0.10] 9 [0.60] (a=-1.503, b=0.776)	No	No	No	No
Selected Sources Beyond 200 mi (320 km)										
29	S. Carolina Gravity Saddle (Extended)	416	259	0.122	6.7 [0.33] 7.0 [0.34] 7.4 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	Yes	No	No	No
29A	SC Gravity Saddle No. 2 (Combo C3)	426	264	0.305	6.7 [0.33] 7.0 [0.34] 7.4 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	Yes	No	No	No
29B	SC Gravity Saddle No. 3 (NW Portion)	416	259	0.183	5.4 [0.33] 6.0 [0.34] 7.0 [0.33]	2 [0.25] 3 [0.25] 4 [0.25] 5 [0.25]	No	No	No	No
30	Charleston (includes NOTA)	551	342	0.573	6.8 [0.33] 7.3 [0.34] 7.5 [0.33]	2 [0.10] 3 [0.10] 4 [0.10] 5 [0.10] 9 [0.60] (a = -1.005, b = 0.852)	No	Yes; ECFS Southern Section	No	Yes; RI of 550 yrs

- a. Closest Distance between site and source measured in Bechtel GIS system using EPRI source files.
b. Pa = probability of activity; from Reference 121
c. Maximum Magnitude (M_{max}) and weights (wts.); from Reference 121

- d. Smoothing options are defined as follows (from Reference 121):
- 1 = Low smoothing on a, high smoothing on b (no prior);
 - 2 = High smoothing on a, high smoothing on b (no prior);
 - 3 = High smoothing on a, high smoothing on b (moderate prior of 1.0);
 - 4 = High smoothing on a, high smoothing on b (moderate prior of 0.9);
 - 5 = High smoothing on a, high smoothing on b (moderate prior of 0.8);
 - 6 = Low smoothing on a, high smoothing on b (moderate prior of 1.0);
 - 7 = Low smoothing on a, high smoothing on b (moderate prior of 0.9);
 - 8 = Low smoothing on a, high smoothing on b (moderate prior of 0.8).
- Weights on magnitude intervals are all 1.0.
9 = a and b values as listed.
- e. Did the source contribute to 99% of EPRI hazard calculated at NAPS?; from Table 2.5-18.
- f. No, unless new geometry proposed in literature.
- g. No, unless EPRI M_{\max} exceeded in literature. For Charleston, M_{\max} from Reference 127 and weights even though new magnitude estimates do not generally exceed majority of EPRI M_{\max} values.
- h. RI = recurrence interval; assumed no change if no new paleoseismic data or rate of seismicity has not significantly changed per Section 2.5.2.6.5.

Table 2.5-11 Comparison of EPRI Characterizations of the Central Virginia Seismic Zone

EPRI Team	Source	Description	Distance ^a		Pa ^b	M _{max} (m _b) and Wts. ^c	Largest M _{max} Value Considered by EPRI Team		Contributed to 99% of EPRI Hazard ^d
			km	mi			m _b	M ^e	
Bechtel	E	Central Virginia	0	0	0.35	5.4 [0.10] 5.7 [0.40] 6.0 [0.40] 6.6 [0.10]	6.6	6.49	Yes
Dames & Moore	40	Central VA Seismic Zone	24	15	1.00	6.6 [0.80] 7.2 [0.20]	7.2	7.51	Yes
Law Engineering ^f	na	na	na	na	na	na	na	na	na
Rondout	29	Central VA	0	0	1.00	6.6 [0.30] 6.8 [0.60] 7.0 [0.10]	7.0	7.16	Yes
Weston	22	Central VA Seismic Zone	0	0	0.82	5.4 [0.19] 6.0 [0.65] 6.6 [0.16]	6.6	6.49	Yes
Woodward-Clyde Consultants	26	Central VA Gravity Saddle	4	3	0.434	5.4 [0.33] 6.5 [0.34] 7.0 [0.33]	7.0	7.16	Yes
Range of Largest M _{max} Value Considered by EPRI Teams = m _b 6.6 - 7.2 M 6.5 - 7.5									
Average of Largest M _{max} Values for 5 EPRI Teams (m _b) = 6.9									
Average of Largest M _{max} Values for 5 EPRI Teams (M) = 7.0									

- a. Closest distance between site and source measured in Bechtel GIS system using EPRI source files.
- b. Pa = probability of activity; from Reference 121
- c. Maximum Magnitude (M_{max}) and weights (wts.); from Reference 121
- d. Source contribution to 99% of EPRI hazard at North Anna from Table 2.5-18.
- e. m_b converted from **M** as described in Section 2.5.2.2.1.
- f. Law Engineering team did not define a Central VA seismic zone, but did define several mafic pluton sources in the central VA area. The seismicity parameters for the pluton sources were calculated from a large region surrounding each pluton, which effectively captured a majority of seismicity from the Central Virginia seismic zone, as described in Section 2.5.2.6.1.

**Table 2.5-12 Seismic Source Zone Parameters from Bollinger Study
(Reference 125)**

Source	Description	a	b	M_{\max} m_{bLG}^a	M_s^a	M^b	Focal Depth Distribution (km)	
							Upper Bound (D_U) 10% Quantile	Lower Bound (D_L) 90% Quantile
RZ6	Central VA	1.18	0.64	6.40	7.10	6.20	4.5	13.4
RZ3	Giles County, VA	1.07	0.64	6.30	6.80	6.06	4.4	15.1
CZ1	Complementary (Background)	2.70	0.84	5.75	5.80	5.36	3.3	18.5
LZ1	Charleston, SC	1.69	0.77	6.90	8.10	6.98	5.0	10.2
RZ4A	Eastern TN	2.72	0.90	7.35	8.75	7.78	7.6	20.8
RZ4	Eastern TN	2.72	0.90	6.45	7.15	6.27	7.6	20.8
RZ5	NW SC and SW NC	2.14	0.82	6.00	6.20	5.66	2.3	11.2
LZ3	South Carolina Piedmont and Coastal Plain	1.86	0.80	6.00	6.20	5.66	0.8	7.4
LZ4	SC Fall Line	1.58	0.81	6.25	6.50	5.99	0.9	6.1
LZ2	Bowman, SC	1.34	0.78	6.00	6.20	5.66	2.4	5.8
LZ5	Area of LZ3 minus Area of LZ4	1.70	0.80	6.00	6.20	5.66	0.9	6.5
LZ6	Savannah River Site	1.34	0.80	6.50	7.20	6.34	0.8	7.4
RZ1	New Madrid, MO (small)	3.32	0.91	7.35	8.75	7.78	3.0	11.6
RZ2	New Madrid, MO (large)	3.43	0.88	6.70	7.65	6.65	2.8	12.4

a. m_b and M_s values presented in Reference 125. The m_b to M_s conversion was defined by Nuttli in a written communication to Bollinger.

b. M converted from m_{bLG} as described in Section 2.5.2.6.5.

Table 2.5-13 Seismic Source Zone Parameters from Chapman and Krimgold Study (Reference 126)

Source	Description	Approx. Distance ^a		Area (sq. km)	a ^b	b ^b	M _{max} ^{c,d} (m _{bLg})	(M)	M _{max} ^e (m _b)
		km	mi.						
1	Giles County, VA	210	130	5.1×10^3	1.07	0.64	7.25	7.53	7.22
2	Central VA	0	0	2.0×10^4	1.18	0.64	7.25	7.53	7.22
3	Eastern TN	510	317	3.7×10^4	2.72	0.90	7.25	7.53	7.22
4	Southern Appalachians (VA, NC, SC, TN)	150	93	7.6×10^4	2.42	0.84	7.25	7.53	7.22
5	Northern VA, MD	60	37	4.3×10^4	1.63	0.84	7.25	7.53	7.22
6	Central Appalachians (PA, NJ, NY)	180	112	6.8×10^4	2.84	0.98	7.25	7.53	7.22
7	Piedmont - Coastal Plain	25	16	4.4×10^5	2.32	0.84	7.25	7.53	7.22
8	Charleston, SC	570	354	1.2×10^3	1.69	0.77	7.25	7.53	7.22
9	Appalachian Foreland (TN, KY, OH, WVA, PA)	175	109	6.5×10^5	3.36	1.00	7.25	7.53	7.22
10	New Madrid, MO	1015	631	6.1×10^3	3.32	0.91	7.25	7.53	7.22

- a. Closest Distance between site and source estimated (approximately) from Figure 1 in Reference 126.
- b. a and b values from Reference 126.
- c. Values listed in Reference 126. With the exception of New Madrid, they assumed all sources would have the same M_{max} as the largest EQ to have occurred in the southeastern U.S. region, the 1886 Charleston, SC event.
- d. Note that more recent estimates of Charleston EQ magnitude are lower than **M** 7.53.
M 7.3 +0.26/-0.26 Reference 90
M 6.8 +0.3/-0.4 Reference 189
- e. m_b converted from **M** as described in Section 2.5.2.2.1.

Table 2.5-14 Summary of Selected USGS Seismic Sources (Reference 127)

Description	M_{\max} (M) and Wts.	Largest M_{\max} Value Considered by USGS	
		M	m_b ^a
Sources within 200 mi (320 km)			
Extended Margin Background	7.5 [1.00]	7.5	7.20
Selected Sources Beyond 200 mi (320 km)			
Charleston	6.8 [0.20] 7.1 [0.20] 7.3 [0.45] 7.5 [0.15]	7.5	7.20
New Madrid	7.3 [0.15] 7.5 [0.20] 7.7 [0.50] 8.0 [0.15]	8.0	7.49
Stable Craton Background	7.0 [1.00]	7.0	6.91

a. m_b converted from **M** as described in Section 2.5.2.2.1.

Table 2.5-15 1989 EPRI PSHA Study Models

Model	Description	Weight
McGuire et al. (Reference 189)	Model developed by EPRI	0.5
Boore and Atkinson (Reference 190)	Published model	0.25
Nuttli (Reference 191)	Published model for peak parameters, combined with Newmark-Hall (Reference 192) amplification factors	0.25

Table 2.5-16 Comparison of PGA Results for North Anna Using 1989 EPRI Sources and Ground Motion Models

Ground motion (PGA)	Original 1989 ^a	Replicated 1989	Difference ^a
Mean 50 cm/s ²	1.6E-3	1.62E-3	+1%
50% 50 cm/s ²	1.4E-3	1.32E-3	-5%
85% 50 cm/s ²	2.9E-3	2.92E-3	+1%
Mean 250 cm/s ²	7.0E-5	7.09E-5	+1%
50% 250 cm/s ²	4.8E-5	4.79E-5	0
85% 250 cm/s ²	1.3E-4	1.35E-4	+4%
mean 500 cm/s ²	9.3E-6	9.46E-6	+2%
50% 500 cm/s ²	5.5E-6	5.62E-6	+2%
85% 500 cm/s ²	1.7E-5	1.76E-5	+4%

a. 1989 results are only available to 2 digits accuracy in Reference 115, which could lead to a +5% apparent difference.

Table 2.5-17 Comparison of Spectral Velocity Results for North Anna Using 1989 EPRI Sources and Ground Motion Models

Parameter	Original 1989 ^a	Replicated 1989	Difference
Median 1E-5 1 Hz amplitude	14.0 cm/s	14.2 cm/s	+1%
Median 1E-5 2.5 Hz amplitude	14.5 cm/s	14.5 cm/s	0%
Median 1E-5 5 Hz amplitude	13.3 cm/s	13.7 cm/s	+3%
Median 1E-5 10 Hz amplitude	10.4 cm/s	10.3 cm/s	-1%

a. Reference 115, Appendix E, Table 3-62

Table 2.5-18 Seismic Sources Contributing to 99% of Hazard for Each 1989 EPRI Team

Earth Science Team	Sources used
Bechtel	24, E, BZ4, BZ5
Dames & Moore	4, 40, 41, 42, 47, 4b, 53
Law Engineering	17, 107, 22, 217, C09, C10, C11, M19, M20, M21, M22, M23, M24, M27
Rondout Associates	28, 29, 30
Woodward-Clyde Cons.	26, 27, 29, 29A, B22
Weston Geophysical Corp.	22, C19, C21, C22, C23, C34, C35

Table 2.5-19 Significant Seismic Source at North Anna by 1989 EPRI Team

Earth Science Team	Seismic source	Description
Bechtel	E BZ5	Central VA seismic zone Local background
Dames & Moore	40	Central VA seismic zone
Law Engineering	17 M22	Eastern basement Local mafic pluton source
Rondout Association	29	Central VA seismic zone
Woodward-Clyde Consultants	27 26 B22	Central VA seismic zone Alternate Central VA seismic zone Local background
Weston Geophysical Corporation	22	Central VA seismic zone

Table 2.5-20 Controlling Earthquake Magnitude and Distances 1989 EPRI Sources and Ground Motion Models

	m_b	M^a	r_{epi} , km	r_{CD}^b , km
Low frequency (1 and 2.5 Hz)	6.2	5.9	31	29
High frequency (5 and 10 Hz)	5.9	5.5	21	20

a. M converted from m_b as described in Section 2.5.2.2.1.

b. r_{CD} converted from r_{epi} as given in Reference 116, model F3.

Table 2.5-21 Spectral Amplitudes Using 1989 EPRI Sources And Ground Motion Models

Frequency	Median/Mean	1989 Ground Motions
1 Hz	10 ⁻⁵ median	0.0910 g
	10 ⁻⁵ mean	0.219 g
2.5 Hz	10 ⁻⁵ median	0.232 g
	10 ⁻⁵ mean	0.519 g
5 Hz	10 ⁻⁵ median	0.439 g
	10 ⁻⁵ mean	0.753 g
10 Hz	10 ⁻⁵ median	0.660 g
	10 ⁻⁵ mean	0.827 g

Table 2.5-22 Updated Seismic Hazard Results at ESP Site

Frequency	Median/Mean	Updated Models	1989 Models	Difference
1 Hz	10 ⁻⁵ median	0.0961 g	0.0910 g	+6%
	10 ⁻⁵ mean	0.134 g	0.219 g	-39%
2.5 Hz	10 ⁻⁵ median	0.316 g	0.232 g	+36%
	10 ⁻⁵ mean	0.364 g	0.519 g	-30%
5 Hz	10 ⁻⁵ median	0.639 g	0.439 g	+46%
	10 ⁻⁵ mean	0.735 g	0.753 g	-2%
10 Hz	10 ⁻⁵ median	1.020 g	0.660 g	+55%
	10 ⁻⁵ mean	1.216 g	0.827 g	+47%

Table 2.5-23 Controlling Earthquake Magnitude and Distances, Updated Models

	m_b	M^a	r_{epi} , km	r_{CD}^b , km
Low frequency (1 and 2.5 Hz)	5.9	5.6	25	24
high frequency (5 and 10 Hz)	5.7	5.3	17	17

a. M converted from m_b as described in Section 2.5.2.2.1.

b. r_{CD} converted from r_{epi} as given in Reference 116, model F3.

Table 2.5-24 Summary of Performance-Based Spectrum Calculations, Base Case

Frequency Hz	Mean 1×10^{-4} Amplitude, g	Mean 1×10^{-5} Amplitude, g	A_R	SF	$A(f)$, g
0.5	0.0298	0.0944	3.17	1.51	0.0450
1	0.0463	0.134	2.89	1.40	0.0648
2.5	0.120	0.364	3.03	1.46	0.175
5	0.235	0.735	3.13	1.49	0.350
10	0.373	1.216	3.26	1.54	0.574
25	0.569	1.99	3.50	1.63	0.930
100 (PGA)	0.214	0.753	3.52	1.64	0.351

Table 2.5-25 Spectral Accelerations Corresponding to Mean 5×10^{-5} Annual Frequency

Frequency	Spectral Acceleration at 5×10^{-5} , g	Combined frequency, Hz	Average spectral Acceleration, g
1	0.0652	1.75	0.118
2.5	0.170		
5	0.339	7.5	0.443
10	0.547		

Table 2.5-26 Controlling Earthquake Magnitudes and Distances Corresponding to Mean 5×10^{-5} Annual Frequency

Frequencies	M	r_{CD} , km
Low (1 and 2.5 Hz)	5.5	30
High (5 and 10 Hz)	5.3	23

Table 2.5-27 Summary of Spectrum Calculations for Sensitivity Study with Increased Alternate Minimum Magnitude

Frequency Hz	Mean 1×10^{-4} Acceleration, g	Mean 1×10^{-5} Acceleration, g	A_R	SF	$A(f)$, g
0.5	0.0289	0.0942	3.26	1.54	0.0446
1	0.0453	0.133	2.94	1.42	0.0643
2.5	0.108	0.344	3.19	1.52	0.164
5	0.194	0.657	3.39	1.59	0.309
10	0.291	1.033	3.55	1.65	0.481
25	0.427	1.60	3.75	1.73	0.737
100 (PGA)	0.160	0.607	3.79	1.74	0.279

Table 2.5-28 Summary of Spectrum Calculations for Sensitivity Study with Alternate Aleatory Ground Motion Uncertainties

Frequency Hz	Mean 1×10^{-4} Acceleration, g	Mean 1×10^{-5} Acceleration, g	A_R	SF	$A(f)$, g
0.5	0.0241	0.0688	2.85	1.39	0.0335
1	0.0424	0.119	2.81	1.37	0.0581
2.5	0.114	0.335	2.94	1.42	0.162
5	0.23	0.683	2.97	1.43	0.330
10	0.356	1.089	3.06	1.47	0.522
25	0.519	1.76	3.39	1.59	0.827
100 (PGA)	0.2	0.658	3.29	1.56	0.311

Table 2.5-29 Zone IIA Constituents

Location	Thickness Sampled, ft	Coarse-Grained		Fine-Grained		SC
		SP/GP	SM	ML	MH/CL/CH	
Units 1&2	2204	9.4%	67.8%	1.5%	20.3%	1%
Units 3&4	1112	17.5%	78.8%	3.7%	— ^a	—
SWR	1223	23.3%	44.7%	22.7%	6.3%	3%
ISFSI	451	—	45.5%	2.4%	47%	5.1%
ESP	105	2.4%	68.5%	20.2%	—	8.9%
Average		10.5%	61.1%	10.1%	14.7%	3.6%

Sources: Table 2.5-30 through Table 2.5-36, and Table 2.5-38

a. Dash in box denotes absence of that constituent at that location

Table 2.5-30 Summary of Units 1&2 Borings—Soils

Borehole Details					Soil Zone Thickness				Zone IIA N-Values		
Boring	Northing	Easting	Elev.	Depth	Fill	I	IIA	IIB	No.	Range	Median
	ft	ft	ft	ft	ft	ft	ft	ft		blows/ft	blows/ft
1	144,104	2,204,897	275	87	— ^a	1	35	—	7	24 to 600	138
2	144,381	2,204,733	285	97	—	3	29	—	—	—	—
3	144,667	2,204,564	279	80	—	2	33	—	—	—	—
4	144,000	2,204,665	291	104	—	—	25	—	—	—	—
5	144,175	2,204,567	294	116	—	1	20	7	—	—	—
6	144,348	2,204,464	289	110	—	1	28	—	—	—	—
7	144,559	2,204,340	275	151	—	—	55	—	—	—	—
8	143,897	2,204,438	299	97	—	1	7	—	—	—	—
9	144,176	2,204,273	281	92	—	8	55	—	—	—	—
10	144,463	2,204,108	256	79	—	2	31	—	7	17 to 1220	151
11	143,794	2,204,206	307	107	—	—	22	7	—	—	—
12	143,964	2,204,103	289	106	—	1	17	—	—	—	—
13	144,139	2,204,000	270	90	—	—	—	24	—	—	—
14	144,358	2,203,876	275	87	—	1	42	—	—	—	—
15	143,742	2,203,980	317	117	—	5	34	5	—	—	—
16	143,971	2,203,814	297	117	—	—	30	—	—	—	—
17	144,253	2,203,655	271	94	—	1	67	—	—	—	—
18	143,582	2,203,751	314	130	—	1	21	—	—	—	—
19	143,751	2,203,649	298	120	—	3	22	—	—	—	—
20	143,932	2,203,549	283	104	—	2	18	—	—	—	—
21	144,144	2,203,423	275	93	—	10	37	—	—	—	—
22	143,479	2,203,521	317	123	—	4	49	—	—	—	—
23	143,758	2,203,356	305	97	—	1	7	10	—	—	—
24	144,041	2,203,191	293	90	—	3	57	—	—	—	—
25	143,371	2,203,289	305	112	—	1	49	—	—	—	—
26	143,655	2,203,126	297	97	—	4	2	—	—	—	—
27	143,938	2,202,959	279	92	—	4	36	—	4	16 to 107	36
28	144,060	2,204,552	295	115	—	—	25	—	—	—	—

Table 2.5-30 Summary of Units 1&2 Borings—Soils

Borehole Details					Soil Zone Thickness				Zone IIA N-Values		
Boring	Northing	Easting	Elev.	Depth	Fill	I	IIA	IIB	No.	Range	Median
	ft	ft	ft	ft	ft	ft	ft	ft		blows/ft	blows/ft
29	144,129	2,204,515	294	115	—	13	7	—	—	—	—
30	144,015	2,204,418	293	92	—	—	24	—	—	—	—
31	144,036	2,204,256	281	100	—	—	7	—	—	—	—
32	143,960	2,204,294	288	109	—	—	15	—	—	—	—
34	144,297	2,204,385	286	86	—	—	45	—	—	—	—
35	144,238	2,204,136	273	75	—	—	40	5	—	—	—
36	144,206	2,204,139	272	72	—	—	60	—	—	—	—
37	144,711	2,204,201	251	65	—	—	50	—	—	—	—
38	144,675	2,204,103	244	57	—	—	40	—	—	—	—
39	143,985	2,204,582	293	112	—	—	31	15	—	—	—
40	143,892	2,204,320	297	112	—	4	11	27	—	—	—
41	143,335	2,203,820	326	77	—	—	77	—	—	—	—
42	142,737	2,204,067	305	76	—	—	76	—	—	—	—
43	143,737	2,204,722	285	60	—	2	42	8	6	69 to 140	88
44	143,119	2,204,974	275	76	—	—	76	—	—	—	—
45	143,282	2,204,569	309	76	—	—	76	—	—	—	—
46	143,167	2,204,242	317	75	—	4	71	—	—	—	—
47	143,528	2,204,284	302	76	—	—	76	—	—	—	—
48	143,020	2,204,469	294	76	—	6	70	—	—	—	—
49	144,222	2,204,490	291	120	—	—	42	—	—	—	—
50	144,123	2,204,232	287	83	—	—	53	—	9	4 to 65	9
51	144,703	2,202,598	253	20	—	—	2	—	—	—	—
52	143,765	2,202,970	285	27	—	9	18	—	—	—	—
53	144,082	2,202,414	301	27	—	19	8	—	—	—	—
54	144,402	2,201,850	300	27	—	3	24	—	—	—	—
55	144,474	2,202,231	323	27	—	9	18	—	—	—	—
101	145,187	2,203,051	282	92	—	5	36	—	—	—	—
102	142,058	2,205,639	288	100	—	—	70	15	—	—	—

Table 2.5-30 Summary of Units 1&2 Borings—Soils

Borehole Details					Soil Zone Thickness				Zone IIA N-Values		
Boring	Northing	Easting	Elev.	Depth	Fill	I	IIA	IIB	No.	Range	Median
	ft	ft	ft	ft	ft	ft	ft	ft		blows/ft	blows/ft
103	141,134	2,206,732	265	125	—	—	80	22	7	22 to 277	52
104	143,840	2,204,196	304	150	—	—	19	—	—	—	—
105	144,041	2,204,072	274	150	—	—	30	—	2	6 to 7	7
106	144,206	2,203,930	274	150	—	—	57	13	—	—	—
60			290	93	0%	5%	89%	6%	42		52
Total			Median		Percentage			Total	Median		

Source: Reference 146

a. Dash in box denotes absence of that soil in boring, or no test performed.

Table 2.5-31 Summary of Units 1 & 2 Borings—Rock

Borehole Details					Top of Rock Elevation		Median Recovery/RQD					
Boring	Northing	Easting	Depth	Elev.	III	III-IV or IV	III		III-IV		IV	
	ft	ft	ft	ft	ft	ft	Rec.	RQD	Rec.	RQD	Rec.	RQD
1	144,104	2,204,897	87	275	216	239	64%	0%	87%	9%	100%	46%
2	144,381	2,204,733	97	285	— ^a	253	—	—	—	—	79%	63%
3	144,667	2,204,564	80	279	245	226	100%	52%	—	—	96%	32%
4	144,000	2,204,665	104	291	—	267	—	—	90%	0%	90%	22%
5	144,175	2,204,567	116	294	273	251	92%	70%	100%	35%	95%	55%
6	144,348	2,204,464	110	289	259	234	83%	22%	100%	86%	98%	93%
7	144,559	2,204,340	151	275	—	220	—	—	—	—	98%	62%
8	143,897	2,204,438	97	299	—	289	—	—	—	—	75%	40%
9	144,176	2,204,273	92	281	218	215	29%	25%	—	—	100%	97%
10	144,463	2,204,108	79	256	216	223	55%	33%	—	—	81%	70%
11	143,794	2,204,206	107	307	285	212	60%	0%	—	—	100%	28%
12	143,964	2,204,103	106	289	—	268	—	—	—	—	97%	80%
13	144,139	2,204,000	90	270	246	240	22%	0%	91%	75%	100%	85%
14	144,358	2,203,876	87	275	225	211	30%	0%	—	—	90%	70%
15	143,742	2,203,980	117	317	278	249	50%	20%	—	—	93%	82%
16	143,971	2,203,814	117	297	—	267	—	—	—	—	100%	90%
17	144,253	2,203,655	94	271	—	203	—	—	—	—	100%	97%
18	143,582	2,203,751	130	314	292	225	10%	0%	—	—	87%	60%
19	143,751	2,203,649	120	298	273	234	25%	8%	—	—	75%	66%
20	143,932	2,203,549	104	283	263	245	33%	16%	—	—	95%	88%
21	144,144	2,203,423	93	275	235	206	25%	0%	—	—	96%	66%
22	143,479	2,203,521	123	317	264	254	43%	15%	57%	11%	91%	44%
23	143,758	2,203,356	97	305	287	274	76%	56%	—	—	95%	78%
24	144,041	2,203,191	90	293	—	233	—	—	—	—	80%	71%
25	143,371	2,203,289	112	305	255	205	0%	0%	—	—	100%	73%
26	143,655	2,203,126	97	297	291	288	96%	65%	—	—	70%	59%
27	143,938	2,202,959	92	279	239	210	17%	0%	—	—	78%	40%

Table 2.5-31 Summary of Units 1 & 2 Borings—Rock

Borehole Details					Top of Rock Elevation		Median Recovery/RQD					
Boring	Northing	Easting	Depth	Elev.	III	III-IV or IV	III		III-IV		IV	
	ft	ft	ft	ft	ft	ft	Rec.	RQD	Rec.	RQD	Rec.	RQD
28	144,060	2,204,552	115	295	—	270	—	—	100%	25%	100%	38%
29	144,129	2,204,515	115	294	—	274	—	—	100%	63%	—	—
30	144,015	2,204,418	92	293	—	269	—	—	100%	60%	100%	77%
31	144,036	2,204,256	100	281	274	230	80%	42%	47%	17%	90%	47%
32	143,960	2,204,294	109	288	—	273	—	—	—	—	97%	50%
34	144,297	2,204,385	86	286	206	241	62%	9%	—	—	80%	47%
35	144,238	2,204,136	75	273	233	—	50%	29%	—	—	—	—
36	144,206	2,204,139	72	272	—	212	—	—	75%	42%	—	—
37	144,711	2,204,201	65	251	—	201	—	—	—	—	75%	43%
38	144,675	2,204,103	57	244	—	204	—	—	—	—	67%	32%
39	143,985	2,204,582	112	293	243	262	90%	42%	67%	18%	88%	70%
40	143,892	2,204,320	112	297	282	228	70%	21%	49%	4%	—	—
41	143,335	2,203,820	77	326	—	—	—	—	—	—	—	—
42	142,737	2,204,067	76	305	—	—	—	—	—	—	—	—
43	143,737	2,204,722	60	285	—	—	—	—	—	—	—	—
44	143,119	2,204,974	76	275	—	—	—	—	—	—	—	—
45	143,282	2,204,569	76	309	—	—	—	—	—	—	—	—
46	143,167	2,204,242	75	317	—	—	—	—	—	—	—	—
47	143,528	2,204,284	76	302	—	—	—	—	—	—	—	—
48	143,020	2,204,469	76	294	—	—	—	—	—	—	—	—
49	144,222	2,204,490	120	291	—	249	—	—	83%	62%	85%	33%
50	144,123	2,204,232	83	287	—	234	—	—	—	—	95%	92%
51	144,703	2,202,598	20	253	251	—	65%	17%	—	—	—	—
52	143,765	2,202,970	27	285	—	—	—	—	—	—	—	—
53	144,082	2,202,414	27	301	—	—	—	—	—	—	—	—
54	144,402	2,201,850	27	300	—	—	—	—	—	—	—	—
55	144,474	2,202,231	27	323	—	—	—	—	—	—	—	—

Table 2.5-31 Summary of Units 1 & 2 Borings—Rock

Borehole Details					Top of Rock Elevation		Median Recovery/RQD					
Boring	Northing	Easting	Depth	Elev.	III	III-IV or IV	III		III-IV		IV	
	ft	ft	ft	ft	ft	ft	Rec.	RQD	Rec.	RQD	Rec.	RQD
101	145,187	2,203,051	92	282	242	236	83%	40%	—	—	82%	62%
102	142,058	2,205,639	100	288	—	—	—	—	—	—	—	—
103	141,134	2,206,732	125	265	—	—	—	—	—	—	—	—
104	143,840	2,204,196	150	304	—	298	—	—	55%	17%	100%	88%
105	144,041	2,204,072	150	274	244	242	80%	67%	—	—	92%	79%
106	144,206	2,203,930	150	274	216	204	57%	4%	96%	40%	100%	95%
60			5589	290	250	236	58%	18%	88%	30%	92%	66%
Total			Total	Median								

Source: Reference 146

a. Dash in box denotes absence of that rock in boring, and no Recovery/RQD recorded.

Table 2.5-32 Summary of Units 3 & 4 Borings—Soils

Borehole Details					Soil Zone Thickness				Zone IIA N-Values		
Boring	Northing	Easting	Elev.	Depth	Fill	I	IIA	IIB	No.	Range	Median
	ft	ft	ft	ft	ft	ft	ft	ft		blows/ft	blows/ft
601	144,563	2,203,695	269	64	5	—	19	—	2	16 to 100	58
602	144,490	2,203,510	277	70	21	—	—	—	—	—	—
603	144,495	2,203,615	274	85	14	—	19	20	2	105 to 175	140
604	144,500	2,203,731	270	85	3	—	16	10	1	40	40
605	144,425	2,203,535	277	70	15	—	14	—	3	35 to 123	54
606	144,338	2,203,843	270	70	2	—	22	11	4	18 to 140	48
607	144,235	2,203,570	270	65	2	—	26	7	5	13 to 250	32
608	144,270	2,203,882	270	87	2	—	33	37	3	31 to 146	143
609	144,232	2,203,803	271	90	2	—	54	7	5	13 to 140	21
610	144,188	2,203,705	271	96	2	—	70	9	8	22 to 225	27
611	144,165	2,203,610	271	76	2	—	48	—	5	15 to 220	33
612	144,125	2,203,515	270	80	7	—	46	5	1	13	13
613	144,195	2,203,910	270	65	2	—	42	—	7	15 to 90	30
614	144,160	2,203,825	271	70	2	—	38	—	5	18 to 33	23
615	144,125	2,203,723	270	65	2	—	33	4	4	12 to 44	28
616	144,100	2,203,638	271	64	1	—	32	—	5	9 to 45	24
617	144,063	2,203,548	271	70	2	—	38	5	7	26 to 136	94
618	144,140	2,203,930	270	54	2	—	32	—	5	14 to 44	32
619	144,065	2,203,749	271	49	1	—	12	—	2	65 to 110	87
620	144,108	2,203,859	270	46	1	—	9	3	1	40	40
621	144,005	2,203,700	271	50	— ^a	—	2	—	—	—	—
622	143,510	2,203,535	271	79	1	—	19	10	3	41 to 360	210
623	143,915	2,203,670	272	79	2	—	12	—	2	49 to 510	275
624	143,960	2,203,985	271	175	1	—	9	—	2	49 to 150	100
625	143,905	2,203,845	270	40	5	—	—	—	1	6	6
626	143,870	2,203,686	272	150	1	—	7	—	1	119	119
627	143,911	2,204,068	271	78	3	—	7	—	—	—	—

Table 2.5-32 Summary of Units 3 & 4 Borings—Soils

Borehole Details					Soil Zone Thickness				Zone IIA N-Values		
Boring	Northing	Easting	Elev.	Depth	Fill	I	IIA	IIB	No.	Range	Median
	ft	ft	ft	ft	ft	ft	ft	ft		blows/ft	blows/ft
628	143,878	2,203,980	271	78	3	—	—	—	—	—	—
629	143,795	2,203,780	272	79	1	—	—	—	—	—	—
630	143,775	2,203,725	271	78	3	—	—	—	—	—	—
631	143,345	2,204,005	322	105	—	11	77	—	8	13 to 262	48
632	143,815	2,204,355	294	75	1	—	15	18	3	44 to 116	56
633	143,880	2,204,570	284	59	8	—	5	15	—	—	—
634	143,945	2,204,790	284	62	8	—	25	8	5	23 to 145	65
635	143,995	2,204,960	275	65	-	2	19	18	—	—	—
636	144,415	2,203,750	270	70	3	—	26	15	5	15 to 400	200
637	144,340	2,203,570	271	75	10	—	20	—	3	14 to 200	42
638	144,660	2,203,660	268	50	3	—	5	20	1	116	116
639	144,590	2,203,475	274	61	23	—	8	10	2	128 to 160	144
640	144,290	2,203,935	269	82	-	—	47	35	8	22 to 242	50
641	143,205	2,203,855	270	88	2	—	55	—	10	16 to 300	28
642	144,175	2,203,655	271	75	2	—	52	—	7	19 to 94	26
643	144,109	2,203,586	270	72	2	—	30	8	6	18 to 400	55
644	143,825	2,203,745	271	50	5	—	-	—	—	—	—
645	143,895	2,204,010	271	78	5	—	-	—	—	—	—
646	144,665	2,203,790	268	47	8	—	39	—	8	20 to 240	68
647	144,705	2,203,430	256	40	—	—	28	—	5	13 to 200	44
47			271	71	12%	1%	71%	16%	155	—	50
Total				Median	Percentage				Total		Median

Source: Reference 8

a. Dash in box denotes absence of that soil in boring, or no test performed.

Table 2.5-33 Summary of Units 3 & 4 Borings—Rock

Boring	Borehole Details				Top of Rock El.		Median Recovery/RQD					
	Northing	Easting	Depth	Elev.	III	IV or III-IV	III		III-IV		IV	
	Ft	Ft	Ft	Ft	Ft	Ft	Rec.	RQD	Rec.	RQD	Rec.	RQD
601	144,563	2,203,695	64	269	237	245	98%	39%	95%	73%	—	—
602	144,490	2,203,510	70	277	238	255	84%	30%	69%	29%	—	—
603	144,495	2,203,615	85	274	209	230	57%	6%	100%	50%	100%	85%
604	144,500	2,203,731	85	270	251	190	75%	27%	—	—	100%	69%
605	144,425	2,203,535	70	277	248	—	98%	45%	—	—	—	—
606	144,338	2,203,843	70	270	205	223	20%	0%	100%	60%	—	—
607	144,235	2,203,570	65	270	235	227	—	—	100%	55%	—	—
608	144,270	2,203,882	87	270	235	188	75%	23%	—	—	93%	49%
609	144,232	2,203,803	90	271	208	—	87%	14%	—	—	—	—
610	144,188	2,203,705	96	271	— ^a	191	—	—	100%	86%	—	—
611	144,165	2,203,610	76	271	—	221	—	—	—	—	97%	96%
612	144,125	2,203,515	80	270	—	212	—	—	—	—	98%	75%
613	144,195	2,203,910	65	270	226	—	100%	51%	—	—	—	—
614	144,160	2,203,825	70	271	231	224	70%	5%	93%	55%	97%	69%
615	144,125	2,203,723	65	270	232	227	—	—	78%	60%	—	—
616	144,100	2,203,638	64	271	238	227	67%	53%	95%	83%	—	—
617	144,063	2,203,548	70	271	226	221	96%	44%	—	—	94%	94%
618	144,140	2,203,930	54	270	—	236	—	—	—	—	100%	90%
619	144,065	2,203,749	49	271	249	258	92%	0%	—	—	93%	93%
620	144,108	2,203,859	46	270	259	257	—	—	—	—	99%	77%
621	144,005	2,203,700	50	271	269	246	69%	65%	—	—	100%	100%
622	143,510	2,203,535	79	271	246	241	75%	10%	—	—	100%	84%
623	143,915	2,203,670	79	272	258	234	80%	35%	—	—	100%	87%
624	143,960	2,203,985	175	271	—	261	—	—	—	—	98%	80%
625	143,905	2,203,845	40	270	—	265	—	—	—	—	100%	90%
626	143,870	2,203,686	150	272	—	264	—	—	94%	40%	98%	91%
627	143,911	2,204,068	78	271	261	246	75%	20%	100%	66%	100%	91%
628	143,878	2,203,980	78	271	258	242	90%	9%	100%	61%	100%	90%

Table 2.5-33 Summary of Units 3 & 4 Borings—Rock

Borehole Details					Top of Rock El.		Median Recovery/RQD					
Boring	Northing	Easting	Depth	Elev.	III	IV or III-IV	III		III-IV		IV	
	Ft	Ft	Ft	Ft	Ft	Ft	Rec.	RQD	Rec.	RQD	Rec.	RQD
629	143,795	2,203,780	79	272	269	262	50%	20%	100%	80%	100%	90%
630	143,775	2,203,725	78	271	268	251	100%	58%	100%	75%	100%	75%
631	143,345	2,204,005	105	322	—	234	—	—	52%	28%	—	—
632	143,815	2,204,355	75	294	262	—	80%	70%	—	—	—	—
633	143,880	2,204,570	59	284	257	229	70%	15%	100%	50%	—	—
634	143,945	2,204,790	62	284	251	—	96%	60%	—	—	—	—
635	143,995	2,204,960	65	275	224	236	86%	23%	—	—	86%	52%
636	144,415	2,203,750	70	270	241	—	60%	18%	—	—	—	—
637	144,340	2,203,570	75	271	241	227	65%	35%	50%	29%	85%	81%
638	144,660	2,203,660	50	268	—	239	—	—	75%	35%	—	—
639	144,590	2,203,475	61	274	232	218	70%	8%	—	—	85%	50%
640	144,290	2,203,935	82	269	222	—	95%	39%	—	—	-	-
641	143,205	2,203,855	88	270	214	197	75%	35%	—	—	100%	73%
642	144,175	2,203,655	75	271	217	208	100%	20%	—	—	98%	70%
643	144,109	2,203,586	72	270	230	218	60%	40%	90%	70%	-	-
644	143,825	2,203,745	50	271	266	256	93%	31%	90%	30%	-	-
645	143,895	2,204,010	78	271	—	266	—	—	100%	40%	100%	68%
646	144,665	2,203,790	47	268	—	—	—	—	—	—	—	—
647	144,705	2,203,430	40	256	228	—	80%	25%	—	—	—	—
47			3461	271	238	234	80%	27%	95%	60%	100%	82%
Total			Total	Median								

Source: Reference 8

a. Dash in box denotes absence of that rock in boring, and no Recovery/RQD recorded.

Table 2.5-34 Summary of Service Water Reservoir Borings—Soils

Borehole Details					Soil Zone Thickness				Zone IIA N-Values			
Boring	Northing	Easting	Elev.	Depth	Fill	I	IIA	IIB	No.	Range	Median	
	ft	ft	ft	ft	ft	ft	ft	ft		blows/ft	blows/ft	
P-10	142,876	2,204,869	283	27	— ^a	—	27	—	4	20 to 142	34	
P-11	143,495	2,204,410	324	53	13	—	40	—	7	13 to 23	16	
P-12	143,561	2,204,416	298	30	—	—	30	—	4	17 to 25	18	
P-15	143,150	2,204,700	321	72	28	—	44	—	1	19	19	
P-16	143,050	2,204,607	321	70	32	—	38	—	7	18 to 107	28	
P-17	142,958	2,204,529	321	77	32	—	45	—	9	17 to 137	22	
S1-1	143,495	2,204,430	326	92	12	—	80	—	12	17 to 100	26	
S1-2	143,565	2,204,435	297	75	—	—	75	—	7	15 to 100	33	
S1-3	143,078	2,204,777	285	64	—	—	64	—	9	31 to 155	63	
SWR-1	143,470	2,204,492	306	58	—	—	43	15	27	9 to 24	17	
SWR-2	143,438	2,204,492	306	58	—	—	50	8	33	11 to 84	18	
SWR-3	143,076	2,203,686	321	100	—	—	100	—	19	12 to 142	45	
SWR-4	143,396	2,203,983	320	101	—	—	101	—	20	16 to 400	30	
SWR-5	143,391	2,204,753	321	105	26	—	79	—	17	12 to 226	23	
SWR-6	143,127	2,204,712	321	104	15	—	89	—	18	16 to 400	25	
SWR-7	142,942	2,204,532	321	82	15	—	67	—	13	8 to 37	19	
SWR-8	142,951	2,204,302	321	72	10	—	62	—	13	9 to 109	25	
SWR-9	142,982	2,204,061	321	67	12	—	55	—	11	8 to 274	50	
SWR-10	143,133	2,204,685	321	64	31	—	33	—	13	14 to 36	21	
SWR-11	142,980	2,204,685	286	38	16	—	22	—	5	17 to 300	48	
SWR-12	142,893	2,204,598	289	49	15	—	34	—	—	—	—	
SWR-13	143,242	2,204,792	321	72	27	—	45	—	9	13 to 62	22	
22			321	71	18.5%	0	80%	1.5%	258			25
Total			Median		Percentage				Total			Median

Source: Reference 5

a. Dash in box denotes absence of that soil in boring, or no test performed.

Table 2.5-35 Summary of Service Water Reservoir Borings—Rock

Borehole Details					Top of Rock Elev. ^a	
Boring	Northing	Easting	Depth	Elev.	III	III-IV or IV
	ft	ft	ft	ft	ft	ft
P-10	142,876	2,204,869	27	283	— ^b	—
P-11	143,495	2,204,410	53	324	—	—
P-12	143,561	2,204,416	30	298	—	—
P-15	143,150	2,204,700	72	321	—	—
P-16	143,050	2,204,607	70	321	—	—
P-17	142,958	2,204,529	77	321	—	—
S1-1	143,495	2,204,430	92	326	—	234
S1-2	143,565	2,204,435	75	297	—	222
S1-3	143,078	2,204,777	64	285	—	221
SWR-1	143,470	2,204,492	58	306	248	—
SWR-2	143,438	2,204,492	58	306	248	—
SWR-3	143,076	2,203,686	100	321	—	221
SWR-4	143,396	2,203,983	101	320	—	219
SWR-5	143,391	2,204,753	105	321	—	216
SWR-6	143,127	2,204,712	104	321	—	217
SWR-7	142,942	2,204,532	82	321	—	—
SWR-8	142,951	2,204,302	72	321	—	—
SWR-9	142,982	2,204,061	67	321	—	—
SWR-10	143,133	2,204,685	64	321	—	—
SWR-11	142,980	2,204,685	38	286	—	—
SWR-12	142,893	2,204,598	49	289	—	—
SWR-13	143,242	2,204,792	72	321	—	—
22			1530	321	248	221
Total			Total	Median		

Source: Reference 5

a. Top of rock is estimated since there was no rock coring.

b. Dash in box denotes absence of that rock in boring.

Table 2.5-36 Summary of ISFSI Borings—Soils

Borehole Details					Soil Zone Thickness				Zone IIA N-Values		
Boring	Northing	Easting	Elev.	Depth	Fill	I	IIA	IIB	No.	Range	Median
	ft	ft	ft	ft	ft	ft	ft	ft		blows/ft	blows/ft
F-2	142,000	2,202,990	320	70	— ^a	—	65	—	14	14 to 78	18
F-4	141,982	2,202,850	317	59	—	—	34	15	9	15 to 125	21
F-5	141,982	2,203,200	318	115	—	—	64	—	15	9 to 44	25
F-6	141,864	2,202,850	316	59	—	—	44	—	11	13 to 110	19
F-7	141,864	2,203,000	320	105	—	—	75	—	18	10 to 165	21
F-8	141,864	2,203,200	318	69	—	—	35	29	9	16 to 36	24
F-9	141,746	2,202,850	311	105	—	—	55	4	13	7 to 56	21
F-10	141,746	2,203,000	315	74	—	—	50	19	12	20 to 80	27
F-11	141,746	2,203,200	309	69	—	—	29	10	8	32 to 160	42
9			317	70	0	0	85.4	14.6	109		21
Total			Median		Percentage				Total		Median

Source: Reference 6

a. Dash in box denotes absence of that soil in boring, or no test performed.

Table 2.5-37 Summary of ISFSI Borings—Rock

Borehole Details					Top of Rock Elev.	Avg. Recovery/ RQD	
Boring	Northing	Easting	Depth	Elev.	III	III	
	ft	ft	ft	ft	ft	Rec.	RQD
F-2	142,000	2,202,990	70	320	255	0%	0%
F-4	141,982	2,202,850	59	317	268	50%	20%
F-5	141,982	2,203,200	115	318	254	15%	0%
F-6	141,864	2,202,850	59	316	272	23%	6%
F-7	141,864	2,203,000	105	320	245	11%	0%
F-8	141,864	2,203,200	69	318	254	80%	0%
F-9	141,746	2,202,850	105	311	252	20%	4%
F-10	141,746	2,203,000	74	315	246	95%	36%
F-11	141,746	2,203,200	69	309	260	41%	8%
9			725	317	254	23%	4%
Total			Total	Median			

Source: Reference 5

Table 2.5-38 Summary of ESP Borings, Observation Wells, and CPTs—Soils

Borehole/OW/CPT Details					Soil Zone Thickness				IIA N-Values		
Boring/ OW/CPT	Northing ft	Easting ft	Elev. ft	Depth ft	Fill ft	I ft	IIA ft	IIB ft	No.	Range blows/ft	Median blows/ft
B-801	144,034	2,203,740	249	50	19	—	—	—	—	—	—
B-802	143,639	2,203,383	271	90	3	—	3	—	1	44	44
B-803	143,603	2,202,766	292	170	— ^a	—	31	—	9	12 to 31	22
B-804	143,179	2,202,137	320	60	—	2	21	—	8	5 to 24	8
B-805	144,043	2,203,249	271	90	—	—	23	5	8	12 to 100	22
B-806	143,098	2,200,979	299	65	2	—	6	—	2	18 to 22	20
B-807	143,530	2,200,983	311	72	—	—	21	21	10	12 to 100	16
7			292	72	15%	1%	67%	17%	38	—	21
Median			Percentage			Total		Median			
Total					Soil Thickness, ft						
OW-841	144,238	2,203,806	252	34	24						
OW-842	142,716	2,202,151	337	50	50						
OW-843	143,407	2,202,059	321	49	49						
OW-844	143,591	2,203,592	274	25	24						
OW-845	143,540	2,202,743	297	55	33						
OW-846	143,527	2,202,724	297	33	33						
OW-847	142,627	2,203,450	320	50	50						
OW-848	144,535	2,203,275	285	47	33						
OW-849	144,468	2,201,733	299	50	50						
9			297	49	33						
Median											
CPT-821	143,647	2,203,355	271	4	4						
CPT-822	144,057	2,203,239	271	23	23						
CPT-823	143,532	2,202,758	296	32	32						
CPT-824	143,736	2,203,012	276	4	4						
CPT-825	143,160	2,202,269	333	52	52						
CPT-827	144,370	2,200,571	277	58	58						
CPT-828	144,334	2,200,068	270	5	5						
CPT-830	143,531	2,203,002	308	16	16						
8			276	20	20						
Median											

Source: Reference 147

a. Dash in box denotes absence of that soil in boring, or no test performed.

Table 2.5-39 Summary of ESP Borings, Observation Wells, and CPTs—Rock

Borehole/OW/CPT Details					Top of Rock Elev.		Median Recovery/RQD					
Boring/ OW/CPT	Northing ft	Easting ft	Depth ft	Elev. ft	III ft	III-IV or IV ft	III		III-IV		IV	
							Rec.	RQD	Rec.	RQD	Rec.	RQD
B-801	144,034	2,203,740	50	249	230	229	— ^a	—	—	—	100%	100%
B-802	143,639	2,203,383	90	271	265	263	—	—	88%	44%	100%	84%
B-803	143,603	2,202,766	170	292	262	244	—	—	—	—	100%	100%
B-804	143,179	2,202,137	60	320	298	287	—	—	80%	47%	100%	98%
B-805	144,043	2,203,249	90	271	243	232	—	—	90%	70%	100%	90%
B-806	143,098	2,200,979	65	299	292	288	25%	5%	86%	65%	—	—
B-807	143,530	2,200,983	72	311	276	254	—	—	46%	0%	—	—
7			597	292	265	254	25%	5%	86%	47%	100%	98%
Total			Total	Median								
OW-841	144,238	2,203,806	34	252	228							
OW-842	142,716	2,202,151	50	337	—							
OW-843	143,407	2,202,059	49	321	—							
OW-844	143,591	2,203,592	25	274	250							
OW-845	143,540	2,202,743	55	297	264							
OW-846	143,527	2,202,724	33	297	—							
OW-847	142,627	2,203,450	50	320	—							
OW-848	144,535	2,203,275	47	285	252							
OW-849	144,468	2,201,733	50	299	—							
9			393	297	251							
Total			Total	Median								
CPT-821	143,647	2,203,355	4	271								
CPT-822	144,057	2,203,239	23	271								
CPT-823	143,532	2,202,758	32	296								
CPT-824	143,736	2,203,012	4	276								
CPT-825	143,160	2,202,269	52	333								
CPT-827	144,370	2,200,571	58	277								
CPT-828	144,334	2,200,068	5	270								
CPT-830	143,531	2,203,002	16	308								
8			194	276								
Total			Total	Median								

a. Dash in box denotes absence of that soil in boring, or no test performed. Source: Reference 147.

Table 2.5-40 Summary of Soil Sampling Results

Location	No. of Boreholes	Borehole Median, ft			Percentage per Zone				Zone IIA N-Values	
		Elevation	Total Depth	Soil Thickness	Fill %	I %	IIA %	IIB %	Number	Median blows/ft
Units 1&2	60	290	93	40	0	5	89	6	42	52
Units 3&4	47	271	71	34	12	1	71	16	155	50
SWR	22	321	71	71	18	0	80	2	258	25
ISFSI	9	317	70	64	0	0	85	15	109	21
ESP	7	292	72	23	15	1	67	17	38	21

Sources: Reference 5, Reference 6, Reference 146, Reference 8 and Reference 147

Table 2.5-41 Summary of Rock Coring Results

Location	III			III-IV			IV		
	Thickness ft	Recovery %	RQD %	Thickness ft	Recovery %	RQD %	Thickness ft	Recovery %	RQD %
Units 1&2	702	58	18	493	88	30	1896	92	66
Units 3&4	647	88	27	491	95	60	732	100	82
ISFSI	197	23	4	— ^a	—	—	—	—	—
ESP	94	25	5	91	86	47	255	100	98

Sources: Reference 6, Reference 146, Reference 8 and Reference 147

a. Dash in box denotes absence of that rock in boring, or no recovery/RQD recorded.

Table 2.5-42 Summary of Laboratory Tests Performed

Test	Units 1 & 2	SWR	ISFSI	ESP	Total
Soil					
Moisture content	72	339	30	9	450
Percent passing #200 sieve	— ^a	260	-	-	260
Sieve analysis	15	63	19	10	107
Sieve and hydrometer analysis	-	4	-	5	9
Atterberg limits ^b	4	16	13	5	38
Unit weight	71	163	11	-	245
Mineral analysis (thin section)	1	27	-	-	28
Permeability	4	-	1	-	5
pH	2	-	-	4	6
Sulfate	2	-	-	4	6
Chloride	-	-	-	4	4
Moisture density (Proctor)	2	-	3	-	5
CBR	-	-	3	-	3
Consolidation	5	15 ^c	3	-	23
Unconfined compression	2	-	5	-	7
Triaxial compression (UU)	19 ^d	62	5	-	86
Triaxial compression (CIU) w/pp	5	8	6	-	19
Triaxial compression (cyclic)	2	15	-	-	17
Direct shear	-	2	-	-	2
Shockslope	3	-	-	-	3
Rock					
Unit weight	-	-	-	19	19
Unconfined compression	24	-	-	13	37
Unconfined compression w/stress-strain	6	-	-	6	12

Sources: Reference 5, Reference 6, Reference 146, Reference 8 and Reference 147.

a. Dash denotes no test performed.

b. Atterberg limit tests only listed for plastic samples tested.

c. Includes 5 constant strain tests with pore pressure measurement.

d. Includes 8 tests on prepared soil samples.

Table 2.5-43 Summary of ESP Laboratory Test Results

Sample Identification			Moisture Content %	Atterberg Limits			% Finer #200 Sieve	Chemical Tests		
Boring	Sample Number	Depth ft		Liquid Limit	Plastic Limit	Plasticity Index		pH	Chlorides mg/kg	Sulfates Mg/kg
B-801	SS-1	0-1.5	22.2	39	29	10		6.3	130	<27
B-801	SS-5	8.5-10	— ^a	—	—	—	39.9	—	—	—
B-801	SS-6	13.5-15	—	—	—	—	55.1	—	—	—
B-802	SS-2	3.7-5.2	—	—	—	—	19.5	—	—	—
B-803	SS-3	6.1-7.6	18.9	30	26	4	-	—	—	—
B-803	SS-4	8.6-10.1	23.2	—	—	—	24.4	—	—	—
B-803	SS-6	13.7-15.3	—	—	—	—	20.9	5.7	100	<23
B-803	SS-8	23.6-25.1	—	—	—	—	18.5	—	—	—
B-804	SS-3	3.5-5	—	—	—	—	54.2	—	—	—
B-804	SS-6	11-12.5	—	—	—	—	46.1	—	—	—
B-804	SS-8	18.5-20	—	—	—	—	22.1	—	—	—
B-805	SS-4	7.5-9	27.2	NP ^b	NP	NP	27.5	—	—	—
B-805	SS-7	18.5-20	—	—	—	—	25.1	—	—	—
B-806	SS-3	5.6-7.1	—	—	—	—	27.1	6.7	920	<24
B-807	SS-3	4.5-6	40.1	49	45	4	—	—	—	—
B-807	SS-6	12.3-13.8	42.8	46	40	6	—	5.7	170	<28
B-807	SS-8	21.8-23.8	28.9	41	34	7	42.6	—	—	—
B-807	SS-10	31.5-33	26.7	—	—	—	37.7	—	—	—
B-807	SS-12	41.4-42.9	21.8	—	—	—	44.2	—	—	—

Source: Reference 147

a. Dash denotes no test performed.

b. NP – Non Plastic

Table 2.5-44 Summary of ESP Laboratory Test Results—Rock

Boring Number	Depth, ft	Zone	Unconfined Compressive Strength, ksi	Modulus of Elasticity, ksi	Poisson's Ratio
B-801	24.1-24.8	IV	27.21	— ^a	—
B-801	48.7-49.7	IV	28.42	8670	0.27
B-802	20.4-21.0	III-IV	8.64	—	—
B-802	44.9-45.6	IV	11.76	—	—
B-802	66.0-66.7	IV	14.71	4613	0.24
B-802	85.3-85.9	IV	9.37	—	—
B-803	54.1-54.7	IV	13.01	—	—
B-803	70.4-71.1	IV	23.21	7133	0.34
B-803	90.3-91.0	IV	27.59	—	—
B-803	129.4-130.1	IV	26.73	—	—
B-803	155.6-156.4	IV	22.03	7173	0.33
B-804	38.9-39.9	IV	27.15	—	—
B-804	43.5-44.9	IV	25.20	—	—
B-804	49.9-50.5	IV	12.30	3190	0.43
B-805	41.3-41.9	III-IV	3.40	336	0.15
B-805	80.8-81.6	IV	4.43	—	—
B-806	25.1-25.8	III	0.61	—	—
B-806	42.6-43.2	III-IV	2.72	—	—
B-806	64.1-64.5	IV	27.36	—	—

Source: Reference 147

a. Dash denotes no test performed.

Table 2.5-45 Summary of Geotechnical Engineering Properties

Stratum	IIA		IIB	III	III-IV	IV
Description	Coarse-grained	Fine-grained	Saprolite w/10 to 50% Core Stone	Moderately to Highly Weathered Quartz Gneiss w/Biotite	Slightly to Moderately Weathered Quartz Gneiss w/Biotite	Fresh to Slightly Weathered Quartz Gneiss w/Biotite
	Saprolite	Saprolite				
Rock properties						
Recovery, %	—	—	—	60	90	100
RQD, %	—	—	—	20	50	95
Unconfined compressive strength, ksi	—		—	0.6	4	12
USCS symbol	SP, SM, SC	ML, CL, MH, CH	Mainly SM	—	—	—
Range of fines content, %	15 to 45	—	—	—	—	—
Natural moisture content, w, %	—	26	—	—	—	—
Undrained shear strength, c _u , ksf	—	2.0	—	—	—	—
Effective cohesion, c′, ksf	0.25	0.5	—	—	—	—
Effective friction angle, ϕ′, degrees	30	25	40	—	—	—
Total unit weight, γ, pcf	125		130	145	163	163
SPT N-value, N ₆₀ , blows/ft	20		100	—	—	—
Shear and compression wave velocity						
Shear wave velocity range, ft/sec	600 to 1350		—	—	—	4000 to 8000
Shear wave velocity average, ft/sec	950		1600	2000	3300	6300
Compression wave velocity average, ft/sec	2100		3500	4500	7400	14,000

Table 2.5-45 Summary of Geotechnical Engineering Properties

Stratum	IIA		IIB	III	III-IV	IV
Description	Coarse-grained	Fine-grained	Saprolite w/10 to 50% Core Stone	Moderately to Highly Weathered Quartz Gneiss w/Biotite	Slightly to Moderately Weathered Quartz Gneiss w/Biotite	Fresh to Slightly Weathered Quartz Gneiss w/Biotite
	Saprolite	Saprolite				
Elastic and shear moduli						
Elastic modulus (high strain), E _{hs}	1200 ksf		3500 ksf	120 ksi	1000 ksi	3750 ksi
Elastic modulus (low strain), E _{ls}	9500 ksf		28,000 ksf	300 ksi	1000 ksi	3750 ksi
Shear modulus (high strain), G _{hs}	450 ksf		1300 ksf	50 ksi	375 ksi	1400 ksi
Shear modulus (low strain), G _{ls}	3500 ksf		10,000 ksf	125 ksi	375 ksi	1400 ksi
Consolidation characteristics						
Recompression ratio, RR	0.015		—	—	—	—
Coeff. of secondary compression, C _α	0.0008		—	—	—	—
Coeff. of subgrade reaction, k ₁ , kcf	230		1500	-	-	-
Coefficient of sliding against concrete	0.35		0.45	0.6	0.65	0.7
Poisson's ratio, μ (high strain)	0.35		0.3	0.33	0.33	0.33
Static earth pressure coefficients						
Active, K _a	0.33		0.22	—	—	—
Passive, K _p	3.0		4.6	—	—	—
At-rest, K _o	0.5		0.36	—	—	—
Hydraulic conductivity, cm/sec	5 × 10 ⁻⁴		—	—	—	—

Note: Dash denotes no design parameter given

Table 2.5-46 ZPA Results from SHAKE Analysis

Depth, ft	V _s , ft/sec	Profile 1	Profile 2	Profile 3	V _s , ft/sec	Profile 4
0.0	700	0.59g	– ^a	–	1275	0.41g
2.5	700	0.55g	–	–	1275	0.39g
5.0	700	0.46g	–	–	1275	0.35g
7.5	700	0.37g	–	–	1275	0.34g
10.0	700/950	0.41g	–	–	1275/1380	0.31g
12.5	950	0.36g	–	–	1380	0.28g
15.0	950	0.34g	–	–	1380	0.27g
17.5	950	0.36g	–	–	1380	0.28g
20.0	950/1200	0.35g	–	–	1380/1500	0.30g
22.5	1200	0.32g	–	–	1500	0.31g
25.0	1200	0.30g	–	–	1500	0.29g
27.5	1200	0.29g	–	–	1500	0.30g
30.0	1200/1600	0.34g	0.49g	–	1500/1600	0.31g
35.0	1600	0.34g	0.40g	–	1600	0.31g
40.0	1600/2000	0.28g	0.31g	0.45g	1600/2000	0.28g
45.0	2000	0.23g	0.29g	0.39g	2000	0.26g
50.0	2000	0.21g	0.28g	0.29g	2000	0.20g
55.0	2000/3300	0.22g	0.24g	0.26g	2000/3300	0.22g
60.0	3300	0.19g	0.24g	0.22g	3300	0.20g
65.0	3300	0.16g	0.24g	0.18g	3300	0.20g
70.0	3300	0.16g	0.22g	0.17g	3300	0.19g
Outcrop	6300	0.22g	0.22g	0.22g	6300	0.22g

a. Dash denotes soil not present.

Soil/Rock Columns

1. Profile from 0 to 70 feet, with 30 feet of unimproved Zone IIA saprolite, 10 feet of Zone IIB saprolite, 15 feet of Zone III rock, and 15 feet of Zone III-IV rock.
2. Profile from 30 to 70 feet depth for foundation sitting on 10 feet of Zone IIB saprolite, 15 feet of Zone III weathered rock, and 15 feet of Zone III-IV rock.

3. Profile from 40 to 70 feet depth for foundation sitting on 15 feet of Zone III weathered rock and 15 feet of Zone III-IV rock.
4. Profile from 0 to 70 feet, with 30 feet of improved Zone IIA saprolite, 10 feet of Zone IIB saprolite, 55 feet of Zone III weathered rock, and 15 feet of Zone III-IV rock.

Table 2.5-47 Allowable Bearing Capacity Values

Zone	Allowable Bearing Capacity, ksf
IIA	4
IIB	8
III	16
III-IV	80
IV	160

Note: The above values include a factor of safety against bearing failure of at least 3.

Minimum assumed foundation width is 5 feet. Minimum assumed foundation depth is 3 feet. For the Zone IIA saprolite, the 4 ksf allowable bearing capacity does not consider settlement.

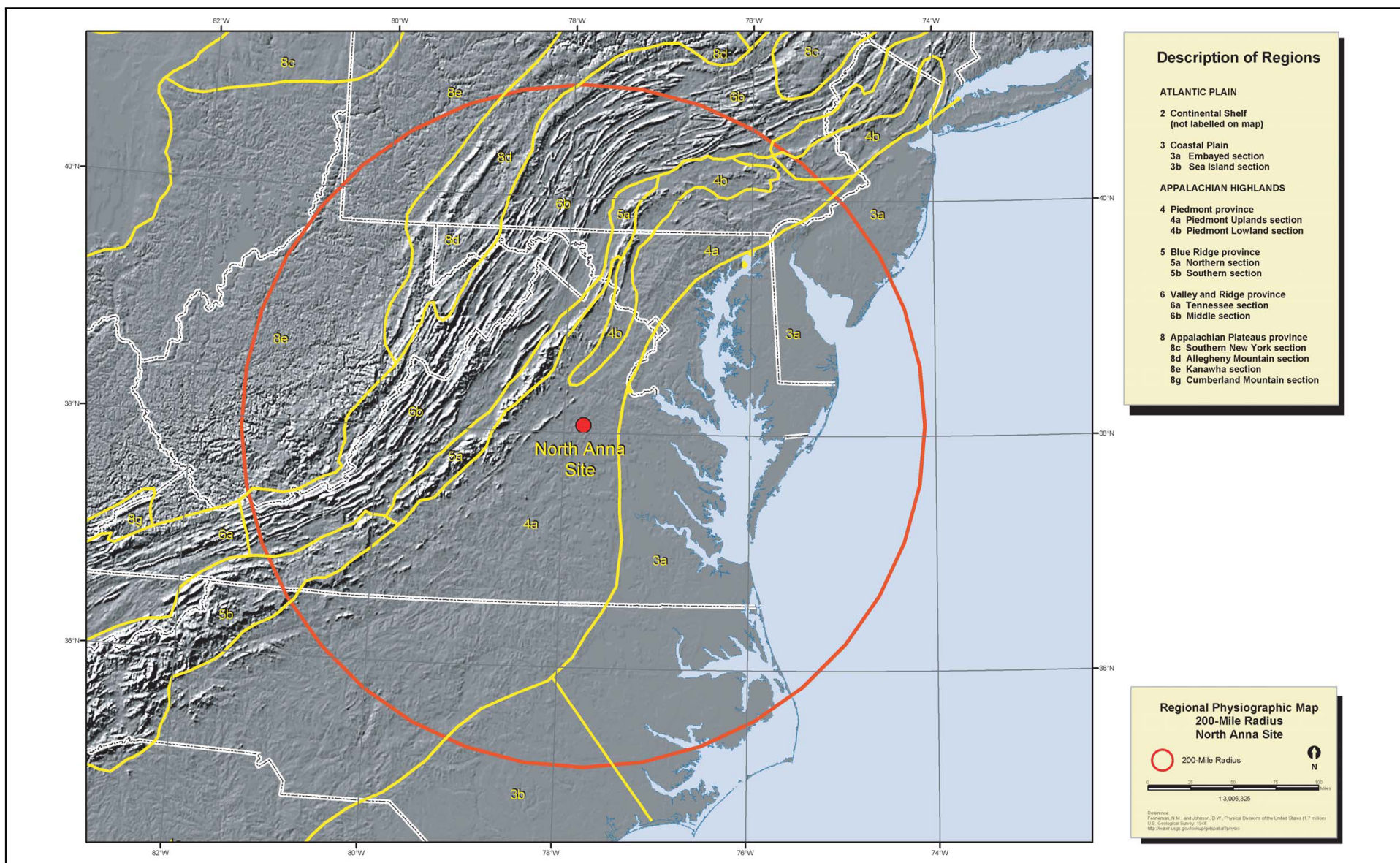
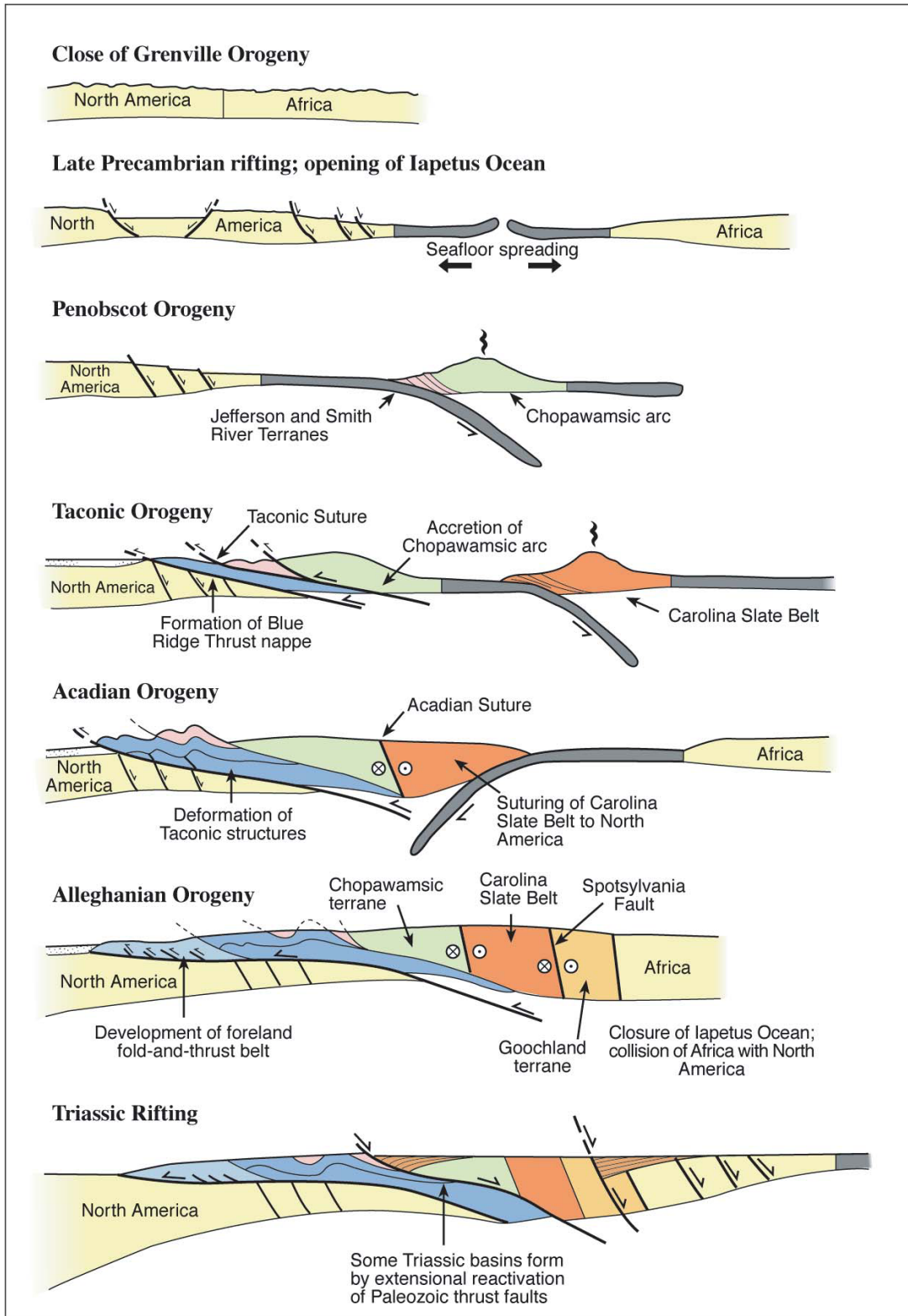


Figure 2.5-1 Regional Physiographic Map (200-Mile Radius)



Modified from Hatcher, 1987

Figure 2.5-2 Evolution of the Appalachian Orogen (after Hatcher, 1987)

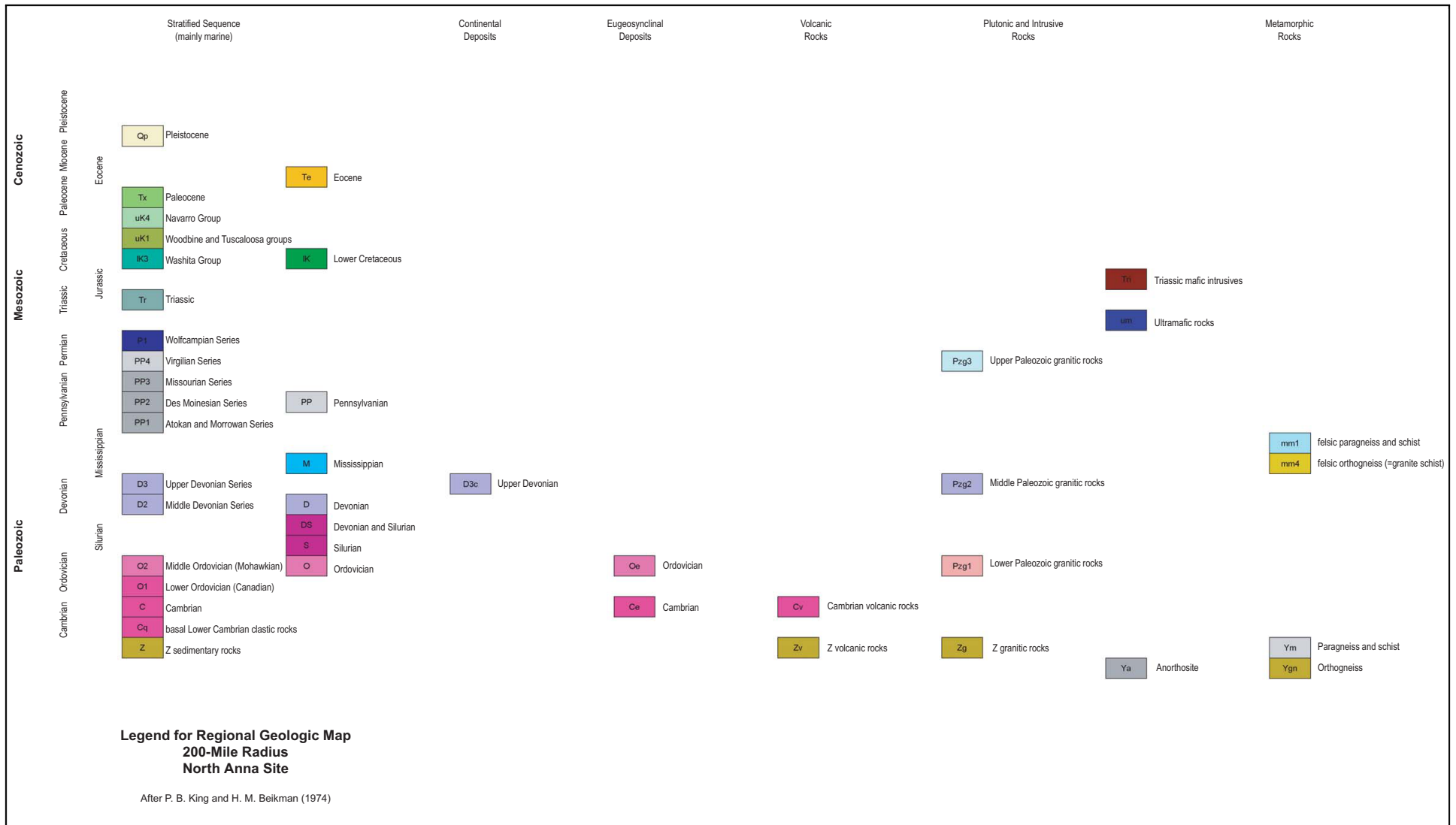


Figure 2.5-3 Regional Geologic Map (200-Mile Radius) (Sheet 2 of 2)

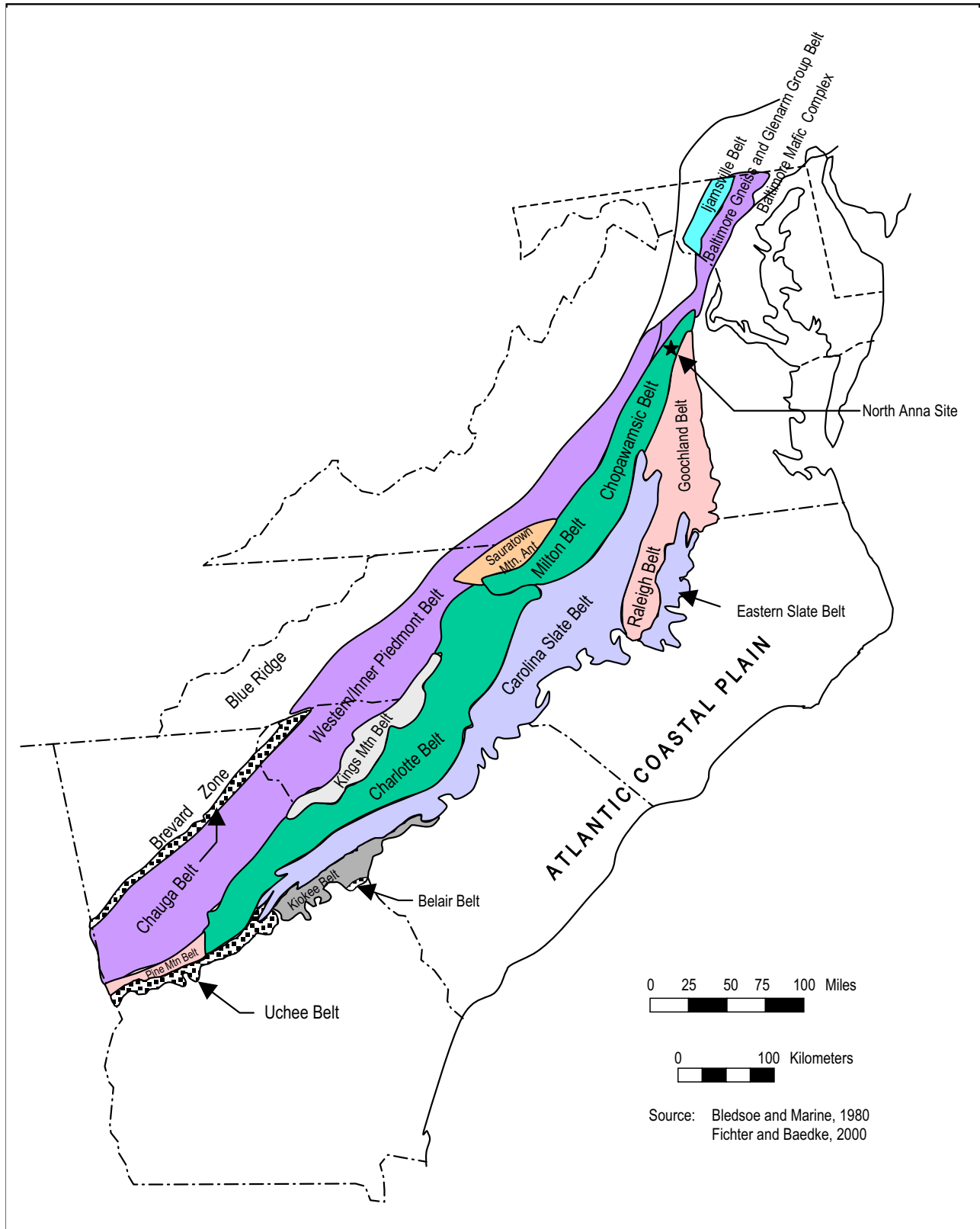


Figure 2.5-4 Lithotectonic Belts of the Piedmont Province

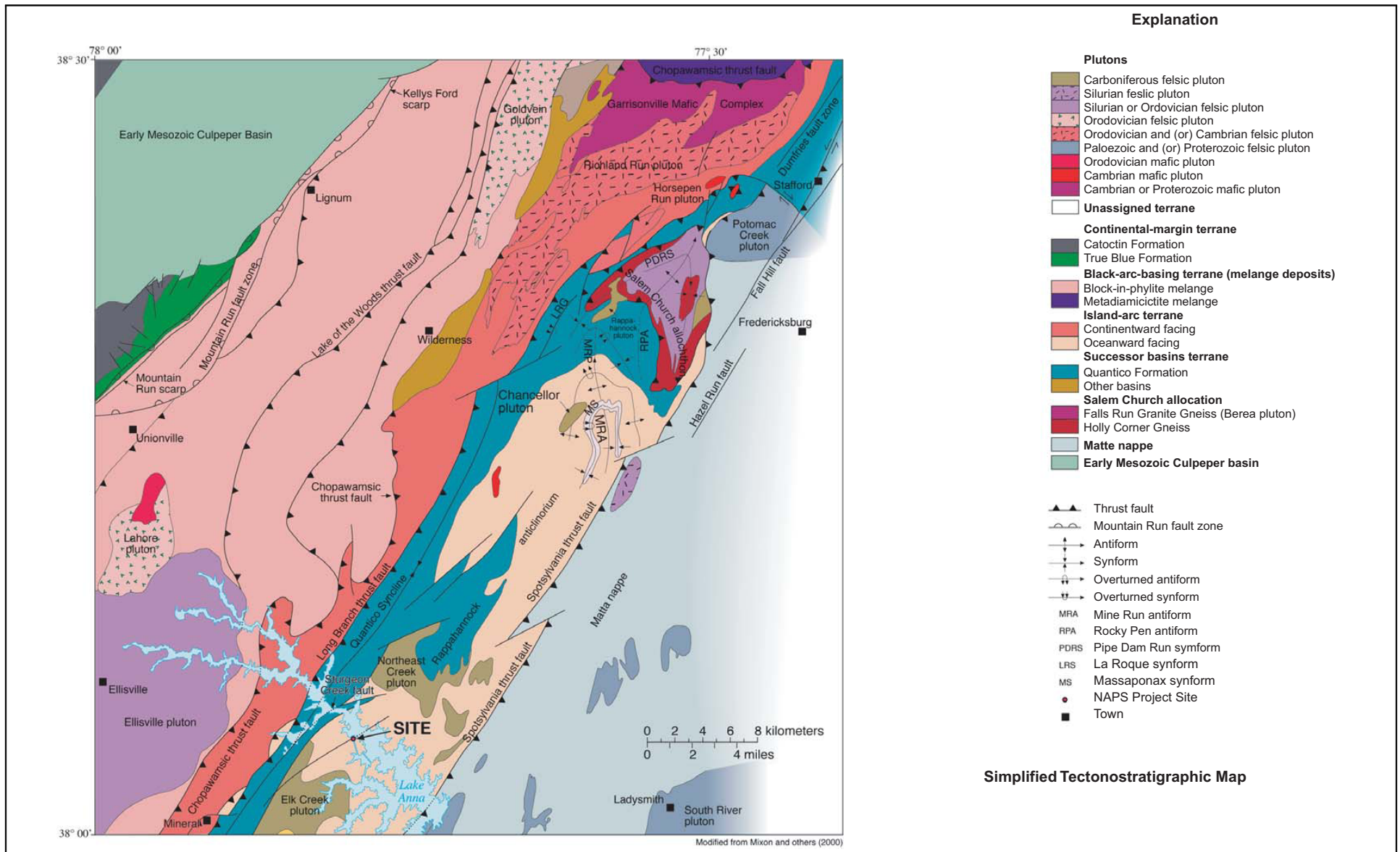


Figure 2.5-5 Simplified Tectonostratigraphic Map

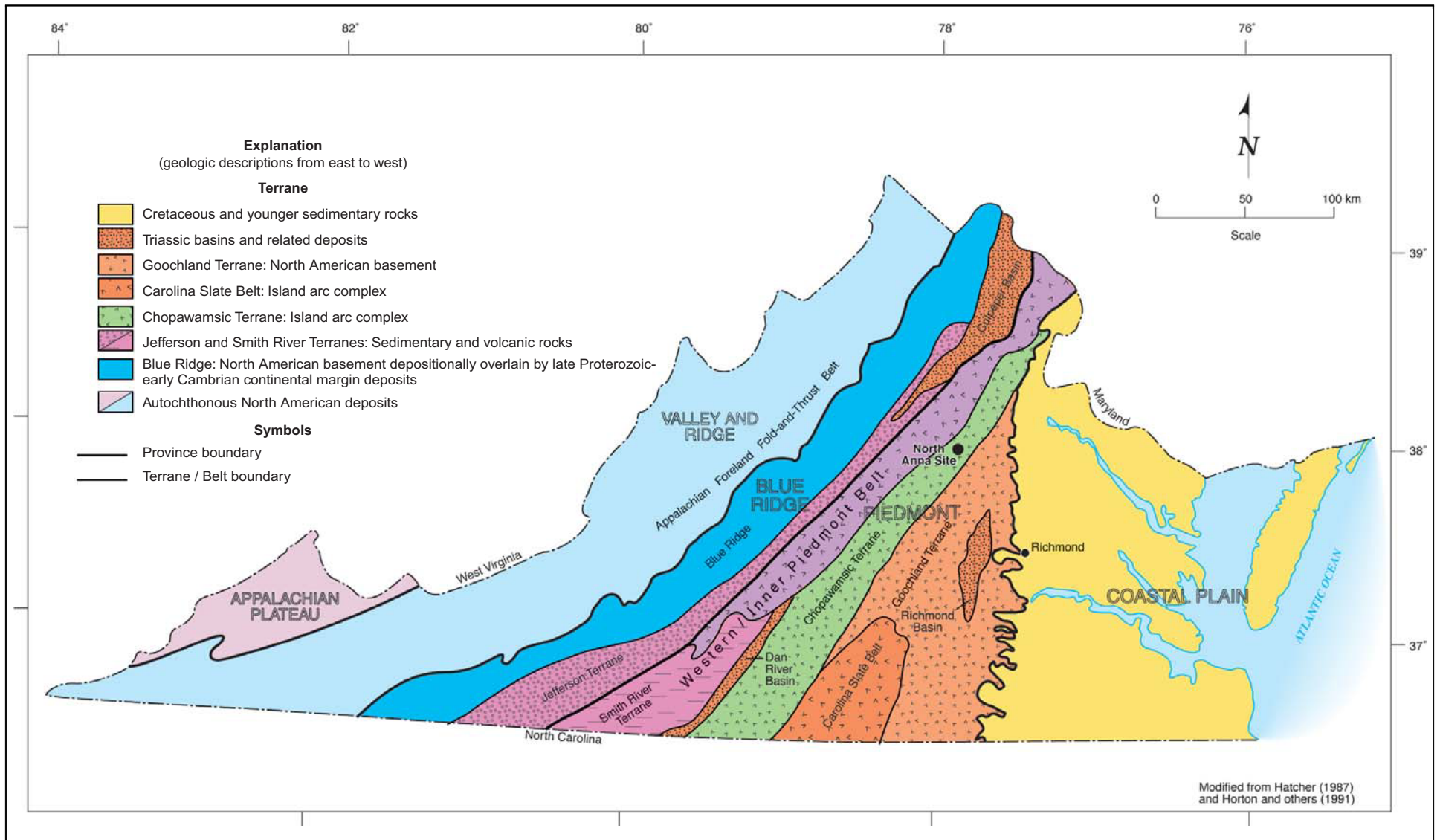


Figure 2.5-6 Simplified Tectonic Map of Virginia

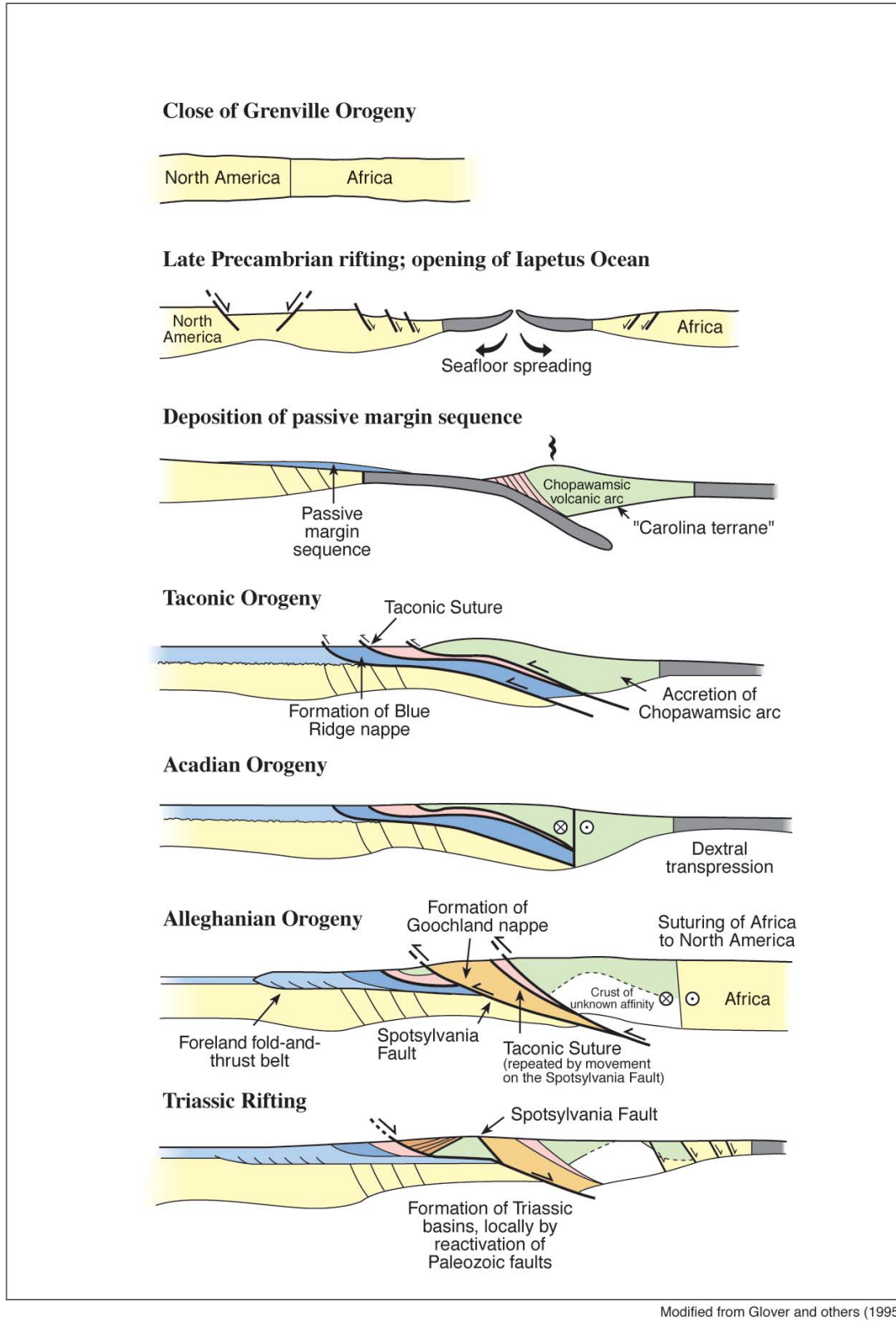


Figure 2.5-7 Evolution of the Appalachian Orogen (after Glover and others, 1995)

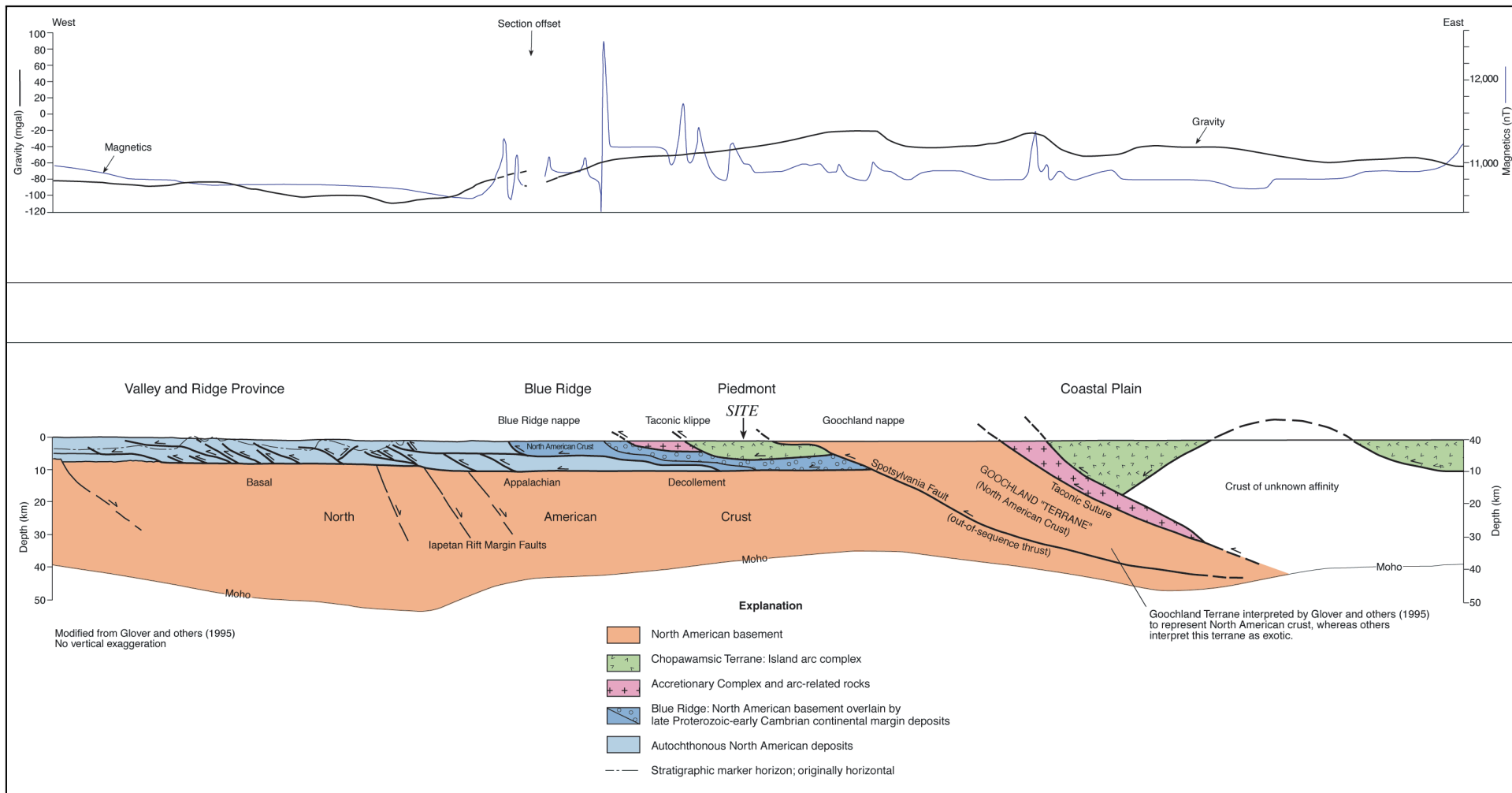


Figure 2.5-8 Crustal Section Through Appalachian Orogen (200-mile radius)

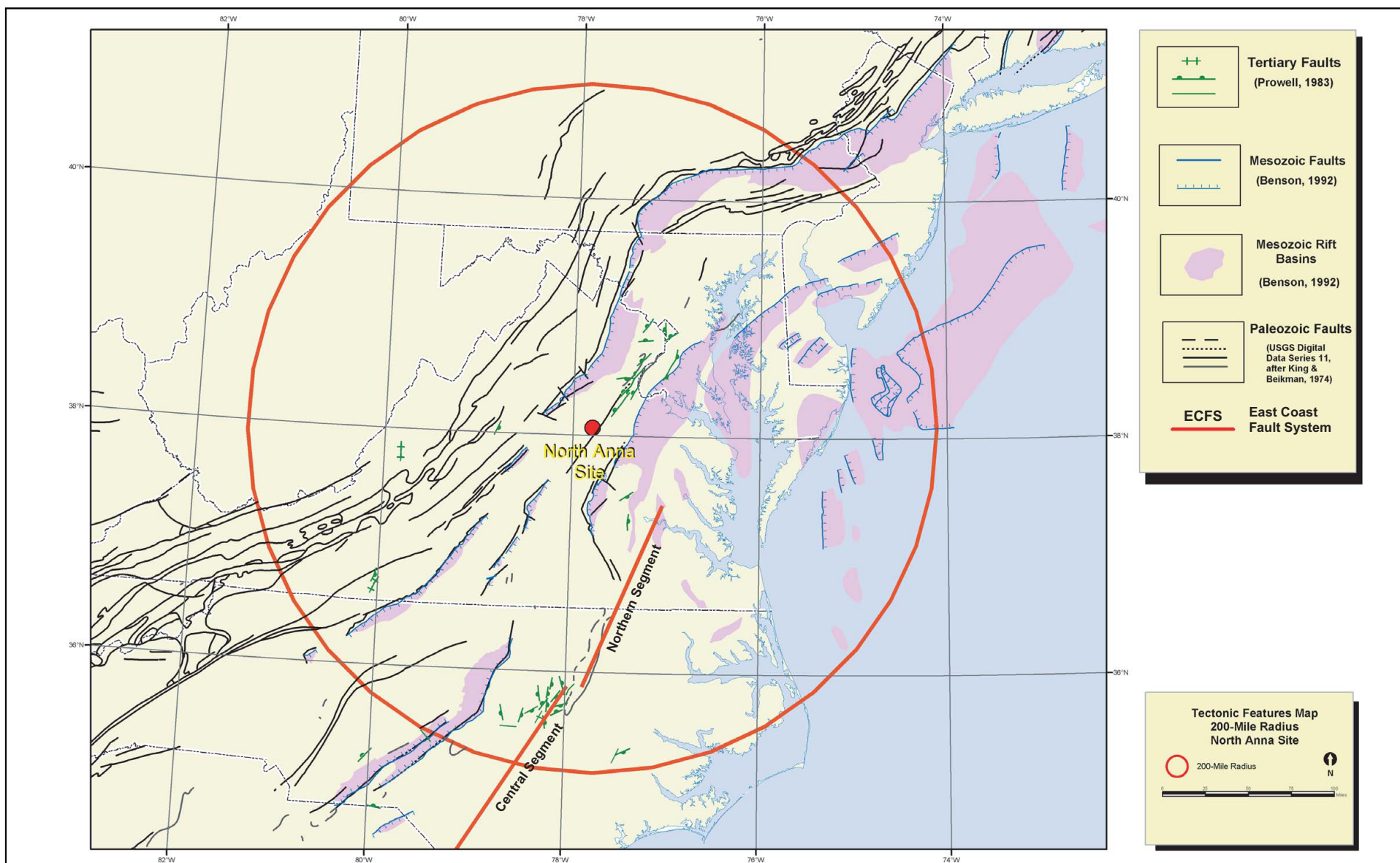


Figure 2.5-9 Tectonic Features Map (200-mile radius)

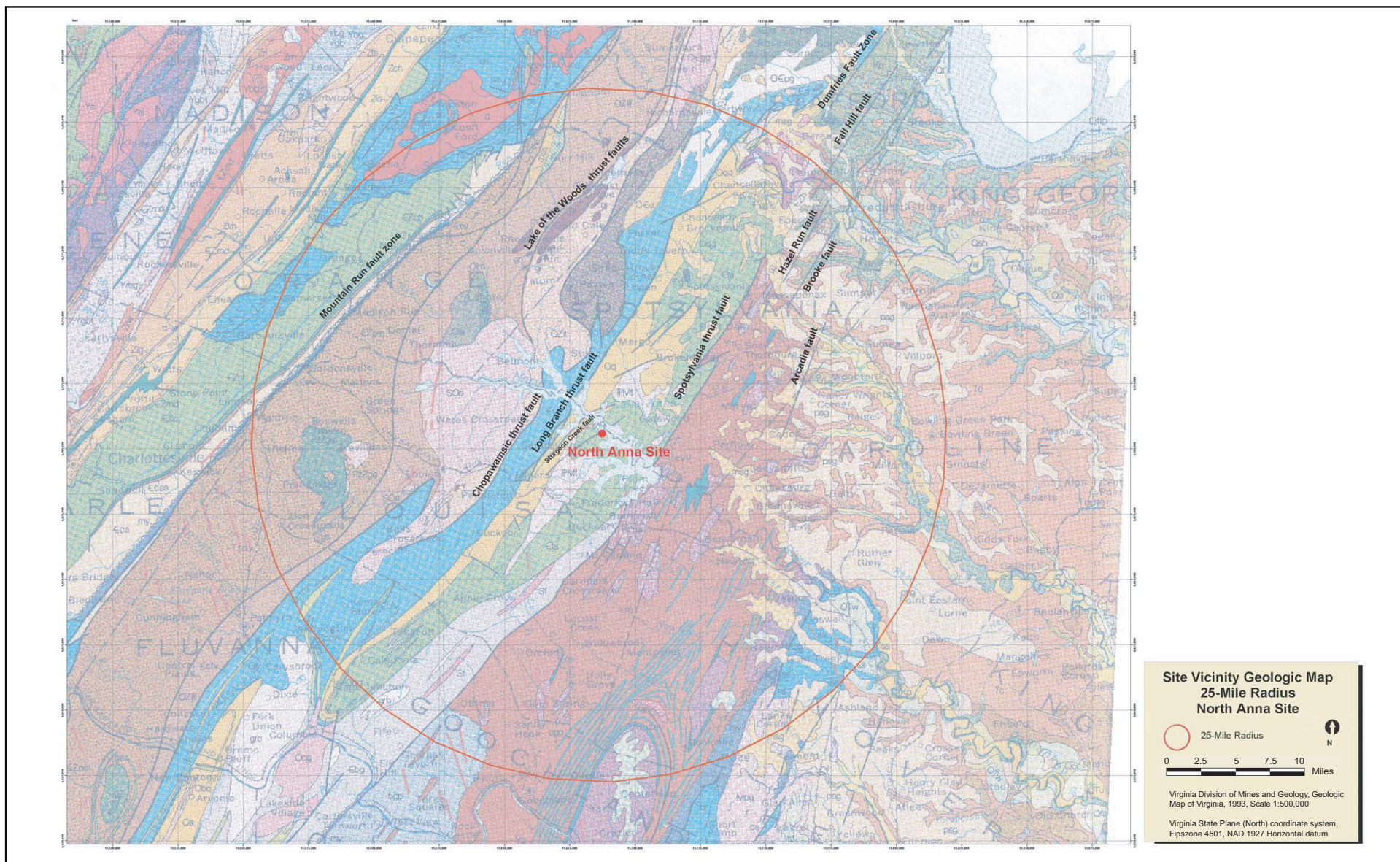


Figure 2.5-10 Site Vicinity Geologic Map (25-Mile Radius) (Sheet 1 of 2)

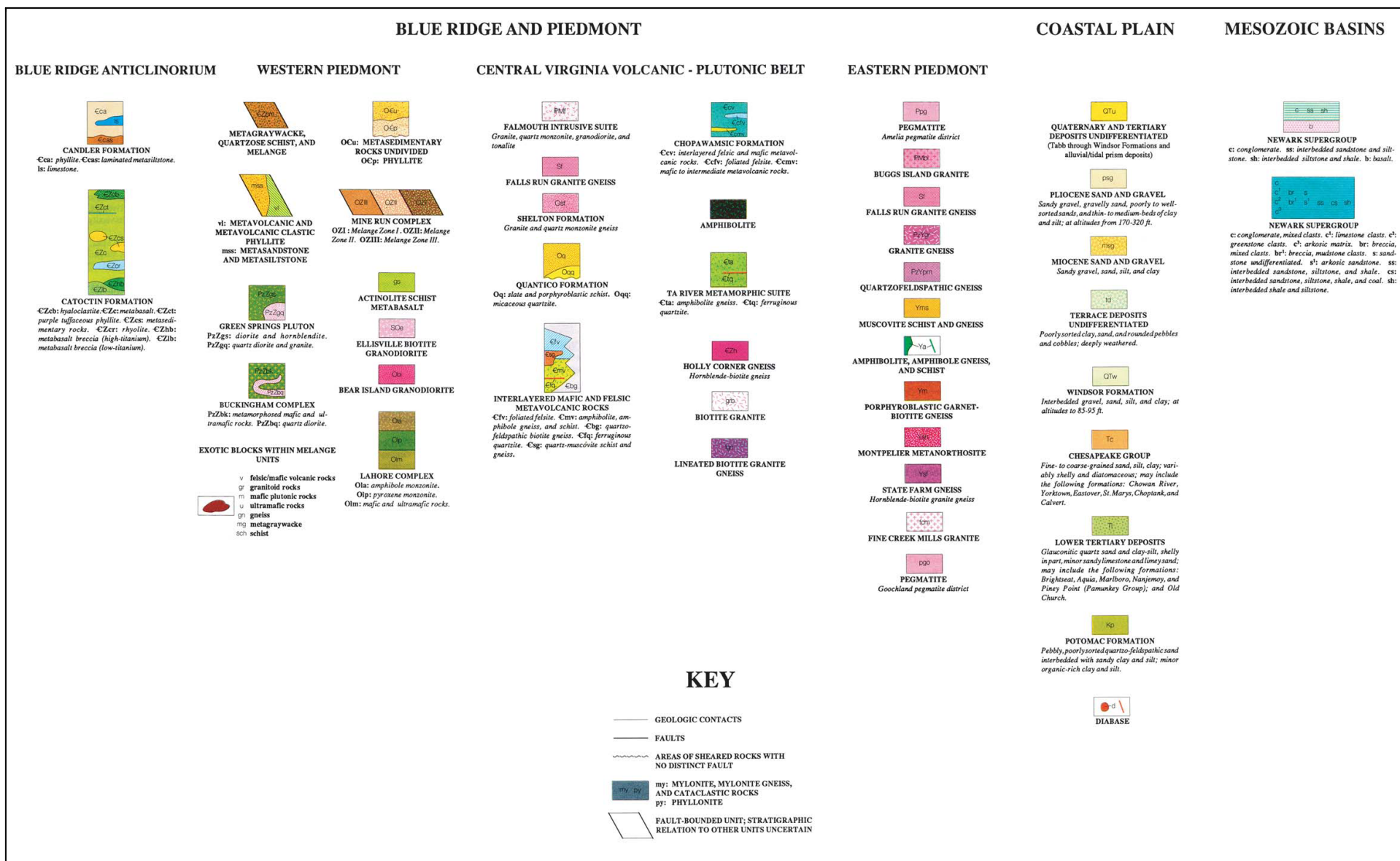


Figure 2.5-10 Site Vicinity Geologic Map (25-Mile Radius) (Sheet 2 of 2)

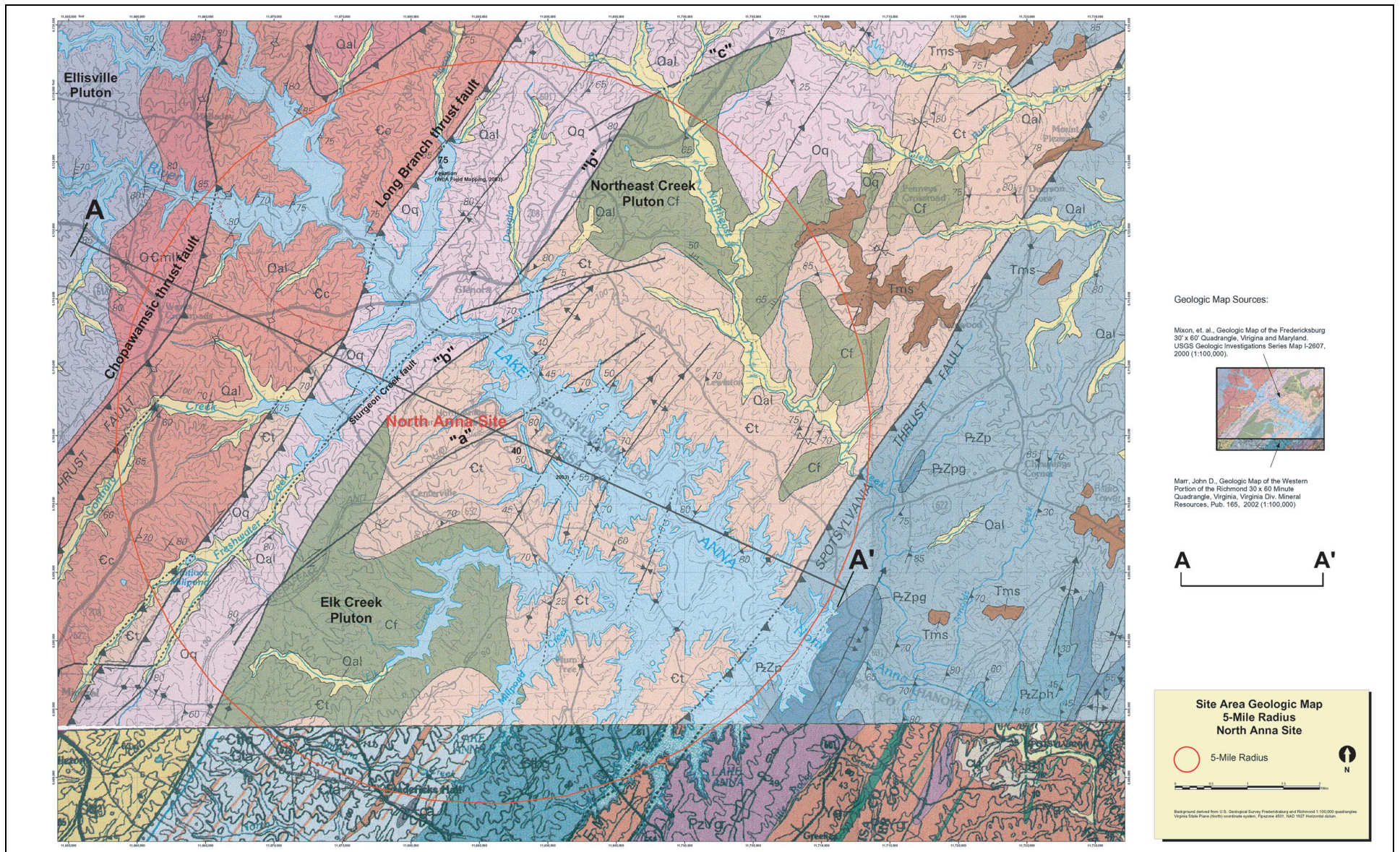
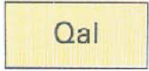

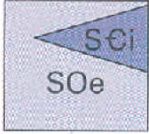

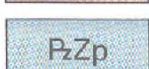


Figure 2.5-11 Site Area Geologic Map (5-Mile Radius) (Sheet 1 of 2)

Legend for Site Area Geologic Map: 5-Mile Radius

Fredericksburg Geologic Quadrangle (1:100,000)

	Qal	Alluvium (Quaternary)
	Tms	Sand and Gravel (Miocene)
	Cf	Falmouth Intrusive Suite (Carboniferous)
	SEi SOe	Ellisville Pluton (Silurian)
	Oq	Quantico Formation (Ordovician)
	OCmII	Mine Run Complex (Cambrian-Ordovician)
	Ec	Chopawamsic Formation (Camb. and/or Ord.)
	Et	Ta River Metamorphic Suite (Camb. and/or Ord.)
	PzZp	Po River Metamorphic Suite (late Precambrian to early Paleozoic).

Richmond Geologic Quadrangle (1:100,000)












	al	Alluvium (Quaternary)
	Mfi	Falmouth Intrusive Suite (Carboniferous)
	SOeg	Ellisville Pluton (Silurian)
	Oq	Quantico Formation (Ordovician)
	OZII	Mine Run Complex (Cambrian-Ordovician)
	Ccv	Chopawamsic Formation (Camb. and/or Ord.)
	Ccmv	
	Ccv	
	Ctb Cta	Ta River Metamorphic Suite (Camb. and/or Ord.)
	Ctfq	
	Ctbq	

Figure 2.5-11 Site Area Geologic Map (5-Mile Radius) (Sheet 2 of 2)

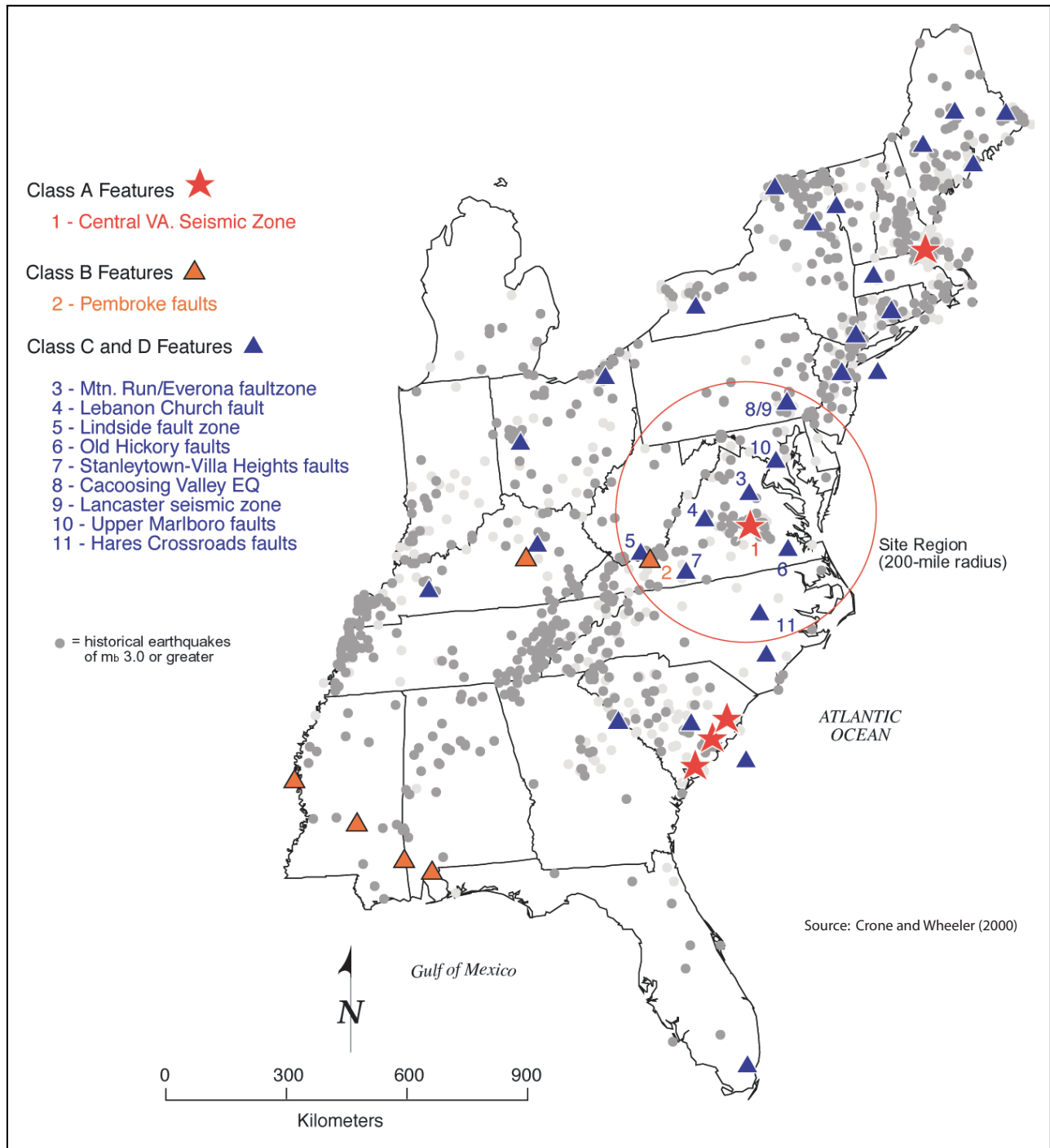


Figure 2.5-12 Quaternary Features Map

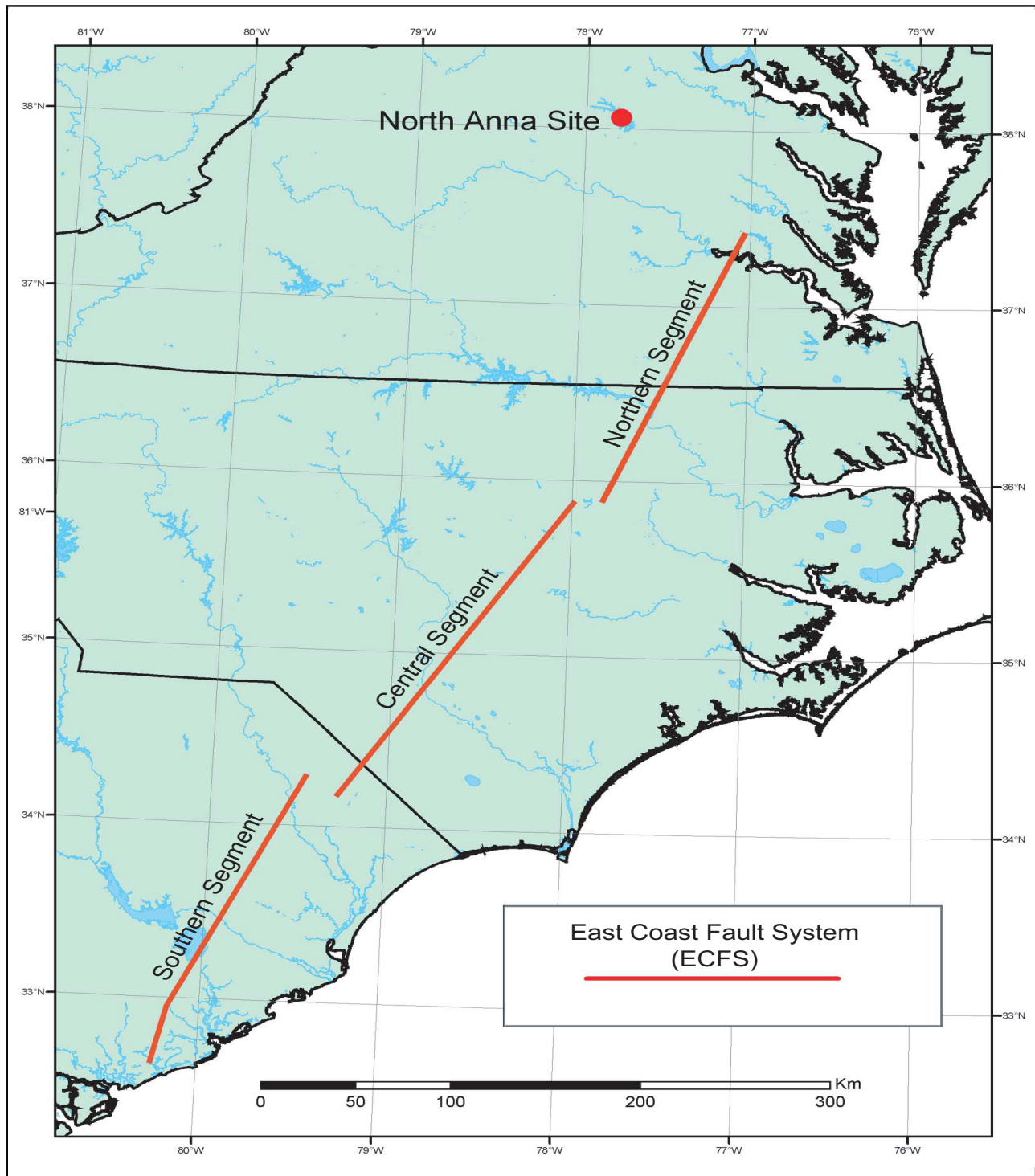


Figure 2.5-13 Northern, Central, and Southern Segments of the East Coast Fault System

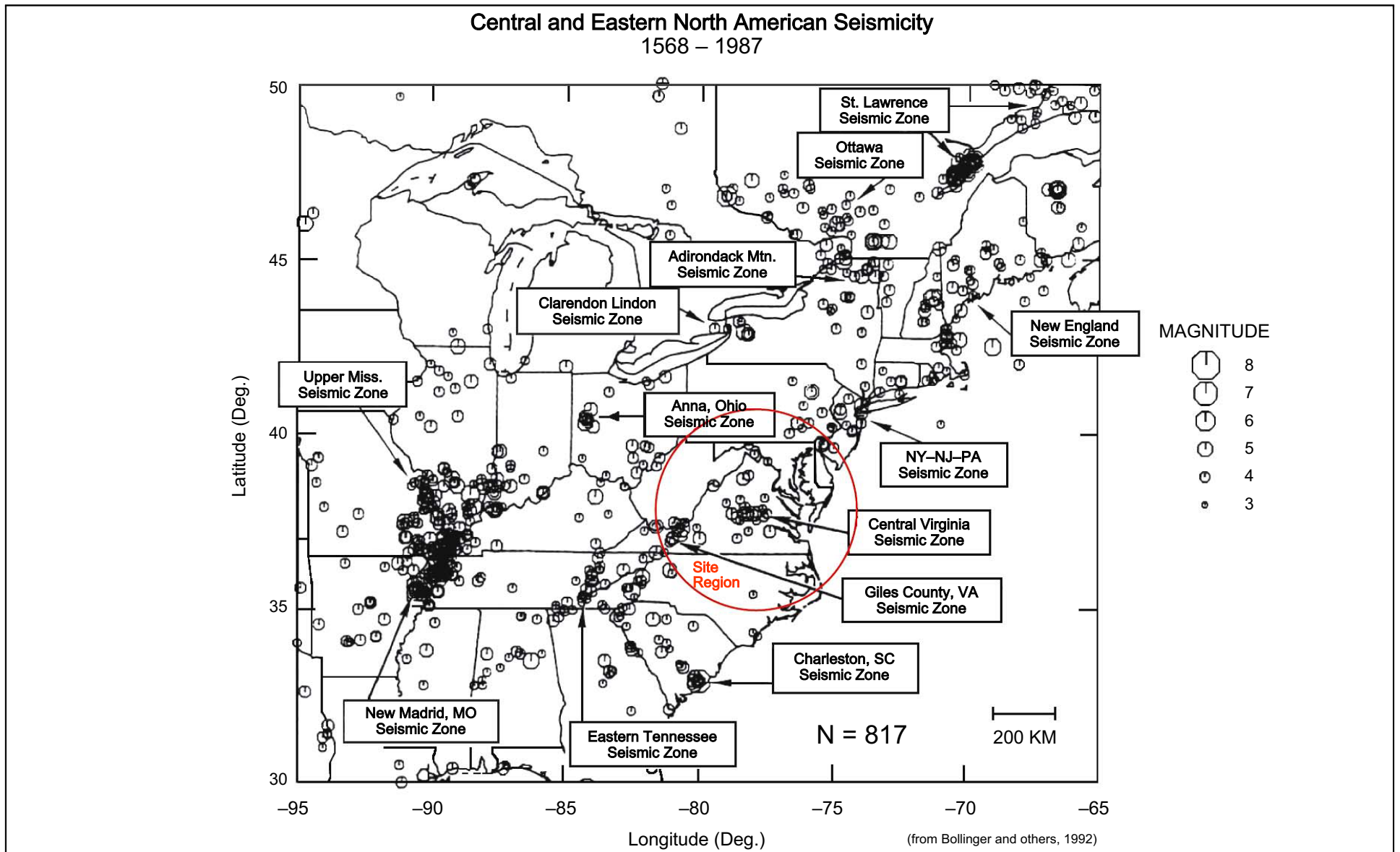


Figure 2.5-14 Seismic Source Zones and Seismicity in Central and Eastern North America