ClinchRiverESPHFNPEm Resource

From: Edmondson, Carla <cedmondson@tva.gov>
Sent: Monday, October 02, 2017 1:07 PM
To: Fetter, Allen; Sutton, Mallecia
Subject: [External_Sender] CNL-17-100 CRN Response to RAI 5
Attachments: CNL-17-100 CRN Response to RAI 5, 02.05.01-03 and 02.05.01-05 .pdf

Subject letter has been transmitted to the NRC ML17275A215 (Hard copies to follow via UPS)

CNL-17-100 CRN Response to RAI 5

On behalf of
Joe Shea
VP Nuclear Regulatory Affairs & Support Services

Carla Edmondson
Executive Management Assistant to Joe Shea
423-751-2638

Hearing Identifier: ClinchRiver_ESP_HF_NonPublic
Email Number: 441

Mail Envelope Properties (7D5D7C9A93A2F1418E8AF559D2DAFAF099BBE0E5)

Subject: [External_Sender] CNL-17-100 CRN Response to RAI 5
Sent Date: 10/2/2017 1:06:37 PM
Received Date: 10/2/2017 1:09:41 PM
From: Edmondson, Carla

Created By: cedmondson@tva.gov

Recipients:
"Fetter, Allen" <Allen.Fetter@nrc.gov>
Tracking Status: None
"Sutton, Mallecia" <Mallecia.Sutton@nrc.gov>
Tracking Status: None

Post Office: TVACHAXCH2.main.tva.gov

Files	**Size**	**Date & Time**
MESSAGE	290	10/2/2017 1:09:41 PM
CNL-17-100 CRN Response to RAI 5, 02.05.01-03 and 02.05.01-05 .pdf	3935025	

Options
Priority: Standard
Return Notification: No
Reply Requested: No
Sensitivity: Normal
Expiration Date:
Recipients Received:

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

CNL-17-100

September 29, 2017

10 CFR 52, Subpart A

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

Clinch River Nuclear Site
NRC Docket No. 52-047

Subject: Response to Request for Additional Information Number 5, Questions 02.05.01-03 and 02.05.01-05, Regarding Basis Geologic and Seismic Information 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-16-162, "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
3. NRC Electronic Mail, "Issuance of RAI pertaining to Section 2.5.1, Basis Geologic and Seismic Information (RAI Number 5, eRAI-8991)," dated August 1, 2017
4. Letter from TVA to NRC, CNL-17-099, "Response to Request for Additional Information Number 5, Questions 02.05.01-01 and 02.05.01-02, Regarding Basis Geologic and Seismic Information and RAI Number 6, Questions 02.05.04-01 and 02.05.04-02, Regarding Stability of Subsurface Materials and Foundations in Support of Early Site Permit Application for Clinch River Nuclear Site," dated September 15, 2017

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. By letter dated October 21, 2016 (Reference 2), TVA provided supplemental information related to geologic characterization information, surface deformation, stability of subsurface materials and foundation, in support of the early site permit application. By electronic mail dated August 1, 2017 (Reference 3), Nuclear Regulatory Commission (NRC) issued a request for additional Information (RAI) regarding stability of subsurface materials and foundations associated with the CRN Site.

Enclosures 1 and 2 to this letter provide the response to the RAI 5, Questions 02.05.01-03 and 02.05.01-05, respectively, including Site Safety Analysis Report (SSAR) markups. The SSAR markups will be incorporated in a future revision of the early site permit application. The response to RAI 5, Questions 02.05.01-01 and 02.05.01-02, was provided in Reference 4. As noted in Reference 3, the response to RAI 5, Questions 02.05.01-04 and 02.05.01-06 will be provided in a separate letter.

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 29th day of September 2017.

Respectfully,

J. W. Shea
Digitally signed by J. W. Shea
DN: cn=J. W. Shea, o=Tennessee Valley Authority, ou=Nuclear Licensing, email=jwshea@tva.gov, c=US
Date: 2017.09.29 12:34:45 -04'00'

J. W. Shea
Vice President, Nuclear Regulatory Affairs and Support Services

Enclosures:

1. Response to NRC RAI Number 5, Question 02.05.01-03
2. Response to NRC RAI Number 5, Question 02.05.01-05

cc: See page 3

cc: (Enclosures)

A. Fetter, Project Manager, Division of New Reactor Licensing (1 copy)

cc: (without Enclosures)

V. McCree, Executive Director of Operations, USNRC
C. Haney, Regional Administrator, Region II, USNRC
M. Johnson, Deputy Executive Director for Reactor and Preparedness Programs, USNRC
V. Ordaz, Acting Director, Office of New Reactors, USNRC
F. Akstulewicz, Director, Division of New Reactor Licensing, USNRC
J. Colaccino, Branch Chief, Division of New Reactor Licensing, USNRC
M. Sutton, Project Manager, Division of New Reactor Licensing, USNRC
P. Vokoun, Project Manager, Division of New Reactor Licensing, USNRC
T. Dozier, Project Manager, Division of New Reactor Licensing, USNRC
M. M. McIntosh, Regulatory Specialist, Eastern Regulatory Field Office, Nashville District, USACE

Enclosure 1
Response to NRC RAI Number 5, Question 02.05.01-03

NRC RAI 02.05.01-03 Question

Geophysical Data

SSAR (Rev 0) Section 2.5.1.2.4.2.1 Geophysical Data, identifies two seismic reflection surveys, SRL-1 and SRL-2, conducted at the CRN Site. The SSAR (Rev 0) concludes that the many anomalies in the data could not be resolved by various processing routines and that none of the Alleghenian thrust faults that are located within the site location were identified in these data.

In addition, SSAR (Rev 0) Section 2.5.1.2.5.1 Karst Hazards, uses the same seismic reflection profiles to conclude that continuous, uninterrupted bedding at depth beneath the site suggests that large hypogenic karst collapse features are not present.

Staff notes that SSAR (Rev 0) Section 2.5.1.2.5.1.1 Karst in the Site Vicinity and Area, describes seismic reflection and seismic refraction data at the ORR used to identify buried sinkholes (Doll et al., 2005). Doll et al conclude that seismic reflection was less successful detecting voids within the bedrock; that seismic reflection data do not accurately represent the structure of the karst features; and that karst was found to significantly influence the quality of stacked seismic reflection profiles.

These features (tectonic faults and karst related voids) represent potentially adverse site conditions that affect compliance with 10 CFR 100.23 (c-d). However, based on the information provided in the SSAR (Rev 0), as well as the Doll et al. 2005 publication, it seems that neither karst voids nor known thrust faults at the site can be reliably identified by this geophysical method. Provide a technical basis for the applicability of the CRN seismic reflection investigations to resolve thrust structures (blind or otherwise) and voids and draw conclusions based on the seismic reflection. Including limits at which such features may be present but undetected at the site.

TVA RAI 02.05.01-03 Response

Thrust faults in foreland fold-thrust belts worldwide have been successfully imaged using seismic reflection geophysical techniques (e.g., References 1 through 5). Therefore, this technique was applied to identify possible similar subsurface structures at the CRN Site.
The two seismic reflection surveys conducted at the CRN Site do not appear to image foreland fold-thrust belt faults, including previously mapped faults near the site (Whiteoak Mountain, Chestnut Ridge, and Copper Creek faults). The reasons that these faults were not imaged is not a function of the inability of seismic reflection to image foreland fold-thrust belt faults, but the location of the survey lines relative to the faults. For instance, the trace of the Whiteoak Mountain fault is approximately 10,000 ft northwest of the northwestern extent of both seismic reflection survey lines. Projection of this fault into the subsurface indicates it likely occurs at elevations of -7,000 ft with respect to mean sea level (MSL) to -8,000 ft MSL at the CRN Site, which is well below the depth imaged in seismic reflection profiles SRL-1 and SRL-2. The mapped trace of the Copper Creek fault crosses seismic reflection survey line SRL-1 at its southeastern end, which occurs where loss of data redundancy (fold) precludes reliable imaging or interpretation (Reference 6). The Chestnut Ridge fault of Lemiszki (Reference 7) is a relatively small-displacement thrust fault interpreted to juxtapose Chepultepec Dolomite against the Kingsport Formation (also dolomite) below the CRN Site (see cross section in SSAR Figure 2.5.1-64). The Chestnut Ridge fault trace occurs approximately 1,000 to 1,400 ft

northwest of seismic reflection profiles SRL-2 and SRL-1, respectively. Based on the cross section of Lemiszki (Reference 7; see SSAR Figure 2.5.1-64), the Chestnut Ridge fault should occur beneath the CRN Site at approximately 2,500 ft depth. The estimated depth imaged by the seismic reflection profiles SRL-1 and SRL-2 is approximately 3,500 ft, based on two-way travel times and inferred seismic velocities (Reference 6). Therefore, the fault could be imaged in the seismic reflection profiles, but there is no apparent offset of reflectors. Potential explanations for the lack of conspicuous offset in the seismic reflection data include: 1) there is not enough acoustic contrast between the two similar units to produce a strong seismic reflection, or 2) there is little stratigraphic offset.

The Alleghanian thrust faults that are located within the site area were not identified in seismic reflection profiles SRL-1 and SRL-2 primarily due to logistical constraints on survey line length (Reference 6). While these faults were not imaged due to this and the reasons outlined above, the method is a technically viable approach to detect previously unknown thrust structures at the site. There is no conspicuous offset of reflectors visible in the available data. Therefore, it does not appear that there are unknown blind faults beneath the site.

The seismic reflection data at the CRN Site was primarily collected to evaluate the bedrock structure and potential thrust faults in foreland fold-thrust belt as discussed above. The inherent uncertainty in seismic reflection data limits its capability to address the presence of karst. However, seismic reflection has been used to successfully evaluate karst at other sites. Discussions of hypogene dissolution examples in Biscayne Bay, Florida (References 8 through 10), and in the Shenandoah Valley, Virginia (Reference 11) are illustrated with figures from these references (see SSAR Figures 2.5.1-84 and 2.5.1-85). Geophysical studies in Biscayne Bay, Florida, demonstrate the applicability of seismic reflection to identify karst dissolution features. However, the karst features identified in Biscayne Bay are much larger than voids expected at the CRN Site.

The absence of karst evidence at the CRN Site as interpreted using seismic reflection data does not preclude the presence of voids at the site. The seismic reflection data is another tool to be used along with other data collection methods, such as boreholes, for karst evaluation.

SSAR Subsections 2.5.1.2.4.2.1 and 2.5.1.2.5 are being revised as indicated in the SSAR markups below to reflect the ability to image foreland fold-thrust belt faults and karst dissolution features in seismic reflection profiles, respectively. The SSAR Subsection 2.5.1 markups reflect changes provided in TVA's letter 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. The SSAR markups will be incorporated in a future revision of the early site permit application.

References:

1. Bally, A.W., Gordy, P.L., and Stewart, G.A., Structure, seismic data, and orogenic evolution of southern Canadian Rocky Mountains: Bulletin of Canadian Petroleum Geology, v. 14, no. 3, p. 337-381, 1966.

2. Roure F., Choukroune P., Berastegui X., Muñoz J.A., Villien A., Matheron P., Bareyt M., Seguret M., Camara P., and Deramond J., ECORS deep seismic data and balanced cross sections: Geometric constraints on the evolution of the Pyrenees: Tectonics, v. 8, no. 1, p. 41-50, 1989.

3. McBride, J.H., Barazangi, M., Best, J., Al-Saad, D., Sawaf, T., Al-Otri, M., and Gebran, A., Seismic reflection structure of intracratonic Palmyride fold-thrust belt and surrounding Arabian platform, Syria: American Association of Petroleum Geologists Bulletin, v. 74, no. 3, p. 238-259, 1990.

4. Hatcher, R.D., Jr., P.J. Lemiszki, and J.B. Whisner, *Character of rigid boundaries and internal deformation of the southern Appalachian foreland fold-thrust belt*, J.W. Sears, T.A. Harms, and C.A. Evenchick, (eds.), *Whence the Mountains? Inquiries into the Evolution of Orogenic Systems: A Volume in Honor of Raymond A. Price: Boulder, Colorado*, Geological Society of America Special Paper 433, pp. 243–276, 2007.

5. Lin, A.T., Yao, B., Hsu, S., Liu, C., and Huang, C., Tectonic features of the incipient arc-continent collision zone of Taiwan: Implications for seismicity: Tectonophysics, v. 479, no. 1-2, p. 28-42, 2009.

6. AMEC Environment and Infrastructure Inc., Data Report Rev. 4. Geotechnical Exploration and Testing, Clinch River SMR Project, Oak Ridge, Tennessee. AMEC Project No. 6468-13-1072, October 2014.

7. Lemiszki, P. J., Geologic Map of the Elverton Quadrangle, Tennessee, Draft OpenFile Map, scale 1:24,000, 2015.

8. Cunningham, K., and C. Walker, Seismic-Sag Structural Systems in Tertiary Carbonate Rocks Beneath Southeastern Florida, USA: Evidence for Hypogenic Speleogenesis?, A. Klimchouk and D. Ford (eds.), Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins, Ukrainian Institute of Speleology and Karstology, Special Paper 1, pp. 151–158, 2009.

9. Cunningham, K.J., Walker, C., and Westcott, R.L., Near-surface marine seismic-reflection data define potential hydrogeologic confinement bypass in the carbonate Floridan Aquifer system, southeastern Florida, 2012, Society of Economic Geologists 2012 Annual Meeting, 6 pages, 2012.

10. Reese, R.S., and Cunningham, K.J., Hydrogeologic framework and salinity distribution of the Floridan Aquifer System of Broward County, Florida: U.S. Geological Survey Scientific Investigations Report 2014-5029, 60 p., 2014.

11. Doctor, D. J., Orndorff, W., Maynard, J., Heller, M. J., and Casile, G. C. Karst geomorphology and hydrology of the Shenandoah valley near Harrisonburg, Virginia, in Bailey, C.M., and Coiner, L.V., eds., Elevating Geoscience in the Southeastern United States: New Ideas about Old Terranes—Field Guides for the GSA Southeastern Section Meeting, Blacksburg, Virginia, 2014: Geological Society of America Field Guide 35, p. 161–213, 2014.

SSAR Markups

SSAR Subsection 2.5.1.2.4.2.1 is being revised as indicated. Underlines indicates text to be added. Strikethroughs indicates text to be deleted.

2.5.1.2.4.2.1 Geophysical Data

Seismic reflection and seismic refraction surveys were conducted at the CRN Site to support the subsurface investigations (Reference 2.5.1-214). The primary objectives of the seismic reflection surveys were to 1) interpret the contact between the Knox Group and overlying Chickamauga Group rocks; 2) interpret the dip of bedding between borehole locations; and 3) identify possible subsurface structures beneath the survey lines. The primary objective of the seismic refraction surveys was to map the depth to bedrock at the site.

2.5.1.2.4.2.1.1 Seismic Reflection Data

Seismic reflection has been a reliable geophysical method for successfully imaging stratigraphy and faults in foreland fold-thrust belts, including the southern Appalachian Valley and Ridge (e.g., References 2.5.1-102 and 2.5.1-316). Hatcher et al. (Reference 2.5.1-102) present numerous balanced geologic cross sections throughout the eastern Tennessee Valley and Ridge Province that rely heavily on seismic reflection data, demonstrating the applicability of this method to delineate the subsurface structural geology in a foreland fold-thrust system. Additionally, Hatcher et al. (Reference 2.5.1-9) present a line drawing of their interpretation of a seismic reflection profile that was acquired along Tennessee Highway 95, approximately 2 mi. northeast of the CRN Site (Figure 2.5.1-83). Hatcher et al. (Reference 2.5.1-9) interpret the Whiteoak Mountain and Copper Creek faults on this profile, based on the mapped locations of the faults relative to the seismic reflection survey line and, for the Whiteoak Mountain fault, strong reflectors in the hanging wall that truncate reflectors in the interpreted footwall (Figure 2.5.1-83). Similar truncations are not visible along the Copper Creek fault in this seismic reflection profile, which is interpreted by Hatcher et al. (Reference 2.5.1-9) to represent parallel bedding above and below the fault (Figure 2.5.1-83, Sheet 2 of 2).

Two seismic reflection surveys, SRL-1 and SRL-2, were conducted at the CRN Site (Reference 2.5.1-214) (also see Subsection 2.5.4.4.2.1). The locations of the seismic reflection survey lines are presented in Figure 2.5.1-29, and the processed P-wave seismic reflection profiles are presented in Figure 2.5.1-36. Data quality decreases on the edges of seismic reflection profiles due to a decrease in data redundancy (fold). Noise contamination, out-of-plane reflectors and spatial aliasing effects are mitigated better in areas with increased fold, due to the statistical effects of signal enhancement associated with increased fold (Reference 2.5.1-214). Noise effects, therefore, are more pronounced at the ends of each line where fold decreases (Reference 2.5.1-214). In Figure 2.5.1-36, orange subvertical lines on the interpreted profiles represent areas where the fold is significantly decreased and the effects of noise contamination do not permit accurate interpretation (Reference 2.5.1-214).

Vertical resolution of seismic reflection data is generally defined as one-quarter of the wavelength (Reference 2.5.1-317). As wavelength is equal to seismic velocity divided by the dominant frequency, the best vertical resolution of seismic reflection profiles SRL-1 and SRL-2 is on the order of approximately 10 m (33 ft), based on assumed seismic compressional wave velocities of 12,500 to 20,000 ft/sec (Reference 2.5.1-214) and an assumed signal frequency spectra on the order of 125 Hz. However, wavelength depends on velocities above and below a specific reflector, so a reliable estimate of vertical resolution that covers the entire time sections of both lines is not possible with the current data.

Unmigrated seismic reflection profiles of SRL-1 and SRL-2 (Figure 2.5.1-36, with interpretation and without interpretation) show continuous, moderately southeast-dipping reflectors, which is consistent with geologic observations at the ground surface and from borehole data (Reference 2.5.1-214). The ~~Several~~ anomalies described below could not be resolved by enhanced stack options, including: spectral whitening; a FX predictive deconvolution enhancement filter; and, finite difference time migration. The survey lines were purposefully extended beyond the area of the plant site so that migration would not be necessary to obtain the data quality needed beneath the site. In any case, the lengths of the survey lines were constrained by the Clinch River arm of the Watts Bar Reservoir to the south and Chestnut Ridge to the north. Because of these spatial constraints, the survey lines could not have been easily extended to obtain the additional data required to resolve these artifacts. Migration did not add value to the data interpretation in the target area beneath the proposed plant site.

Several anomalies ~~that appear~~ were identified in the seismic reflection ~~lines were noted during the investigation~~ profiles; these anomalies are not interpreted to represent geologic features (Figure 2.5.1-36) (Reference 2.5.1-214, Appendix D.2). In SRL-1, three anomalies were encountered (A-1, A-2, and A-3 in Figure 2.5.1-36, Sheet 2). Anomalies A-1 and A-3 represent areas where dip of reflectors changes abruptly near the ends of the line, and are interpreted as artifacts associated with out-of-plane reflectors or spatial aliasing (Figure 2.5.1-36, Sheet 2) (Reference 2.5.1-214, Appendix D-2). Anomaly A-2 distorts the reflector associated with the top of the Knox Group, and is attributed to a tuning phenomenon from resonating dominant frequencies in a wedgelike geologic structure (Figure 2.5.1-36, Sheet 2) (Reference 2.5.1-214, Appendix D-2).

Two additional anomalies are described in SRL-2 (Figure 2.5.1-36, Sheet 4). Anomaly A-4 represents a gap in a prominent reflector, and is attributed to out-of-plane reflectors or spatial aliasing (Reference 2.5.1-214). The lack of offset in the reflectors that flank this gap, in addition to no imaged diffractions in the seismic horizons above or below the anomaly, support the interpretation that this anomaly does not represent a fault (Reference 2.5.1-214). Anomaly A-5 presents as a stair-step feature in the Knox Group horizon, and appears to be related to interference between the seismic reflector and linear noise that bisects the reflector (Figure 2.5.1-36, Sheet 4) (Reference 2.5.1-214).

~~None of t~~ The Alleghanian thrust faults ~~that are~~ located within the site area were not identified in geophysical data collected at the site, primarily due to logistical constraints on survey line length (Reference 2.5.1-214). Additionally, the~~se~~ seismic reflection data, combined with seismic refraction ~~surveys~~ and borehole data, did not reveal any evidence for previously unknown blind subsurface structures at the site (Figures 2.5.1-30 and 2.5.1-36; Reference 2.5.1-214).

Paragraph 10 of SSAR Subsection 2.5.1.2.5.1, Subheading "Karst Conceptual Models," is being revised as indicated. Underlines indicates text to be added.

2.5.1.2.5.1 Karst Hazards

Karst Conceptual Models

Paragraph 10

The mixing of fresh water and salt water in coastal settings can also result in hypogene dissolution. Cunningham and Walker (Reference 2.5.1-41) <u>and Cunningham et al. (Reference 2.5.1-318)</u> describe multistoried vertical sag features evident in high resolution seismic reflection profiles from Biscayne Bay, Florida <u>(Figure 2.5.1-84)</u>. They interpreted these stacked sag features<u>, which range in diameter from 170 m (560 ft) to 3.2 km (10,500 ft),</u> as evidence for coalesced, collapsed paleocave systems. Cunningham and Walker (Reference 2.5.1-41) proposed two hypogene mechanisms to explain these broad structural sags. They postulate upward flow driven by Kohout convection with dissolution by mixed fresh and saline groundwaters <u>(Figure 2.5.1-85)</u> and/or upward ascension of hydrogen-sulfide-charged groundwater derived from dissolution and reduction of calcium sulfates in deeper strata. Additionally, the faults associated with these collapse features may serve as pathways for upward ground water flow. This setting is highly susceptible to both epigenic and hypogenic karst processes due to the high porosity and permeability of Florida limestones and the frequent mixing of salt water and fresh water in groundwaters near the coast (Reference 2.5.1-295).

Paragraph 3 of SSAR Subsection 2.5.1.2.5.1.2, Subheading "Karst-Related Subsurface Features at the Site," is being revised as indicated. Underlines indicates text to be added.

2.5.1.2.5.1.2 Karst Processes and Features at the Clinch River Nuclear Site

Karst-Related Subsurface Features at the Site

Paragraph 3

Additionally, two seismic reflection survey lines were completed at the site during the CRN Site field investigation (Figure 2.5.1-36, Subsection 2.5.1.2.4.2.1). Both seismic reflection profiles show planar beds of uniformly dipping strata. The types of large-scale karst-related stacked sag structures and associated small faults observed in the Biscayne Bay, Florida, seismic reflection profiles (Reference 2.5.1-41) <u>(Figure 2.5.1-84)</u> are not visible in the CRN lines, nor on a seismic reflection profile along Tennessee route 29 on the ORR in the CRN Site vicinity. The uniformity of the planar beds imaged by these seismic reflection profiles is evidence for the lack of any large-scale karst collapse or stacked sag features along these survey lines.

The following references are being added to SSAR Subsection 2.5.1.3. Underlines indicates text to be added.

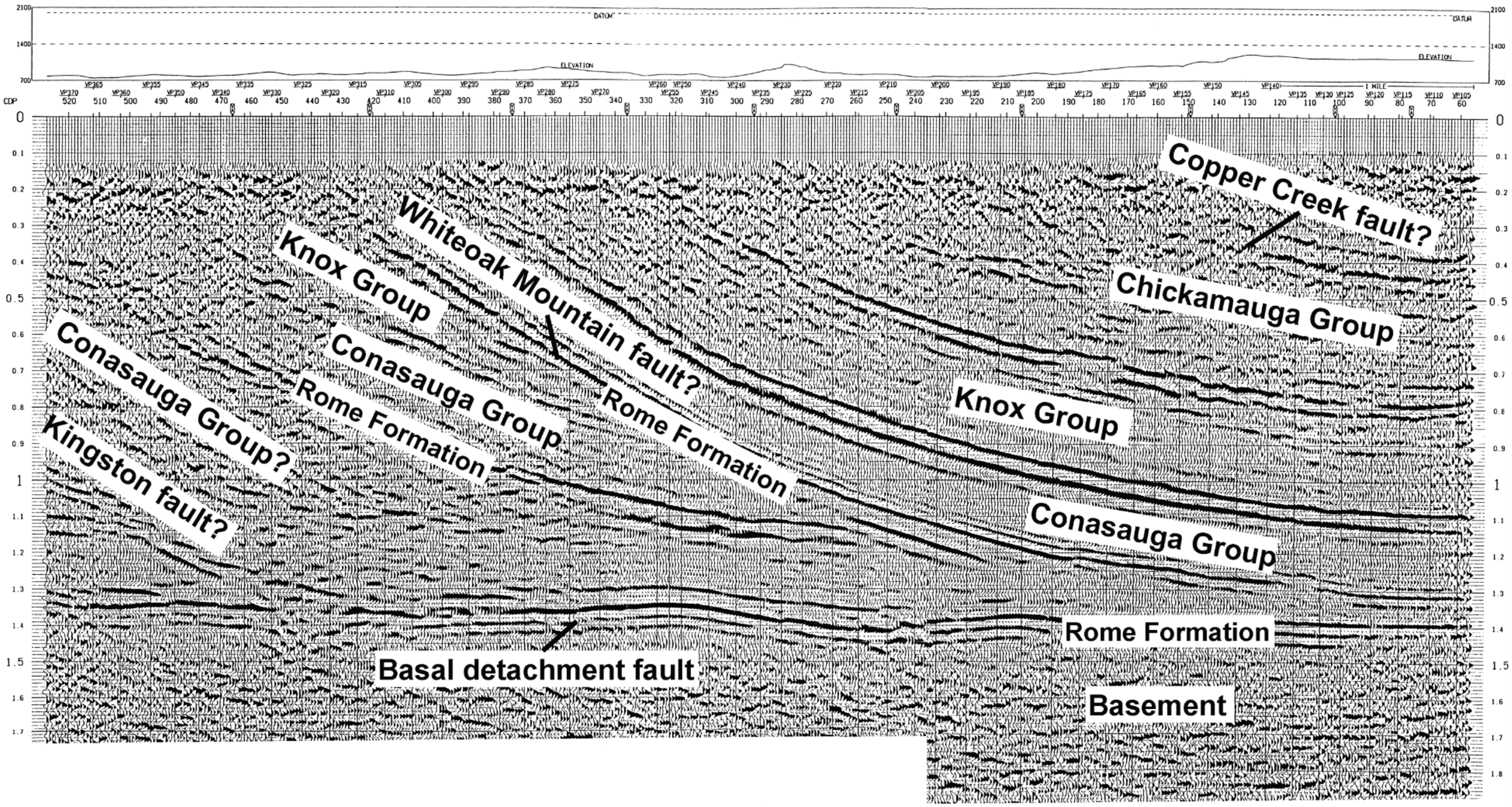
2.5.1.3 References

2.5.1-316. Bally, A.W., Gordy, P.L., and Stewart, G.A., Structure, seismic data, and orogenic evolution of southern Canadian Rocky Mountains: Bulletin of Canadian Petroleum Geology, v. 14, no. 3, p. 337-381, 1966.

2.5.1-317. ASTM, Standard Guide for Using the Seismic-Reflection Method for Shallow Subsurface Investigation: Designation D7128-05, 26 p, 2010.

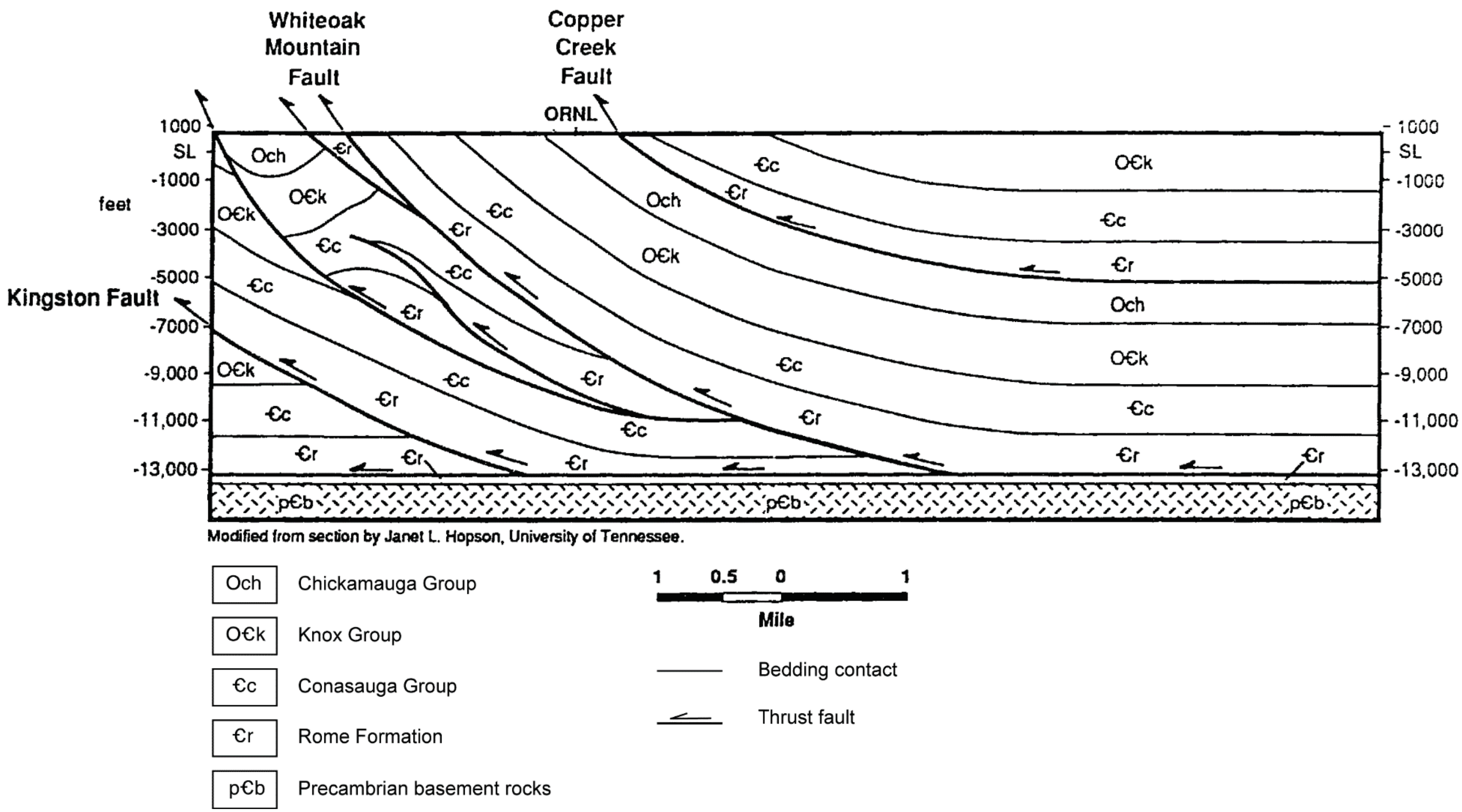
2.5.1-318. Cunningham, K. J., Walker, C., and Westcott, R. L., Near-surface marine seismic-reflection data define potential hydrogeologic confinement bypass in the carbonate Floridan Aquifer system, southeastern Florida, 2012, Society of Economic Geologists 2012 Annual Meeting, 6 pages, 2012.

<u>New SSAR Figure 2.5.1-83 is being added to SSAR Subsection 2.5.1:</u>



Note: Vertical axis is two-way travel time (seconds)

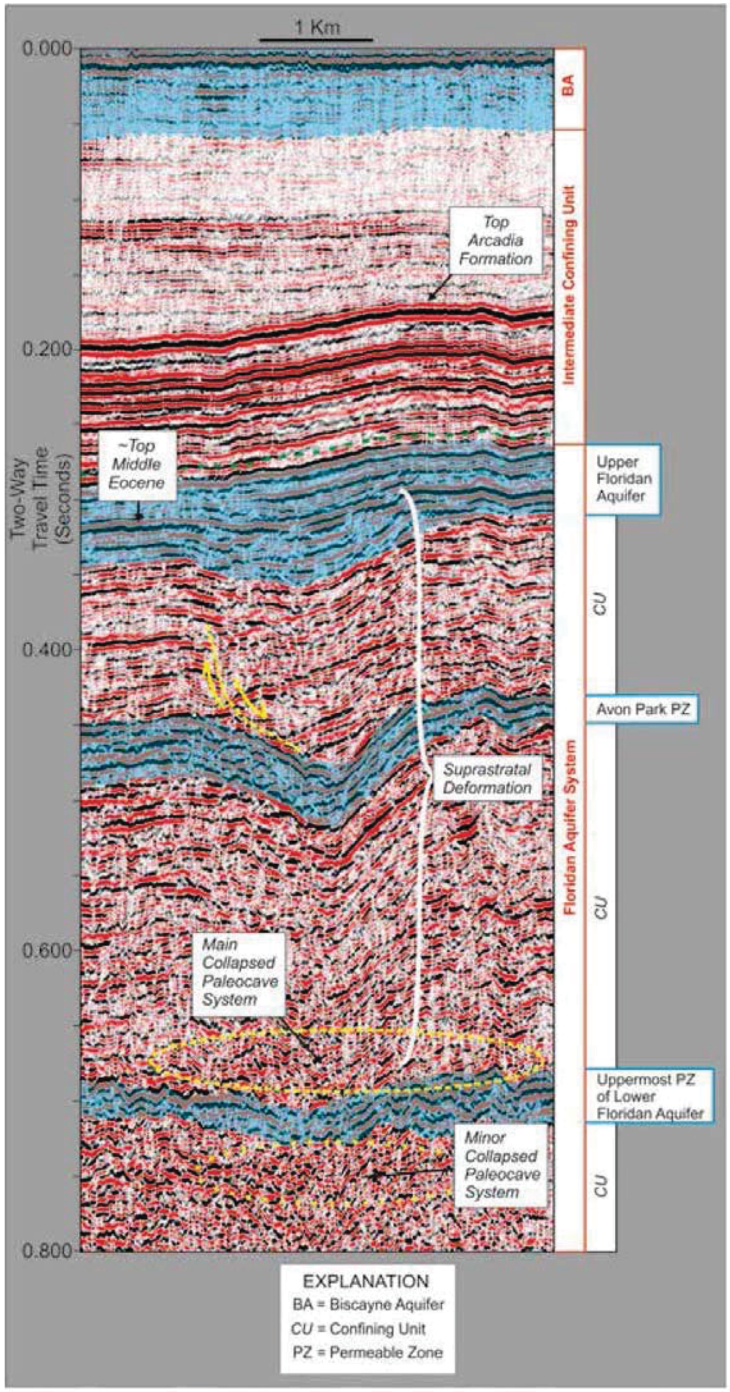
Figure 2.5.1-83 (Sheet 1 of 2) Interpreted Seismic Reflection Profile from Tennessee Highway 95



Source: Reference 2.5.1-9.

Figure 2.5.1-83 (Sheet 2 of 2) Geologic Cross Section Based on Seismic Reflection Profile from Tennessee Highway 95

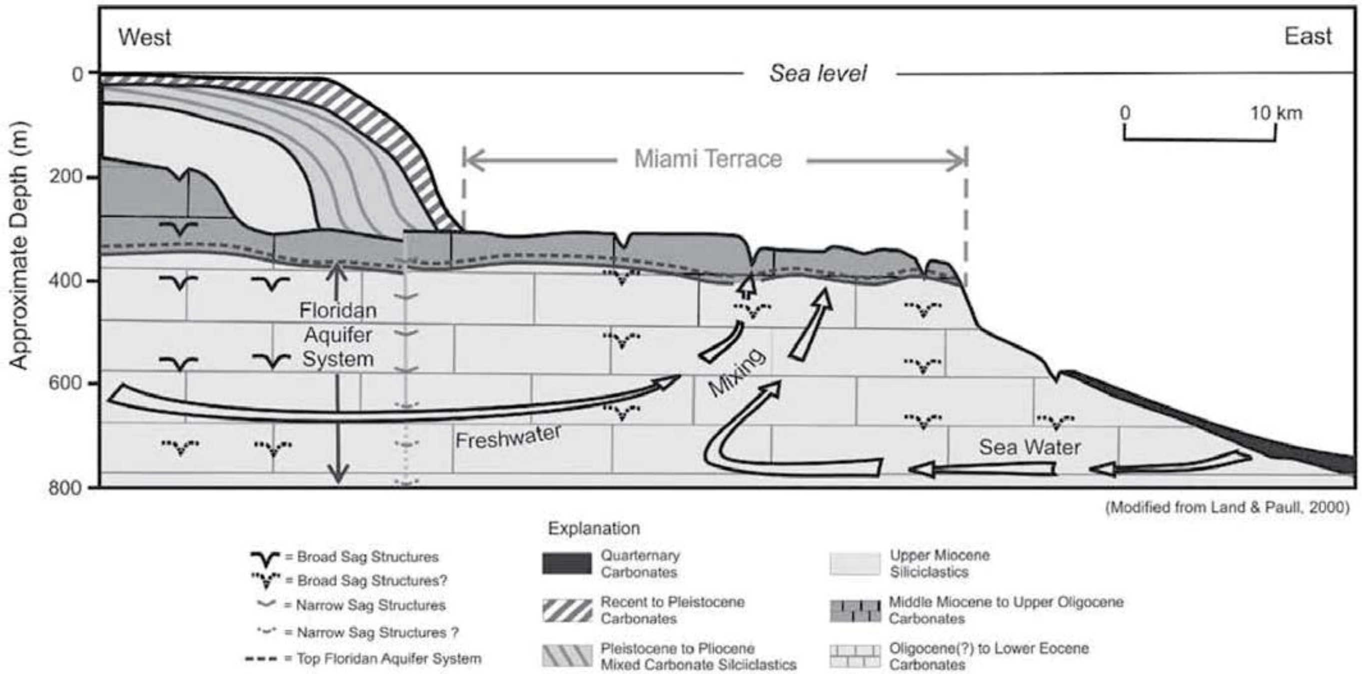
New Figure 2.5.1-84 is being added to SSAR Subsection 2.5.1:



Source: Reference 2.5.1-318

Figure 2.5.1-84 Seismic Reflection Profile from Biscayne Bay, Florida, Showing Large Scale Sag Features Attributed to Hypogene Dissolution

New Figure 2.5.1-85 is being added to SSAR Subsection 2.5.1:



Source: Reference 2.5.1-41

Figure 2.5.1-85 Schematic Cross Section of Biscayne Bay Showing a Possible Model for Hypogene Dissolution

Enclosure 2
Response to NRC RAI Number 5, Question 02.05.01-05

NRC RAI 02.05.01-05 Question

Karst

TVA letter CNL-16-162, Enclosure 2 discusses the nature of karst and limestone dissolution at the CRN site. The potential for karst development and the presence of undetected voids directly affects the demonstration of compliance with 10 CFR 100.23 (d)(2). Additional information is needed to support the SSAR's technical basis for karst development.

a. SSAR (Rev 0) 2.5.3.2.3 Karst, indicates that seismic refraction surveys at the site were used to characterize carbonate dissolution features. Becasue no data were presented in the SSAR (Rev 0) regarding the characterization of the seismic refraction surveys, please discuss the specific evaluation of the seismic refraction data with respect to detecting carbonate dissolution features.

b. The SSAR (Rev 0) 2.5.1.2.5.1 CRN site karst conceptual model indicates under item 9: "Evidence of hypogene processes is not documented at the CRN Site". The SSAR indicates that some deep phreatic groundwater circulation may be occurring in the Chickamauga carbonate rock beneath the ORR area, and dissolution conduits and cavities may be present to depths of more than 800 ft. (Reference 2.5.1-213, Ausich & Meyer, 1990). Although not discussed in the karst conceptual model, other sections of the SSAR have discussed other possible instances of hypogene karst systems in the area such as: Doll et al, reference 2.5.1-244, 2.5.1-245; TDEC hydrogeologists reference 2.5.1- 299; Nativ and others, reference 2.5.1-300 and 2.5.1-301; Wolf et al., 1997. Please provide a discussion of the potential for hypogene systems or features at the CRN site within TVA's conceptual model which also includes relevant information from these citations.

TVA RAI 02.05.01-05 Response

a. The primary objective of the seismic refraction surveys was to map the depth to bedrock at the Clinch River Nuclear (CRN) Site, although these data were also reviewed to potentially identify subsurface karst features. As discussed in SSAR Subsection 2.5.1.2.5.1.2, the seismic refraction data are not effective in terms of assessing the presence or absence of karst features, primarily because the lines were collected in areas that had been graded during Clinch River Breeder Reactor Project (CRBRP) activities in the 1970s and 1980s. In some places, significant thicknesses of bedrock had been removed and a thin layer of fill emplaced over the graded bedrock surface. In other places, thick fill had been emplaced to backfill the 1983 excavation or to fill small valleys. The seismic refraction profiles primarily show the extent of fill and depth to bedrock.

   The seismic refraction tomography profiles are being added to the SSAR as figures, and a description of the methods of data collection are being added to SSAR Subsection 2.5.1.2.4.2.1 as indicated in the SSAR markups below. A discussion of the significance of the seismic refraction data to the assessment of karst was previously included in SSAR Subsection 2.5.1.2.1.5.2, and is being revised as indicated in the SSAR markups below to amplify the discussion and refer to the new figures. The SSAR markups will be incorporated in a future revision of the early site permit application.

b. Deep karst may be of deep phreatic origin, of hypogene origin, or both. A deep phreatic process involves deep circulation of meteoric water in an unconfined or semi-confined setting. Hypogene dissolution is considered a specific case in which confined water rises from great depths through the soluble formation (Reference 1). These waters may be hydrothermal, may contain high concentrations of sulphur or carbon dioxide so are highly aggressive, and may carry exotic minerals.

   Direct evidence of hypogene dissolution processes was not documented at the CRN Site or within the Oak Ridge Reservation (ORR). Most evidence is consistent with dissolution by epigenetic processes in the vadose and phreatic zones. This evidence includes the decrease in frequency of fractures and dissolution cavities with depth in boreholes (Reference 2), phreatic passage geometry and morphology of known caves and solution conduits within the ORR (References 3 through 5), and the lack of secondary minerals characteristic of hypogene processes. Springs in the ORR have water chemistry and temperatures typical of meteoric water (References 6 and 7), in contrast to the warm, mineral-rich waters of hypogene springs (Reference 8). Finally, seismic reflection profiles across the site show continuous, uninterrupted bedding at depth beneath the CRN Site suggesting that large hypogenic karst collapse features such as those documented in Biscayne Bay, Florida (References 9 and 10) are not present, at least along the two dimensional profile lines.

   Evidence does exist, however, for deep phreatic dissolution. Deep phreatic karst pathways likely occur in the ORR area based on data from local groundwater studies. Groundwater studies by References 11 and 12 show contamination of the deep aquifers by hazardous wastes originating on the ORR, indicating relatively rapid penetration of meteoric waters to depths of more than 800 ft, likely facilitated by the presence of karst dissolution pathways.

   Rapid, deep flow is also suggested by the presence of contaminants in residential water wells in the Hood Ridge area, located 0.5 mi east across the Clinch River arm of the Watts Bar Reservoir (river) from the CRN Site, and four miles southwest along strike from known surface waste disposal sites at the Oak Ridge National Laboratory (ORNL). Well water analyses compiled by the Tennessee Department of Environment and Conservation (TDEC) (Appendix C of Reference 6), show the presence of contaminants consistent with an ORNL source. These include radioactive, metallic, and non-metallic inorganic contaminants, and volatile organic compounds (VOCs). If the source is ORNL, their presence suggests long-distance movement of groundwater southwest along strike, including flow beneath the river bed, and implies connections between the shallow and deep aquifers. For further information, see TVA's previously submitted letter CNL-17-115, "Supplemental Information Related to Groundwater Hydrology in Support of Early Site Permit Application for Clinch River Nuclear Site," dated August 25, 2017.

   The occurrence of deep phreatic karst dissolution in the ORR area is not unexpected based on the local geologic stratigraphy and structure. Geologic factors favorable to deep phreatic dissolution include long flow paths, steeply dipping strata, faults and/or fractures, rock types that are susceptible to dissolution, and locally confined and/or semi-confined aquifers (Reference 8). Reference 13 notes the presence of cavities in water wells to depths greater than 600 ft in the Valley and Ridge province of Tennessee.

SSAR Subsection 2.5.1.2.5.1 is being revised as indicated in the SSAR markups below to include additional detail so that the karst model more clearly distinguishes between and addresses the evidence for hypogene processes and deep phreatic processes. Two additional points are being added to the karst model. Point 9 discusses the absence of evidence for hypogene processes and acknowledges that lack of evidence does not preclude the occurrence of hypogene processes in the past or at greater depths. Point 10 provides evidence for ongoing deep phreatic circulation and dissolution.

In addition, a discussion of geologic mapping of the excavation conducted in 1983 for the Clinch River Breeder Reactor Project (CRBRP) is being added as indicated in the SSAR markups below to SSAR Subsection 2.5.1.2.5.1.2 to aid in the understanding and assessment of karst hazards at the CRN Site. The excavation mapping was presented in a report by Drakulich (SSAR Reference 2.5.1-303). The excavation mapping report provides direct observations of weathering and karst features in the Fleanor member and Rockdell Formation. In the interest of providing a more complete assessment, a discussion of karst dissolution features exposed in the excavation, including illustrations excerpted from the report, is being added as indicated in the SSAR markup below in Subsection 2.5.1.2.5.1.2, "Karst Processes and Features at the Clinch River Nuclear Site," Subheading "*Karst Features in the CRBRP Excavation.*" The SSAR Subsection 2.5.1 markups reflect changes provided in TVA's letter 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. The SSAR markups will be incorporated in a future revision of the early site permit application.

1. Klimchouk, A., Morphogenesis of hypogenic caves: Geomorphology, v. 106, p. 100-117, 2009.

2. AMEC Environment and Infrastructure Inc., Data Report Rev. 4. Geotechnical Exploration and Testing, Clinch River SMR Project, Oak Ridge, Tennessee. AMEC Project No. 6468-13-1072, October 2014.

3. Rubin, P.A., The geology of Cherokee Caverns. Available at http://www.cherokeecaverns.com/Cavern_Geology.php, 2014.

4. Rubin, P.A., and P.J. Lemiszki, Structural and stratigraphic controls on cave development in the Oak Ridge area, Tennessee, T. Gangaware, et al., (eds.), Seventh Tennessee Water Resources Symposium and Student Symposium, Tennessee Section of the American Water Resources Association, Nashville, Tennessee, pp. 1–6, 1992.

5. Doll, W.E., J.E. Nyquist, P.J. Carpenter, R.D. Kaufmann, and B.J. Carr, Geophysical Surveys of a Known Karst Feature, Oak Ridge Y-12 Plant, Oak Ridge, Tennessee, G. Fernandez and R. Bauer, (eds.), Geo-engineering for underground facilities, ASCE Geotechnical Special Publication No. 90, pp. 684–694, 1999.

6. Tennessee Department of Environment and Conservation (TDEC), Environmental Monitoring Report 2015, Authorization number 327040, 2016.

7. Davies, Gareth, Jones, Sidney, and Gephart, Thomas, Personal communication regarding evidence for deep karst dissolution at the Oak Ridge Reservation, telephone interview conducted September 9, 2016, by Janet Sowers, Kevin Clahan, Mike Buga, Alan Troup, Rebecca Carr, Matt Huebner, Hillol Guha, and Walter Justice, 2016.

8. Doctor, D. H., and Orndorff, W., Deep phreatic influence on the origin of caves and karst in the central Appalachian Great Valley, in: Chavez, T., and Reehling, P., eds., Proceedings of DeepKarst 2016: Origins, resources, and management of hypogene karst, National Cave and Karst Research Institute, Symposium 6, p. 89-104, 2016.

9. Cunningham, K., and C. Walker, Seismic-Sag Structural Systems in Tertiary Carbonate Rocks Beneath Southeastern Florida, USA: Evidence for Hypogenic Speleogenesis?, A. Klimchouk and D. Ford (eds.), Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins, Ukrainian Institute of Speleology and Karstology, Special Paper 1, pp. 151–158, 2009.

10. Cunningham, K.J., Walker, C., and Westcott, R.L., Near-surface marine seismic-reflection data define potential hydrogeologic confinement bypass in the carbonate Floridan Aquifer system, southeastern Florida, 2012, Society of Economic Geologists 2012 Annual Meeting, 6 pages, 2012.

11. Nativ, R., The Brine Underlying the Oak Ridge Reservation, Tennessee, USA: Characterization, Genesis, and Environmental Implications, Geochimica et Cosmochimica Acta, Vol. 60, No. 5, p. 787-801, 1996.

12. Nativ, R., Halleran, A., Hunley, A., Evidence for Ground-Water Circulation in the Brine-Filled Aquitard, Oak Ridge, Tennessee, Ground Water, Vol. 35, No. 4. P 647-713, 1997.

13. Wolfe, W. J., Haugh, C. J., Webbers, A., and Diehl, R. H., Preliminary conceptual models of the occurrence, fate, and transport of chlorinated solvents in karst regions of Tennessee, U. S. Geological Survey, Water Resources Investigations Report 97-4097, 1997.

SSAR Markups

SSAR Subsection 2.5.1.2.4.2.1.2 is being added as indicated. Underlines indicates text to be added.

2.5.1.2.4.2.1.2 Seismic Refraction Data

Six seismic refraction lines were acquired at the CRN Site (Figure 2.5.1-29). The data are presented as seismic tomography models (Figure 2.5.1-86). Such models can be used to resolve complex velocity structure that cannot be imaged using layer-based modelling techniques (Reference 2.5.1-214). The primary objective of the seismic refraction surveys was to map the depth to bedrock in graded and filled areas within the central portion of the site. The data were also reviewed to identify anomalies that might indicate the presence of geologic structures such as blind faults or large karst dissolution features beneath the fill. The resolution of these data is not sufficient to identify small-scale features (less than 10 ft). The results of this review are presented in Subsection 2.5.1.2.5.1.2.

Paragraph 12 of SSAR Subsection 2.5.1.2.5.1, Subheading "Karst Conceptual Models," is being revised as indicated. Underlines indicates text to be added.

2.5.1.2.5.1 Karst Hazards

Karst Conceptual Models

Paragraph 12

The major lines of evidence Doctor and Orndorff present for hypogene dissolution and deep phreatic dissolution of caves in the AGV are (1) the random landscape position of the caves, (2) the complex geometry of cave passages, (3) the presence of many thermal and travertine springs, and (4) the observation of cavities in water wells to depths of more than 1,000 ft. Caves appear to be randomly distributed beneath the landscape without regard for the modern stream networks. Cave elevations do not cluster about stream terrace elevations, nor do they cluster at any elevation that might reflect pauses in regional downcutting. Passages are not related to positions of modern trunk streams. Instead, cave passages are maze-like with vertical extents of over 20 m (76 ft). They follow joints, faults, and bedding planes, and have phreatic features such as cupolas and feeder tubes. Caves are known to occur in isolated hills with no inlets or outlets, far from base level streams. In an interview (Reference 2.5.1-298) and publication (Reference 2.5.1-319), Doctor also noted the presence of exotic mineral deposits, including dog-tooth spar, gypsum, iron, or fluorite, as evidence of hypogene processes (Figure 2.5.1-87). Present-day thermal and travertine springs indicate that hypogene conditions likely still exist at depth, and the presence of very deep dissolution cavities in water wells supports hypogene dissolution as an ongoing process. Figure 2.5.1-71 shows Doctor and Orndorff's (Reference 2.5.1-296) model of how the interaction of a fault and a fold can result in hypogene dissolution by waters rising along a fault.

Paragraphs 2 and 4 of SSAR Subsection 2.5.1.2.5.1.2, Subheading "Karst-Related Subsurface Features at the Site," are being revised as indicated. Underlines indicates text to be added. Strikethroughs indicates text to be deleted.

2.5.1.2.5.1.2 Karst Processes and Features at the Clinch River Nuclear Site

Karst-Related Subsurface Features at the Site

Paragraph 2

Seismic refraction ~~tomography~~ surveys are useful to image near-surface karst features such as an irregular top of bedrock and shallow cavities (References 2.5.1-255 and 2.5.1-256). This method and other geophysical methods are often used in karst terrain to complement borehole analysis. A seismic refraction ~~tomography~~ survey, consisting of six lines, each 500 to 600 ft in length, was conducted at the site to map depth to rock (Figure 2.5.1-29) (Reference 2.5.1-214). These surveys were conducted primarily in areas that had been graded as part of CRBRP construction activities. The soil and rock under the high points had been removed, and fill hadbeen emplaced in the low points to create a planar ground surface. The resulting tomography models, therefore, primarily delineate the top of bedrock and the margins of the fill (Figure 2.5.1-86). The seismic refraction tomography profiles show the general shape of the top-of-rock. Where they can be correlated, the borehole top-of-rock corresponds to a compressional wave velocity (V_p) of 7,000 fps to 11,000 fps. The thickest fill is shown on Figure 2.5.1-86, Sheet 6, along line SRS-6 located within the 1983 CRBRP excavation. Here, the bottom of the excavation at 712.5 ft MSL corresponds to a V_p of about 11,000 fps. No features were observed in the seismic refraction data that could clearly be attributed to karst phenomena.

Paragraph 4

An additional source of subsurface information is documentation of the condition of the rock exposed during the 1983 excavation for the CRBRP foundation. The Fleanor Shale and Rockdell Formation strata were exposed during the excavation. Continuous exposure of rock provides a more robust picture of the dissolution network than borehole data. ~~However, few records of the excavation were located. Those available~~ Geologic mapping and documentation of karst features in the excavation (Reference 2.5.1-303) are summarized below.

SSAR Subsection 2.5.1.2.5.1.2, Subheading "Karst Features in the CRBRP Excavation," is being revised as indicated. Underlines indicates text to be added. Strikethroughs indicates text to be deleted.

2.5.1.2.5.1.2 Karst Process and Features at the Clinch River Nuclear Site

Karst Features in the CRBRP Excavation

~~A potential source of information regarding subsurface karst development would be geologic documentation of the CRBRP nuclear island excavation made in 1983 (Figure 2.5.1-54). This excavation extended to an elevation of 712.5 ft primarily in the Fleanor Shale and partly in the Rockdell Formation, with 75-fthigh near-vertical faces on the north, east, and south sides, and a 26-degree slope on the west side (References 2.5.1-100, 2.5.1-246, and 2.5.1-257). The CRN plant excavation may extend down through and bear on these same units. Continuous foundation exposures are the best way to evaluate the density, size and shape, and continuity of potential dissolution features, as well as the variability in the depth, severity, and lateral persistence of weathering. The CRBRP PSAR (Reference 2.5.1-100) proposed a program of geologic mapping and photography to document the condition of the rock units with respect to weathering, fractures, and dissolution, and Kummerle and Benvie (Reference 2.5.1-257) mention that geologic mapping was conducted. However, geologic records of the CRBRP excavation were not available to the CR SMR Project.~~

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. Excavations for the CRBRP were virtually complete before the project was cancelled in November of 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) (Figure 2.5.1-88). Two excavations were made, a large excavation (480 ft long x 360 ft wide, and 100 ft deep) for the nuclear island (Figure 2.5.1-54) and a smaller excavation (180 ft x 180 ft shallow depth) for the Equalization Basin. The nuclear island excavation extended to an elevation of 712.5 ft MSL, with 75-ft-high near-vertical faces on the north, east, and south sides, and a 26-degree slope on the west side (References 2.5.1-100, 2.5.1-246, and 2.5.1-257).

The nuclear island excavation exposed the Fleanor member, a dusky red, shaley, calcareous siltstone with thin interbeds of limestone, over most of the walls and floor. The southeast wall exposed the Rockdell Formation. The Fleanor member exhibited deep chemical weathering of siltstone strata, with minor dissolution of its thin limestone interbeds (Reference 2.5.1-303). The siltstone was fresh at the base of the excavation, but found prone to slaking and disintegration upon exposure to weathering. Joints in the weathered zone at the top of the excavation were open or clay filled, and became less frequent and tight with depth within the unweathered rock. Similarly, the frequency and the extent of dissolution features were found to decrease with depth.

Limestone beds of the overlying Rockdell Formation were exposed on the southeast wall of the nuclear island excavation and contained a concentration of solution cavities at an elevation of approximately 780 ft MSL (Figure 2.5.1-89). 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 (Reference 2.5.1-303) does not mention the presence of dissolution cavities within the Fleanor member. A brief statement by geologists Rubin and Lemiszki (Reference 2.5.1-240) ~~provides some insight into the geologic conditions exposed in the CRBRP excavation:~~ confirms that the greatest number and largest cavities occurred in the Rockdell Formation, and comments on small cavities within the Fleanor member as well:

> "…during foundation construction a number of cavities were revealed with average diameters of 0.5 to 1 m. The largest cavities occur in the thick to massive limestone beds of the Rockdell Formation."… "In addition a surprising number of small cavities are present in the mudstone-rich Fleanor Shale."

An example of similar small cavities may be the dissolution-enlarged joints observed in thin interbeds of limestone of the Blackford Formation in a road cut exposure in the City of Oak Ridge, Tennessee (Figure 2.5.1-55). Dissolution is restricted to the approximately 1 ft-thick limestone beds, which are bounded between adjacent beds of calcareous siltstone. The cavities are now filled with soil.

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 MSL, 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 soft and prone to disintegration and slaking would be mitigated by the planned concrete base mat.

SSAR Subsection 2.5.1.2.5.1.2, Subheading "Karst Model for the Site," is being revised as indicated. Underlines indicates text to be added. Strikethroughs indicates text to be deleted.

2.5.1.2.5.1.2 Karst Process and Features at the Clinch River Nuclear Site

Karst Model for the Site

The conceptual model for karst development at the CRN Site, presented below, is developed to be consistent with concepts, observations and data derived from regional, local, and site-specific studies. The model is partially illustrated in Figure 2.5.1-73 and described by the following points:

1. The bedrock surface beneath the mantle of residual soil is undergoing dissolution from downward penetrating meteoric water, resulting in an irregular top of rock with pinnacles and intervening dissolution slots, or cutters, formed along vertical joints. Soil filling the slots can trickle down ~~can be washed down the slots~~ into dissolution ~~passages~~ cavities within the rock, creating voids which may ~~can~~ stope upwards through the soil and ~~eventually~~ collapse or subside to form sinkholes.

2. The soil-bedrock interface, termed the *epikarst* (Reference 2.5.1-7, p. 120), is characterized by soft soils, cavities, and shallow groundwater. Rainwater (stormflow) is temporarily stored in the epikarst zone, draining both laterally along the top of bedrock, and downward through enlarged bedrock joints into the deeper karst system.

3. At the CRN Site, evidence of both vadose (above the water table) and phreatic (below the water table) dissolution is present and appears to be controlled by the structure of the subsurface strata (i.e. bedding planes, joints, and fractures). Karst dissolution is clearly evident in the cavities encountered in boreholes and in cavities observed in the walls of the CRBRP excavation.

   ~~Major phreatic dissolution pathways are strike-parallel. Groundwater flow is constrained by low-carbonate units, resulting in strike-parallel drainage systems. Phreatic conduits are localized in the high-carbonate beds, often near the intersection of the groundwater table with a bedding plane or high angle-strike-parallel joint~~

4. The dominant orientation of phreatic dissolution pathways is strike-parallel. Groundwater flow is constrained by low-carbonate units, resulting in strike-parallel drainage systems. Phreatic conduits are localized in the high-carbonate beds, often near the intersection of a bedding plane or high angle-strike-parallel joint. Additional dissolution pathways occur down-dip following bedding planes and lithologic contacts, and along joints.

5. The thicker and purer carbonate beds have larger and more numerous cavities and sinkholes. The Rockdell, Eidson (member), Benbolt, and Witten formations, the most carbonate-rich units in the Chickamauga Group, have relatively higher numbers of sinkholes and borehole cavities than other units. The Fleanor, Blackford, and Bowen formations the most carbonate-poor units in the Chickamauga Group, have no mapped sinkholes and smaller and fewer borehole cavities than other units.

6. Cavities in the carbonate-poor units occur within thin carbonate interbeds. The siltstone itself is calcareous and weathers primarily by dissolution; however, it leaves a silty residuum which inhibits the development of continuous conduits.

7. Long-term erosion, stream incision, and landscape lowering have resulted in older dissolution passages formed ~~below the groundwater table~~ in the phreatic zone being abandoned, segmented, filled with sediment and flowstone, and ultimately collapsed. Rock above the present groundwater table may contain any combination of active vadose passages and abandoned and/or filled vadose and phreatic passages.

8. Borehole data show that subsurface dissolution is most intense near the surface and decreases steadily with depth. Small numbers of cavities are observed below the water table. This is consistent with observations of decreased fracturing frequency and groundwater flow rates with depth in the ORR studies (Reference 2.5.1-9).

9. Direct evidence of hypogene dissolution processes is not documented at the CRN Site or within the ORR. Most evidence is consistent with dissolution by epigenetic processes in the vadose and phreatic zones. ~~Fracture frequency as well as dissolution cavities significantly decrease with depth based on analyses of borehole logs~~. This evidence includes the decrease in frequency of fractures and dissolution cavities with depth in boreholes (Reference 2.5.1-214), phreatic passage geometry and morphology of known caves and solution conduits within the ORR (References 2.5.1-240, 2.5.1-244, and 2.5.1-253), and the lack of secondary minerals characteristic of hypogene processes. Springs in the ORR have water chemistry typical of meteoric water (Reference 2.5.1-299) rather than warm, mineral-rich waters of hypogene springs (Reference 2.5.1-296). Finally, ~~S~~seismic reflection profiles across the site show continuous, uninterrupted bedding at depth beneath the site suggesting that large hypogenic karst collapse features are not present, at least along the two dimensional profile lines. ~~However, groundwater studies in the ORR area indicate some deep phreatic groundwater circulation may be occurring in the Chickamauga carbonate rock beneath the ORR area, and dissolution conduits and cavities may be present to depths of more than 800 ft (Reference 2.5.1-213).~~

   Lack of evidence for hypogene processes does not necessarily mean these processes were not active in the past or may occur at great depths in the present. Geotechnical explorations and field observations focus on the near-surface. In addition, paleo-hypogenic karst features may have been significantly modified or erased by more recent epigenic processes.

10. Evidence from local groundwater studies supports deep phreatic dissolution in the CRN site vicinity. The occurrence of deep phreatic processes is consistent with the presence of favorable factors such as long flow paths, steeply dipping strata, faults and/or fractures, rock types that are susceptible to dissolution, and locally confined and/or semiconfined aquifers. Groundwater studies in the ORR area by Nativ and colleagues (References 2.5.1-300 and 2.5.1-301) show contamination of the deep aquifers by hazardous wastes originating on the ORR, indicating relatively rapid penetration of meteoric waters to depths of more than 800 ft (Reference 2.5.1-300). Wolfe et al (Reference 2.5.1-292) note the presence of cavities in water wells to depths greater than 600 feet.

~~In summary, k~~Karst was characterized at the CRN Site by an initial review of regional and local karst literature and data, followed by collection of new data for the site area and the site itself. A number of subsurface investigations were performed at the CRN Site to evaluate the presence or absence of karst. These studies included (1) geotechnical boreholes to a minimum elevation of approximately 260 ft NAVD88 (540 ft depth) and angled boreholes specifically for karst evaluation, (2) two seismic reflection lines, (3) field reconnaissance and mapping of surficial karst features in the site area, (4) consideration of observations from the previous CRBRP excavation, (5) evaluation of hydrothermal activity in the site region, (6) mineralogy and geochemistry of karst features, (7) review of karst models provided by others for the AGV of Virginia, and (8) comparison of karst features at the CRN Site to potential karst analogues in Florida.

~~At the CRN Site, evidence of both vadose and phreatic dissolution is present and appears to be controlled by the structure of the subsurface strata (i.e. bedding planes, joints, and fractures). Karst dissolution is clearly evident in the cavities encountered in boreholes, and in sinkhole features at the site. The extent of deep phreatic dissolution, below the water table, could not be evaluated based on the limits of subsurface data. However, deep phreatic dissolution likely occurs based on local groundwater studies, and the presence of favorable factors such as long flow paths, steeply dipping bedding, faults and/or fractures, rock types that are susceptible to dissolution, and locally confined and/or semi-confined aquifers~~

~~No exhumed paleo-hypogenic karst features have observed in the site area. Evidence for paleo-hypogenic karst including secondary or exotic minerals in caves, and hydrothermal or travertine springs are not documented in the site area. No saline water was encountered in wells to 300 ft depth at the CRN Site. Most springs in the Oak Ridge Reservation have water chemistry typical of meteoric water (Reference 2.5.1-299). Cave passage geometry in the site area is consistent with formation by vadose or phreatic epigenic processes; isolated maze caves typical of hypogenic processes are not common in the site vicinity. These observations do not rule out the possibility that paleo-hypogenic karst features may have been modified by more recent epigenic processes.~~

To provide a more detailed delineation of karst features below the floor of the proposed excavation, a surface geologic mapping and subsurface exploration program will be implemented during site excavation as described in Subsection 2.5.1.2.6.10.

The following reference is being added to SSAR Subsection 2.5.1.3. Underlines indicates text to be added.

2.5.1.3 References

2.5.1-319 Doctor, D. J., Orndorff, W., Maynard, J., Heller, M. J., and Casile, G. C. Karst geomorphology and hydrology of the Shenandoah valley near Harrisonburg, Virginia, 2014, *in* Bailey, C.M., and Coiner, L.V., eds., Elevating Geoscience in the Southeastern United States: New Ideas about Old Terranes—Field Guides for the GSA Southeastern Section Meeting, Blacksburg, Virginia, 2014: Geological Society of America Field Guide 35, p. 161–213, doi:10.1130/2014.0035(06).

SSAR Subsection 2.5.3.2.3 is being revised as indicated. Underlines indicates text to be added. Strikethroughs indicates text to be deleted.

2.5.3.2.3 Karst

Carbonate dissolution features that occur at the CRN Site and within the site area (5-mi radius) were identified using new data acquired for this ESPA, including (1) detailed analysis of high-resolution LiDAR-based digital elevation data and aerial photography; (2) field reconnaissance mapping; (3) seismic refraction surveys at the site; and (4) analysis of soil and rock-core borings drilled at the site. New data were compiled with existing site-specific data developed for the CRBRP, local investigations, and reports (e.g., References 2.5.3-21, 2.5.3-5 and 2.5.3-6; 2.5.3-10; 2.5.3-7; and 2.5.3-3). A comprehensive evaluation of karst features is provided in Subsection 2.5.1.2.5.

Within the site area, a total of 2797 karst depressions were identified (Figure 2.5.1-47). Of these, 1210 were classified as sinkholes at least 2 ft deep with an area of 100 ft^2 (see Subsection 2.5.1.2.5). The occurrence of karst depressions is strongly controlled by lithology; geologic units that comprise the highest depression densities consist of thick, relatively pure carbonates. These include the Knox Group dolomites and more pure limestones of the Chickamauga and Conasauga Groups. Stratigraphic units that contain interbedded carbonate and siliciclastic lithologies (e.g., Benbolt and the upper Blackford formations of the Chickamauga Group) have a moderate to few number of depressions, and those dominated by siliciclastics(sandstone, siltstone, shale) have very few to no depressions. Additionally, geologic structures (e.g., fractures, folds) can exert a strong influence in the development of karst features (Reference 2.5.3-10).

Bedrock at the CRN Site location primarily consists of the Chickamauga Group, with Knox Group rocks in the northwest portion of the 0.6-mi radius (Figure 2.5.1-37). Rubin and Lemiszki (Reference 2.5.3-10) reported that, in this structural position within the Valley and Ridge (hanging wall of the Whiteoak Mountain thrust sheet), the Rockdell, Benbolt, and Witten formations are the purest and thickest carbonate units, and the Fleanor Shale is a major potential barrier to down-dip conduit development. Bedding dip, faults, and fractures in the carbonates act as infiltration pathways and sites for potential dissolution, while groundwater flow is constrained by the presence of siliciclastic units. This results in the development of laterally extensive strike-parallel cave systems (Reference 2.5.3-10). Twenty-four caves were identified in the karst inventory of the site area (see Subsection 2.5.1.2.5), all of which formed in the Copper Ridge Dolomite, Chepultepec Dolomite, or Maynardville Limestone (see Subsection 2.5.1.2.5).

Karst-related surface features at the site, identified during the CRBRP and during the current investigation, include large funnel- and dish-shaped sinkholes and small holes in the ground. Two major sinkhole clusters occur within the 0.6-mi site radius: one in the Knox Group (at the contact between the Kingsport Formation and Mascot Dolomite) and the other in the Chickamauga Group (Witten Formation) (see Subsection 2.5.1.2.5).

In addition to analysis of the ground surface, seismic refraction tomography ~~surveys~~ profiles were ~~conducted~~reviewed to possibly identify features related to carbonate dissolution in the shallow subsurface (Reference 2.5.3-3) (see Figure 2.5.1-86). ~~These~~Seismic refraction surveys were conducted ~~primarily~~ in areas that had been graded as part of CRBRP construction activities to map the depth of bedrock (Reference 2.5.3-3). The deep excavation of the site had

been partially backfilled to create a planar ground surface following the termination of the project., and The resulting tomography models were generated primarily to delineate the margins of the fill and the top of bedrock in the graded portion where epikarst zones had been removed and partially backfilled,. The seismic refraction data were additionally reviewed to possibly identify any anomalies that could represent potential large karst dissolution features at the site; and no conspicuous features in these data were identified that can clearly be attributed to karst phenomena.

A total of 180 exploratory rock core borings have been collected at the site (104 for the CRBRP and 76 for the current investigation), 42 percent of which encountered one or more cavities. Cavities were encountered in every stratigraphic unit that was drilled underlying or adjacent to the power block area, including the Blackford Formation, Eidson Member, Fleanor Shale, Rockdell Formation, and Benbolt Formation. The frequency and size of cavities are observed to be greater in units with higher carbonate content and, generally, decrease with depth (see Subsection 2.5.1.2.5).

Existing SSAR Figure 2.5.1-29 is being replaced with the following:

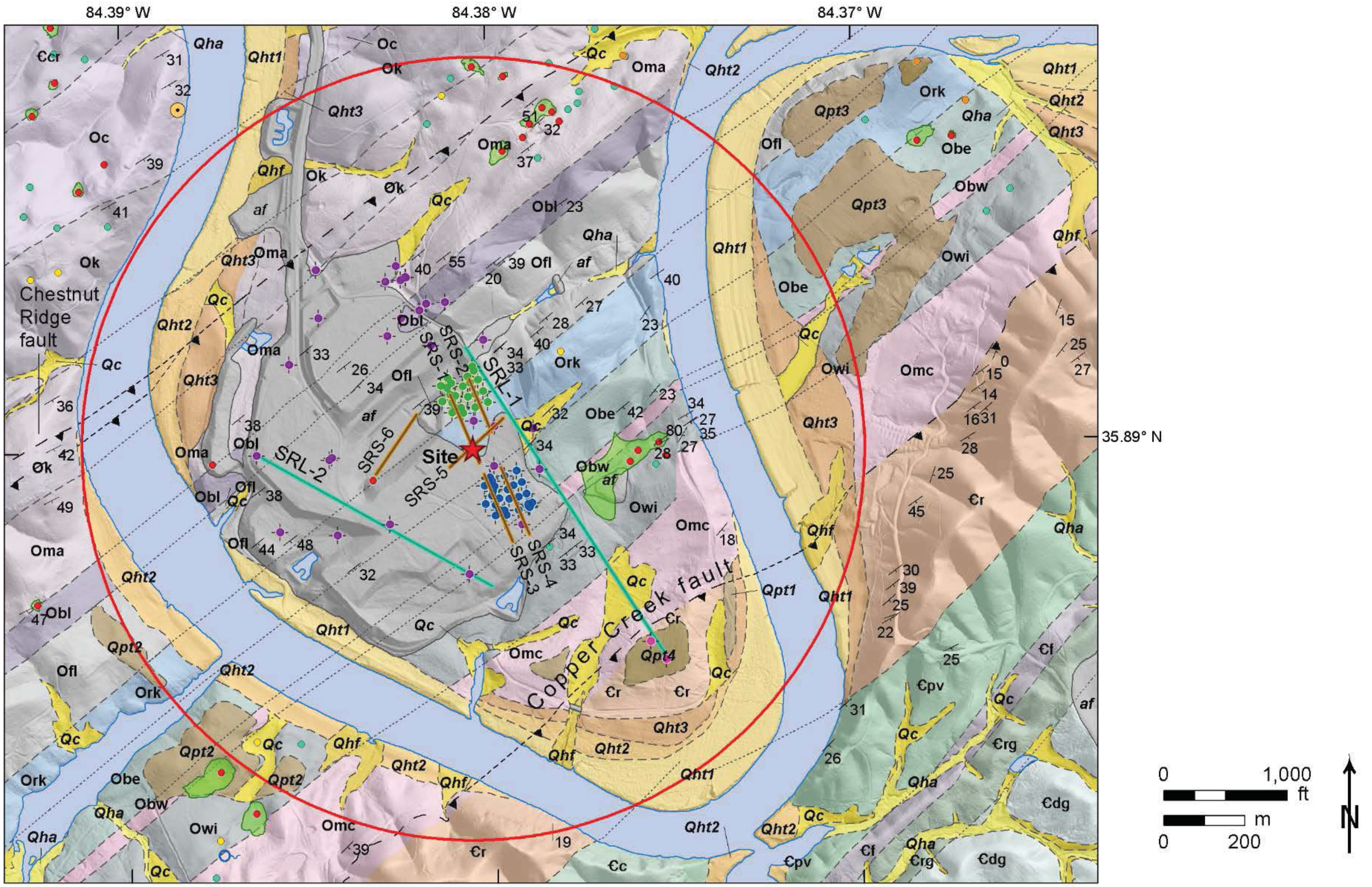


Figure 2.5.1-29. (Sheet 1 of 2) Site Location Geologic Map Showing Borings

Quaternary Units

Quaternary

- *af* — Artificial Fill
- *Qha* — Alluvium
- *Qc* — Colluvium
- *Qhf* — Alluvial Fan
- *Qht1*, *Qht2*, *Qht3* — Holocene Clinch River Terraces
- *Qpt1*, *Qpt2*, *Qpt3*, *Qpt4*, *Qpt5* — Pleistocene Clinch River Terraces

Geologic Structures

- Thrust Fault — *dashed where approximate, dotted where concealed*
- Contact — *dashed where approximate, dotted where concealed*

Karst Features

- Cave
- Closed depression ≥ 2 ft deep and 100 sq ft area
- Three-sided depression
- Two-sided depression
- Shallow closed depression < 2 ft deep
- Spring
- Closed depression ≥ 2 ft deep and 2000 sq ft area

Explorations

Borings

- CC Series
- MP-100 Series
- MP-200 Series
- MP-400 Series

- SRL — Seismic Reflection Line
- SRS — Seismic Refraction Line

Bedrock Units

Chickamauga Group

Middle Ordovician

- Omc — Moccasin Fm. *siltstone with limestone interbeds*
- Owi — Witten Fm. *limestone with shale interbeds*
- Obw — Bowen Fm. *siltstone with limestone interbeds*
- Obe — Benbolt Fm. *limestone with siltstone interbeds*
- Ork — Rockdell Fm. *limestone with siltstone interbeds*
- Ofl — Fleanor Shale mbr. of the Lincolnshire Fm. *shale and siltstone with limestone*
- Obl — Blackford Fm. (includes Eidsen mbr.) *limestone and siltstone*

Knox Group

Lower Ordovician

- Oma — Mascot Dolomite *dolomite with chert, limestone and sandstone*
- Ok — Kingsport Fm. *dolomite with chert, limestone and sandstone*
- Olv — Longview Dolomite *dolomite and chert*
- Oc — Chepultepec Dolomite *dolomite with chert, limestone and sandstone*

Upper Cambrian

- Ꞓcr — Copper Ridge Dolomite *dolomite with chert, limestone and sandstone*

Conasauga Group

- Ꞓc — Conasauga Group - undivided

Middle Cambrian

- Ꞓrg — Rogersville Shale *shale with mudstone and siltstone interbeds*
- Ꞓf — Friendship Fm. (Rutledge Ls.) *limestone, dolomite, siltstone and shale*
- Ꞓpv — Pumpkin Valley Shale *shale with mudstone and siltstone interbeds*

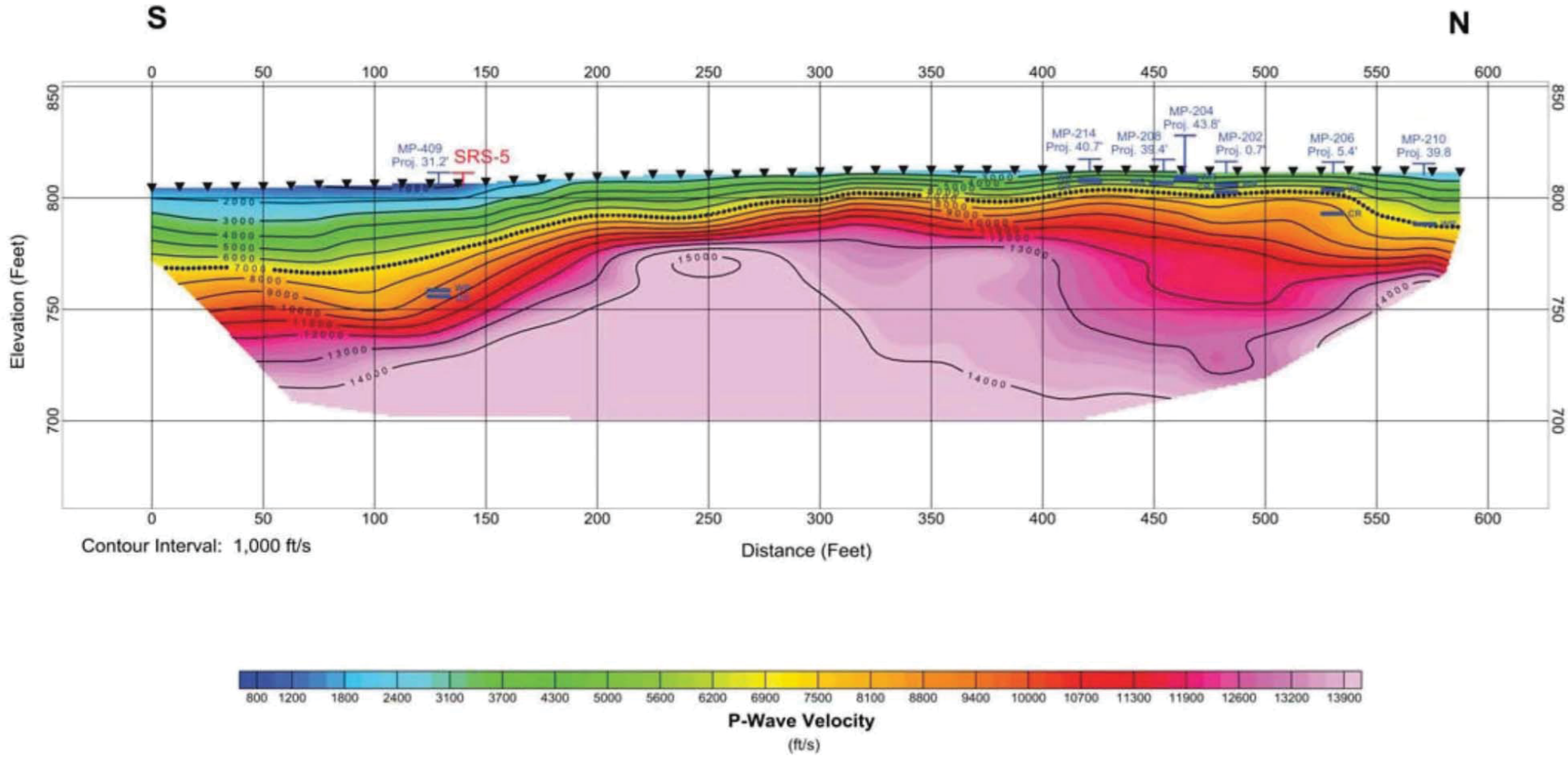
Rome Formation

Lower Cambrian

- Ꞓr — Rome Fm. - undivided *sandstone, shale and siltstone with interbeds of dolomite*

Figure 2.5.1-29. (Sheet 2 of 2) Site Location Geologic Map Showing Borings

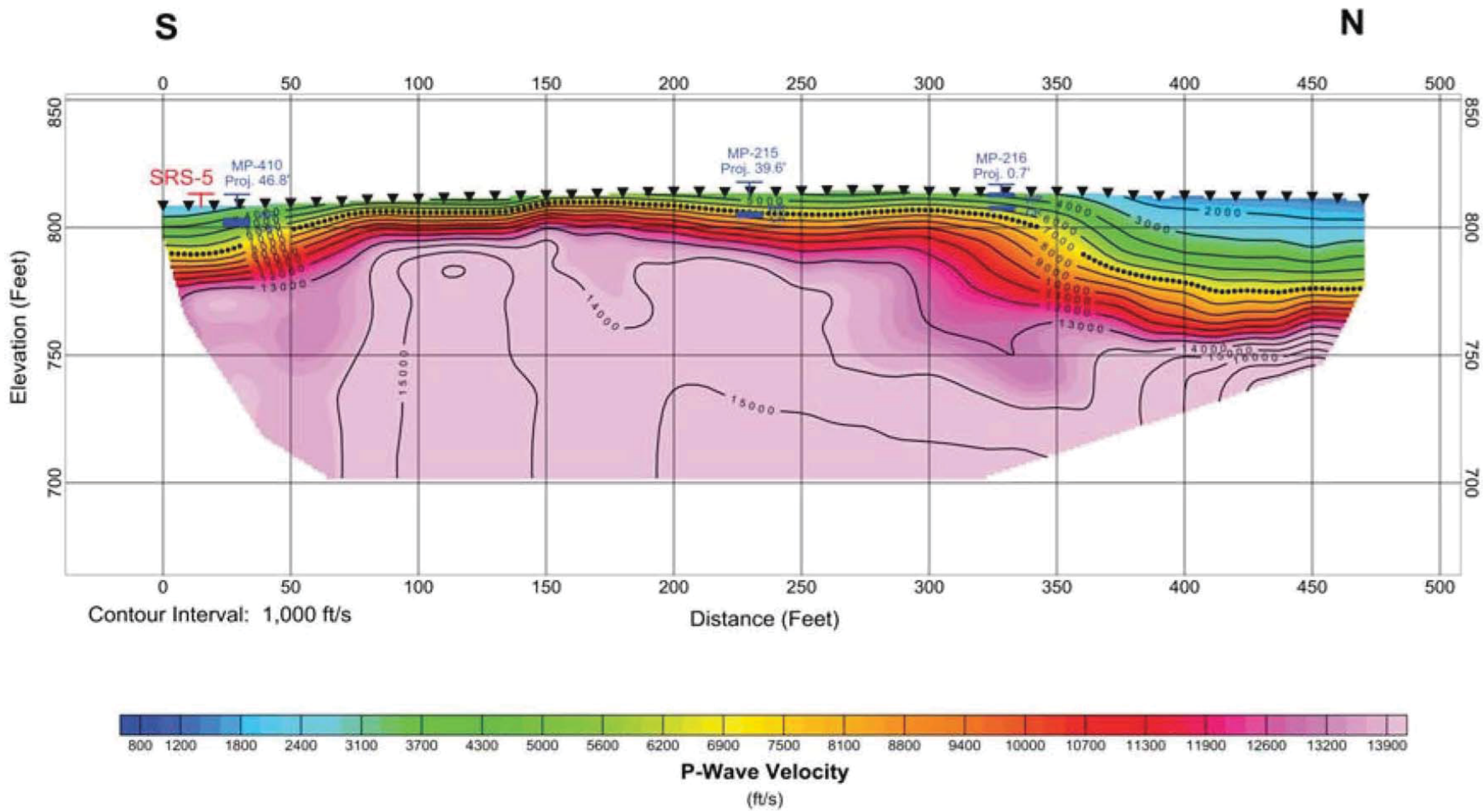
New SSAR Figure 2.5.1-86 is being added to SSAR Subsection 2.5.1:



Source: Reference 2.5.1-214.

See explanation on Sheet 7.

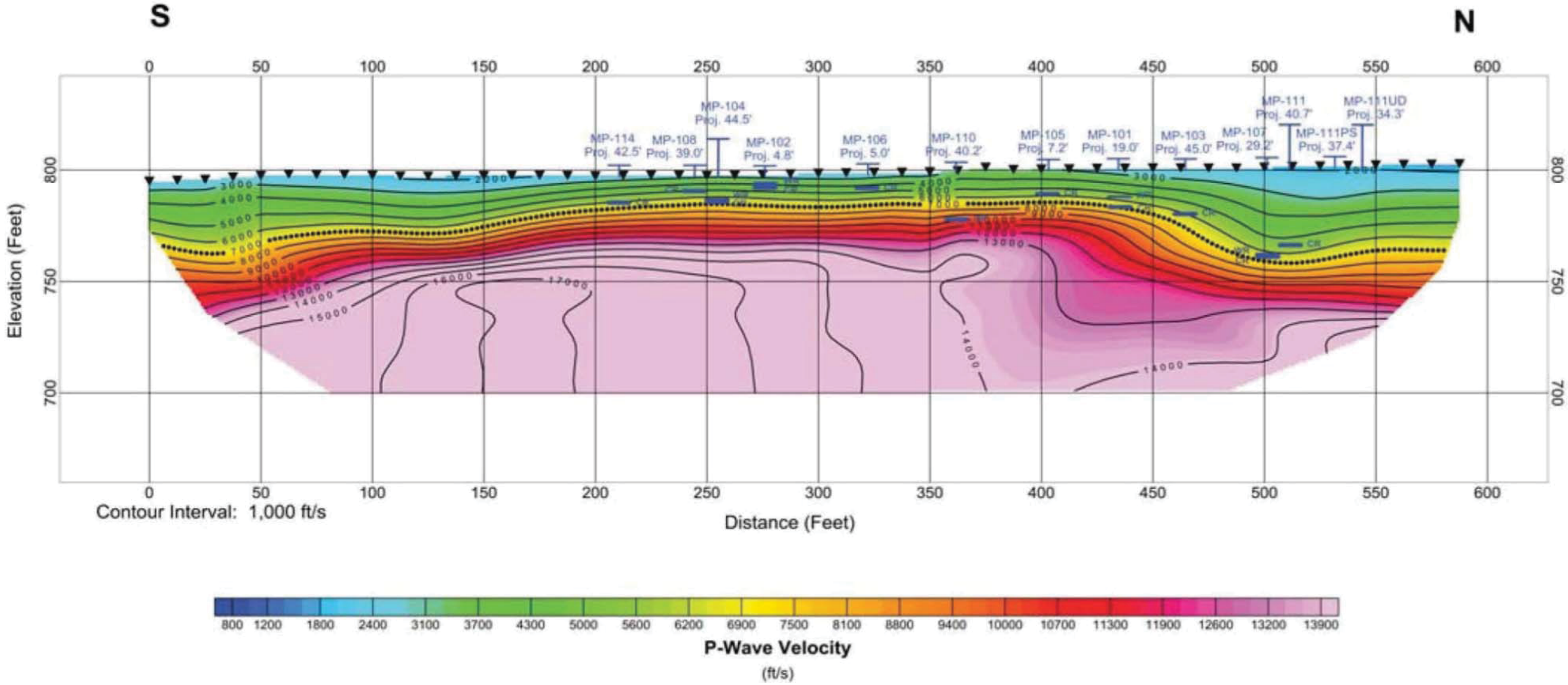
Figure 2.5.1-86 (Sheet 1 of 7) Seismic Tomography Model SRS-1



Source: Reference 2.5.1-214.

See explanation on Sheet 7.

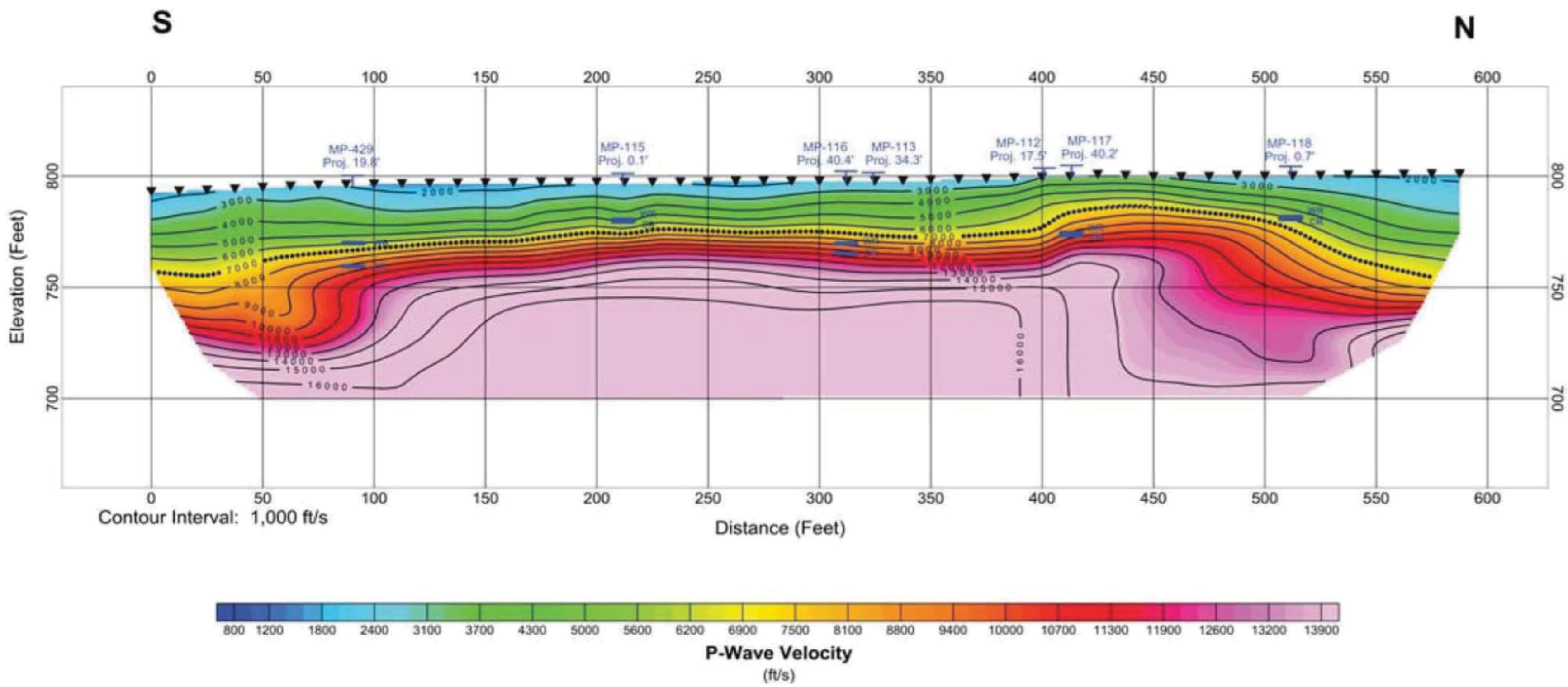
Figure 2.5.1-86 (Sheet 2 of 7) Seismic Tomography Model SRS-2



Source: Reference 2.5.1-214.

See explanation on Sheet 7.

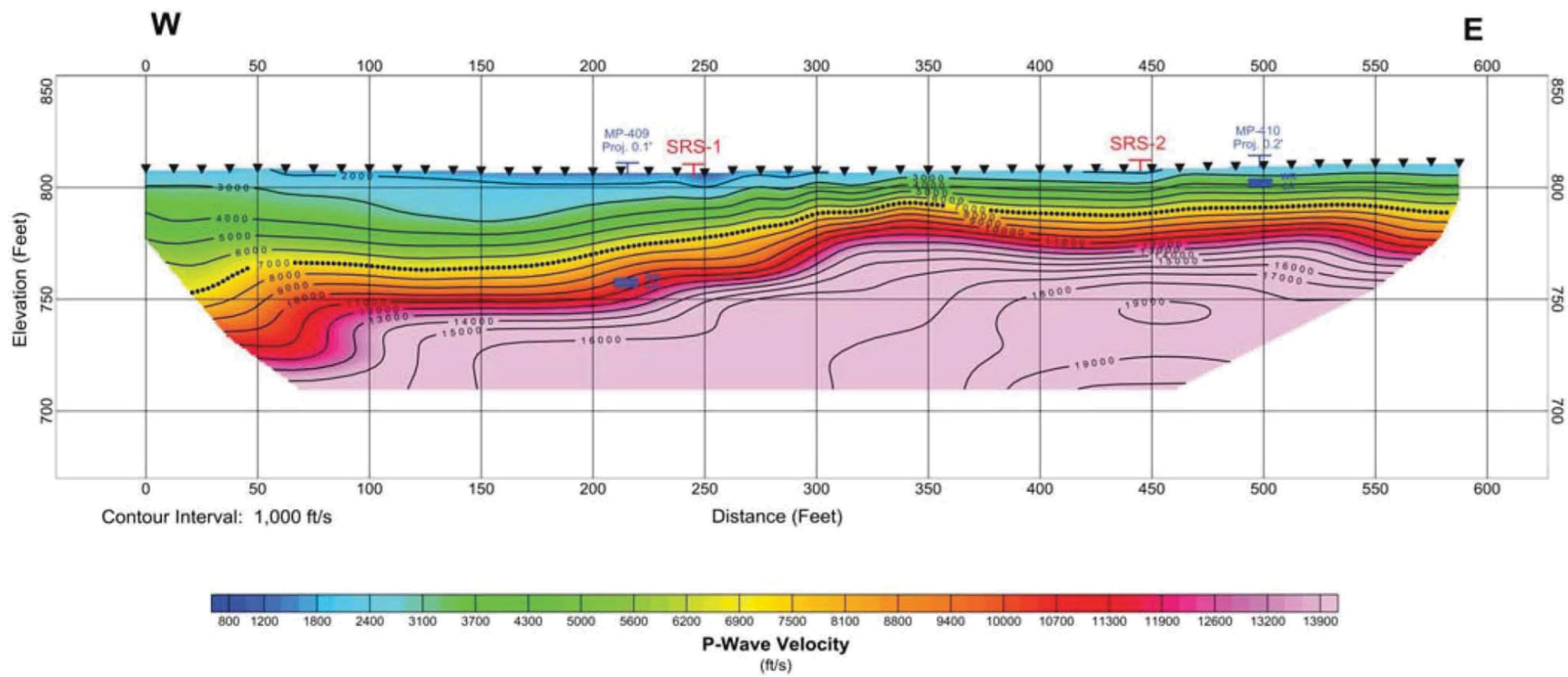
Figure 2.5.1-86 (Sheet 3 of 7) Seismic Tomography Model SRS-3



Source: Reference 2.5.1-214.

See explanation on Sheet 7.

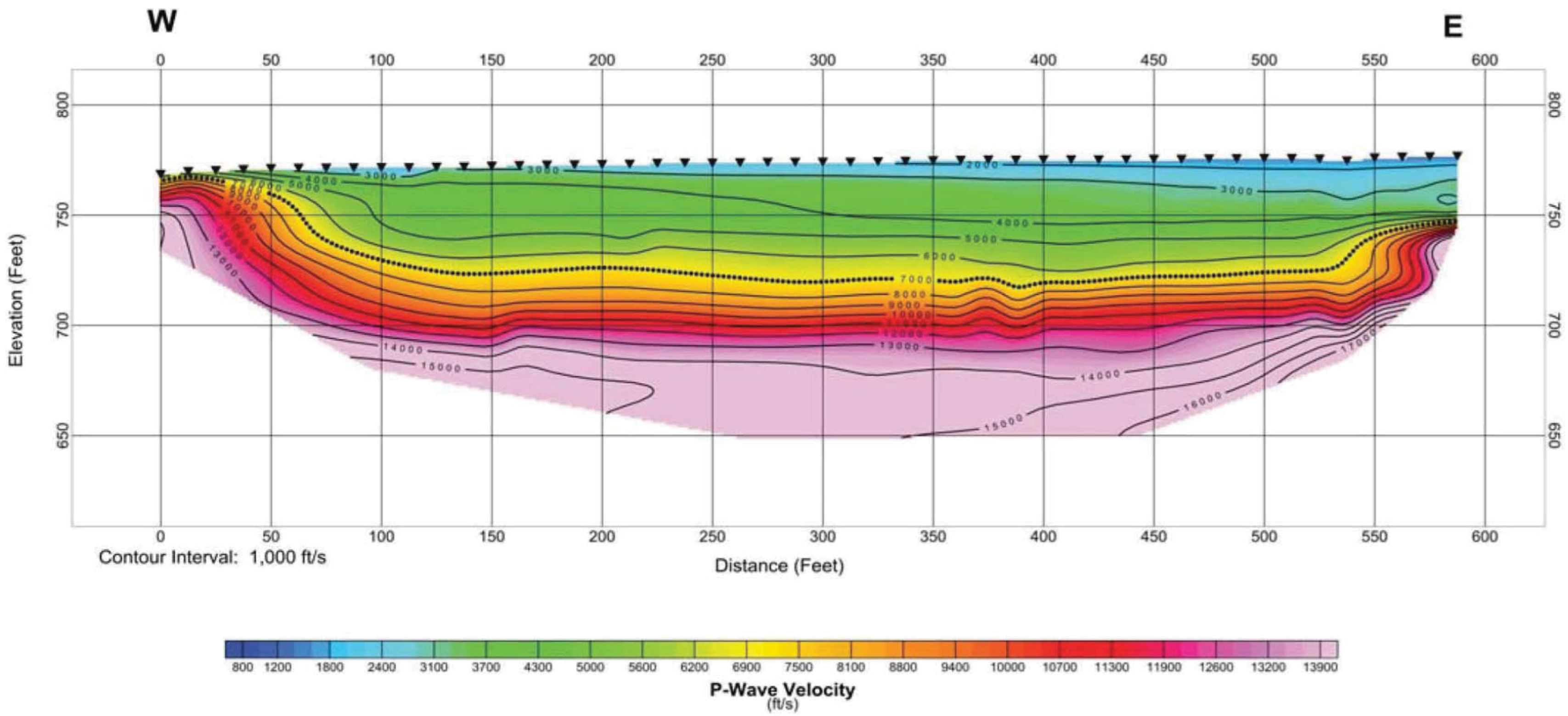
Figure 2.5.1-86 (Sheet 4 of 7) Seismic Tomography Model SRS-4



Source: Reference 2.5.1-214.

See explanation on Sheet 7.

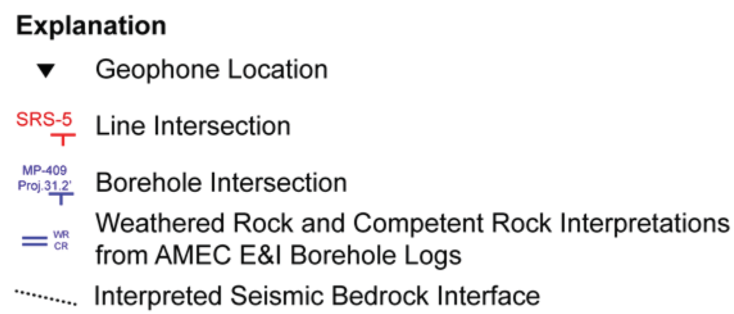
Figure 2.5.1-86 (Sheet 5 of 7) Seismic Tomography Model SRS-5



Source: Reference 2.5.1-214.

See explanation on Sheet 7.

Figure 2.5.1-86 (Sheet 6 of 7) Seismic Tomography Model SRS-6



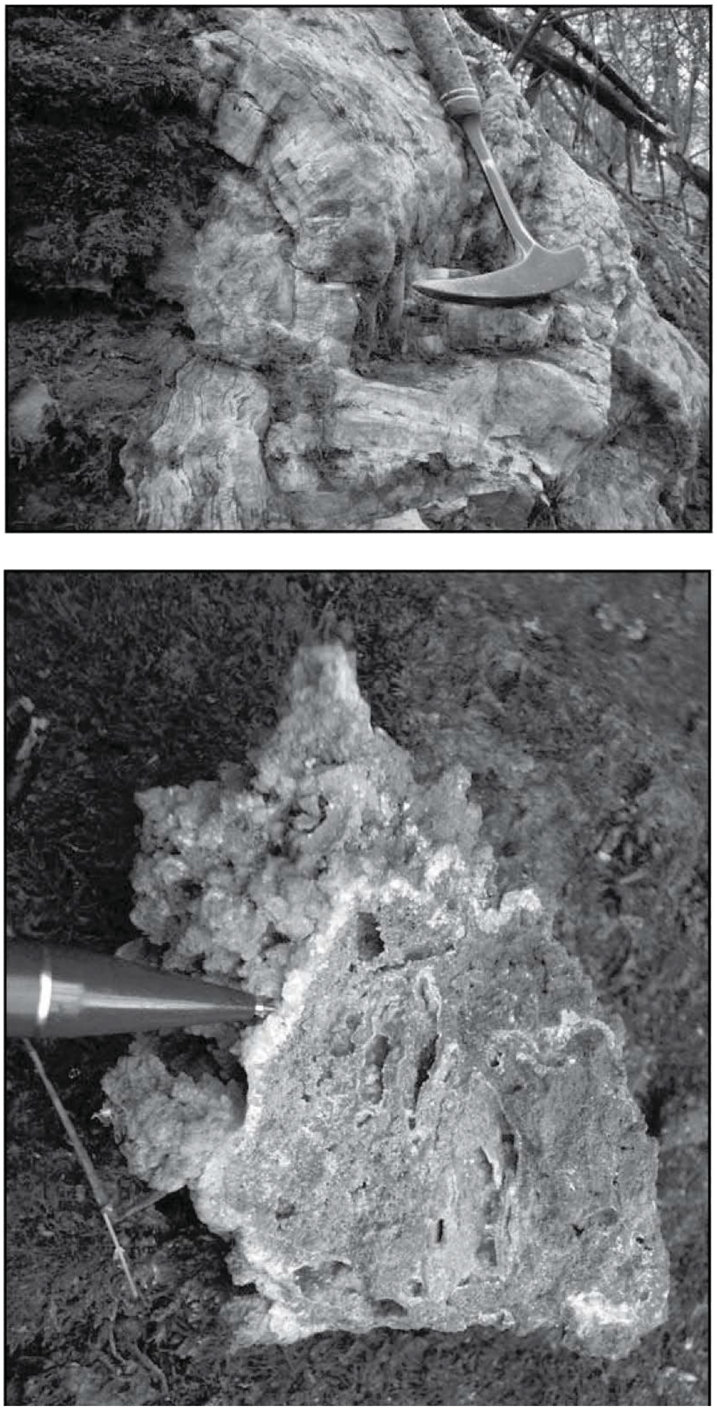
Source: Reference 2.5.1-214.

See Sheets 1-6.

Figure 2.5.1-86 (Sheet 7 of 7) Explanation for Seismic Tomography Models

New SSAR Figure 2.5.1-87 is added to SSAR Subsection 2.5.1:

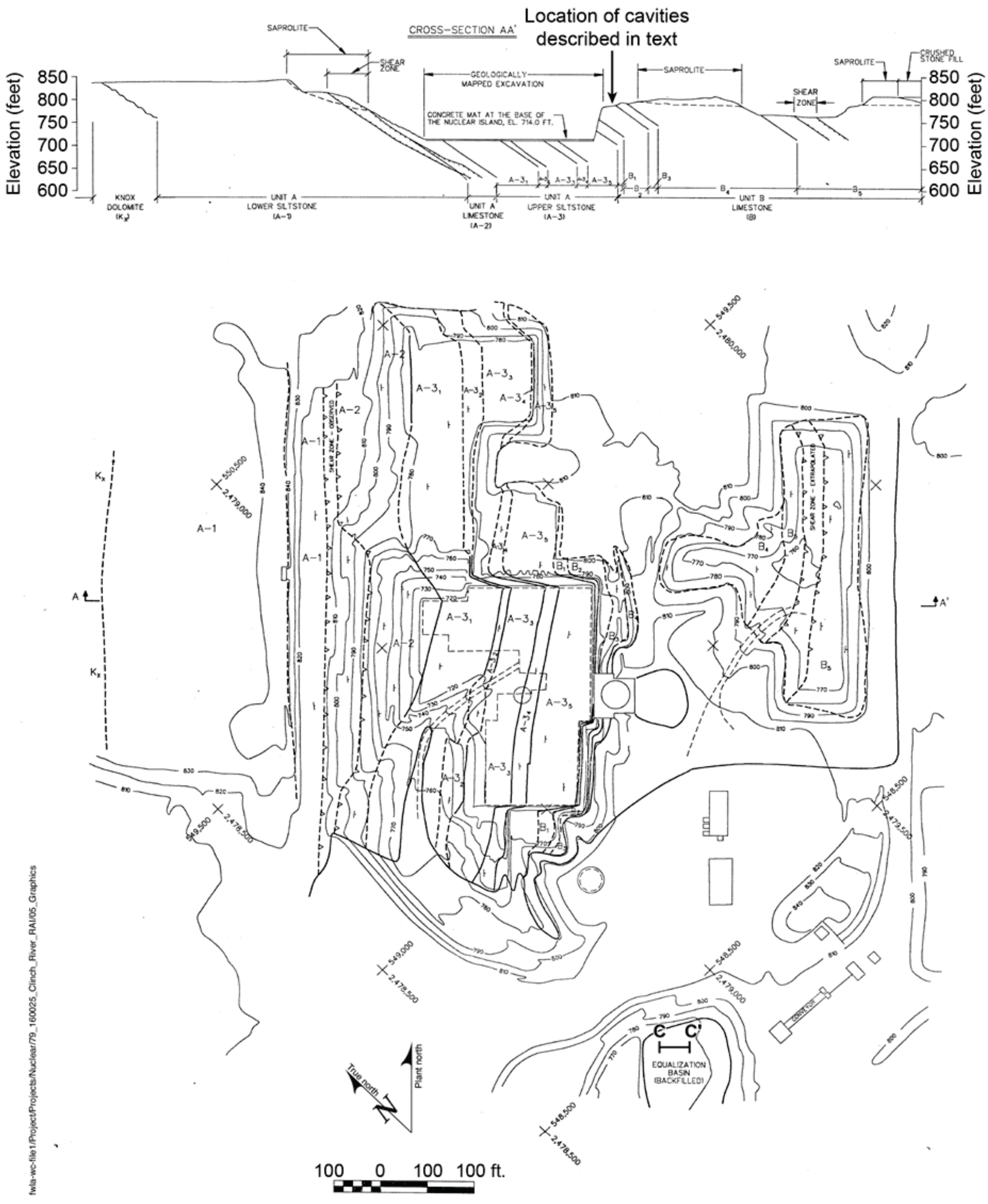
A)
B)



Source: Reference 2.5.1-319.

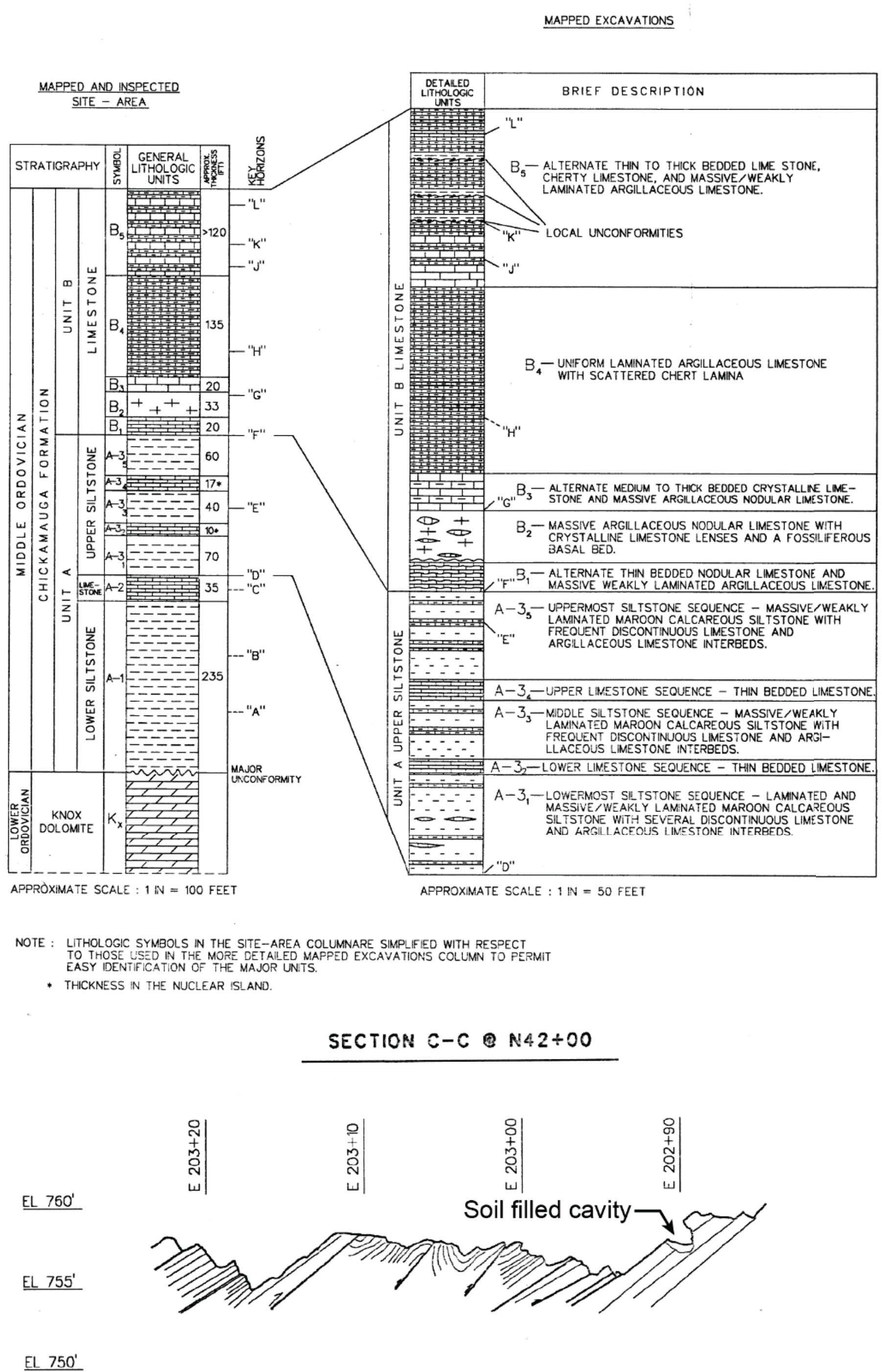
Figure 2.5.1-87. Crystalline Calcite Deposits Indicating a Hypogene Origin in Caves of Shenandoah Valley, Virginia

New SSAR Figure 2.5.1-88 is added to SSAR 2.5.1:



Source: Reference 2.5.1-301.

Figure 2.5.1-88 (Sheet 1 of 2) Geologic Map of the 1983 CRBRP Excavations



Note: Modified from Drakulich, 1984, Drawing 12720EY-Plate 2 and 12720-EY-Plate 4.

Source: Reference 2.5.1-303.

Figure 2.5.1-88. (Sheet 2 of 2) Geologic Column and Cross Section of the 1983 CRBRP Excavations

New SSAR Figure 2.5.1-89 is being added to SSAR Subsection 2.5.1:

PHOTOGRAPH 26
SOLUTION CAVITIES ALONG BEDDING AND STRIKE-JOINTS ON THE BENCH (EL. 780 FT) ABOVE FACE IV (UPPER), AND KARSTIFIED LIMESTONE IN THE EQUALIZATION BASIN, WITH NUMEROUS CAVITIES

Source: Reference 2.5.1-303

Figure 2.5.1-89. Cavities in the Rockdell Formation Exposed in the 1983 CRBRP Excavations