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June 19, 2009

ATTN: Document Control Desk
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

BELL BEND NUCLEAR POWER PLANT
RESPONSE TO RAI SET 1
BNP-2009-122 Docket No. 52-039

References: 1) M. Canova (NRC) to R. Sgarro (PPL Bell Bend, LLC), Bell Bend COLA – Request for Information No. 1 (RAI No. 1) – RGS2-1849, email dated April 20, 2009

2) BNP-2009-079, R. R. Sgarro (PPL Bell Bend, LLC) to U.S. Nuclear Regulatory Commission, "Response to RAI No. 1", dated May 20, 2009

The purpose of this letter is to respond to the request for additional information (RAI) identified in the NRC correspondence to PPL Bell Bend, LLC (Reference 1). On May 20, 2009, PPL Bell Bend, LLC requested an extension for the RAI response submittal timeline to complete the responses (Reference 2). This letter provides those RAI responses.

This RAI addresses Basic Geologic and Seismic Information, as discussed in Section 2.5.1 of the Final Safety Analysis Report (FSAR), as submitted in Part 2 of the Bell Bend Nuclear Power Plant Combined License Application (COLA).

The enclosure provides our response to RAI No. 1, Questions 02.05.01-1 through 02.05.01-7, which include revised COLA content. A Licensing Basis Document Change Request has been initiated to incorporate these changes in a future revision of the COLA. This future revision of the COLA is the only new regulatory commitment.

If you have any questions or need additional information, please contact the undersigned at 570.802.8102.

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

Executed on June 19, 2009

Respectfully,

Rocco R. Sgarro

Rocco R. Sgarro

Enclosure: As stated

D079/
NRO

cc: (w/o Enclosures)

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Enclosure 1

Response to NRC Request for Additional Information Set No. 1
Bell Bend Nuclear Power Plant

Question 02.05.01-1

FSAR Section 2.5.1 provides Figure 2.5-6 as a geologic map for the 25 mile or 40 km radius of the BBNPP site. The application refers to Figure 2.5-6 many times throughout the Chapter. This map is a cut-out or excerpt of a general state geologic map of Pennsylvania. In order for NRC staff to understand the presentation in the text of the regional and vicinity level discussions for geologic history, stratigraphy and structural/tectonic features as they relate to the Bell Bend site, the staff needs a map that is more detailed and has higher resolution than Figure 2.5-6. Please provide such a geologic map, with an appropriate scale, to show additional detail for the vicinity of the BBNPP site. An appropriate scale is one such that a new reader can examine the geologic map and see that the relationship that is being described in the text is in fact corroborated by the mapping.

Response

Figure 2.5-6, Physiographic Provinces of Pennsylvania (Geologic Map) with Sections 25 Mile (40 km) and 5 Mile (8 km) Radii, as submitted in Letter BNP-2008-006, has been incorporated into Revision 1 of the COLA as Figure 2.5-182. Revision 1 of the COLA also includes three additional figures that were not included in Revision 0 that provide further detail. The cut-out area identified on Figure 2.5-182 was further expanded in the following figures:

- Figure 2.5-197, Site Area Geologic Map 0.6-mile (1 km) Radius;
- Figure 2.5-198, Site Area Geologic Map 5-mile (8 km) Radius; and
- Figure 2.5-199, Site Area Geologic Map 25-mile (40 km) Radius.

Additionally, the references to Figure 2.5-182 (Figure 2.5-6 in COLA Revision 1) in Section 2.5.1 have been updated in Revision 1 to refer to the more detailed versions of the figures, where appropriate.

COLA Impact

The additional figures and text edits mentioned above have already been incorporated into Revision 1 of the COLA. Therefore, no additional COLA changes are required in response to this question.

The figures referenced in the Response (Figures 2.5-182, 2.5-197, 2.5-198, and 2.5-199) are attached on the following pages for the convenience of the reader.

Figure 2.5-182 {Physiographic Provinces of Pennsylvania (Geologic Map of Pennsylvania) 25 Mile (40 km) and 5 Mile (8 km) Radii}

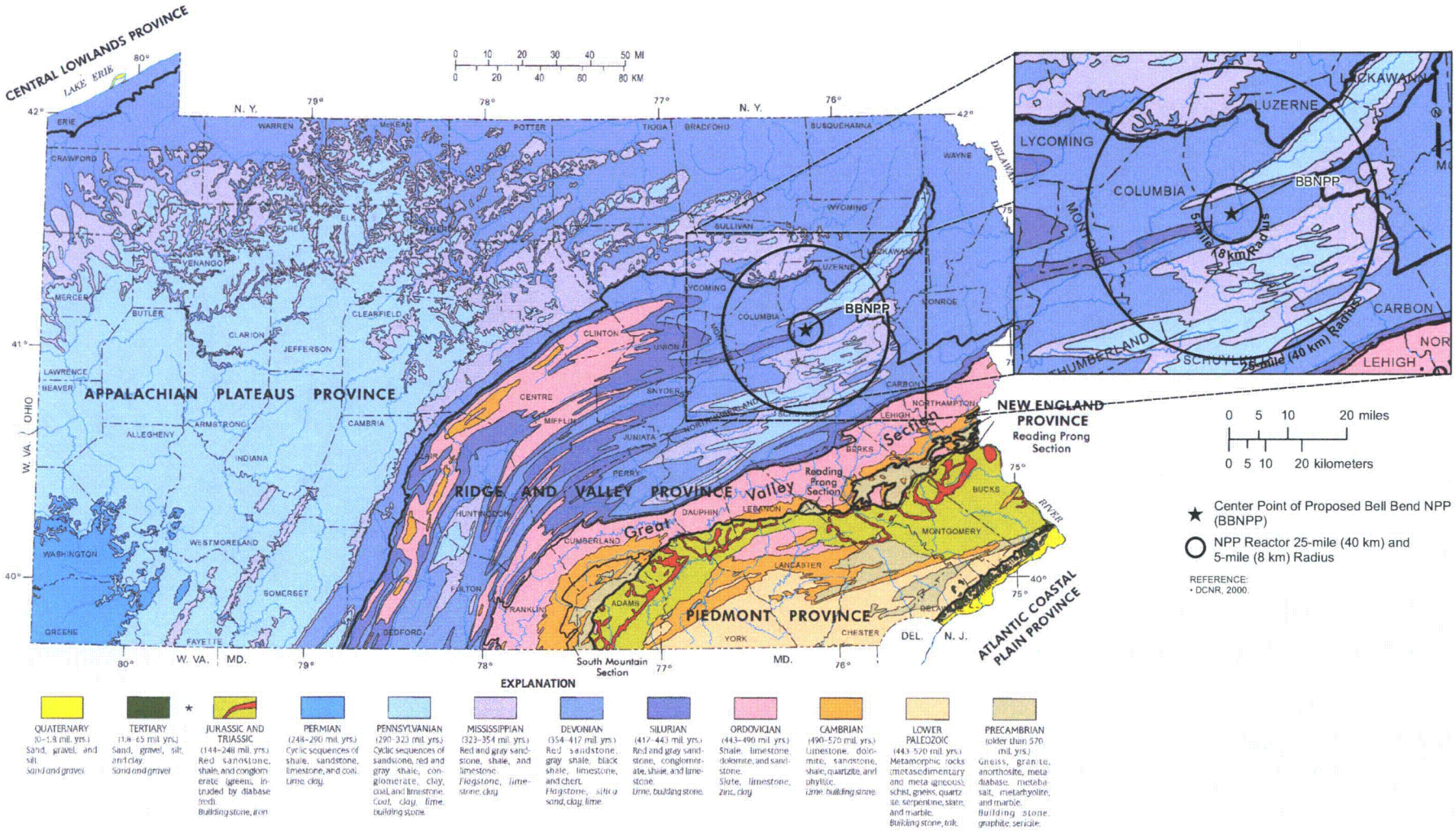
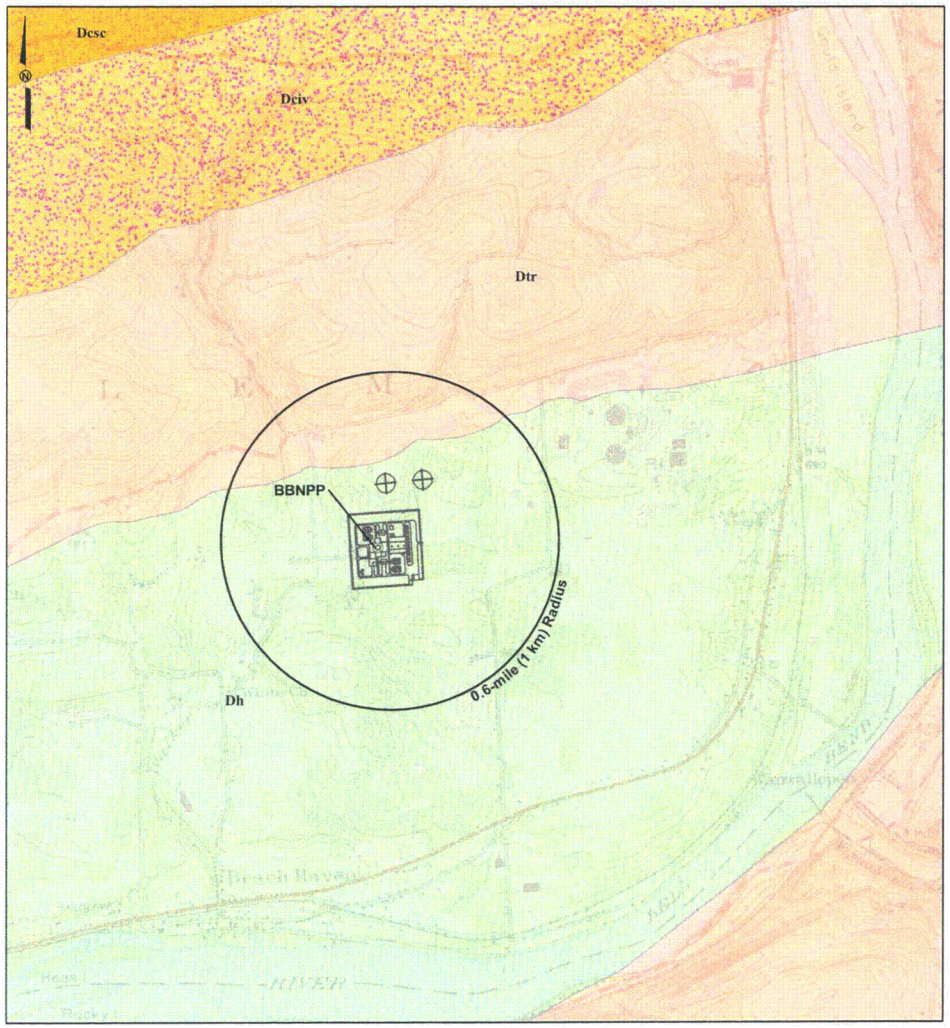


Figure 2.5-197 {Site Area Geologic Map 0.6-mile (1 km) Radius}



LEGEND

Unit Descriptions

Pennsylvanian
- Pl — Llewellyn Formation
- Pp — Pottsville Formation

Mississippian
- Mmc — Mauch Chunk Formation
- Mb — Burgoon Sandstone
- Mp — Pocono Formation
- MDhm — Huntley Mountain Formation
- MDsk — Spechty Kopf Formation

Devonian
- Dck — Catskill Formation

Catskill Formation Members:
- Dcb — Buddys Run Member
- Dcd — Duncannon Member
- Dccf — Clarks Ferry Member
- Dcsc — Sherman Creek Member
- Dcbs — Berry Run & Sawmill Run Members, undivided
- Dcp — Packerton Member
- Dclr — Long Run Member
- Dciv — Irish Valley Member
- Dtr — Trimmers Rock Formation
- Dh — Hamilton Group
- Doo — Onondaga & Old Port Formations, undivided
- DSkt — Keyser & Tonoloway Formations, undivided

Silurian
- Swc — Wills Creek Formation
- Sbm — Bloomsburg & Mifflintown Formations, undivided
- Sc — Clinton Group

---- Fault - Inferred

—— Fault

★ Center Point of Proposed Bell Bend NPP (BBNPP)

○ NPP Reactor 0.6-mile (1 km) Radius

0 0.25 0.5 1 miles

0 0.5 1 kilometers

REFERENCES:
- sk-12198-004-001, 2008.
- Berg, 1980.
- King, 1974.
- USGS, 1989.
- ESRI, 2007.

Figure 2.5-198 {Site Area Geologic Map 5-mile (8km) Radius}

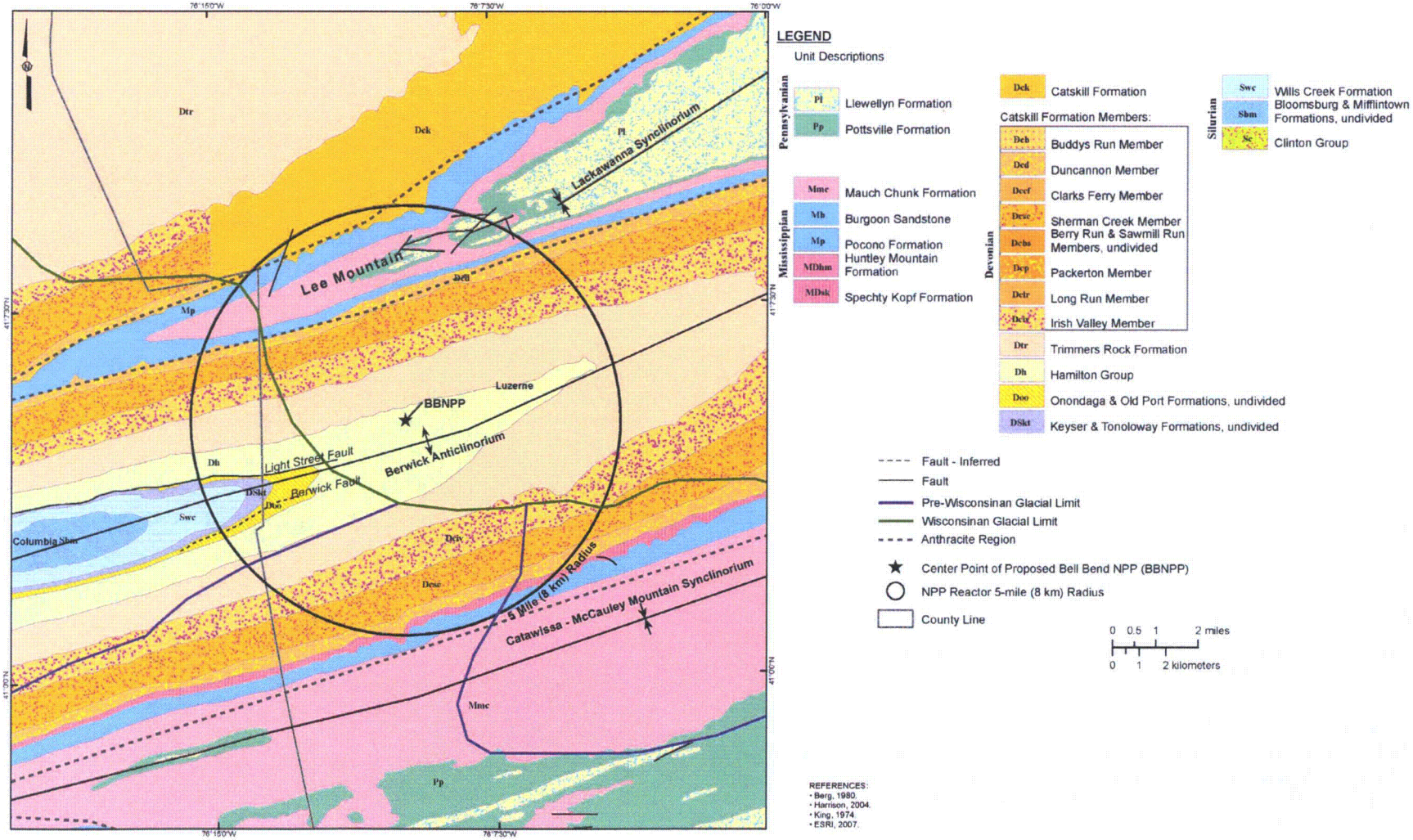
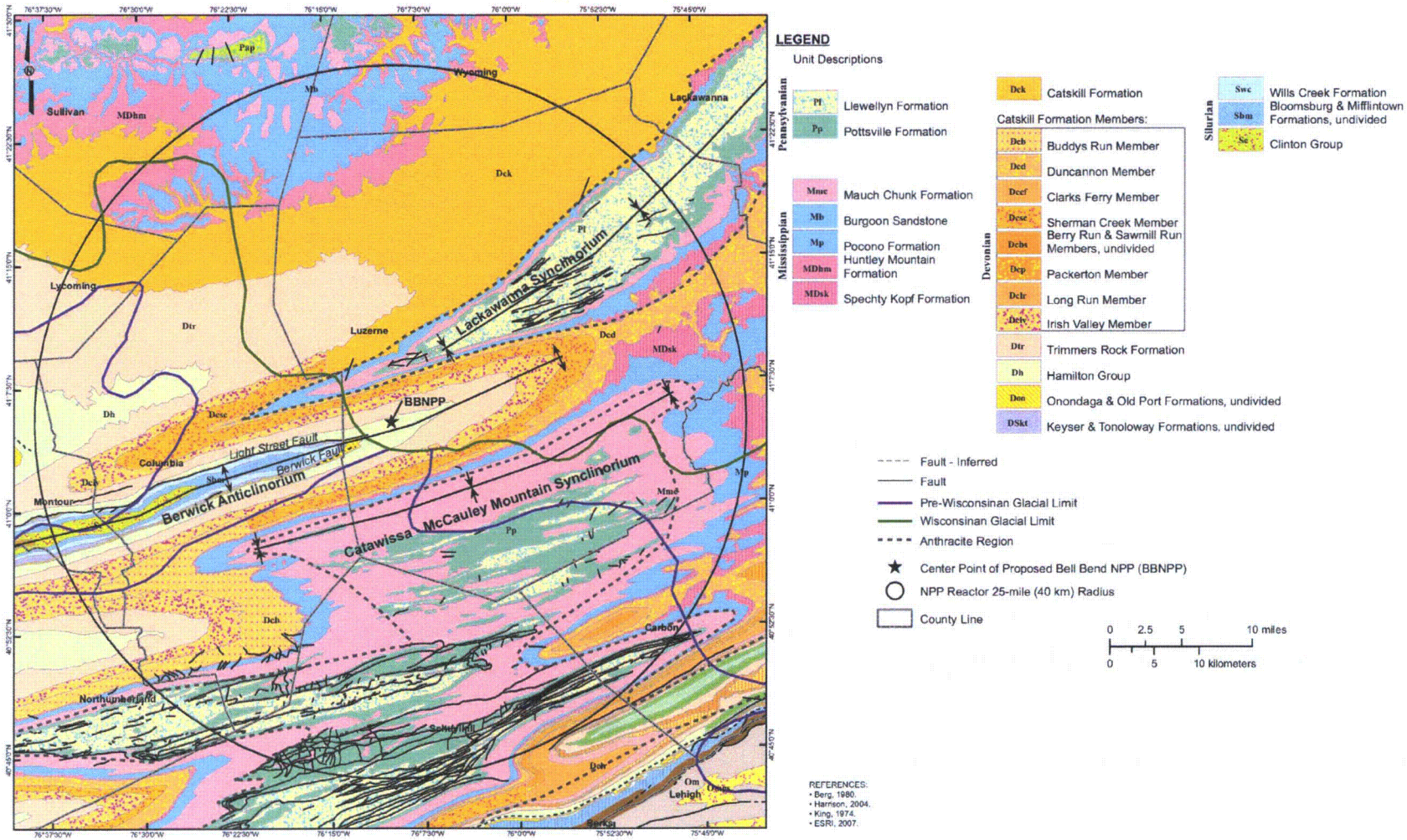


Figure 2.5-199 {Site Area Geologic Map 25-mile (40km) Radius}



Question 02.05.01-2

FSAR Section 2.5.1.1.2 (starting on page 23 of BNP-2008-006 Attachment 1) provides a discussion about the regional geologic history around the BBNPP. Please provide a clear, distinct discussion of the development of the tectonic provinces of the Blue Ridge, Piedmont and Mesozoic rift basin provinces and the tectonic features within these provinces. Please discuss the terranes that occur within a 200-mile radius of the BBNPP site, including the Grenville-aged Avondale and West Chester Massifs, the Taconic and Alleghanian terranes such as the Philadelphia Structural block and associated shear zones, and the Westminster, Baltimore, and Reading Prong Provinces.

In order for NRC staff to assess the character of the regional geology and follow the discussion in the text please provide additional figures. Include a figure showing tectonostratigraphic provinces within the 200 mile radius to guide the discussion. Include figures that show details of the tectonostratigraphic provinces, at the appropriate scales, as they are discussed in text.

Response

Revision 1 of FSAR Section 2.5.1.1.1.6, Physiography and Geomorphology of the Blue Ridge Physiographic Province, provides a discussion of the Blue Ridge Physiographic Province. This section will be revised as part of a future revision to the COLA to improve the discussion of the historical development of the tectonic province. The revised discussion is included in the following pages.

Revision 1 of FSAR Section 2.5.1.1.1.3, Physiography and Geomorphology of the Piedmont Physiographic Province, provides a discussion of the Piedmont Physiographic Province. This section will be revised as part of a future revision to the COLA to improve the discussion of the historical development of the tectonic province. The revised discussion is included in the following pages.

Revision 1 of FSAR Section 2.5.1.1.2.7, Early Mesozoic Extensional Episode (Triassic Rifting), will be revised as part of a future revision to the COLA to provide a more detailed description. Additional Mesozoic Rift Basins were included on Figure 2.5-208, Mesozoic Basins and Associated Known Faults. Generalized rift basin structures are described on Figure 2.5-212, Generic Distribution of Structures and Features in Mesozoic Rift Basins. The additional descriptive text and the new and amended figures are included in the following pages.

The terranes that occur within a 200-mile radius of the BBNPP site are described in Revision 1 of FSAR Section 2.5.1.1.4.4.3, Relevant Tectonic Features with Associated Seismicity and 2.5.1.1.4.4.4, Relevant Tectonic Features with no Associated Seismicity. Those FSAR sections will be revised as shown as part of a future revision to the COLA to discuss the Grenville-aged Avondale and West Chester Massifs, the Taconic and Alleghanian Terranes such as the Philadelphia Structural Block and associated Rosemont Shear Zone, and the Potomac and Westminster Terranes with the associated Pleasant Grove Shear Zone, and the Baltimore Gneiss, and Reading Prong provinces. Figure 2.5-214, Development of the Reading Prong Nappe Megasystem, has been inserted to present the history of the Reading Prong. The Philadelphia Structural Block and the associated Rosemont Shear Zone are discussed in detail in the new Section 2.5.1.1.4.4.4.20, Philadelphia Structural Block. The Potomac and Westminster Terranes and the associated Pleasant Grove Shear Zone, were also added as a new section in Relevant Tectonic Features with No Associated Seismicity (new text Section 2.5.1.1.4.4.4.21 and new Figure 2.5-230). The Baltimore Gneiss Terrane was another section included within the Relevant Tectonic Features with No Associated Seismicity (new text Section 2.5.1.1.4.4.4.22 and new Figure 2.5-231). Additionally, a discussion on the West Chester and Avondale Massifs will be included in Section 2.5.1.1.2.3, Taconic Orogeny and Clastic Wedge Deposition, along with the new Figure 2.5-211, Location Map for West Chester and Avondale Massifs and Figure 2.5-213, Idealized Cross Section of the Reading Prong, West

Chester and Avondale Massifs, and the Philadelphia Terrane. The locations of the provinces described in these sections are provided on Figure 2.5-232. The new and revised discussions and figures are included in the following pages.

To support the additional discussions on relevant Tectonostratigraphic Provinces occurring within the 200-mile radius of the BBNPP the features are all depicted in new Figures 2.5-228 and 2.5-229, where respectively exposed with gravity and magnetic anomalies.

COLA Impact

COLA Part 02 (FSAR) will be revised as part of a future revision as described in the Response above. Markups of the FSAR text and the revised figures are provided below.

2.5.1.1.1.3 Physiography and Geomorphology of the Piedmont Physiographic Province

The Piedmont Physiographic Province extends southwest from New York, through southeast Pennsylvania, to Alabama and lies southeast of and adjacent to, the Ridge and Valley Physiographic Province as shown in Figure 2.5-5. The Piedmont Province is about 60 mi (97 km) wide in southeastern Pennsylvania and narrows northward to about 10 mi (16 km) wide in southeastern New York. Elevation in the Piedmont Province ranges from 20-1,355 feet (6-413 m) mean sea level (msl) (DCNR, 2007b; DCNR, 2007c; and DCNR, 2007d).

In Pennsylvania, the Piedmont Province is divided into the Piedmont Lowland Section, the Gettysburg-Newark Lowland Section, and the Piedmont Upland Section. With the exception of the Piedmont Lowland Section, the majority of the Piedmont Province consists mainly of rolling low hills and valleys (DCNR, 2007a). The Piedmont Lowland Section consists of broad, moderately dissected valleys separated by broad low hills and is developed primarily on limestone and dolomite rock highly susceptible to karst topography (DCNR, 2007b). The Gettysburg-Newark Lowland Section runs adjacent to the Great Valley Section of the Ridge and Valley Province as shown in Figure 2.5-183. The Gettysburg-Newark Section consists of rolling low hills and valleys developed on sedimentary fluvial and lacustrine clastic rock deposits that represent a series of exposed faulted rift basins (Root, 1999). Metamorphic rocks of varying affinity comprise the surface rock outside of the rift basins within the Gettysburg-Newark Lowland Section. The Piedmont Upland Section exhibits gently rolling hills and valleys. Drainage in the Piedmont Upland Section is often controlled by a well developed foliation in predominant schists with drainage developing along foliation or normal to foliation (DCNR, 2007).

Geologically, the Piedmont Province consists of a variety of sharply folded and faulted supracrustal metasedimentary and plutonic intrusive rocks that are generally younger than the 880-1,000 million year old rocks of the Blue Ridge Province to the west (Milici, 2009). In addition, thick sections of Early Mesozoic sedimentary rocks containing intruded and extruded mafic igneous rocks fill rift basins that are widely distributed in the Piedmont and beneath the Atlantic Coastal Plain. The metasediments within the Piedmont Province may be as young as Ordovician. These Precambrian through lower Paleozoic crystalline rocks extend to the east under the Upper Jurassic through Cenozoic sediments of the Atlantic Coastal Plain Province.

2.5.1.1.1.6 Physiography and Geomorphology of the Blue Ridge Physiographic Province

The Blue Ridge Province extends less than 50 miles (80 km) into Pennsylvania from the south and is approximately 70 miles (113 km) from the BBNPP site. The Blue Ridge Physiographic Province is bounded on the east by the Piedmont Province and on the west by the Valley and Ridge Province as shown in Figure 2.5-5 (USGS, 2002). Figure 2.5-182 (DCNR 2000c) and Figure 2.5-183 (Sevon, 2002) do not include the Blue Ridge in the statewide designation of physiographic provinces. ~~The Blue Ridge Province extends from Pennsylvania to Georgia in a northeast-southwest direction and is underlain primarily by metamorphosed Precambrian and Early Paleozoic igneous and sedimentary rock (VADOT, 2008).~~The Blue Ridge Province, also known as the Blue Ridge Thrust Belt Province (Milici, 2009), underlies parts of eight States from central Alabama to southern Pennsylvania in a northeast-southwest direction and is underlain primarily by metamorphosed Precambrian and Early Paleozoic igneous and sedimentary rock (VADOT, 2008). The Blue Ridge Province is recognized as the core of the Appalachian Mountains, emplaced during Alleghanian tectonism along a regional detachment structure (Hatcher 2004).

Along its western margin, the Blue Ridge is thrust over the folded and faulted margin of the Appalachian basin, so that a broad segment of Paleozoic strata extends eastward for tens of miles, buried beneath these subhorizontal crystalline thrust sheets. At the surface, the Blue Ridge consists of a mountainous to hilly region, the main component of which is the Blue Ridge Mountains that extend from Georgia to Pennsylvania. Surface rocks consist mainly of a core of moderate- to high-rank crystalline metamorphic or igneous rocks, which, because of their superior resistance to weathering and erosion, commonly rise above the adjacent areas of low-grade metamorphic and sedimentary rock (Milici, 2009). The province is bounded on the north and west by the Paleozoic strata of the Appalachian Basin Province and on the south by Cretaceous and younger sedimentary rocks of the Gulf Coastal Plain. It is bounded on the east by metamorphic and sedimentary rocks of the Piedmont Province.

Soils of the Blue Ridge are predominantly colluvium with small amounts of alluvium along the rivers and streams (VADOT, 2008). Residuum occurs locally but is limited in thickness and lateral extent due to aggressive erosive forces caused by steep topography. The Blue Ridge is a long, linear province which ranges in width from about 5 mi (8 km) in Maryland to over 50 mi (80 km) in North Carolina. Elevations in the Blue Ridge Province exceed 6,600 (2,012m) feet in North Carolina and Tennessee.

Reconstructions for the central Appalachians disagree about the boundary between North American native terranes and accreted exotic terranes. Horton et al (1989) in Kline, 1991, interpreted part of the Virginia Blue Ridge province as an exotic terrane, called the Jefferson terrane, accreted to North America in the Ordovician. Kline (Kline, 1991), implies a common provenance for all the sediments and casts doubt on the exoticity of the Jefferson terrane, based on the presence of a common suite of distinctive detrital grains in Jefferson terrane units and in proven native North American metasedimentary rocks and basement.

2.5.1.1.2.3 Taconic Orogeny and Clastic Wedge Deposition

The North American craton became a convergent margin with the onset of the Taconic Orogeny at the end of the Middle Ordovician and continuing through the Middle Silurian (Gao et al, 2000). The Taconic Highlands, an island arc terrane (Trembley, Bedard, and Lauziere, 1997) converged to the east of the North American craton and became the dominant source of detritus to the Appalachian basin. Along the margin of the craton, especially in New England and Canada, suites of ocean floor and island arc were accreted to the continent along with what is regionally called the Taconic Thrust Belt (Hayman and Kidd, 2002). Deformation from the Taconic orogeny was imparted throughout the continental margin, as metamorphic events of Taconian (457 Ma) time are recorded in the Blue Ridge of western North Carolina (Moecher and Miller, 2004). An example of Taconic deformation within the site region (200 mi (322 km) radius) is the development of the Hamburg Nappe (Pohn, 2000), an overthrusted fold derived from folding of basinal sediment due to thrusting of the Taconic front onto the continent. Similar structures include the Lebanon Valley, Irish Mountain, Applebutter, Musconetcong and Lon Station-Paulins Kill which form the Musconetcong nappe megasystem.

Comprised of slabs of the Brandywine Microcontinent during the Taconic Orogeny, the West Chester, Avondale and Woodville Massifs were thrust northwestward upon the continental shelf onto previously emplaced Octoraro Sea deposits (Faill, 1999a). A location map for the West Chester and Avondale massifs is shown in Figure 2.5-211 (Low, 2002). The Street Road Fault separates the Avondale Massif to the southeast from the West Chester Massif to the northwest (Bosbyshell 2009). The Rosemont Fault to the east of the Avondale Massif separates the massif complex from the Wissahickon (Philadelphia Terrane) and the James Run and Wilmington Complex magmatic arcs (Faill, 1999a). Included and exposed in both the West Chester and Avondale Massifs are basement rocks of the Baltimore Gneiss, including a variety of compositions at amphibolite and granulite grade metamorphism. Granulite facies metamorphism is found in the eastern Avondale, but comprises most of the West Chester Massif, composed of heterogeneous felsic, intermediate and mafic compositions of gneiss (Blackmer 2005). The idealized cross section in Figure 2.5-213 shows the close relation of these two massifs with the Philadelphia terrane to the SE, as well as the Reading meganappe to the NW.

2.5.1.1.2.7 Early Mesozoic Extensional Episode (Triassic Rifting)

During the Late Triassic, at the onset of the breakup of Pangea, the eastern North American plate and African plate began to separate to create the Atlantic Ocean. A series of rift basins, such as the Gettysburg-Newark basin developed in southeastern Pennsylvania and along the North American coastline, respectively in what is referred to as the North American Rift System (Schlische, 2002). The rift basins are arranged primarily in northeast-southwest asymmetric trend and are located from South Carolina through Massachusetts (USGS, 1985). Normal faulting under the extensional regime often occurred along pre-existing Paleozoic structures (Olsen and Schlische, 1990)

Subsequently, the basins were filled with sediments such as conglomerates, sandstones and shales and exhibit evidence of syn-rift deposition (lessening of offset upward in the basin deposits) (Schlische, 2002). The Culpepper, Gettysburg, ~~and~~ Newark, Hartford, Taylorsville, and Norfolk Basins lie within or close to the outside limit of the site region (200 mi (322 km) radius and are shown on ~~Figure 2.5-190~~Figure 2.5-208.

Figure 2.5-7 shows the Newark Basin in a cross section of the Middle U.S. Atlantic Passive Margin. Schlische and Withjack (Schlische, 2002b; Withjack, 2005) include the Taylorsville and Norfolk Basins (Figure 2.5-208) as part of these Mesozoic Basins. They also consider the Hartford Basin as a sub-basin, South of the Connecticut Valley Basins, which includes the small Deerfield sub-basin to the North. Figure 2.5-212 (Schlische, 2002a) depicts a geologic map and cross sections of an idealized, dip-slip dominated Mesozoic rift basin in eastern North America (a) with syn-rift units thickening toward the border fault in transverse section and thickening toward the center of the basin in longitudinal section. Figure 2.5-212 also shows a geologic map of an idealized rift basin containing multiple sub-basins related to large-scale segmentation of a border-fault system (b). A geologic map of a basin with both dip-slip and strike slipdominated margins is shown in (c). The idealized basin geometry shown in Figure 2.5-212 does not include the effects of basin inversion.

As basin subsidence continued through the Triassic, the depositional environment within the basin became increasingly sub-aqueous. Outboard of the basins, carbonate platform deposition along the nascent continental margin occured. Mantle derived basaltic intrusions occurred within the faulted crust which are evident in diabase dikes and sheets of the Piedmont Province of the eastern United States (Philpotts et al, 1985). During the early Jurassic period, the process of seafloor spreading caused deep-seated magma to approach the surface. Volcanic deposits ranging from 6-9.3 mile (10-15 km) thickness formed along the entire U.S Atlantic margin in the Middle Jurassic (Sheridan et al, 1993). The magma created the basalt located in the Gettysburg-Newark basin of the Piedmont province (Schlische, 2003). Northwest-southeast-directed post rift activities in the Mesozoic basin caused inversion to many structures present during this time (Withjack, 1998). Following rifting, subsidence, and volcanism, the Atlantic Margin became a passive .margin. The structural and seismotectonic influence of Mesozoic rifting affects the site region (200 mi (322 km) with respect to potential seismogenic structures. These structures, such as the Ramapo Fault (Section 2.5.1.1.4.4.2.2), the Martic Fault (Section 2.5.1.1.4.4.4.14), the East Border Fault (Section 2.5.1.1.4.4.4.15), and the Yellow Breeches Fault (Section 2.5.1.1.4.4.4.5) have exhibited seismogenic potential (Ratcliffe, 1971) and are discussed in further detail in ~~Section 2.5.1.1.4~~these sections.

2.5.1.1.4.4.3.5 Reading Prong

The Reading Prong massif is a major Precambrian complex, one of several outcropping between the sedimentary rocks of the Appalachian basin and the Paleozoic metamorphic terrains of New England and the southeastern Piedmont (Wolf, 2003), with its closest approach to the site approximately 50 mi (80 km) east of the BBNPP (Feature 51 in Figure 2.5-190). Metamorphism of the Reading Prong rocks occurred during the Grenville Orogeny, approximately 1.2 billion years ago, and the area was also extensively intruded by synorogenic granites during the same Grenville event. Subsequently, between the Late Proterozoic and the Mesozoic, the rocks throughout the region suffered periodic episodes of deformation that was especially intense during the Late Permian Alleghanian Orogeny when the region was pervasively fractured during the development of imbricated thrust sheets (Wolf, 2003). The rocks of the Reading Prong are allochthonous and represent an overlapping stack of thrust sheets that have been thrust over the Paleozoic Rocks of the Great Valley to the north (Senior, 2006). The thrusting juxtaposed the Precambrian rocks in a structurally high position relative to the thick section of lower Paleozoic rocks immediately to the west.

A schematic representation of the development of the Reading Prong nappe megasystem is depicted in Figure 2.5-214 (Drake, 1999). In Figure 2.5-214 (Item A), extensional faults related to the opening of a small ocean basin or the Iapetus Ocean formed on the margin of the Laurentian craton during the Late Proterozoic or earliest Cambrian. Continuing in Figure 2.5-214 (Item B), the shelf collapse related to the attempted subduction of Laurentia beneath the Microcontinent at the beginning of the Taconic orogeny allowed the formation of the Martinsburg foreland basin during the Middle Ordovician. Finally in Figure 2.5-214 (Item C) the closing of the small ocean basin or the Iapetus Ocean during the early Late Ordovician Taconic orogeny reactivated the extensional faults as thrust faults, forming the nappe megasystem. Thrust faulting during the Alleghanian orogeny greatly complicated the nappe megasystem. Rifting related to the opening of the Atlantic Ocean during the Late Triassic reactivated the thrust faults on the southeast as listric extensional faults. The amount, if any, of extensional movement of the other thrust faults is currently not known. This model presented by Drake (Drake, 1999) suggests three periods of movement on the same faults: extensional, contractional, and extensional. Figure 2.5-213, in a non eroded idealized cross section, shows the close relation between The Reading Prong Province and the nappes that contain the West Chester and Avondale Massifs, as well as the Philadelphia Terrane to the SE. Continental shelf that constitutes the ramp, in which the Reading meganappe and the York terrane thrust, is shown to the NW.

2.5.1.1.4.4 Regional Tectonic Structures

A tectonic map of the important structures in the BBNPP site region is shown in Figure 2.5-188, and Figure 2.5-232, while cross sections are shown in Figure 2.5-7. Since the EPRI study (EPRI, 1986) was completed, new tectonic features have been proposed and described in the site region, and previously described features have been

2.5.1.1.4.4.4 Relevant Tectonic Features with No Associated Seismicity

A total of ~~21~~24 tectonic features have been identified with no associated seismicity.

Of these ~~21~~24, five are located within the site vicinity (25 mi (40 km) radius). Tectonic structures and features closest to the BBNPP site are relatively more important because of their proximity and are discussed first. These five features and other structures listed in this subsection are shown Figure 2.5-12 (site vicinity), and Figure 2.5-188 and Figure 2.5-232 (site region). Based on review of published literature and historical seismicity, there is no reported geomorphic expression, historical seismicity, or Quaternary deformation along any of the twenty-one features identified below. Thus they are not considered to be a capable tectonic source for calculating the seismic hazard for BBNPP.

- Berwick Anticlinorium (Section 2.5.1.1.4.4.4.1)
  - Light Street Thrust Fault (Section 2.5.1.1.4.4.4.1.1)
  - Berwick Fault (Section 2.5.1.1.4.4.4.1.2)
- Lackawanna Synclinorium (Section 2.5.1.1.4.4.4.2)
- Anthracite Region (Section 2.5.1.1.4.4.4.3)
- Scranton Gravity High (Section 2.5.1.1.4.4.4.4)
- Yellow Breeches Fault Zone (Section 2.5.1.1.4.4.4.5)
- Rome Trough (Section 2.5.1.1.4.4.4.6)
- Pleasant Valley-Huntingdon Valley Fault (Section 2.5.1.1.4.4.4.7)
- Transylvania Fault Zone (Section 2.5.1.1.4.4.4.8)
- Plummers Island and Pleasant Grove Shear Zones (Section 2.5.1.1.4.4.4.9)
- Newark-Gettysburg Basin (Section 2.5.1.1.4.4.4.10)
- Hartford Basin (Section 2.5.1.1.4.4.4.11)
- Connecticut Basin (Section 2.5.1.1.4.4.4.12)
- Brandywine Fault System (Section 2.5.1.1.4.4.4.13)
- Martic Fault (Section 2.5.1.1.4.4.4.14)
- East Border Fault (Section 2.5.1.1.4.4.4.15)
- Catawissa-McCauley Mountain Synclinorium (Section 2.5.1.1.4.4.4.16)
- Broadtop Synclinorium (Section 2.5.1.1.4.4.4.17)
- Sweet Arrow Fault (Section 2.5.1.1.4.4.4.18)
- Chestnut Ridge Anticline (Section 2.5.1.1.4.4.4.19)
- Philadelphia Structural Block (Section 2.5.1.1.4.4.4.20)
- Potomac and Westminster Terranes including the Pleasant Grove Shear Zone (Section 2.5.1.1.4.4.21
- Baltimore Gneiss Terrane (Section 2.5.1.1.4.4.4.22)

2.5.1.1.4.4.4.20 Philadelphia Structural Block

The Philadelphia Structural Block is located in the Piedmont physiographic province of Pennsylvania and New York. This block is currently comprised of three stratigraphic units; the Wissahickon Formation, the Wilmington Complex, and the Springfield Pluton. Originally the Block was comprised of only the Wissahickon Formation. The Wissahickon Formation is thought to have originated as part of a peri- Gondwanan back-arc basin during the Late Cambrian or Early Ordovician (Bosbyshell, 2009). Metamorphism of the Wissahickon Formation began during the Taconic Orogeny with the collapse of the Cambrian-Ordovician Laurentian passive margin beneath the Wilmington Complex, the root of the Taconic volcanic arc. This collapse created the Llanerch Thrust Zone. The Wilmington Complex was then thrust over the Wissahickon Formation, concurrent with the intrusion of the Springfield granodiorite pluton into the Wissahickon (Valentino, 1999).

Significant transcurrent displacements along ductile shear zones indicate a tectonic history of oblique convergence and orogen-parallel displacement (Hill, 2006). These strike-slip shear zones bound and cross-cut the Philadelphia Structural Block. To the northwest the block is bound by the Rosemont Shear Zone, and to the north, the Pleasant Grove- Huntingdon Valley Shear Zone. These shear zones separate the Philadelphia Structural Block from the West Chester and Avondale Grenvillian basement massifs. Another shear zone, the Crum Creek, cross cuts the metamorphic zones of the Wissahickon formation and is thought to be the conjugate pair of the Rosemont shear zone (Valentino, 1995). The most pervasive period of metamorphism in the Wissahickon Formation and the right-lateral transpressive deformation in the Rosemont Shear Zone, and corresponding sinistral movement along the Crum Creek Shear Zone, are Devonian in age (Bobsyshell, 2009). This timing correlates with the Acadian Orogeny in the Central Appalachians.

There is no seismicity associated with this structure, and it is considered to be non-capable under the present stress regime.

2.5.1.1.4.4.4.21 Potomac and Westminster Terranes including the Pleasant Grove Shear Zone

The Westminster and Potomac Terranes are exposed in Maryland, Virginia and Washington DC. It is proposed that the Potomac was thrust onto the Westminster along the Pleasant Grove Fault during the Devonian Acadian Orogeny. The Westminster was thrust westward along the Martic Thrust onto the Cambrian/Ordovician continental margin during the Ordovician Taconic Orogeny (Kunk, 2004a).

The rocks of the Westminster Terrane are dominated by phyllites and are proposed to represent offshore, deepwater, post rift deposits (Kunk, 2004b). Rocks of the Potomac Terrane are proposed to be turbidites deposited in a deep ocean trench. Within the Piedmont Province, the Westminster and Potomac Terranes show foliation that mainly strikes northeasterly and dips steeply to the southeast (Southworth, 2006).

The Pleasant Grove Fault, also known as the Pleasant Grove Shear Zone is a Taconic suture which placed the Potomac Terrane on top of and to the east of the Westminster Terrane. It is approximately 60-km long and the zone of deformation is as much as 3-km wide (Southworth, 2006). The shear zone contains dextral strike-slip indicators and similar deformational structures on both the east and west sides of the fault. Along the length of the shear zone, cooling ages range from 371 Ma in the Potomac Terrane to 364-308 Ma north of the Potomac River (Devonian to Carboniferous). The age of most recent dextral shearing is indicated by mica growth and has been dated at approximately 311 Ma (Southworth, 2006). Figure 2.5-230 shows part of Potomac River region depicting the Westminster and Potomac Terranes tectonostratigraphic location and relationships with bordering terranes and associated shear zones.

2.5.1.1.4.4.4.22 Baltimore Gneiss Terrane:

The Baltimore Gneiss is defined as the basement gneisses observed at the lowest stratigraphic level in the Central Piedmont. Planck (Planck, 2001) reports that the gneiss has been observed in the cores of thirteen anticlines, domes and nappes from Baltimore, MD to Philadelphia, PA. It is a Proterozoic age gneiss containing quartz, pink/white feldspar, biotite, garnet, hornblende, magnetite, titanite and zircon. The Glenarm and Wissahickon group rocks were deposited in marine rift basins floored by Baltimore Gneiss (Blackmer, 2005). The gneiss is also exposed in the Avondale and West Chester Massifs and includes amphibolite and granulite grade metamorphic compositions. The Setters Formation and Cockeysville Marble also unconformably overlie the Baltimore Gneiss (Blackmer, 2005). The northeast-southwest belt of metamorphic rocks northwest of Baltimore, which commonly includes exposures of Baltimore Gneiss, is known as the Baltimore Gneiss Terrane. The Grenville-age gneiss and sediments were thrust northwestward into a nappe structure and deformed during the Ordovician Taconic Orogeny (Lang, 1996). Figure 2.5-231 shows the Baltimore Gneiss tectonostratigraphic location within the Eastern Maryland Piedmont depicting the relationships with bordering terranes.

2.5.1.3 References

Aber, 2001. Appalachian Mountains, J. S. Aber, Website: http://academic.emporia.edu/aberjame/struc_geo/appalach/appalach.htm, Date accessed: January 23, 2008.

Aggarwal, 1978. Earthquakes, Faults, and Nuclear Power Plants in Southern New York and New Jersey, Science, Volume 200, p 425-429, Y. Aggarwal and L. Sykes, 1978.

Anglin, 1981. Microseismicity in the mid-St. Lawrence Valley Charlevoix zone, Bulletin of the Seismological Society of America, Volume 71, p 1553-1560, F. Anglin and G. Buchbinder, 1981.

Anglin, 1984. Seismicity and Faulting in the Charlevoix Zone of the St. Lawrence Valley, Bulletin of the Seismological Society of America, Volume 74, Number 2, p 595-603, F.M. Anglin, April, 1984.

Armbruster, 1987. The 23 April 1984 Martic Earthquake and The Lancaster Seismic Zone In Eastern Pennsylvania, Bulletin of the Seismological Society of America, Volume 77, Number 2, p 877-890, J. Armbruster and L. Seeber, 1987.

Bailey, 1998. Late Neoproterozoic Extension-Related Magma Emplacement in the Central Appalachians: An Example from the Polly Wright Cove Pluton, The Journal of Geology, Volume 106, p 347-359, Christopher M. Bailey and Richard P. Tollo, 1998.

Bankey, 2002. Magnetic Anomaly Map of North America, U.S. Geological Survey, scale 1:10,000,000, 1 sheet, V. Bankey, A. Cuevas, D. Daniels, C. Finn, I. Hernandez, P. Hill, R. Kucks, W. Miles, M. Pilkington, C. Roberts, W. Roest, V. Rystrom, S. Shearer, S. Snyder, R. Sweeney and J. Velez, 2002.

Barnes, 2002. The Geological Story of Pennsylvania (3rd ed.), Pennsylvania Geological Survey, 4th ser., Educational Series 4, p 1-44, J.H. Barnes and W.D. Sevon, 2002.

Behrendt, 1983. Structural elements of the U.S. Atlantic margin delineated by the second vertical derivative of the aeromagnetic data, U.S. Geological Survey Geophysical Investigation Map GP-956, scale 1-2,500,000, J. Behrendt and M. Grim, 1983.

Bennington, 2006. Geology of New York and New Jeresey, Hofstra University, 21 p, J. B. Bennington and C. Merguerian, 2006.

Bent, 1992. A re-examination of the 1925 Charlevoix, Quebec, earthquake, Bulletin of the Seismological Society of America, Volume 82, p 2097-2113, A. Bent, 1992.

Benson, 1992. Map of the exposed and buried Early Mesozoic rift basins/synrift rocks of the U.S. Middle Atlantic Continental Margin, Miscellaneous Map Series No. 5, Delaware Geological Survey, University of Delaware, Newark, R. Benson, 1992.

Berg, 1980. Geologic map of Pennsylvania, Pennsylvania Geological Survey, 4th ser., Map1, scale 1:250,000, 3 sheets, T.M. Berg, 1980.

Berg, 1999. Part II, Stratigraphy and Sedimentary Tectonics, Chapter 8: Devonian-Mississippian Transition, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 128-137, T.M. Berg, 1999.

Blackmer, 2005., Preliminary Bedrock Geologic Map of a Portion of The Wilmington 30- By 60-Minute Quadrangle, Southeastern Pennsylvania, Open-File Report OFBM-05-01.0, Pennsylvania Geological Survey, Fourth Series, Blackmer, G. C., Harrisburg, 2005.

Bobyarchick, 2007. Kinematics of the Everona Fault, Central Virginia, Bobyarchick Andy R., , Geological Society of America Abstracts with Programs, Session No. 33, Cenozoic Tectonics in the Southeastern United States, Vol. 39, No. 2, p. 89, March 2007.

Bosbyshell, 2009. Amphibolite Geochemistry in the Wissahickon Formation, Philadelphia, PA: New Results and Implications for Wilmington Complex- Laurentia Collision, Geological Society of America Abstracts with Programs, Vol. 41, No. 3, H. Bosbyshell.

Bradley, 2002. Emsian Synorogenic Paleogeography of the Maine Appalachians, The Journal of Geology, Volume 110, p 483-492, Dwight Bradley and Robert Tucker, 2002.

Bradley, 1989. Taconic Plate Kinematics as Revealed by Foredeep Stratigraphy, Appalachian Orogen, Tectonics, Volume 8, No. 5, p 1037-1049, D.C. Bradley, 1989.

Braile, 1997. New Madrid Seismicity, Gravity Anomalies, and Interpreted Ancient Rift Structures, Seismological Research Letters, Volume 68, Number 4, p 599-610, Lawrence W. Braile, William J. Hinze, G. Randy Keller, July/August 1997.

Braun, 1988. Glacial Geology of the Anthracite and North Branch Susquehanna Lowland Regions, p 1-25, D. Braun, 1988.

Braun, 2004. Late Wisconsin Deglaciation of the Great Bend- Tunkhannock Region of Northeastern Pennsylvania, Guidebook for the 67th Annual Reunion of the Friends of the Pleistocene, p 1-26, D. Braun, 2004.

Braun, 2007. Surfical Geology of the Red Rock 7.5-Minute Quadrangle, Luzerne, Sullivan, and Columbia Counties, Pennsylvania, Pennsylvania Geological Survey, Fourth series, Open-File Report OFSM 07-10.0, 19p, Portable Document Format (PDF), Duane D. Braun, 2007.

Brezinski, 1999. Part II, Stratigraphy and Sedimentary Tectonics, Chapter 9: Mississippian, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 138-147, D.K. Brezinski, 1999.

Castle, 2005. Petrophysics of Lower Silurian sandstones and integration with the tectonic-stratigraphic framework, Appalachian basin, United States, AAPG Bulletin, Volume 89, Number 1, p 41-60, James W. Castle and Alan P. Byrnes, January 2005.

CFR, 2007. Geologic and Seismic Sitting Criteria, Title 10, Part 100.23, Code of Federal Regulations, CFR, 2007.

Eusden, 2000. Timing of the Acadian Orogeny in Northern New Hampshire, The Journal of Geology, Volume 108, p 219-232, J. Dykstra Eusden, Jr., Chris A. Guzofski, Alexander C. Robinson, and Robert D. Tucker, 2000.

Evans, 1989. Appalachian Stress Study, Analysis of Devonian Shale Core: Some Implications for the Nature of Contemporary Stress Variations and Alleghanian Deformation in Devonian Rocks, Journal of Geophysical Research, Volume 94, Number B6, p 7155-7170, Keith F. Evans, Gerhard Oertel, Terry Engelder, June 1989.

Faill, 1973. Tectonic development of the Triassic Newark-Gettysburg Basin in Pennsylvania, Geological Society of America Bulletin, Volume 84, p 725-740, R. T. Fail, 1973.

Faill, 1997. A Geologic History of the North-Central Appalachians, Part 1, Orogenesis from the Mesoproterozoic through the Taconic Orogeny, Journal of Science, Volume 297, p 551-619, R. Faill, 1997.

Faill, 1999. Part III. Structural Geology and Tectonics, Chapter 19 Appalachian Mountain Section of the Ridge and Valley Province, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 268-285, R. Fail and R. Nickelsen, 1999.

Faill, 1999a. Chapter 33 - Paleozoic in The Geology of Pennsylvania, Commonwealth of Pennsylvania, Department of Conservation and Natural Resources, Bureau of Topographic and Geological Survey, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, Faill, R. T.

Faill, 2004. The Birdsboro Basin, Pennsylvania Geology, Volume 34, Number 4, p 2-11, R. T. Fail, 2004.

Fichter, 2000. Cross Section J: The Devonian Acadian Orogeny and Catskill Clastic Wedge, in The Geological Evolution of Virginia and the Mid-Atlantic Region, p 1-6, L.S. Fichter, 2000.

Fletcher, 1977. Earthquakes related to hydraulic mining and natural seismic activity in western New York State, Journal of Geophysical Research, Volume 82, p 3767-3780, J. B. Fletcher and L .R. Sykes, 1977.

Frey, 1973. Influence of Salina Salt on Structure in New York-Pennsylvania Part of Appalachian Plateau, AAPG Bulletin, Volume 57, Number 6, p 1027-1037, M. Gordon Frey, June 1973.

Gao, 2000. Along-Axis Segmentation and Growth History of the Rome Trough in the Central Appalachian Basin, AAPG Bulletin, Volume 84, Number 1, p 75-99, Dengliang Gao, Robert C. Shumaker, and Thomas H. Wilson, January 2000.

Gelinas, 1993. Evaluation of liquefaction-susceptible materials near moderate magnitude historical earthquakes in New England, [abs], Seismological Research Letters, Volume 64, p 259-260, R. L. Gelinas, H. M. A. Kempinen, and D. C. Amick, 1993.

Harrison, 2004. The Lackawanna synclinorium, Pennsylvania: A salt-collapse structure, partially modified by thin-skinned folding, Geological Society of America Bulletin, Volume 116, Number 11/12, p 1499-1514, Michael J. Harrison, Stephen Marshak, John H. McBride, November/December 2004.

Hasson, 1988. Lithofacies and paleogeography of the Conasauga Group, (Middle and Late Cambrian) in the Valley and Ridge province of east Tennessee, Geological Society of America Bulletin, Volume 100, p 234-246, Kenneth O. Hasson and C. Stephen Haase, February 1988.

Hatcher, 1987. Tectonics of the southern and central Appalachian internides, Annual Reviews of Earth and Planetary Science, Volume 15, p 337-362, R. Hatcher Jr., 1987.

Hawman, 1992. Structure of the crust and upper mantlebeneath the great Valley and Allegheny Plateau of eastern Pennsylvania, II, Gravity modeling and migration of wide-angle reflection data, Journal of Geophysical Research, Volume 97, p 393-415, R. B. Howmann and R. A. Phinney, 1992.

Hayman, 2002. Reactivation of prethrusting, synconvergence normal faults as ramps within the Ordovician Champlain-Taconic thrust system, GSA Bulletin, Volume 114, Number 4, p 476-489, Nicholas W. Hayman and W. S. F. Kidd, April 2002.

Heckel, 1998. Stratigraphic Model for Glacial-Eustatic Pennsylvanian Cyclothems in Highstand Nearshore Detrital Regimes, The Journal of Geology, Volume 106, p 373-383, Philip H. Heckel, Martin R. Gibling, and Norman R. King, 1998.

Heidbach, 2008. The release 2008 of the World Stress Map (available online at www.world-stress-map.org), O. Heidbach, M. Tingay, A. Barth, J. Reinecker, D. Kurfess and B. Muller, 2008.

Herman, 2005. Joints and Veins in the Newark Basin, New Jersey in Regional Tectonic Perspective, View from the 21st Century, 22nd Annual Meeting of the Geological Association of New Jersey, College of New Jersey, Ewing, New Jersey, p 75-116, Gregory C. Herman, 2005.

Herrmann, 1978. A seismological study of two Attica, New York earthquakes, Bulletin of the Seismological Society of America, Volume 68, p 641-651, R. B. Herrmann, 1978.

Hibbard, 2006. Lithotectonic map of the Appalachian Orogen, Canada-United States of America, Geological Survey of Canada Map 02096A, 2 sheets, Scale 1: 1,500,000, J. Hibbard, C. Van Staal, D. Rankin and H. Williams, 2006.

Hickman, 1985. In Situ Stress, Natural Fracture Distribution, and Borehole Elongation in the Auburn Geothermal Well, Auburn, New York, Journal of Geophysical Research, Volume 90, Number B7, p 5497-5512, Stephen H. Hackman, John H. Healy, and Mark D. Zoback, June 1985.

Hill, 2006. The Role of Transcurrent Shear Zones in the History of the Wissahickon Formation, Geological Society of America Abstracts with Programs, Vol. 38, No. 7, pg. 301, M. Hill, October 2006.

Johnston, 1985b. A basement block model for Southern Appalachian Seismicity, Geological Society of America-Abstracts with Programs, Volume 17, Number 2, p 97, A. Johnston and D Reinbold, 1985.

Kafka, 1985. Earthquake Activity in the Greater New York City Area: Magnitudes, Seismicity and Geologic Structures, Bulletin of the Seismological Society of America, Volume 75, Number 5, p 1285-1300, A. Kafka, E. Schlesinger-Miller and N. Barstow, 1985.

Kauffman, 1999. Part II, Stratigraphy and Sedimentary Tectonics, Chapter 4: Eocambrian, Cambrian, and Transition to Ordovician, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 59-73, M.E. Kauffman, 1999.

King, 1974. A digital representation of the 1974 P.B. King and H.M. Beikman Map: U.S. Geological Survey Digital Data Series DDS-11, downloaded from http://pubs.usgs.gov/dds/dds11/kb.html.

King, 1978. The New York-Alabama lineament: Geophysical Evidence for a Major Crustal Break in the Basement Beneath the Appalachian Basin, Geology, Volume 6, p 312-318, E. King and I. Zietz, 1978.

King, 1999. Part IV. Regional Geophysics, Chapter 24 Aeromagnetics, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 323-327, E. King, 1999.

Kline, 1991. Provenance of Arkosic Metasediments in the Virginia Blue Ridge: Constraints on Appalachian Suspect Terrane Models, American Journal of Science, Vol. 291, February, 1991.

Klitgord, 1988. U. S. Atlantic Continental Margin: Structural and Tectonic Framework, R. Sheridan and J. Grow, eds., The Atlantic Continental Margin, U.S., Geological Society of America, The Geology of North America, Volume 1-2, p 19-55, K. Klitgord, D. Hutchinson and H. Schouten, 1988.

Klitgord, 1995. Mid-Atlantic Continental Margin: The Mesozoic-Cenozoic Continent-Ocean Boundary, in L. Glover III and K. Klitgord, Chief Compilers, E-3 Southwestern Pennsylvania to Baltimore Canyon Trough, Geological Society of America Continent/Ocean Transect #19, Explanatory Pamphlet, K. Klitgord, C. Poag, L. Glover, R. Sheridan, D. Hutchinson, R. Mixon and R. Benson, 1995.

Koch, 1978. Geology and geophysics of the Moodus seismic area, Connecticut, Geological Society of America Abstracts with Programs, Volume 10, Number 2, p 71, B. F. Koch, R. J. Fahey, S. S. Quarrier, and J. F. Kick, 1978.

Kochanov, 1999. Sinkholes in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Educational Series 11, 33 p. Kochanov, W. E., 1999,

Kolata, 1997. Structural Underpinnings and Neotectonics of the Southern Illinois Basin: An Overview, Seismological Research Letters, Volume 68, Number 4, p 499-510, Dennis R. Kolata and Thomas G. Hildenbrand, July/August 1997.

Komor, 1998. Sources of Geospatial Data for Central and Western New York - 1998, U.S. Geological Survey, Open-File Report 99-191, 42 p, S.C. Komor, 1998

Kucks, 1999. Bouguer Gravity Anomaly Data Grid for the Conterminous US, Kucks, 1999.

Kulander, 2005. Regional Seismic Lines Across the Rome Trough and Allegheny Plateau of Northern West Virginia, Western Maryland, and Southwestern Pennsylvania, US Geological Survey, pamphlet to accompany Map I-2791, C.S. Kulander, and R. Ryder, 2005.

Kunk, 2004a. Constraints in the Thermal History of the Potomac and Westminster Terranes in Maryland, Virginia, and Washington D.C.: Extraction Of Useful Ages From Complex 40ar/39ar Age Spectra, Paper No. 29-12, Northeastern Section (39th Annual) and Southeastern Section (53rd Annual) Joint Meeting (March 25–27, 2004), Kunk, M.J., Wintsch, R.P., Southworth, C.S., Mulvey, B.K., Naeser, C.W., And Naeser, N.D., Geological Society of America Abstracts with Programs, Vol. 36, No. 2.

Kunk, 2004b. Multiple Paleozoic Metamorphic Histories, Fabrics, and Faulting in the Westminster and Potomac Terranes, Central Appalachian Piedmont, Northern Virginia and Southern Maryland, U.S. Geological Survey, 9 p, M. Kunk, R. Wintsch, C. Southworth, B. Mulvey, C. Naeser and N. Naeser, 2004.

Lang, 1996. Pressure-temperature-reaction history of metapelitic rocks from the Maryland Piedmont on the basis of correlated garnet zoning and plagioclase-inclusion composition, Helen M. Lang, American Mineralogist, Volume 81.

Laughrey, 1998. Geochemistry and Origin of Some Natural Gases in the Plateau Province, Central Appalachian Basin, Pennsylvania and Ohio, AAPG Bulletin, Volume 82, Number 2, p 317-335, C. D. Laughrey and F. J. Baldassare, February 1998.

Laughrey, 1999. Part II, Stratigraphy and Sedimentary Tectonics, Chapter 6: Silurian and Transition to Devonian, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 91-107, C.D. Laughrey, 1999.

Laughrey, 2004. Petroleum geology and geochemistry of the Council Run gas field, north central Pennsylvania, AAPG Bulletin, Volume 88, Number 2, p 213-239, Christopher D. Laughrey, Dan A. Billman and Michael R. Canich, February 2004.

Lavin, 1982. Major lineaments and the Lake Erie-Maryland crustal block, Tectonics, Volume 1, p 431-440, P. M. Lavin, D. L. Chaffin, and W. F. Davis, 1982.

Lavin, 1999. Gravity, The Geology of Pennsylvania, Part IV. Regional Geophysics, Chapter 23, p 317-321, P. Lavin, 1999.

Lemieux, 2000. Stratigraphy and structure of the St. Lawrence Lowland in the Charlevoix area, Quebec: relationships to impact cratering, Geological Survey of Canada, Current Research 2000-D2, p 1-7, Y. Lemieux, A. Tremblay, and D. Lavoie, 2000.

Lotto, 1997. Seismic stratigraphy of the New York bight, NY/NJ continental shelf, Geological Society of America Abstracts with Programs, Volume 29, Number 1, p 62, L. Lotto, M. A. Allison, W. C. Schwab, B. Butman, D. Foster, J. Denny, and W. Corso, 1997.

Low, 2002. Geohydrology of Southeastern Pennsylvania, Water-Resources Investigations Report 00-4166, U.S. Geological Survey, U.S. Department of the Interior, In cooperation with the Pennsylvania Department of Conservation and Natural Resources, Bureau of Topographic and Geologic Survey, Dennis J. Low, Daniel J. Hippe, and Dawna Yannacci.

Lyons, 1982. Gravity Anomaly Map of the United States, Society of Exploration Geophysicists, Scale 1: 2,500,000, P. Lyons and N. O'hare, 1982.

MacLachlan, 1999. Part VI, Geologic History, Chapter 34: Mesozoic, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 435-449, D.B. MacLachlan, 1999.

Marple, 2000. 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, Number 2, p 200-220, R. Marple and P. Talwani, February 2000.

Marple, 2004. Relationship of the Stafford Fault Zone to the Right-Stepping Bends of the Potomac, Susquehanna and Delaware Rivers and Related Upstream Along the U.S. Mid-Atlantic Fall Line: In Southeastern Geology, Volume 42, Number 3, p 123-144, R. Marple, 2004.

McDonnell, 2008. Physical Geography of New York, T. McDonnell, Website: http://www.nygeo.org/ny_geo.html, Date accessed: April 9, 2008.

McElroy, 2007. Bedrock Geologic Map of the Allensville Quadrangle, Huntingdon and Mifflin Counties, Pennsylvania, Pennsylvania Geological Survey, 4th ser., OpenFile Report OFBM 07-02.0, T.A. McElroy and D.M. Hoskins, 2007.

Mclaughlin, 2002. Results of Trenching Investigations Along the New Castle Railroad Survey-1 Seismic Line, New Castle, Delaware, Delaware Geological Survey, Open-File Report 43, 19 p, P. McLaughlin, S. Baxter, K. Ramsey, T. McKenna and S. Strohmeier, 2002.

Merguerian, 1996. Stratigraphy, Structural Geology, and Ductile- and Brittle Faults of New York City, Website: http://www.dukelabs.com/Abstracts%20and%20Papers/CM1996c.htm, 26 p, Date accessed: March 25, 2008.

Merguerian, 1997. Bronx River diversion- Neotectonic implications, International Journal of Rock Mechanics and Mining Sciences, Volume 34, Number 3-4, Paper Number 298, C. Merguerian and J. E. Sanders, 1997.

Milici, 2006. Assessment of Appalachian Basin Oil and Gas Resources: Devonian Shale-Middle and Upper Paleozoic Total Petroleum System, US Geological Survey, Open-File Report Series 2006-1237, p 1-70, R.C. Milici and C.S. Swezey, 2006.

Milici, 2009. The Blue Ridge Thrust Belt Province (068), Piedmont Province (069), Atlantic Coastal Plain Province (070), Adirondack Uplift Province (071), and New England Province

(072), U.S. Geological Survey Digital Data Series DDS-30, Release 2, one CD-ROM, Milici, R.C. Online Linkage: http://certmapper.cr.usgs.gov/data/noga95/prov68/text/prov68.pdf.

Miller, 2000. Sequence Stratigraphy of Upper Mississippian Strata in the Central Appalachians: A Record of Glacioeustasy and Tectonoeustasy in a Foreland Basin Setting, AAPG Bulletin, Volume 84, Number 2, p 210-233, Daniel J. Miller and Kenneth A. Eriksson, February 2000.

Millot, 2001. Proterozoic Eon: Mesoproterozoic Era- Greenville Orogeny, L. Sniatkowski ed., J. Millot, 2001.

Mixon, 1977. Stafford Fault System: Structure Documenting Cretaceous and Tertiary Deformation Along the Fall Line in Northeastern Virginia, Geology, Vol. 5, p. 437-440, R. Mixon and W. Newell, 1977.

Mixon, 2000. Geologic Map of the Fredricksburg 30' x 60' Quadrangle, Virginia and Maryland, Report 2607, IMAP, R. Mixon, L. Pavlides, D. Powars, A. Froelich, R. Weems, J. Schindler, W. Newell, L. Edwards, and L. Ward, 2000.

Mitra, 1988. Effects of Deformation Mechanisms on Reservoir Potential in Central Appalachian Overthrust Belt, AAPG Bulletin, Volume 72, Number 5, p 536-554, Shankar Mitra, May 1988.

Moecher, 2004. Precise Time and Conditions of Peak Taconian Granulite Facies Metamorphism in the Southern Appalachian Orogen, U.S.A., with Implications for Zircon Behavior during Crustal Melting Events, The Journal of Geology, Volume 112, p 289-304, David P. Moecher, Scott D. Samson, and Calvin F. Miller, 2004.

Moecher, 1999. The Distribution, Style, and Intensity of Alleghanian Metamorphism in South-Central New England: Petrologic Evidence from the Pelham and Williamantic Domes, The Journal of Geology, Volume 107, p 449-471, David P. Moecher, 1999.

Mueller, 2008. Crustal Evolution in the Southern Appalachian Orogen: Evidence from Hf Isotopes in Detrital Zircons, The Journal of Geology, Volume 116, p 414-422, Paul A. Mueller, George D. Kamenov, Ann L. Heatherington, and Joshua Richards, 2008.

Murphy, 2000. Proto-Avalonia: A 1.2-1.0 Ga tectonothermal event and constraints for the evolution of Rodinia, Geology, Volume 28, Number 12, p 1071-1074, J.B. Murphy, R.A. Strachan, R.D. Nance, K.D. Parker, M. B. Fowler, December 2000.

National Atlas, 2008. Shaded Relief (200 Meter) 2008.downloaded from www.nationalatlas.gov/ mld/srld48i.html, U.S. National Atlas, 2008.

Nelson, 1983. The Clingman Lineament: Aeromagnetic Evidence for a Major Discontinuity in the North American Basement, Geological Society of America, Southeastern Section, Abstracts with Programs, Volume 13, Number 1, p 31, A. Nelson and I. Zietz, January 1983.

NJGS, 2003. Generalized Glacial Sediments of New Jersey, New Jersey Geological Survey, Website: http://www.state.nj.us/dep/njgs/geodata/dgs96-1.gif, Date accessed: December 14, 2007.

Pavlides, 1994. Early Paleozoic Alkalic and Calc-Alkalic Plutonism and Associated Contact Metamorphism, Central Virginia Piedmont, U.S. Geological Survey Professional Paper 1529, L. Pavlides, J. Arth, J. Sutter, T. Stern and H. Cortesini Jr., 1994.

Pazzaglia, 1993. Stratigraphy, Petrography, and Correlation of Late Cenozoic Middle Atlantic Coastal Plain Deposits: Implications for Late-Stage Passive-Margin Geologic Evolution, Geological Society of American Bulletin, Volume 105, p 1617-1634, F.J. Pazzaglia, 1993.

Pazzaglia, 1994. Late Cenozoic Flexural Deformation of the Middle U.S. Atlantic Passive Margin, Journal of Geophysical Research, Volume 99, Number B6, p 12143-12157, F. J. Pazzaglia and T.W. Gardner, 1994.

Pelletier, 2004. Estimate of three-dimensional flexural-isostatic response to unloading: Rock uplift due to late Cenozoic glacial erosion in the western United States, Geology, Volume 32, Number 2, p 161-164, Jon D. Pelletier, February 2004.

Pierce, 1966. Tuscarora Fault, an Acadian(?) bedding-plane fault in central Appalachian Valley and Ridge Province, AAPG Bulletin, Volume 50, Number 2, p 385-390, Kenneth L. Pierce and Richard L. Armstrong, February 1966.

Plank, 2001. Geochemistry of the Mafic Rocks, Delaware Piedmont and Adjacent Pennsylvania and Maryland: Confirmation of Arc Affinity, Delaware Geological Survey, Report of Investigations No. 60, State of Delaware, Margaret O. Plank, LeeAnn Srogi, William S. Schenck, and Terry A. Plank.

Pohn, 2000. Lateral Ramps in the Folded Appalachians and in Overthrust Belts Worldwide- a Fundamental Element of Thrust-Belt Architecture, U.S. Geological Survey Bulletin 2163, p 1-63, H.A. Pohn, 2000.

Pohn, 2001. Lateral Ramps in the Folded Appalachians and in Overthrust Belts Worldwide- A Fundamental Element of Thrust-Belt Architecture, U.S. Geological Survey Bulletin 2163, p 1-21, H.A. Pohn, 2001.

Ratcliffe, 1971. The Ramabo Fault System in New York and Adjacent Northern New Jersey-A Case of Tectonic Heredity, Geological Society of America Bulletin, Volume 82, p 125-142, N. Ratcliffe, 1971.

Ratcliffe, 1982. Results of Core Drilling of the Ramapo Fault at Sky Meadow Road, Rockland County, New York, and Assessment of Evidence for Reactivation to Produce Current Seismicity, U.S. Geological Survey Miscellaneous Investigations, Map I-1401, 1 sheet, N. Ratcliffe, 1982.

Ratcliffe, 1984. Brittle fault fabrics, mineralogy, and geometry of border faults of the Newark basin, NY-NJ, from drill-core information, Geological Society of America Abstracts with Programs, Volume 16, Number 1, p 57, N. M. Ratcliffe and W. C. Burton, 1984.

Ratcliffe, 1985. Proceedings of the Second U.S. Geological Survey Workshop on the Early Mesozoic Basins of the Eastern United States, U.S. Geological Circular 946, G.R. Robinson, Jr., and A.J. Froelich eds., U.S. Geological Survey, Ratcliffe, 1985.

Saylor, 1999. Part II, Stratigraphy and Sedimentary Tectonics, Chapter 3C: Precambrian and Lower Paleozoic Metamorphic and Igneous Rocks- in the Subsurface, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 51-57, T.E. Saylor, 1999.

Scharnberger, 2006. The Lancaster Seismic Zone of the Southeast Pennsylvania in relation to the Gettyburg-Newark Basin, Geological Society of America, Abstracts with Programs, Volume 38, Number 2, p 83, C. Scharnberger, 2006.

Schlische, 2002. Progress in Understanding the Structural Geology, Basin Evolution, and Tectonic History of the Eastern North American Rift System, Structural Geology of the Eastern North American Rift System, p 23-64, Schlische, 2002.

Schlische, 2002b. Relative Timing of CAMP, Rifting, Continental Breakup, and Basin Inversion: Tectonic Significance, in Hames, W.E., McHone, G.C., Renne, P.R., and Ruppel, C., eds., The Central Atlantic Magmatic Province, American Geophysical Union Monograph 136, Roy W. Schlische, Martha Oliver Withjack, and Paul E. Olsen.

Schlische, 2003. Progress in Understanding the Structural Geology, Basin Evolution, and Tectonic History of the Eastern North American Rift System, P. Letourneau and P. Olsen, eds., The Great Rift Valleys of Pangaea in Eastern North America, Volume 1, p 21-64, R. Schlische, 2003.

Schwab, 1997. Seafloor Characterization Offshore of the New York-New Jersey Metropolitan Area Using Sidescan-Sonar, U.S. Geological Survey, Open-File Report 00-295,16 p, Schwab, 1997.

Seborowski, 1982. Tectonic implications of recent earthquakes near Ansville, New York, Bulletin of the Seismological Society of America, Volume 72, p 1601-1609, D. D. Seborowski, G. Williams, J. A. Kelleher, and C. T. Statton, 1982.

Seeber, 1998. The 1994 Cacoosing Valley Earthquakes Near Reading, Pennsylvania: A Shallow Rupture Triggered By Quarry Unloading, Journal of Geophysical Research, Volume 103, Number B10, p 24,505-24,521, L. Seeber, J. Armbruster, W. Kim, N. Barstow and C. Scharnberger, 1998.

Senior, 2006. Arsenic, Boron, and Fluoride Concentrations in Ground Water in and Near Diabese Intrusions, Newark Basin, Southeastern Pennsylvania, Lisa A. Senior, Ronald A. Sloto, United States Geological Survey, Scientific Investigations Report 2006-5261, 105 p.

Sevon, 1999. Part VI, Geologic History, Chapter 35: Cenozoic, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 451-455, W.D. Sevon and G.M. Fleeger, 1999.

Sevon, 2000. Regolith in the Piedmont Upland Section, Piedmont Province, York, Lancaster and Chester Counties, Southeastern Pennsylvania, Southeastern Geology, Volume 39, Number 3 and 4, p 223-241, W. Sevon, October 2000.

Sheridan, 1988. The Atlantic Continental Margin, U.S.Geological Society of America, The Geology of North America, Volume 1-2, p 610, R. Sheridan and J. Grow, 1988.

Sheridan, 1993. Deep seismic reflection data of EDGE U.S. mid-Atlantic continental-margin experiment: Implications for Appalachian sutures and Mesozoic rifting and magmatic underplating, Geology, Volume 21, p 563-567, Robert E. Sheridan, Douglas L. Musser, Lynn Glover, III, Manik Talwani, John I. Ewing, W. Steven Holbrook, G. Michael Purdy, Robert Hawman, and Scott Smithson, June 1993.

Shrake, 1991. Pre-Mount Simon basin under the Cincinnati Arch: Geology, Volume19, p.139142, 1991.

Shumaker, 2002. Reinterpreted Oriskany structure at the North Summit field, Chestnut Ridge anticline, Pennsylvania, AAPG Bulletin, Volume 86, Number 4, p 653-670, Robert C. Shumaker, April 2002.

Southworth, 2002. Digital Geologic Map and Database of the Frederick 30' x 60' Quadrangle, Maryland, Virginia, and West Virginia, Version 1.0, Compiled by Scott Southworth, Aeromagnetic map and digital topographic map by D. Daniels, Digital compilation by J.E. Reddy and D. Denenny, Pamphlet to accompany Open-File Report 02-437, U.S. Geological Survey, Reston, Virginia, S. Southworth, D. Brezinski, A.A. Drake, W.C. Burton, R.C. Orndorff, and A.J. Froelich, 2002

Southworth, 2006. Central Appalachian Piedmont and Blue Ridge tectonic transect, Potomac River corridor, in Pazzaglia, F.J., ed., Excursions in Geology and History: Field Trips in the Middle Atlantic States: Geological Society of America Field Guide 8, Southworth, S., Drake, A.A., Jr., Brezinski, D.K., Wintsch, R.P., Kunk, M.J., Aleinikoff, J.N., Naeser, C.W., and Naeser, N.D.

Spoljaric, 1972. Geology of the Fall Zone in Delaware, Delaware Geological Survey, p 30, N. Spoljaric, March 1972.

Spoljaric, 1973. Normal Faults in Basement Rocks of the Northern Coastal Plain, Delaware, Geological Society of America Bulletin, Volume 84, p 2781-2783, N. Spoljaric, 1973.

SSES FSAR, 2003. Susquenhanna Steam Electric Station Units 1 and 2 Final Safety Analysis Report, Section 2.5, Geology, Seismology, and Geotechnical Engineering, Rev. 58, Pennsylvania Power and Light, 2003.

Stanford, 1995. Possible Pliocene-Pleistocene Movement on a Reactivated Mesozoic Fault In Central New Jersey, Geological Society of America Abstracts with Programs, Volume 27, Number 1, p 83, S. Stanford, D. Jagel, and D. Hall, 1995.

Steltenpohl, 1988. Kinematics of the Towaliga, Bartletts Ferry, and Goat Rock fault zones, Alabama: The late Paleozoic dextral shear system in the southernmost Appalachians, Geology, Volume 16, p 852-855, Mark. G. Steltenpohl, September 1988.

Stern, 2005. Isostatic rebound due to glacial erosion within the Transantarctic Mountains, Geology, Volume 33, Number 3, p 221-224, T.A. Stern, A.K. Baxter, P.J. Barrett, March 2005.

USNRC, 2007. Exelon Generation Company, LLC, ESP Site, DOKET NO. 52-007, Early Site Permit, Early Site Permit No. ESP-001. U.S. Nuclear Regulatory Commission, March 2007.

VADOT, 2008. Aggregate Plant Certification Study Guide, The Virginia Dept. of Transportation, 32nd Ed., Appendix F, P. F-1~F-26, VADOT, 2008

Valentino, 1995. Paleozoic transcurrent conjugate shear zones in the central Appalachian piedmont of southeastern Pennsylvania, Journal of Geodynamics, Volume 19, Issues 3-4, May-July 1995, D. Valentino, and M. Hill.

Valentino, 1999. Interaction between Paleozoic strike-slip and thrust shear zones in the Philadelphia Structural Block, Central Appalachian Piedmont, Geological Society of America, Special Paper 330, D.W. Valentino, R.W. Valentino, and B.J. Lamport.

Van Diver, 1993. Plate Tectonics, Roadside Geology of Pennsylvania, Roadside Geology Series, 352 p, Van Diver, 1993.

Varnes, 1978. Slope Movement Types and Processes, in Schuster, R.L., and Krizek, R.J., eds., Landslides-Analysis and control: National Research Council, Washington, D.C., Transportation Research Board, Special Report 176, p 11-33, R.L. Schuster and R.J. Krizek, 1978.

VDEQ, 2008. Virginia's Mineral and Energy Resources, Virginia Resource-Use Education Council, Virginia's Natural Resources Education Guide, 17 p., VDEQ, 2008.

Ver Straeten, 2000. Bulge Migration and Pinnacle Reef Development, Devonian Appalachian Foreland Basin, The Journal of Geology, Volume 108, p 339-352, Charles A. Ver Straeten and Carlton E. Brett, 2000.

Vlahoic, 1998. Joint hypocenter-velocity inversion for the eastern Tennessee seismic zone, Journal of Geophysical Research, Volume 103, p 4,879-4,896, G. Vlahoic, C. A. Powell, M. C. Chapman, and S. Sibol, 1998.

Wallach, 2002. The presence, characteristics and earthquake implications of the St. Lawrence fault zone within and near Lake Ontario (Canada-USA), J.L. Wallach, Tectonophysics 353 (2002) 45- 74

Way, 1999. Part IV. Physiography, Chapter 29: Appalachian Mountain Section of the Ridge and Valley Province, in C.H. Shultz ed., The Geology of Pennsylvania: Pennsylvania Bureau of Topographic and Geologic Survey Special Publication 1, p 353-361, J.H. Way, 1999.

Weary, 2005., An Appalachian Regional Karst Map and Progress Towards a New National Karst Map: U.S. Geological Survey Scientific Investigation Report 2005-5160, p. 93-102, Weary, D. J., 2005

Weems, 1998. New 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, 52 p, R. E. Weems, 1998.

Weems, 2002. Structural and tectonic setting of the Charleston, South Carolina, region: Evidence from the Tertiary stratigraphic record, GSA Bulletin, Volume 114, Number 1, p 24-42, Robert E. Weems and William C. Lewis, January 2002.

Wentworth, 1983. Regenerate Faults of Small Cenozoic Offset - Probable Earthquake Sources in the Southeastern United States, U.S. Geological Survey, Professional Paper 1313-S, C. Wentworth and M. Mergner-Keefer, 1983.

Wheeler, 1996. Earthquakes and the Southeastern Boundary of the Intact Iapetan margin in Eastern North America, Seismological Research letters, Volume 67, Number 5, p 77-83, R. Wheeler, 1996.

Wheeler, 1997. Boundary Separating the Seismically Active Reelfoot Rift from the Sparsely Seismic Rough Creek Graben, Kentucky and Illinois, Seismological Research Letters, Volume 68, Number 4, p 586-598, Russell L. Wheeler, July/August 1997.

Wheeler, 2005. Known or suggested Quaternary tectonic faulting, central and eastern United States-New and updated assessments for 2005, U.S. Geological Survey Open-File Report 20051336, p 37, R. L. Wheeler, 2005.

Wheeler, 2006. Quaternary tectonic faulting in the Eastern United States, Engineering Geology, Volume 82 (2006), p 165-186, R.L. Wheeler, 2006.

Williams, 1987. Groundwater Resources of the Berwick-Bloomsburg-Danville Area, East-Central Pennsylvania, Pennsylvania Bureau of Topographic and Geologic Survey, Water Resources Report 61, J.H. Williams and D.A. Eckhardt, 1987.

Wise, 1998. Lancaster County seismic zone (Penna)- Reactivation of a tectonic structural feature. Geological Society of America Abstracts with Programs, Volume 30, Number 7, p A-320, D. U. Wise and T. R. Faill, 1998.

Withjack, 2005a. A Review of Tectonic Events on the Passive Margin of Eastern North America, 25th Annual Bob F. Perkins Research Center: Petroleum Systems of Divergent Continental Margin Basins, Martha Oliver Withjack and Roy W. Schlische, Martha Oliver Withjack, and Paul E. Olsen.

Withjack, 1998. Diachronous Rifting, Drifting, and Inversion on the Passive Margin of Central Eastern North America: An Analog for Other Passive Margins, AAPG Bulletin, Volume 82, Number 5A, p 817-835, M.O. Withjack, R.W. Schlische, and P.E. Olsen, 1998.

Withjack, 2005. The Early Mesozoic Birdsboro Central Atlantic Margin Basin in the Mid-Atlantic Region, Eastern United States: Discussion, GSA Bulletin, Volume 117, Number 5/6, p 823-832, R.W. Schlische and M.O. Withjack, 2005.

Wolf, 2003. Ferroaxinite from Lime Crest Quarry Sparta, New Jersey, Adam Wolf, John Rakovan, Christopher Cahill, Rocks and Minerals, Volume 78, pp. 252-256.

Wong, 2005. Potential Losses in a Repeat of the 1886 Charleston, South Carolina, Earthquake, Earthquake Spectra, Volume 21, Number 4, p 1157-1184, Ivan Wong, Jawhar

Figure 2.5-208 {Mesozoic Basins and Associated Known Faults}

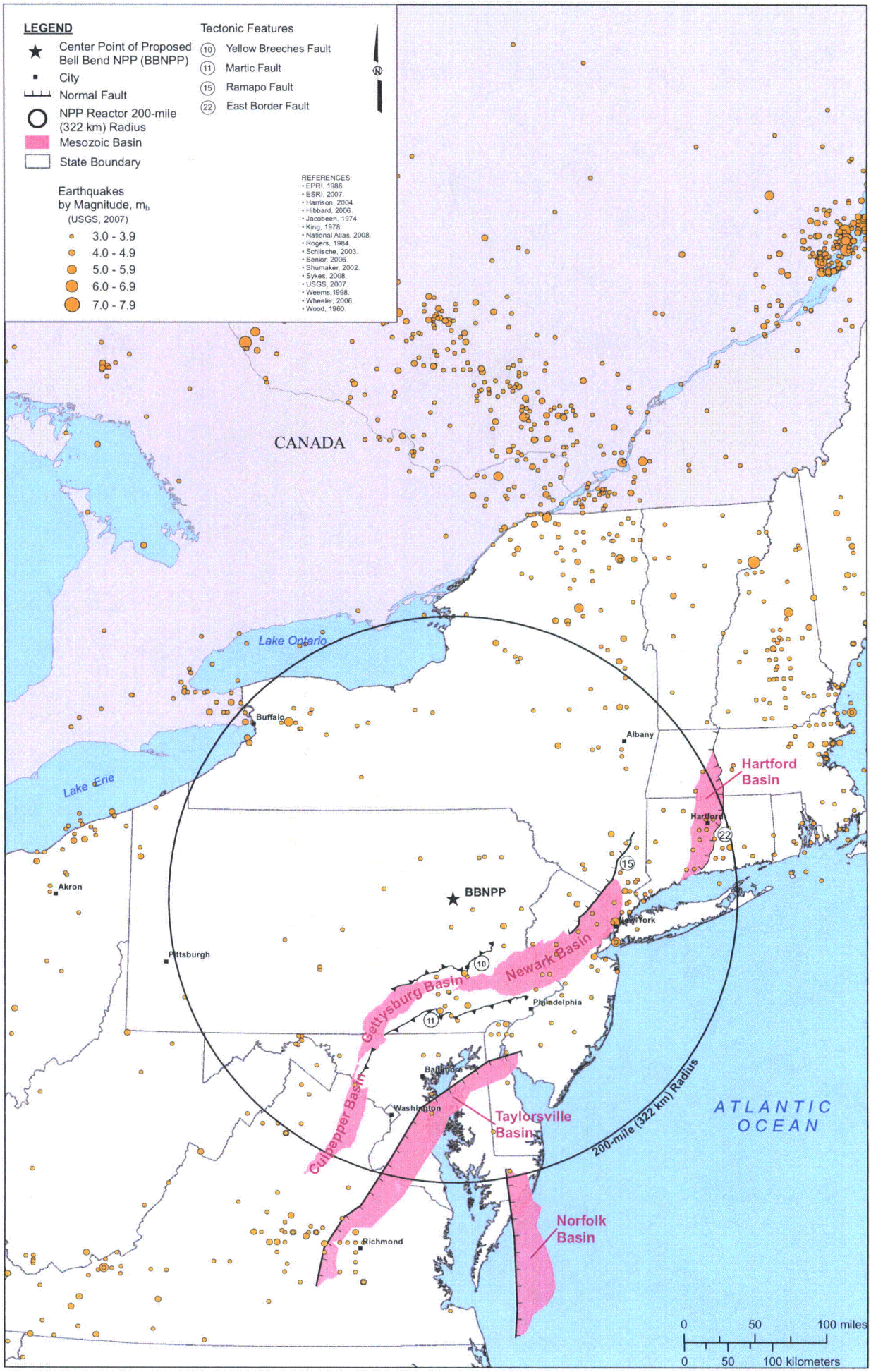
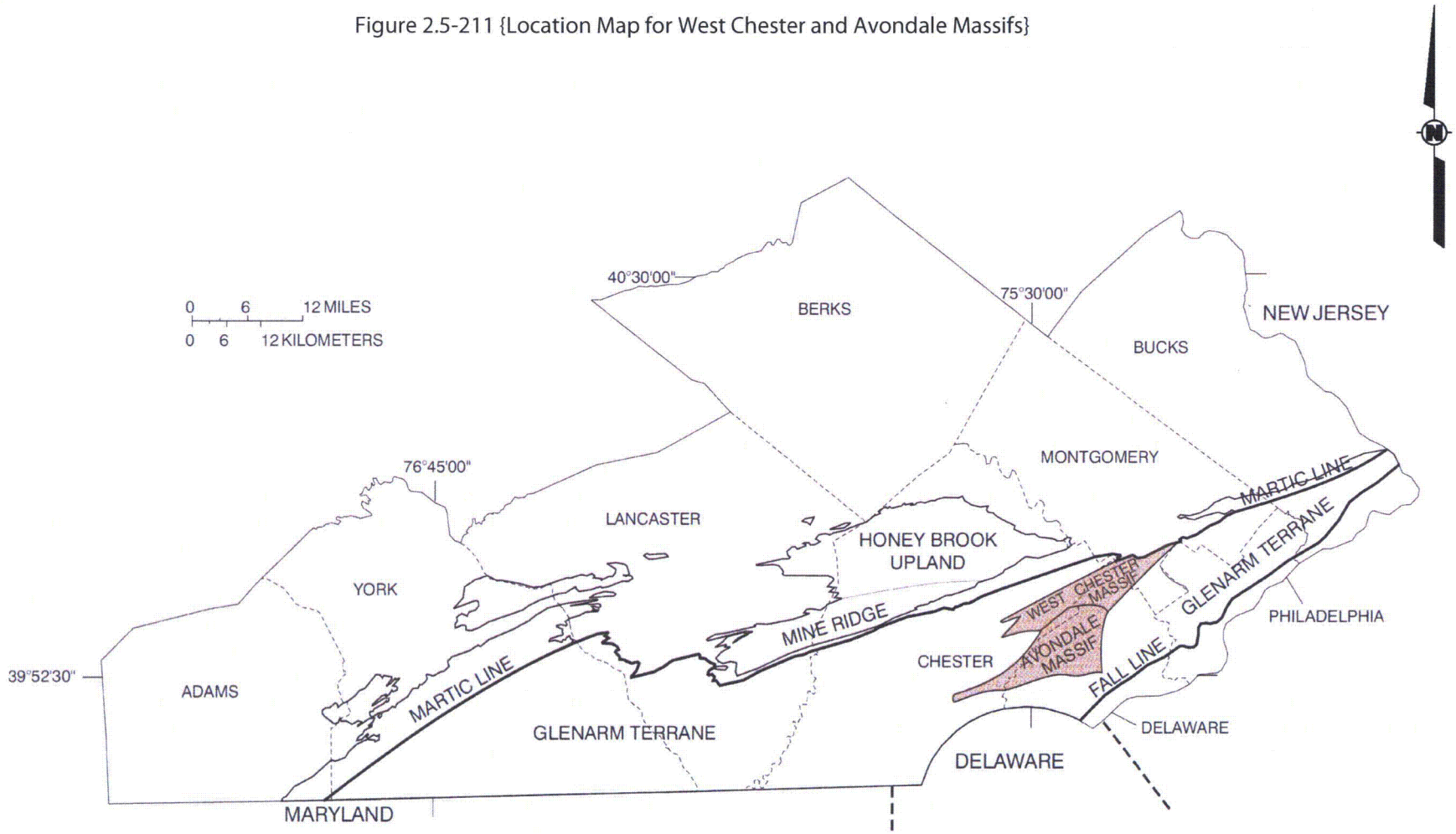
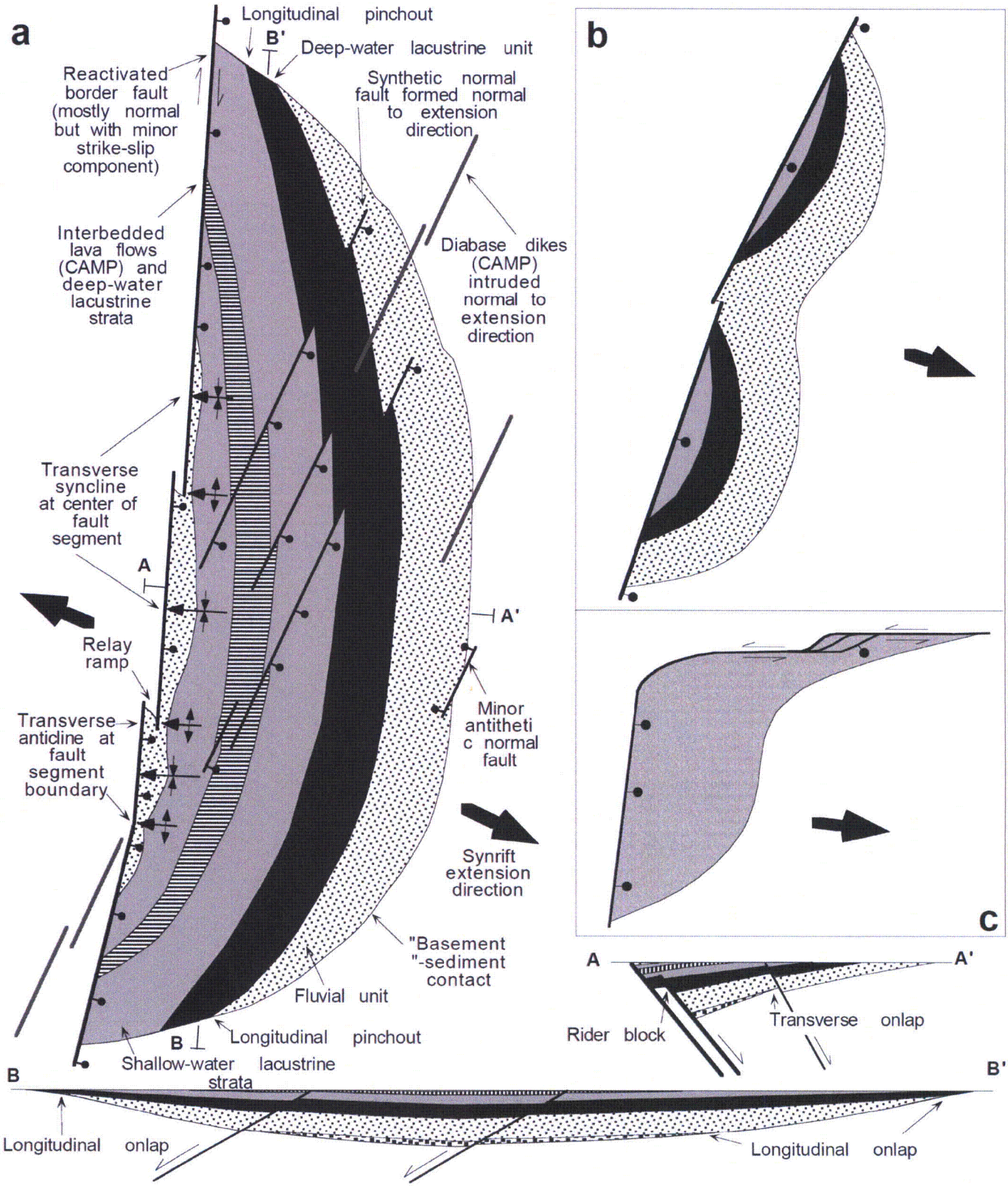


Figure 2.5-211 {Location Map for West Chester and Avondale Massifs}



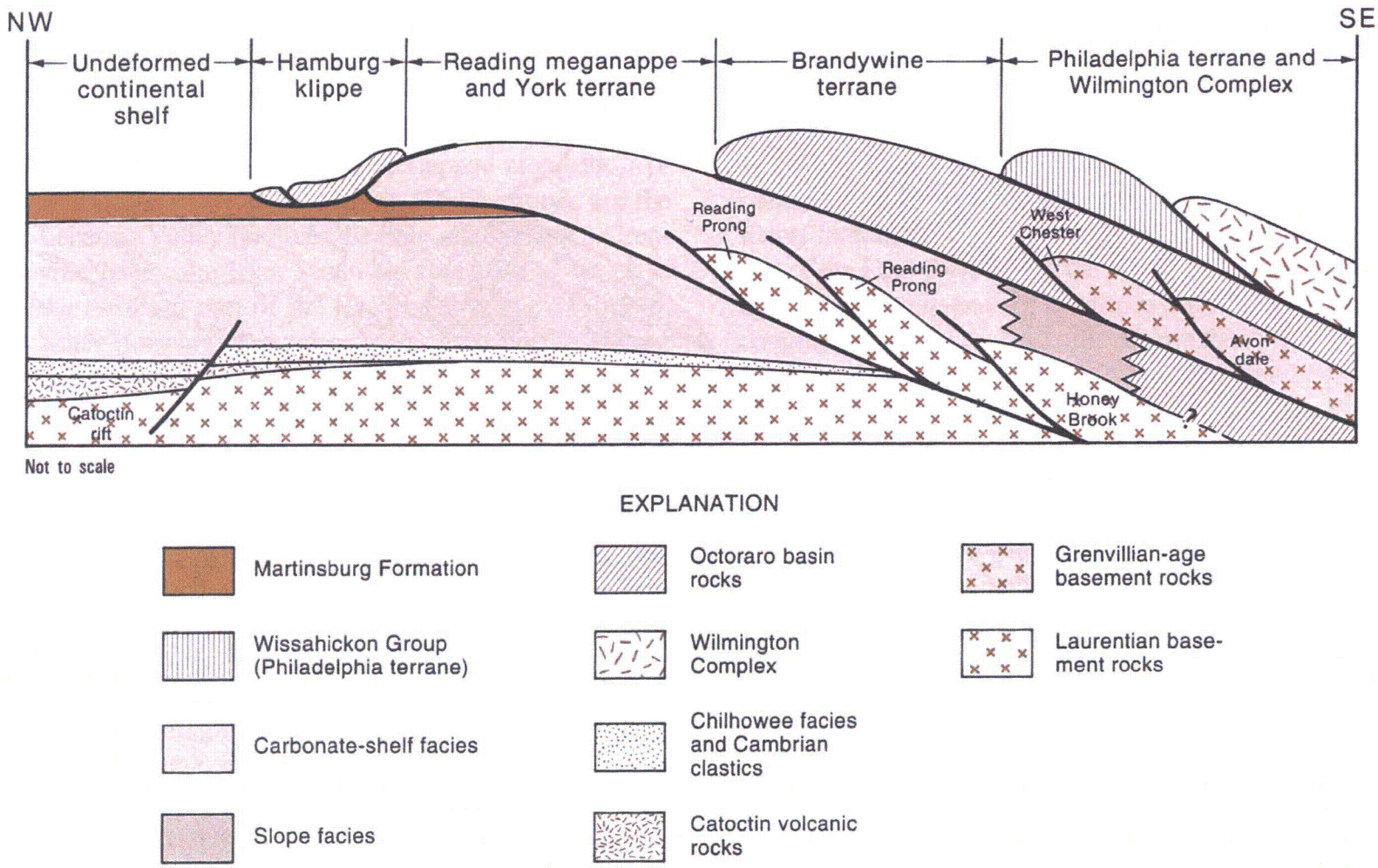
REFERENCE: Low, 2002

Figure 2.5-212 {Generic Distribution of Structures and Features in Mesozoic Rift Basins}



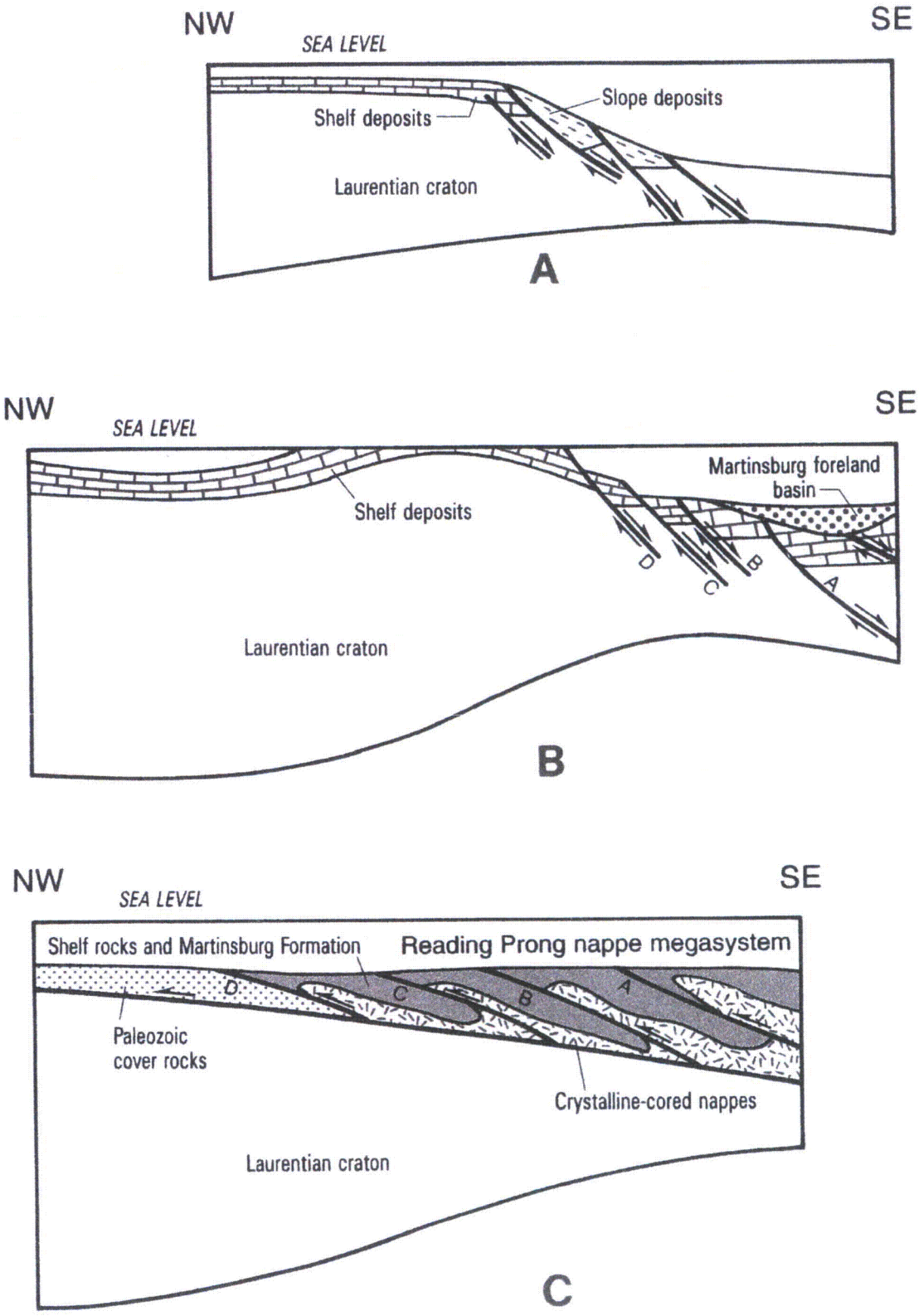
REFERENCE: Schlische, 2002b

Figure 2.5-213 {Idealized Cross Section of the Reading Prong, West Chester and Avondale Massifs, and the Philadelphia Terrane}



REFERENCE: Faill, 1999

Figure 2.5-214 {Development of the Reading Prong Nappe Megasystem}



Not to scale

REFERENCE; Drake, 1999

Figure 2.5-228 {Tectonostratigraphic Provinces with Regional Bouguer Anomaly}

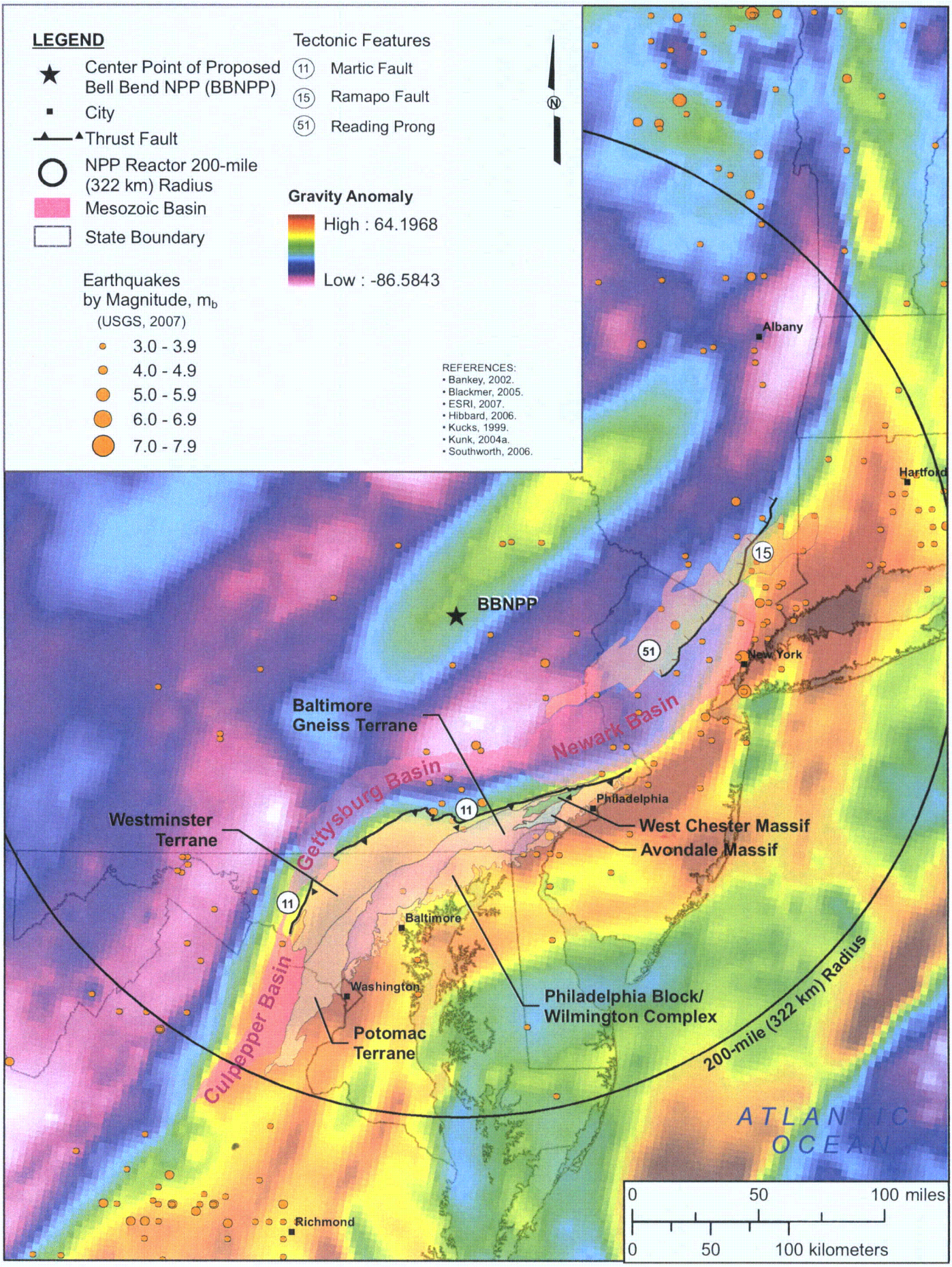


Figure 2.5-229 {Tectonostratigraphic Provinces with Regional Magnetic Anomaly}

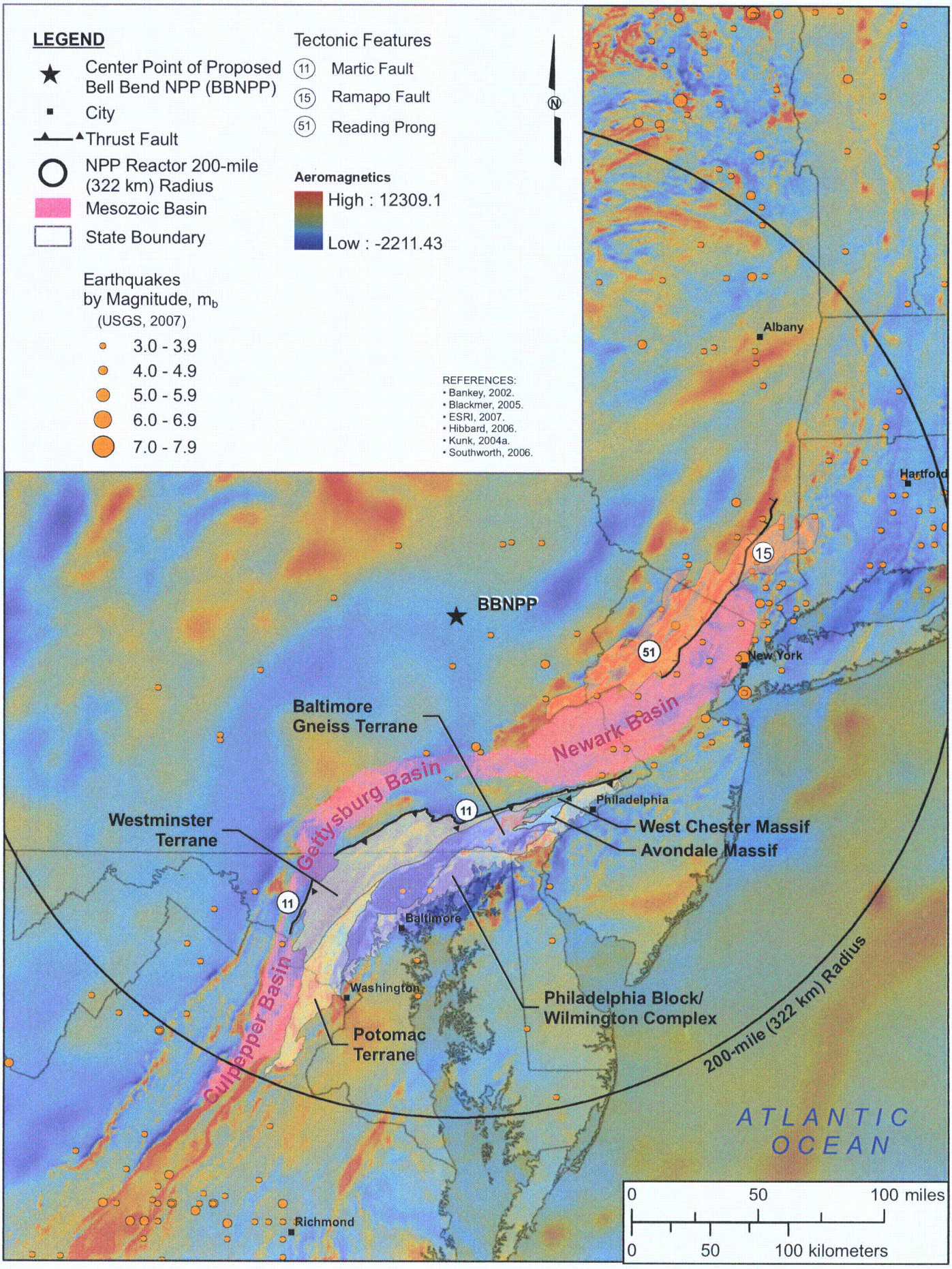
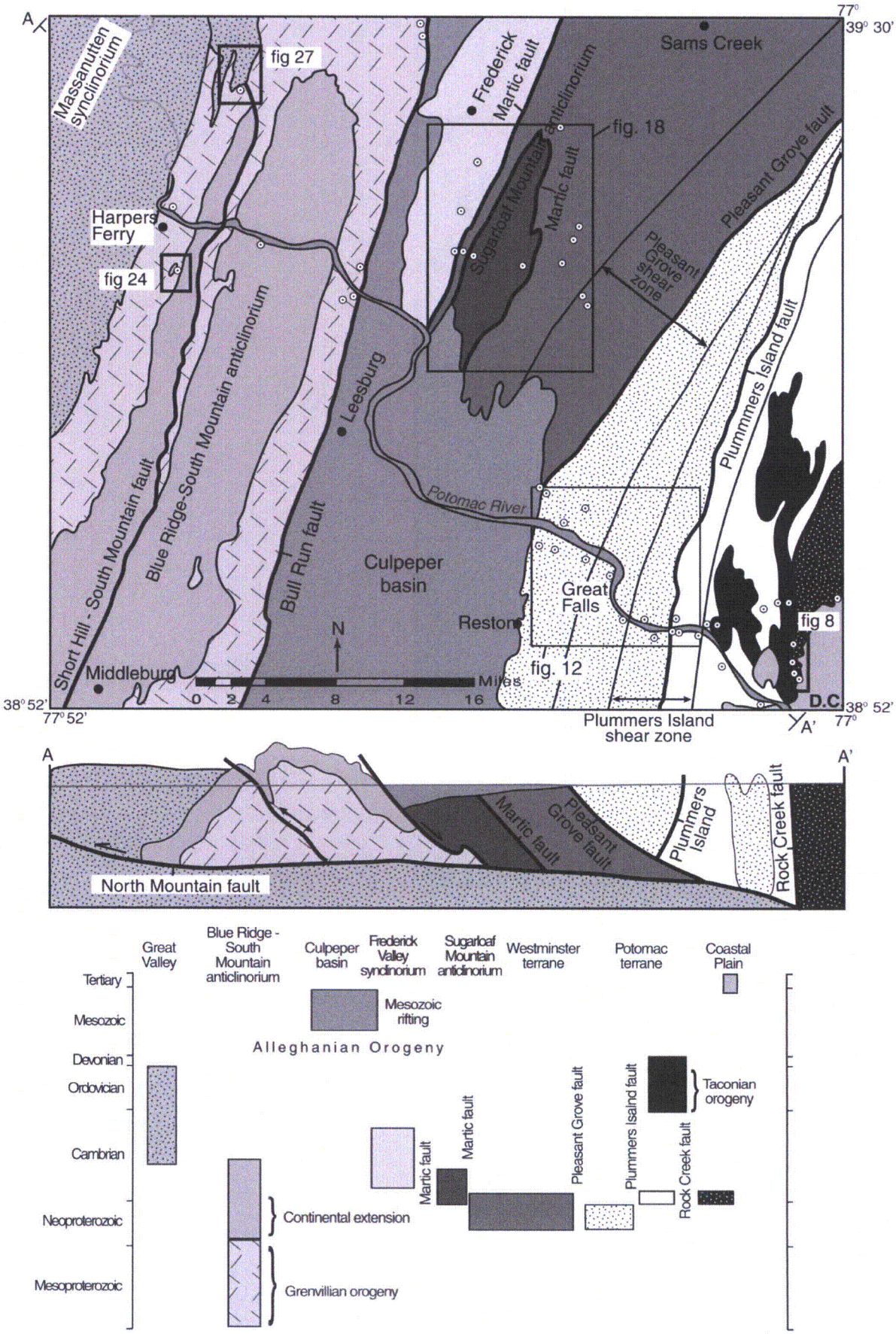
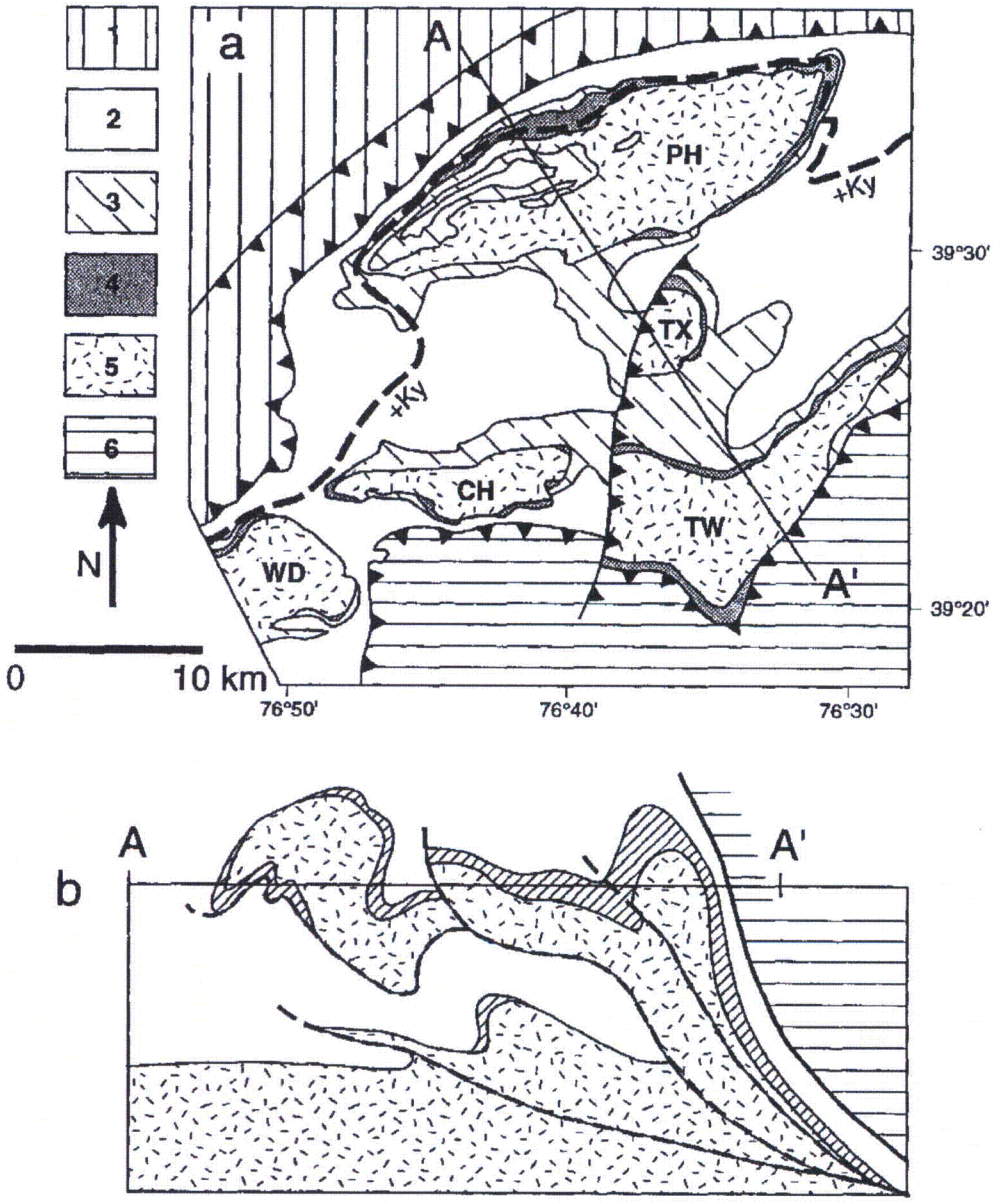


Figure 2.5-230 {Generalized Geologic Map and Cross Section in the Potomac River Region}



REFERENCE: Southworth, 2006

Figure 2.5-231 {Generalized Geologic Map and Cross Section of the Eastern Maryland Piedmont}

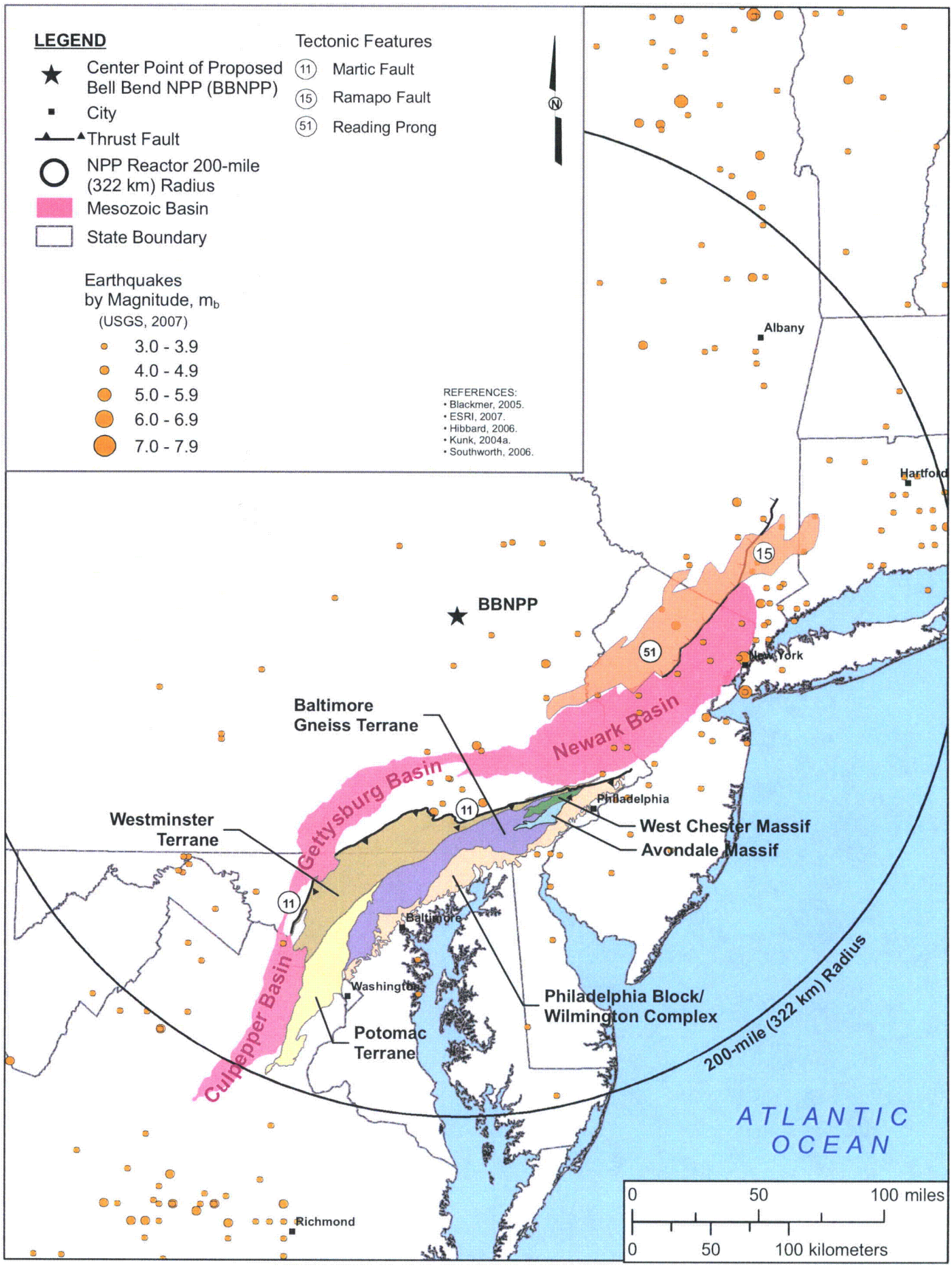


(a) Generalized geologic map of the eastern Maryland Piedmont.
1 = Low- to medium-grade metasediments of the western Piedmont; 2 = Loch Raven Formation, mainly pelitic schist; 3 = Cockeysville Marble; 4 = Setters Formation, quartzite and pelitic schist; 5 = Baltimore Gneiss, felsic basement gneiss; 6 = Baltimore Mafic Complex, island arc complex that collided with the Baltimore Gneiss terrane (units 2-5) during the Taconic Orogeny (at approximately 470 Ma). Anticlines in which the Baltimore Gneiss is exposed are labeled PH (Phoenix), TX (Texas), TW (Towson), CH (Chattolanee), and WD (Woodstock).
The line labeled A-A' shows the approximate location of the schematic cross section shown in b.

(b) Schematic cross section A-A' through the Baltimore area.
The random dash pattern represents the Baltimore Gneiss; the diagonal line pattern represents the Cockeysville and Setters Formations combined; the unpatterned area is the Loch Raven Formation, and the horizontal line pattern represents the Baltimore Mafic Complex. Bold dashed lines indicate thrust faults inferred by Fisher on the basis of the structural style of similar units in the Philadelphia area.

REFERENCE: Lang, 1996

Figure 2.5-232 {Tectonostratigraphic Provinces within the Site Region (200 mile, 320 km Radius)}



Question 02.05.01-3

FSAR Section 2.5.1.1.2 (BNP-2008-006 Attachment 1 - Page 329) provides Figure 2.5-10 which is a conceptual geologic evolution of the Eastern continental margin by R. D. Hatcher. Figure 2.5-10 is not referred to in the FSAR nor are the components of the figure, the geologic evolution of the Eastern continental margin, discussed in text.

In order for NRC staff to evaluate the Regional Geologic history, please provide a discussion that is built upon such a conceptual model for the Central Appalachian Orogen with respect to the 200 mile radius of BBNPP.

Response

Figure 2.5-10, Evolution of the Appalachian Orogen, as submitted in Letter BNP-2008-006, was incorporated into Revision 1 of the COLA as Figure 2.5-6. In Revision 0 of the COLA, Figure 2.5-10 was referenced in a section that described the Plate Tectonic Evolution of the Atlantic Margin. That former section described the regional tectonic history and was divided into: Late Proterozoic and Paleozoic Tectonics and Assembly of the North American Continental Crust, Mesozoic Rifting and Passive Margin Formation, and Cenozoic Vertical Tectonics. The Late Proterozoic and Paleozoic Tectonics and assembly of North American Continental Crust subsection description was assimilated into Section 2.5.1.1.2, Regional Geologic History, in Revision 1 of the COLA. The Mesozoic rifting and passive margin formation and Cenozoic vertical tectonics subsections was assimilated into Section 2.5.1.1.4.1, Contemporary Plate Tectonic Setting of the Atlantic Margin, in Revision 1 of the COLA. These two sections constitute the geologic history discussion requested by the comment. Figure 2.5-6 is associated with the discussion provided in FSAR Section 2.5.1.1.2, but should also be referenced in Section 2.5.1.1.4.1. Consequently, references to Figure 2.5-6 will be added to both FSAR sections.

COLA Impact

COLA Part 02 (FSAR) will be revised as part of a future revision. Proposed text changes to both sections are presented below.

2.5.1.1.2 Regional Geologic History

The BBNPP site is located within the Appalachian orogenic belt, a geologic region marked by a complex history of orogenic events, rift sequences, subsequent depositional sequences, eustatic and local sea level changes, and glacial events. The region's position along an active continental margin at intervals in the Proterozoic and Paleozoic Era has developed the structural and stratigraphic characteristics that define the seismotectonic setting. Episodes of continental collisions, depicted on Figure 2.5-6, have produced a series of terranes separated, in part, by low angle detachment faults (Pohn, 2000). Sources of seismicity may occur in the stratigraphy along structures within the North American basement, along the terranes, and over thrust plates. Tectonic episodes of continental rifting (Figure 2.5-6) have produced high angle normal and boundary faults that extend to the aforementioned detachment faults and in

2.5.1.1.4.1 Contemporary Plate Tectonic Setting of the Atlantic Margin

The Late Precambrian to recent geologic history and plate tectonic evolution of the site region is summarized in Section 2.5.1.1.2 and Figure 2.5-6. Several recent studies have concentrated on the relationship between the stratigraphy and structure during the Paleozoic era as it relates to orogenies and plate tectonics (Pazzaglia, 1994) (Pohn, 2000 and 2001) (Hibbard, 2006)

Question 02.05.01-4

FSAR Section 2.5.1.1.4 (BNP-2008-006 Attachment 1 - Page 34) provides a discussion about the Regional Tectonic Setting. Figure 2.5-15 (BNP-2008-006 Attachment 1 – Page 337) frequently referred to in that section has too many different types of features crowded together on a regional scale map and is difficult to read. In order for the NRC staff to evaluate all the tectonic features within a 200 mile radius of the BBNPP, please revise Figure 2.5-15 for clarity and add other figures showing more detailed scale maps to support specific discussions in the text. Specifically:

1. Separate the EPRI tectonic interpretations and illustrate them on their own maps. (EPRI tectonic interpretations are generic and not a replacement for geologic/tectonics structure maps.)
2. Provide a separate illustration of seismic source zones.
3. Provide a separate figure with all Mesozoic basins (exposed, covered, and offshore) within the regional radius and the associated faults that are known.
4. Provide a separate figure for potential field features in greater detail than shown generically in Figure 2.5-15, and include the underlying potential field data and the interpretation.
5. Indicate the age of the structures (e.g. PC, Pz, Mz, Cz) where possible.

Response

1. and 2. Figure 2.5-15, Regional Tectonic Features, as submitted in Letter BNP-2008-006, has been incorporated into Revision 1 of the COLA as Figure 2.5-188, Regional Tectonic Features. In FSAR Revision 1, that figure has been split into twelve figures, in two groups of six. One group includes the separate tectonic interpretations for each of the six EPRI Groups and the other group includes the separate seismic source zones for each of the six EPRI groups. These individual figures as incorporated in Revision 1 of the FSAR are identified below:

FIGURE NUMBER	FIGURE TITLE
TECTONIC INTERPRETATIONS	
Figure 2.5-13	Tectonic Interpretations by Bechtel Group
Figure 2.5-14	Tectonic Interpretations by Dames and Moore
Figure 2.5-15	Tectonic Interpretations by Law Engineering
Figure 2.5-16	Tectonic Interpretations by Rondout Associates
Figure 2.5-17	Tectonic Interpretations by Weston Geophysical
Figure 2.5-18	Tectonic Interpretations by Woodward-Clyde Consultants
SEISMIC SOURCE ZONES	
Figure 2.5-19	Bechtel Group EPRI Source Zones
Figure 2.5-20	Dames & Moore EPRI Source Zones
Figure 2.5-21	Law Engineering EPRI Source Zones
Figure 2.5-22	Rondout Associates EPRI Source Zones
Figure 2.5-23	Weston Geophysical EPRI Source Zones
Figure 2.5-24	Woodward-Clyde Consultants EPRI Source Zones

3. Figure 2.5-190, Regional Tectonic Basins with Gravity and Magnetic Anomalies, identifies the Mesozoic basins within the region. An additional figure has been provided as Figure 2.5-208, Mesozoic Basins and Associated Known Faults, which identifies the Mesozoic basins within the regional radius and the associated faults. This figure will be incorporated into the FSAR in a future revision.

4. Four new figures in Revision 1 illustrate the gravity and magnetic anomalies within the region and within the site vicinity (Figures 2.5-25 through 2.5-28). The description of the information provided on these figures is described in FSAR Section 2.5.1.1.4.3, Gravity and Magnetic Data and Features of the Site Region and Site Vicinity. Additionally, four new figures that show the relationships between the tectonic structures and the potential fields in the region have also been created (Figures 2.5-215 through Figure 2.5-218). These figures will be incorporated into the COLA in a future revision. Descriptions of these features on the figures are included in Sections 2.5.1.1.4.4.3, Relevant Tectonic Features with Associated Seismicity, 2.5.1.1.4.4.4, Relevant Tectonic Features with no Associated Seismicity, and 2.5.1.2.4.1 Structures of the Crystalline Basement.

FIGURE NUMBER	FIGURE TITLE
Figure 2.5-25	Regional Bouguer Gravity Anomaly Map
Figure 2.5-26	Site Vicinity Bouguer Gravity Anomaly Map
Figure 2.5-27	Regional Magnetic Anomaly Map
Figure 2.5-28	Site Vicinity Magnetic Anomaly Map
Figure 2.5-215	Regional Tectonic Features with Bouguer Anomaly
Figure 2.5-216	Regional Tectonic Basins with Bouguer Anomaly
Figure 2.5-217	Regional Tectonic Features with Magnetic Anomaly
Figure 2.5-218	Regional Tectonic Basins with Magnetic Anomaly

5. The ages of the structures were not added to the 22 figures in question, because the additional detail would further clutter the drawings, making them more difficult to read. Additionally, many of the structures are not dateable (e.g. seismic source zones and some geophysical features), some are amalgamations of multiple features (e.g. the Tectonic Zones by the EPRI groups) having a possible range of dates, and others have ages that are disputed among the authors of the papers reviewed for this report. Ages of significant features are discussed in the text, as appropriate.

COLA Impact

COLA Part 02 (FSAR) will be revised during a future revision to include the five additional figures. The text in the referenced sections will be revised to reflect the supporting figure changes. The markups of the referenced text sections and the additional figures are provided below.

2.5.1.1.4.3 Gravity and Magnetic Data and Features of the Site Region and Site Vicinity

Gravity and magnetic anomaly datasets of the site region have been published since the 1986 EPRI study. Regional maps of the gravity and magnetic fields are presented for North America by the Geological Society of America (GSA), as part of the Society's Decade of North America Geology (DNAG) project (Tanner, 1987) (Hinze, 1987) as shown in Figure 2.5-25 and Figure 2.5-26 (Kucks,1999) and Figure 2.5-27 and Figure 2.5-28 (Bankey, 2002).

2.5.1.1.4.3.1 Gravity Data and Features

Gravity data compiled at 1:5,000,000-scale for the DNAG project provide documentation of previous observations that the gravity field in the site region is characterized by a long-wavelength, east-to-west gradient in the Bouguer gravity anomaly over the continental margin (Kucks,1999) (Figure 2.5-25, Figure 2.5-215 and Figure 2.5-216). Bouguer gravity values increase eastward from about -80 milligals (mgal) in the Ridge and Valley Province of western Virginia to about +10 mgal in the Coastal Plain Province (Figure 2.5-25, Figure 2.5-215 and Figure 2.5-216). Gravity highs, or positive anomalies, are created by accumulations of dense rock units while gravity lows are from mass deficiencies. The folded and faulted structures, basins, igneous intrusions, lithologic variations, and basement uplifts create variations in mass. Gravity anomalies occur from density contrast in size, depth, and structural depth. Long wavelengths show shallow structures or highly concentrated deep structures. Shorter wavelengths are created by shallower structures (Lavin, 1999). As shown on (Figure 2.5-25, Figure 2.5-215 and Figure 2.5-216), gradient gravity extends from Canada to Alabama and parallels the Appalachian Mountains. The Mesozoic rift basins show gravity lows and northeast-trending border faults (Figure 2.5-216).

The gravity map also shows northeast-trending, long wavelengths of gravity highs and lows. The alignments are variations of thickness of the sedimentary rocks and crustal structures (Lavin, 1999). Low gravity dominates the western part of Pennsylvania and eastern Ohio, including areas such as Beaver Falls gravity lows and Somerset gravity high. The Chambersburg anomaly is another low, broad, northeast-trending gravity low which extends the length of the Appalachian Mountain system. In the northeast, the Scranton gravity high (Feature 34 on Figure 2.5-190, Figure 2.5-216 and Figure 2.5-25) is surrounded by the Williamsport and Reading lows. The lows are deep Paleozoic sedimentary basin and/or increased crustal thickness. The Scranton gravity high is related to mafic material during late Precambrian rifting (Lavin, 1999). All anomalies were known at the time of the 1986 EPRI study. In summary, gravity data published since the mid-1980's confirm and provide additional documentation of previous observations (i.e., pre-EPRI) across this region of eastern North America, and do not reveal any new anomalies related to geologic structures previously unknown to EPRI (EPRI, 1986) that would impact the BBNPP site.

2.5.1.1.4.3.2 Magnetic Data and Features

Magnetic data compiled for the 2002 Magnetic Anomaly Map of North America reveal numerous northeast-southwest-trending magnetic anomalies, generally parallel to the structural features of the Appalachian orogenic belt (Bankey, 2002) (Figure 2.5-27). The magnetic map allows a visualization of the geological structure of the upper crust in the subsurface showing the spatial geometry of bodies of rock and the presence of faults and folds. Prominent north- to northeast-trending magnetic anomalies in the BBNPP site region (Figure 2.5-217 and Figure 2.5-218) include the interior New York-Alabama Lineament, the New Bloomfield high, subsurface nappes near Scranton and Allentown, anomalies over largely subsurface Proterozoic rocks at the Reading Prong, Philadelphia and Lancaster, and an inferred basement fault located south of Pittsburgh (King,1999). The 1,000 mi (1,609 km) long lineament in aeromagnetic maps of the eastern U.S. is referred to as the "New York-Alabama Lineament" (NY-AL) (~~Figure 2.5-27~~Feature 28 on Figure 2.5-217).

The NY-AL primarily is defined by a series of northeast-southwest trending linear magnetic anomalies in the Ridge and Valley province of the Appalachian fold belt. The NY-AL is located about 50 mi (80 km) northwest of the BBNPP site. Based on studies by King (King, 1999), the NY-AL lineament divides the basement into two magnetically distinct areas (Figure 2.5-27 and Figure 2.5-217). To the southeast, the few anomalies present are very broad and have gentle gradients consistent with the profound basement depths of the region. To the northwest, numerous anomalies indicate a basement composed of large units of rock with strongly contrasting magnetic properties. King (King, 1999) has interpreted the NY-AL to be a major strike-slip fault in the Precambrian basement beneath the thin-skinned, fold-and-thrust structures of the Ridge and Valley province and created a base model for the Appalachian fold belt.

The Clingman-Ocoee lineament is an approximately 750 mi (1,207 km) long, northeast-trending aeromagnetic lineament that passes through parts of the Blue Ridge and eastern Ridge and Valley provinces from Alabama to Pennsylvania (King, 1999). The Clingman-Ocoee lineament is sub-parallel to and located about 30 to 60 mi (48 to 97 km) east of the NY-AL. These lineaments are located about 50 mi (80 km) southeast of the BBNPP site. The Clingman-Ocoee lineament is interpreted to represent a source or sources in the Precambrian basement beneath the accreted and transported Appalachian terrains (Nelson, 1983). The Clingman-Ocoee block is a Precambrian basement block bounded by the NY-AL and Clingman-Ocoee lineaments (Johnston, 1985b).

The Newark and Gettysburg rift basins consist of clastic rocks (Featured on Figure 2.5-218). The basins present magnetic anomalies consisting of elongated shaped bodies of diabase. The Mesozoic rocks have been downfaulted against Proterozoic and Paleozoic rocks (King, 1999).

The Buckingham Mountain anomaly is produced by a fault-bound structure creating a northeast trending ridge, and dividing the Newark basin. The faults cut the Mesozoic rocks and bound small diabase sheets on the north, just as the larger sheets are bounded along the northern boundary fault. The Buckingham magnetic high indicates a large subsurface ridge of magnetic Proterozoic rocks extending 15 mi (24 km) southwest (King, 1999).

The magnetic anomalies over the Reading Prong (Feature 51 on Figure 2.5-217) are produced by a complex of magnetite-rich, gneissic Proterozoic rocks at the surface (King, 1999). These rocks are related to the center of a nappe system that is over thrusted from the southeast. Small anomalies occur east of Lancaster and are related to gneisses exposed in the Minde Ridge anticline and related structures. The magnetic data indicate similar rocks at shallow depths to the west toward Lancaster and to the east of the Honey Brook Upland, under the Triassic Basin (King, 1999).

2.5.1.1.4.4.3.1 New York-Alabama Lineament

The New York-Alabama Lineament (NY-AL) is a northeast trending lineament characterized by aeromagnetic mapping and regional gravity data which extends more than 1,000 mi (1,609 km) from Alabama to New York (King, 1978). The closest approach of the NY-AL is approximately 30 mi (48 km) west of the BBNPP site (Feature 28 in Figure 2.5-188, Figure 2.5-215 and Figure 2.5-217). The NY-AL in Pennsylvania has been disrupted or offset between two major features called the Tyrone-Mt. Union

2.5.1.1.4.4.3.2 Hudson River Valley Trend

Also known as the Hudson River Line (HRL), this feature trends north-south for about 156 mi (251 km) along the Hudson River Valley Trend, coming as close as 120 mi (193 km) NE of the BBNPP Site (Feature 27 in Figure 2.5-188, Figure 2.5-215 and Figure 2.5-217). The feature is weakly associated with the western part of the isostatic gravity low at the New Jersey border to the southeastern edge of Adirondack gravity high. Due to large uncertainty in subsurface geometry, the actual structure of the feature is not determined (EPRI, 1986). Based on early instrumentally recorded seismicity (Yang,

2.5.1.1.4.4.3.3 Pittsburgh-Washington and Tyrone-Mt Union Lineament

These two major lineaments have been identified from analysis of regional gravity and magnetic patterns, LANDSAT images and geological data (Lavin, 1982). Trending NW-SE, they cross the Appalachian orogen to the vicinity of Lake Erie (EPRI, 1986). The Pittsburgh-Washington (PW) and Tyrone-Mt. Union (TMU) lineaments are expressions of deep crustal fracture zones which extend over a distance of 375 mi (604 km) across western Pennsylvania and parts of surrounding states. The PW-TMU lineaments are located approximately 115 mi (185 km) southwest of BBNPP site (Features 29 and 30 in Figure 2.5-188, Figure 2.5-215 and Figure 2.5-217) (Rodgers, 1984). The TMU and PW lineaments are parallel and form the NE and SW boundaries of the Lake Erie-Maryland

2.5.1.1.4.4.3.4 Bristol Block Geopotential Trends

The Bristol Block is an area of magnetic and gravity lows and extends from Tennessee to Pennsylvania. It is bordered by the New York-Alabama lineament on the west, and by the Clingman-Ocoee lineament on the east (Feature 31 on Figure 2.5-188, Figure 2.5-215 and Figure 2.5-217). The northern portion of the Block is located about 80 mi (129 km) southwest of the site (EPRI, 1986). It includes a series of low gravity and magnetic anomalies associated with some earthquakes, since these anomalies extend over a large area. Small earthquakes occur within this block but not all the tectonic features within the block are associated with earthquakes. The Giles County, Virginia seismic zone, which is located within the Bristol block, has been considered separately as seismic source zone (EPRI, 1986). Even though there is associated seismicity with this feature it is not considered a capable source, and it is not a characteristic tectonic source for the BBNPP site.

2.5.1.1.4.4.4.4 Scranton Gravity High

The Scranton Gravity High (SGH) is located underneath the BBNPP site (Feature 34 in Figure 2.5-216, Figure 2.5-190, and in Figure 2.5-25).

2.5.1.2.4.1 Structures in the Crystalline Basement

Available geophysical data in surrounding areas indicate that the basement likely consists of exotic crystalline magmatic arc material (Hansen, 1986; Glover, 1995). Regional geologic cross sections developed from geophysical, gravity, and aeromagnetic surveys, as well as limited deep borehole data from outside of the BBNPP site area, suggest that complexly deformed, metamorphosed crystalline igneous rocks of Precambrian and Paleozoic age are likely present at approximately -33,000 ft (-10,058 m) msl (Figure 2.5-187 and Figure 2.5-191) (Crawford, 1999; King, 1974; and Gold, 2005). The basement map in Figure 2.5-187 (Gold, 2005) confirms the depth to the basement rocks as well as the relative featurelessness of that surface beneath the site.

To supplement the discussion of basement structures, regional and site vicinity maps of the gravity and magnetic fields are presented in Figure 2.5-25 and Figure 2.5-26 (Kucks,1999) and Figure 2.5-27 and Figure 2.5-28 (Bankey, 2002). Regional Tectonic Features and Basins are depicted on potential base maps in Figure 2.5-215, Figure 2.5-216, Figure 2.5-217 and Figure 2.5-218. None of these data reveal new anomalies related to geologic structures. The following sections discuss the local gravity and magnetic anomalies, as presented in more detail in Section 2.5.1.1.4.3.

Figure 2.5-208 {Mesozoic Basins and Associated Known Faults}

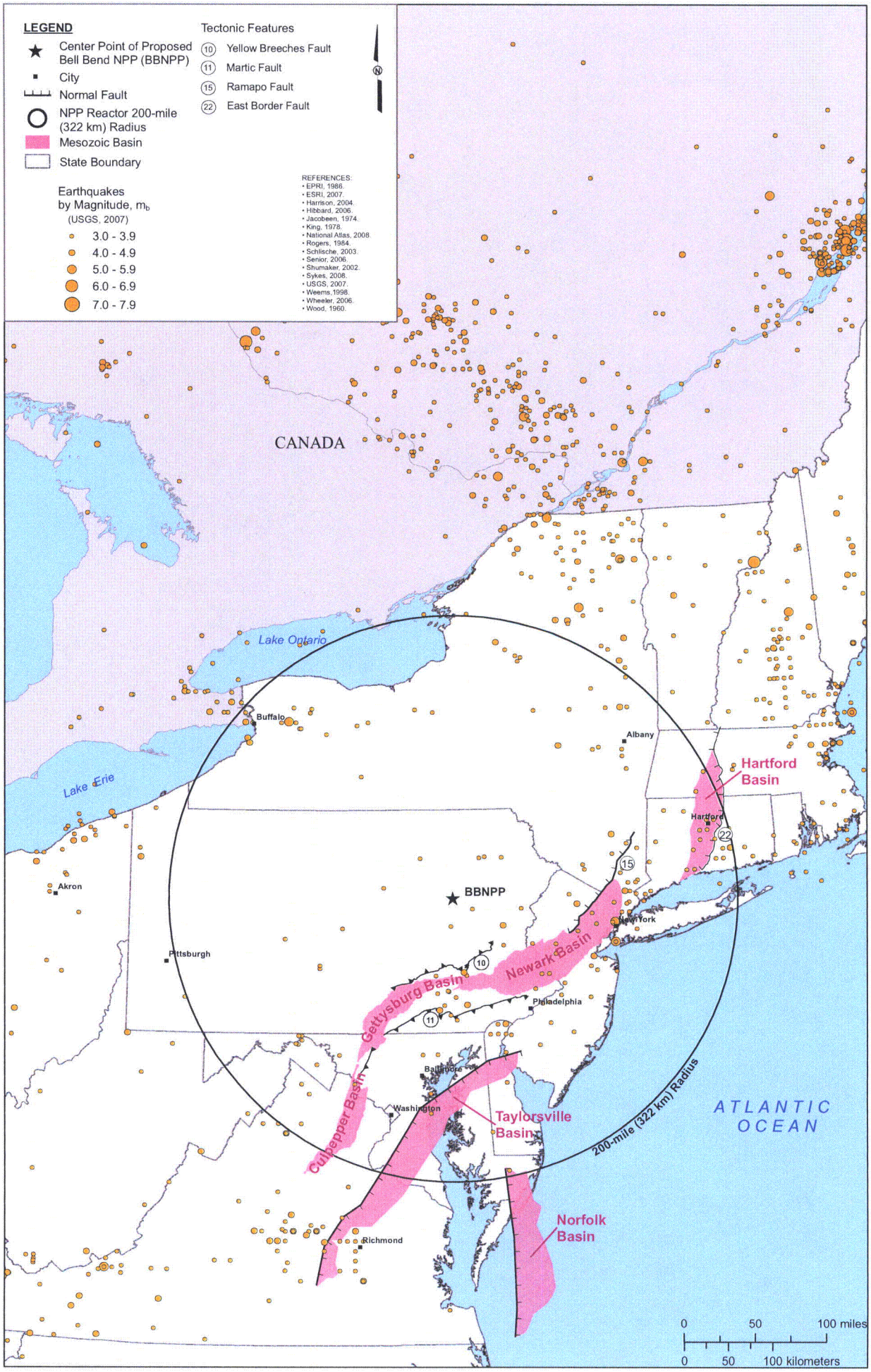


Figure 2.5-215 {Regional Tectonic Features with Bouguer Anomaly}

LEGEND

- ★ Center Point of Proposed Bell Bend NPP (BBNPP)
- City
- NPP Reactor 200-mile (322 km) Radius
- State Boundary

Earthquakes by Magnitude, m_b (USGS, 2007)

- 3.0 - 3.9
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9

Tectonic Features

1. Moodus Seismic Zone
2. Lackawanna Synclinorium
3. Dobbs Ferry Fault Zone
4. Mosholu Fault
5. New York Bright Fault
6. Kingston Fault
7. Cacoosing Valley Earthquake
8. Lancaster Seismic Zone
9. New Castle County Faults
10. Yellow Breeches Fault
11. Martic Fault
12. Pleasant Valley - Huntingdon Valley Fault
13. Plummers Island Fault
14. Light Street Fault
15. Ramapo Fault
16. Rosemont Shear Zone
17. Transylvania Fault System
18. Stafford Fault System
19. Brandywine Fault
20. Clarendon-Linden Fault Zone
21. Clinton-Newbury Liquefaction
22. East Border Fault
23. Offset Glaciated Surfaces
24. Furlong-Flemington Fault System
25. Upper Marlboro Faults
26. Fall Lines
27. Hudson River Valley Trend
28. New York-Alabama Lineament
29. Tyrone-Mt. Union Lineament
30. Pittsburgh-Washington Lineament
31. Bristol Block Geopotential Trends
32. Berwick Fault
35. Anthracite Region
36. St. Lawrence Valley Rift
37. Charlevoix - La Malbaie
38. Lebanon - Pennsylvania Geopotential Trend
39. Pennsylvania Aulacogen
40. Adirondack Uplift
41. Latitude 40° N Fault Zone
44. Valley and Ridge Fold and Thrust Zone
45. Mohawk River Trend
46. Attica, NY Intersection Feature
47. New Jersey Isostatic Gravity Saddle
48. Broadtop Synclinorium
49. Sweet Arrow Fault
50. Chestnut Ridge Anticlinorium
51. Reading Prong
52. Peekskill - Stamford Seismic Boundary

Gravity Anomaly: High – Low

N

REFERENCES:
- EPRI, 1986.
- ESRI, 2007.
- Harrison, 2004.
- Hibbard, 2006.
- Jacobeen, 1974.
- King, 1978.
- Kucks, 1999.
- National Atlas, 2008.
- Rogers, 1984.
- Senior, 2006.
- Shumaker, 2002.
- Sykes, 2008.
- Weems,1998.
- Wheeler, 2006.
- Wood, 1960.

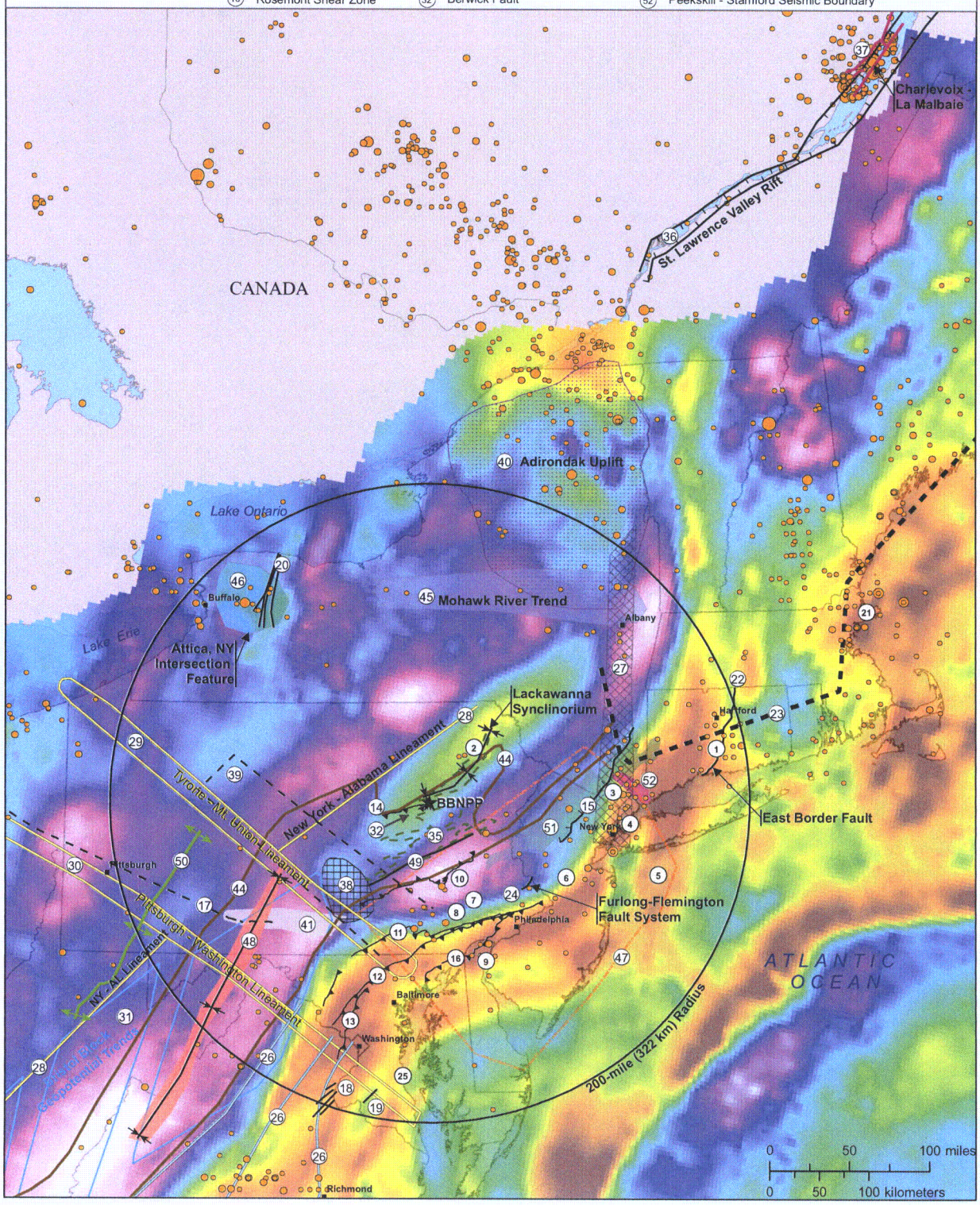


Figure 2.5-216 (Regional Tectonic Basins with Bouguer Anomaly)

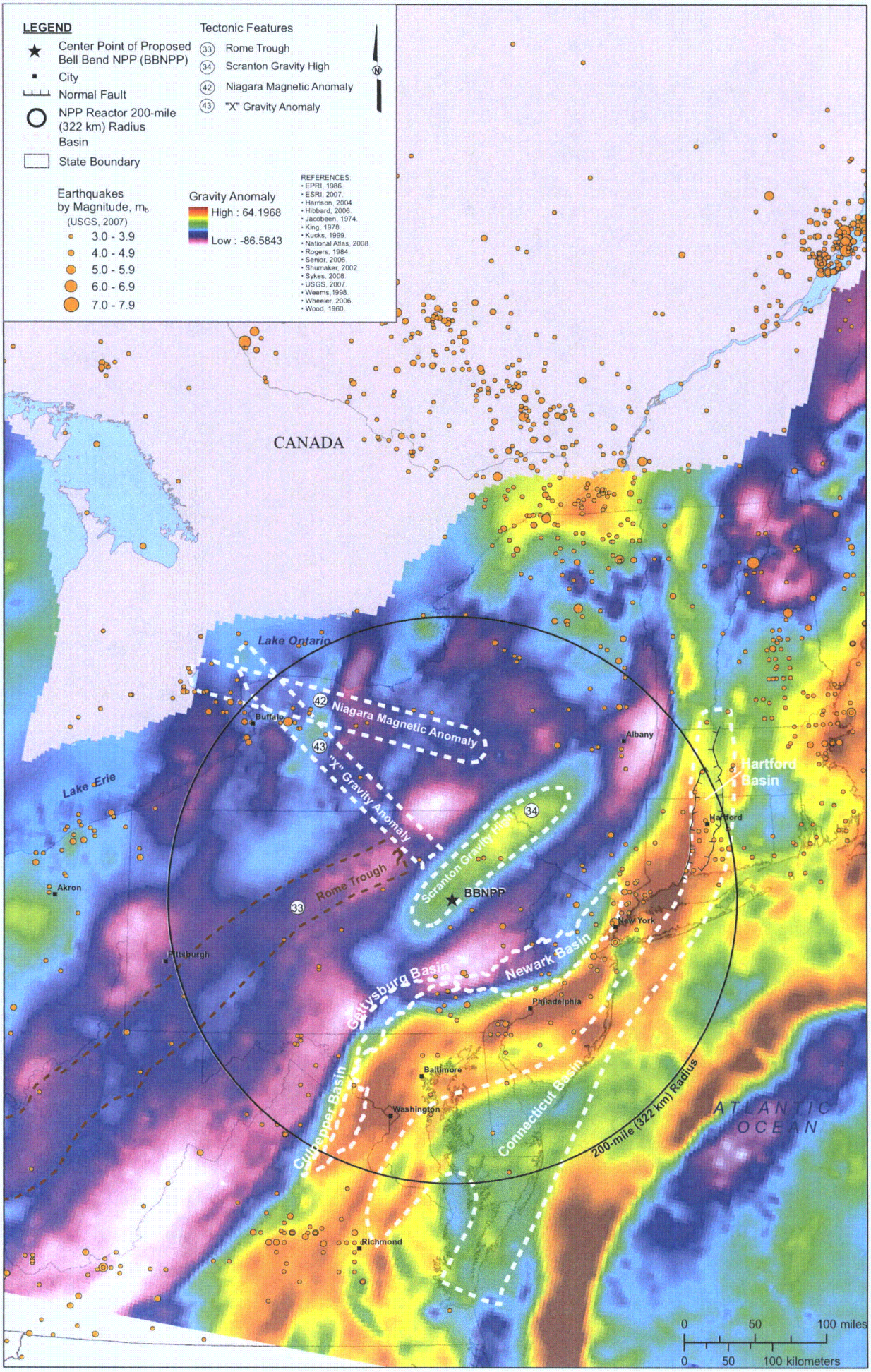


Figure 2.5-217 {Regional Tectonic Features with Magnetic Anomaly}

LEGEND

- ★ Center Point of Proposed Bell Bend NPP (BBNPP)
- City
- NPP Reactor 200-mile (322 km) Radius
- State Boundary

Earthquakes by Magnitude, m_b (USGS, 2007)

- 3.0 - 3.9
- 4.0 - 4.9
- 5.0 - 5.9
- 6.0 - 6.9
- 7.0 - 7.9

Tectonic Features

1. Moodus Seismic Zone
2. Lackawanna Synclinorium
3. Dobbs Ferry Fault Zone
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6. Kingston Fault
7. Cacoosing Valley Earthquake
8. Lancaster Seismic Zone
9. New Castle County Faults
10. Yellow Breeches Fault
11. Martic Fault
12. Pleasant Valley - Huntingdon Valley Fault
13. Plummers Island Fault
14. Light Street Fault
15. Ramapo Fault
16. Rosemont Shear Zone
17. Transylvania Fault System
18. Stafford Fault System
19. Brandywine Fault
20. Clarendon-Linden Fault Zone
21. Clinton-Newbury Liquefaction
22. East Border Fault
23. Offset Glaciated Surfaces
24. Furlong-Flemington Fault System
25. Upper Marlboro Faults
26. Fall Lines
27. Hudson River Valley Trend
28. New York-Alabama Lineament
29. Tyrone-Mt. Union Lineament
30. Pittsburgh-Washington Lineament
31. Bristol Block Geopotential Trends
32. Berwick Fault
35. Anthracite Region
36. St. Lawrence Valley Rift
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40. Adirondack Uplift
41. Latitude 40° N Fault Zone
44. Valley and Ridge Fold and Thrust Zone
45. Mohawk River Trend
46. Attica, NY Intersection Feature
47. New Jersey Isostatic Gravity Saddle
48. Broadtop Synclinorium
49. Sweet Arrow Fault
50. Chestnut Ridge Anticlinorium
51. Reading Prong
52. Peekskill - Stamford Seismic Boundary

Aeromagnetics

High : 12309.1
-0
Low : -2211.43

Legend

N

REFERENCES:

- Bankey, 2002.
- EPRI, 1986.
- ESRI, 2007.
- Harrison, 2004
- Hibbard, 2006.
- Jacobeen, 1974
- King, 1978.
- National Atlas, 2008
- Rogers, 1984.
- Senior, 2006.
- Shumaker, 2002.
- Sykes, 2008.
- Weems, 1998.
- Wheeler, 2006.
- Wood, 1960.

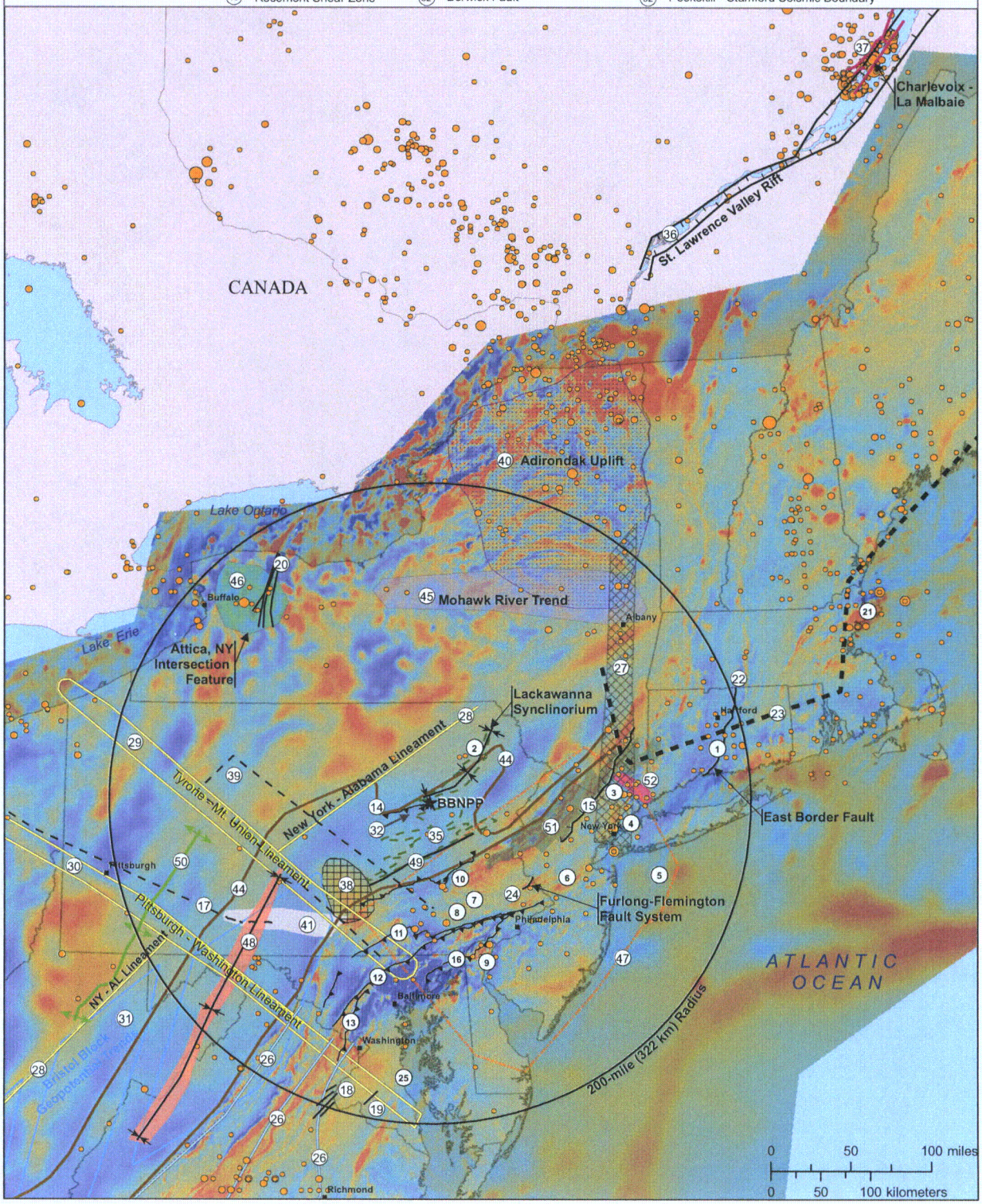
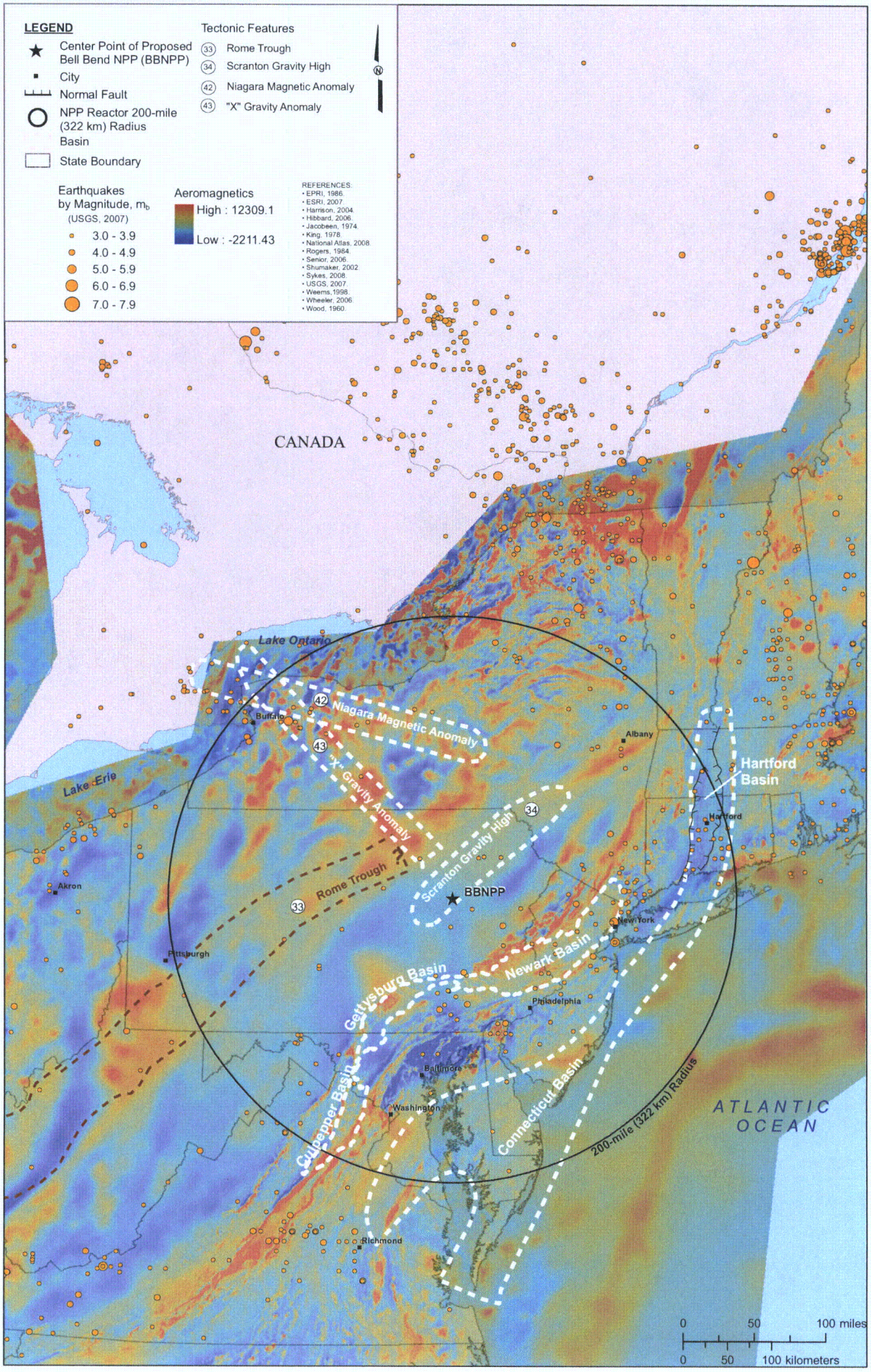


Figure 2.5-218 {Regional Tectonic Basins with Magnetic Anomaly}



Question 02.05.01-5

FSAR Section 2.5.3.1.2 refers the reader to Figure 2.5-105s (page 471) for illustration of the LiDAR data used to characterize the BBNPP vicinity (25 mile radius). The applicant also stated that the aerial reconnaissance investigated geomorphology and targeted numerous previously mapped geologic features and potential seismic sources (e.g., Berwick fault, Light Street fault, and Berwick Anticlinorium). The LiDAR figure that is provided is un-useable, either using paper copy or electronic image. Features in the central portion of the figure are unreadable.

In order for NRC to evaluate the integrity of the youngest surfaces for stability or surface faulting please provide legible figures or Arc View shape files for examining the LiDAR data. Please post the local glacial feature/deposit contacts on this figure for the 5 mile radius scale as well as the trace of the Lightstreet and Berwick faults at the 25 mile radius scale.

Response

Figure 2.5-105s, LiDAR Image with Topographic Sections Across the Site Vicinity, as submitted in Letter BNP-2008-006, was incorporated into Revision 1 of the COLA as Figure 2.5-206. Additional LiDAR figures have been developed to include the requested information. This information will be incorporated into a future revision of the COLA. The additional figures are provided in the pages that follow.

- Figure 2.5-206 has been revised for the following: improved LiDAR data just available for Luzerne County, smaller radius for the image, and more detail on three shorter sections.
- Figure 2.5-209 shows the BBNPP site geology on the LiDAR data base map.
- Figure 2.5-210 shows a detailed topographic section (35x vertical exaggeration) for the zone nearest to the site, which is based on the latest available LiDAR data.
- Figure 2.5-219 depicts the Surficial Sediment Description, including glacial derived features and deposit contacts, overlaid on the LiDAR data base map. This map cannot be expanded beyond this image shown in the figure, since the current Figure includes the entire extent of the available map.
- Figure 2.5-220 presents the same LiDAR data base map without the Surficial Sediment Description, to assist reviewers in viewing the LiDAR information at the same scale as Figure 2.5-219, but without the geological overlay.
- Figure 2.5-221 presents the Site Area Geology (to a radius of 5 miles) as an overlay on the Luzerne County LiDAR data.
- Figure 2.5-222 presents the same LiDAR data set as in Figure 2.5-221, but without the geology.
- Figure 2.5-223 is an attempt to improve the clarity of the LiDAR data in the lower elevations where the BBNPP is located by removing the higher elevations from the image and adjusting the color flood to lighten the remaining image.
- Figure 2.5-224 presents the geology within the Site Vicinity (25 mile radius) as an overlay to the LiDAR data from Luzerne County.
- Figure 2.5-225 presents the same LiDAR data for Luzerne County, but without the geology.

NOTE: These geologic maps include the Berwick and Lightstreet faults, as well as the geologic features available at each presented scale.

COLA Impact

COLA Part 02 (FSAR) will be revised to include the additional figures in a future revision. Additionally, the following text sections will be revised to address the additional figures:

- Section 2.5.1.2.4.4.3, Interpretation of Aerial Photography and LiDAR Imagery;
- Section 2.5.1.2.4.4.4, Field Reconnaissance;
- Section 2.5.3.1.2, Interpretation of Aerial Photography and LiDAR Imagery; and
- Section 2.5.3.1.3, Field Reconnaissance.

These markups of the referenced text sections and the revised figures are provided in the following pages.

2.5.1.2.4.4.3 Interpretation of Aerial Photography and LIDAR Imagery

Aerial reconnaissance within a 25 mi (40 km) radius of the site was conducted by various personnel using aerial photographs from numerous publications. Figure 2.5-136 is a sample of the aerial imagery used, and it contains selected way points from the field reconnaissance. LIDAR imagery of the BBNPP site vicinity was also acquired for review and interpretation. The ~~central portion of the~~ LIDAR image contains elevation data with a 2 ft (0.6 m) contour interval. ~~For clarity, the remainder of the image is a shaded relief representation without contours.~~ The aerial reconnaissance investigated geomorphology and targeted numerous previously mapped geologic features and potential seismic sources (e.g., Berwick fault, Light Street fault, and Berwick Anticlinorium).

Figure 2.5-206 and 2.5-210 contain four topographic cross-sections (A, B, C on Figure 2.5-206, and D on Figure 2.5-210) based on the new LiDAR data set from Luzerne County. The intent of these figures is to review the LiDAR data set in both plan and section view to evaluate the detailed surface of the land as captured by the LiDAR process.

Figure 2.5-209 shows the BBNPP site geology on the LiDAR data base map. Figure 2.5-219 depicts the surficial sediment description including glacial derived features and deposit contacts overlaid on the LiDAR data base map. The same LiDAR data base map without the surficial sediment description is shown in Figure 2.5-220.

The site area geology is presented on the LiDAR data base map in Figure 2.5-221 and Figure 2.5-222 shows the same image without the site area geology. Figure 2.5-223 is similar to Figure 2.5-222 but has the higher altitudes eliminated to show the detail for the lower elevations where the BBNPP site is located.

The site vicinity geology along with the LiDAR base map is presented in Figure 2.5-224. Figure 2.5-225 shows the LIDAR base map without the site vicinity geology. Figure 2.5-224 and Figure 2.5-225 include not only the trace for the Lightstreet and Berwick faults, but also all of the described geologic features at this scale.

The interpretation of the plan-view LiDAR maps incorporates an evaluation of the fracture traces and lineaments visible on the images as linear valleys and swales and straight segments of streams. The features are especially visible for the site on Figure 2.5-220. The orientations of the fractures observed in the outcrop of the Mahantango Shale are within the reported envelope of orientations reported by Inners (1978, Figure 3). There is a single dominant set striking just west of north, with a subordinate set at nearly right angles to the first. These appear to be nearly vertical. The right-angle bend in Walker Run to the southwest of the BBNPP center point, illustrates those trends, as the Run has eroded through the glacial cover to expose the underlying structures. Other orientations are present in the outcrop areas of formations to the north and south of the Mahantango, as is also reported by Inners (1978, Figures 4 and 5).

The topographic cross sections presented in Figures 2.5-206 and 2.5-210 display no offsets that are attributable to the actions of the Berwick or Light Street Faults. The current work confirms the work by Inners (1978) who reports the faults to be locally buried beneath the glacial terrace gravels. In the excavations for the Susquehanna Units, Inners found several slickensided surfaces at low-angles to the bedding planes located less than 1 mile (1.6 km) to the northeast of the site (Figure 2.5-209). He interpreted these surfaces as wedge faults that usually developed along small-scale drag folds during the folding of the units during the Alleghanian Orogeny, approximately 250 Ma (Inners, 1978). The current investigation found a similar slickensided surface at a distance of 0.30 miles (.50 km) to the southwest of the site (Figure 2.5-209). The throw on these faults is usually less than three feet (Inners, 1978), and the field team observed no offset of the glacial materials overlying this feature in the field. Section D on Figure 2.5-210 passes through the area of the slickensided surfaces to the northeast of the site, and does not indicate any offsets that could be attributed to these old, low-angle, and low throw faults.

2.5.1.2.4.4.4 Field Reconnaissance

Information developed from the literature and the imagery interpretation was supplemented by field reconnaissance within a 25 mi (40 km) radius of the site. These field-based studies were performed to verify, where possible, the existence of mapped bedrock faults in the BBNPP site area and to assess the presence or absence of geomorphic features suggestive of potential Quaternary fault activity along the mapped faults, or previously undetected faults. Features reviewed during the field reconnaissance and office-based analysis of aerial photography and LIDAR imagery were based on a compilation of existing regional geologic information in the vicinity of the BBNPP site. As shown on topographic section B-B' on Figure 2.5-206 there is no topographic offset to indicate recent movement of either Light Street or Berwick Faults.

Field reconnaissance was conducted by geologists in teams of two or more. Field reconnaissance visits in 2007, ~~and~~ 2008, and 2009 focused on exposed portions of the Mahantango Formation, other formation exposures along the faces of Lee and Nescopeck Mountains, and roads traversing the site vicinity. Key observations and discussion items were documented in field notebooks and photographs. Field locations were logged by hand on detailed topographic base maps and with hand-held Global Positioning System (GPS) receivers (Figure 2.5-209). There were no faults or other

forms of deformation noted in the field. No surface expression of either the Berwick or Light Street faults was noted, consistent with the conclusions documented in the literature. Figure 2.5-126 and Figure 2.5-127 (Waypoint 12 on Figure 2.5-207) show that there is no offset in the Quaternary deposits along Syber Creek, where the trace of Light Street Fault crosses it. Photos of the shale bedrock on the site show the steeply dipping nature of the strong persistent cleavage. Bedding dipping to the NNW is visible but highly obscured by this cleavage~~bedding~~ (Figure 2.5-132 and Waypoint WF3 on Figure 2.5-136). Outcrops in a nearby borrow area show an undeformed contact between the glacial overburden and the shale bedrock (Figure 2.5-133, Figure 2.5-134, and Figure 2.5-135 and Waypoint WF5 on Figure 2.5-136).

A third reconnaissance was conducted during the fall of 2008, to investigate the occurrence of potential liquefaction features along the Susquehanna River. The field reconnaissance was carried out by a team of geologists and engineers from Paul C. Rizzo Associates, Inc, and John Sims & Associates from both the land and water approaches to the river banks. The investigation was conducted for the course of the river for a reach of 25 miles (40 km) upstream and downstream of the site (Figure 2.5-207). Because of the prevalent bedrock exposures in both the river banks and the river bottoms, they found few locations where liquefaction conditions were possible and no evidence that liquefaction had occurred. Figure 2.5-128 through Figure 2.5-131 show the rocky nature of the riverbed and its banks and some of the typical exposures found during the investigation (for Waypoints WP1, WP10, WP20, and WP22 respectively).

A reconnaissance was conducted during the Spring of 2009 to further investigate the occurrence of potential liquefaction features along the Susquehanna River. The study was conducted along approximately 10 miles of the Susquehanna River along the south and east bank in areas accessible by auto and on foot. The investigated areas lie south and east of the BBNPP site within the Berwick 7.5-minute topographic quadrangle.

Two tributaries of the Susquehanna River, the Wapwallopen and Little Wapwallopen creeks, were found to run on bedrock and are relatively small, but similar to other tributaries of the Susquehanna and this region. These two tributaries, like many other streams in the original study, have been disturbed by coal mining activities.

Following the additional reconnaissance, the conclusions about the low potential for liquefaction of the area remain unchanged. The rugged terrain of the Allegheny Mountains, narrow floodplains, and intense modification of the topography through anthracite coal mining confirm those conclusions. The Susquehanna River is a gently meandering river with numerous rock-core islands and boulder-cobble gravel bars. At nearly all sites that were visited, bedrock was present or nearby. The ubiquitous presence of bedrock at or near the surface militates against liquefaction and the presence of paleoliquefaction structures. The tributaries of the Susquehanna River have narrow floodplains. Coal mining debris from mine waste dumps, carried by the tributary streams of the Susquehanna River, form the visible floodplain deposits of the tributaries.

Fine-grained sediments, when present, are thin and lack the usual prerequisite for liquefiable deposits, which are fine to medium sand overlain by 1-2 meters of fine-upward silt with a clay cap. However, the banks are commonly vegetated, which significantly reduces accessibility to exposures in the river banks. Further modification of the banks by manmade stone walls, built to prevent erosion or the railroad right-of-way and sections of an early canal, exist through the studied section of the Susquehanna River.

2.5.3.1.2 Interpretation of Aerial Photography and LIDAR Imagery

Aerial reconnaissance within a 25 mi (40 km) radius of the site was conducted by various personnel using aerial photographs from numerous publications. Figure 2.5-136 is a sample of the aerial imagery used, and it contains selected way points from the field reconnaissance. LIDAR imagery of the BBNPP site vicinity was also acquired for review and interpretation. The ~~central portion of the~~ LIDAR image contains elevation data with a 2 ft (0.6 m) contour interval. ~~For clarity, the remainder of the image is a shaded relief representation without contours.~~

Figure 2.5-206 and 2.5-210 contain four topographic cross-sections (A, B, C on Figure 2.5-206, and D on Figure 2.5-210) based on the new LiDAR data set from Luzerne County. The intent of these figures is to review the LiDAR data set in both plan and section view to evaluate the detailed surface of the land as captured by the LiDAR process.

Figure 2.5-209 shows the BBNPP site geology on the LiDAR data base map. Figure 2.5-219 depicts the surficial sediment description including glacial derived features and deposit contacts overlaid on the LiDAR data base map. The same LiDAR data base map without the surficial sediment description is shown in Figure 2.5-220.

The site area geology is presented on the LiDAR data base map in Figure 2.5-221 and Figure 2.5-222 shows the same image without the site area geology. Figure 2.5-223 is similar to Figure 2.5-222 but has the higher altitudes eliminated to show the detail for the lower elevations where the BBNPP site is located.

The site vicinity geology along with the LiDAR base map is presented in Figure 2.5-224. Figure 2.5-225 shows theLIDAR base map without the site vicinity geology. Figure 2.5-224 and Figure 2.5-225 include not only the trace for the Lightstreet and Berwick faults, but also all of the described geologic features at this scale.

The interpretation of the plan-view LiDAR maps incorporates an evaluation of the fracture traces and lineaments visible on the images as linear valleys and swales and straight segments of streams. The features are especially visible for the site on Figure 2.5-220. The orientations of the fractures observed in the outcrop of the Mahantango Shale are within the reported envelope of orientations reported by Inners (1978, Figure 3). There is a single dominant set striking just west of north, with a subordinate set at nearly right angles to the first. These appear to be nearly vertical. The right-angle bend in Walker Run to the southwest of the BBNPP center point, illustrates those trends, as the Run has eroded through the glacial cover to expose the underlying structures. Other orientations are present in the outcrop areas of formations to the north and south of the Mahantango, as is also reported by Inners (1978, Figures 4 and 5).

The topographic cross sections presented in Figures 2.5-206 and 2.5-210 display no offsets that are attributable to the actions of the Berwick or Light Street Faults. The current work confirms the work by Inners (1978) who reports the faults to be locally buried beneath the glacial terrace gravels. In the excavations for the Susquehanna Units, Inners found several slickensided surfaces at low-angles to the bedding planes located less than 1 mile (1.6 km) to the northeast of the site (Figure 2.5-209). He interpreted these surfaces as wedge faults that usually developed along small-scale drag folds during the folding of the units during the Alleghanian Orogeny, approximately 250 Ma (Inners, 1978). The current investigation found a similar slickensided surface at a distance of 0.30 miles (.50 km) to the southwest of the site (Figure 2.5-209). The throw on these faults is usually less than three feet (Inners, 1978), and the field team observed no offset of the glacial materials overlying this feature in the field. Section D on Figure 2.5-210 passes through the area of the slickensided surfaces to the northeast of the site, and does not indicate any offsets that could be attributed to these old, low-angle, and low throw faults.

The aerial reconnaissance investigated geomorphology and targeted numerous previously mapped geologic features and potential seismic sources (e.g., Berwick fault, Light Street fault, and Berwick Anticlinorium).

2.5.3.1.3 Field Reconnaissance

Information developed from the literature and the imagery interpretation was supplemented by field reconnaissance within a 25 mi (40 km) radius of the site. These field-based studies were performed to verify, where possible, the existence of mapped bedrock faults in the BBNPP site area and to assess the presence or absence of geomorphic features suggestive of potential Quaternary fault activity along the mapped faults, or previously undetected faults. Features reviewed during the field reconnaissance and office-based analysis of aerial photography and LIDAR imagery were based on a compilation of existing regional geologic information in the vicinity of the BBNPP site, as referred to in Section 2.5.3.1.2. As shown on topographic section B-B' on Figure 2.5-206 there is no topographic offset to indicate recent movement of either Light Street or Berwick Faults.

Field reconnaissance was conducted by geologists in teams of two or more. Field reconnaissance visits in 2007, ~~and~~ 2008, and 2009 focused on exposed portions of the Mahantango Formation, other formation exposures along the faces of Lee and Nescopeck Mountains, and roads traversing the site vicinity. Key observations and discussion items were documented in field notebooks and photographs. Field locations were logged by hand on detailed topographic base maps and with hand-held Global Positioning System (GPS) receivers (Figure 2.5-209). There were no faults or other forms of deformation noted in the field. No surface expression of either the Berwick or Light Street faults was noted, consistent with the conclusions documented in the literature. Figure 2.5-126 and Figure 2.5-127 (Waypoint 12 on Figure 2.5-207) show that there is no offset in the Quaternary deposits along Syber Creek, where the trace of Light Street Fault crosses it. Photos of the shale bedrock on the site show the steeply dipping

nature of the strong persistent cleavage. Bedding dipping to the north-northwest is visible, but highly obscured by this cleavage~~bedding~~ (Figure 2.5-132 and Waypoint WF3 on Figure 2.5-136). Outcrops in a nearby borrow area show an undeformed contact between the glacial overburden and the shale bedrock (Figure 2.5-133, Figure 2.5-134, and Figure 2.5-135 and Waypoint WF5 on Figure 2.5-136).

A third reconnaissance was conducted during the fall of 2008, to investigate the occurrence of potential liquefaction features along the Susquehanna River. The field reconnaissance was carried out by a team of geologists and engineers from Paul C. Rizzo Associates, Inc, and John Sims & Associates from both the land and water approaches to the river banks. The investigation was conducted for the course of the river for a reach of 25 miles (40 km) upstream and downstream of the site (Figure 2.5-207). Because of the prevalent bedrock exposures in both the river banks and the river bottoms, they found few locations where liquefaction conditions were possible and no evidence that liquefaction had occurred. Figure 2.5-128 through 2.5-131 show the rocky nature of the riverbed and its banks and some of the typical exposures found during the investigation (for Waypoints WP1, WP10, WP20, and WP22 respectively).

A reconnaissance was conducted during the Spring of 2009 to further investigate the occurrence of potential liquefaction features along the Susquehanna River. The study was conducted along approximately 10 miles of the Susquehanna River along the south and east bank in areas accessible by auto and on foot. The investigated areas lie south and east of the BBNPP site within the Berwick 7.5-minute topographic quadrangle.

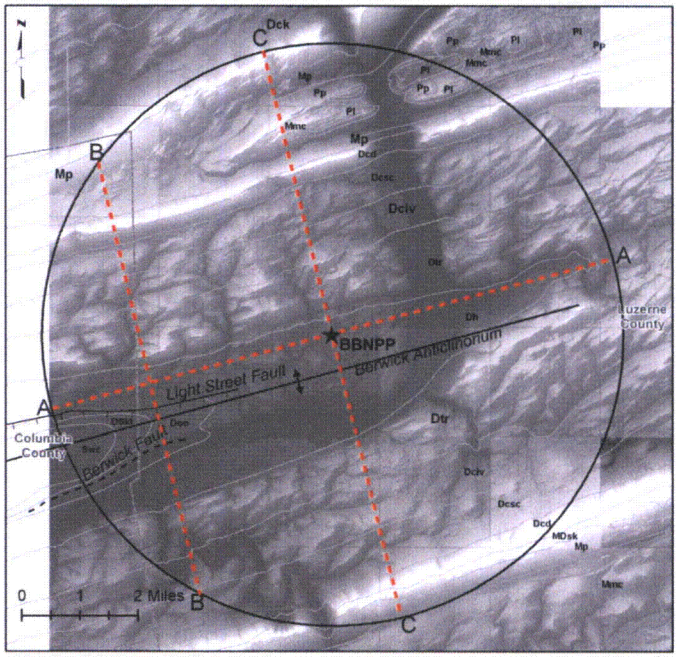
Two tributaries of the Susquehanna River, the Wapwallopen and Little Wapwallopen creeks, were found to run on bedrock and are relatively small, but similar to other tributaries of the Susquehanna and this region. These two tributaries, like many other streams in the original study, have been disturbed by coal mining activities.

Following the additional reconnaissance, the conclusions about the low potential for liquefaction of the area remain unchanged. The rugged terrain of the Allegheny Mountains, narrow floodplains, and intense modification of the topography through anthracite coal mining confirm those conclusions. The Susquehanna River is a gently meandering river with numerous rock-core islands and boulder-cobble gravel bars. At nearly all sites that were visited, bedrock was present or nearby. The ubiquitous presence of bedrock at or near the surface militates against liquefaction and the presence of paleoliquefaction structures. The tributaries of the susquehanna have narrow floodplains. Coal mining debris from mine waste dumps, carried by the tributary streams of the Susquehanna, form the visible floodplain deposits of the tributaries.

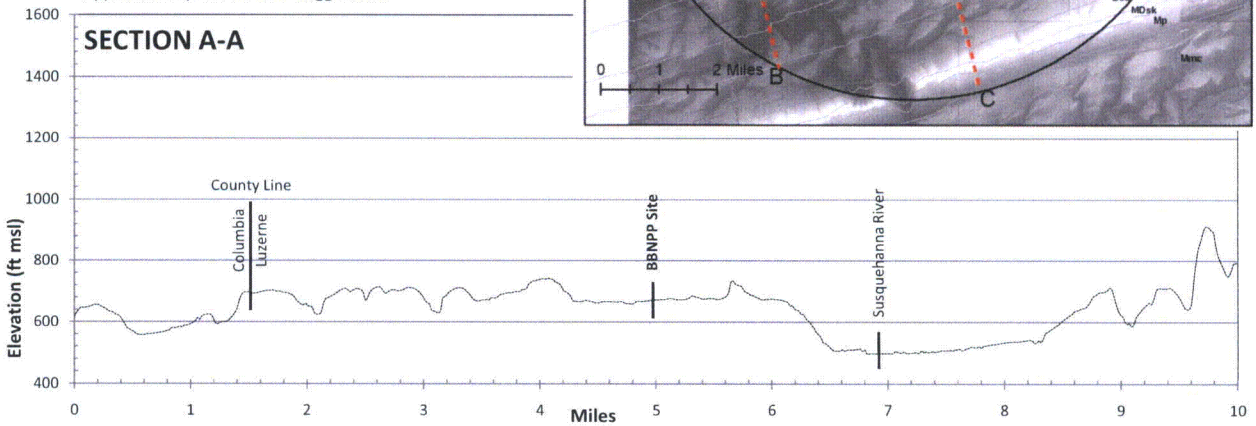
Fine-grained sediments, when present, are thin and lack the usual prerequisite for liquefiable deposites, which are fine to medium sand overlain by 1-2 meters of fine-upward silt with a clay cap. However, the banks are commonly vegetated, which significantly reduces accessibility to exposures in the river banks. Further modification of the banks by manmade stone walls, built to prevent erosion or the railroad right-of-way and sections of an early canal, exist through the studied section of the Susquehanna River.

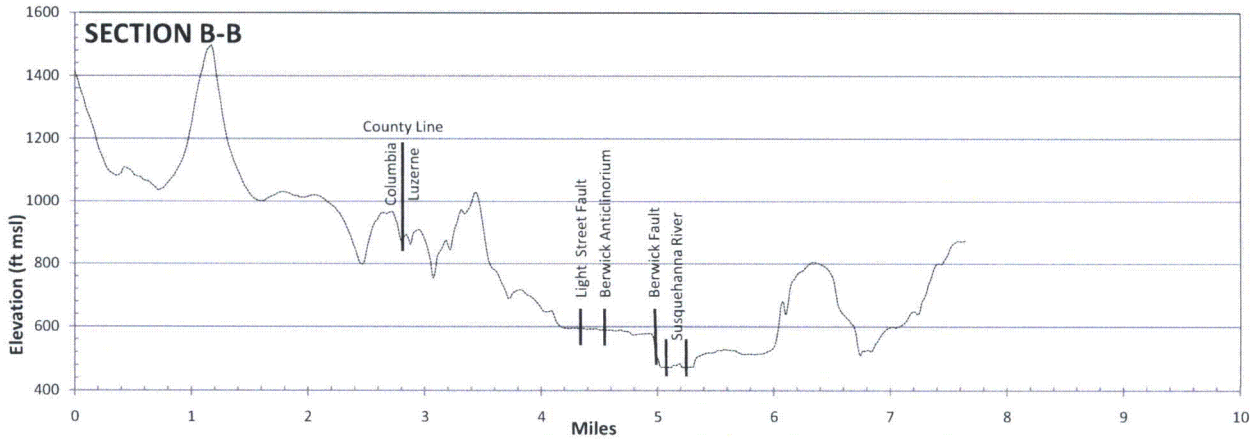
Figure 2.5-206 {LiDAR Image with Topographic Sections Across the Site Vicinity}

LOCATION MAP



Approximately 10X vertical exaggeration





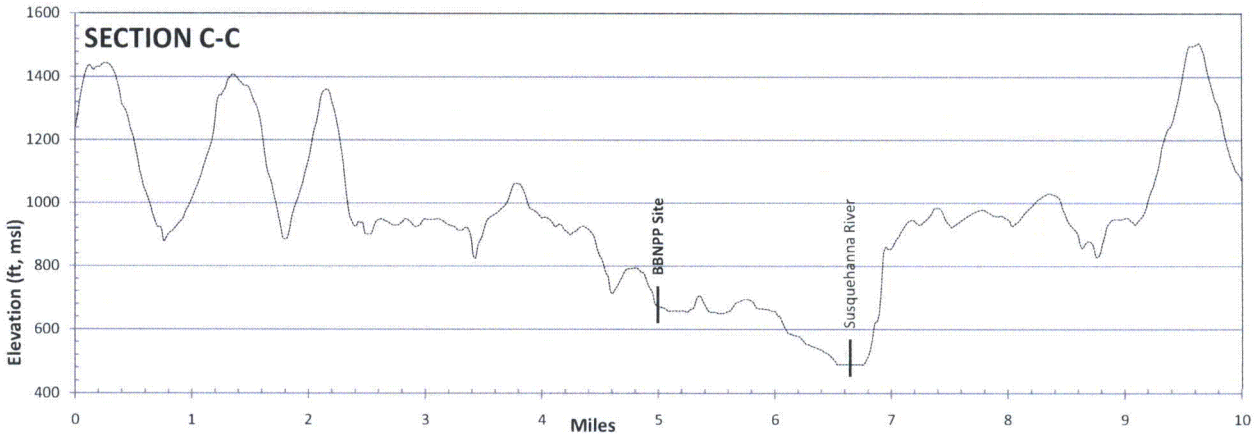
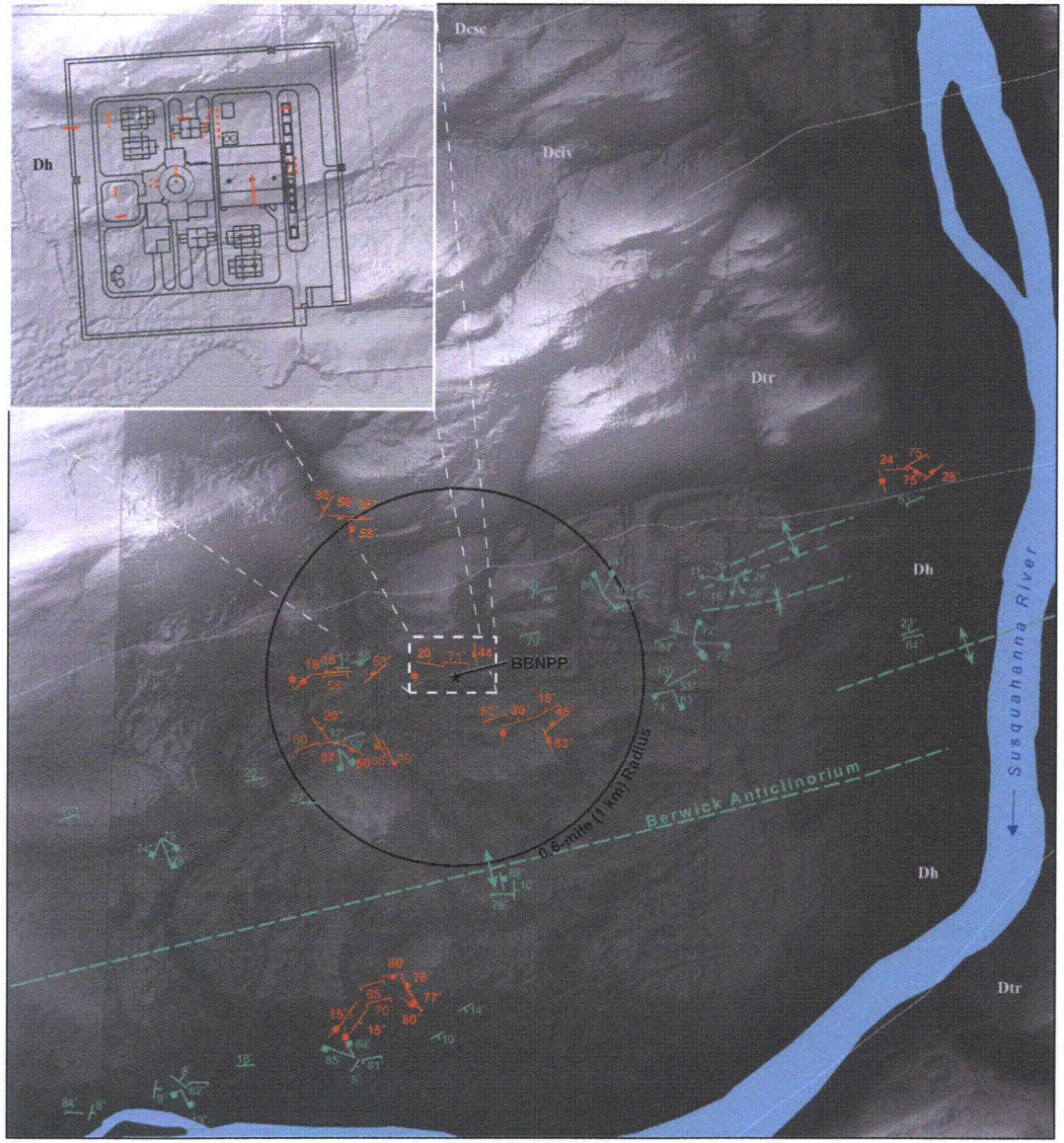


Figure 2.5-209 {Site Geology in Available LiDAR Data Base map}



LEGEND

Unit Descriptions - Contact Boundary Only

Pennsylvanian

- Pl — Llewellyn Formation
- Pp — Pottsville Formation

Mississippian

- Mmc — Mauch Chunk Formation
- Mb — Burgoon Sandstone
- Mp — Pocono Formation
- MDhm — Huntley Mountain Formation
- MDsk — Spechty Kopf Formation

Devonian

- Dck — Catskill Formation

Catskill Formation Members:

- Dcb — Buddys Run Member
- Dcd — Duncannon Member
- Dccf — Clarks Ferry Member
- Dcsc — Sherman Creek Member
- Dcbs — Berry Run & Sawmill Run Members, undivided
- Dcp — Packerton Member
- Dclr — Long Run Member
- Dciv — Irish Valley Member
- Dtr — Trimmers Rock Formation
- Dh — Hamilton Group
- Doo — Onondaga & Old Port Formations, undivided
- DSkt — Keyser & Tonoloway Formations, undivided

Silurian

- Swc — Wills Creek Formation
- Sbm — Bloomsburg & Mifflintown Formations, undivided
- Sc — Clinton Group

- Fault - Inferred
- Fault
- Strike and Dip (field verified 05-21-09)
- Joint (field verified 05-21-09)
- Joint - Vertical (field verified 05-21-09)
- Cleavage (field verified 05-21-09)
- Azimuth and Plunge of Slickenslide (field verified 05-21-09)
- Strike and Dip of Minor Fault (field verified 05-21-09)

Approximate Location of Weston Anomalies

- Interpreted from Seismic Refraction Profile
- Interpreted from Top of Geophysical Bedrock

- Strike and Dip (Inners, 1978)
- Joint - Vertical (Inners, 1978)
- Joint (Inners, 1978)
- Fine / Coarse — Cleavage (Inners, 1978)
- Anticline - Approximate (Inners, 1978)
- Syncline - Approximate (Inners, 1978)
- Azimuth and Plunge of Slickenline of Bedding and Fault Planes (Inners, 1978)
- Strike and Dip of Minor Fault (Inners, 1978)
- ★ Center Point of Proposed Bell Bend NPP (BBNPP)
- ○ NPP Reactor 0.6-mile (1 km) Radius

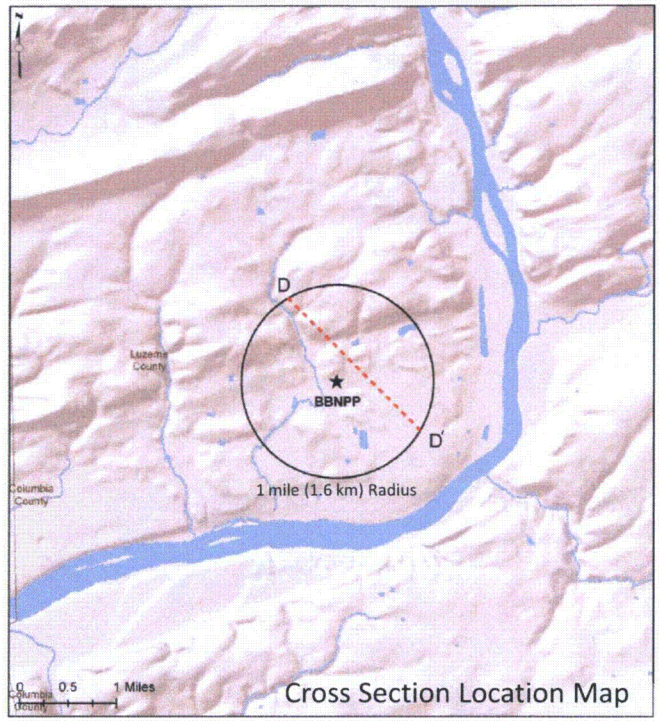
REFERENCES:

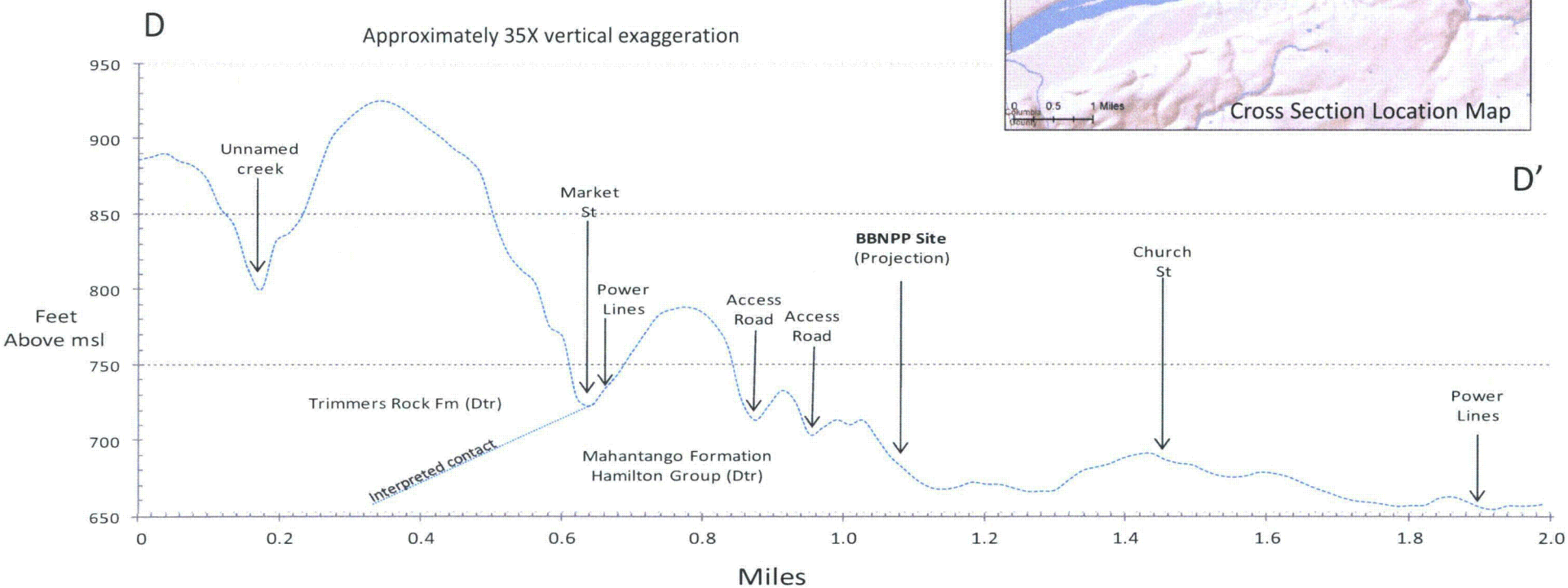
- Berg, 1980.
- Inners, 1978.
- King, 1974.
- PAMAP, 2008.
- USGS, 1989.
- ESRI, 2007.
- Weston, 2008.
- sk-12198-004-001.dwg, 2008.

0 0.25 0.5 1 miles

0 0.5 1 kilometers

Figure 2.5-210 {Topographic Section for the Zone Nearest to the Site Based on LiDAR Data}





REFERENCE: PAMAP, 2008

Figure 2.5-219 {Surficial Sediment Description Overlaid in LiDAR Data Base Map }

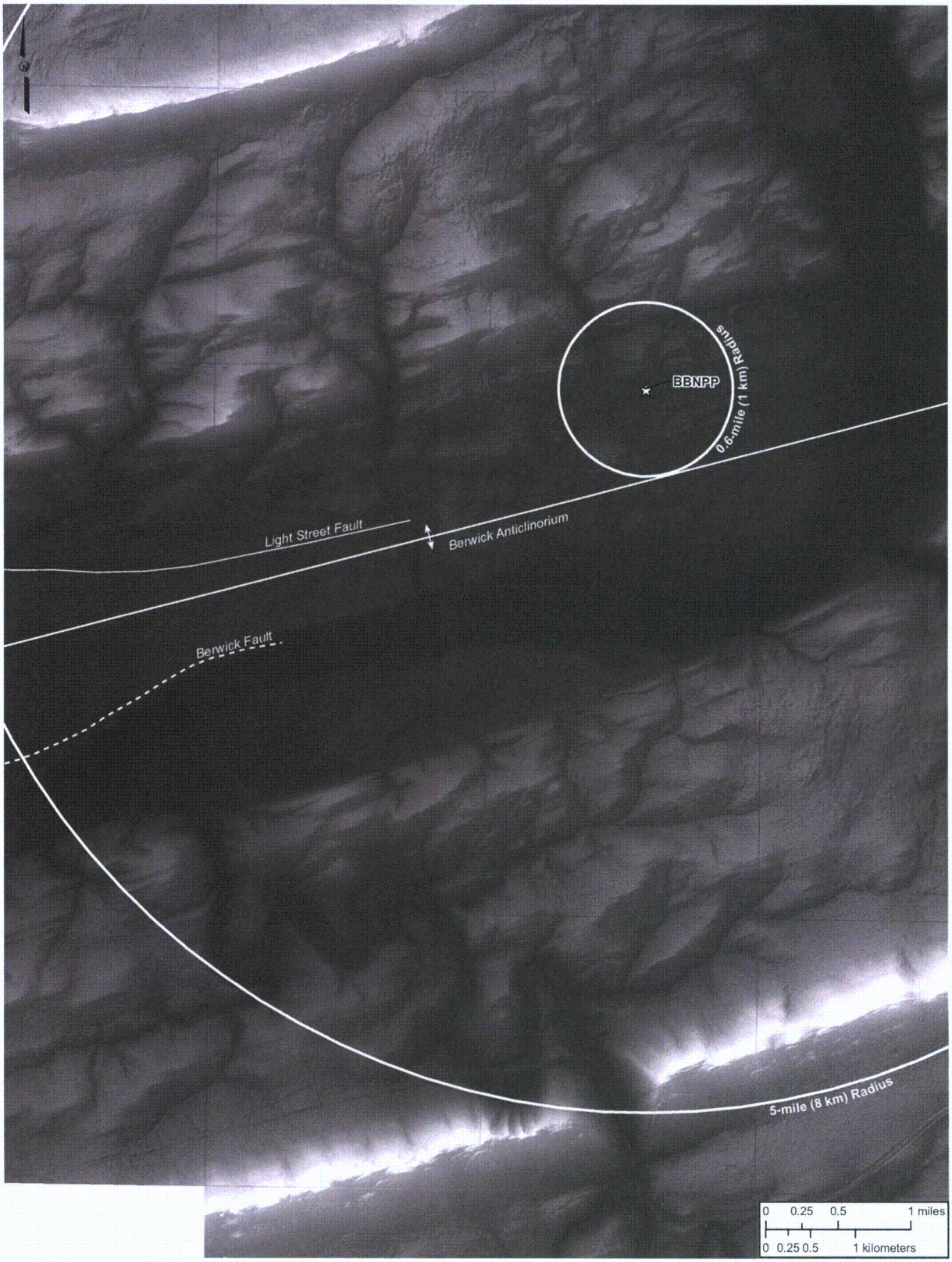
LEGEND:

- ☆ Proposed Center Point of Bell Bend NPP (BBNPP)
- ○ NPP Reactor 0.6-mile (1 km) and 5-mile (8 km) Radii
- - - Inferred Fault
- —— Fault
- ↕ Anticline

ARTIFICIAL FILL af	ALLUVIUM Qal	ALLUVIAL FAN Qf	ALLUVIUM AND WOOD-FORDIAN OUTWASH, UNDIVIDED Qwoa	SWAMP DEPOSIT Qs	ALLUVIUM AND COLLUVIUM UNDIVIDED Qao	COLLUVIUM Qc	COLLUVIUM AND HILL, UNDIVIDED Qcl	EOLIAN MANTLE Qem	TALUS Qt	BOULDER COLLUVIUM Qbc
WOOD-FORDIAN OUTWASH Qwo	WOOD-FORDIAN KAME TERRACE Qwkt	WOOD-FORDIAN KAME TERRACE AND OUTWASH, UNDIVIDED Qwkto	WOOD-FORDIAN FRONTAL KAME Qwfk	WOOD-FORDIAN ICE-CONTACT STRATIFIED DRIFT Qwic	WOOD-FORDIAN GROUND MORAINE Qwgm	WOOD-FORDIAN END MORAINE Qwem	ALTONIAN OUTWASH Qao	ALTONIAN TILL Qat	ILLINOIAN KAME TERRACE Qikt	ILLINOIAN TILL Qit

REFERENCE:
- Inners, 1978.
- PAMAP, 2008.

Figure 2.5-220 {LiDAR Data Base Map Without Overlaid Surficial Sediment Description}



LEGEND:

- Proposed Center Point of Bell Bend NPP (BBNPP)
- NPP Reactor 0.6-mile (1 km) and 5-mile (8 km) Radii
- Inferred Fault
- Fault
- Anticline

ARTIFICIAL FILL af	ALLUVIUM Qal	ALLUVIAL FAN Qf	ALLUVIUM AND WOOD-FORDIAN OUTWASH, UNDIVIDED Qwoa	SWAMP DEPOSIT Qs	ALLUVIUM AND COLLUVIUM UNDIVIDED Qao	COLLUVIUM Qc	COLLUVIUM AND TILL, UNDIVIDED Qct	EOLIAN MANTLE Qem	TALUS Qt	BOULDER COLLUVIUM Qbc
WOOD-FORDIAN OUTWASH Qwo	WOOD-FORDIAN KAME TERRACE Qwkt	WOOD-FORDIAN KAME TERRACE AND OUTWASH, UNDIVIDED Qwkto	WOOD-FORDIAN FRONTAL KAME Qwfk	WOOD-FORDIAN ICE-CONTACT STRATIFIED DRIFT Qwic	WOOD-FORDIAN GROUND MORAINE Qwgm	WOOD-FORDIAN END MORAINE Qwem	ALTONIAN OUTWASH Qao	ALTONIAN TILL Qat	ILLINOIAN KAME TERRACE Qikt	ILLINOIAN TILL Qit

REFERENCE:
- Inners, 1978.
- PAMAP, 2008.

Figure 2.5-221 {Site Area Geology in Available LiDAR Data Base Map}

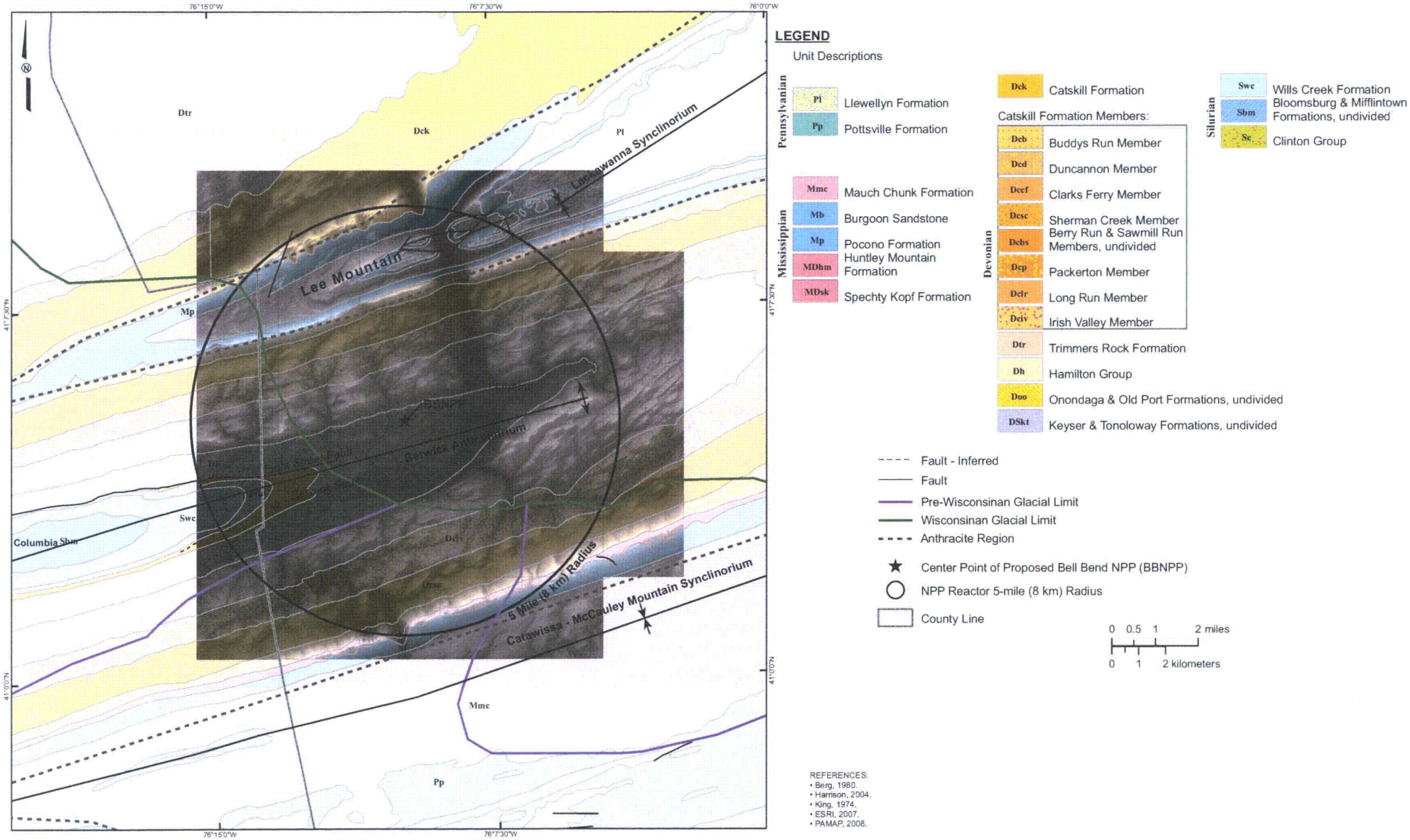


Figure 2.5-222 (LiDAR Data Base Map Without Overlaid Site Area Geology)

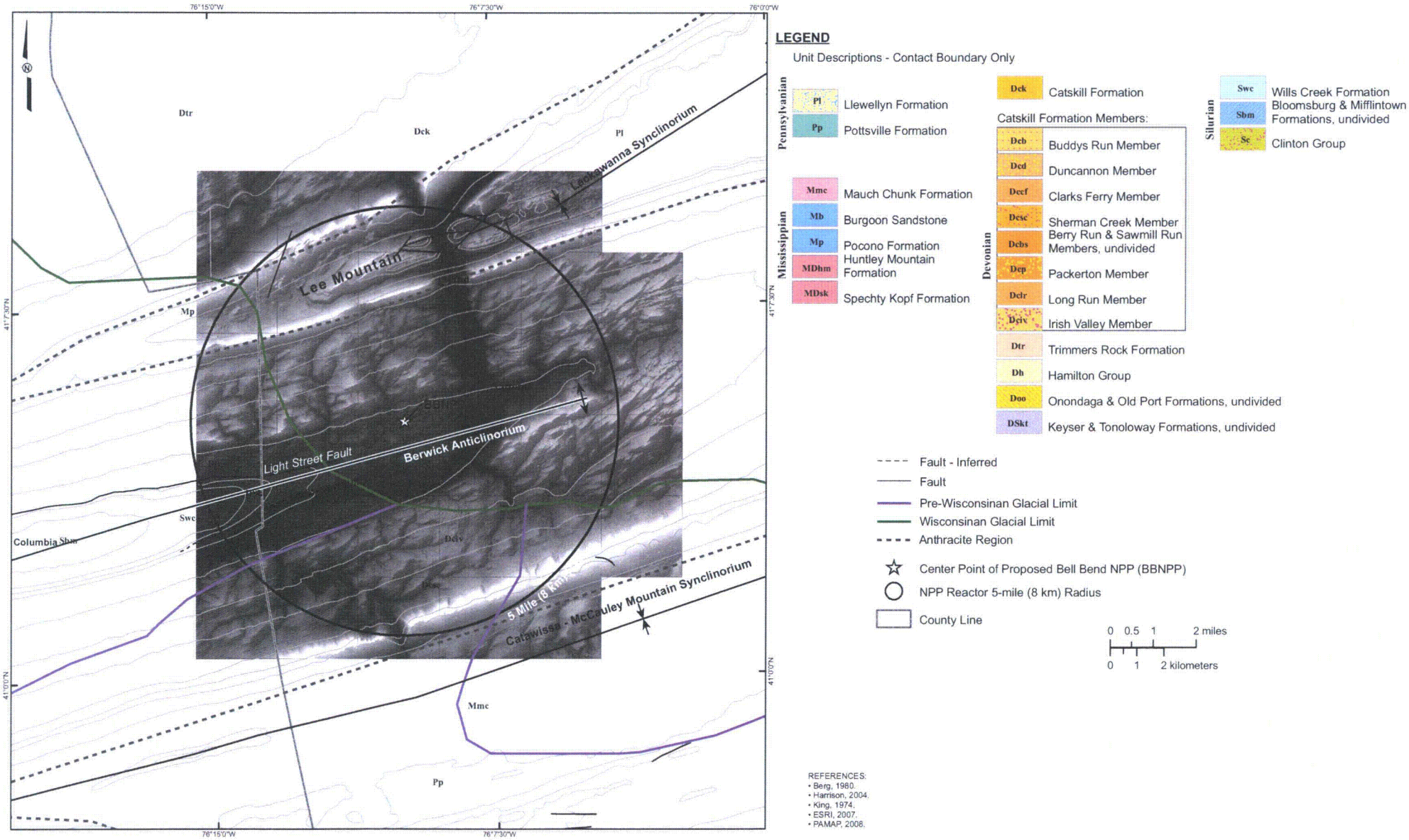


Figure 2.5-223 {Stretched LiDAR Data Base map Without Overlaid Site Area Geology and Higher Altitudes }

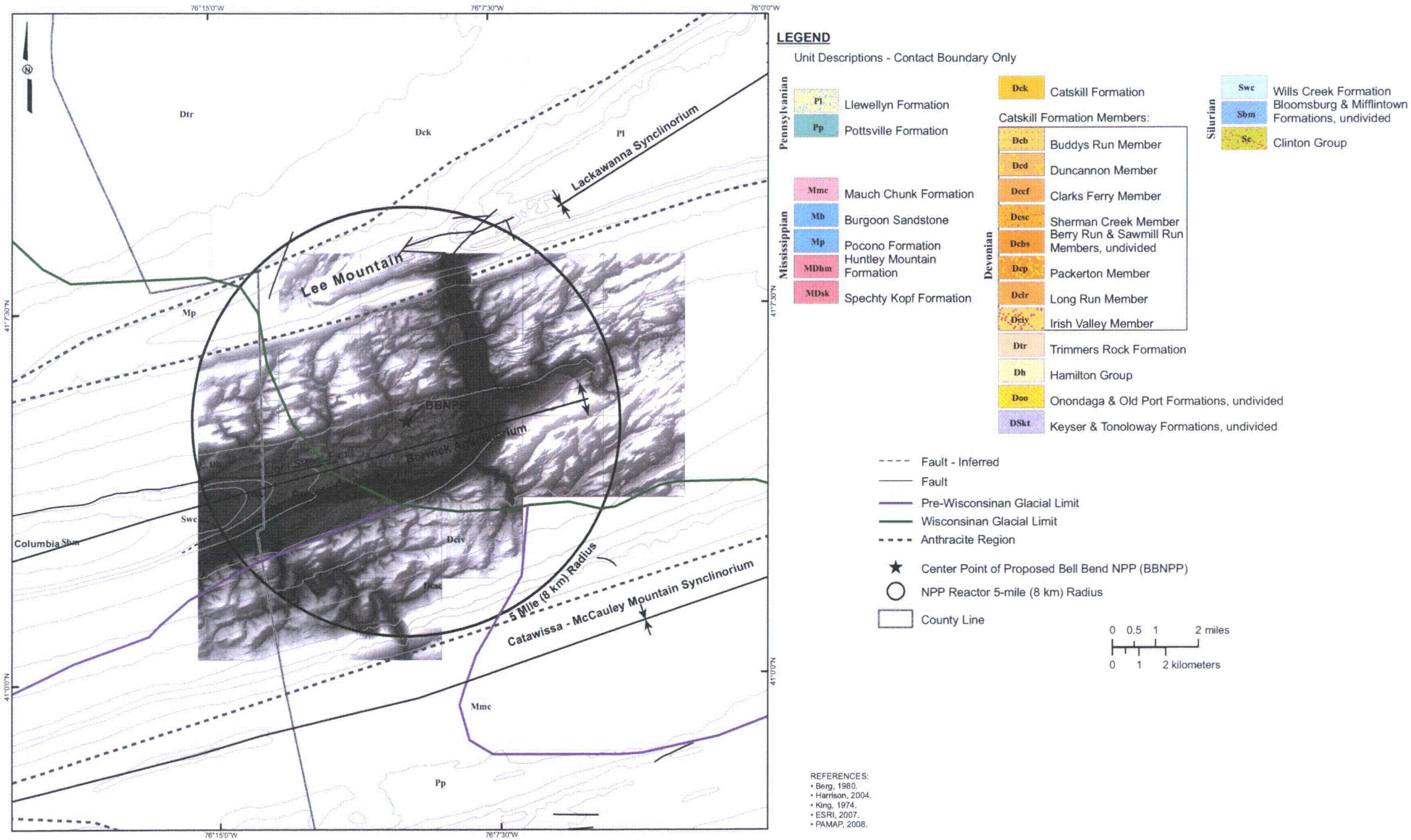
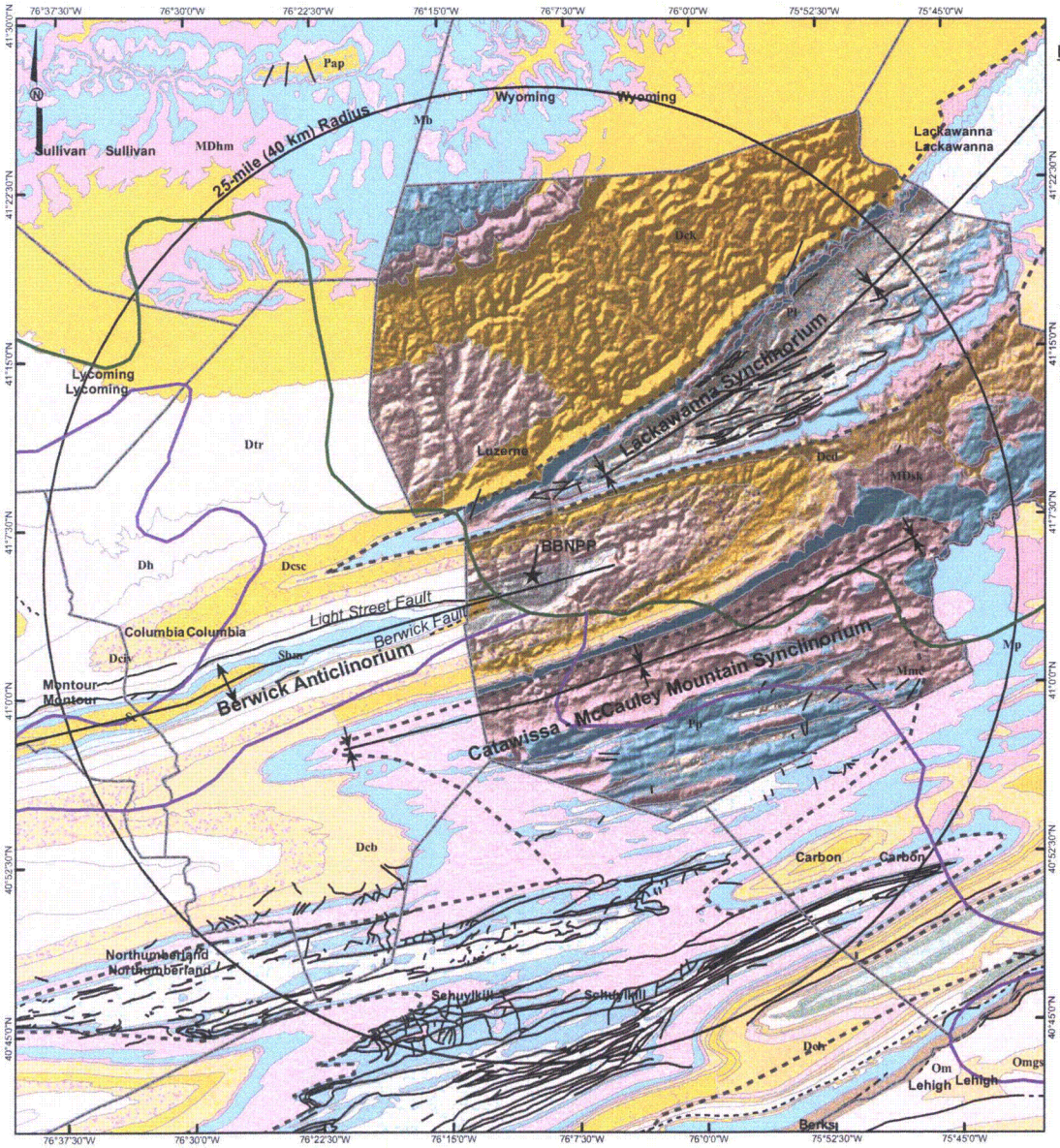


Figure 2.5-224 {Site Vicinity Geology in Available LiDAR Data Base Map}



LEGEND

Unit Descriptions

Pennsylvanian

- Pl — Llewellyn Formation
- Pp — Pottsville Formation

Mississippian

- Mmc — Mauch Chunk Formation
- Mb — Burgoon Sandstone
- Mp — Pocono Formation
- MDhm — Huntley Mountain Formation
- MDsk — Spechty Kopf Formation

Devonian

- Dck — Catskill Formation

Catskill Formation Members:

- Deb — Buddys Run Member
- Ded — Duncannon Member
- Decf — Clarks Ferry Member
- Desc — Sherman Creek Member
- Dcbs — Berry Run & Sawmill Run Members, undivided
- Dcp — Packerton Member
- Dclr — Long Run Member
- Dciv — Irish Valley Member

- Dtr — Trimmers Rock Formation
- Dh — Hamilton Group
- Doo — Onondaga & Old Port Formations, undivided
- DSkt — Keyser & Tonoloway Formations, undivided

Silurian

- Swc — Wills Creek Formation
- Sbm — Bloomsburg & Mifflintown Formations, undivided
- Sc — Clinton Group

- Fault - Inferred
- Fault
- Pre-Wisconsinan Glacial Limit
- Wisconsinan Glacial Limit
- Anthracite Region
- ★ Center Point of Proposed Bell Bend NPP (BBNPP)
- ○ NPP Reactor 25-mile (40 km) Radius
- County Line

0 2.5 5 10 miles

0 5 10 kilometers

REFERENCES:
- Berg, 1980.
- Harrison, 2004.
- King, 1974.
- ESRI, 2007.
- PAMAP, 2008.

Figure 2.5-225 {LiDAR Data Base Map Without Overlaid Site Vicinity Geology}

LEGEND

Unit Descriptions

Pennsylvanian

- Pl — Llewellyn Formation
- Pp — Pottsville Formation

Mississippian

- Mmc — Mauch Chunk Formation
- Mb — Burgoon Sandstone
- Mp — Pocono Formation
- MDhm — Huntley Mountain Formation
- MDsk — Spechty Kopf Formation

Devonian

- Dck — Catskill Formation

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- Dcd — Duncannon Member
- Dccf — Clarks Ferry Member
- Dcsc — Sherman Creek Member
- Dcbs — Berry Run & Sawmill Run Members, undivided
- Dcp — Packerton Member
- Dclr — Long Run Member
- Dcfv — Irish Valley Member
- Dtr — Trimmers Rock Formation
- Dh — Hamilton Group
- Doo — Onondaga & Old Port Formations, undivided
- DSkt — Keyser & Tonoloway Formations, undivided

Silurian

- Swc — Wills Creek Formation
- Sbm — Bloomsburg & Mifflintown Formations, undivided
- Sc — Clinton Group

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- Fault
- Pre-Wisconsinan Glacial Limit
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- ★ Center Point of Proposed Bell Bend NPP (BBNPP)
- ○ NPP Reactor 25-mile (40 km) Radius
- County Line

0 2.5 5 10 miles

0 5 10 kilometers

REFERENCES:

- Berg, 1980.
- Harrison, 2004.
- King, 1974.
- ESRI, 2007.
- PAMAP, 2008.

Question 02.05.01-6

FSAR Section 2.5.3.1.3 refers the reader to Figure 2.5-105t, which illustrates the Site Vicinity topography and the field stations pertaining to recent geologic field reconnaissance. In order for the NRC to evaluate whether the field work performed to characterize the Bell Bend site is complete, for each station (way point 1-5) please provide what feature(s) were examined and what was found. Include any geologic structure measurements taken (strike and dip of bedding, foliation, cleavage, minor fold axes, and offsets on any feature), any fluvial deposit that could contain evidence of paleoliquefaction. Also include specific references to photographs that were taken at the stations.

Response

The following provides a cross reference between the figure numbers in Letter BNP-2008-006 and Revision 1 of the FSAR.

> Figure 2.5-105t, Topographical Map of Site Area 25-mile (40 km) Radius with Waypoints from Field Reconnaissance, as submitted in Letter BNP-2008-006, was incorporated into Revision 1 of the FSAR as Figure 2.5-207.

Additional field reconnaissance has been conducted to better characterize the local geology, specifically remnants of the Mahantango Formation bedding planes within the strong imprint of the cleavage. The results of this more detailed investigation are included as text changes in multiple FSAR sections. Results from these recent measurements of bedding planes, cleavage, and joint sets at seven locations within the outcrop of the Mahantango Formation, as well as the measurements from Inners (Inners, 1978) are also presented in a new figure (Figure 2.5-209). Figure 2.5-209 depicts the site geology in a base map built with the available LiDAR data set, including the results of the most recent site reconnaissance and field observations referenced in Inners, 1978. Changes were also made to the titles of Figures 2.5-132 and 2.5-134 in order to refer to the precise geologic feature as well as to the accurate strike and dip.

Changes to the text were made in the following FSAR Sections:

- 2.5.1.1.2.6, Alleghanian Orogeny
- 2.5.1.1.4.4.4.1, Berwick Anticlinorium
- 2.5.1.2.2, Site Area Geologic History
- 2.5.1.2.4.2, Berwick Anticlinorium
- 2.5.1.2.4.4.1, Subsurface Investigations at the BBNPP Site
- 2.5.1.2.4.4.2, Geophysical Investigations
- 2.5.1.2.4.4.4, Field Reconnaissance
- 2.5.1.2.6.4, Deformational Zones
- 2.5.3.1.1, Subsurface Investigations at the BBNPP Site
- 2.5.3.1.2, Interpretation of Aerial Photography and LIDAR Imagery
- 2.5.3.1.3, Field Reconnaissance
- 2.5.4.2.1, BBNPP Soil Profile

COLA Impact

RAI Questions 02.05.01-6 and 02.05.01-7 address similar issues and the same COLA sections. Because the responses for these questions involve text changes and figures in common FSAR sections, the mark-up text and new figures are not repeated for both questions. Instead, for the sake of clarity, the COLA Impact and FSAR mark-ups for both questions are provided in the response to Question 02.05.01-7.

Question 02.05.01-7

FSAR Section 2.5.1.4 discusses the attitude of bedding planes in several locations in the text. The reported bedding plane attitudes are highly variable and inconsistent with a location on the northwest limb of and just off of the axis of a major, open, anticline. The staff would expect the bedding planes to be gently dipping to the north-west or practically horizontal unless there is perhaps another structure, such as other folds or a hidden fault, complicating local structural elements. Please identify any such structure, if one exists. The text states:

- Page 89: The BBNPP site is situated on the northern limb of the fold, with beds that are steeply dipping.
- Page 91: The investigation at the BBNPP site indicates that the site is underlain by unfaulted Middle Devonian shale dipping 15 to 85 degrees, and covered by a layer of undeformed glacial outwash and till (Figures 2.5-96, 2.5-97, 2.5-98, 2.5-99, 2.5-100, and 2.5-100a). A note on all these figures indicates that the average bedrock orientation is a N20° E strike with a 70° dip to the south-east.
- Page 92: The velocity model developed for the site depicts the bedrock surface to be nearly flat lying from west to east and dipping to the south.

Because there are significant fold structures in the area, it appears incorrect to apply average strike and dip. The location of the site on the northwest limb of the fold would suggest that the bedding planes dip in a north-west directions rather than a south-east direction. A range of dip between 15 to 85 degrees in a localized area would call for some explanation given the location in the Valley and Ridge province. Please provide any location-specific structural measurements that are available.

Although the resolution appears limited, the photo figures of rock outcrops (Figures 2.5-105q, 2.5-105p, 2.5-105n) seem to show steeply dipping, intersecting cleavage planes producing the steeply dipping fabric. The loose material at the base of the outcrops looks like classic pencil cleavage. In particular, Figure 2.5-105p, where the man is looking at the cliff, bedding planes seems to be dipping much less than 70 degrees (not to be confused with cleavage). Please explain whether cleavage and bedding have been confused and lumped together in the strike and dip measurements provided throughout the text in various locations.

In order for NRC staff to understand the character of the geologic materials in the site area and site location, please explain and clarify the information regarding the following specific structural items described in the text.

(a) Specific strike and dip of correctly and consistently identified rock fabric features, located on a map, actually define structure. The spatial distribution and values of strikes and dips can outline unrecognized folds and perhaps faults. To evaluate whether such unrecognized folds and faults may exist, please provide a geologic map showing the locations and values of all strike-and-dip measurements in the Mahantango Formation at or near the site.

(b) Please locate the outcrops that are shown in Figures 105j (p. 462) and 105n (p. 466) on the map that is requested in part a, and show the bedding orientations, cleavage orientations, and joint orientations at these outcrops.

(c) The log of borehole 306 shows an unusually deep water table (figs. 2.5-97 and 2.5-100a, p. 443 and 447). Refraction profiles show that at seven places the bedrock surface deepens abruptly by several tens

of feet (figs. 104 and 105a-f, p. 451 and 453-458). The map of the elevations of the top of bedrock shows at least two elevation anomalies that trend north to north-northeast (fig. 2.5-105, p. 452). The anomalies might represent increased permeability or increased weathering along unrecognized faults. Please show all of these anomalies on an uncolored version of figure 2.5-105, to aid NRC staff in assessing the possibility of unrecognized faults. Please design the figure so that it can be overlaid on the map requested in part a.

(d) Please modify the LiDAR topographic section DD so that the vertical scale for the zone nearest the site takes full advantage of the LiDAR data resolution. Please use a scale in 10s of feet rather than 100s of feet.

Response

General Response:
The following table provides a cross reference between the figure numbers in Letter BNP-2008-006 and Revision 1 of the COLA.

BNP-2008-006 FIGURE REFERENCE	FIGURE TITLE	COLA REVISION 1 FIGURE REFERENCE
Figure 2.5-96	Geotechnical Site Cross Section A-A'	Figure 2.5-200
Figure 2.5-97	Geotechnical Site Cross Section B-B'	Figure 2.5-201
Figure 2.5-98	Geotechnical Site Cross Section C-C'	Figure 2.5-202
Figure 2.5-99	Geotechnical Site Cross Section D-D'	Figure 2.5-203
Figure 2.5-100	Geotechnical Site Cross Section E-E'	Figure 2.5-204
Figure 2.5-100a	Geotechnical Site Cross Section F-F'	Figure 2.5-205
Figure 2.5-104	Seismic Velocity Contours	Figure 2.5-117
Figure 2.5-105	Bedrock Elevation Contour	Figure 2.5-118
Figure 2.5-105a	Refraction Survey Page 1 of 6	Figure 2.5-119
Figure 2.5-105b	Refraction Survey Page 2 of 6	Figure 2.5-120
Figure 2.5-105c	Refraction Survey Page 3 of 6	Figure 2.5-121
Figure 2.5-105d	Refraction Survey Page 4 of 6	Figure 2.5-122
Figure 2.5-105e	Refraction Survey Page 5 of 6	Figure 2.5-123
Figure 2.5-105f	Refraction Survey Page 6 of 6	Figure 2.5-124
Figure 2.5-105j	Rocky Bed of the Susquehanna River at the Berwick Ridge	Figure 2.5-128
Figure 2.5-105n	Shale Outcrop at the Site with Steeply Dipping Beds (85 Degrees to the ENE)	Figure 2.5-132
Figure 2.5-105p	Shale in Borrow Area Dipping 15 Degrees, and Overlain by Glacial Till	Figure 2.5-134
Figure 2.5-105q	Continuous Contact Between Glacial Till and Top of Shale Bedrock	Figure 2.5-135

Additional field reconnaissance has been conducted on and near the BBNPP site to better characterize cleavage and bedding at observable surface features. The recent reconnaissance in the nose of this anticlinorium identified additional features that lead to reevaluation of the prevalent structures. The steeply, closely to very closely spaced, south-east dipping cleavage produced a strong imprint in the widely spaced bedding planes of the Mahantango Formation that resulted in a lack of clarity being

introduced in the FSAR text. In some cases, cleavage was referred to as bedding and the respective text has been modified to address this issue. Additionally, intersecting planes of both bedding and cleavage produced breaks that were found to form localized, more intense, long pencil-shaped pieces, typical of the nose of folds.

Although tight folds were expected to be found at the site, because they had been found in excavations for Susquehanna Steam Electric Station Units 1 and 2, no indications of such folds were found in any of the outcrops visited during the site reconnaissance visits.

Response to Questions 7a and 7b:
A more detailed search during the recent field reconnaissance was able to identify only a few remnants of the bedding planes gently dipping to the north north-west, within the strong imprint of the cleavage on the shales of the Mahantango Formation. Results from these recent reconnaissance measurements of bedding planes, cleavage, and joint sets, as well as the same types of measurements from Inners (Inners, 1978) are presented on a new figure (Figure 2.5-209). Figure 2.5-209 depicts the site geology in a base map built with the available LiDAR data set, including the results of the most recent site reconnaissance and the field observations referenced in Inners, 1978. Changes were also made to the titles of Figures 2.5-132 and 2.5-134 in order to refer to the identified geologic features as well as providing accurate strike and dip information.

Changes to the text were made in the following FSAR Sections:

- 2.5.1.1.2.6, Alleghanian Orogeny
- 2.5.1.1.4.4.4.1, Berwick Anticlinorium
- 2.5.1.2.2, Site Area Geologic History
- 2.5.1.2.4.2, Berwick Anticlinorium
- 2.5.1.2.4.4.1, Subsurface Investigations at the BBNPP Site
- 2.5.1.2.4.4.2, Geophysical Investigations
- 2.5.1.2.4.4.4, Field Reconnaissance
- 2.5.1.2.6.4, Deformational Zones
- 2.5.3.1.1, Subsurface Investigations at the BBNPP Site
- 2.5.3.1.2, Interpretation of Aerial Photography and LIDAR Imagery
- 2.5.3.1.3, Field Reconnaissance
- 2.5.4.2.1, BBNPP Soil Profile

Response to Question 7c:
The unusually deep water level shown in boring B-306 on Figures 2.5-97 and 2.5-100a, (new figures 2.5-201 and 2.5-205) on pages 443 and 447 (~100 feet deeper than surrounding measurements), was not recorded in the field during drilling, as seen on the attached page from the boring log. The groundwater level depth (GWL DEPTH) at the bottom of the page shows "N/A" (not available) at the time of drilling. A monitoring well (MW-311C1) was constructed in this boring in September 2007, and the water levels measured in it are reported on Table 2.4-44 from in Rev 1 FSAR. The measured water levels from this well were on the order of 100 feet deeper than the surrounding measurements from nearby wells and the hydrogeological staff preparing Section 2.4.12 for the FSAR considered them unuseable and did not use them in preparing the potentiomentric maps or the hydrographs for the FSAR. The depressed water levels are an artifact of the installation of the well, where the well was evacuated during the installation process. Because the well screen experienced a poor hydraulic connection to the aquifer (it was completed in an unfractured part of the unit), the water level did not recover quickly and does not reflect an accurate representation of the ambient groundwater level.

Consequently, Figures 2.5-201 and 2.5-205 have been revised to reflect an interpolated water table elevation for the B-306 location, using the data from the potentiometric maps showing the local groundwater elevations in the shallow bedrock aquifer (elevations of 657-661 feet on Figures 2.4-89 through 2.4-92 in the Rev 1 FSAR). The data on those maps came from multiple wells deemed to produce reliable data, and covers the area surrounding the B-306 location.

Anomalies observed in the seismic refraction profiles (Figures 2.5-119 through 2.5-124) and in the top of bedrock surface (Figure 2.5-125) are presented as red lines on Figure 2.5-226, using an uncolored version of Figure 2.5-118 as a base. A new Figure 2.5-227 was created to allow a comparison to Figure 2.5-209, knowing that the area shown on Figure 2.5-226 is only a very small portion of Figure 2.5-209. An inset similar to Figure 2.5-227 was also placed on Figure 2.5-209 to represent the area just around the containment area and to facilitate comparisons.

An area of elevated bedrock surface is visible to the northwest of the Nuclear Island on both Figures 2.5-125 and 2.5-226. Another area of elevated bedrock surface is revealed by the seismic investigation data to the northeast of the island on Figure 2.5-226, but without borings in that vicinity as shown on Figure 2.5-125, the geologic data cannot confirm that finding. The similarities between the two data sets in other areas under investigation give weight to the seismic interpretation in that northeast corner of Figure 2.5-125. The geologic data on Figure 2.5-125 show an apparent offset with a nearly north-south orientation near the Easting of +100 feet. However, the seismic data show the same anomaly, but because of a higher density of data in that corner of the map it is shaped more like a valley than an offset, with an eastern wall to match the western one depicted on the geologic figure. The anomaly is marked on the figures by a pair of converging red dashed lines.

There is no indication in the LiDAR data base map on Figure 2.5-227 of any offset in the exposed bedrock surface adjacent to this NS trend. If the observed anomaly were a fault, motion along that fault would have been expressed in offset or changes in alignment of that rock face immediately north of the site. The following are alternative interpretations for the changes in the bedrock surface:

- Erosion of the valley floor by a tributary to the Susquehanna River prior to the emplacement of the valley fill and prior to glaciation;
- Glacial gouging of the valley floor prior to the placement of the fill; or
- Differential weathering among small-scale folds and fractures associated with the formation of the Berwick Anticlinorium. Folds of this nature were not observed in outcrop for this investigation, but during the construction of the Susquehanna Units 1 and 2, small-scale folds were observed and mapped in the foundation excavations.

Response to Question 7d:

A new figure was created to better depict LiDAR topographic section DD with a more appropriate scale. This figure (Figure 2.5-210) shows a topographic cross section, parallel to the original topographic section DD, generated with the available LiDAR data set.

COLA Impact

This RAI Response includes the Responses for Questions 02.05.01-6 and 02.05.01-7 together, since the comments address similar locations in the report. The markup pages reflecting the FSAR changes to text are attached immediately to this document. Revised Figures are attached on the following pages.

2.5.1.1.2.6 Alleghanian Orogeny

Convergence of Peri Gondwana with Laurentia at margins identified in modern geographic terms as northwest Africa and eastern North America led to the formation of the supercontinent of Pangaea. The continental collision caused the eastern and southern margins of North America to undergo uplift and deformation in what is referred to as the Alleghanian Orogeny. Late Pennsylvanian dextral transpression (a combination of convergent and transform plate boundaries) was the initial interaction of the aforementioned continents (Engelder and Whitaker, 2006). As the convergent margin evolved in the early Permian, intense brittle and ductile deformation in the form of thrusting, folding, and varying degrees of metamorphism took place (Steltenpohl, 1988) and (Schumaker, 2002). The current geologic setting along the eastern, southeastern, and south-central (although much is now buried under Gulf Coast Basin sediment) United States is strongly defined by Alleghanian deformation. In many cases, pre-existing faults related to Grenville, Taconic, or Acadian deformation were reactived to develop regional detachment structures or decollements along which the Piedmont, Blue Ridge, and Ridge and Valley were transported as much as 180 mi (300) km to the northwest in the middle to late Permian (Engelder and Whitaker, 2006) This crustal shortening and overthrusting developed the structural setting of deep seated regional thrust faults, intense folding, and varying degrees of metamorphism that is prevalent in the Ridge and Valley, Blue Ridge, and Piedmont Physiographic provinces. Thoughout the Alleghanian orogenic process the stress regime maintained a dextral or right lateral transpressional component (Ong et al, 2007) with the exception of Latest Permian dextral motion (Steltenpohl, 1988). This predominant dextral transpression is at least partially responsible for the oroclinal structures in the Ridge and Valley and Blue Ridge Provinces. A large potentially oroclinal component of the Ridge and Valley exists within the site region (200 mi (322 km) radius that can be seen on Figure 2.5-182 as the change in regional structural fabric from a north east strike to a east-northeast strike. Change of structural orientation of 19 degrees to the east of dominant strike is measured in northeast Pennsylvania (Harrison et al, 2004).

Examples of Alleghanian deformation within the site vicinity (25 mi (40 km) radius) and site area (5 mi (8 km) radius) include the Berwick and Light Street Faults, depicted on Figure 2.5-198 and discussed in Section 2.5.1.2.4.1 and Section 2.5.1.2.6.4 These faults are recognized as exhibiting reverse, to the northwest vergence and are classified as Alleghanian thrust faults (Inners, 1978). Field studies did not identify offset in terrace gravels overlying the Light Street and Berwick Faults (Inners, 1978). In addition, the Berwick Anticlinorium~~e~~, an east-northeast striking, gently northeast plunging anticline trends directly through the site area (5 mi (8 km) radius). The Berwick Anticlinorium~~e~~ is a~~n a~~symmetrical structure in the site area (5 mi (8 km) radius) with both the north-northwest and south-southwest limbs dipping with an averaged 35 degree NNW and SSW respectively~~steeply to the north-northwest and the southern limb dipping more gently to the south-southeast~~. The orientation of this structure is classic Ridge and Valley Alleghanian deformation as presented by Hatcher (Hatcher, 1987). In addition to crustal deformation, the Alleghanian Orogeny had an important effect on the depositional regime in the Appalachian Basin and essentially closed the basin at the end of the

2.5.1.1.4.4.4.1 Berwick Anticlinorium

The principal bedrock structure within the site area is the Berwick Anticlinorium (also referred to as the Montour Anticline (Pohn, 2001)), which has been described (Inners, 1978) as "a moderately complex, first order fold which trends in a northeast-southwest direction". The bedrock map and section of the Berwick Quadrangle (Inners, 1978) shows the formations at the BBNPP site area to consist of Silurian, Devonian, and Carboniferous rocks that have been gently folded, with limited faulting (Figure 2.5-193 and 2.5-27b). The BBNPP site is situated on the northern limb of the fold, with beds that are ~~steeply~~ dipping between 10 and 20 degrees to the north-northwest. Two faults have been mapped in the vicinity: the Light Street fault located on the northern limb of the fold, and the Berwick fault, inferred to be on the southern limb of the fold. The northeast ends of both faults lie within the site area, but do not directly underlie the site. Both faults are considered folded faults, therefore there is limited chance for these to be reactivated in the contemporary stress regime.

2.5.1.2.2 Site Area Geologic History

This subsection presents an overview of the geologic history of the site area. The overall geologic history and tectonic framework of the region are outlined in Section 2.5.1.1.2 and Section 2.5.1.1.4. A detailed discussion of the surface faulting within 25 mi (40 Km) of the BBNPP site area is provided in Section 2.5.3. The following geologic history of the area around the BBNPP site is summarized based on the recent detailed field studies, and literature review which includes compilations by the Pennsylvania Department of Conservation and Natural Resources and publications by (Braun, 2007). Each has been integral in characterizing the site area (5.0 mile (8km) radius).

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The site area was subjected to brittle deformation in the form of folding and thrusting that developed the structural makeup of the Ridge and Valley Province within which the site area lies. The Berwick and Light Street Faults, depicted on Figure 2.5-198 and discussed in Section 2.5.1.2.4.1 are examples of this Alleghanian deformation within the site area (5 mi (8 km) radius), and are not recognized as active. In addition, the Berwick Anticlinorium~~e~~, an east-northeast striking, gently northeast plunging anticline trends directly through the site area (5 mi (8 km) radius). The Berwick Anticlinorium~~e~~ is a~~n~~ ~~a~~symmetrical structure in the site area (5 mi (8 km) radius) with both the north-northwest and south-southeast limbs dipping with an averaged 35 degree NNW and SSE respectively~~steeply to the north-northwest and the southern limb dipping more gently to the south-southeast~~. The structure imparted by the Alleghanian Orogeny is significant to the topography, drainage, and seismicity of the site area, defining the major landforms (elongated ridges and valleys), drainage patterns, and structural discontinuities within the Paleozoic strata. By the end of the Permian Period, the Appalachian Mountains had been subjected to significant erosion providing source material for an alluvial plane

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The surface at the site is comprised of glacial deposits from the Wisconinan glaciation that is discussed in Section 2.5.1.1.2. As briefly discussed in Section 2.5.1.2.1, with respect to physiography, the formation of karst is also part of the geologic history of the site area (5 mi (8 km) radius). Approximately five miles to the west within the Tonoloway and Keyser Formations, as shown on Figure 2.5-198, karst feature development is exhibited. The Tonoloway Formation is a thinly bedded limestone up to 100 ft. (30m) thick in the site area (5 mi (8 km) radius) and the Keyser Formation is a fossiliferous limestone up to 125 ft. (38 m) thick. Both lithologies are susceptible to the development of karst features due to dissolution of calcium carbonate within the rock. However, the formation of karst geomorphology is not applicable to the site location (0.6 mi (1 km) radius), as carbonate rocks are not at or near the surface of the site (Inners, 1978). Figure 2.5-29 notes the stratigraphic position of these formations beneath the site location (0.6 mi (1 km) radius). The Tonoloway and Keyser Formations are at depths as great as 1,500 feet under the site location (0.6 mi (1 km) radius) due to the dip of the northern limb and plunge of the axis of the ~~position of the site on the steeply dipping northern limb of the previously discussed northeast plunging~~ Berwick Anticlinorium~~e~~. ~~The dip of the northern limb and plunge of the axis of this anticline places the Keyser and Tonoloway at significant depths under the BBNPP site location (0.6 mi (1 km) radius).~~ The geologic history of the site is complex, but the current geologic processes affecting the site are limited to weathering and erosion of existing material, and subjection to the regional stress field that affects the passive Atlantic margin (Figure 2.5-8, (Heidbach, 2008)) shows the current stress fields in the eastern portion of North America, and minimal isostatic uplift. With respect to seismic stability and geologic hazards due to the site area (5 mi (8 km) radius) geologic history, the site area (5 mi (8 km) radius) and site location (0.6 mi (1 km) radius) are positioned in a stable geologic setting.

2.5.1.2.4.2 Berwick Anticlinorium

The principal bedrock structure within the site area is the Berwick Anticlinorium (also referred to as the Montour Anticline (Pohn, 2001)), which has been described (Inners, 1978) as "a moderately complex, first order fold which trends in a northeast-southwest direction". The bedrock map and section of the Berwick Quadrangle (Inners, 1978) shows the formations at the BBNPP site area to consist of Silurian, Devonian, and Carboniferous rocks that have been gently folded, with limited faulting (Figure 2.5-193 and Figure 2.5-194). The BBNPP site is situated on the northern limb of the fold~~, with beds that are steeply dipping~~. Two faults have been mapped in the vicinity: the Light Street fault located on the northern limb of the fold, and the Berwick fault inferred to be on the southern limb of the fold. The northeast end of both faults lies within the site area, but do not directly underlie the site.

2.5.1.2.4.4.1 Subsurface Investigations at the BBNPP Site

Geologic sections developed from geotechnical data collected from 45 boreholes as part of the BBNPP study (as discussed in Section 2.5.4) provide detailed information in the upper 400 ft (122 m) of strata for the presence of structures directly beneath the site. The investigation at the BBNPP site indicates that the site is underlain by unfaulted Middle Devonian shale of the Mahantango Formation. Bedding planes of the formation have been measured at and near the site with strike azimuth measurements ranging

from 61 to 100 degrees and dip angles between 10 and 20 degrees to the north-northwest~~dipping 15 to 85 degrees, and covered by a layer of undeformed glacial outwash and till~~ (Figure 2.5-200, Figure 2.5-201, Figure 2.5-202, Figure 2.5203, Figure 2.5-204, and Figure 2.5-205). The bedding plane observations within the Mahantango Formation are obscured by strong overprinting from a steeply dipping cleavage.

Cleavage planes have been measured at and near the site with strike azimuth measurements ranging from 60 to 92 degrees and dip angles between 58 and 75 degrees to the south-southeast.

2.5.1.2.4.4.2 Geophysical Investigations

Seismic refraction surveys were performed to support site characterization studies for the BBNPP (Section 2.5.4.2.2.2.3). Because earth materials exhibit characteristic wave propagation velocities, they can be classified simply in terms of their seismic velocity. Seismic refraction data were interpreted for this study to assist in characterizing the local subsurface geologic materials regarding depths to glacial till, to weathered or fractured bedrock, and to competent bedrock. Seismic refraction surveys were operated along 6 profile lines totaling 4,000 linear feet (1,219 m) of coverage. The data for the surveys were collected from January 7 through 10, 2008 using approved quality assurance procedures. The complete report of this survey (Weston, 2008) is included in COLA Part 11G.

Figure 2.5-116 is a map depicting the layout of the 6 lines used during the survey (along Lines 1 through 3, oriented north-south; and Lines A through C, oriented east-west). Seismic P-wave velocity profiles, as interpreted by the SeisOpt @2D™ software are presented on Figure 2.5-117. These profiles are plotted without vertical exaggeration, with the vertical scale measuring elevation in feet, msl. These interpreted velocity profiles indicate a generally flat-lying eroded bedrock surface overlain by a variably thin veneer of overburden material. Figure 2.5-118 is a representation of the surface of the bedrock, as indicated by an interpreted velocity of at least 14,000 fps (4,267 mps). The velocity model developed for the site depicts the bedrock surface to be apparently nearly flat lying from west to east and indications of dipping to the south are a result of the strong overprinting cleavage discussed in Section 2.5.1.2.4.4.1.

The seismic profiles constructed from manual calculations are presented in Figure 2.5-119 through Figure 2.5-124. These differ from the software-derived profiles, in that they have fewer layers, depict the depths of the units more accurately, and do not show the lateral changes in velocities that may be an artifact of the processing by the SeisOpt @2D™ software. The manual profiles also show the tops of the local bedrock as determined from borings installed during the site subsurface investigation. As is evident on the Figures, these tops compare favorably with the tops of the bedrock surface determined by seismic methods. The map of the top of the Mahantango Shale from the boring log data (Figure 2.5-125) shows the same apparent east-west strike and southward dip of the strong cleavage as the surface shown in Figure 2.5118 that was developed from the geophysical data.

2.5.1.2.4.4.4 Field Reconnaissance

Information developed from the literature and the imagery interpretation was supplemented by field reconnaissance within a 25 mi (40 km) radius of the site. These field-based studies were performed to verify, where possible, the existence of mapped bedrock faults in the BBNPP site area and to assess the presence or absence of geomorphic features suggestive of potential Quaternary fault activity along the mapped faults, or previously undetected faults. Features reviewed during the field reconnaissance and office-based analysis of aerial photography and LIDAR imagery were based on a compilation of existing regional geologic information in the vicinity of the BBNPP site. As shown on topographic section B-B' on Figure 2.5-206 there is no topographic offset to indicate recent movement of either Light Street or Berwick Faults.

Field reconnaissance was conducted by geologists in teams of two or more. Field reconnaissance visits in 2007, ~~and~~ 2008, and 2009 focused on exposed portions of the Mahantango Formation, other formation exposures along the faces of Lee and Nescopeck Mountains, and roads traversing the site vicinity. Key observations and discussion items were documented in field notebooks and photographs. Field locations were logged by hand on detailed topographic base maps and with hand-held Global Positioning System (GPS) receivers (Figure 2.5-209). There were no faults or other forms of deformation noted in the field. No surface expression of either the Berwick or Light Street faults was noted, consistent with the conclusions documented in the literature. Figure 2.5-126 and Figure 2.5-127 (Waypoint 12 on Figure 2.5-207) show that there is no offset in the Quaternary deposits along Syber Creek, where the trace of Light Street Fault crosses it. Photos of the shale bedrock on the site show the steeply dipping nature of the strong persistent cleavage. Bedding dipping to the NNW is visible but highly obscured by this cleavage~~bedding~~ (Figure 2.5-132 and Waypoint WF3 on Figure 2.5-136). Outcrops in a nearby borrow area show an undeformed contact between the glacial overburden and the shale bedrock (Figure 2.5-133, Figure 2.5-134, and Figure 2.5-135 and Waypoint WF5 on Figure 2.5-136).

A third reconnaissance was conducted during the fall of 2008, to investigate the occurrence of potential liquefaction features along the Susquehanna River. The field reconnaissance was carried out by a team of geologists and engineers from Paul C. Rizzo Associates, Inc, and John Sims & Associates from both the land and water approaches to the river banks. The investigation was conducted for the course of the river for a reach of 25 miles (40 km) upstream and downstream of the site (Figure 2.5-207). Because of the prevalent bedrock exposures in both the river banks and the river bottoms, they found few locations where liquefaction conditions were possible and no evidence that liquefaction had occurred. Figure 2.5-128 through Figure 2.5-131 show the rocky nature of the riverbed and its banks and some of the typical exposures found during the investigation (for Waypoints WP1, WP10, WP20, and WP22 respectively).

A reconnaissance was conducted during the Spring of 2009 to further investigate the occurrence of potential liquefaction features along the Susquehanna River. The study was conducted along approximately 10 miles of the Susquehanna River along the south and east bank in areas accessible by auto and on foot. The investigated areas lie south and east of the BBNPP site within the Berwick 7.5-minute topographic quadrangle.

Two tributaries of the Susquehanna River, the Wapwallopen and Little Wapwallopen creeks, were found to run on bedrock and are relatively small, but similar to other tributaries of the Susquehanna and this region. These two tributaries, like many other streams in the original study, have been disturbed by coal mining activities.

Following the additional reconnaissance, the conclusions about the low potential for liquefaction of the area remain unchanged. The rugged terrain of the Allegheny Mountains, narrow floodplains, and intense modification of the topography through anthracite coal mining confirm those conclusions. The Susquehanna River is a gently meandering river with numerous rock-core islands and boulder-cobble gravel bars. At nearly all sites that were visited, bedrock was present or nearby. The ubiquitous presence of bedrock at or near the surface militates against liquefaction and the presence of paleoliquefaction structures. The tributaries of the Susquehanna River have narrow floodplains. Coal mining debris from mine waste dumps, carried by the tributary streams of the Susquehanna River, form the visible floodplain deposits of the tributaries.

Fine-grained sediments, when present, are thin and lack the usual prerequisite for liquefiable deposites, which are fine to medium sand overlain by 1-2 meters of fine-upward silt with a clay cap. However, the banks are commonly vegetated, which significantly reduces accessibility to exposures in the river banks. Further modification of the banks by manmade stone walls, built to prevent erosion or the railroad right-of-way and sections of an early canal, exist through the studied section of the Susquehanna River.

2.5.1.2.6.4 Deformational Zones

The Light Street fault (DCNR, 2007) and the Berwick Anticlinorium (Inners, 1978) have been mapped at or within the 5 miles (8 km) radius of the BBNPP site. The Berwick Anticlinorium is an east-northeast striking, gently northeast plunging anticlinal structure with an axial trace that trends directly through the site area (5 mi (8 km) radius) and site location (0.6 mi (1 km) radius). The Berwick Anticlinorium~~e~~ is ~~an a~~symmetrical structure in the site area (5 mi (8 km) radius) with both the north-northwest and south-southeast limbs dipping with an averaged 35 degree NNW and SSE respectively~~steeply to the north-northwest and the southern limb dipping more gently to the south-southeast~~. The relevance of the Berwick Anticlinorium is that the dip of the limbs have the potential to provide sliding planes within an excavation. In addition, axial plane cleavage may have the potential to result in toppling failure from an excavation slope. Any excavations into bedrock or bedrock slopes will be mapped and monitored during excavation and backfill. Field mapping efforts did not successfully identify surface expression of the Berwick Fault or the Light Street Fault. Deformation including fracturing and folding was mapped in outcrop and is discussed in Section 2.5.3.2. In addition, a thorough literature search was conducted to identify previous studies that have identified any form of deformation in the ~~de~~bedrock or identified in the stratified glacial deposits.

2.5.3.1.1 Subsurface Investigations at the BBNPP Site

Geologic sections developed from geotechnical data collected from 45 boreholes as part of the BBNPP study (as discussed in Section 2.5.4) provide detailed information in the upper 400 ft (122 m) of strata for the presence of structures directly beneath the site. The interpretations developed from the previous investigation at the SSES site confirm the interpretation of the new borehole data at the BBNPP site:

> unfaulted Middle Devonian shale shallowly dipping ~~steeply~~ to the north-northwest, with a strong south-southeast dipping cleavage, and covered by a layer of undeformed glacial outwash and till (Figure 2.5-200, Figure 2.5-201, Figure 2.5-202, Figure 2.5-203, Figure 2.5204, and Figure 2.5-205).

Although the bedrock formations underlying the BBNPP ~~site are steeply dipping and~~ have experienced folding during the Alleghanian Orogeny (Williams, 1987; Faill, 1999), surficial sediments of the site display no signs of faulting or folding during the Pleistocene to Holocene time period (Figure 2.5-196), and rest unconformably on the eroded surface of the tilted beds of the local shale bedrock.

Figure 2.5-116 is a map depicting the layout of the 6 lines used during the survey (along Lines 1 through 3, oriented north-south; and Lines A through C, oriented east-west). Seismic P-wave velocity profiles, as interpreted by the SeisOpt @2D™ software are presented on Figure 2.5-117. These profiles are plotted without vertical exaggeration, with the vertical scale measuring elevation in feet, msl. These interpreted velocity profiles indicate a generally flat-lying eroded bedrock surface overlain by a variably thin veneer of overburden material. Figure 2.5-118 is a representation of the surface of the bedrock, as indicated by an interpreted velocity of at least 14,000 fps (4,267 mps). The velocity model developed for the site depicts the bedrock surface to be apparently nearly flat lying from west to east and indications of dipping to the south are a result of strong overprinting cleavage as discussed in Section 2.5.1.2.4.4.1.

The subsurface profiles constructed from manual calculations are presented in Figure 2.5-119 through 2.5-124. These differ from the software-derived profiles, in that they have fewer layers, depict the depths of the units more accurately, and do not show the lateral changes in velocities that may be an artifact of the processing by the SeisOpt @2D™ software. The manual profiles also show the tops of the local bedrock as determined from borings installed during the site subsurface investigation. As is evident on the Figures, these tops compare favorably with the tops of the bedrock surface determined by seismic methods. The map of the top of the Mahantango Shale from the boring log data (Figure 2.5-125) shows ~~the same~~ east-west strike and southward inclination similar to~~dip as~~ the surface shown in Figure 2.5-118 that was developed from the geophysical data.

2.5.3.1.2 Interpretation of Aerial Photography and LIDAR Imagery

Aerial reconnaissance within a 25 mi (40 km) radius of the site was conducted by various personnel using aerial photographs from numerous publications. Figure 2.5-136 is a sample of the aerial imagery used, and it contains selected way points from the field reconnaissance. LIDAR imagery of the BBNPP site vicinity was also acquired for review and interpretation. The ~~central portion of the~~ LIDAR image contains elevation data with a 2 ft (0.6 m) contour interval. ~~For clarity, the remainder of the image is a shaded relief representation without contours.~~

Figure 2.5-206 and 2.5-210 contain four topographic cross-sections (A, B, C on Figure 2.5-206, and D on Figure 2.5-210) based on the new LiDAR data set from Luzerne County. The intent of these figures is to review the LiDAR data set in both plan and section view to evaluate the detailed surface of the land as captured by the LiDAR process.

Figure 2.5-209 shows the BBNPP site geology on the LiDAR data base map. Figure 2.5-219 depicts the surficial sediment description including glacial derived features and deposit contacts overlaid on the LiDAR data base map. The same LiDAR data base map without the surficial sediment description is shown in Figure 2.5-220.

The site area geology is presented on the LiDAR data base map in Figure 2.5-221 and Figure 2.5-222 shows the same image without the site area geology. Figure 2.5-223 is similar to Figure 2.5222 but has the higher altitudes eliminated to show the detail for the lower elevations where the BBNPP site is located.

The site vicinity geology along with the LiDAR base map is presented in Figure 2.5-224. Figure 2.5-225 shows theLIDAR base map without the site vicinity geology. Figure 2.5-224 and Figure 2.5-225 include not only the trace for the Lightstreet and Berwick faults, but also all of the described geologic features at this scale.

The interpretation of the plan-view LiDAR maps incorporates an evaluation of the fracture traces and lineaments visible on the images as linear valleys and swales and straight segments of streams. The features are especially visible for the site on Figure 2.5-220. The orientations of the fractures observed in the outcrop of the Mahantango Shale are within the reported envelope of orientations reported by Inners (1978, Figure 3). There is a single dominant set striking just west of north, with a subordinate set at nearly right angles to the first. These appear to be nearly vertical. The right-angle bend in Walker Run to the southwest of the BBNPP center point, illustrates those trends, as the Run has eroded through the glacial cover to expose the underlying structures. Other orientations are present in the outcrop areas of formations to the north and south of the Mahantango, as is also reported by Inners (1978, Figures 4 and 5).

The topographic cross sections presented in Figures 2.5-206 and 2.5-210 display no offsets that are attributable to the actions of the Berwick or Light Street Faults. The current work confirms the work by Inners (1978) who reports the faults to be locally buried beneath the glacial terrace gravels. In the excavations for the Susquehanna Units, Inners found several slickensided surfaces at low-angles to the bedding planes located less than 1 mile (1.6 km) to the northeast of the site (Figure 2.5-209). He interpreted these surfaces as wedge faults that usually developed along small-scale drag folds during the folding of the units during the Alleghanian Orogeny, approximately 250 Ma (Inners, 1978). The current investigation found a similar slickensided surface at a distance of 0.30 miles (.50 km) to the southwest of the site (Figure 2.5-209). The throw on these faults is usually less than three feet (Inners, 1978), and the field team observed no offset of the glacial materials overlying this feature in the field. Section D on Figure 2.5-210 passes through the area of the slickensided surfaces to the northeast of the site, and does not indicate any offsets that could be attributed to these old, low-angle, and low throw faults.

2.5.3.1.3 Field Reconnaissance

Information developed from the literature and the imagery interpretation was supplemented by field reconnaissance within a 25 mi (40 km) radius of the site. These field-based studies were performed to verify, where possible, the existence of mapped bedrock faults in the BBNPP site area and to assess the presence or absence of geomorphic features suggestive of potential Quaternary fault activity along the mapped faults, or previously undetected faults. Features reviewed during the field reconnaissance and office-based analysis of aerial photography and LIDAR imagery were based on a compilation of existing regional geologic information in the vicinity of the BBNPP site, as referred to in Section 2.5.3.1.2. As shown on topographic section B-B' on Figure 2.5-206 there is no topographic offset to indicate recent movement of either Light Street or Berwick Faults.

Field reconnaissance was conducted by geologists in teams of two or more. Field reconnaissance visits in 2007, ~~and~~ 2008, and 2009 focused on exposed portions of the Mahantango Formation, other formation exposures along the faces of Lee and Nescopeck Mountains, and roads traversing the site vicinity. Key observations and discussion items were documented in field notebooks and photographs. Field locations were logged by hand on detailed topographic base maps and with hand-held Global Positioning System (GPS) receivers (Figure 2.5-209). There were no faults or other forms of deformation noted in the field. No surface expression of either the Berwick or Light Street faults was noted, consistent with the conclusions documented in the literature. Figure 2.5-126 and Figure 2.5-127 (Waypoint 12 on Figure 2.5-207) show that there is no offset in the Quaternary deposits along Syber Creek, where the trace of Light Street Fault crosses it. Photos of the shale bedrock on the site show the steeply dipping nature of the strong persistent cleavage. Bedding dipping to the north-northwest is visible, but highly obscured by this cleavage~~bedding~~ (Figure 2.5-132 and Waypoint WF3 on Figure 2.5-136). Outcrops in a nearby borrow area show an undeformed contact between the glacial overburden and the shale bedrock (Figure 2.5-133, Figure 2.5-134, and Figure 2.5-135 and Waypoint WF5 on Figure 2.5-136).

A third reconnaissance was conducted during the fall of 2008, to investigate the occurrence of potential liquefaction features along the Susquehanna River. The field reconnaissance was carried out by a team of geologists and engineers from Paul C. Rizzo Associates, Inc, and John Sims & Associates from both the land and water approaches to the river banks. The investigation was conducted for the course of the river for a reach of 25 miles (40 km) upstream and downstream of the site (Figure 2.5-207). Because of the prevalent bedrock exposures in both the river banks and the river bottoms, they found few locations where liquefaction conditions were possible and no evidence that liquefaction had occurred. Figure 2.5-128 through 2.5-131 show the rocky nature of the riverbed and its banks and some of the typical exposures found during the investigation (for Waypoints WP1, WP10, WP20, and WP22 respectively).

A reconnaissance was conducted during the Spring of 2009 to further investigate the occurrence of potential liquefaction features along the Susquehanna River. The study was conducted along approximately 10 miles of the Susquehanna River along the south and east bank in areas accessible by auto and on foot. The investigated areas lie south and east of the BBNPP site within the Berwick 7.5-minute topographic quadrangle.

Two tributaries of the Susquehanna River, the Wapwallopen and Little Wapwallopen creeks, were found to run on bedrock and are relatively small, but similar to other tributaries of the Susquehanna and this region. These two tributaries, like many other streams in the original study, have been disturbed by coal mining activities.

Following the additional reconnaissance, the conclusions about the low potential for liquefaction of the area remain unchanged. The rugged terrain of the Allegheny Mountains, narrow floodplains, and intense modification of the topography through anthracite coal mining confirm those conclusions. The Susquehanna River is a gently meandering river with numerous rock-core islands and boulder-cobble gravel bars. At nearly all sites that were visited, bedrock was present or nearby. The ubiquitous presence of bedrock at or near the surface militates against liquefaction and the presence of paleoliquefaction structures. The tributaries of the susquehanna have narrow floodplains. Coal mining debris from mine waste dumps, carried by the tributary streams of the Susquehanna, form the visible floodplain deposits of the tributaries.

Fine-grained sediments, when present, are thin and lack the usual prerequisite for liquefiable deposites, which are fine to medium sand overlain by 1-2 meters of fine-upward silt with a clay cap. However, the banks are commonly vegetated, which significantly reduces accessibility to exposures in the river banks. Further modification of the banks by manmade stone walls, built to prevent erosion or the railroad right-of-way and sections of an early canal, exist through the studied section of the Susquehanna River.

2.5.4.2.1 BBNPP Soil Profile

The natural topography at the BBNPP site, at the time of the subsurface exploration, was a gently sloping open field cut across by a highly eroded east-west trending bedrock anticlinorium~~e with a dip of approximately 70°~~. The maximum variation in relief was about 144.5 ft (44 m) across the site. Ground surface elevations at the time of exploration ranged from approximately 800 ft to 656 ft (244 to 200 m) mean sea level (msl), with an average elevation of about 680 ft (207 m). The ground surface elevations in the Powerblock area ranged from about 656 ft to 675 ft (200 to 206 m), with the centerline of the BBNPP through the Reactor Building at an elevation of 666.6 ft (203.2 m). The Powerblock includes the Reactor Building, Fuel Pool Building, Reactor Auxiliary Building, Safeguard Buildings, Radioactive Waste Processing Building, Emergency Power Generating Buildings, Essential Service Water System (ESWS) Cooling Towers, and Turbine Building.

The BBNPP subsurface investigation focused on the upper 400 ft (122 m) of the subsurface structure. The site geology is comprised of glacial soil deposits underlain by bedrock, which is, on average, 38.9 ft (11.9 m) below the ground surface. The subsurface structure is divided into the following stratigraphic units:

- Overburden Soil: - Glacial Till
- Bedrock: - Mahantango Formation

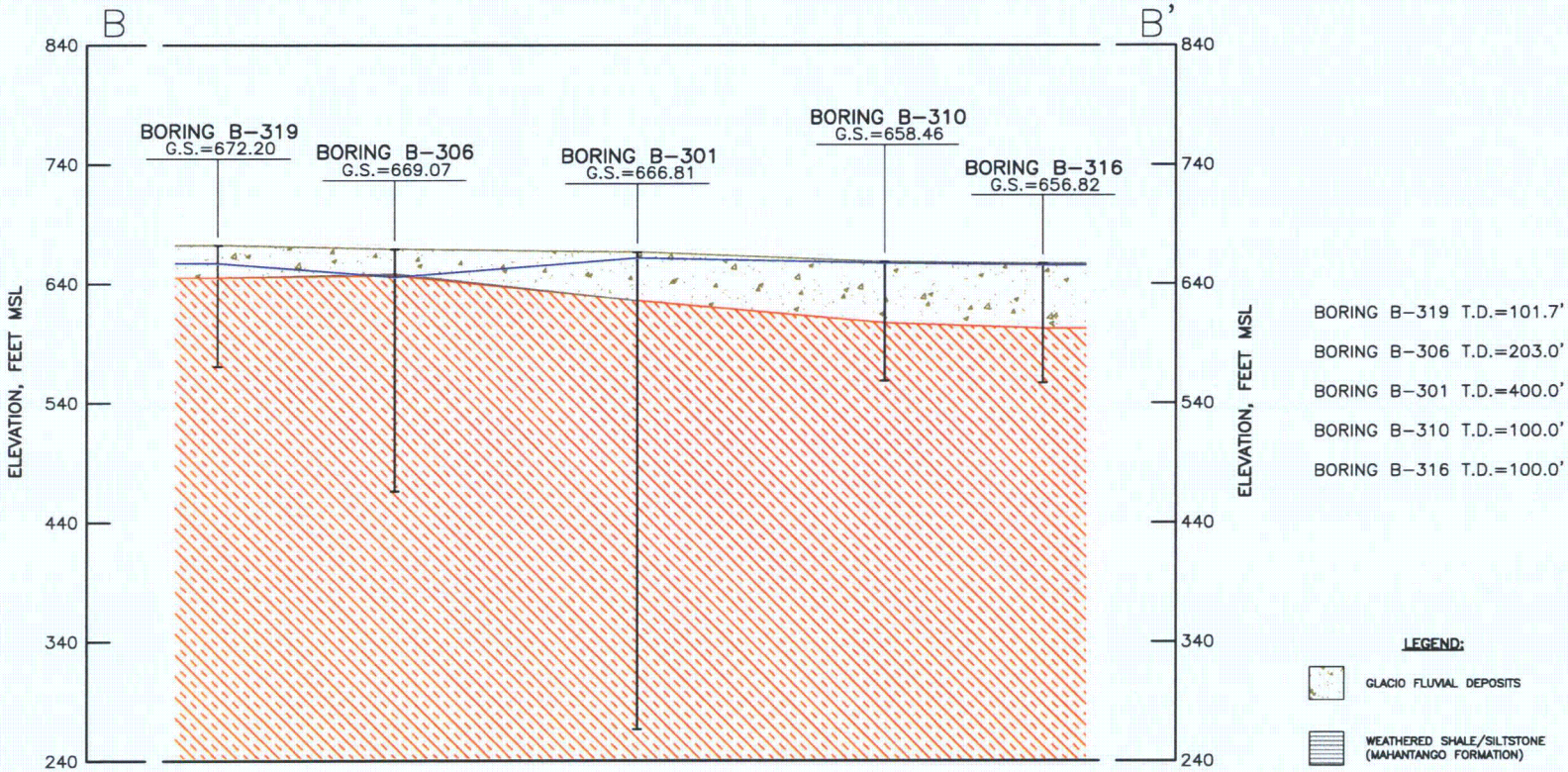
Identification of soil and rock layers was based on their physical and engineering characteristics. The characterization of the soils and rocks was based on a suite of tests performed on these soils and rocks, consisting of standard penetration tests (SPT) in soil borings including auto-hammer energy measurements, geophysical testing, pressuremeter tests (PMTs) and laboratory testing.

~~Figure 2.5-137~~Figure 2.5-180 provides a general soil column profile. Overall, the subsurface conditions encountered throughout the site are uniform, in both depth and area extension.

Figure 2.5-132 {Shale Outcrop at the Site with Steeply Dipping ~~Beds~~Cleavage (85 Degrees to the ~~ENE~~SSE)}

Figure 2.5-134 {Shale in Borrow Area Dipping 15 Degrees NNW, and Overlain by Glacial Till}

Figure 2.5-201 {Geotechnical Site Cross Section B-B}



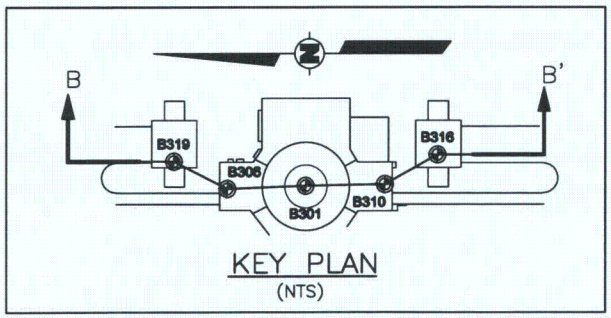
GEOTECHNICAL SECTION B-B'

LEGEND:

- GLACIO FLUVIAL DEPOSITS
- WEATHERED SHALE/SILTSTONE (MAHANTANGO FORMATION)
- SHALE/SILTSTONE (MAHANTANGO FORMATION)
- APPROXIMATE WATERLINE

VERTICAL SCALE: 100 0 100 FEET

HORIZONTAL SCALE: 200 0 200 FEET



KEY PLAN
(NTS)

NOTES:

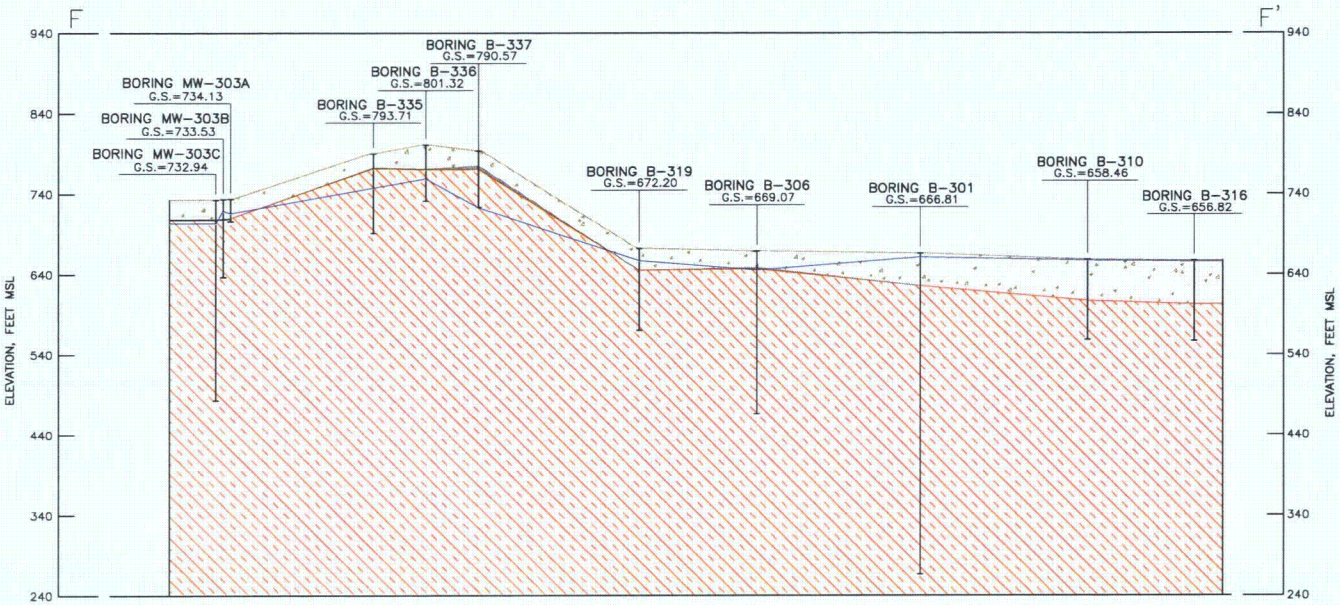
1. THE DEPTH AND THICKNESS OF SOIL AND ROCK STRATA INDICATED ON THE SUBSURFACE PROFILE WERE OBTAINED BY INTERPOLATING BETWEEN BORINGS. INFORMATION ON ACTUAL SOIL AND ROCK CONDITIONS EXIST ONLY AT BORING LOCATIONS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.
2. USGS FIELD CLASSIFICATION USED.
3. SOIL AND ROCK CLASSIFICATION MADE IN ACCORDANCE WITH ASTM D2487-06 AND ASTM D2488-06.
4. SITE-MAHANTANGO BEDROCK AVERAGE ORIENTATION-STRIKE (N 20°E) DIP (70° SE).

THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.

THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.

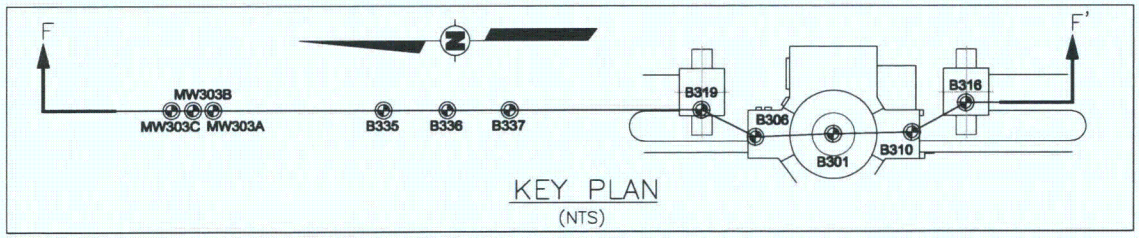
CAD FILE: 073891819.dwg

Figure 2.5-205 {Geotechnical Site Cross Section F-F}



BORING B-303C T.D.=250.0'
BORING B-303B T.D.=97.0'
BORING B-303A T.D.=56.0'
BORING B-335 T.D.=70.0'
BORING B-336 T.D.=70.0'
BORING B-337 T.D.=99.5'
BORING B-319 T.D.=101.7'
BORING B-306 T.D.=203.0'
BORING B-301 T.D.=400.0'
BORING B-310 T.D.=100.0'
BORING B-316 T.D.=100.0'

GEOTECHNICAL SECTION F-F'



KEY PLAN
(NTS)

LEGEND:

- GLACIO FLUVIAL DEPOSITS
- WEATHERED SHALE/SILTSTONE (MAHANTANGO FORMATION)
- SHALE/SILTSTONE (MAHANTANGO FORMATION)
- APPROXIMATE WATERLINE

VERTICAL SCALE
100 0 100 FEET

HORIZONTAL SCALE
400 0 400 FEET

NOTES:

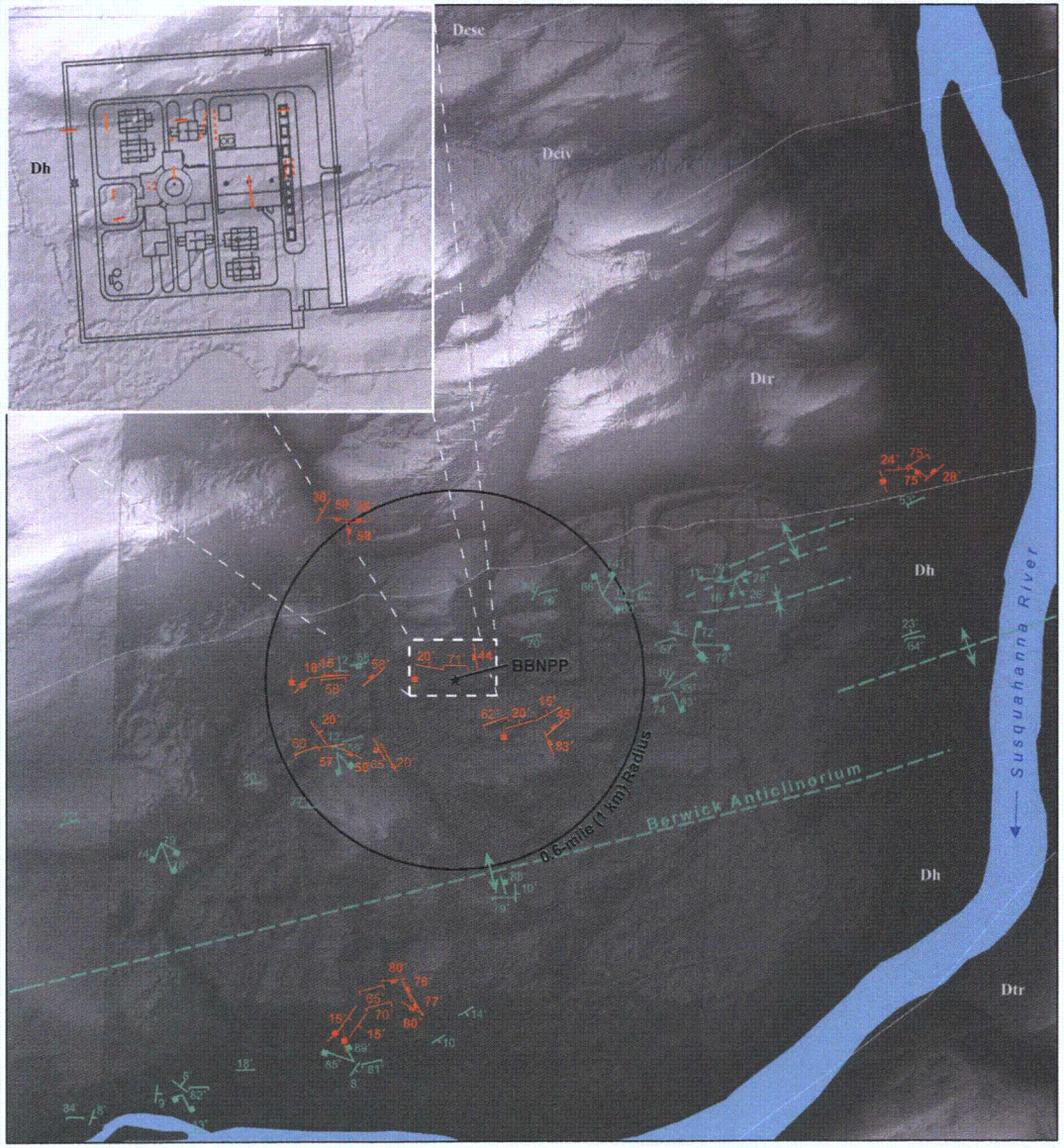
1. THE DEPTH AND THICKNESS OF SOIL AND ROCK STRATA INDICATED ON THE SUBSURFACE PROFILE WERE OBTAINED BY INTERPOLATING BETWEEN BORINGS. INFORMATION ON ACTUAL SOIL AND ROCK CONDITIONS EXIST ONLY AT BORING LOCATIONS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.
2. USGS FIELD CLASSIFICATION USED.
3. SOIL AND ROCK CLASSIFICATION MADE IN ACCORDANCE WITH ASTM D2487-06 AND ASTM D2488-06.
4. SITE-MAHANTANGO BEDROCK AVERAGE ORIENTATION-STRIKE (N 20°E) DIP (70° SE).

THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.

THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.

CAD FILE: 073891B14.dwg

Figure 2.5-209 {Site Geology in Available LiDAR Data Base map}



LEGEND

Unit Descriptions - Contact Boundary Only

Pennsylvanian

- Pl — Llewellyn Formation
- Pp — Pottsville Formation

Mississippian

- Mmc — Mauch Chunk Formation
- Mb — Burgoon Sandstone
- Mp — Pocono Formation
- MDhm — Huntley Mountain Formation
- MDsk — Spechty Kopf Formation

Devonian

- Dck — Catskill Formation

Catskill Formation Members:

- Dcb — Buddys Run Member
- Dcd — Duncannon Member
- Dccf — Clarks Ferry Member
- Dcsc — Sherman Creek Member
- Dcbs — Berry Run & Sawmill Run Members, undivided
- Dcp — Packerton Member
- Dclr — Long Run Member
- Dciv — Irish Valley Member
- Dtr — Trimmers Rock Formation
- Dh — Hamilton Group
- Doo — Onondaga & Old Port Formations, undivided
- DSkt — Keyser & Tonoloway Formations, undivided

Silurian

- Swc — Wills Creek Formation
- Sbm — Bloomsburg & Mifflintown Formations, undivided
- Sc — Clinton Group

- Fault - Inferred
- Fault
- Strike and Dip (field verified 05-21-09)
- Joint (field verified 05-21-09)
- Joint - Vertical (field verified 05-21-09)
- Cleavage (field verified 05-21-09)
- Azimuth and Plunge of Slickenslide (field verified 05-21-09)
- Strike and Dip of Minor Fault (field verified 05-21-09)

Approximate Location of Weston Anomalies

- Interpreted from Seismic Refraction Profile
- Interpreted from Top of Geophysical Bedrock

- Strike and Dip (Inners, 1978)
- Joint - Vertical (Inners, 1978)
- Joint (Inners, 1978)
- Fine / Coarse Cleavage (Inners, 1978)
- Anticline - Approximate (Inners, 1978)
- Syncline - Approximate (Inners, 1978)
- Azimuth and Plunge of Slickenline of Bedding and Fault Planes (Inners, 1978)
- Strike and Dip of Minor Fault (Inners, 1978)
- ★ Center Point of Proposed Bell Bend NPP (BBNPP)
- ○ NPP Reactor 0.6-mile (1 km) Radius

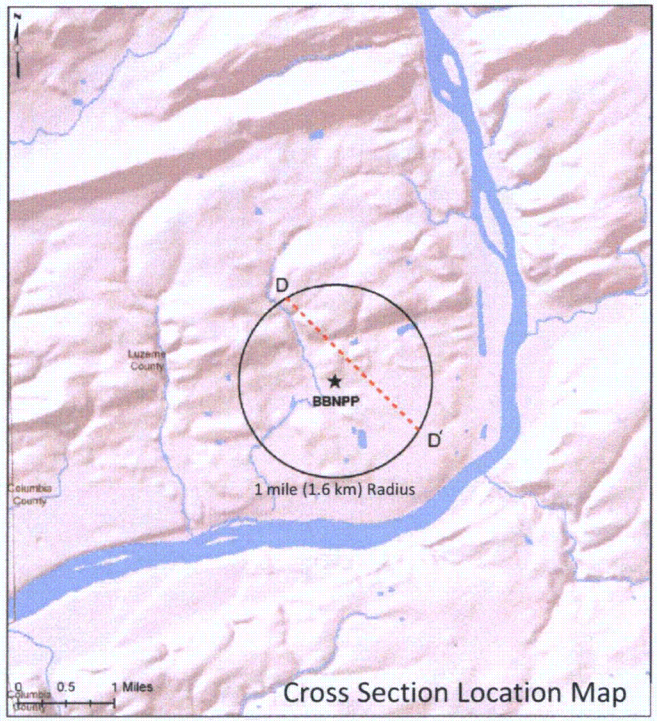
REFERENCES:

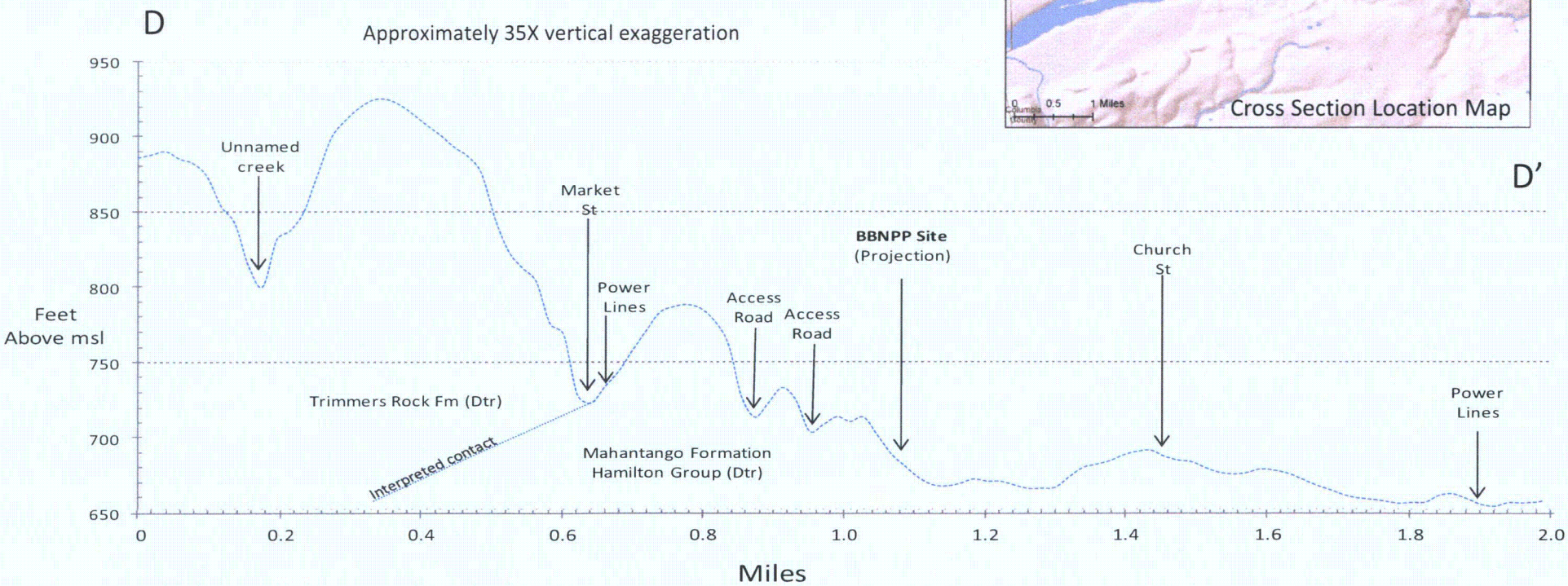
- Berg, 1980.
- Inners, 1978.
- King, 1974.
- PAMAP, 2008.
- USGS, 1989.
- ESRI, 2007.
- Weston, 2008.
- sk-12198-004-001.dwg, 2008.

0 0.25 0.5 1 miles

0 0.5 1 kilometers

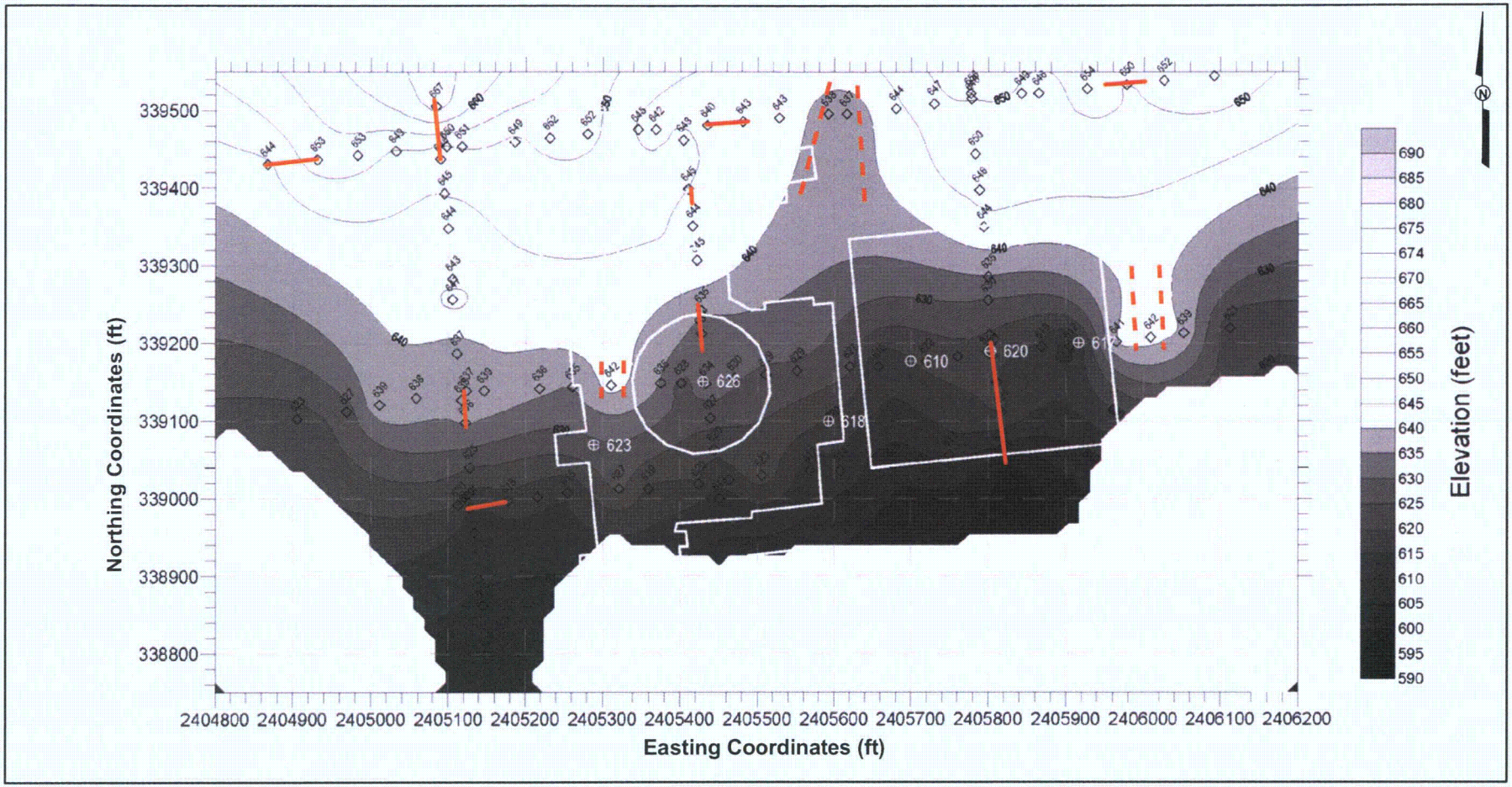
Figure 2.5-210 {Topographic Section for the Zone Nearest to the Site Based on LiDAR Data}





REFERENCE: PAMAP, 2008

Figure 2.5-226 {Uncolored Bedrock Elevation Contours Map with Anomalous Intervals/Areas from Seismic Refraction Survey}



LEGEND

Approximate Location of Weston Anomalies

Interpreted from Seismic Refraction Profile

Interpreted from Top of Geophysical Bedrock

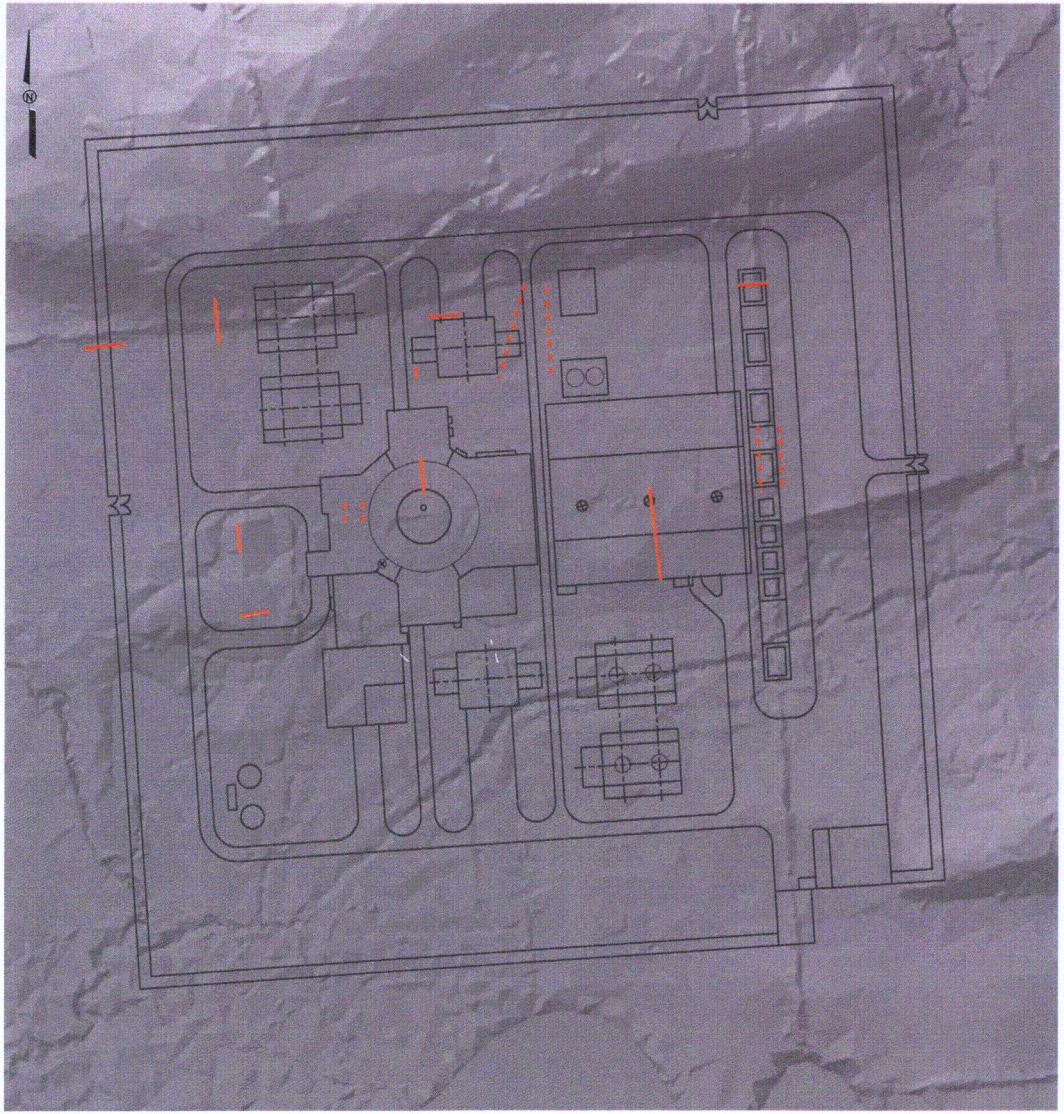
0 100 200 400 Feet

0 25 50 100 Meters

REFERENCES:

Weston, 2008.

Figure 2.5-227 {Anomalous Intervals/Areas from Seismic Refraction Survey in LiDAR Data Base Map}



LEGEND

Approximate Location of Weston Anomalies

Interpreted from Seismic Refraction Profile

Interpreted from Top of Geophysical Bedrock

0 100 200 400 Feet

0 25 50 100 Meters

REFERENCES:
- PAMAP, 2008.
- Weston, 2008.

Paul C. Rizzo Associates, Inc.
CONSULTANTS

Bell Bend NPP **PROJECT NO. 07-3891**

LOG OF BORING NO. B-306

COORDINATES
N 339313.213 E 2405413.688

SURFACE EL: 669.07

ELEVATION (FEET MSL)	DEPTH (FEET)	SAMPLE NO. OR RUN NO.	BLOW/6" & (N) OR % REC. & (RQD)	RECOVERY (ft.)	PROFILE	DESCRIPTION	USCS SYMBOL	REMARKS
	0							
	2	S-1	4-6 5 (11)	1.1		Sandy Silt (ml) - 20% sand, 50% silt, 30% clay, subangular, spherical, fine sand, soft, 0.02" max size, medium plasticity, medium dry strength, low dilatancy, medium toughness, dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4), moist, no reaction to HCL, stiff, 3.0'	ml	PPT= 1.0 tsf
666.1	4	S-2	4-5 21 (26)	1.2		Silty Sand (sm) - 10% cobbles, 75% sand, 15% silt, fine to medium, angular to subrounded sand, moderately hard, nonplastic, moderate yellowish brown (10YR 5/4), moist, no reaction to HCl, medium dense, 4.5'	sm	Sandstone cobble encountered at bottom of spoon.
664.6	6	S-3	30-40 47 (87)	1.2		Well Graded Gravel with Sand (gw) - 55% cobbles, 15% gravel, 30% sand, hard sandstone cobble subrounded to angular, fine to coarse gravel and sand, hard, 3.0" max size, nonplastic, light olive gray (5Y 6/1) to brownish gray (5YR 4/1) to pale yellowish, brown (10YR 6/2), dry, no reaction to HCl, very dense.	gw	
		S-4	21-31 25 (56)	1.4				
	8	S-5	19-50/4 (50)	0.7				
	10	S-6	23-29 26 (55)	0.9		10.5'		
658.6		S-7	22-34 32 (66)	1.0		Silty Sand with Gravel (sm) - 20% gravel, 60% sand, 20% silt, fine to coarse gravel, spherical to flat, soft, fine to coarse, subrounded to subangular sand, 0.25" max size, low plasticity, low dry strength, low dilatency, low toughness, dark yellowish brown, (10YR 4/2), moist, no reaction to HCL, dense. 12.0'	sm	
657.1	12	S-8	50/3 (50+)	0.2		Well Graded Gravel (gw) - 90% cobbles, 10% gravel, subangular to angular, hard, 3.0" max size, nonplastic, dark yellowish orange (10YR 6/6), wet, no reaction to HCl, very dense.	gw	
	14	S-9	50/3 (50+)	0.25		Well Graded Gravel (gw) - 90% cobbles, 10% gravel, fine grained cobble, hard, subangular, gravel, 3.0" max size, hard, nonplastic, yellowish gray (5Y 8/1), wet, no reaction to HCl, very dense.		

DATE STARTED: 10/8/07
DATE COMPLETED: 10/10/07
FIELD GEOLOGIST: JLO
CHECKED BY: DAR
APPROVED BY: RJB
DRILLING CO.: Terracon

GWL: DEPTH: N/A DATE/TIME: N/A
GWL: DEPTH: N/A DATE/TIME: N/A
DRILLING METHOD: SPT/Tricone/NQ Rock Core

DRILLER: Craig VanVactor HELPER: Terry Duncan

NOTES: Bedrock part of the Mahantango Formation

RIG: CME 75 Truck