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Presentation to the ACRS Subcommittee

Safety Review of the Clinch River Nuclear (CRN) Site, Early Site Permit Application

Chapter 2, Section 2.5: Geology, Seismology, and Geotechnical Engineering

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DRAFT SLIDES for
October 17, 2018

CRN Site Audits and Site Visit

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- **July 17 & 18, 2013 - Site Audit:** Staff visited the proposed site before the ESP application was submitted to observe the initial field activities being conducted by the applicant for collecting subsurface geotechnical and geologic data (Report ML13210A3070).
- **May 8 & 9, 2017 - Site Audit:** Staff visited the proposed site to discuss information derived from the continuing geologic, seismic, geophysical, and geotechnical investigations being conducted by the applicant for characterizing the site (Report ML17223A428).
- **January 30 & 31, 2018 - Site Visit:** Staff visited the proposed site to confirm the applicant's interpretations regarding faults, shear-fracture zones, and karst features (Report ML18220A749).

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Section 2.5.1 - Geologic Characterization Information

Section 2.5.3 - Surface Deformation

Content of CRN Site ESP SSAR Section 2.5.1

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Section 2.5.1 - Geologic Characterization Information

- 2.5.1.1 - Regional Geology within 320 km (200 mi) of the site: Physiography and geomorphic processes, geologic history and tectonic evolution, stratigraphy, tectonic setting (including distribution of seismicity and stress in the eastern U.S.), and non-tectonic geologic hazards (including karst).

- 2.5.1.2 - Local Geology within 40 km (25 mi), 8 km (5 mi), and 1 km (0.6 mi) of the site: Physiography and geomorphic processes, geologic history, stratigraphy and lithology, structural geology (including faults and shear-fracture zones), geologic hazards (including karst), and site engineering geology (including potential effects of human activities).

Physiographic Provinces in the CRN Site Region

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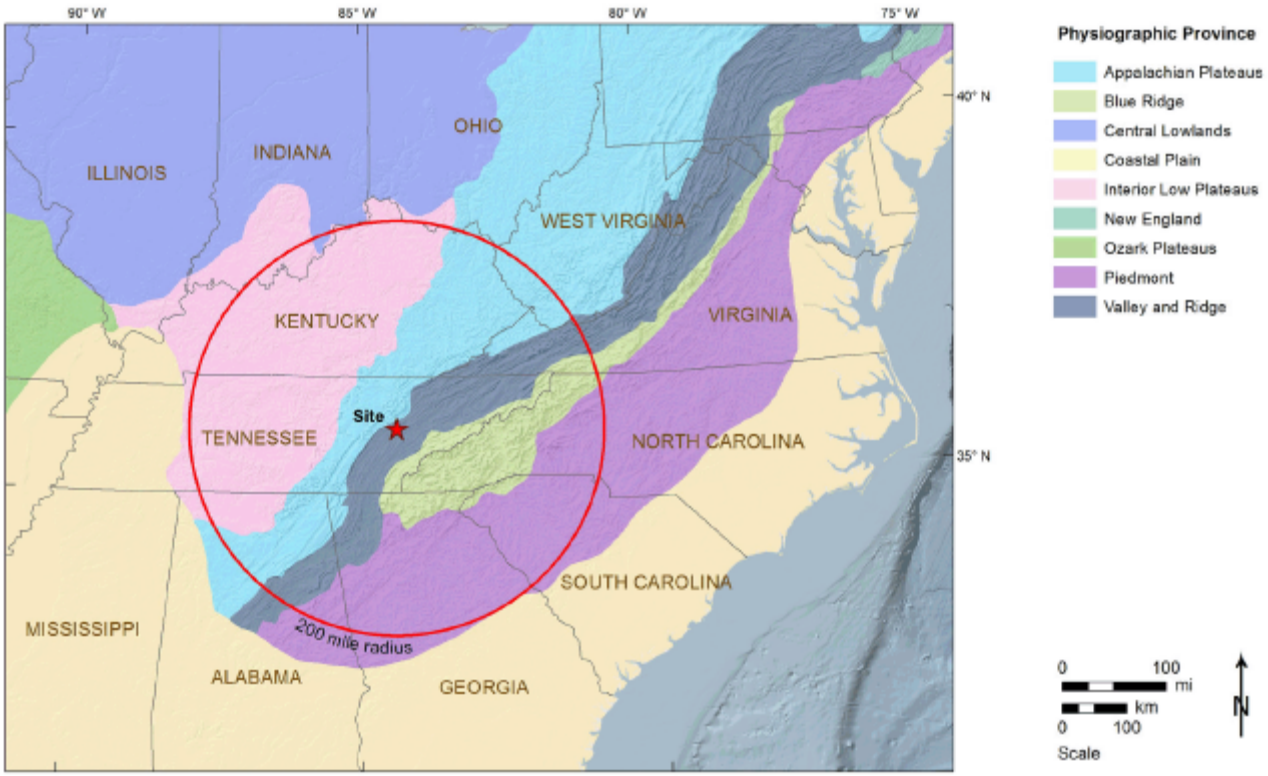

Parallel ridges and valleys of the Valley and Ridge province developed as a result of differential weathering and erosion of folded and faulted sedimentary rock units that occur in the province.

(Reproduced from SSAR Figure 2.5.1-1)

Key Geologic Features of Interest for Section 2.5.1

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Regional Thrust Faults and Localized Shear-Fracture Zones

- Neither of these features is well-exposed at the surface at the site. Staff examined them in rock core samples provided by the applicant during the site audits and site visit. Both features are generally parallel to bedding

- Thrust faults are tectonic in origin and regional structures. Shear-fracture zones are more localized and contain features of both non-tectonic and probable tectonic origin

- Staff focused on documenting that the thrust faults and the shear-fracture zones are older than Quaternary (i.e., > 2.6 Ma in age) and, consequently, pose negligible hazard for the site.

CRN Site Subsurface Stratigraphy, Faults, and Shear-Fracture Zones

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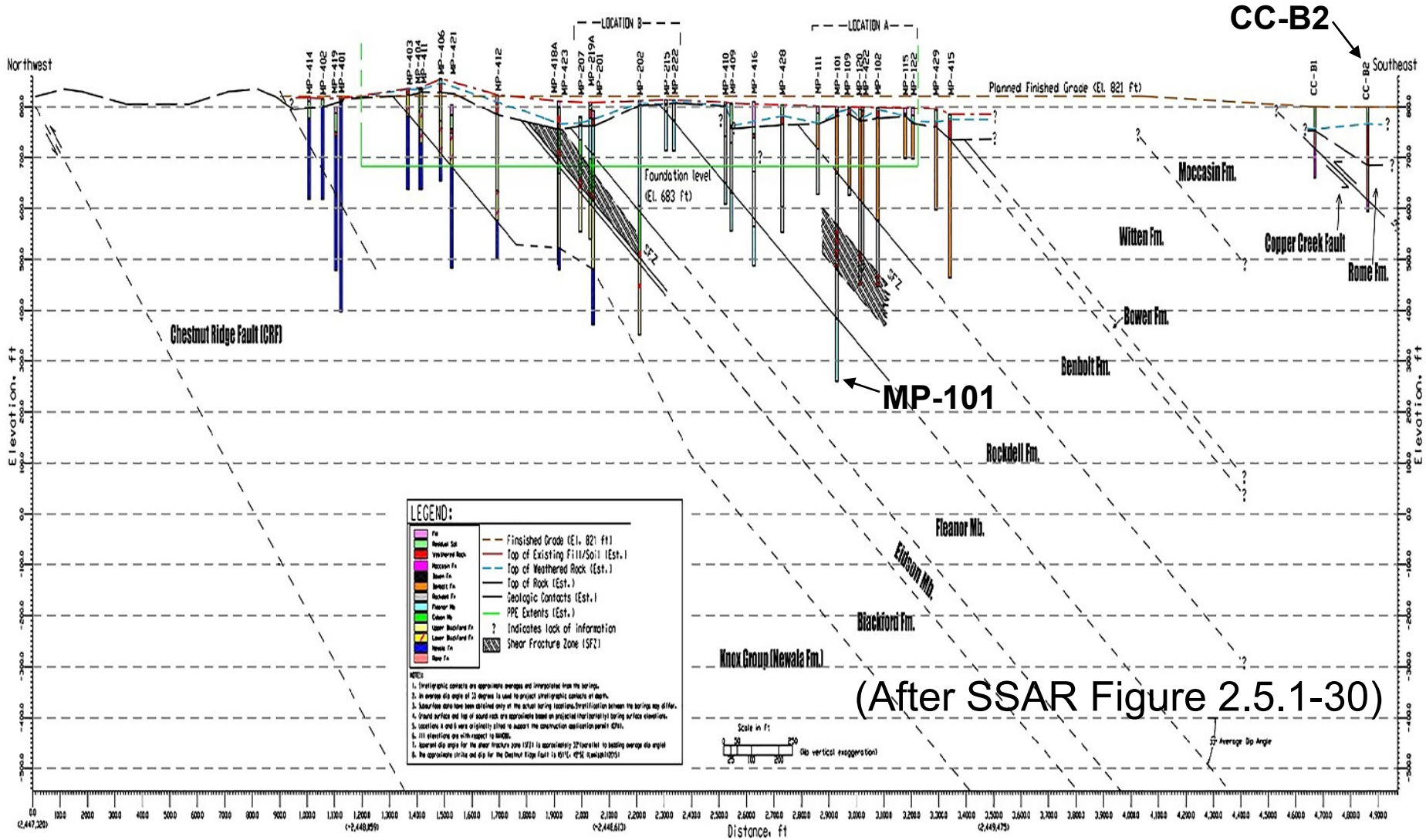

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Carbonate Strata Examined by Staff during the 01/2018 Site Visit

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Exposure of the Fleanor Formation at the site location showing amount and direction of dip of bedding commonly seen at the CRN Site (i.e., about 33 degrees southeast).

Thrust Faults

- Thrust faults are characteristic of the Valley and Ridge Province in which the site is located and do occur in the site area. There is no surface expression of any thrust faults in the site area.
- Although not exposed at the surface, the Copper Creek and Chestnut Ridge faults are located within 1 km (0.6 mi) of the site.
- During the site audits and site visit, staff examined the Copper Creek Fault in core from Borehole CC-B2. We will look at the subsurface expression of the fault in that borehole!

Geologic Map Showing Locations of Thrust Faults in the Site Area

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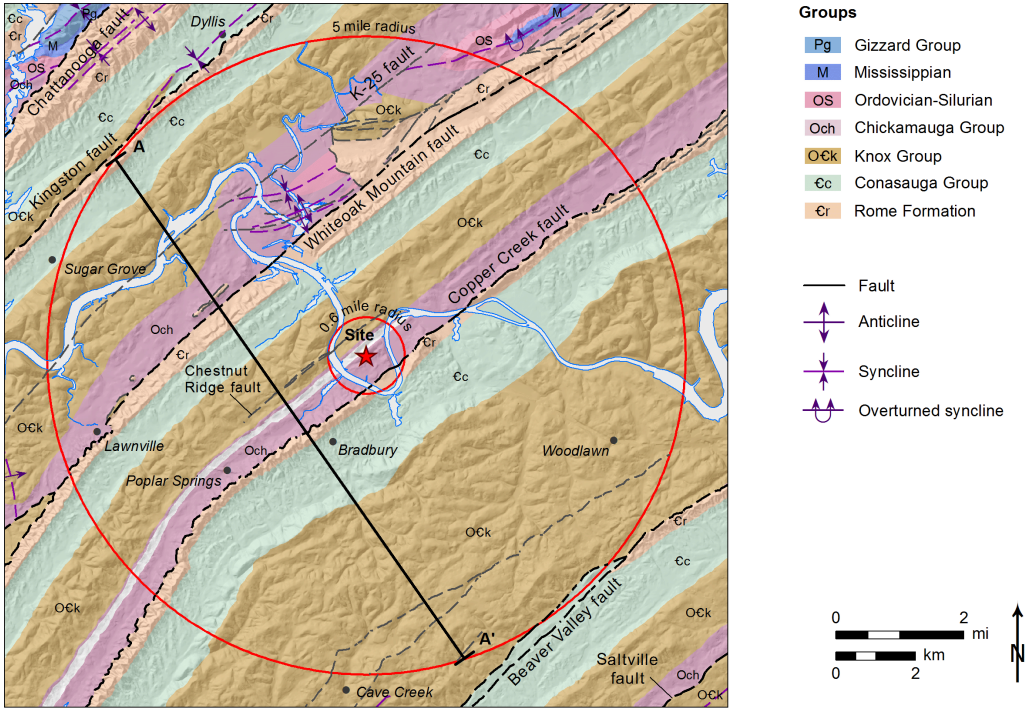

(Reproduced from SSAR Figure 2.5.1-34)

Fault gouge produced by crushing and grinding of rock units due to displacement along the Copper Creek Fault is dated at **279.5 +/- 11.3 Ma**. Reported displacement along the fault is 12-50 km (7.4-31 mi).

Note that the site lies between the northeast-striking, southeast-dipping Copper Creek and Whiteoak Mountain thrust faults.

Fault gouge marking the Copper Creek Fault in Borehole CC-B2. Note the clear distinction between the gouge, dated at ~280 Ma, and intact rock. (G. Stirewalt image, January 2018)

Shear-Fracture Zones

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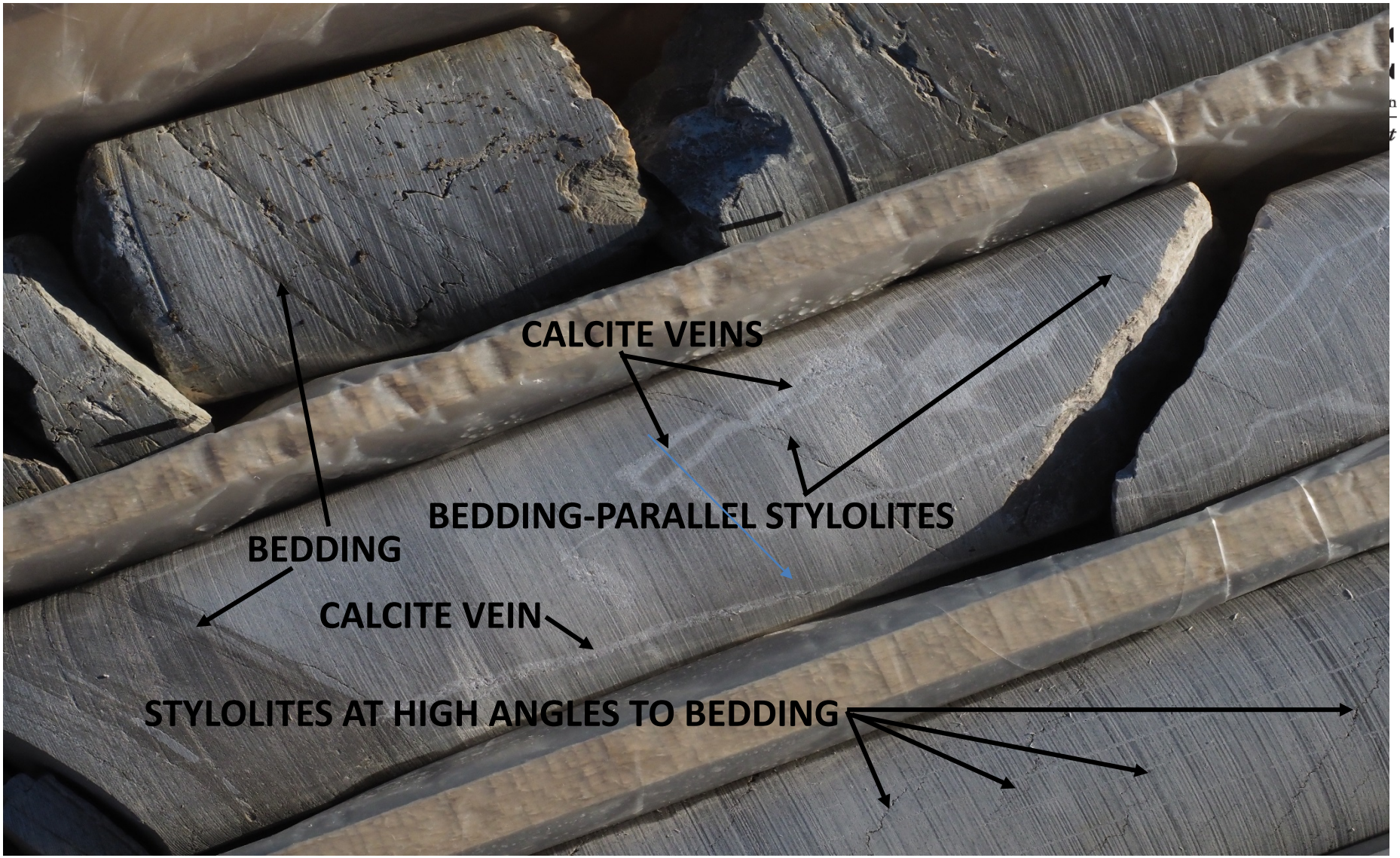
- Shear-fracture zones at the site contain pressure solution features (stylolites) oriented parallel and perpendicular to bedding. These features tell a story about orientation of stresses that affected the shear-fracture zones.

- Non-tectonic bedding-parallel stylolites (earliest) formed during deposition and lithification of sedimentary units due to vertical overburden pressures. Bedding-perpendicular stylolites (latest) likely formed in response to near-horizontal stresses related to transport of thrust sheets (~280 Ma) and suggest tectonic overprinting.

- During the site audits and site visit, staff examined the shear-fracture zone that occurs in the Rockdell Formation in core from Borehole MP-101.



Shear-fracture zone penetrated in borehole MP-101. The stylolites must have developed at two different times because they form essentially perpendicular to the causative stress. (G. Stirewalt image, January 2018)

Staff's Conclusions for CRN ESP SSAR Section 2.5.1

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- No tectonic features with the potential for adversely affecting suitability of the site occur in the site region, site vicinity, site area or at the site location (i.e., no data suggest the presence of Quaternary tectonic features). The primary tectonic event registered in the rock units, regional thrust faults, is dated at ~280 Ma. No field evidence suggests the shear-fracture zones are younger than that event.

- Karst is the primary non-tectonic feature with the potential to adversely affect suitability of the site.

- The applicant described geologic characteristics of the site region, site vicinity, site area and site location in SSAR Section 2.5.1 in full compliance with regulatory requirements in 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23(c) and in accordance with guidance in RG 1.208.

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Content of CRN ESP SSAR Section 2.5.3

Section 2.5.3 - Surface Deformation

- 2.5.3.1 through 2.5.3.8 - Information related to assessment of features that might indicate a potential for tectonic (including geologic features observed in the East Tennessee Seismic Zone) and non-tectonic (i.e., specifically karst-related features) surface deformation at the site.

Key Review Topics of Interest for Section 2.5.3

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The staff reviewed the following key topics for the potential for tectonic and non-tectonic surface deformation at the CRN site.

- The relationship of potential tectonic surface deformation to observed seismicity in the East Tennessee Seismic Zone is undetermined.
- Due to carbonate rocks in the subsurface, direct observation of karst features and ongoing dissolution processes in site vicinity, and interpreted cavities in core as indicated by missing segments, karst has the potential to cause surface deformation at the CRN Site

Distribution of mapped karst features in the CRN site area

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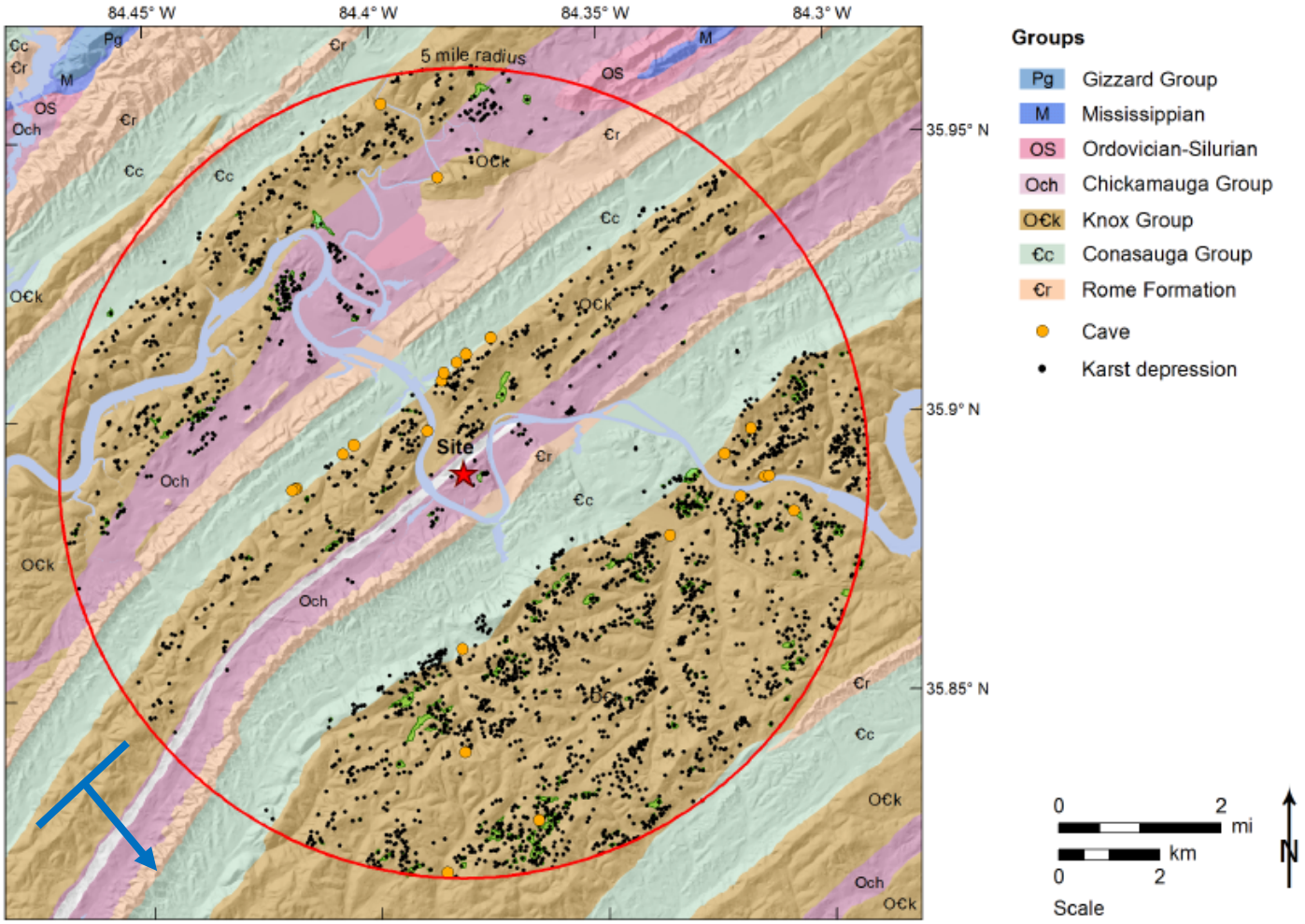

Swale: small wet depression
Swallet: slightly larger depression through which water drains
Sinkhole: surface depression as a result of subsurface collapse due to dissolution

(After SSAR Figure 2.5.1-47)

Cavities in core from borings

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Interpreted cavities of varying thicknesses recorded in numerous boreholes.

Pinnacle and cutter surficial karst features

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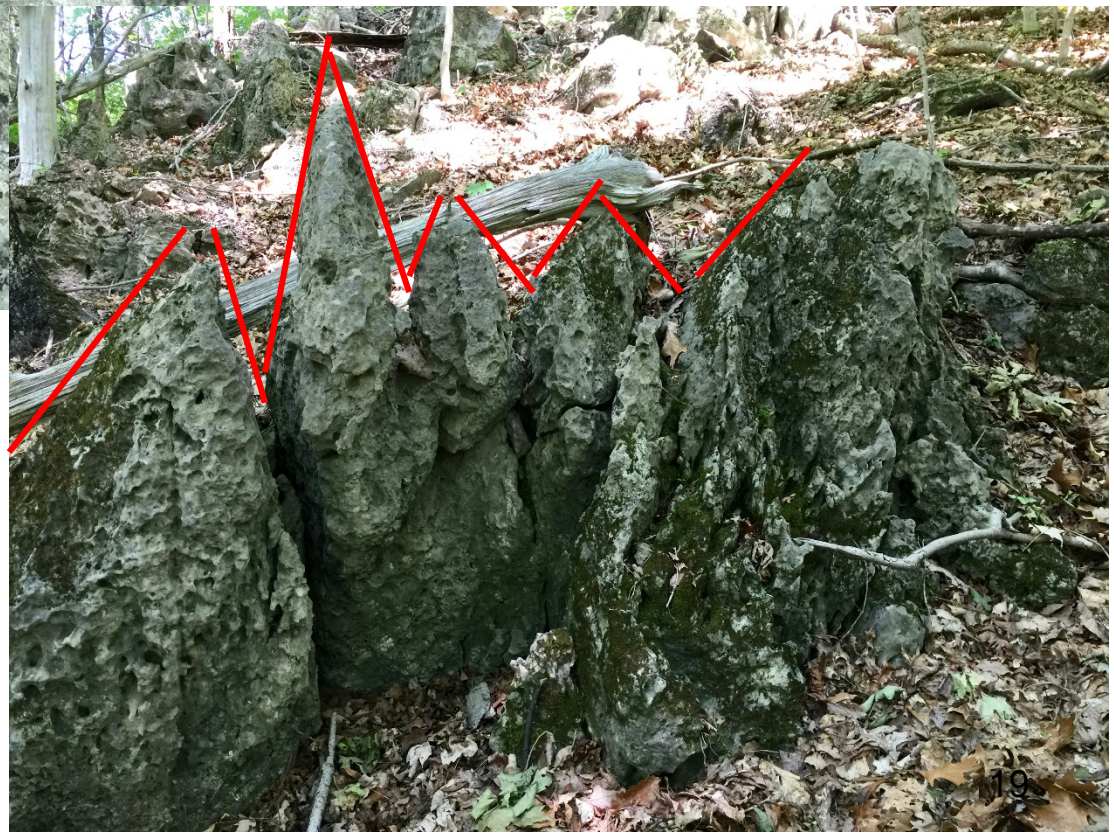
Dissolution features along joints and bedding planes resulting in cavities in the exposed rock



Swales, swallets, and sinkholes as surficial karst features

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Sinkhole within the site area with steep slope and ponded water

Entrance to Copper Ridge Cave

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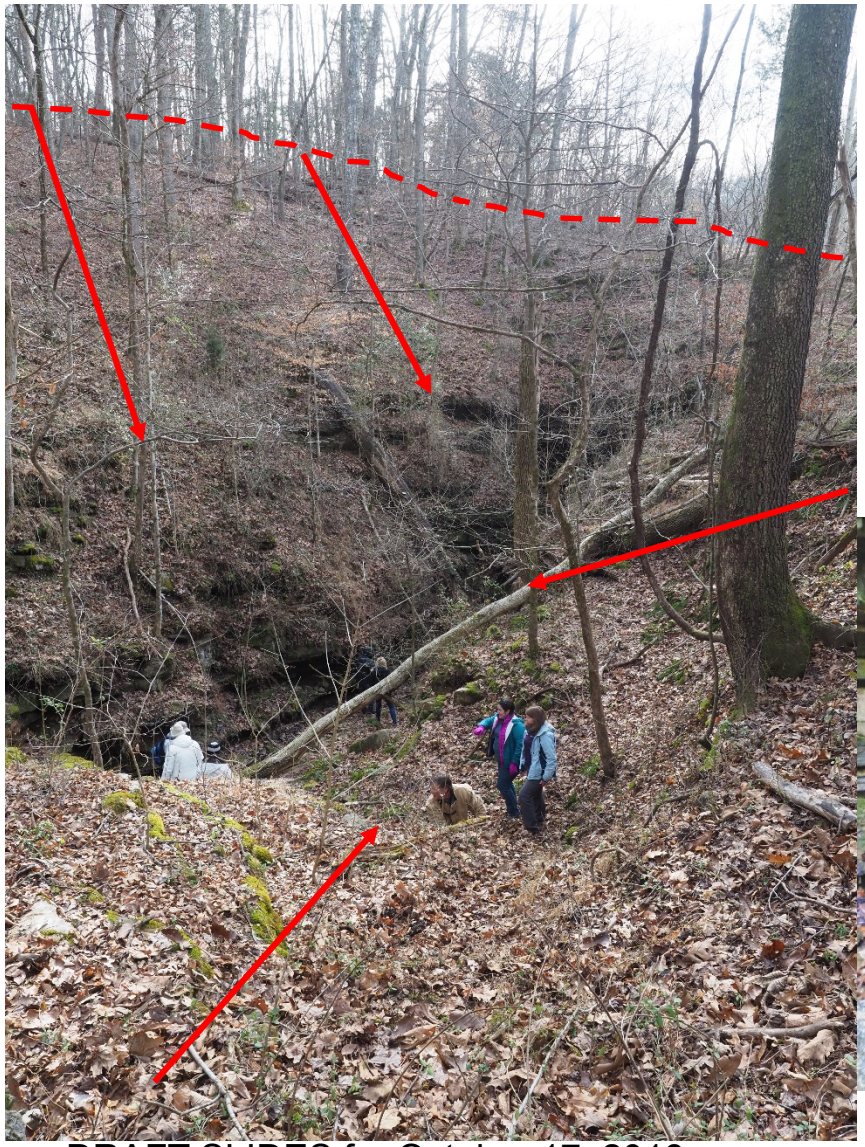

Copper Ridge Cave is the largest cave the staff visited in the Clinch River site area

Drainage flows into the cave entrance from the surrounding depression with dissolution along joints and bedding planes, including a 90-degree turn

Geologic Mapping Permit Condition

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In SSAR Section 2.5.1.2.6.10, the applicant acknowledged the need to perform detailed geologic mapping for documenting the presence or absence of karst features, faults, or shear-fracture zones in plant foundation materials. To address this need, the staff identified Permit Condition 1 in SER Section 2.5.3.5 as stated below:

- The applicant for a combined license (COL) or a construction permit (CP) that references this early site permit (ESP) shall perform detailed geologic mapping of excavations for safety-related engineered structures; examine and evaluate geologic features discovered in those excavations; and notify the Director of the Office of New Reactors, or the Director's designee, once excavations for safety-related structures are open for examination by NRC staff.

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Staff's Conclusions for CRN ESP SSAR Section 2.5.3

- Negligible potential exists for tectonic surface deformation that could adversely affect suitability of the CRN Site. Karst is the primary potential hazard for non-tectonic surface deformation at the CRN Site.

- The applicant described information related to assessment of features that might have a potential for producing tectonic and non-tectonic surface deformation at the site in SSAR Section 2.5.3 in full compliance with regulatory requirements in 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23(d) and in accordance with guidance in RG 1.208.

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Section 2.5.2 – Vibratory Ground Motion

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Key Review Topics of Interest for Section 2.5.2

- Treatment of Eastern Tennessee Seismic Zone (ETSZ)
- Approach to developing site-response analysis
- Development of 2-D site response analysis

Treatment of Eastern Tennessee Seismic Zone (ETSZ)

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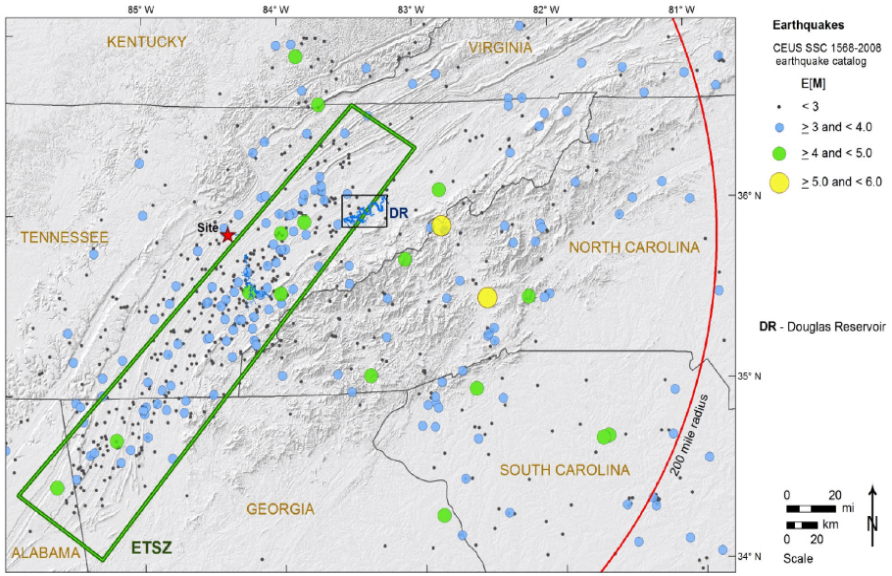
- ETSZ is region of elevated seismicity rates.
  - Small magnitude earthquakes
  - Occur within basement rocks below sedimentary section
- Included in NUREG-2115 within seismotectonic and M_{max} source zones
  - Sensitivity studies done during study to ensure that source zones adequately capture seismicity in ETSZ
- Recent geologic studies interpret potential for larger (**M**≥6.5) earthquakes



SSAR Figure 2.5.2-26

Treatment of ETSZ

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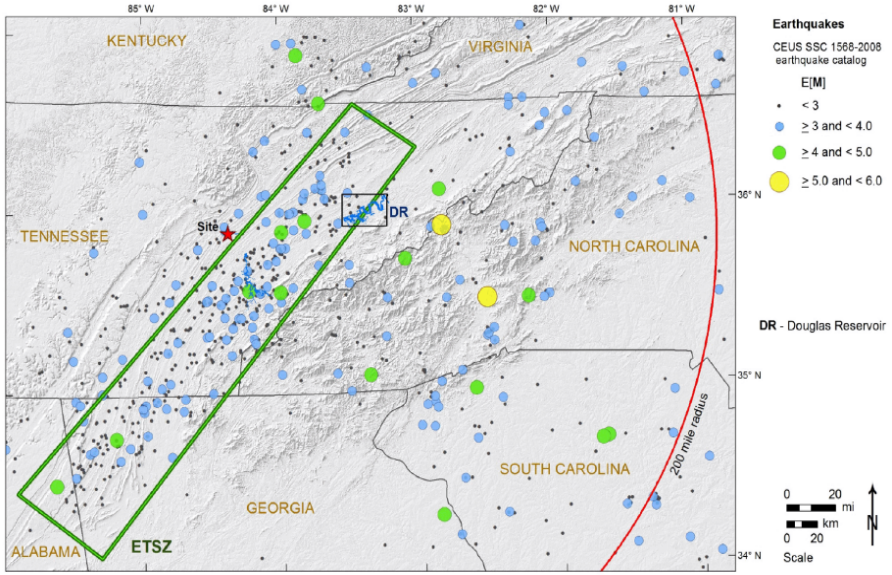
- Applicant performed two sensitivity studies following SSHAC guidance for Level II study
  - Evaluate M_{max}
  - Evaluate Magnitude-Frequency relations
- M_{max} values in NUREG-2115 encompass proposed M_{max} developed using new data
- Recurrence of large magnitude events in NUREG-2115 consistent with proposed values in new geologic studies
- Staff concludes that NUREG-2115 adequately captures current understanding of seismic hazard in the ETSZ



SSAR Figure 2.5.2-26

PSHA Confirmatory Calculations

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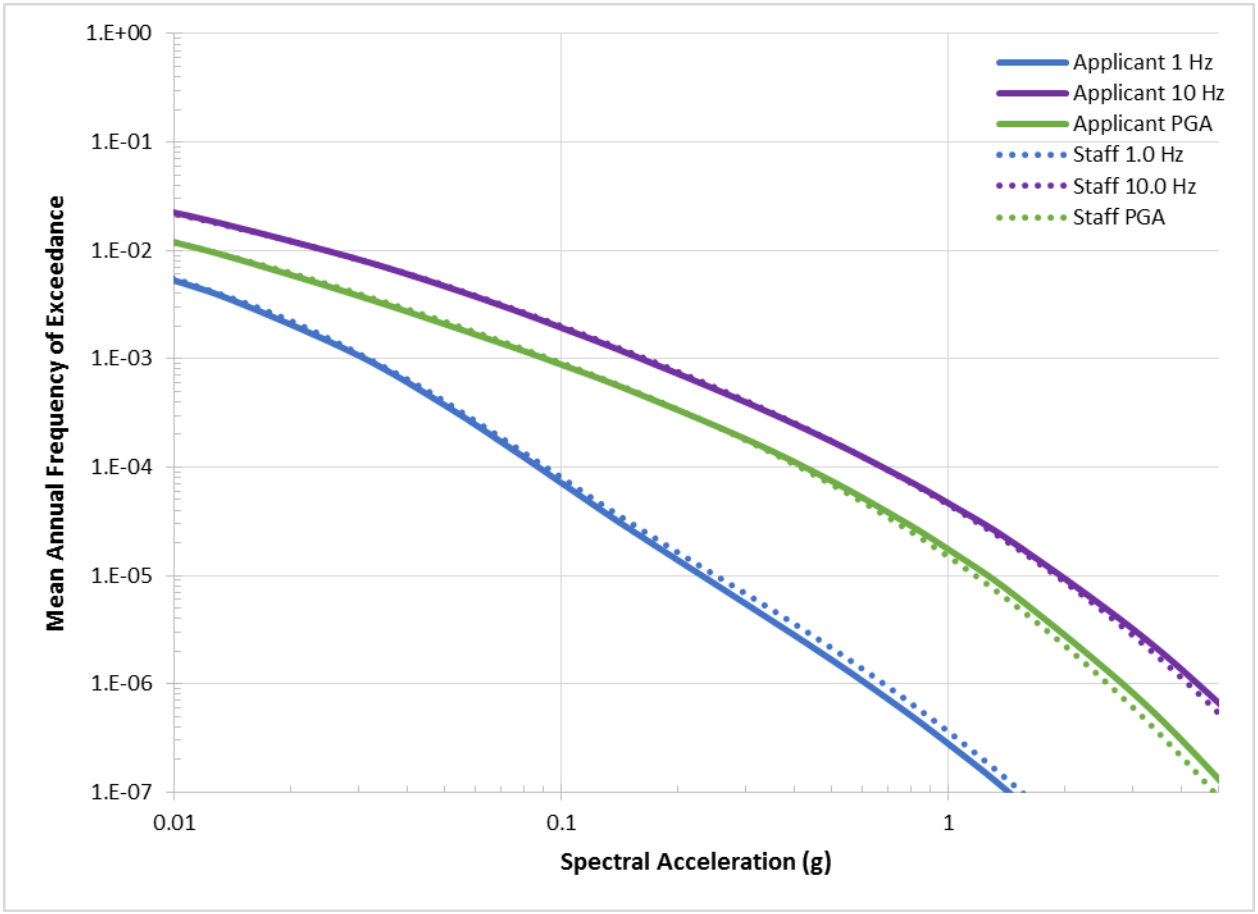

Staff independently calculated seismic hazard curves at the CRN site. Comparisons show that the seismic hazard curves are in good agreement at the annual frequency of exceedances of interest: 10^{-4}, 10^{-5}, and 10^{-6}

Approach to Site Response Inputs

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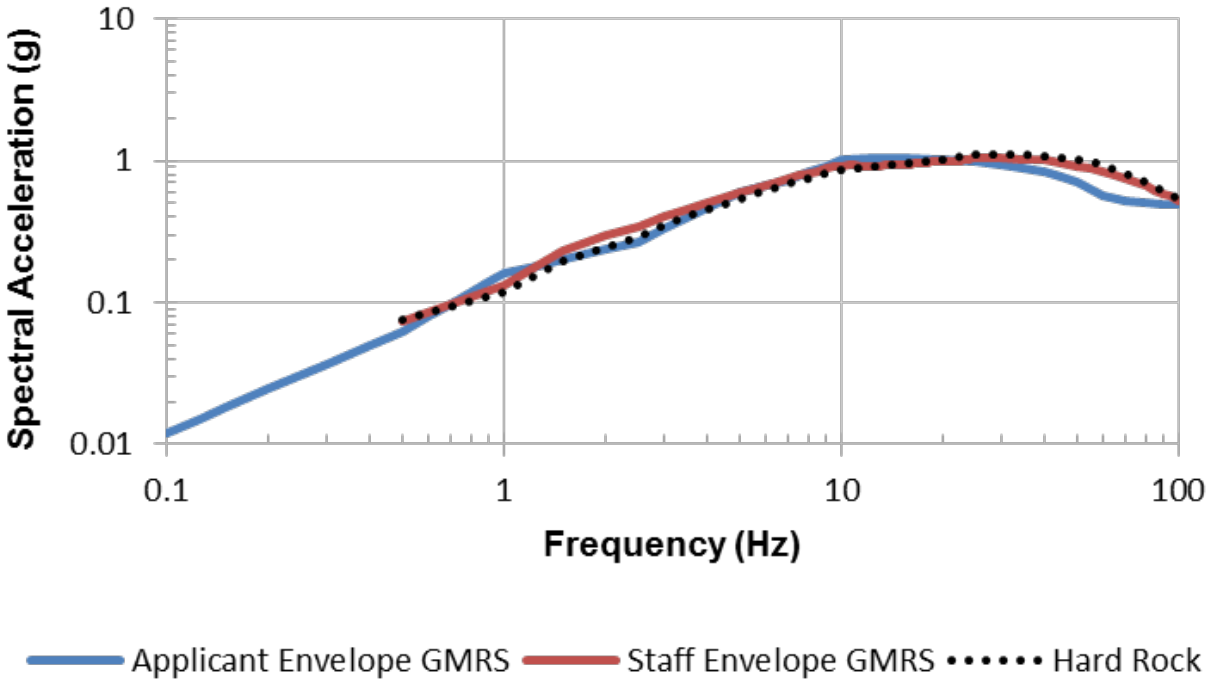
- CRN Site has significantly dipping rock layers
  - Approximately 30 degrees
- High seismic velocities
  - 5,000 to >10,000 fps
- Applicant developed site response inputs using
  - 3 profiles for each location
  - Log mean seismic velocity as function of depth as base case
  - Upper and lower case using log standard deviation
  - Effect of smearing geologic units together

- Staff requested that applicant explain how the use of multiple base cases accurately accounts for dip across site
- Applicant responded the smearing of units is appropriate because mean and range of values at a specific depth is maintained, implicitly accounting for stratigraphic variations.
- Staff performed confirmatory site response considering dip explicitly (i.e. upsection; middle; and downsection profiles)
- Staff truncated profiles at the top of the Knox Group due to thickness and velocity of layer
- Staff's results are consistent with applicant's

GMRS Confirmatory Analysis



Staff developed alternative input parameters for site response analysis. Staff independently calculated site response and developed a site GMRS based on its preferred inputs. Site GMRS developed by staff is consistent with that developed by the applicant

2-D Site Response

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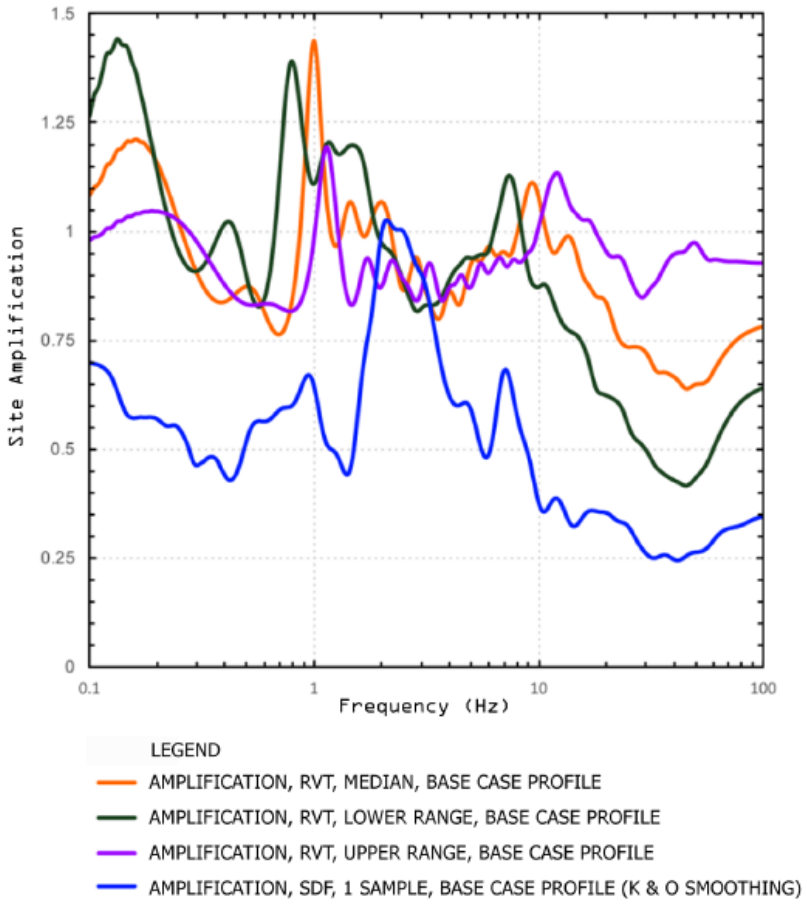
- CRN site has significantly dipping (>30 degrees) rock layers in subsurface
- RG 1.208 states that for sites with complicated subsurface structure, a multi-dimensional approach to site response may be necessary
- Applicant developed a 2-D site response analysis and compared amplification functions to 1-D results developed using 2-D inputs
- Staff requested that applicant compare 2-D results to 1-D results used in developing GMRS
- Applicant's 2-D results compare favorably with 1-D results, satisfying staff's concern



SSAR Figure 2.5.2-108

Staff Conclusions - Section 2.5.2

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- The applicant provided a thorough characterization of the seismic sources surrounding the site, as required by 10 CFR 100.23
- The applicant adequately addressed the uncertainties inherent in the characterization of these seismic sources through a PSHA, and its PSHA follows the guidance provided in RG 1.208
- Applicant's GMRS adequately represents the regional and local seismic hazards and accurately includes the effects of the local site subsurface properties

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Section 2.5.4 - Stability of Subsurface Materials and Foundations

Summary of CRN ESP SSAR Section 2.5.4

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- SSAR Section 2.5.4 presents the engineering properties of subsurface materials, and evaluation of stability of subsurface materials and foundations at the CRN Site.
- SER Section 2.5.4 includes:
  - The staff's evaluation of engineering properties of subsurface materials; foundation interfaces; geophysical surveys; excavation and backfill; groundwater conditions; response of soil and rock dynamic loading; liquefaction potential; stability of foundations
  - 16 COL Action Items
  - 1 Permit Condition

Plant Parameter Envelope

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- In order to provide sufficient geotechnical information at the site without having a specific design, the applicant provided a surrogate design in its application. The surrogate plant approach covers a set of bounding parameters: the plant parameter envelope (PPE).

- Under the PPE approach, the resulting ESP will be applicable for a range of reactor designs if their relevant design parameters fall into the PPE.

CRN ESP Site Exploration

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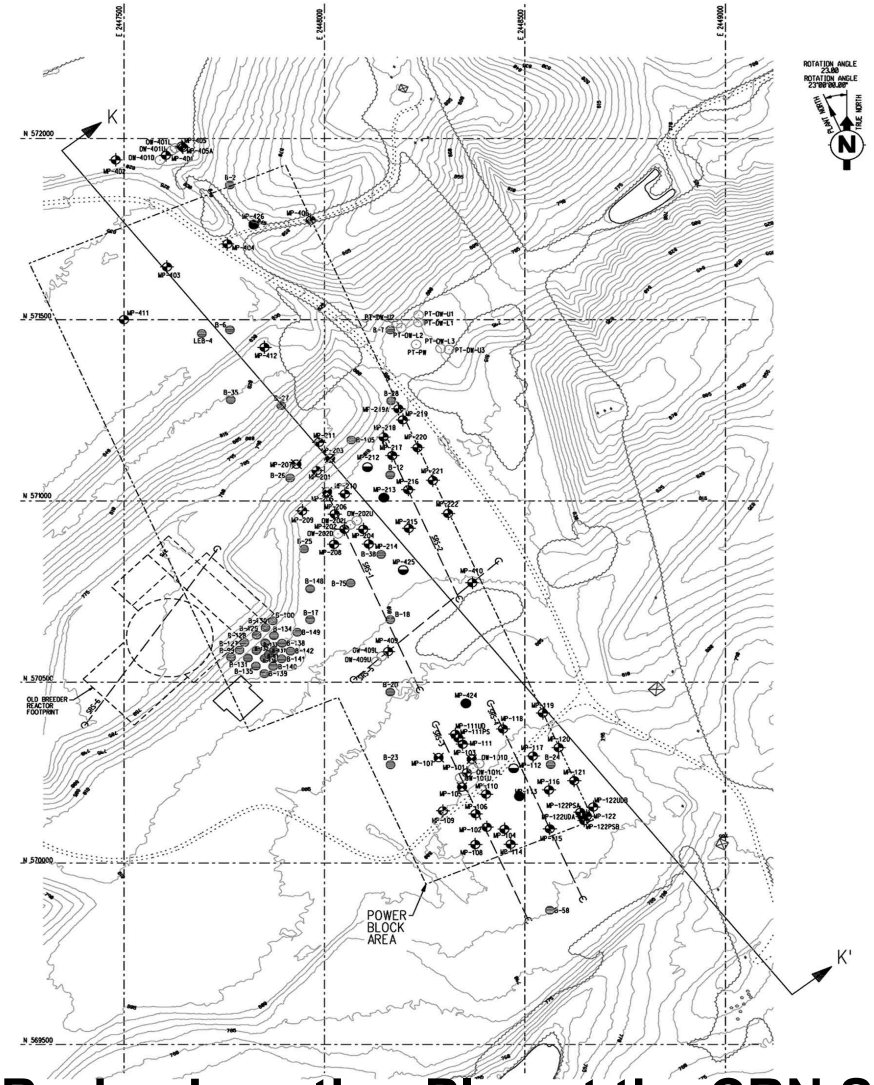

Boring Location Plan at the CRN Site

(Reproduced from SSAR Figure 2.5.4.)

Site Stratigraphy

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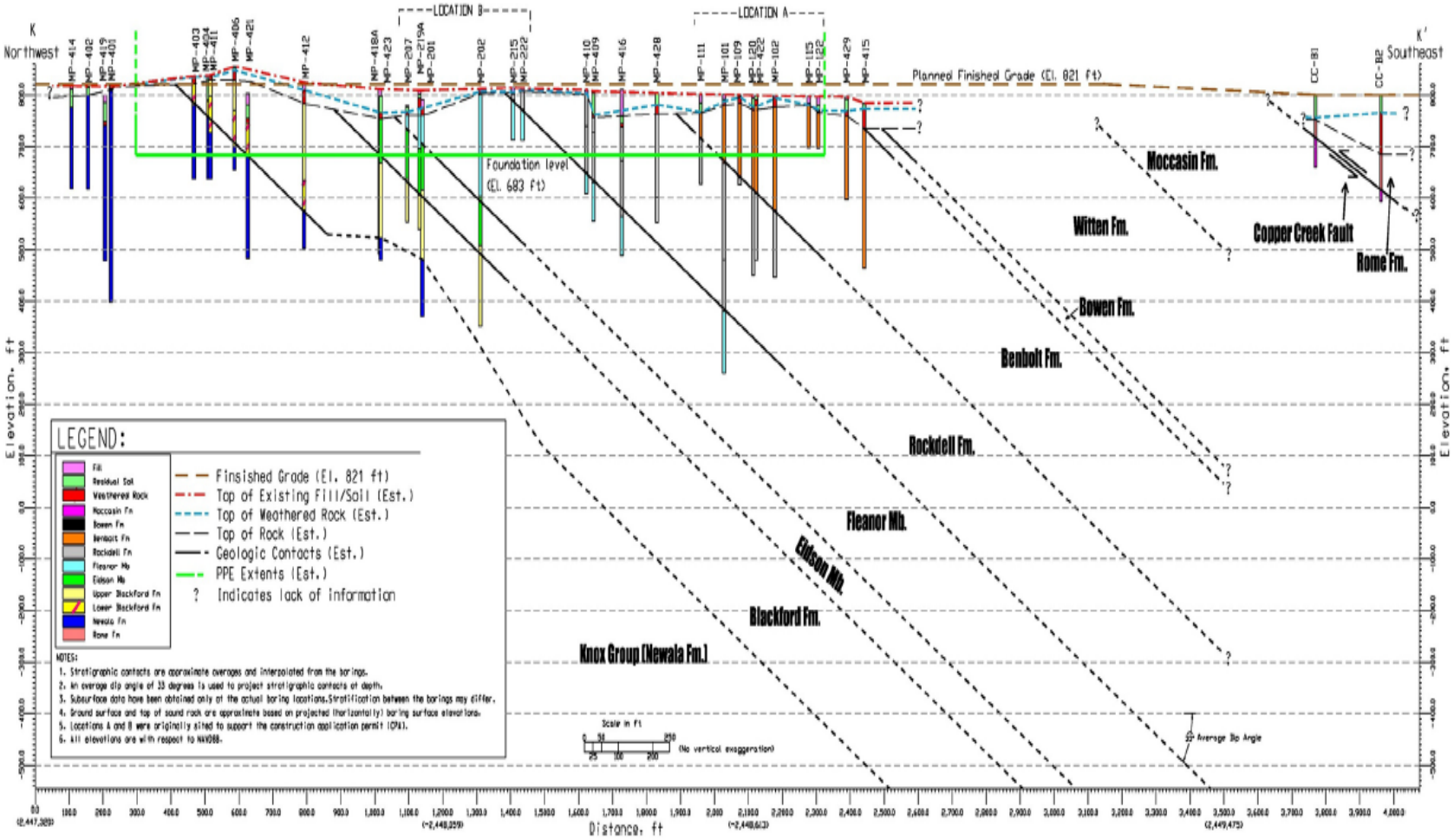

Geotechnical Cross-Section of the Stratigraphy of the Power Block Area
(Reproduced from SSAR Figure 2.5.4-1)

Key Review Topics of Interest for Section 2.5.4

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<u>Assessment of the Effects of Underground Voids on Foundation Stability</u>

- Karst exists at the CRN Site and the underground voids may adversely affect the foundation stability.
- The applicant's site investigation for ESP application provided preliminary information on void distribution and size.
- The staff reviewed the applicant's PLAXIS 2-D Finite Element (FE) model that assessed the effects of postulated underground voids on foundation stability at the CRN Site.
- The staff concludes that the applicant conducted an appropriate preliminary evaluation to determine potential karstic cavity impacts on the foundations.
- This analysis should be site location and technology specific, therefore the staff identified COL Action Item 2.5-2 which establishes that a future applicant referencing this ESP should reevaluate the potential of karstic cavity impacts, within the zone of influence of the foundation under all design loading conditions, on foundation stabilities for safety-related structures.

Key Review Topics of Interest for Section 2.5.4

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Foundation Stability Analysis for CRN Site with Inclined Strata

- The CRN Site consists of multiple inclined layers of various rock formations with possible weakened interfaces between the formations.
- The staff reviewed the applicant's multiple traditional methods and Finite Element (FE) methods used to assess foundation stability at the CRN Site.
- The staff concludes that the traditional methods results are in good agreement with those obtained from the finite element model and that the selected PPE values related to the site stability analyses are appropriate.
- The staff identified COL Action Items 2.5-12 through 2.5-14 for the COL or CP applicant to address the foundation stability of the site once a reactor technology and the specific location and extent of Seismic Category 1 structures is identified.

COL Action Items

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COL Action Items 2.5-1 through 2.5-16 specifies technology and site location specific actions that need to be addressed by the COL or CP applicant when referencing this ESP. Those COL Action Items are related to the following site characteristics:

- Site Geologic Features
- Properties of Subsurface materials
- Excavation and backfill
- Groundwater condition
- Static and dynamic stability
- Design criteria
- Techniques to Improve Subsurface Conditions

Permit Condition

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The site investigation data shows that the discontinuities, shear fractures zones, and weathered fracture zones typically exist within weathered rock in the uppermost 30.5 m (100 ft), where most of the cavities are encountered at the CRN Site. The rock mass characterization described in the application is mainly for bedrock stratigraphic units below 24.4 m (80 ft) (El. 225.9 m (741 ft) NAVD88), the staff identified **Permit Condition 2** in SER Section 2.5.4.5 as stated below:

> An applicant for a combined license (COL) or a construction permit (CP) that references this early site permit shall remove the material above El. 225.9 m (741 ft) NAVD 88 in areas where safety-related structures will be located, to minimize the adverse effects of discontinuities, weathered and shear-fracture zones, and karst features on the stability of subsurface materials and foundations. The applicant shall also perform additional geotechnical investigations, in accordance with RG 1.132, at the excavation level to identify any potential geologic features that may adversely impact the stability of subsurface materials and foundations.

Staff Conclusions – Section 2.5.4

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- The applicant adequately determined the site-specific engineering properties of the subsurface materials underlying the CRN Site, and conducted sufficient evaluation of the stability of subsurface materials and foundations, based on the results of field and laboratory tests and the state of the art methodology, and in accordance with RG 1.132, RG 1.138, and RG 1.198.
- The staff concludes that the applicant meets the requirements of 10 CFR Part 52.17(a)(1)(vi) and 10 CFR Part 100.23(c) for this ESP application regarding the stability of subsurface materials and foundations.

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Section 2.5.5 - Stability of Slopes

Section 2.5.5- Stability of Slopes

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- The NRC staff reviewed SSAR Section 2.5.5, which provides general description of the site related to slope stability analysis.
- There are no existing slopes on the site at this time, either natural or manmade, that could affect the stability of the site.
- The applicant deferred the actual slope stability analysis to the COL or CP application.
- To address the need for future slope stability analyses, the staff identified COL Action Item 2.5-17 as stated below:

  An applicant for a COL or CP application that references this early site permit should perform a slope stability analysis of any safety-related slopes, including dams and dikes, consistent with the selected reactor technology.

Staff Conclusions – Section 2.5.5

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- The applicant provided necessary information on site topography and geologic characteristics, and adequately described the slope characteristics at the site.

- The staff concludes that the SSAR Section 2.5.5 is adequate and acceptable because it meets applicable requirements of 10 CFR Part 50, Appendix S, 10 CFR Part 52.17(a)(1)(vi) and 10 CFR Part 100.23.