Tennessee Valley Authority, 1101 Market Street, Chattanooga, TN 37402

CNL-16-184

December 15, 2016

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

Clinch River Nuclear Site
NRC Project No. 785

Subject: Submittal of Additional Supplemental Information Related to Stability of Subsurface Materials and Foundation in Support of Early Site Permit Application for Clinch River Nuclear Site

References:
1. Letter from TVA to NRC, CNL-16-081, "Application for Early Site Permit for Clinch River Nuclear Site," dated May 12, 2016
2. Letter from TVA to NRC, CNL-16-134, "Schedule for Submittal of Supplemental Information in Support of Early Site Permit Application for Clinch River Nuclear Site," dated August 11, 2016
3. Letter from TVA to NRC, CNL-16-162, “Submittal of Supplemental Information Related to Geologic Characterization Information, Surface Deformation, and Stability of Subsurface Materials and Foundation in Support of Early Site Permit Application for Clinch River Nuclear Site,” dated October 21, 2016
4. Letter from TVA to NRC, CNL-16-170, “Submittal of Supplemental Information Related to Vibratory Ground Motion in Support of Early Site Permit Application for Clinch River Nuclear Site,” dated October 28, 2016

By letter dated May 12, 2016 (Reference 1), Tennessee Valley Authority (TVA) submitted an application for an early site permit (ESP) for the Clinch River Nuclear (CRN) Site in Oak Ridge, TN. Subsequent to the submittal of the application, and consistent with interactions with NRC staff, TVA identified certain aspects of the application that it intends to supplement. By letter dated August 11, 2016 (Reference 2), TVA provided a plan for submitting the identified supplemental information. By letter dated October 21, 2016 (Reference 3), TVA submitted supplemental information related to geologic characterization information, surface deformation, and stability of subsurface materials and foundation in support of the Early Site Permit Application (ESPA) for the CRN Site. By letter dated October 28, 2016 (Reference 4), TVA submitted supplemental information related to vibratory ground motion in support of the ESPA for the CRN Site.

On November 1, 2016, a public meeting was held between Nuclear Regulatory Commission (NRC) and TVA to discuss the supplemental information submitted in References 3 and 4. On November 21, 2016, a second public meeting was held between NRC and TVA. As a result of these meetings, TVA is providing additional information related to stability of subsurface materials and foundation provided in Enclosure 3, of Reference 3. Specifically, the enclosure to this letter provides additional information, including markups of the affected Site Safety Analysis Report section, related to karst features as discussed in the November 1 and 21, 2016 public meetings. These changes will be incorporated into a future revision of the ESPA.

There are no new regulatory commitments associated with this submittal. If any additional information is needed, please contact Dan Stout at (423) 751-7642.

I declare under penalty of perjury that the foregoing is true and correct. Executed on this 15th day of December 2016.

Respectfully,

J. W. Shea
Vice President, Nuclear Licensing

Enclosure:

Additional Supplemental Information Related to Stability of Subsurface Materials and Foundation of the Early Site Permit Application for Clinch River Nuclear Site

cc (enclosure):

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cc (without enclosure):

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C. Haney, Regional Administrator, Region II, USNRC
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ENCLOSURE

ADDITIONAL SUPPLEMENTAL INFORMATION RELATED TO STABILITY OF SUBSURFACE MATERIALS AND FOUNDATION OF THE EARLY SITE PERMIT APPLICATION FOR CLINCH RIVER NUCLEAR SITE

By letter dated May 12, 2016 (Reference 1), Tennessee Valley Authority (TVA) submitted an application for an early site permit for the Clinch River Nuclear (CRN) Site in Oak Ridge, TN. Subsequent to the submittal of the application, and consistent with interactions with NRC staff, TVA identified certain aspects of the application that it intends to supplement. By letter dated August 11, 2016 (Reference 2), TVA provided a plan for submitting the identified supplemental information. By letter dated October 21, 2016 (Reference 3), TVA submitted supplemental information related to geologic characterization information, surface deformation, and stability of subsurface materials and foundation in support of the Early Site Permit Application (ESPA) for the CRN Site. By letter dated October 28, 2016 (Reference 4), TVA submitted supplemental information related to vibratory ground motion in support of ESPA for the CRN Site.

On November 1, 2016, a public meeting was held between Nuclear Regulatory Commission (NRC) and TVA to discuss the supplemental information submitted in References 3 and 4. On November 21, 2016, a second public meeting was held between NRC and TVA to further discuss supplemental information related to karst features. During this meeting, TVA presented a plan to perform a relational analysis comparing the CRN Site with the Clinch River Breeder Reactor Project (CRBRP) Site and a plan to provide an estimate of void/cavity site. These two evaluations are discussed below.

TVA also discussed an approach to a reasoned evaluation of the CRN Site based on representative foundation assumptions and committed in the November 21, 2016 meeting to provide a schedule for making that study available for NRC staff review. As discussed further below, TVA expects that evaluation to be in the form of a 2-D PLAXIS study scheduled for completion by February 28, 2017.

This enclosure provides additional information, including markups of the affected Site Safety Analysis Report (SSAR) sections, related to karst features as discussed in the November 1 and 21, 2016 public meetings. These changes will be incorporated into a future revision of the ESPA.

Supplement Item (from Reference 2)

A. *TVA will provide a markup of the applicable ESPA sections to include additional information for "Karst Features," regarding:*

   - *the size (both in vertical and horizontal directions) and spatial distribution of subsurface voids at the site, and;*
   - *a plan for additional geophysical studies and a preliminary grouting program to evaluate and address the voids within the sub-foundation area (zone of influence) are large enough to affect the stability of foundations and structures during the life time of a planned nuclear power plant.*

Supplemental Information

Consistent with regulatory guidance in the Standard Review Plan and Regulatory Guide 1.206, SSAR Section 2.5.1.2.5.1.1 discusses karst features in the region and vicinity of the CRN Site, while SSAR Section 2.5.1.2.5.1.2 discusses karst features at the CRN Site. Information specific to the CRN Site subsurface investigations is provided, as well as information gathered during excavation of the foundation for the CRBRP at its location adjacent to the CRN Site.

A catalog of potential karst cavities encountered during subsurface investigation (i.e., borings) for both the CRBRP and CRN Site is provided in SSAR Table 2.5.1-11. This catalog includes the length of the cavity (vertical extent of rod drop) and provides the data for the distribution of depth and size of karst features depicted in revised SSAR Figure 2.5.1-52. SSAR Figure 2.5.1-51 is a cross section that depicts the spatial relationship of the cavities, indicated in borings associated with the CRN Site subsurface investigation, with example Reactor Building Locations A and B and depth associated with the power block area.

To support conclusions regarding site suitability for the ESPA, additional information to address the following two areas is being provided:

1. Relational Analysis: A comparison of the CRN Site with the CRBRP Site with regard to safety-related structures was made using information from the CRN Site subsurface investigation and the CRBRP Site subsurface investigation; The Preliminary Safety Analysis Report (SSAR Reference 2.5.1-100) and the NRC's Safety Evaluation Report (Reference 5). This comparison included a review of the following elements:

    - geology with respect to geologic formation, rock type, geologic structure, and karst and
    - voids/cavities encountered at and below the depth of foundation

2. Estimate of Hypothetical Large Void: An estimate of the size of the hypothetical large void for the power block area was made based on existing data for the CRBRP and CRN Sites and considering each of the geologic units immediately beneath the designated power block area. The estimated size is based on the height of the largest cavities encountered in boreholes at and below the elevation of 740 ft NAVD88. This elevation corresponds to the shallowest embedment depth of the range of proposed small modular reactor (SMR) technologies (see proposed SSAR Subsection 2.5.1.2.3.4 in the ESPA markup). The hypothetical large void described is intended to be used for the evaluation of foundation stability to support the demonstration of site suitability and is not a prediction of what may be encountered during excavation.

In addition, a reasoned evaluation using a 2-D PLAXIS study to determine the minimum undetected void size that could adversely impact safety-related structures is underway, based on representative foundation assumptions. These assumptions will include varying foundation depth for three different embedment depths, thereby providing a representative analysis to cover a range of anticipated SMR embedment depths. The results of that study are expected to be available for NRC staff review by February 28, 2017.

SSAR Section 2.5.1.2.6.10 currently outlines additional actions to be detailed in the combined license application (COLA) and completed as a part of excavation and construction to confirm the current understanding of karst at the CRN Site, to ensure that the size, distribution, and extent of karst cavities are sufficiently understood, and to understand the potential impact of karst on safety-related structures. These actions, which will be coordinated with the NRC, include:

- Performing detailed geologic mapping of excavation walls during excavation/construction, allowing documentation of the characteristics of dissolution features in the near-surface carbonate rock units and verification of the decrease in cavity size and abundance with depth, as predicted by the subsurface investigation and geological mapping.

- Performing a technology-specific PLAXIS, or similar, analysis in support of COLA to provide information about the minimum size of a potential undetected cavity that could adversely affect foundation performance for a given range of depths below safety-related structures.

- Designing and conducting additional surface geophysical surveys during excavation/construction to detect cavities below the foundation elevation that are larger than the minimum postulated that could adversely affect foundation performance as determined by the technology-specific PLAXIS analysis.

- Performing confirmatory drilling or borehole testing during excavation/construction to characterize the source of geophysical anomalies, if detected.

- Developing a grouting program, based upon the information obtained by the geologic mapping, geophysical surveys and technology-specific PLAXIS (or similar analysis), to mitigate the effect of voids or cavities on foundation performance at and below the foundation levels of safety-related structures.

Duke Energy Florida and Florida Power and Light Company have addressed the potential for karst and have developed associated plans for its mitigation in the COLAs for Levy County (Reference 6) and Turkey Point Units 6 and 7 (Reference 7), respectively. These applications include plans for excavation mapping at the time of construction and grouting programs based upon postulated void size and the building/foundation design for the NRC-certified AP1000. The actions to be performed in association with the CRN Site COLA, as indicated in SSAR 2.5.1.2.6.10, are consistent with those developed for Levy County and Turkey Point Units 6 and 7.

Relational Analysis

General

The proposed sites for the CRBRP and the CRN are co-located on the peninsula landform nearly surrounded by the incised Clinch River arm of the Watts Bar Reservoir and are located in the Valley and Ridge physiographic province of eastern Tennessee. The general site area is underlain by a sequence of Cambrian to lower Ordovician carbonate and clastic rocks that strike northeast and dip at an angle of about 33 degrees to the southeast.

The geology as mapped for the CRBRP is shown on Figure 1. The geology, as mapped for the CRN Site is shown on SSAR Figure 2.5.1-37 (as revised by the Supplemental Information A, Enclosure 1). The relationship between the stratigraphic units defined for each project is summarized on SSAR Table 2.5.1-1. The lithologic characteristics of the CRBRP excavation and anticipated for the CRN power block area are described in more detail below.

This relational analysis considers the proposed CRBRP and CRN Sites and evaluates the similarities in geology and occurrences of karst features.

Geology

Local Stratigraphy

The site-specific stratigraphies defined for the CRBRP and the CRN Sites are shown on SSAR Table 2.5.1-1. As documented in the references indicated in SSAR Table 2.5.1-1, the stratigraphic interpretations shown in the table indicate that the Middle Ordovician-age Chickamauga Group is separated from the underlying Cambrian to Lower Ordovician Knox Group by an erosional surface. The CRBRP Unit A Lower Siltstone corresponds with the Blackford Formation. The Unit A Limestone corresponds with the Eidson member of the Lincolnshire Formation. The Unit A Upper Siltstone corresponds with the Fleanor member of the Lincolnshire Formation. The Unit B Limestone corresponds with the Rockdell Formation. Stratigraphic units overlying Unit B were not anticipated for, nor did they occur in, the excavation for the CRBRP and were mapped as undifferentiated Chickamauga. As shown on Figures 1 and 2, the foundations for the CRBRP were located primarily in the Unit A Upper Siltstone to the northwest and the Chickamauga Unit B Limestone to the southeast. This corresponds with the Fleanor member and the lower Rockdell Limestone as currently mapped for the CRN Site.

As shown on SSAR Figure 2.5.1-30 (as revised by Supplemental Item 2 of Enclosure 2 of Reference 4), the CRN Site power block area has a foundation elevation of 683 ft NAVD88. The stratigraphic units that occur at this elevation in the power block area include the upper Knox Group (Newala Formation) through the overlying Blackford Formation, Eidson and Fleanor members, Rockdell Formation and the Benbolt Formation.

The following descriptions of local stratigraphic units are summarized below based on the information in SSAR Subsection 2.5.1.2.3.3.

> Knox Group – Newala Formation - The Newalla Formation is a fine- to medium-grained, variegated (gray, pink, and green) crystalline dolomite. Nodular and bedded variegated jasperoidal chert is common, and several 5 to 15 ft thick limestone and dolomitic limestone interbeds are observed. It is typically described on the boring logs as fine- to medium-grained, light olive-gray to light gray and dusky-red to gray, and locally mottled with weak red. It is moderately to thickly bedded, fresh, with few irregular chert nodules and chert beds with coarse dolomite crystals (gray to gray-brown). Trace healed/filled fractures with indurated clay mineral fill (dark reddish-brown) are noted on boring logs. Dolomite-healed fractures, trace fossils, trace dolomite-filled pits and vugs (separate/non-touching), and stylolites occur. Weak (delayed) to no reaction to hydrochloric acid (HCl), which signifies relatively low calcium carbonate content, are observed. A thin (less than 1.0 ft) olive gray chert and dolomite-cemented fine- to coarse-grained quartz sandstone with fine gravel-sized rounded chert clasts is also noted.
>
> Limestone interbeds typically consist of gray limestone to dolomitic limestone (micrite) that is strong, laminated to very thinly- and moderately-bedded, locally nodular, slightly-weathered to fresh, and partially dolomitized with dolomite crystals as matrix and along laminations and bedding. Stylolites, trace chert nodules (reddish-brown), healed fractures with calcite/dolomite throughout, trace to few dolomite and calcite filled pits and vugs (separate/non-touching, few open with calcite/dolomite lining), and trace scattered quartz sand grains, and weak to strong HCl reaction are observed.

Two Newala member samples logged in the field as fine- to coarse-grained crystalline dolomite taken approximately 79.0 and 216.5 ft below ground surface from borehole MP-401 were analyzed for carbonate content. These tests yielded 77 percent and 90 percent calcite equivalent, respectively (SSAR Reference 2.5.1-214).

The Newala Formation was not fully penetrated during the drilling investigation, and its thickness at the CRN Site is not known, but is regionally estimated to be 900–1200 ft (SSAR Reference 2.5.1-97).

Chickamauga Group - Blackford Formation - Above its disconformable contact with the Newalla Formation of the Knox Group, the lower facies of the Lower Blackford formation is logged as greenish gray to dark greenish gray to very dark gray, grading to reddish black and dark gray, locally mottled dolomitic limestone (micrite). It is occasionally oolitic, moderately to thickly bedded, fresh, and stylolitic. Trace dolomite-filled pits and weak HCl reaction are also observed. A few coarse sand to fine gravel-sized angular chert fragments and trace subrounded clasts of dolomite and crystalline dolomite are also observed. These chert and dolomite clasts are presumably rip-up clasts derived from the underlying Newala Formation (SSAR Reference 2.5.1-9). Laboratory and petrographic analyses were not performed on the Lower Blackford Formation. The upper facies of the Lower Blackford Formation is logged as a dark gray to gray, strong, micritic limestone. It is laminated to moderately bedded, fresh, argillaceous, and demonstrates repeating fining upward sequences with some disturbed bedding. It exhibits a slightly nodular appearance, slight bioturbation, and is interbedded with few, very thin to moderately bedded chert lenses and nodules (reddish brown, very dusky red, and reddish black to gray and very dark gray, a few with red jasper specks). Trace calcite-filled pits and strong HCl reaction have been observed.

The Upper Blackford is described as a gray, calcareous siltstone, laminated to moderately bedded, interbedded with little to some limestone with few to little chert beds, lenses and nodules. The calcareous siltstone is logged as black to reddish black to very dusky red to very dark greenish gray, locally mottled with dark gray to dark greenish gray, and laminated to moderately bedded and fresh. The Upper Blackford siltstone contains a few to little laminated to moderately interbedded, strong limestones (micrite/ wackestone/packstone). The interbeds are locally nodular, gray to greenish gray, and dark gray to very dark gray containing a trace to little, very thin to thin jasperoidal chert beds, lenses and nodules (variegated, dark gray to black, brown, olive, orange, and very dusky red, with calcite filled tensional fractures). The interbeds are moderately-to strongly-bioturbated with vertical and horizontal burrows and contain trace calcite filled pits and separate calcite lined (open) vugs. The limestone often exhibits calcite-healed tensional fractures oriented orthogonal to bedding. Strong HCl reactions are noted.

Results of the thermogravimetric analysis indicate the Upper Blackford Formation averages 64.09 weight percent calcium carbonate and 28.26 mass percent insoluble residue. A second sample logged in the field as calcareous siltstone and taken approximately 69 ft below the top (true depth) of the Upper Blackford Formation from borehole MP-202 was analyzed for carbonate content using ASTM D-4373. This test yielded 39 percent calcite equivalent, indicative of significant calcium carbonate content variability in the Upper Blackford (SSAR Reference 2.5.1-214).

Eidson Member -The lower member of the Lincolnshire Formation, the Eidson member, is described on the CRN Sire boring logs as a gray, laminated to thinly bedded, fresh, argillaceous, micritic limestone. The geologic map includes the Eidson member as part of the Blackford Formation (SSAR Figure 2.5.1-29). It exhibits little to some, laminated to thinly interbedded, greenish black to black and very dark gray calcareous siltstone and few, very thin chert lenses and nodules (dark gray to black with calcite-healed tensional fractures orthogonal to bedding). Trace calcite filled pits, sparry calcite "bird's eyes," and stylolites are observed. It is locally fossiliferous with weak to moderate bioturbation and a strong HCl reaction. Average true thickness of the Eidson member at the CRN Site is approximately 86 ft (SSAR Table 2.5.1-3).

A single sample logged in the field as micritic limestone taken approximately 53.5 ft below the top (true depth) of the Eidson member from borehole MP-202 was submitted to the laboratory for petrographic examination, X-ray diffraction and thermogravimetric analyses. Results of the petrographic examination are summarized in SSAR Table 2.5.1-5. Results of the thermogravimetric analysis indicate the Eidson member micritic limestone sample consists of 67.42 weight percent calcium carbonate and averaged 28.47 mass percent insoluble residue. Two Eidson member samples logged in the field as micritic limestone taken approximately 28 ft and 41 ft below the top (true depth) of the Eidson member from borehole MP-202 were analyzed for carbonate content using ASTM D-4373. These tests yielded 51 percent and 54 percent calcite equivalent, respectively (SSAR Reference 2.5.1-214).

Fleanor Member - The Fleanor member is described in the CRN Site boring logs as a dusky red to very dusky red, laminated to moderately bedded calcareous siltstone with few to little dark gray to very dark gray micritic limestone interbeds and strong HCl reaction. The interbeds are bioturbated with trace calcite filled pits and burrows. The basal 10 ft of the Fleanor member consistently exhibits a sharp gradation to a dark greenish gray to dark grayish olive calcareous siltstone with the same lithology as described above. Similarly, the top 12 to 23 ft of the Fleanor member is dark gray to very dark gray to greenish black, slight to moderately bioturbated, calcareous siltstone gradually grading to the dusky red calcareous siltstone that makes up the majority of the Fleanor member. Three samples indicated a carbonate content of about 32 percent and a fourth sample contained about 45 percent calcite equivalent.

Rockdell Formation - The Rockdell Formation is predominantly a gray micritic limestone, very thinly- to moderately-bedded, interbedded with few to little calcareous siltstone, trace chert beds, lenses and nodules, stylolites, fossils and sparry calcite "bird's eyes." It is interbedded with thicker (greater than 5 ft thick) calcareous siltstone units. The Rockdell Formation is divided into a lower and upper unit corresponding to Unit C and D of Stockdale (SSAR Reference 2.5.1-109) and Lee and Ketelle (Reference 2.5.1-110). Lying above the Fleanor member of the Lincolnshire Formation, Unit C of the Rockdell Formation is described on the boring logs as a gray to bluish-gray to very dark gray, very thinly to moderately bedded limestone (micrite/ wackestone/ grainstone). It is logged as fresh, with few to little, laminated to very thin and thin, wavy and irregular, shaly, very dark gray to black calcareous siltstone interbeds and trace thin chert beds and nodules. It exhibits a strong HCl reaction and locally exhibits trace fossils, calcite filled pits and vugs/bioturbation.

A single sample logged in the field as micritic limestone and taken approximately 120 ft below the top of Rockdell Formation Unit D (true depth) from borehole MP-101 was submitted to the laboratory for petrographic examination, X-ray diffraction and thermogravimetric analyses. Results of the thermogravimetric analysis indicate the Rockdell Formation Unit D micritic limestone sample yielded 94.48 weight percent calcium carbonate and averaged 2.78 mass percent insoluble residue. A total of three Rockdell Formation Unit D limestone samples were taken from MP-101, which were analyzed for carbonate content using ASTM D-4373. These tests yielded results of 45, 62 and 75 percent calcite equivalent (SSAR Reference 2.5.1-214). One sample of a Rockdell Formation Unit C micritic limestone from borehole MP-101 yielded 48 percent calcite equivalent (SSAR Reference 2.5.1-214).

Benbolt Formation - The Benbolt Formation is a gray limestone, very thinly to moderately bedded, interbedded with few to little shaly calcareous siltstone interbeds, and is locally fossiliferous. It is described on the boring logs as a gray and bluish-gray to dark bluish-gray, very thinly- to thinly-bedded, locally moderately bedded and nodular limestone (micrite/wackestone). Bedding is roughly planar to wavy becoming wispy/irregular and diffuse with depth. Trace stylolites, trace pyrite replacing fossils, trace calcite filled pits and vugs (separate/non-touching) and strong HCl reaction are observed. Few very thin chert beds, lenses, and nodules (dark gray to black, with calcite filled tensional fractures orthogonal to bedding) are also noted. It is interbedded with little to some laminated to thin, dark gray to very dark gray calcareous siltstone.

Two distinct relatively thick (greater than 5 ft) calcareous siltstone interbeds are observed in all borings that penetrate the lower portion of the Benbolt Formation. The lowermost interbed is consistently 18.0 to 21.5 ft thick, and on average, its base is observed to lie approximately 16.0 ft above the base of the Benbolt Formation. It is logged as a very dark greenish-gray to greenish-black, laminated to thinly-bedded calcareous siltstone. It is weak to medium strong with moderately bedded appearance and is interbedded with few to little, locally to some, laminated to thin, gray to dark gray micritic limestone.

The upper interbed is consistently 5.9 to 6.8 ft thick, and on average, the base is observed to lie approximately 44.0 ft above the base of the Benbolt Formation. It is logged as a dark gray to very dark greenish gray, medium strong to strong, laminated to thinly-bedded calcareous siltstone. It is interbedded with little to some laminated to thin gray micritic limestone.

A single sample logged in the field as micritic limestone and taken approximately 79 ft above the base of the Benbolt Formation (true depth) from borehole MP-101 was submitted to the laboratory for petrographic examination, X-ray diffraction and thermogravimetric analyses. Results of the thermogravimetric analysis indicate the Benbolt micritic limestone sample yielded 79.93 weight percent calcium carbonate and averaged 16.04 mass percent insoluble residue. A sample logged in the field as calcareous siltstone and taken approximately 35.5 ft above the base (true depth) of the Benbolt Formation from borehole MP-101 was analyzed for carbonate content using ASTM D-4373. This test yielded 27 percent calcite equivalent (SSAR Reference 2.5.1-214).

Local Structural Geology

Geologic field mapping and acoustic televiewer (ATV) log data indicate bedding at the site overwhelmingly strikes 050–070 with southeast dips that range between 20 and 50 degrees (SSAR References 2.5.1-97 and 2.5.1-106). Mean orientations reported during the CRBRP ranged from 052/31 (derived using 3-point problems) to 052/37 from surface mapping (SSAR Reference 2.5.1-100). A recent estimate based on surface mapping and 3-point problems from key horizons in boreholes yielded a similar 052/33. ATV log data of total borehole measurements (n=4733) yielded a mean bedding attitude of 063/33 (SSAR Figures 2.5.1-38, Sheets 1 and 2); orientation between different stratigraphic units was consistent down-hole. Additionally, seismic reflection data supports consistent dip of strata between borehole locations (SSAR Figure 2.5.1-36). Geologic cross-sections that were constructed using subsurface contacts observed in boreholes also indicate bedding dips are consistent throughout the site (SSAR Figure 2.5.1-30). The similarities between the CRBR Site and the CRN Site are shown on Figures 1 and 2 and revised SSAR Figures 2.5.1-30 and 2.5.1-37 (as revised by Supplemental Item 2 of Enclosure 2, of Reference 4 and Supplemental Information A of Enclosure 1 of Reference 3, respectively). These figures show that the stratigraphic units in the CRBR excavation and in CRN location B are identical. The differences in stratigraphic nomenclature are discussed above and shown in SSAR Table 2.5.1-1. SSAR Subsection 2.5.1.2.4 contains additional detail on local structural geology.

Dissolution and Karst

Karst hazards at the CRN Site are described in SSAR Subsection 2.5.1.2.5.1. The data clearly show concentrations of depressions in certain geologic units (SSAR Table 2.5.1-7 and SSAR Figure 2.5.1-47). Depression density, DD, was greatest in members of the Knox Group. Between twenty and thirty depressions per square kilometer were observed in the Mascot Dolomite, Longview Dolomite, Chapultepec Dolomite, and Copper Ridge Dolomite. The Longview and underlying formations in the Knox Group as well as the Stones River Group occur northwest of the power block area. Ten to twenty depressions per square kilometer were observed in four formations of the Stones River Group and in the Kingsport Formation of the Knox Group. The Witten and Rockdell Formation, members of the Chickamauga Group, average eight to nine depressions per square kilometer. The Rockdell underlies the southern portion of the power block area, while the Witten Formation crops out south of the power block area and dips to the southeast. Other members of the Chickamauga Group contained less than three depressions per square kilometer.

Data for area ratio, RD, or the area of all closed depressions per area of bedrock unit, show similar patterns, with a few significant differences (SSAR Table 2.5.1-7). Again, members of the Knox Group and Stones River Group have the highest area ratios, typically 1 to 3 percent. The Witten Formation of the Chickamauga Group, also shows an area ratio in this range. Several wide depressions likely account for this relatively high area ratio. The Longview Dolomite, which has a very high depression density, forms a steep-sided topographic ridge due to the presence of significant chert beds. Due to the steep slopes, depressions are typically of the two-sided and three-sided type that do not count toward the area ratio, thus the Longview Dolomite has a relatively low RD area ratio. Area ratio data more closely correlate with the density of closed depressions, type D on SSAR Table 2.5.1-7.

The above analysis shows that geologic units having the highest depression density and area ratios are those characterized by thick and relatively pure carbonate lithology. These include the Knox Group dolomites, and the more pure limestones of the Chickamauga Group, Stones River Group, and the Conasauga Group. Units that contain interbedded carbonate and clastic lithologies, such as the Benbolt and Blackford Formations of the Chickamauga Group have a moderate number to few depressions, and those dominated by clastic material (sandstone, siltstone, shale), have very few to no depressions. The presence of chert in the carbonate does not appear to influence the number of depressions, but may influence the type of depressions present.

SSAR Figure 2 and revised SSAR Figures 2.5.1-30 and 2.5.1-51 are geologic cross sections drawn parallel to dip. Figure 2 indicates the extent of the CRBRP excavation. SSAR Figure 2.5.1-30 (as revised by Supplemental Item 2 of Enclosure 2 of Reference 3) is based on borings drilled in support of the CRN Site subsurface investigation and indicates the extent of the power block area. SSAR Figure 2.5.1-51 (as modified by this enclosure) incorporates data from both the CRBRP and the CRN Site subsurface investigations. This figure shows the locations of cavities based on the combined project data. Figure 2 shows that the excavation for the CRBRP was planned primarily in the Unit A Upper Siltstone (current Fleanor member) and to a lesser extent in the Unit B Limestone (current lower Rockdell Formation). The stratigraphy and structure of the CRBRP Site is similar to Location B within the CRNP power block area (Figure 2 and modified SSAR Figure 2.5.1-30). Except for the Mascot Formation, the karst depression densities and area ratios for the other stratigraphic units within the power block area are all less than those in the stratigraphic units noted above as occurring to the northwest and southeast of the power block area.

Voids/Cavities Encountered at and Below the Depth of Foundation

The results of the CRBRP Site investigation can be used to enhance and further inform the understanding of the geology and engineering suitability of the CRN Site. The CRBRP Site investigation began in 1972, and site drilling was completed in 1980 (SSAR Reference 2.5.1-100 and Reference 8), whereas the CRN Site investigation was conducted in 2013 (SSAR Reference 2.5.1-214). As these investigations were conducted at the same site with overlapping borehole coverage and comparable drilling and logging methods, geologic observations and interpretations can be correlated and compared from one dataset to the other. The deep excavation for the CRBRP nuclear island in 1983 was primarily in the Fleanor member (calcareous siltstone), and foundation conditions on this rock type were found to be excellent (Reference 8).

Geotechnical Site Investigations

The boundary of the 2013 CRN Site geotechnical site investigation overlaps to a large extent with that of the 1972-1980 CRBRP Site geotechnical site investigation (Figure 3). A total of 104 borings were drilled during the CRBRP Site investigation (SSAR Reference 2.5.1-100), and 74 were drilled for the CRN Site investigation (SSAR Reference 2.5.1-214). Both drilling programs included widely distributed borings to fully characterize the site stratigraphy and concentrated most borings in the areas of safety-related facilities. The northern cluster of CRN Site borings, which corresponds to proposed Location B, is centered northeast of the greatest concentration of borings related to the CRBRP Site investigation and occurs within the same geologic unit (Figure 3). The southern cluster of CRN Site borings, which corresponds to proposed Location A, is centered within the Benbolt formation, a slightly younger geologic unit with similar lithologic characteristics. These three concentrations of borings fall within the Chickamauga Group, a middle Ordovician sequence of limestones, silty and cherty limestones, and calcareous siltstones.

Cavities encountered in both site investigations were logged to the nearest tenth of a foot, with bottom and top elevations of the cavity recorded. A total of 216 cavities were logged during the

CRBRP Site investigation, whereas the CRN Site program logged a total of 23 cavities. The fewer number of cavities encountered in the CRN Site borings is consistent with removal of the cavity-rich near-surface strata during the deep CRBRP excavation and associated grading activities prior to 2013 (Figure 3). This combined cavities dataset is illustrated on the distribution of cavities cross section (SSAR Figure 2.5.1-51) and on the plot of cavity size versus elevation (SSAR Figure 2.5.1-52). Additionally, the distribution of cavity size versus elevation of the CRN Site data is consistent with that of the CRBRP Site data. Based on the quality and compatibility of both boring investigations, the combined dataset was used for CRN Site analysis of cavities in boreholes.

CRBRP Excavation Records

Excavations for the CRBRP Site were virtually complete before the project was cancelled in November 1983. The excavations were mapped and described in detail prior to backfilling to provide documentation of the geology and structure exposed during the excavation (Reference 8). Two excavations were made–a large excavation (480 ft long x 360 ft wide, and 100 ft deep) for the nuclear island and a smaller excavation (180 ft x 180 ft shallow depth) for the Equalization Basin.

The nuclear island excavation exposed the Fleanor member, primarily a shaly calcareous siltstone at the site, over most of the walls and floor. The Fleanor member exhibited deep chemical weathering of siltstone strata, with minor dissolution of its thin limestone interbeds. The siltstone was fresh at the base of the excavation, but found prone to slaking and disintegration upon subaerial exposure.

The base of the overlying Rockdell Formation, primarily limestone at the site, was exposed on the southeast wall of the nuclear island excavation and contained a concentration of solution cavities at an elevation of approximately 780 ft. The cavities had a maximum radius of a few feet, with lengths ranging “from a few feet to several tens of feet” along discontinuities (Reference 8). Most cavities were partially filled with lateritic clay and silt. Cavities exposed during the excavation were cleaned and plugged with concrete.

The excavation mapping report concluded that the site was suitable for development of the proposed facility or other industrial facilities based on the character of the rock exposed (Reference 8. The planned foundation level of the CRBRP, 714 ft, was below the zone of weathered siltstone observed in the excavation, and the limestone at that elevation was found to be hard and sound. No cavities were described on the floor of the excavation. Any weathered siltstone found to be softer and prone to disintegration and slaking would be mitigated by the planned concrete basemat.

Conclusions

The aforementioned relational analysis provides a comparison of the CRN Site with the CRBRP Site with including geology (with respect to geologic formation, rock type, geologic structure and occurrence and character of karst) and karst voids/cavities encountered at and below the depth of foundations. The results of the relational analysis form the basis for using subsurface data from both sites to formulate an estimate of a hypothetical large void that may be encountered below the proposed power block, which is included as the second item within this response. The geologic units mapped in the CRBRP excavation (Fleanor member and Rockdell Formation) are the same as those occurring in Location B of the CRN Site power block area. Except for the Mascot Formation, the karst depression densities and area ratios for the other stratigraphic units within the power block area are all less than those in the stratigraphic units noted above as occurring to the northwest and southeast of the power block area; indicating that the power block area carbonates appear to have similar dissolution characteristics to the Rockdell Formation.

Estimate of Hypothetical Large Void

Information related to the estimate of the hypothetical large void is provided as a new section in the markup to SSAR 2.5.1.2.3.

References

1. Letter from TVA to NRC, CNL-16-081, "Application for Early Site Permit for Clinch River Nuclear Site," dated May 12, 2016

2. Letter from TVA to NRC, CNL-16-134, "Schedule for Submittal of Supplemental Information in Support of Early Site Permit Application for Clinch River Nuclear Site," dated August 11, 2016

3. Letter from TVA to NRC, CNL-16-162, “Submittal of Supplemental Information Related to Geologic Characterization Information, Surface Deformation, and Stability of Subsurface Materials and Foundation in Support of Early Site Permit Application for Clinch River Nuclear Site,” dated October 21, 2016

4. Letter from TVA to NRC, CNL-16-170, “Submittal of Supplemental Information Related to Vibratory Ground Motion in Support of Early Site Permit Application for Clinch River Nuclear Site,” dated October 28, 2016

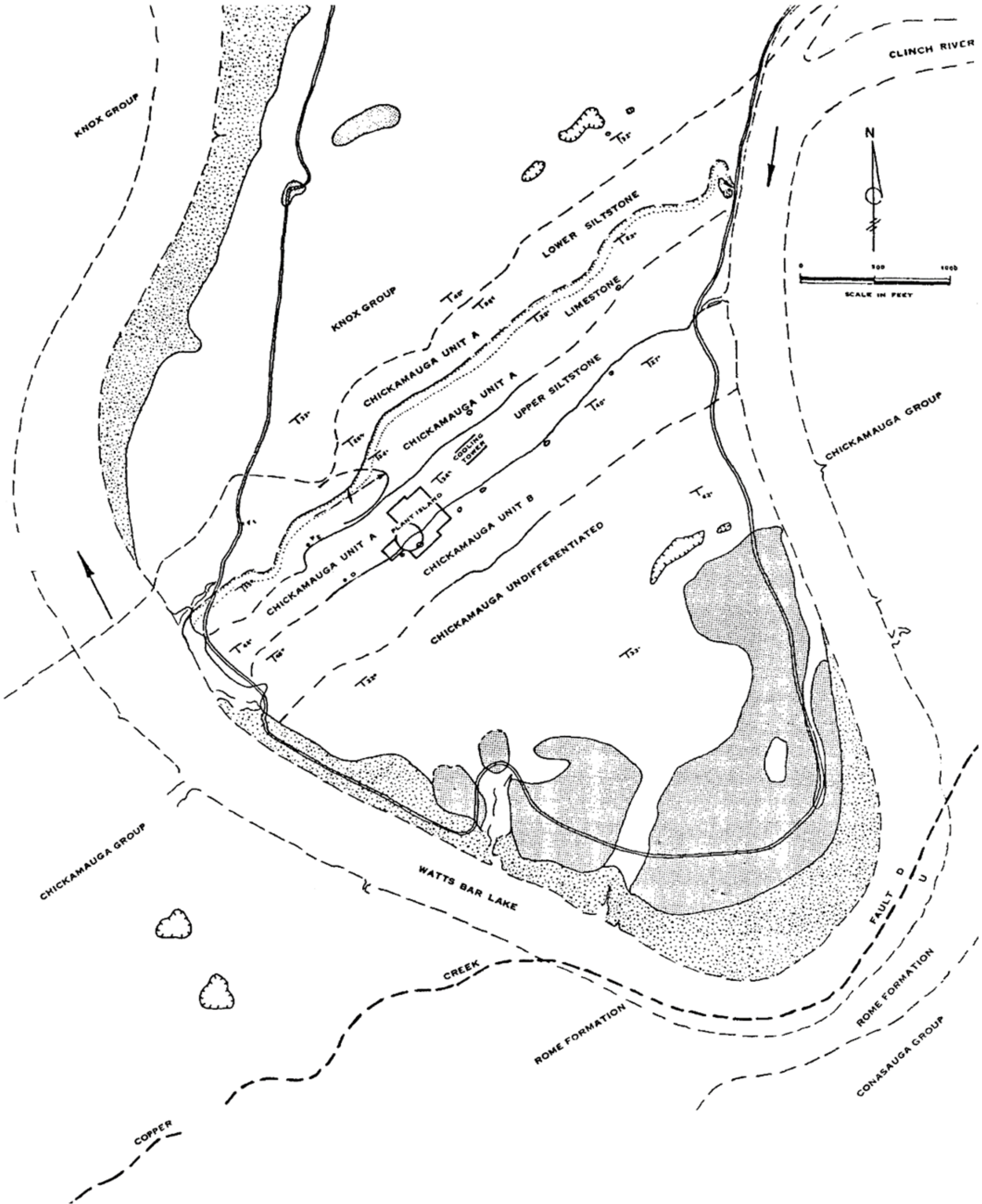
5. NRC, Safety Evaluation Report related to the construction of the Clinch River Breeder Reactor Plant, NUREG-0986, Vol. 1, 1983.

6. Duke Energy Florida, LLC, Levy Nuclear Plants COL Application, Rev. 9, April 6, 2016.

7. Florida Power and Light Company, Turkey Point Units 6 and 7 COL Application, Rev. 7, October 14, 2015.

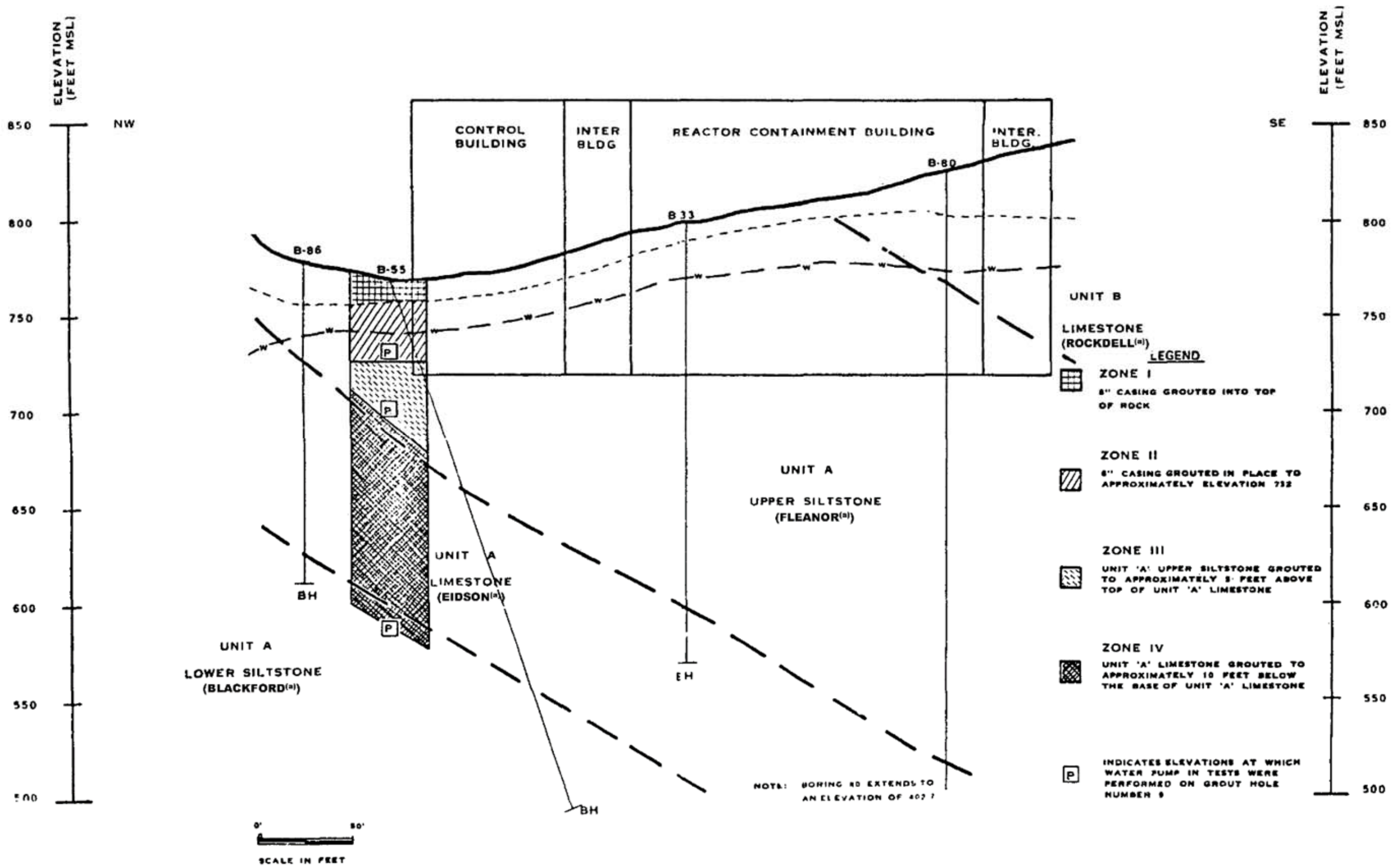
8. Drackulich, N. S., Geologic mapping of the Clinch River Breeder Reactor plant excavations, prepared for the U. S. Department of Energy and CRBRP Project Management Corporation: Stone and Webster Engineering Company, Cherry Hill, NJ, Report No. 12720.50-G(C)-1, 1984.

Figure 1 CRBRP Site Geologic Map



From CRBR PSAR Vol 3 (SSAR Reference 2.5.1-238, App 2C, Figure 1)

Figure 2 CRBRP Site Geologic Cross Section

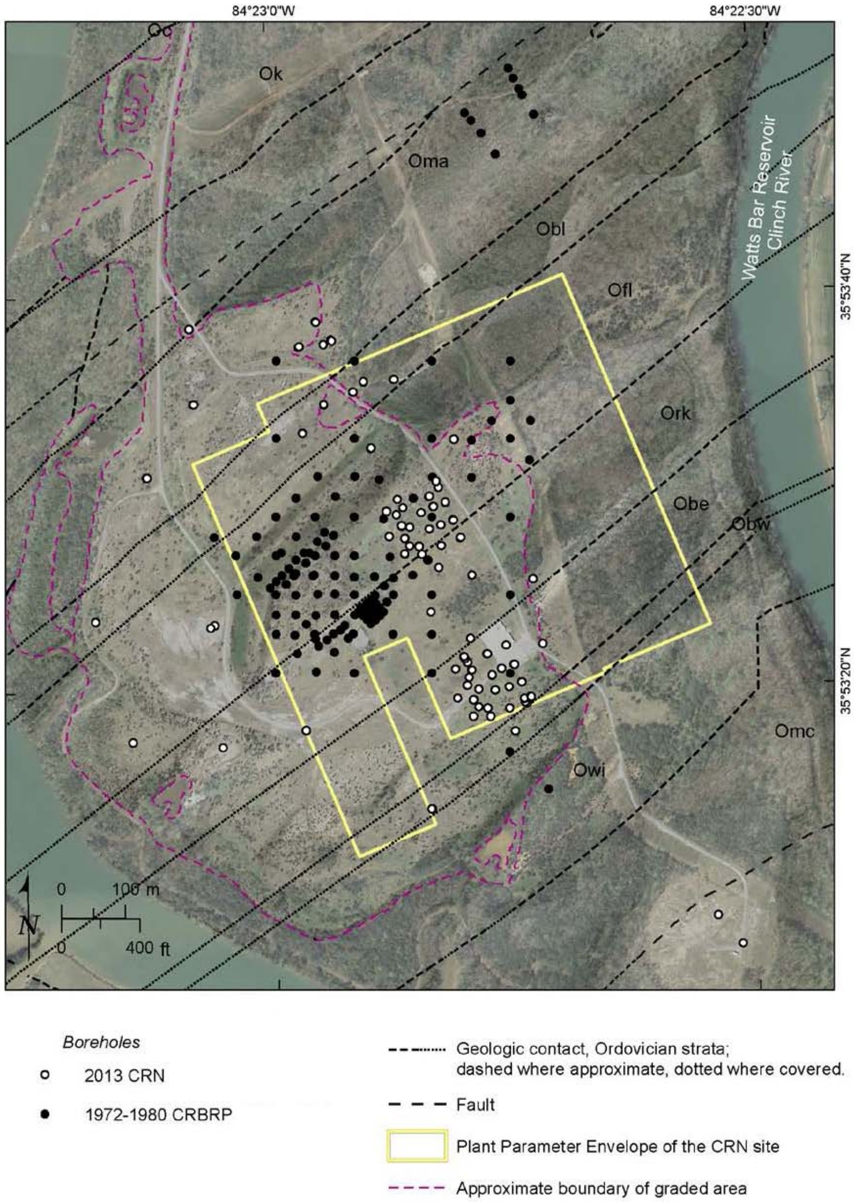


Note:

SSAR Figure 2.5.1-30

From CRBR PSAR Vol 3 (SSAR Reference 2.5.1-238, App 2C, Figure 4)

Figure 3 Borehole Plan for CRBRP and CRN Investigations



Note:
See SSAR Figure 2.5.1-79 for explanation of geologic units
1972 –1980 CRPRP borehole data from SSAR Reference 2.5.1-100

The following new SSAR Subsection 2.5.1.2.9, "Relational Analysis," is being added:

2.5.1.2.9 Relational Analysis

General

The proposed sites for the CRBRP and the CRN are co-located on the peninsula landform nearly surrounded by the incised Clinch River arm of the Watts Bar Reservoir and are located in the Valley and Ridge physiographic province of eastern Tennessee. The general site area is underlain by a sequence of Cambrian to lower Ordovician carbonate and clastic rocks that strike northeast and dip at an angle of about 33 degrees to the southeast.

The geology as mapped for the CRBRP is shown on Figure 2.5.1-80. The geology, as mapped for the CRN Site is shown on Figure 2.5.1-37. The relationship between the stratigraphic units defined for each project is summarized on Table 2.5.1-1. The lithologic characteristics of the CRBRP excavation and anticipated for the CRNP power block area are described in more detail below.

Geology

<u>*Local Stratigraphy*</u>

The site-specific stratigraphies defined for the CRBRP and the CRN Sites are shown on SSAR Table 2.5.1-1. As documented in the references associated with SSAR Table 2.5.1-1, the stratigraphic interpretations shown in the table indicate that the Middle Ordovician-age Chickamauga Group is separated from the underlying Cambrian to Lower Ordovician Knox Group by an erosional surface. The CRBRP Unit A Lower Siltstone corresponds with the Blackford Formation. The Unit A Limestone corresponds with the Eidson Member of the Lincolnshire Formation. The Unit A Upper Siltstone corresponds with the Fleanor member of the Lincolnshire Formation. The Unit B Limestone corresponds with the Rockdell Formation. Stratigraphic units overlying Unit B were not anticipated for, nor did they occur in, the excavation for the CRBRP and were mapped as undifferentiated Chickamauga. As shown on Figures 2.5.1-80 and 2.5.1-81, the foundations for the CRBRP were located primarily in the Unit A Upper Siltstone to the northwest and the Chickamauga Unit B Limestone to the southeast. This corresponds with the Fleanor member and the lower Rockdell Limestone as currently mapped for the CRN Site. Descriptions of these stratigraphic units are provided in Subsection 2.5.1.2.3.3:

As shown on Figure 2.5.1-30, the CRN Site power block area has a foundation elevation of approximately 683 ft NAVD88. The stratigraphic units that occur at this elevation in the power block area include the upper Knox Group (Newala Formation) through the overlying Blackford Formation, Eidson and Fleanor members, Rockdell Formation and the Benbolt Formation. Descriptions of these stratigraphic units are also provided in Subsection 2.5.1.2.3.3.

Local Structural Geology

Geologic field mapping and acoustic televiewer (ATV) log data indicate bedding at the site overwhelmingly strikes 050–070 with southeast dips that range between 20 and 50 degrees (SSAR References 2.5.1-97 and 2.5.1-106). Mean orientations reported during the CRBRP PSAR Project ranged from 052/31 (derived using 3-point problems) to 052/37 from surface mapping (SSAR Reference 2.5.1-100). A recent estimate based on surface mapping and 3-point problems from key horizons in boreholes yielded a similar 052/33. ATV log data of total borehole measurements (n=4733) yielded a mean bedding attitude of 063/33 (Figures 2.5.1-38, Sheets 1 and 2); orientation between different stratigraphic units was consistent down-hole. Additionally, seismic reflection data supports consistent dip of strata between borehole locations (SSAR Figure 2.5.1-36). Geologic cross-sections that were constructed using subsurface contacts observed in boreholes also indicate bedding dips are consistent throughout the site (SSAR Figure 2.5.1-30). The similarities between the CRBRP Site and the CRN Site are shown on Figures 2.5.1-30, 2.5.1-37, 2.5.1-80, and 2.5.1-81. These figures show that the stratigraphic units in the CRBRP excavation and in CRN location B are identical. The differences in stratigraphic nomenclature are discussed above and shown in SSAR Table 2.5.1-1. Subsection 2.5.1.2.4 contains additional detail on local structural geology.

Dissolution and Karst

Karst hazards at the CRN Site are described in Subsection 2.5.1.2.5.1.

The data clearly show concentrations of depressions in certain geologic units (Table 2.5.1-7 and Figure 2.5.1-47). Depression density, DD, was greatest in members of the Knox Group. Between twenty and thirty depressions per square kilometer were observed in the Mascot Dolomite, Longview Dolomite, Chapultepec Dolomite, and Copper Ridge Dolomite. Ten to twenty depressions per square kilometer were observed in four formations of the Stones River Group and in the Kingsport Formation of the Knox Group. The Witten and Rockdell Formation, members of the Chickamauga Group, average eight to nine depressions per square kilometer. The Rockdell underlies the southern portion of the power block area, while the Witten Formation crops out south of the power block area and dips to the southeast. Other members of the Chickamauga Group contained less than three depressions per square kilometer.

Data for area ratio, RD, or the area of all closed depressions per area of bedrock unit, show similar patterns, with a few significant differences (Table 2.5.1-7). Again, members of the Knox Group and Stones River Group have the highest area ratios, typically 1 to 3 percent. The Witten Formation of the Chickamauga Group, also shows an area ratio in this range. Several wide depressions likely account for this relatively high area ratio. The Longview Dolomite, which has a very high depression density, forms a steep-sided topographic ridge due to the presence of significant chert beds. Due to the steep slopes, depressions are typically of the two-sided and three-sided type that do not count toward the area ratio, thus the Longview Dolomite has a relatively low RD area ratio. Area ratio data more closely correlate with the density of closed depressions, type D on Table 2.5.1-7.

The above analysis shows that geologic units having the highest depression density and area ratios are those characterized by thick and relatively pure carbonate lithology. These include the Knox Group dolomites, and the more pure limestones of the Chickamauga Group, Stones River Group, and the Conasauga Group. Units that contain interbedded carbonate and clastic lithologies, such as the Benbolt and Blackford formations of the Chickamauga Group have a moderate number to few depressions, and those dominated by clastic material (sandstone, siltstone, shale), have very few to no depressions. The presence of chert in the carbonate does not appear to influence the number of depressions, but may influence the type of depressions present.

Figures 2.5.1-30, 2.5.1-51, and 2.5.1-81 are geologic cross sections drawn parallel to dip. Figure 2.5.1-81 indicates the extent of the CRBR Site excavation. Figure 2.5.1-30 is based on borings drilled in support of the CRN Site subsurface investigation and indicates the extent of the power block area. Figure 2.5.1-51 incorporates data from both the CRBRP and the CRN Site subsurface investigations. This figure shows the locations of cavities based on the combined project data. Figure 2.5.1-81 shows that the excavation for the CRBRP was planned primarily in the Unit A Upper Siltstone (current Fleanor member) and to a lesser extent in the Unit B Limestone (current lower Rockdell Formation). The stratigraphy and structure of the CRBRP Site is similar to Location B within the CRN power block area (Figures 2.5.1-30 and 2.5.1-81). These figures show that the stratigraphic units in the CRBRP excavation and in CRN location B are identical. The differences in stratigraphic nomenclature are discussed above and shown in SSAR Table 2.5.1-1. Except for the Mascot Formation, the karst depression densities and area ratios for the other stratigraphic units within the power bloc area are all less than those in the stratigraphic units noted above as occurring to the northwest and southeast of the power block area.

Voids/Cavities Encountered at and Below the Depth of Foundation

The results of the CRBRP Site investigation can be used to enhance and further inform the understanding of the geology and engineering suitability of the CRN Site. The CRBRP Site investigation began in 1972, and site drilling was completed in 1980 (References 2.5.1-100 and 2.5.1-303), whereas the CRN Site investigation was conducted in 2013 (Reference 2.5.1-214). As these investigations were conducted at the same site with overlapping borehole coverage and comparable drilling and logging methods, geologic observations and interpretations can be correlated and compared from one dataset to the other. The deep excavation for the CRBRP nuclear island in 1983 was primarily in the Fleanor member (calcareous siltstone), and foundation conditions on this rock type were found to be excellent (Reference 2.5.1-303).

<u>Geotechnical Site Investigations</u>

The boundary of the 2013 CRN Site geotechnical site investigation overlaps to a large extent with that of the 1972-1980 CRBRP Site geotechnical site investigation (Figure 2.5.1-74). A total of 104 borings were drilled during the CRBRP Site investigation (Reference 2.5.1-100), and 74 were drilled for the CRN Site investigation (Reference 2.5.1-214). Both site investigations included widely distributed borings to fully characterize the site stratigraphy and concentrated most borings in the areas of safety-related facilities. The northern cluster of CRN Site borings, which corresponds to proposed Location B, is centered northeast of the greatest concentration of borings related to the CRBRP Site investigation and occurs within the same geologic unit (Figure 2.5.1-74). The southern cluster of CRN Site borings, which corresponds to proposed Location A, is centered within the Benbolt formation, a slightly younger geologic unit with similar lithologic characteristics. These three concentrations of borings fall within the Chickamauga Group, a middle Ordovician sequence of limestones, silty and cherty limestones, and calcareous siltstones.

Although the CRBRP and CRN Site boring investigations utilized a different stratigraphic nomenclature, the unit designations are directly correlative. The positions of formation contacts correlate well between CRN and CRBRP borings, which demonstrates consistency in topographic survey and geologic logging. Both programs began rock coring at the top of rock and cored continuously to boring termination.

Cavities encountered in both site investigations were logged to the nearest tenth of a foot, with bottom and top elevations of the cavity recorded. A total of 216 cavities were logged during the CRBRP Site investigation, whereas the CRN Site program logged a total of 23 cavities. The fewer number of cavities encountered in the CRN Site borings is consistent with removal of the cavity-rich near-surface strata during the deep CRBRP excavation and associated grading activities prior to 2013 (Figure 2.5.1-74). This combined cavities dataset is illustrated on the distribution of cavities cross section (Figure 2.5.1-51) and on the plot of cavity size versus elevation (Figure 2.5.1-52). Additionally, the distribution of cavity size vs. elevation of the CRN Site data is consistent with that of the CRBRP Site data. Based on the quality and compatibility of both boring investigations, the combined dataset was used for CRN Site analysis of cavities in boreholes.

CRBRP Excavation Records

Excavations for the CRBRP Site were virtually complete before the project was cancelled in November 1983. The excavations were mapped and described in detail prior to backfilling to provide documentation of the geology and structure exposed during the excavation (Reference 2.5.1-303). Two excavations were made, a large excavation (480 ft long x 360 ft wide, and 100 ft deep) for the nuclear island and a smaller excavation (180 ft x 180 ft shallow depth) for the Equalization Basin.

The nuclear island excavation exposed the Fleanor member, primarily a shaly calcareous siltstone at the site, over most of the walls and floor. The Fleanor member exhibited deep chemical weathering of siltstone strata, with minor dissolution of its thin limestone interbeds. The siltstone was fresh at the base of the excavation, but found prone to slaking and disintegration upon subaerial exposure.

The base of the overlying Rockdell Formation, primarily limestone at the site, was exposed on the southeast wall of the nuclear island excavation and contained a concentration of solution cavities at an elevation of approximately 780 ft. The cavities had a maximum radius of a few feet, with lengths ranging “from a few feet to several tens of feet” along discontinuities (Reference 2.5.1-303). Most cavities were partially filled with lateritic clay and silt. Cavities exposed during the excavation were cleaned and plugged with concrete.

The excavation mapping report concluded that the site was suitable for development of the proposed facility or other industrial facilities based on the character of the rock exposed (Reference 2.5.1-303). The planned foundation level of the CRBRP, 714 ft, was below the zone of weathered siltstone observed in the excavation, and the limestone at that elevation was found to be hard and sound. No cavities were described on the floor of the excavation. Any weathered siltstone found to be softer and prone to disintegration and slaking would be mitigated by the planned concrete base mat.

Conclusions

The aforementioned relational analysis provides a comparison of the CRN Site with the CRBRP Site with respect to geologic formation, rock type, geologic structure and occurrence and character of karst and voids/cavities encountered at and below the depth of foundations. The results of the relational analysis form the basis for using subsurface data from both sites to formulate an estimate of a hypothetical large void that may be encountered below the proposed power block, which is included as the second item within this response. The geologic units mapped in the CRBRP Site excavation (Fleanor member and Rockdell Formation) are the same as those occurring in Location B of the CRN Site power block area. Except for the Mascot Formation, the karst depression densities and area ratios for the other stratigraphic units within the power block area are all less than those in the stratigraphic units noted above as occurring to the northwest and southeast of the power block area; indicating that the power block area carbonates appear to have similar dissolution characteristics to the Rockdell Formation.

The following new SSAR Subsection 2.5.1.2.3.4, "Estimate of Hypothetical Large Void," is being added and the existing Subsection 2.5.1.2.3.4, "Unconsolidated Soils/Fill/Terraces," is being renumbered as SSAR Subsection 2.5.1.2.3.5:

2.5.1.2.3.4 Estimate of Hypothetical Large Void

An estimate of a hypothetical large void was made based upon existing data from the CRBRP and CRN Site subsurface investigation and consideration of the geologic units immediately beneath the designated power block area. The estimated size is based on the height of the largest cavities encountered in boreholes at and below the elevation of 740 ft NAVD88 (Table 2.5.1-19). This elevation corresponds to the shallowest embedment depth of the range of proposed technologies and also corresponds to the pool elevation of the Watts Bar Reservoir. Additional explanation follows below. The hypothetical large void described is intended to be used for the evaluation of foundation stability to support the demonstration of site suitability and is not a prediction of what may be encountered during excavation.

Data review

A review of the cavity data from the CRN and CRBRP Site drilling programs reveal several trends illustrated in Figures 2.5.1-75 through 2.5.1-77. The data are segregated by geologic formation to assess the likelihood of the presence of cavities, as well as to estimate cavity size within each geologic unit. Each data plot presents the cavity center-point elevation versus cavity length within the borehole. For this analysis, karst cavity data were partitioned into three elevation intervals. Intervals were as follows: (1) above the CRN Site proposed plant grade of elevation 821 ft NAVD88; (2) between elevations 821 ft NAVD88 and 740 ft NAVD88, the shallowest embedment depth considered and also the Watts Bar Reservoir pool elevation; and (3) lower than elevation 740 ft NAVD88. A comparison of the compiled borehole data shows that the majority of cavities: (1) occur above the elevation 740 ft NAVD88 pool elevation of the Watts Bar Reservoir, and (2) are less than 2 ft in height. The Eidson and Rockdell units show the largest and greatest frequency of cavities. The largest cavity encountered in any borehole has a height of 16.5 ft and occurs at elevation 789 ft NAVD88.

The cavities that occur below the current Watts Bar Reservoir elevation of 740 ft NAVD88, which is the current Watts Bar Reservoir elevation as well as the shallowest embedment depth considered in this investigation, are assumed to reflect dominantly phreatic development below the water table. Cavities in the vadose zone, the area above the water table, may be related to either vadose processes only, or vadose dissolution overprinted on originally phreatic cavities. The relative amount of dissolution attributed to vadose versus phreatic processes in the latter case cannot be determined or quantified from borehole data.

Based on the compiled borehole data, the highest frequency and largest size of cavities occur within the Rockdell and the Eidson units (Table 2.5.1-19, Figure 2.5.1-51). These two units also contain the greatest thicknesses of pure limestone beds relative to other Chickamauga Group strata encountered at the site. More detail regarding the variability of carbonate content by stratigraphic unit is demonstrated in the geophysical logs for these units (Reference 2.5.1-214). Natural gamma radiation increases with the proportion of silt and clay in the formation and the alternating high and low levels reflect the locations of siltstone and limestone beds, respectively (Figure 2.5.1-78; Reference 2.5.1-9). Additionally, carbonate contents were determined from rock core samples during the CRN subsurface investigation (Figure 2.5.1-49). These methods demonstrate the variability of carbonate content both between and within the stratigraphic units at the CRN Site.

The spatial distribution of cavities is consistent with the trends discussed above. A map of boreholes indicating the presence and elevation interval of cavities is presented in Figure 2.5.1-79. Several boreholes within the Rockdell Formation in the south-center of the power block area exhibit cavities in the middle and lower elevation intervals. The boreholes and cavities occur along strike with bedding. However, elevations of individual cavities within this cluster do not appear to correlate directly. Boreholes B-144 and B-145, spaced approximately 33 ft apart, have cavities at elevation 781 ft NAVD88, although connectivity between cavities is uncertain.

Theoretical Conduit Shape

Karst cavity shapes can vary widely, but their morphology is determined by several basic principles. The three dimensional shape of any cavity is governed by its environment of formation, hydrogeologic setting, and rock characteristics. For example, dissolution within the vadose zone, where water is moving downward toward the water table, tends to create slots, shafts, canyons, and passages oriented down dip or following steep joint planes (Reference 2.5.1-305). By contrast, dissolution within the phreatic zone, where water is moving at and below the water table following the hydraulic gradient, tends to create an integrated conduit system with subhorizontal tubular passages that tend to be circular, the most efficient shape for transmittal of water (Reference 2.5.1-305).

The common phreatic tube shape can be modified by factors such as variations in rock solubility, bed thickness, structural discontinuities, geometry of the fracture pathway where dissolution initiated, and the degree to which the initial fractures have been enlarged (Reference 2.5.1-305). The conduit system follows available fractures in response to the hydraulic gradient and may descend or ascend as needed to respond to that gradient, while at the same time following the more open or connected fractures. The resulting pathway enlarges by dissolution, tending toward a circular cross section as dissolution proceeds assuming uniform solubility of the rock.

Hypothetical large void

Based on project data and the understanding that cavities in the phreatic zone comprise portions of an integrated conduit system, the size and shape of a hypothetical large void can be estimated. The estimated size is based on the height of the largest cavities encountered in boreholes at and below the elevation of 740 ft NAVD88 (Table 2.5.1-19). This elevation corresponds to the shallowest embedment depth of the range of proposed technologies and also corresponds to the pool elevation of the Watts Bar Reservoir. The choice of this elevation eliminates voids that would have formed by or been modified by vadose dissolution above the water table and thus captures voids primarily formed by phreatic dissolution below the water table.

The shape of the void is based on the understanding that phreatic conduits are portions of an underground drainage system whose function is to transport water. In this capacity, a phreatic conduit ideal shape is tubular or pipe-like although this is conceptual with regards to the CRN site (Reference 2.5.1-305). Based on observations of cave passage orientation in the Knox Group and older carbonate strata in the Oak Ridge area (Reference 2.5.1-254), and documented strata-bound movement of contaminants in groundwater through the Chickamauga Group at the ORNL site (Reference 2.5.1-304), the dominant direction of flow is expected to follow the strike of bedding.

The characteristics of the hypothetical large void are shown in Table 2.5.1-20. The geometric characteristics are provided as a simple shape, both for ease of subsequent analysis, and to acknowledge a lack of direct observations that support further detail. A hypothetical large void that could occur below foundation level has a cylindrical shape with the long axis oriented N52°E, parallel to strike. The cross section is circular, with a diameter (height and width) of 10 ft, approximately the largest void encountered in the boreholes at or below elevation 740 ft NAVD88, rounded up to the nearest foot (MP-418 in Table 2.5.1-19). Voids encountered above elevation 740 ft NAVD88 are located above the shallowest embedment depth of the range of proposed technologies and may have been modified by vadose dissolution not expected below elevation 740 ft NAVD88. The length may be a few or several tens of feet at the scale of the proposed plant foundation based on the site borehole data, and geologic mapping of the CRBRP excavation (Reference 2.5.1-303).

The hypothetical large void described is intended to be used for the evaluation of foundation stability to support the demonstration of site suitability and is not a prediction of what may be encountered during excavation. The shape and size are based on an interpretation of the documented borehole data, informed by observations of cavities mapped within the Rockdell Formation in the CRBRP excavation, and on professional judgment considering the combined site data and the understanding of karst processes at the CRN Site and within the region.

~~2.5.1.2.3.4~~2.5.1.2.3.5 Unconsolidated Soils/Fill/Terraces

(Note - no change in text, subsection renumbered from 2.5.1.2.3.4 to 2.5.1.2.3.5)

As a result of the revised text in Subsection 2.5.1.2.9, the following references are being added at the end of SSAR Subsection 2.5.1.3:

2.5.1-303 Drakulich, N. S., Geologic mapping of the Clinch River Breeder Reactor plant excavations, prepared for the U. S. Department of Energy and CRBRP Project Management Corporation: Stone and Webster Engineering Company, Cherry Hill, NJ, Report No. 12720.50-G(C)-1, 1984

2.5.1-304 Ketelle, R. J., and R.R. Lee, Migration of a groundwater contaminant plume by stratabound flow in waste area grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee: ORNL/ER-126, prepared by Martin Marietta Energy Systems, Inc., 21 p., 1992.

2.5.1-305 Lauritzen, S.E., and J. Lundberg, Solutional and erosional morphology, Chapter 6.1 in: Speleogenesis, Evolution of Karst Aquifers, A. B. Klimchouk, D. C. Ford, A. N. Palmer, W. Dreybrodt, National Speleological Society, Inc., p. 408-426, 2000.

As a result of the revised text in Subsection 2.5.1.2.9, the following new tables are being added at the end of SSAR Subsection 2.5.1.3:

Table 2.5.1-19
Largest Cavities Encountered in Boreholes, Listed by Height

Borehole	Formation	Cavity Average Elevation (ft)	Cavity Top Elevation (ft)	Cavity Bottom Elevation (ft)	Cavity Height (ft)
B-140	Rockdell	789.0	797.2	780.7	16.5
B-149	Rockdell	811.5	819.1	803.8	15.3
B-17	Rockdell	817.2	824.2	810.2	14.0
MP-418	Eidson	756.8	762.2	751.4	10.8
MP-410	Rockdell	783.2	788.2	778.1	10.1
MP-418	Eidson	735.4	740.1	730.6	9.5
B-50	Rockdell	741.3	745.5	737.0	8.5
B-22	Rockdell	725.8	729.6	722.0	7.6
B-56	Eidson	719.3	722.7	715.9	6.8
B-50	Rockdell	763.5	766.8	760.2	6.6

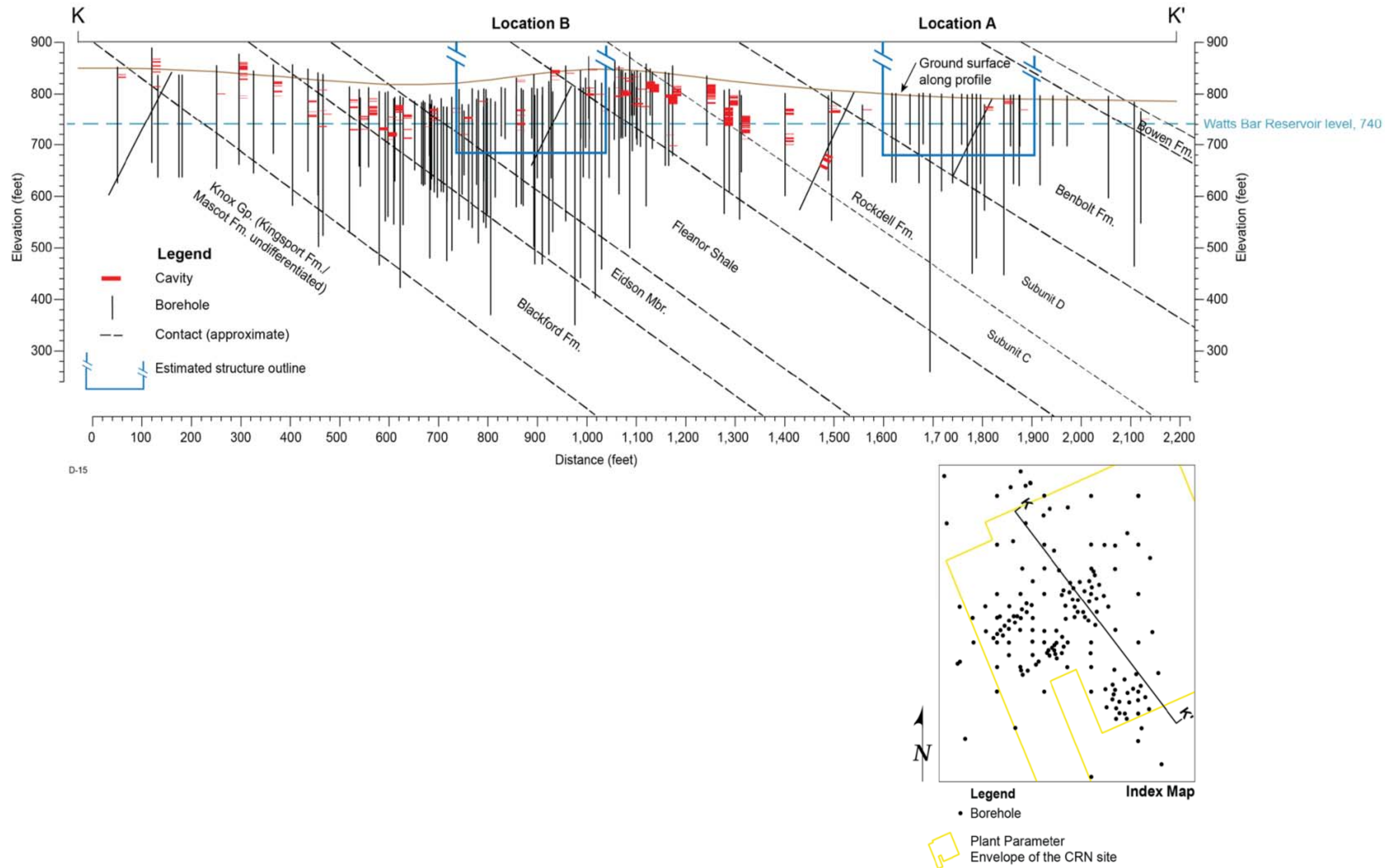
Table 2.5.1-20
Hypothetical Large Void below Foundation Level

Height	Width	Length	3D Shape	Cross-section shape	Orientation of long axis
10 ft	10 ft	Feet to tens of feet	Tube	Circular	N 52°E

As a result of the new Subsection 2.5.1.2.9, the following existing figures are being revised and replaced.

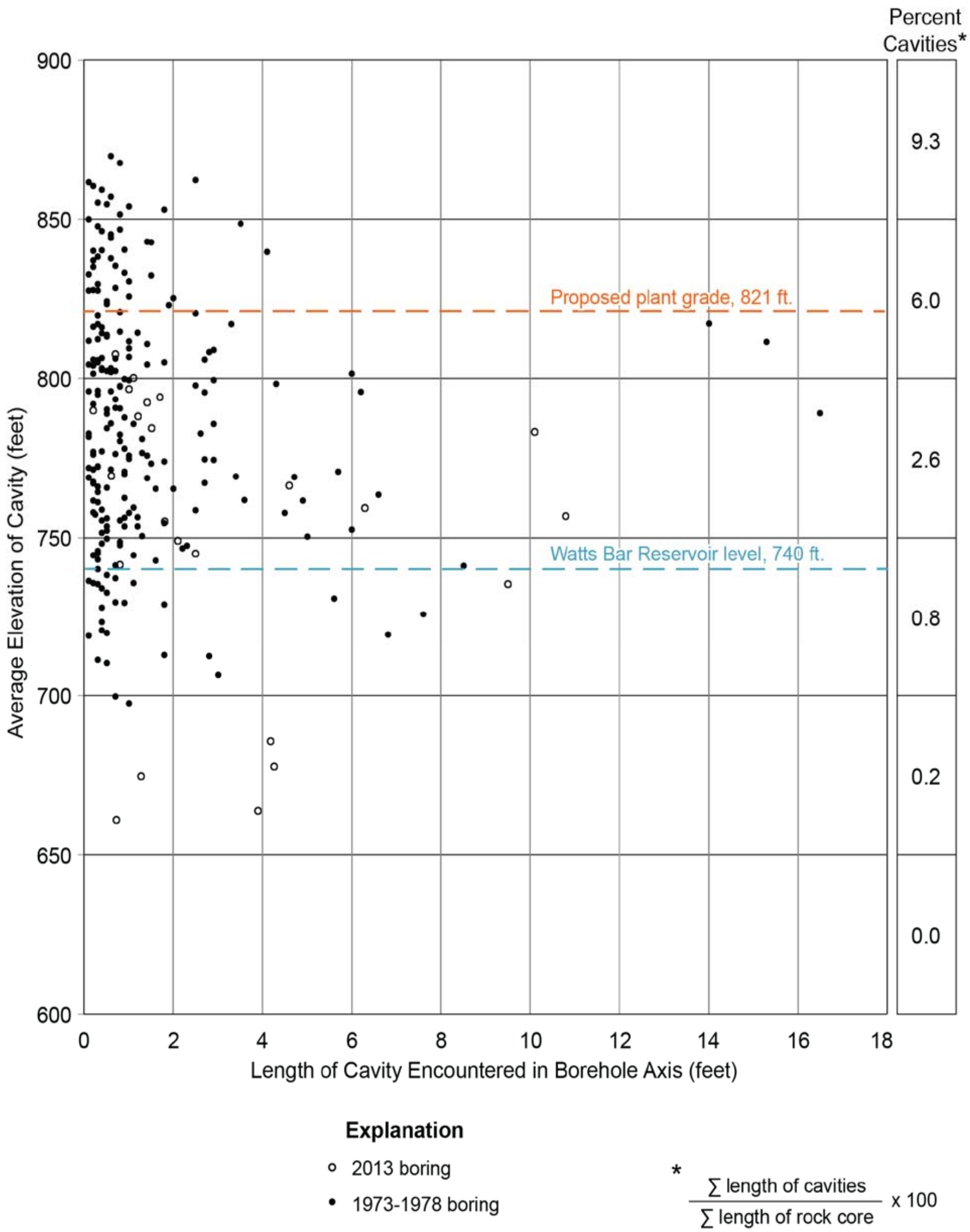
Figure 2.5.1-51. Cross-Section Distribution of Cavities in Rock Core

Figure 2.5.1-52. Cavity Size and Elevation in Borings



Notes:
(1) Boreholes are projected on to a vertical plane oriented perpendicular to bedding strike of N52°E
(2) Borehole data are compiled from the CRBRP (Reference 2.5.1-100) and the CRN investigation (Reference 2.5.1-214)

Figure 2.5.1-51. Cross-Section Distribution of Cavities in Rock Core



Reference 2.5.1-100, Reference 2.5.1-214

Figure 2.5.1-52. Cavity Size and Elevation in Borings

As a result of the new Subsections 2.5.1.2.3.4 and 2.5.1.2.9, the following figures are being added to SSAR Subsection 2.5.1:

Figure 2.5.1-74. Borehole Plan for CRBRP and CRN Investigations

Figure 2.5.1-75. Cavity Size and Elevation: Kingsport, Mascot, and Blackford Formations

Figure 2.5.1-76. Cavity Size and Elevation: Benbolt and Fleanor Formations

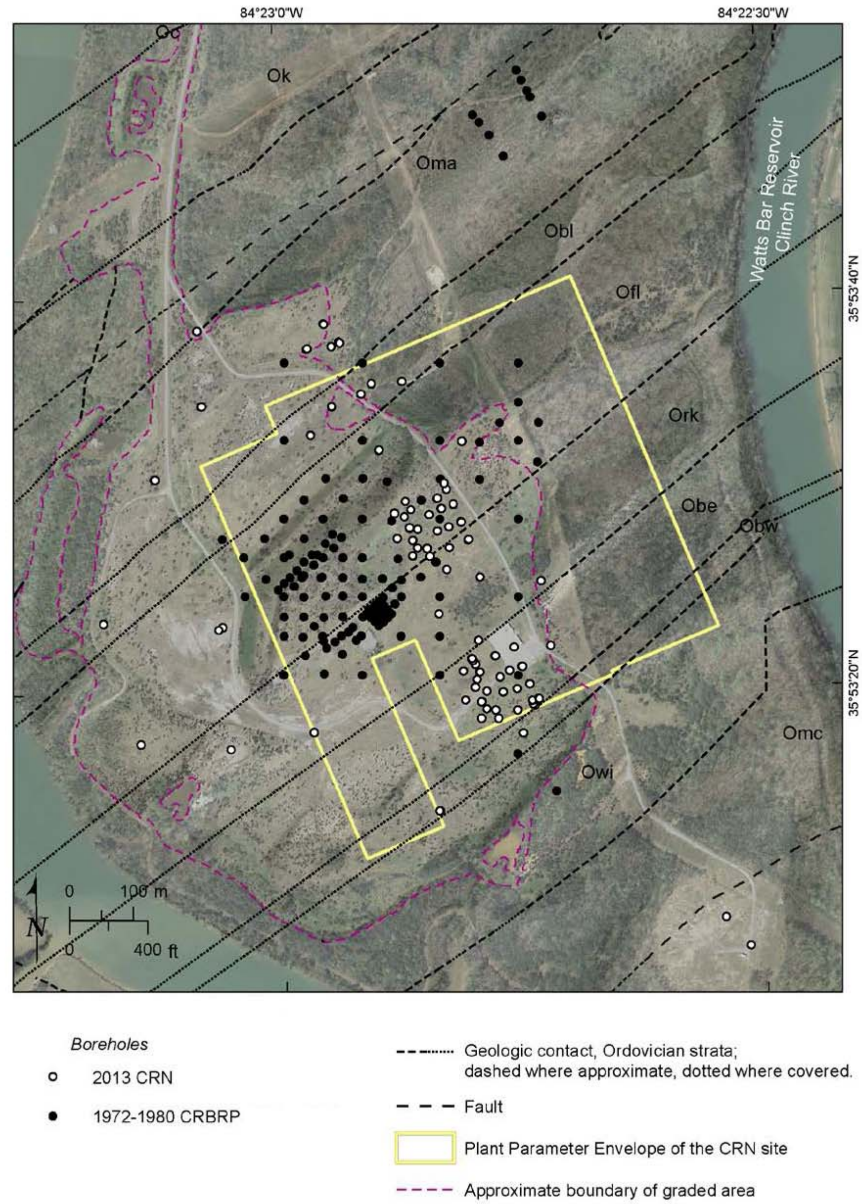
Figure 2.5.1-77. Cavity Size and Elevation: Rockdell and Eidson Formations

Figure 2.5.1-78. Chickamauga Group Stratigraphic Column

Figure 2.5.1-79. Map Distribution of Cavities in Rock Core

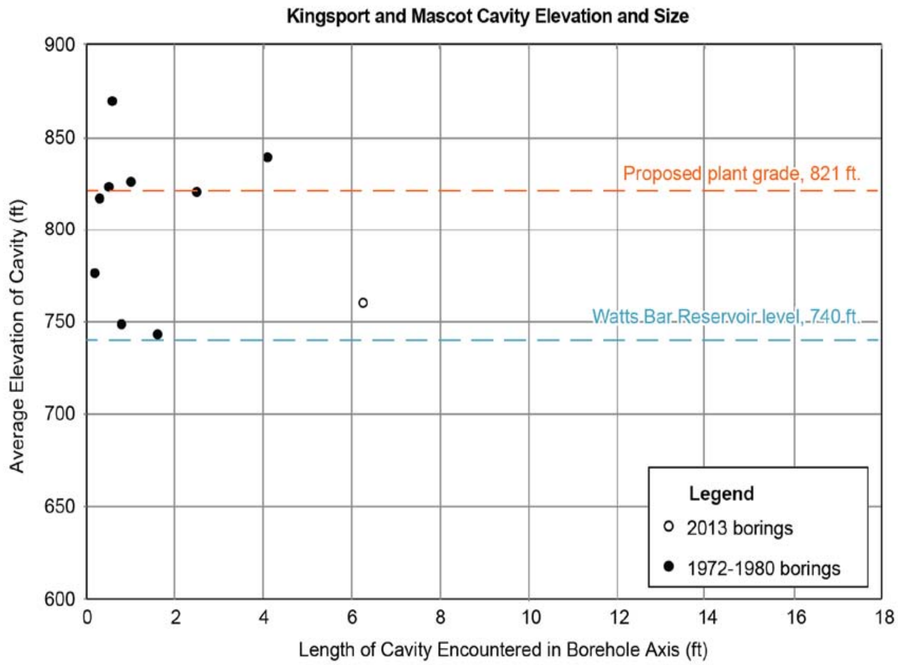
Figure 2.5.1-80. CRBRP Site Geologic Map

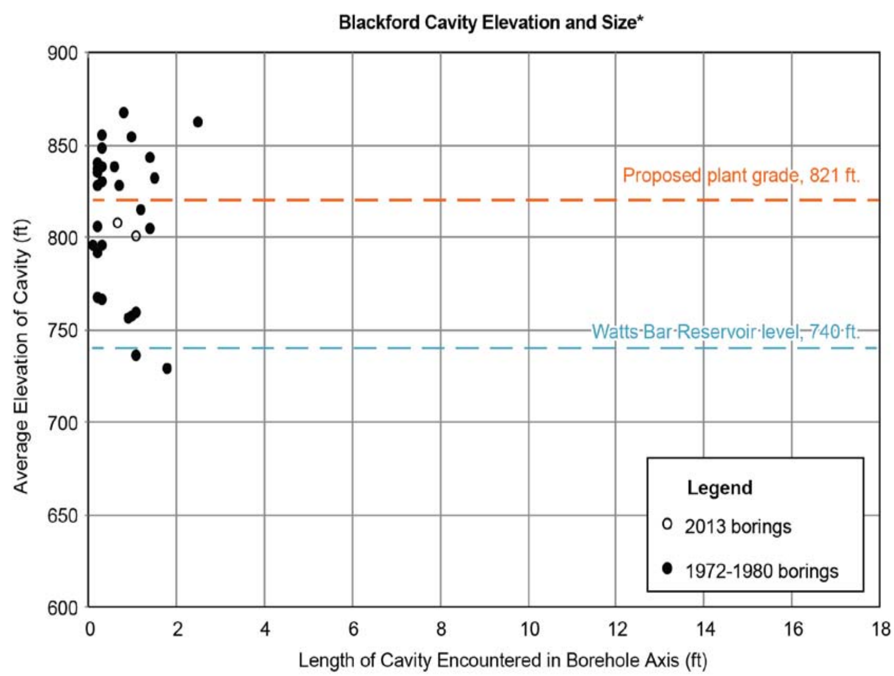
Figure 2.5.1-81. CRBRP Site Geologic Cross Section



Note: See Figure 2.5.1-79 for explanation of geologic units
1972 –1980 CRPRP borehole data from Reference 2.5.1-100

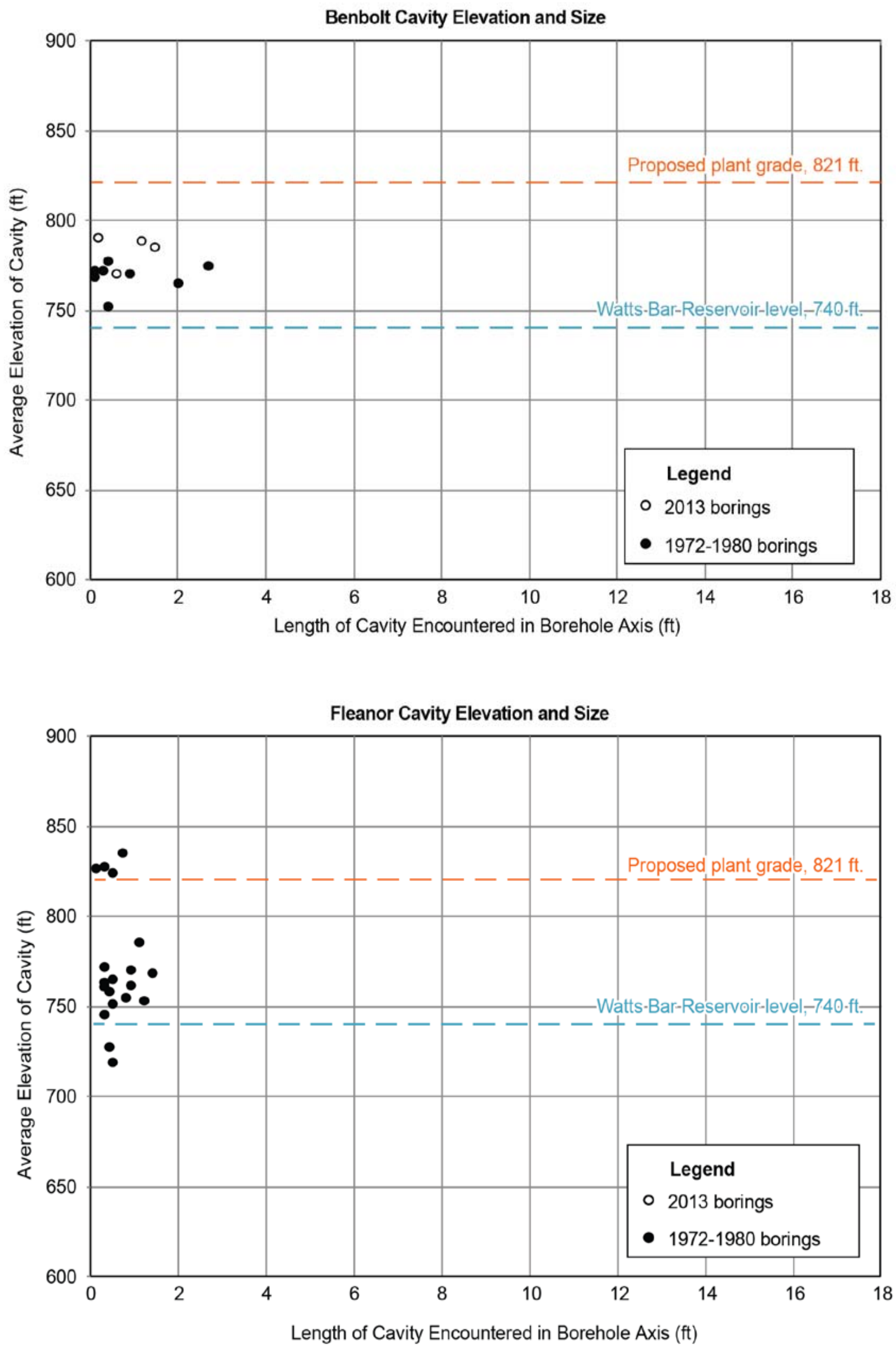
Figure 2.5.1-74. Borehole Plan for CRBRP and CRN Investigations





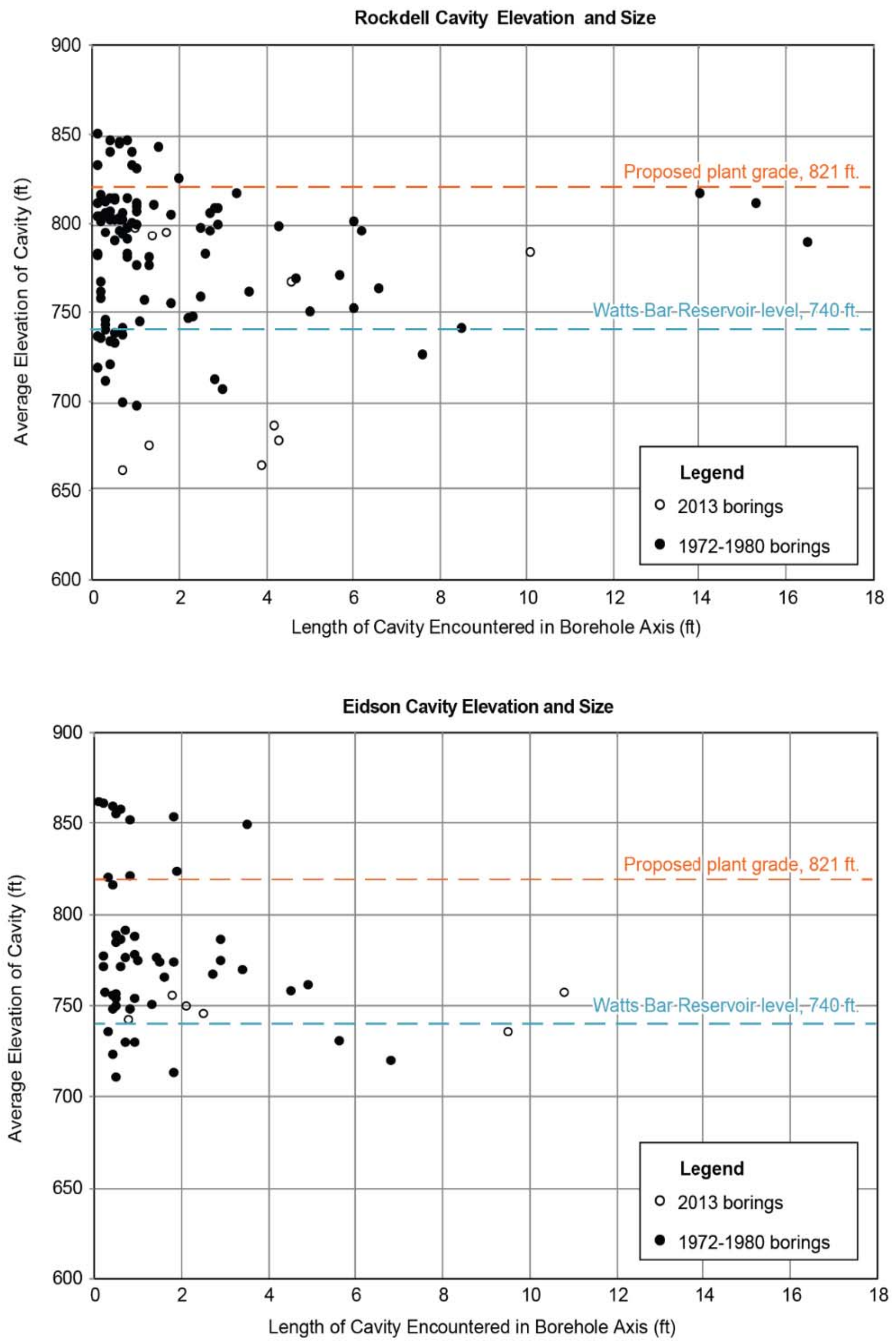
Note: Data from References 2.5.1-100 and 2.5.1-214
*Does not include the Eidson member.

Figure 2.5.1-75. Cavity Size and Elevation: Kingsport, Mascot, and Blackford Formations



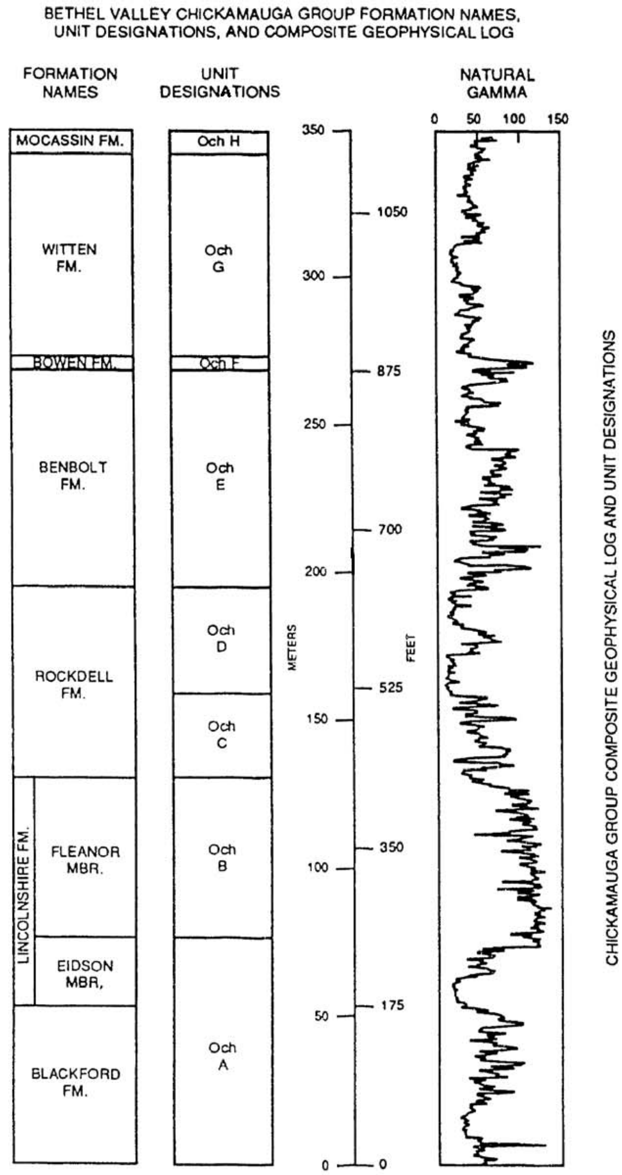
Note: Data from References 2.5.1-100 and 2.5.1-214

Figure 2.5.1-76. Cavity Size and Elevation: Benbolt and Fleanor Formations



Note: Data from References 2.5.1-100 and 2.5.1-214

Figure 2.5.1-77. Cavity Size and Elevation: Rockdell and Eidson Formations



Note: From Reference 2.5.1-9

Figure 2.5.1-78. Chickamauga Group Stratigraphic Column

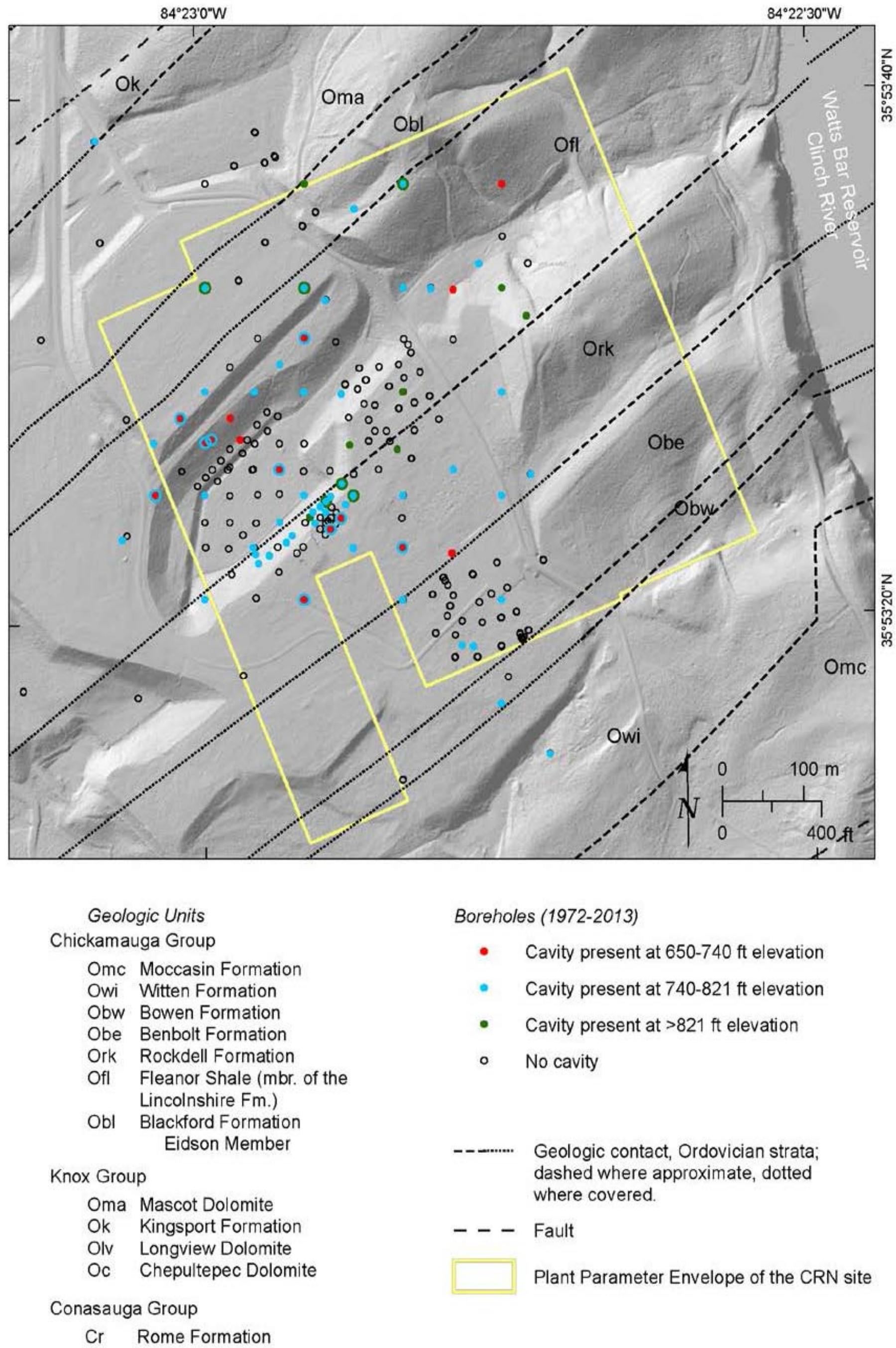
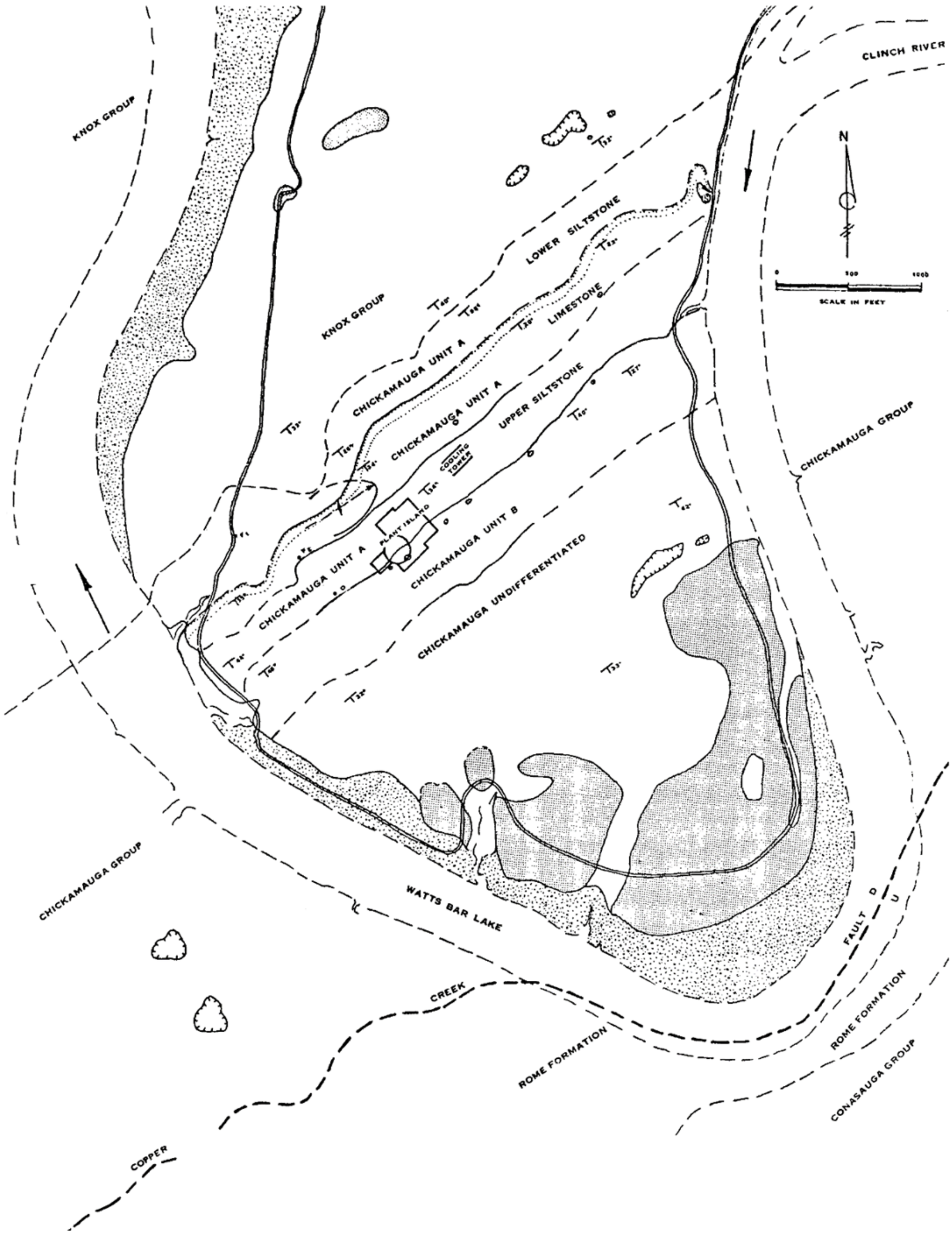
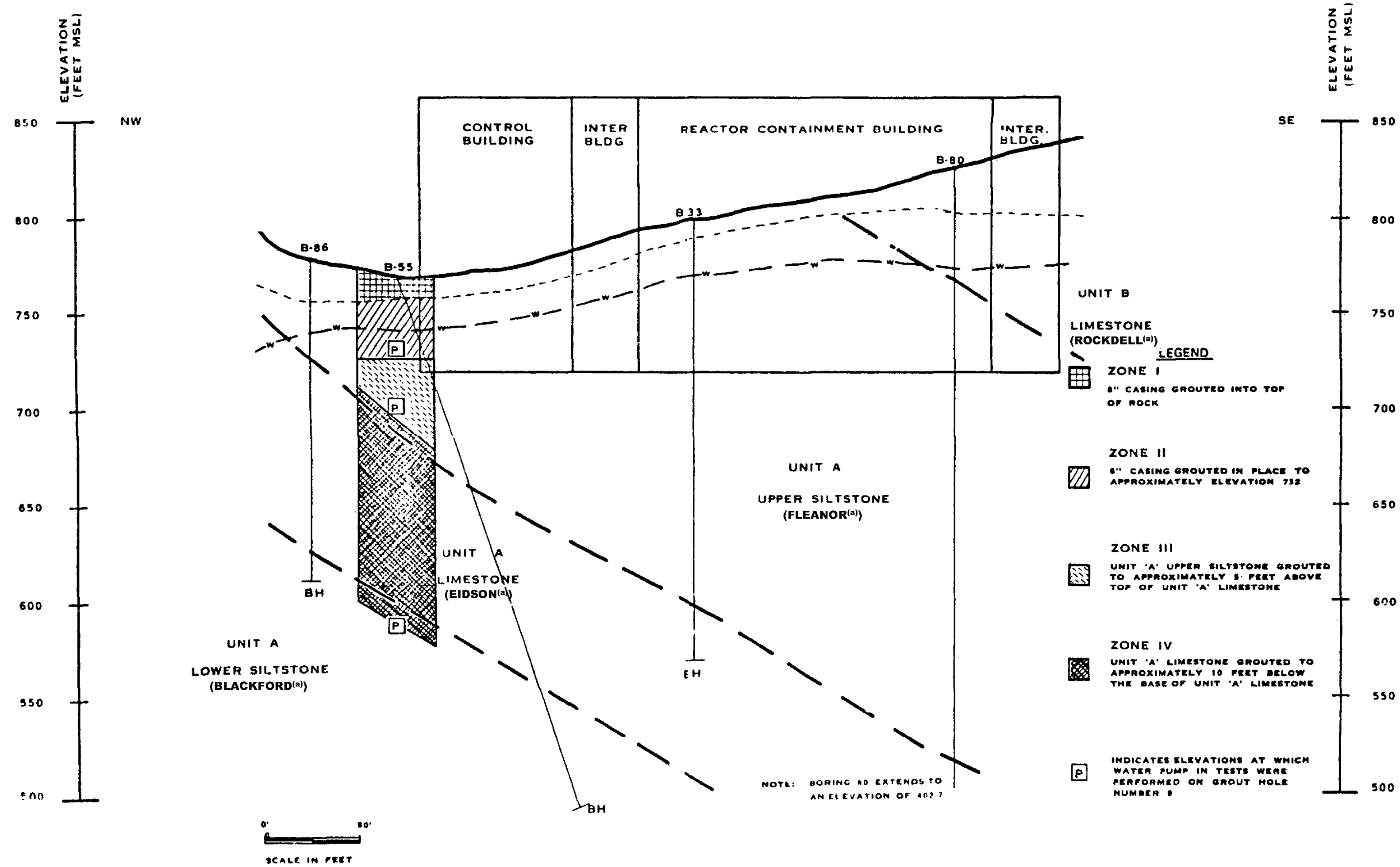


Figure 2.5.1-79. Map Distribution of Cavities in Rock Core



Reference 2.5.1-238

Figure 2.5.1-80. CRBRP Site Geologic Map



From Reference 2.5.1-238
Note:
(a) Description added to facilitate comparison with Figure 2.5.1-30

Figure 2.5.1-81. CRBRP Site Geologic Cross Section