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YUCCA MOUNTAIN – SUPPLEMENTAL RESPONSES TO REQUESTS FOR ADDITIONAL INFORMATION (RAI) -VOLUME 2, CHAPTER 2.1.1.1, FIRST SET AND SECOND SET – Site Description

References:

(1) Ltr, Jacobs to Williams, dtd 12/4/08, "Yucca Mountain - Request for Additional Information – Volume 2, Chapter 2.1.1.1, 1st Set (Department of Energy's Safety Analysis Report Sections 1.1.10, 1.2.2, 1.1.5.2, and 1.1.5.3)"

(2) Ltr, Jacobs to Williams, dtd 12/22/08, "Yucca Mountain - Request for Additional Information – Volume 2, Chapter 2.1.1.1, 2nd Set (Department of Energy's Safety Analysis Report Sections 1.1.4, 1.1.5, 1.3.4)"

(3) Ltr, Williams to Jacobs, dtd 1/12/09, "Yucca Mountain – Request for Additional Information – Volume 2, Chapter 2.1.1.1-1, First Set (Department of Energy's Safety Analysis Report Sections 1.1.10, 1.2.2, 1.1.5.2 and 1.1.5.3) – Site Description"

(4) Ltr, Williams to Jacobs, dtd 3/9/09, "Yucca Mountain – Supplemental Response to Request for Additional Information – Volume 2, Chapter 2.1.1.1, First Set (Department of Energy's Safety Analysis Report Sections 1.1.10, 1.2.2, 1.1.5.2 and 1.1.5.3) – Site Description"

(5) Ltr, Williams to Jacobs, dtd 2/4/09, "Yucca Mountain - Request for Additional Information – Volume 2, Chapter 2.1.1.1, Second Set (Department of Energy's Safety Analysis Report Sections 1.1.4, 1.1.5, and 1.3.4) – Site Description"

(6) Ltr, Williams to Jacobs, dtd 3/20/09, "Yucca Mountain - Request for Additional Information – Volume 2, Chapter 2.1.1.1, Second Set (Department of Energy's Safety Analysis Report Sections 1.1.4, 1.1.5, and 1.3.4) – Site Description"

The purpose of this letter is to transmit the U.S. Department of Energy's (DOE) supplemental responses to RAI Set 1 number 1, identified in reference 1 and Set 2 RAI number 1, identified in reference 2, above. Each supplemental response is provided as a separate enclosure. The responses are based on DOE's understanding of the technical areas requiring further clarification, as discussed in an August 4, 2009, public teleconference. DOE documents cited in supplemental response to Set 2 RAI number 1, which have not been provided to the Nuclear Regulatory Commission, are also enclosed. Enclosures 7 and 8 are being submitted on optical storage media.

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The original DOE response to Set 1 RAI number 1 was provided in reference 3. A supplemental response to this RAI was provided in reference 4. A partial original DOE response to Set 2 RAI number 1 was provided in reference 5 and the remainder of the original DOE response was provided in reference 6.

There is one commitment in the enclosed supplemental response to Set 2 RAI number 1. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

Jeffrey R. Williams, Supervisor
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Office of Technical Management

OTM:SAB-1085

Enclosures (8):

1. Second Supplemental Response to RAI Volume 2, Chapter 2.1.1.1, Set 1, Number 1
2. Supplemental Response to RAI Volume 2, Chapter 2.1.1.1, Set 2, Number 2
3. Albin, A.L.; Singleton, W.L.; Moyer, T.C.; Lee, A.C.; Lung, R.C.; Eatman, G.L.W.; and Barr, D.L. 1997. *Geology of the Main Drift—Station 28+00 to 55+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* Milestone SPG42AM3. Denver, Colorado: Bureau of Reclamation and U.S. Geological Survey. ACC: MOL.19970625.0096. (Provided in hard copy)
4. Barr, D.L.; Moyer, T.C.; Singleton, W.L.; Albin, A.L.; Lung, R.C.; Lee, A.C.; Beason, S.C.; and Eatman, G.L.W. 1996. *Geology of the North Ramp—Stations 4+00 to 28+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970106.0496. (Provided in hard copy)
5. Beason, S.C.; Turlington, G.A.; Lung, R.C.; Eatman, G.L.W.; Ryter, D.; and Barr, D.L. 1996. *Geology of the North Ramp—Station 0+60 to 4+00, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* Denver, Colorado: U.S. Geological Survey. ACC: MOL.19970106.0449. (Provided in hard copy)
6. Eatman, G.L.W.; Singleton, W.L.; Moyer, T.C.; Barr, D.L.; Albin, A.L.; Lung, R.C.; and Beason, S.C. 1997. *Geology of the South Ramp—Station 55+00 to 78+77, Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* Denver, Colorado: U.S. Geological Survey. ACC: MOL.19980127.0396. (Provided in hard copy)
7. Dickerson, R.P. and Drake, R.M., II 2003. Geologic Map of South-Central Yucca Mountain, Nye County, Nevada. Preliminary Working Draft. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20031203.0380. (Provided on OSM)
8. Mongano, G.S.; Singleton, W.L.; Moyer, T.C.; Beason, S.C.; Eatman, G.L.W.; Albin, A.L.; and Lung, R.C. 1999. *Geology of the ECRB Cross Drift—Exploratory Studies Facility, Yucca Mountain Project, Yucca Mountain, Nevada.* Deliverable SPG42GM3. Denver, Colorado: U.S. Geological Survey. ACC: MOL.20000324.0614. (Provided on OSM)

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Document Components Provided on OSM:

[160062]_MOL.20031203.0380.pdf	38,776 kB
[149850]_MOL.20000324.0614.pdf	23,743 kB

Note: These PDF files for supporting responding to Yucca Mountain Repository License Application RAIs were prepared with Adobe Acrobat Version 8 using the current job options file provided by the NRC on its website. Some files included in this submittal may have been initially prepared with another version of Acrobat and another job options file. All files were reviewed using the NRC preflight profile provided on its website and have been determined to meet NRC specifications in the June 2009 revision of Guidance for Electronic Submissions to the NRC. As discussed with NRC staff, the addition of accessibility tagging for compliance with Section 508 of the Rehabilitation Act frequently causes the preflight to return "fonts not embedded" error messages. Specifically, the content is usually flagged as unembedded Times-Roman font. The Adobe preflight errors for unembedded fonts have been reviewed and represent nonprinting and nondisplaying Section 508 tagging information.

RAI Volume 2, Chapter 2.1.1.1, First Set, Number 1: Supplemental Question:

During a teleconference on August 4, 2009, the NRC Staff asked DOE three supplemental questions:

a) On Page 1, last paragraph of RTN 00035-01

"When taken as a whole, the material encountered in Midway Valley is laterally discontinuous and layered. However, when taken at the scale of the surface facilities that are categorized as 'Important to Safety,' it can be interpreted as a homogeneous material with common properties that allow for use of single design parameters (e.g., a friction angle of 39°)."

Where in the response does the DOE identify the shear strength data used to conclude that alluvium (material encountered in the Midway Valley) can be interpreted as homogenous at a scale of ITS structures at the surface facility?

Please identify the shear strength data and explain the uncertainty of the data relative to the 39° friction angle. Also, provide the justification for the use of homogeneous properties in the design and performance analyses of foundations of the ITS surface facility structures.

b) On page 3, last sentence, first paragraph of RTN 00035-01

"Although some units have the tendency to be cemented, there are vertical and lateral variations in the amount of cementation within the unit. These descriptions indicate that (1) uncemented or poorly cemented sediments tend to form the host material for the localized and cemented sediments, (2) locally, the moderately to well-cemented sediments can vary vertically on the scale of one foot to several feet, and (3) by tracing caliche horizons in the test pits, they can be several tens of feet in length. On a scale consistent with the size of the buildings that are categorized as 'Important to Safety,' that is several hundreds of feet across, there will likely be areas with minimal cementation and local areas (both vertically and laterally) with moderately to well-developed cementation; however, these patterns are variable vertically and laterally."

Where in the response does the DOE explain how the variability of cemented and uncemented alluvium has been accounted for in design and performance analyses of foundations of surface facility structures, for example, potential effects on a foundation that is supported partly on cemented alluvium and partly on uncemented alluvium?

c) On Page 4, second sentence of DOE's supplemental response to RAI 1 (RTN 35-01)

"Allowable bearing capacities of 50 ksf and 10 ksf were chosen for use in design evaluations for the seismic design basis ground motion-2 and normal loading cases, respectively."

Address why 50 ksf is acceptable as a limit, if 10 ksf results in a 2-in. settlement?

1. SUPPLEMENTAL RESPONSE

1.1 SHEAR STRENGTH OF ALLUVIUM FOR USE IN ANALYSES: DEVELOPMENT OF 39° FRICTION ANGLE

Because of the coarse-grained nature of the alluvium in Midway Valley, shear strength data could not be directly collected by common methods (e.g., shear box test, triaxial test, standard penetration test). Consequently, the shear strength of the alluvium was determined based on relative density data obtained in test pits, using accepted industry-standard correlations between relative density and the effective friction angle shear strength parameter.

Data from borehole logs, test pits, and trenches throughout Midway Valley indicate that the alluvium consists of dense, coarse-grained granular deposits of gravel with sand or sand with gravel, with minor amounts of cobbles and fines (silt and clay). Few lenses of silt are encountered, and no clay layers or lenses are encountered. The entire alluvial deposit is above the regional water table. Cementation tends to increase with depth. The alluvium consists of interfingering lenses of granular soils. Geotechnical differences in the alluvium can be observed on a small scale (approximately 1 to 10 ft) in both the vertical and horizontal directions. Over the scale of interest for the important to safety (ITS) facilities (50 ft to several hundreds of feet), there are no geotechnical differences in the alluvium that need to be taken into account in establishing conservative values of shear strength for the alluvium in ultimate bearing capacity evaluations of the mat foundations. Thus, modeling the alluvium as a single geotechnical material represented by a conservative value of shear strength is reasonable and appropriate.

When a foundation is loaded to ultimate failure on dense, granular soil, the resulting shear involves the material to a depth below and distances beyond the foundation that are on the order of the foundation width. Because the shear associated with a large mat foundation involves such a large volume of soil, local variations in soil properties over dimensions that are small with respect to the foundation do not control the shear failure. Therefore, it is appropriate to use average shear strength in bearing capacity analyses. A lower-than-average shear strength is conservatively selected in *Soils Report for North Portal Area, Yucca Mountain Project* (BSC 2002a, Section 1.2.2).

The shear strength of the alluvium was determined based on relative density data obtained in test pits TP-WHB-1 to TP-WHB-4 at depths ranging from 4 to 20 ft. The geotechnical classification of the alluvium in the test pits using the Unified Soil Classification System is similar at all depths and is similar to the geotechnical classifications of alluvium in boreholes throughout Midway Valley. Although much of the alluvium has some degree of cementation, cohesion due to cementation is conservatively not included in the determination of shear strength. Consideration of cohesion would increase the shear strength.

The in-place density tests performed in the year 2000 in test pits TP-WHB-1 to TP-WHB-4 are described in *Geotechnical Data for a Potential Waste Handling Building and for Ground Motion for the Yucca Mountain Site Characterization Project* (BSC 2002b, Section 6.2.4). The in-place density was measured by either the water replacement method or the sand cone method. Six water replacement tests were performed using a 6-ft diameter ring, and 16 tests were performed using a 20-in. sand cone. A second set of relative density data was obtained by means of nine in-place 6-ft diameter ring density tests performed in 2005 in test pits TP-WHB-5, TP-WHB-6, and TP-WHB-7, at depths ranging from about 4 to 19 ft, as described in *Technical Report: Geotechnical Data for a Geologic Repository at Yucca Mountain, Nevada* (SNL 2008, Section 6.2.4). These data were not used in the determination of shear strength, but they corroborate the earlier data.

Table 1 provides the relative density data from these tests. The sand cone tests yielded relative densities that are more variable and have a lower mean value than the six ring density tests performed in 2000. Consideration of ring density tests from 2005 corroborate that the sand cone tests yielded relative densities that are more variable and have a lower mean value. Because the ring density test involves a larger sample volume, ring density results are considered to be more representative.

Shear strength was developed using multiple, widely used correlations between relative density and effective friction angle in granular soils and applying them to the relative density data set obtained from the tests performed in 2000 (BSC 2002b, Section I.2.2.1). Eight correlations are used to determine the effective friction angle for granular materials similar to the alluvium in Midway Valley, as shown in Table 2. Each correlation was applied to the mean, the mean minus one standard deviation, and the mean plus one standard deviation values of relative density, providing the uncertainty range for the values of effective friction angle. These values are shown in Table 2.

Based on these results, an effective friction angle of 39° was selected. This value (rounded to the nearest whole degree) is between the average mean friction angle (40.5°) and the average mean minus one standard deviation friction angle (37.0°). Use of this lower-than-average value is appropriate and conservative because, at the scale of the ITS mat foundations, the geotechnical behavior of the alluvium has average characteristics over the very large volume of material.

1.2 VARIABILTY OF CEMENTED AND UNCEMENTED ALLUVIUM

For the evaluations of shear strength associated with a large mat foundation, the dimensions involved are very large compared with the scale on which the geotechnical characteristics vary. Data from borehole logs, test pits, and trenches throughout Midway Valley indicate that the alluvium gradation ranges from coarser granular soil (e.g., well-graded gravel with sand and some cobble content) to a finer granular soil (e.g., poorly graded sand with silt and gravel and trace cobbles). There are few, small lenses of fine-grained alluvium. In addition, cementation varies in both the lateral and vertical directions. The density of the material also varies in both the lateral and vertical directions as a result of differences in material gradation and depositional environment. When viewed on the large scale appropriate to the analyses (hundreds of feet), these variations appear to be random in nature (tens of feet or less in extent), justifying the use of average properties.

The shear strength considered in the design is a conservative value that does not incorporate any cohesion due to cementation. There is no evidence of continuous lenses/layers with regard to cementation whose extent approaches a significant fraction of the length or width of the ITS foundations. The mat foundations are capable of bridging any portions of the soil that may be uncemented (and have lower shear strength) and those portions of the soil that are cohesive (i.e., cemented), due to the ability of reinforced concrete to redistribute peak stresses. Therefore, the mat foundations are appropriately designed considering the average shear strength.

1.3 DIFFERENCE BETWEEN SETTLEMENT AND BEARING CAPACITY

The 50 ksf value is selected so as not to exceed the bearing capacity of the foundation materials during a seismic event. It does not include consideration of settlement.

The foundation design of the ITS surface facilities is based on two separate criteria. The first criterion limits total settlement of these structures. For the controlling load combinations provided in SAR Section 1.2.2, foundations are designed such that a total settlement of 2 in. is not exceeded. The second criterion provides that the foundation pressure does not exceed a bearing capacity (which does not include consideration of settlement) of 50 ksf for extreme (seismic) loads and 10 ksf for normal loads. Both of these criteria must be met to achieve acceptable foundation designs. Due to the size of the mat foundations, the settlement criterion controls the design.

The total and differential settlement estimate values for the surface facilities are provided in Table 1 of RAI 2.2.1.1.7-11-015. The seismically induced total settlement is considered to be insignificant due to the dry and dense nature of the alluvial soils at the site. In addition, cementation of the native alluvium will also reduce the potential for dynamic settlement. Therefore, seismically induced settlement is not included in the total settlement calculations.

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

Bowles, J.E. 1996. *Foundation Analysis and Design.* 5th Edition. New York, New York: McGraw-Hill. TIC: 247039.

BSC (Bechtel SAIC Company) 2002a. *Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project.* ANL-MGR-GE-000003 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20021004.0078.

BSC 2002b. *Soils Report for North Portal Area, Yucca Mountain Project.* 100-00C-WRP0-00100-000-000. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20021015.0323.

Duncan, J.M.; Horz, R.C.; and Yang, T.L. 1989. *Shear Strength Correlations for Geotechnical Engineering*. Blacksburg, Virginia: Virginia Polytechnic Institute and State University, Center for Geotechnical Practice and Research. TIC: 251870.

Hatanaka, M. and Uchida, A. 1996. "Empirical Correlation Between Penetration Resistance and Internal Friction Angle of Sandy Soils." *Soils and Foundations, 36*, (4), 1-9. Tokyo, Japan: Japanese Geotechnical Society. TIC: 252181.

SNL (Sandia National Laboratories) 2008. *Technical Report: Geotechnical Data for a Geologic Repository at Yucca Mountain, Nevada*. TDR-MGR-GE-000010 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080206.0001.

USN (U.S. Department of the Navy) 1986. *Soil Mechanics*. Design Manual 7.01. Alexandria, Virginia: Naval Facilities Engineering Command. TIC: 242885.

Table 1. Comparison of Relative Density Results (in Percent) by Ring Density and Sand Cone Methods

Statistic	Sand Cone (2000)[a]	Ring Density (2000)[a]	Ring Density (2005)[b]	Ring Density (Combined)
Minimum	25	55	60	55
Mean	65.9	72.0	80.0	76.8
Median	68	74.0	74	74
Maximum	120	86	102	102
Standard Deviation	23.4	10.2	17.2	14.9
Coefficient of Variation, %	35.5	14.1	21.5	19.4
Number of tests	16	6	9	15

Source: [a]BSC 2002a, Table 6
[b]SNL 2008, Table 6.2-4.

Table 2. Summary of Effective Friction Angles (in Degrees) from Various Correlations

Correlation Number	Mean – σ	Mean	Mean + σ
(1) Schmertmann – sand[a]	39.4	41.4	43.6
(1) Schmertmann - gravelly sand[a]	41.8	43.3	45.0
(2) USN – well-graded sand (SW)[b]	33.6	36.1	39.1
(2) USN – well-graded gravel (GW)[b]	35.9	39.0	43.0
(3) Meyerhof - clean sand[c]	37.0	42.3	47.5
(3) Meyerhof - gravelly sand[c]	42.0	47.3	52.5
(4) Mitchell and Katti[d]	33.4	35.8	38.1
(5) Hatanaka and Uchida-sandy soils[e]	33.1	38.9	44.7
Average	37.0	40.5	44.2

NOTE: σ = standard deviation.

Source: BSC 2002b, Section I.2.2
[a]Schmertmann's correlation as described by Bowles 1996, p. 100.
[b]USN 1986, p. 7.1-149.
[c]Meyerhof's correlation as described by Duncan et al. 1989, p. 19.
[d]Mitchell and Katti's correlation as described by Duncan et al. 1989, p. 19.
[e]Hatanaka and Uchida 1996, Equation 8.

RAI Volume 2, Chapter 2.1.1.1 Second Set, Number 1: Second Supplemental Question:

In a teleconference with the NRC on August 4, 2009, the NRC discussed the need for clarifying information related to inconsistencies identified with respect to geologic maps and cross-sections submitted as part of responses to RAI Section 2.1.1.1, Set 2, Number 1 (dated February 4, 2009, and March 20, 2009) and RAI Section 2.1.1.1, Set 2, Number 3 (dated February 4, 2009). The consistency questions were as follows:

1) Clarify between fault maps of the subsurface geologic repository operations area (GROA) (Second Set, Number 1, dated February 4, 2009, Figure 4 and SAR Figure 1.1-61), and of the surface GROA (Second Set, Number 1, dated March 20, 2009, Figure 1 and SAR Figure 1.1-64) by showing the current map, which includes the areas between the Solitario Canyon Fault, Bow Ridge Fault, and Paintbrush Canyon Fault or areas near the Paintbrush Canyon Fault.

2) RAI 2.2.1.1.1-2-003, Paragraph 3, pp. 1 to 2—SAR Figure 1.1-61, (e.g., Solitario Canyon Fault splays G & N, Ghost Dance Fault, Sundance Fault) with SAR Figure 1.1-73B. Clarify the inconsistency between the named and unnamed faults on certain geologic cross-sections and the presumed same faults shown on the geologic index map of the GROA.

3) RAI 2.2.1.1.1-2-003, p. 8—Clarify certain incomplete cross-sections (or resubmit cross-sections) to show the spatial relationship of the major faults of significant displacements or faults that influence GROA design, as well as the named and unnamed identified faults shown on the surface and subsurface GROA.

4) Clarify the inconsistency of an unnamed buried fault in Midway Valley that is interpreted as a steeply dipping reverse fault to the north and steeply dipping normal fault to the south (Section SD–SD′, SE–SE′ and Section SA–SA′ of Enclosure 1, p. 19).

5) RAI 2.2.1.1.1-2-001, Paragraph 1—Provide information on the fault displacement data (including the net slip value used, ranges of values, and the distribution of data points on the fault) of observed faults at the surface and subsurface GROA and adjacent to the GROA (e.g., the Solitario Canyon Fault and Bow Ridge Fault, intrablock faults) and the uncertainty associated with displacement values provided.

6) RAI 2.2.1.1.1-2-001, Paragraph 3—Clarify how slickenside data were incorporated into the estimation of fault displacements or clarify how the methods used to estimate fault displacements have not underestimated fault displacements.

7) RAI 2.2.1.1.1-2-001, Paragraph 4, Line 1, p. 8—Clarify the conclusion that the minor undulations in the contact between the base of alluvium-colluvium and the bedrock do not correlate with fault locations, given the uncertainty in the methods used to detect vertical offsets. Also, clarify the estimated resolution of vertical and lateral displacements

of Midway Valley Fault with Quaternary activity in light of these methods and local geology.

1. SECOND SUPPLEMENTAL RESPONSE

To respond to this request for additional information, the DOE is providing seven responses to the clarifying questions as separate sections. In some cases, portions of the questions were interrelated and the detailed response may be provided in a section different from the clarifying question. The following format is used:

- Section 1.1 clarifies the apparent inconsistencies between the fault maps of RAI responses and the SAR figures.

- Section 1.2 clarifies the apparent inconsistencies between the named and unnamed faults between fault maps of the RAI responses and the SAR figures. Cross sections are not discussed in Section 1.2; they are discussed in Section 1.3.

- Section 1.3 shows the spatial relationship of the major faults that influence GROA design and the named and unnamed identified faults in the surface and subsurface GROA. The section provides discussion of revised and newly submitted figures.

- Section 1.4 clarifies the apparent inconsistency of the unnamed buried fault in Midway Valley that is interpreted as a steeply dipping reverse fault to the north and steeply dipping normal fault to the south.

- Section 1.5 provides details of fault displacement data for observed faults at the surface and subsurface GROA and adjacent to the GROA.

- Section 1.6 clarifies how slickenside data were used in how fault displacements were estimated.

- Section 1.7 clarifies that minor undulations in the contact between the base of alluvium–colluvium and the bedrock do not correlate to fault locations; and discusses estimated resolution of displacements in Midway Valley.

1.1 CLARIFY THE INCONSISTENCIES BETWEEN FAULT MAPS OF THE RAI RESPONSES AND THE SAR FIGURES

The inconsistencies between SAR Figure 1.1-61 and Figure 4 (RAI 2.2.1.1.1-2-001, dated February 4, 2009, p. 9), and SAR Figure 1.1-64 and Figure 1 (RAI 2.2.1.1.1-2-001, dated March 20, 2009, p. 9), are related to the date of the information presented and the purpose of the respective illustration. The maps show some inconsistencies between earlier and more recent data but are adequately consistent for design purposes.

SAR Figure 1.1-61 depicts fault locations for the top of bedrock. The faults shown are based on the *Bedrock Geologic Map of the Yucca Mountain Area, Nye County, Nevada* (Day, Dickerson et al. 1998) and abstracted in the *Geologic Framework Model (GFM2000)* (BSC 2004) and reflect the state of knowledge in 1998. Fault labels shown in SAR Figure 1.1-61 refer to their informal identification in the GFM2000. These labels differ in some cases from the formal name shown for the same fault on geologic and other maps in the SAR. The GFM2000 remains the current model for the subsurface GROA facilities design and SAR Figure 1.1-61 accurately reflects the traces of faults modeled in GFM2000 (BSC 2004, Figure 6-2).

The cross sections submitted in the response for RAI 2.2.1.1.1-2-001 (dated February 4, 2009) for the subsurface GROA have been modified to clarify the spatial relationships of the faults included in the GFM2000 between the Bow Ridge Fault and the Solitario Canyon Fault. Figures 1, 3, 4, 5, 6 and 7 from the original response to RAI 2.2.1.1.1-2-001 (dated February 4, 2009) are superseded by the versions (using the same figure numbers) submitted with this supplemental response. Figure 2 from the original response is unchanged but is being submitted for completeness. Figures 8 and 9 are new figures submitted to expand the cross-sections depicting the spatial relationship of the faults. Figure 10 is a new figure and is submitted as an index map showing the lines of section, the GROA, and the areas between the Solitario Canyon Fault, Bow Ridge Fault, and the Paintbrush Canyon Fault. The Bow Ridge and Solitario Canyon faults are the two Quaternary faults with potential for significant displacement that influence design in the GROA.

Figure 4 is updated from the version submitted previously with RAI 2.2.1.1.1-2-001 (dated February 4, 2009). The figure now includes the updated interpretation of the location of the Bow Ridge Fault based on geologic logs from boreholes drilled in 2006 and 2007 (Orrell 2007), which differs from the location incorporated in the GFM2000 (SAR Figure 1.1-61). Additionally, fault labels that are used only in the GFM2000 have been removed from the figure. Many faults that were previously labeled in Figure 4 of the original response are now not labeled. It should also be noted that the Exile Hill Fault has been removed from Figure 4 because investigations have shown it to be insignificant to the structural understanding of the subsurface GROA.

Incorporation of new borehole information for the areas of alluvial cover within the GROA surface facility area resulted in interpretive models of geologic structure reflecting the evolution of understanding and interpretation of sub-alluvial structure for that area. Figure 11 is submitted in this response as a revision to Figure 1 of RAI 2.2.1.1.1-2-001 (dated March 20, 2009), which provides an update to the position of the Bow Ridge Fault with respect to borehole UE-25 RF#76. Additionally, SAR Figure 1.1-64 in the license application will be updated.

1.2 CLARIFY THE INCONSISTENCIES BETWEEN THE NAMED AND UNNAMED FAULTS BETWEEN FAULT MAPS OF THE RAI RESPONSES AND THE SAR FIGURES

Inconsistencies in the depiction of faults on SAR Figures 1.1-61 and 1.1-73(b) result from the different purposes for which they were created. SAR Figure 1.1-61 shows faults that are included as structural elements in the GFM2000 (BSC 2004). That model includes block-bounding faults that exhibit evidence of displacement during the Quaternary Period and intrablock faults that displace Miocene units but show no evidence of Quaternary activity. Of the faults included in the GFM2000 model, only the Solitario Canyon and the Bow Ridge faults (Quaternary faults with potential for significant displacement) influence the design of the subsurface GROA.

SAR Figure 1.1-73 shows faults that were considered during the probabilistic seismic hazard analysis (PSHA) for Yucca Mountain as potential sources of future earthquakes. Information shown on the figure represents the state of knowledge in the mid-1990s when the PSHA was carried out. The displayed faults include those with evidence of displacement during the Quaternary Period, those that were suspected of activity during the Quaternary Period, and other faults that, although not suspected of Quaternary activity, were notable because of their length and proximity to the GROA. Some minor faults that were considered during the PSHA are not shown on Figure 1.1-73 to avoid making the figure harder to read. Complete documentation of faults considered in the PSHA is contained in *Probabilistic Seismic Hazard Analyses for Fault Displacement and Vibratory Ground Motion at Yucca Mountain, Nevada* (CRWMS M&O 1998, Appendix E).

While there is some overlap in the faults shown on the two figures, given the different purposes for which they were created, the difference in the faults displayed is reasonable. Faults without evidence of Quaternary activity, and those not suspected of Quaternary activity, while part of the structural geologic framework of the site, are not considered sources of future earthquake activity.

Based on available geologic data, no additional Quaternary faults with potential for significant displacement are expected to be encountered during construction. The north ramp of the Exploratory Studies Facility (ESF) was excavated through the Bow Ridge Fault; this is the only encounter with a Quaternary fault with potential for significant displacement that is expected during subsurface facilities construction.

1.3 SHOW THE SPATIAL RELATIONSHIP OF THE MAJOR FAULTS THAT INFLUENCE GEOLOGIC REPOSITORY OPERATIONS AREA DESIGN AND THE NAMED AND UNNAMED IDENTIFIED FAULTS IN THE SURFACE AND SUBSURFACE GEOLOGIC REPOSITORY OPERATIONS AREA

The cross sections submitted in the responses for RAI 2.2.1.1.1-2-001 (dated February 4, 2009) for the subsurface GROA have been modified to clarify the spatial relationships of the faults included in the GFM2000 between the Bow Ridge Fault and the Solitario Canyon Fault. Figure 2 from the original response is unchanged but is being re-submitted for completeness. Figures 1, 3, 4, 5, 6, and 7 from the original response to RAI 2.2.1.1.1-2-001 (dated February 4, 2009) are superseded by the versions submitted with this supplemental response. Figures submitted with this response include:

- Figures 1 and 3 include new cross-sections RD–RD′ and RE–RE′ and identify the greater widths of the cross-sections being submitted as part of this response.

- Figure 4 provides the current fault information knowledge at depth and incorporates drilling information. Modifications consist of updating the Bow Ridge Fault location to conform to present knowledge of the feature and identification of the revised and additional section locations.

- On Figure 5 (Section RA–RA′), cross-sections depicting the spatial relationship of the major faults are expanded. The south end point of the section line (RA′) now extends beyond the Ghost Dance Fault trace. The north end point of the cross-section (RA) was not changed. This new cross section contains undifferentiated Quaternary/Tertiary alluvium-colluvium which was not contained in the original figure.

- On Figure 6 (Section RB–RB′), cross-sections depicting the spatial relationship of the faults that influence GROA design are expanded. The west end point of the cross-section (RB) now extends beyond the Solitario Canyon Fault and the figure displays Quaternary/Tertiary alluvium-colluvium that was not originally shown. The east end point of the cross-section (RB′) was not changed.

- Figure 7 (Section RC–RC′) was only changed to revise the color and labeling of a geologic unit for consistency with the legend in Figure 5.

- Figures 8 and 9 (Sections RD–RD′ and RE–RE′) are newly submitted to expand the cross-sections depicting the spatial relationship of the faults. Both cross-sections extend beyond the Solitario Canyon Fault to the west and beyond the Bow Ridge Fault to the east. Figure 8 is located east–west across the center of the repository in the Panel 1 area. Figure 9 is located east–west across the southern end of Panel 2, south of existing Section RC–RC′ to include faults that exist in the GFM2000.

- Figure 10 is an index map showing the surface projection of Quaternary faults at or in proximity to the surface and subsurface GROA.

- Figure 11 is submitted in this response as a revision to Figure 1 of RAI 2.2.1.1.1-2-001 (dated March 20, 2009). Figure 11 provides an update to the position of the Bow Ridge Fault with respect to Borehole UE-25 RF#76. Figure 10 is consistent with the presentation of faults in Figure 11.

1.4 CLARIFY THE INCONSISTENCY OF AN UNNAMED BURIED FAULT IN MIDWAY VALLEY THAT IS INTERPRETED AS A STEEPLY DIPPING REVERSE FAULT TO THE NORTH AND STEEPLY DIPPING NORMAL FAULT TO THE SOUTH

The response to RAI 2.2.1.1.1-2-001 (dated March 20, 2009) interprets the unnamed buried fault in Midway Valley as a scissor fault and such an interpretation is consistent with the data. There is no evidence suggesting the fault offsets Quaternary alluvium, and no evidence within the resolution provided by borehole geologic logs that the alluvium-bedrock contact is offset; the fault is interpreted as a Miocene-age fault and does not impact the layout of surface facilities or contribute to the seismic hazard. In the response to RAI 2.2.1.1.1-2-001 (dated March 20, 2009), this fault was specifically discussed (pages 6 and 7 of 102) because the reverse sense of separation is not typical of faults in the Yucca Mountain area (although there are other examples, such as the Solitario Canyon Fault). Two self-imposed geometric constraints led to the depiction of this fault in this manner:

1. The emphasis during development of the structural framework for the surface GROA was to retain geologic interpretations from *Bedrock Geologic Map of the Yucca Mountain Area, Nye County, Nevada* (Day, Dickerson et al. 1998), *Geologic Framework Model (GFM2000)* ((BSC 2004), and selected faults described in the *Geotechnical Data for a Potential Waste Handling Building and for Ground Motion Analyses for the Yucca Mountain Site Characterization Project* (BSC 2002) to the degree that they remain consistent with additional data acquired since 2001.

2. Where there were no direct geologic constraints, it was determined to use constant dip directions along faults.

The four steps taken in the modeling of this fault, which trace the data and decisions during modeling, were described in the response to RAI 2.2.1.1.1-2-001 (dated March 20, 2009; pages 6 and 7 of 102). Based on the borehole data and sense of separation along the fault, the scissor-fault geometric depiction is consistent with the data. The response to RAI 2.2.1.1.1-2-001 (dated March 20, 2009) also described an alternative (page 7 of 102), which would be to divide the fault into two faults in order to honor the borehole data.

Based on the RF-series boreholes, some of which closely bound the geometry of the fault (or faults if depicted with the alternative geometric relations), there are two important considerations:

1. There is no evidence that the fault offsets the alluvium-bedrock surface, and this relation is true regardless of whether there is one fault or two faults.

2. Regardless of the geometric depiction, the fault(s) only offset the Miocene lithostratigraphic units, and these relations are most consistent with being part of the structural deformation in the Midway Valley area during the Miocene Epoch, as there is no evidence that the fault has been active during the Quaternary Period (Keefer et al. 2004, Table 5).

These two considerations indicate that neither the depiction of the fault as currently interpreted nor the alternative description impact the seismic hazard analysis.

1.5 FAULT DISPLACEMENT DATA FOR OBSERVED FAULTS AT THE SURFACE AND SUBSURFACE GEOLOGIC REPOSITORY OPERATIONS AREA AND ADJACENT TO THE GEOLOGIC REPOSITORY OPERATIONS AREA

The information requested about faults is presented in Section 1.5.1, surface and bedrock geologic maps and reports; Section 1.5.2, geologic maps and reports from the subsurface facilities; and Section 1.5.3, geologic logs of boreholes. Each of these document types is compiled for different reasons and data are presented at different scales. Each document considers the types of data collected on faults and thereby contributes to understanding the characteristics of faults. The only faults that influence surface and subsurface GROA design are those near the GROA that have evidence of Quaternary activity and a potential for significant displacement: the Solitario Canyon and Bow Ridge faults.

1.5.1 Surface and Bedrock Geologic Maps

Two types of surface and bedrock geologic maps and reports document faults and associated characteristics: (1) maps of geographic areas of interest that focus on surface and bedrock deposits (Day, Dickerson et al. 1998; Day, Potter et al. 1998; Dickerson and Drake 1998; Potter et al. 1998; and Dickerson and Drake 2003) and (2) maps of trenches in Quaternary deposits that are summarized in *Evaluation of the Location and Recency of Faulting Near Prospective Surface Facilities in Midway Valley, Nye County, Nevada* (Swan et al. 2001) and *Quaternary Paleoseismology and Stratigraphy of the Yucca Mountain Area, Nevada* (Keefer et al. 2004). These geographic area maps are published at two different scales; Day, Dickerson et al. (1998) is at a scale of 1:12,000, and Day, Potter et al. (1998), Dickerson and Drake (1998), Potter et al. (1998), and Dickerson and Drake (2003) are at a scale of 1:6,000. These maps and associated reports are the primary sources for the definitions of the block-bounding faults (Solitario Canyon, Bow Ridge, and Paintbrush Canyon faults), and these are the only faults in the vicinity of the GROA with evidence of Quaternary activity (Swan et al. 2001 and Keefer et al. 2004). These maps and reports also describe a variety of intrablock faults (none of which have evidence of Quaternary activity). Additionally, these maps and reports document geometric properties of faults including the spatial distribution and orientation of faults, and for many of these faults, the separation (and for some faults the oblique slip or net slip) can be calculated from map relations. For some faults, detailed descriptions of fault characteristics, such as damage zones containing breccia, and variations of features and properties along the fault are presented. These maps and reports provide the best documentation of the lateral continuity and variability of faults.

The reports by Swan et al. (2001) and Keefer et al. (2004) provide the detailed summaries of faults in the area of Yucca Mountain that were evaluated for Quaternary activity. Swan et al. (2001) provide details of the program for geologic mapping and trenching that was done to obtain surface and near-surface geologic data for determining the location and recency of faults located east of Exile Hill in Midway Valley. Keefer et al. (2004) provide data regarding fault geometry and displacements, ages, and characteristics of closely associated Quaternary deposits, paleo-earthquake recurrence intervals, and fault-slip rates collected from trenches excavated across faults or from natural exposures. Results of the numerical dating of soils and other surficial deposits involved in Quaternary fault activity are also discussed. Individual, cumulative, and net cumulative measurements of fault displacement were used in recording faulting events. Where possible, individual dip-slip displacements associated with each faulting event were determined directly, by measuring the displacement of marker horizons across the fault, and then subtracting the offset related to any later events identified higher in the stratigraphic section. This procedure could not be used if the same marker horizons were not present on opposite sides of the fault. For example, at some trench sites, upper Quaternary deposits on the hanging-wall block are faulted against older deposits or bedrock on the footwall block from which younger deposits have been stripped off by erosion. Several different methods were used in those situations. At some trench sites, single-event offsets were based on the thickness of fault-related colluvial wedges, resulting in minimum estimates that are commonly 50% to 80% of the actual surface displacement. An alternative method involved measurement of the vertical separation between a displaced event horizon in the hanging-wall block and the stratigraphically highest, but older, faulted unit on the footwall block to determine the total offset. Displacements per event were then calculated by subtracting the offsets related to individual faulting events that are identifiable at stratigraphically higher event horizons in the hanging-wall blocks from this measurement. A similar technique used the stratigraphic thickness of deposits between successive event horizons on the hanging-wall block as a maximum estimate for the displacement associated with the stratigraphically lower event.

Specific descriptions and data on faults in (or near) the GROA are included in *Quaternary Paleoseismology and Stratigraphy of the Yucca Mountain Area, Nevada* (Keefer et al. 2004):

- Chapter 4 provides a summary of studies in Midway Valley
- Chapter 5 provides a summary of Quaternary faulting on the Paintbrush Canyon, Bow Ridge, and Stagecoach Road faults
- Chapter 7 discusses Quaternary faulting on the Solitario Canyon Fault
- Table 5 (p. 26) provides a summary of characteristics of major faults in the Yucca Mountain area.

1.5.1.1 Uncertainty Considerations

Uncertainties inherent in the methods used in the trenching studies (discussed in Section 1.5.1) are accounted for in the range of reported displacements (Keefer et al. 2004, p. 7).

1.5.2 Geologic Maps and Reports from the Underground Facilities

In the subsurface facilities at Yucca Mountain, five reports and the supporting full periphery geologic maps and detailed line survey data provide detailed documentation and descriptions of faults exposed in the tunnels, alcoves, and niches (Beason et al. 1996; Barr et al. 1996; Albin et al. 1997; Eatman et al. 1997; Mongano et al. 1999). In addition to the lithostratigraphic descriptions of rocks exposed along the tunnels, these five reports provide detailed discussions of (1) faults with more than 4 m of dip-slip separation displacement, (2) faults with less than 4 m of displacement (which includes shears), and (3) fractures. Faults have been defined as discontinuities that have more than 0.1 m of offset (or separation), shears have separations of less than 0.1 m, and fractures have no identifiable separation across the discontinuity (other than the opening of the discontinuity to form an aperture). For faults with separation greater than the diameter of the ESF access main or Enhanced Characterization of the Repository Block (ECRB) Cross-Drift (7.6 m or 5.0 m, respectively), the separation was generally determined from the correlation of lithostratigraphic units. Because this form of evaluation uses lithostratigraphic units, which at least locally are tabular in form and typically tens of meters thick, the resulting separation is only dip-slip separation. Historically, the Drill Hole Wash Fault had been described as an oblique slip fault with a component of strike-slip separation, and two strands of the fault were exposed in the north ramp of the ESF (Barr et al. 1996). Because of the previous emphasis on the oblique- (and possibly strike-) slip on this fault, it is the only fault in the ESF and the ECRB Cross-Drift for which preliminary calculations were made to assess possible strike-slip separation or net-slip offset; however, it was not possible to actually measure the amount of lateral movement (Barr et al. 1996). These five reports provide tables that list faults with greater than 4 m of separation and supporting descriptions of the characteristics of the fault (including widths of associated fracture, breccia, or rubble zones). Faults with less than 4 m of displacement (or separation) typically are described in terms of summaries (e.g., number of faults and shears, average separations, orientation).

There are two important contributions and limitations to descriptions of faults exposed in the tunnels: (1) there are many detailed measurements and descriptions; however, whether from the 7.6 m or 5.0 m tunnels and even where the fault is exposed for long distances along a tunnel, these observations are essentially a point measurement with respect to the entire fault; and (2) of all the faults described in the tunnels, only two (the Solitario Canyon and Bow Ridge faults) are block-bounding faults with demonstrated Quaternary activity that influence GROA design (Table 1), and 18 other faults have separations of greater than 4 m (Table 2).

Table 1. Locations of the Bow Ridge and Solitario Canyon Faults in the ESF and ECRB

Faults	Segment of tunnel (m)	Reference
Bow Ridge Fault	1+99.8 North Ramp ESF	Beason et al. 1996
Solitario Canyon Fault	25+85 ECRB	Mongano et al. 1999

Table 2. Faults with Cumulative Dip-Slip Separation Greater than 4 m in the ESF and ECRB

Faults	Dip-slip separation (m)	Segment of tunnel (m)	Reference
2 (including the Bow Ridge Fault)	4.3 to 128.0	ESF 1+99.8 to 2+13	Beason et al. 1996
9 (including Drillhole Wash Fault)	4.0 to 18.0	ESF 4+00 to 28+00	Barr et al. 1996
0	(largest of 0.63 m)	ESF 28+00 to 55+00	Albin et al. 1997
6	two > 50 m; four < 15 m	ESF 55+00 to 78+77	Eatman et al. 1997
3 (including Solitario Canyon Fault)	"several meters" and > 5.0 m to 260 m	ECRB 11+35 to 25+00 to 25+99	Mongano et al. 1999

1.5.2.1 Uncertainty Considerations in the Geologic Maps and Reports

Geologic data recorded on full periphery geologic maps and detailed line survey data tables consist of various types of angular and linear measurements that are presented and used in different ways. The full periphery geologic maps in the ESF and ECRB Cross-Drift include lithostratigraphic and structural features on 1:125 scale drawings that were developed in the full-periphery style to produce a flat map of the tunnel periphery. Discontinuities and lithostratigraphic contacts with trace lengths longer than 1 m were recorded. The orientation of geologic features was determined using a goniometer for strike azimuth and a Brunton compass for dip values. Detailed line survey data in the ESF were collected along the right wall, 1 to 1.5 m below the springline on the tunnel wall, and in the ECRB Cross-Drift; the detailed line survey data were collected along the left wall, at the springline on the tunnel wall. Trace lengths longer than 30 cm were reported on the survey. Discontinuities that intersect the wall within 30 cm above and below the tape were also considered. Strike azimuth, dip, discontinuity type, trace length, number of visible fracture terminations and types of terminations, aperture, roughness, infilling type, and thickness were recorded.

The five reports discussed in Section 1.5.2 (Beason et al. 1996; Barr et al. 1996; Albin et al. 1997; Eatman et al. 1997; Mongano et al. 1999) provide detailed descriptions of faults. Estimated accuracy and precision values of measurements obtained in the field are presented in Table 3 and consider the field instruments and techniques used in data gathering. Based on the techniques and measurements used, accuracy and precision are assumed to be equal, and are therefore referred to as accuracy. Table 3, developed for this response, lists each type of detailed line survey data for faults and provides estimated accuracy values for angular and length measurements using different methods and scales. For angles, the categories are direct (the measurement tool is laid on the feature), projected (the feature is projected or the measurement tool is approximately oriented), and 3-point calculation (a calculation based on the locations of three points along the feature). The general relationships represented in Table 3 indicate detailed measurements (direct angles and shorter lengths) have greater accuracy (smaller values) than more generalized measurements (3-point calculation of angles or >14 m lengths). These uncertainty estimates in individual measurements are small and (1) result in small spatial variations on a local scale and, (2) for faults with displacement of less than the tunnel diameter, the uncertainty associated with displacement values provided is less than 0.5 m. When evaluating faults with displacement greater than the tunnel diameter, the separations were generally determined from the correlation of lithostratigraphic units. The greatest contributor to the uncertainty results from establishing the thickness of the units that are either determined from relations in the tunnel or from independent sources such as nearby borehole data. Uncertainties for these larger displacements are estimated to be about 10 to 20 m. Using the Bow Ridge Fault as an example, tunnel studies (Beason et al. 1996) noted that normal faulting dropping the pre-Rainier Mesa Tuff bedded tuff (Tmbtl) down into contact with the Tiva Canyon Tuff indicated 128 m of dip-slip separation. This amount of separation matches well with the previous estimate of 125 m (Buesch et al. 1994).

Table 3. Accuracy and Precision Estimates for Angular and Length Measurements in Full Periphery Geologic Map and Detailed Line Survey Data from the *ESF* and *ECRB Cross-Drift*

	Angular measurements (degrees)			**Length measurements (m)**				
Types of data	**Direct**	**Projected**	**3-point calculation**	**Station (m) (FPGM and DLS)**	**>0.01 m to 2 m (tape) (m)**	**>2 m to 6 m (tape) (m)**	**>6 m to 14 m (tape) (m)**	**>14 m (tape) (m)**
Location	NA	NA	NA	0.1	NA	NA	NA	NA
Strike (°)	3	5	8	NA	NA	NA	NA	NA
Dip (°)	3	5	8	NA	NA	NA	NA	NA
Displacement on fault or shear	NA	NA	NA	NA	0.02	0.08	0.25	0.5

NOTE: NA = Not applicable

The table lists types of full periphery geologic map (FPGM) and detailed line survey (DLS) data and provides accuracy and precision values for angular and length measurements using different methods and scales. For angles, the categories are Direct (the measurement tool is laid on the feature), Projected (the feature is projected or the measurement tool is approximately oriented), and 3-point calculation (a calculation based on the locations of three points along the feature). The general relations indicate detailed measurements (Direct angles and smaller lengths) have greater precision and accuracy (smaller values) than more generalized measurements (3-point calculation of angles or >14 m lengths). Accuracy and precision are considered to be equal for the purposes of this table, so only a single value is presented.

1.5.3 Geologic Logs of Boreholes

Borehole geologic logs (from surface or tunnel-based boreholes) provide detailed descriptions of boreholes that intersect faults; however, some of the detailed relations can be difficult to quantify and separate from nonfaulted conditions such as drilling-induced fractures, rubble of core, etc. Typically, for faults penetrated in boreholes or inferred to be between boreholes, the separation along a fault is determined indirectly by evaluating the apparent amount of lithostratigraphic section that has been removed by faulting. Although depths in boreholes are typically measured to the nearest 0.1 ft (based on pipe lengths), lithostratigraphic contacts (and fault contacts) can vary from 0.1 ft to many tens of feet depending on whether the samples are of core or cuttings and the sharpness and contrast of lithostratigraphic features. Additionally, the thicknesses of some lithostratigraphic units are measured in many tens (if not hundreds) of feet; therefore, dip-slip separation along faults can only be moderately constrained. Even more so than with tunnels, borehole observations are only a point measurement with respect to the entire fault.

Of the two faults that influence surface and subsurface GROA design (the Solitario Canyon and Bow Ridge faults), only the Bow Ridge Fault has been penetrated by boreholes. These boreholes include UE-25 NRG#2, UE-25 NRG#2b, UE-25 RF#76, and UE-25 ONC#1. Borehole UE-25 ONC#1 is a short distance north of the south portal of the ESF and is, therefore, outside the GROA. Boreholes UE-25 NRG#2 and UE-25 NRG#2b are on the west side of Exile Hill and have conventional core; however, several feet of core were not recovered, thereby limiting the documentation of lithostratigraphic and structural details of the fault. Borehole UE-25 RF#76 is just west of the northern Aging Pad (17P) with conventional core at the depth of a fault that is interpreted as the Bow Ridge Fault. Assuming a dip of 70°, the 26-ft long section of fault breccia recorded in the borehole is equivalent to about a 9-ft wide fault. This compares well to the approximately 2.7 m (9 ft) width of the Bow Ridge Fault observed in the ESF (Beason et al. 1996, p. 26). An apparent separation of about 92.5 ft occurs on the Bow Ridge Fault near boreholes UE-25 RF#79 and UE-25 RF#80, which are located west of Aging Pad 17P (cross-section SE–SE′ in the response to RAI 2.2.1.1.1-2-001; dated March 20, 2009).

1.6 SLICKENSIDE DATA USAGE AND DISPLACEMENT ESTIMATION

Slickensides, where noted in the collected data, were generally not used in estimation of fault displacement in Miocene rocks, other than as general indicators of direction of movement. Estimation of fault displacement was performed by using as many indicators of the relative positions of three-dimensional features on either side of the faults as possible. Various geologic features such as concentrations of pumice clasts, subzone contacts, concentrations of lithic clasts, and large lithophysae that exist on both sides of faults were used to estimate the net offset. For very large offsets, such as block-bounding faults, stratigraphic separation has been the primary indicator of offset amount. On most large features, the offsets were specifically recorded as stratigraphic separations to denote that the offset amount was derived using projected lithostratigraphic thicknesses and represents primarily dip-slip separation.

Slickensides were used in some Quaternary fault studies (such as Keefer et al. 2004) as general indicators of movement. Specifically, that study states:

> Cumulative dip-slip displacements were adjusted in two ways to determine cumulative net-slip displacements: (1) normal-oblique slip was calculated for any trench site that contains possible slip indicators, such as slickenlines on bedrock shears that are related to Quaternary deformation, or, less reliably, striations on carbonate coatings within fault zones; and (2) at some trench sites, displacement of units that were deformed near the main fault zone, either by backtilting toward the fault surface and (or) by development of antithetic grabens, was measured and evaluated. The effects of this secondary deformation were removed by projecting displaced units into the fault zone from undeformed sections of the hanging wall and footwall before measuring displacements on the main fault zone. All measurement uncertainties are propagated through the derivations of both cumulative and net displacements.

The PSHA considered lateral slip offset for ground motion hazard assessment (CRWMS M&O 1998, Section 4.1) to ensure that fault slip rates and their uncertainty were appropriately characterized, noting that the total amount of fault offset is dependent on whether the fault is a normal fault or an oblique-normal fault. Evaluations of oblique slip and net slip were considered in the evaluations of slip rates as provided in SAR Table 1.1-66.

1.7 MINOR UNDULATIONS IN THE CONTACT BETWEEN THE BASE OF ALLUVIUM–COLLUVIUM AND THE BEDROCK; AND ESTIMATED RESOLUTION OF DISPLACEMENTS IN MIDWAY VALLEY

Faults represented in cross section within Midway Valley are shown to terminate at the base of the alluvium because there is no indication that they penetrate the alluvium, and there are no ground-surface expressions of these faults (Swan et al. 2001; Keefer et al. 2004). As demonstrated through the contouring of alluvium thickness, the alluvium–bedrock contact data are consistent with a top-of-rock surface that is smooth, approximately planar, and thus has very little structural relief. An example of this lack of relief can be found at the Midway Valley Fault. There are large differences in the thicknesses of nonwelded tuffs near the fault and these differences are consistent with deposition across a faulted topography or movement of the fault. The variation in thickness of the alluvium across the fault, however, is within the resolution of the 10-ft contours. In the immediate location of ITS structures, the data do not indicate a structurally controlled bedrock surface at the bottom of the alluvium. Relief in the alluvium-bedrock contact of about one-half contour interval (i.e., 5 ft) cannot be ruled out on the basis of available data. If such relief exists, it could be due to deposition across a fault-line scarp or displacement of basal alluvial deposits, although there is no evidence to suggest the basal deposits have been offset. Age dating of the basal deposits in Midway Valley constrain the most recent episode of faulting to be older than 1.9 million years (Neymark et al. 2007) and thus do not factor into the Quaternary displacement evaluations. The basal sediments of Midway Valley confirm the ages assumed by Swan et al. (2001) and Keefer et al. (2004). Also, except for the Paintbrush Canyon Fault, there is no evidence in Midway Valley of faults displacing surface alluvial deposits.

The fact that the Bow Ridge Fault north of the aging pads marks a significant step in alluvium thickness is strong evidence that, if this type of sharp change in thickness occurred elsewhere in the valley, it would be clearly evident from an analysis of borehole geologic data. UE-25 RF#75 encountered the top of rock at 60 ft on the east side of the Bow Ridge Fault. UE-25 RF#76 encountered the top of rock at 132 ft depth west of the Bow Ridge Fault and encountered the fault at depth. The difference in depth between these two borehole contacts is inconsistent with the interpretation of an approximately planar alluvium–bedrock contact between the boreholes and is more reasonably interpreted as the result of dip-slip displacement on the Bow Ridge Fault. Such structural displacement of the alluvium-bedrock contact is not observed in the evaluation of drilling results elsewhere in the surface GROA.

Uncertainty is addressed by evaluating the level of accuracy of the drilling data and the contouring. Conventional core drilling depths and lithostratigraphic contacts are considered to be accurate to within plus or minus 0.1 ft; sonic core depths are considered accurate to plus or minus 5 ft. Horizontally, borehole locations are very accurately located based on a first-order survey of the borehole collar. The boreholes are assumed to be vertical with only very minor potential deviations within the uppermost 100 to 200 ft; therefore, the spatial location of the alluvium–bedrock contact in a borehole would result in only a small difference laterally compared to the collar location. The alluvium thicknesses are contoured with a 10-ft contour interval. Vertical uncertainty in the alluvium thickness contouring is considered accurate to plus or minus one half of a contour interval (i.e., ± 5 ft).

2. COMMITMENTS TO NRC

The DOE commits to update the LA as described in Section 3. The change will be included in a future LA update.

3. DESCRIPTION OF PROPOSED LA CHANGE

Update SAR Figure 1.1-64 to reflect the updated interpretation of the Bow Ridge Fault location relative to borehole UE-25 RF#76.

4. REFERENCES

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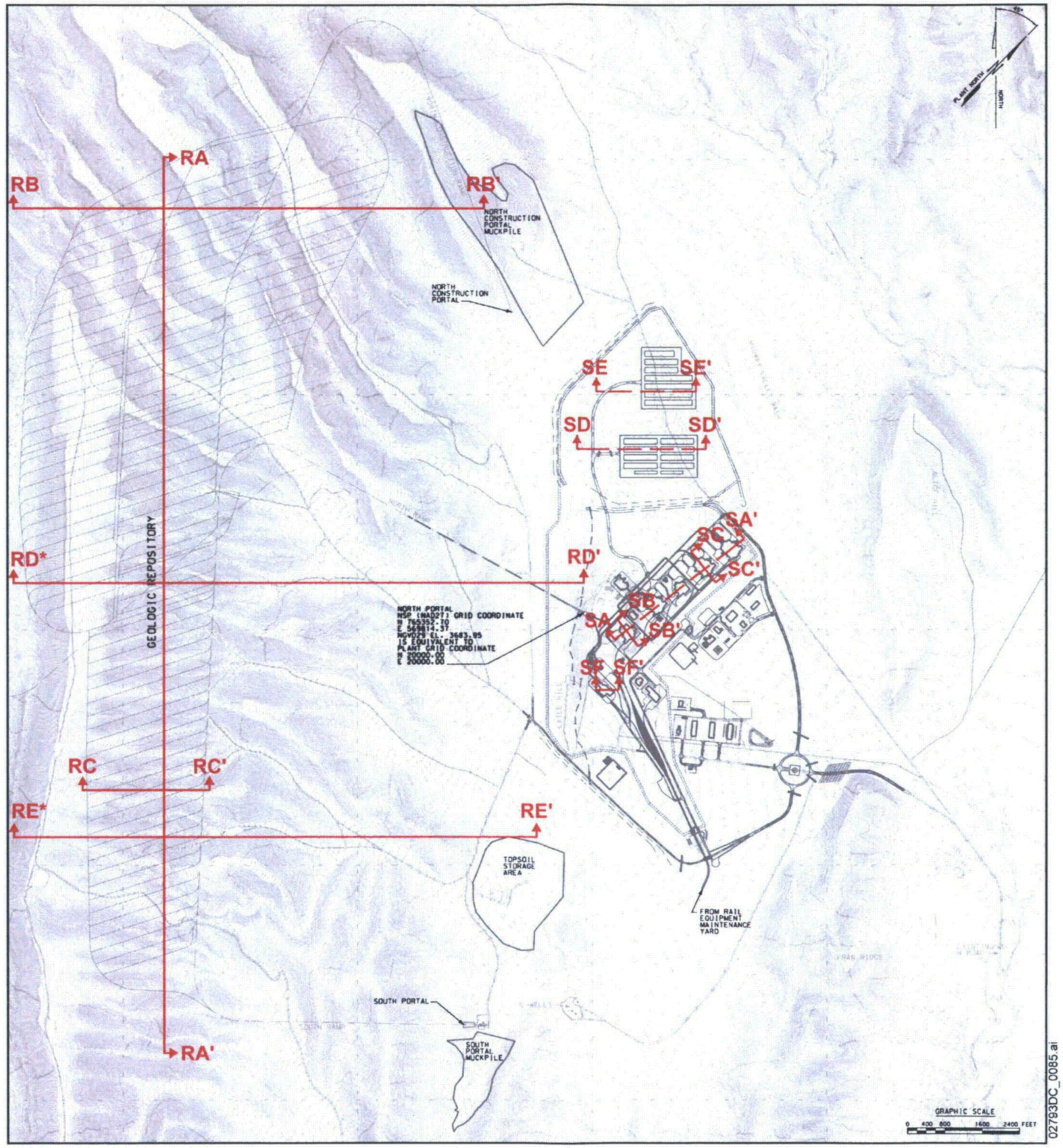

NOTE: Contour interval is 10 ft. Coordinates are Nevada State Plane (NAD27) in feet. Cross section RA–RA' is shown in Figure 5. Cross section RB–RB' is shown in Figure 6. Cross section RC–RC' is shown in Figure 7. Cross section RD–RD' is shown in Figure 8. Cross section RE–RE' is shown in Figure 9. Cross sections SA–SA', SB–SB', SC–SC', SD–SD', SE–SE', and SF–SF' were provided with RAI 2.2.1.1.1-2-001(dated February 4, 2009). *Western end points for Cross Sections RE-RE' and RD-RD' extend beyond the edge of this figure (see Figure 10).

Figure 1. Topographic Map of the Geologic Repository Operations Area

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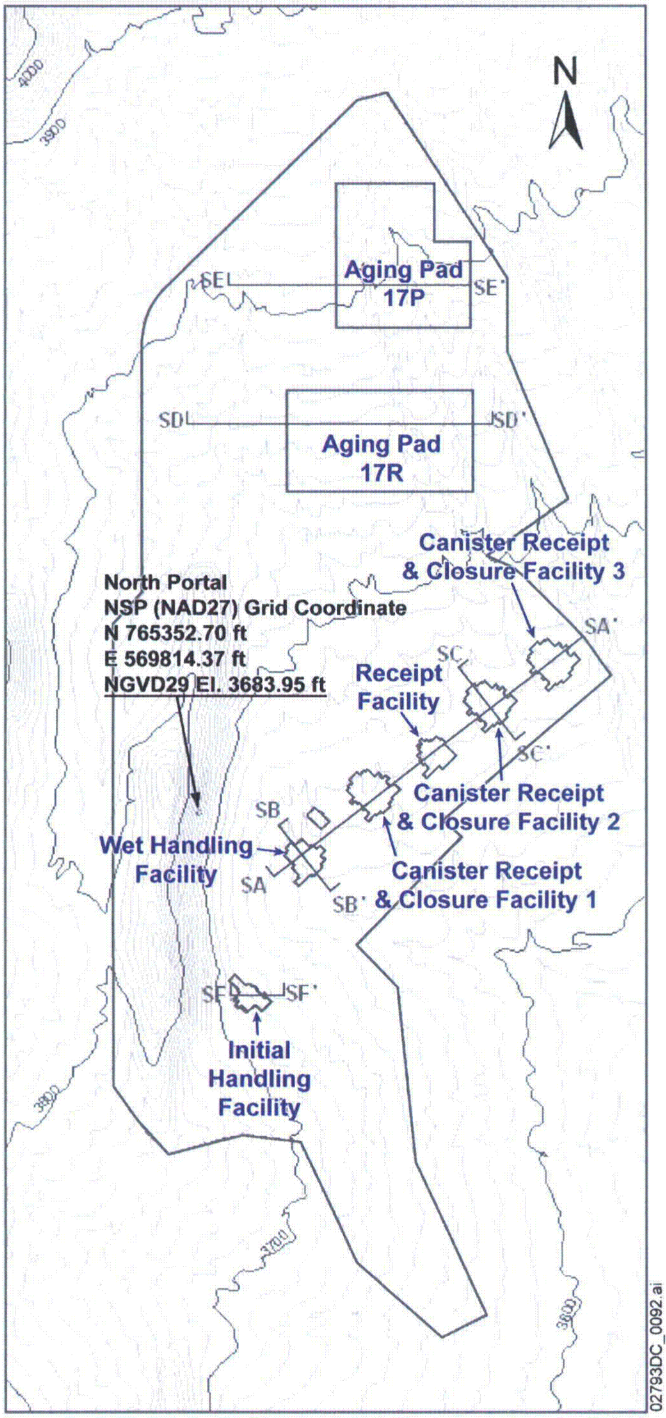

Figure 2. Topographic Map of the Geologic Repository Operations Area–Surface Facilities

NOTE: Contour interval is 10 ft. Cross sections beneath the surface facilities, SA–SA', SB–SB', SC–SC', SD–SD', SE–SE", and SF–SF', were provided with RAI 2.2.1.1.1-2-001 (dated March 20, 2009).

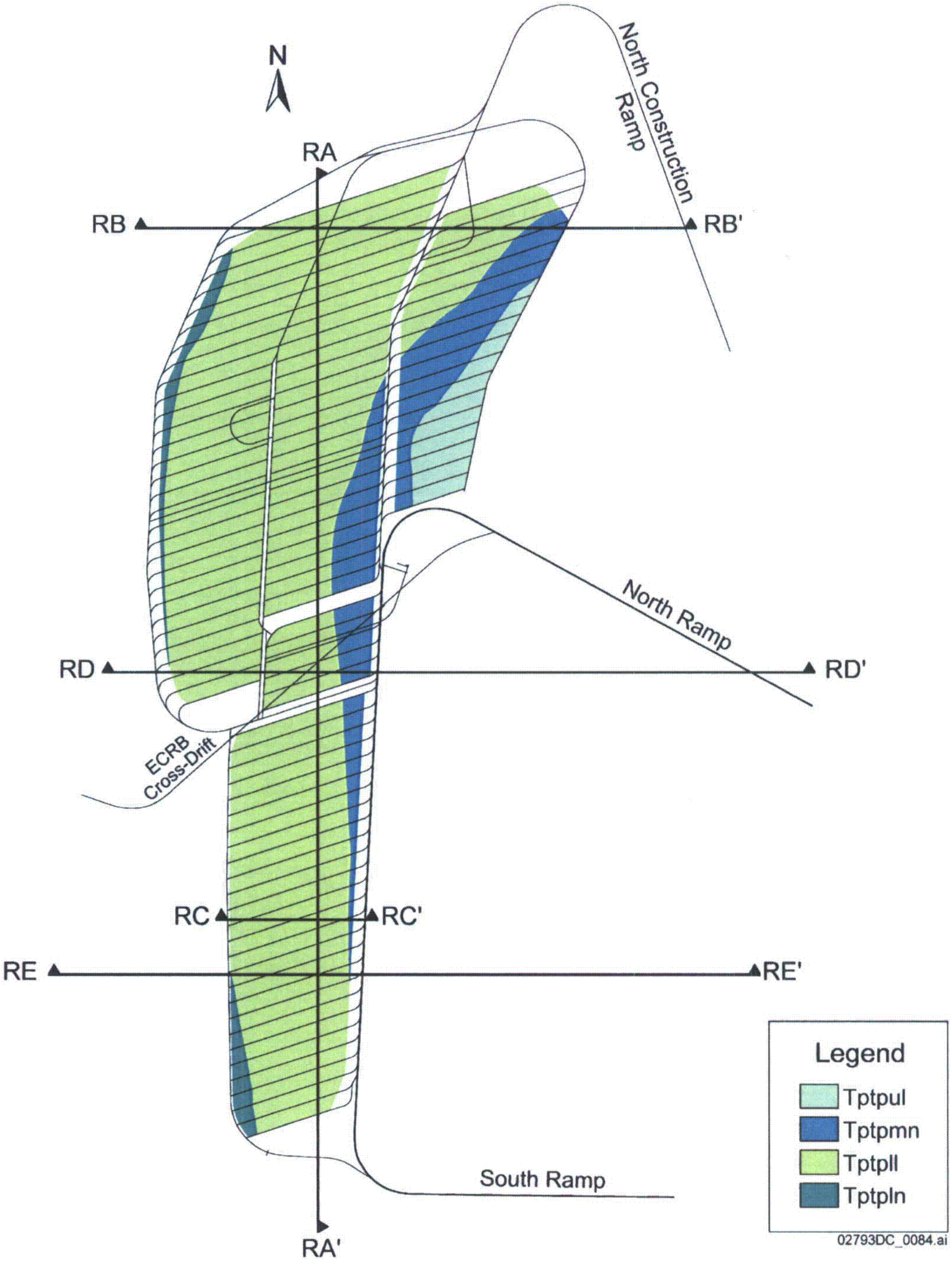

Figure 3. Underground Layout Configuration and Geologic Units of Emplacement Area

NOTE: This figure is similar to Figure 1.3.4-2 in the SAR. However, this figure only shows the lithostratigraphy of the emplacement drifts. Geologic unit coloration is the same as for Figures 5 through 9. Scale is 1:37,500. Cross section RA–RA' is shown in Figure 5. Cross section RB–RB' is shown in Figure 6. Cross section RC–RC' is shown in Figure 7. Cross section RD–RD' is shown in Figure 8. Cross section RE–RE' is shown in Figure 9.

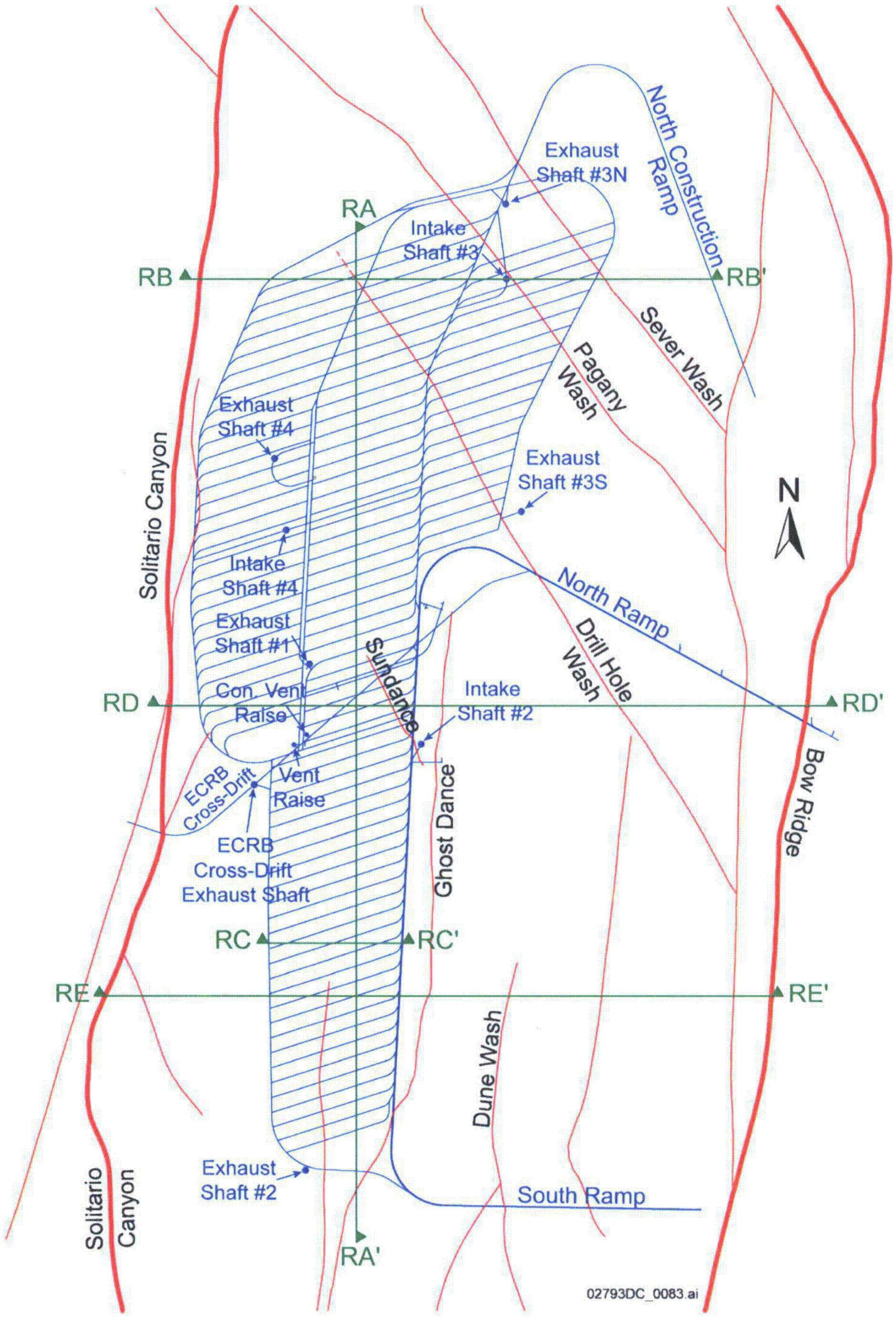

Figure 4. Underground Layout Configuration and Fault Traces at the Emplacement Level

NOTE: This figure is similar to Figure 1.1-61 in the SAR. However, this figure shows the fault traces at the emplacement drift invert elevation. Scale is 1:41,100.
Cross section RA–RA' is shown in Figure 5. Cross section RB–RB' is shown in Figure 6. Cross section RC–RC' is shown in Figure 7. Cross section RD–RD' is shown in Figure 8. Cross section RE–RE' is shown in Figure 9. Quaternary faults with the potential for significant displacement are shown in a heavier line width.

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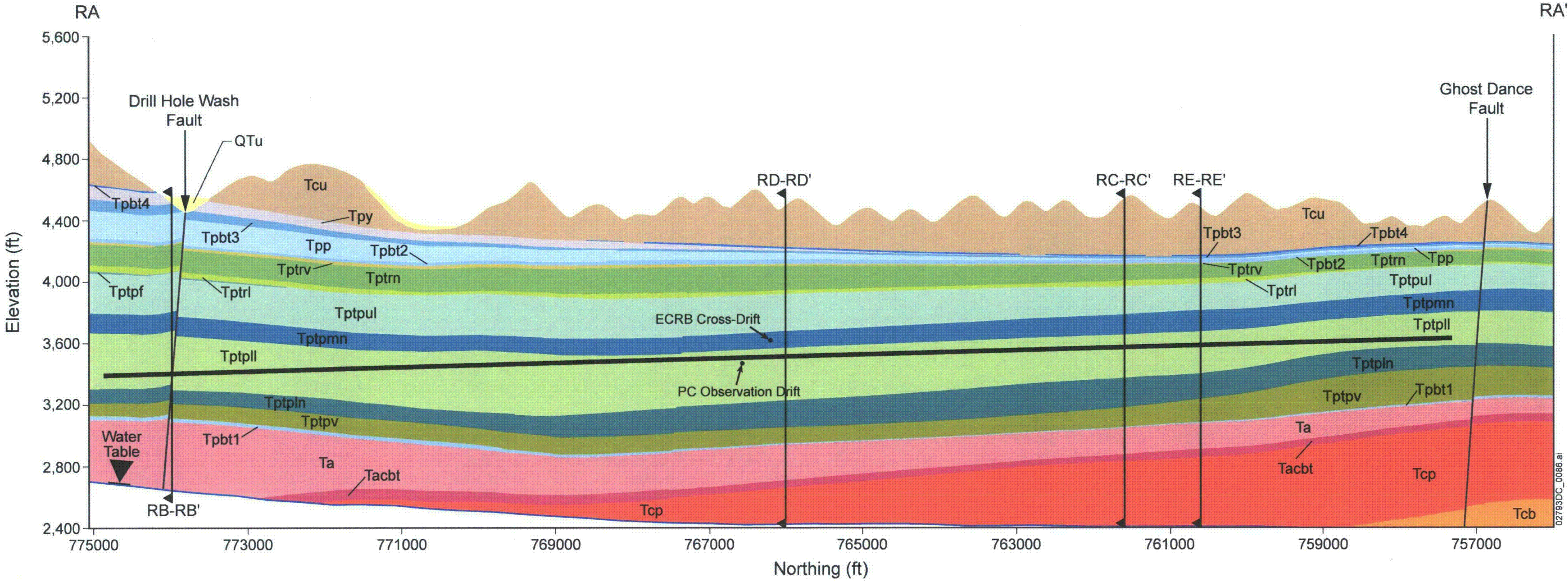

NOTE: Location of section RA–RA' is shown on Figure 1. Section extends from the surface to the top of the water table. Northing coordinates are Nevada State Plane (NAD27) in feet. The extent of subsurface geologic repository excavations is indicated by the black region within Tptpll. The ECRB Cross-Drift location is shown within Tptpmn. The Performance Confirmation Observation Drift location is shown within the Tptpll. Cross section RB–RB' is shown in Figure 6. Cross section RC–RC' is shown in Figure 7. Cross Section RD-RD' is shown in Figure 8. Cross Section RE-RE' is shown in Figure 9.
Vertical exaggeration is 2:1. Vertical scale is 1:7,200. Horizontal scale is 1:14,400.
QTu = undifferentiated Quaternary/Tertiary alluvium-colluvium; Tiva Canyon Tuff undivided (Tcu) = Rainier Mesa Tuff, post-Tiva Canyon bedded tuffs, and Tiva Canyon Tuff; Tpbt4 = pre-Tiva Canyon bedded tuffs; Tpy = Yucca Mountain Tuff; Tpbt3 = pre-Yucca Mountain bedded tuffs; Tpp = Pah Canyon Tuff; Tpbt2 = pre-Pah Canyon bedded tuffs; Tptrv = Topopah Spring Tuff crystal-rich member, vitric zone; Tptrn = Topopah Spring Tuff crystal-rich member, nonlithophysal zone; Tptrl = Topopah Spring Tuff crystal-rich member, lithophysal zone; Tptpf = Topopah Spring Tuff crystal-poor member, lithic-rich zone; Tptpul = Topopah Spring Tuff crystal-poor member, upper lithophysal zone; Tptpmn = Topopah Spring Tuff crystal-poor member, middle nonlithophysal zone; Tptpll = Topopah Spring Tuff crystal-poor member, lower lithophysal zone; Tptpln = Topopah Spring Tuff crystal-poor member, lower nonlithophysal zone; Tptpv = Topopah Spring Tuff crystal-poor member, vitric zone; Tpbt1 = pre-Topopah Spring bedded tuff; Ta = Calico Hills Formation; Tacbt = pre-Calico Hills bedded tuff; Tcp = Prow Pass Tuff; Tcb = Bullfrog Tuff.

Figure 5. Subsurface Geologic Repository Operations Area Geologic Cross Section RA–RA', Looking East

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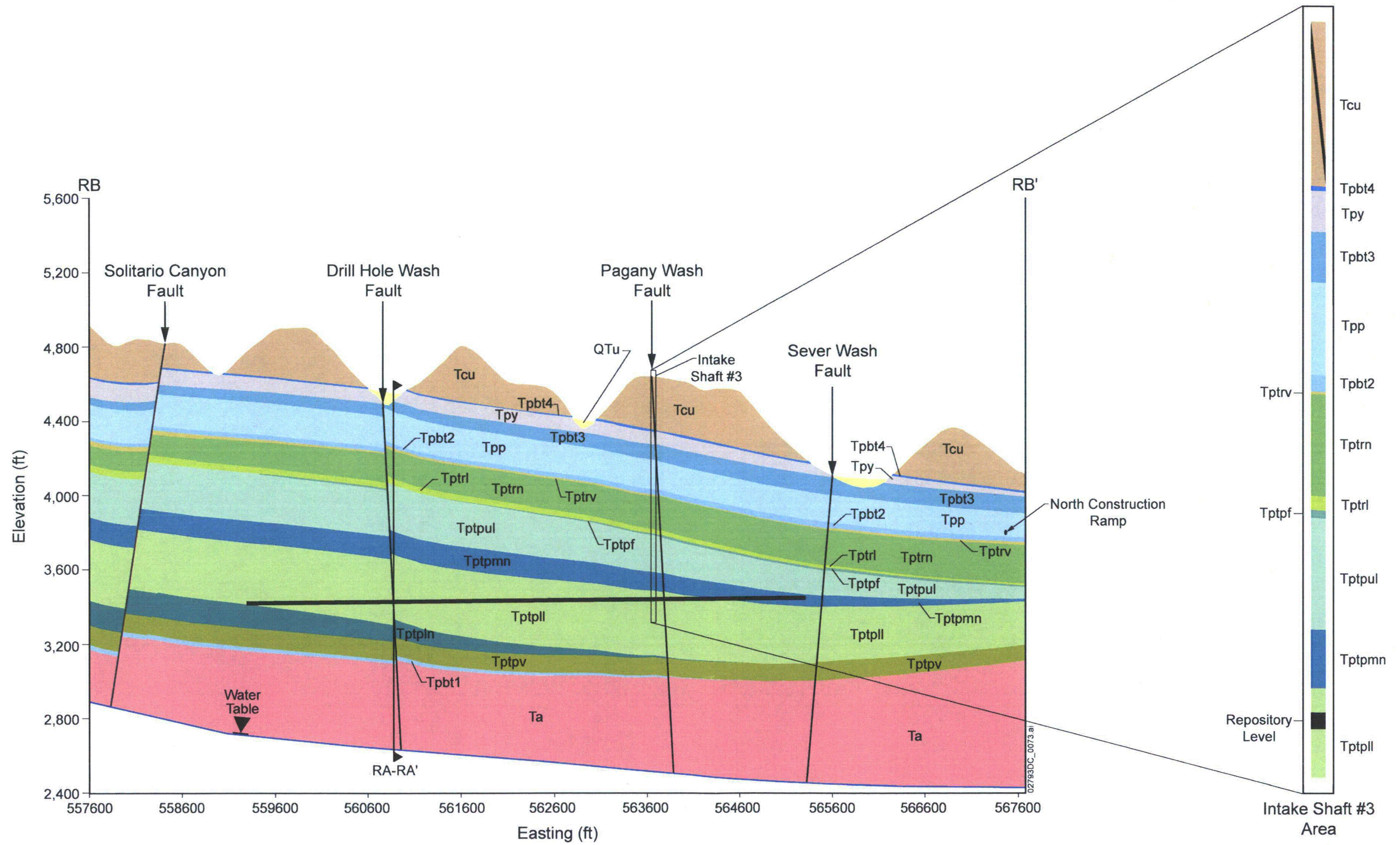

NOTE: Location of section RB–RB' is shown on Figure 1. Section extends from the surface to the top of the water table. Easting coordinates are Nevada State Plane (NAD27) in feet. The extent of subsurface geologic repository excavations is indicated by the black region within Tptpmn, Tptpll, and Tptpln. The North Construction Ramp location is shown within Tpp. Cross section RA–RA' is shown in Figure 5.
Vertical exaggeration of the cross section is 2:1. Vertical scale of the cross section is 1:7,200. Horizontal scale of the cross section is 1:14,400.
The inset shows a larger view of this section through the area of Intake Shaft #3. The repository level is indicated by the black region within Tptpll on the inset. The vertical exaggeration of the inset through Intake Shaft #3 is 1:1. The scale of the inset is 1:2,244.

Stratigraphic unit abbreviations are provided with Figure 5.

Figure 6. Subsurface Geologic Repository Operations Area Geologic Cross Section RB–RB', Looking North

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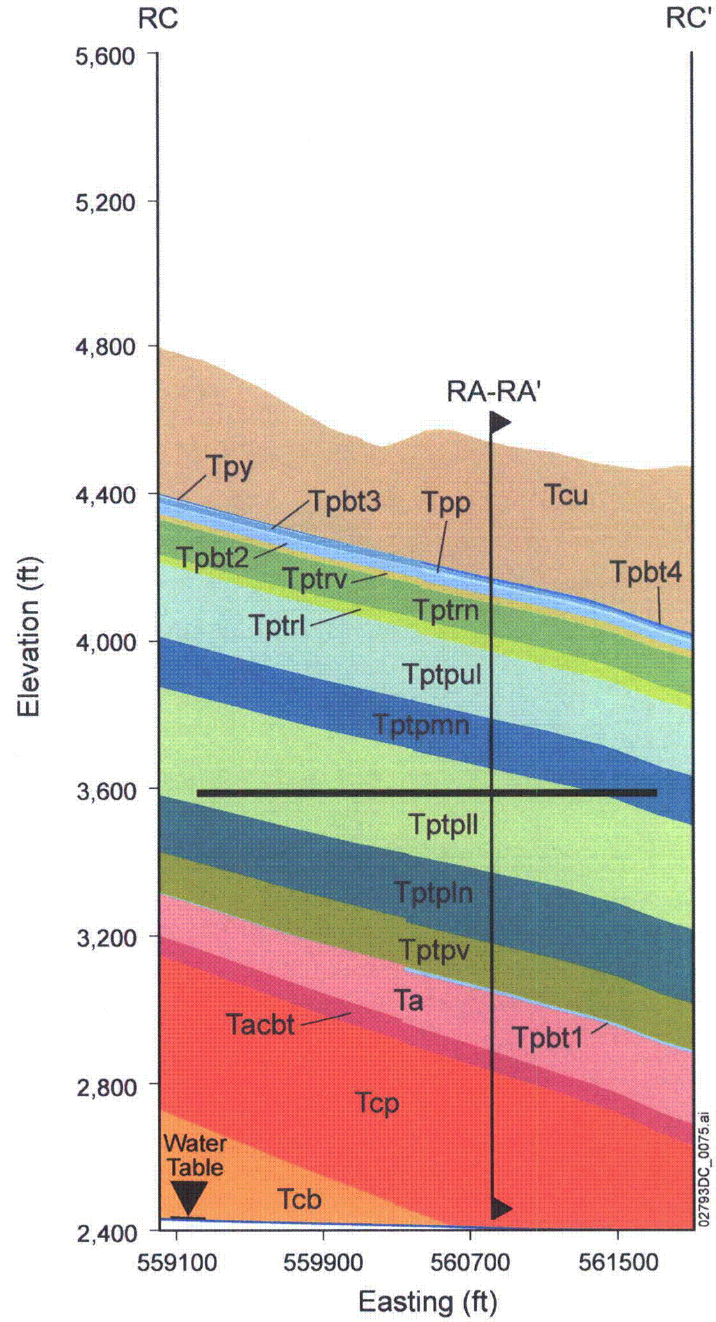

Figure 7. Subsurface Geologic Repository Operations Area Geologic Cross Section RC–RC', Looking North

NOTE: Location of section RC–RC' is shown on Figure 1. Section extends from the surface to the top of the water table. Easting coordinates are Nevada State Plane (NAD27) in feet. The extent of subsurface geologic repository excavations is indicated by the black region within Tptpmn and Tptpll. Cross section RA–RA' is shown in Figure 5.
Vertical exaggeration is 2:1. Vertical scale is 1:7,200. Horizontal scale is 1:14,400.
Stratigraphic unit abbreviations are provided with Figure 5.

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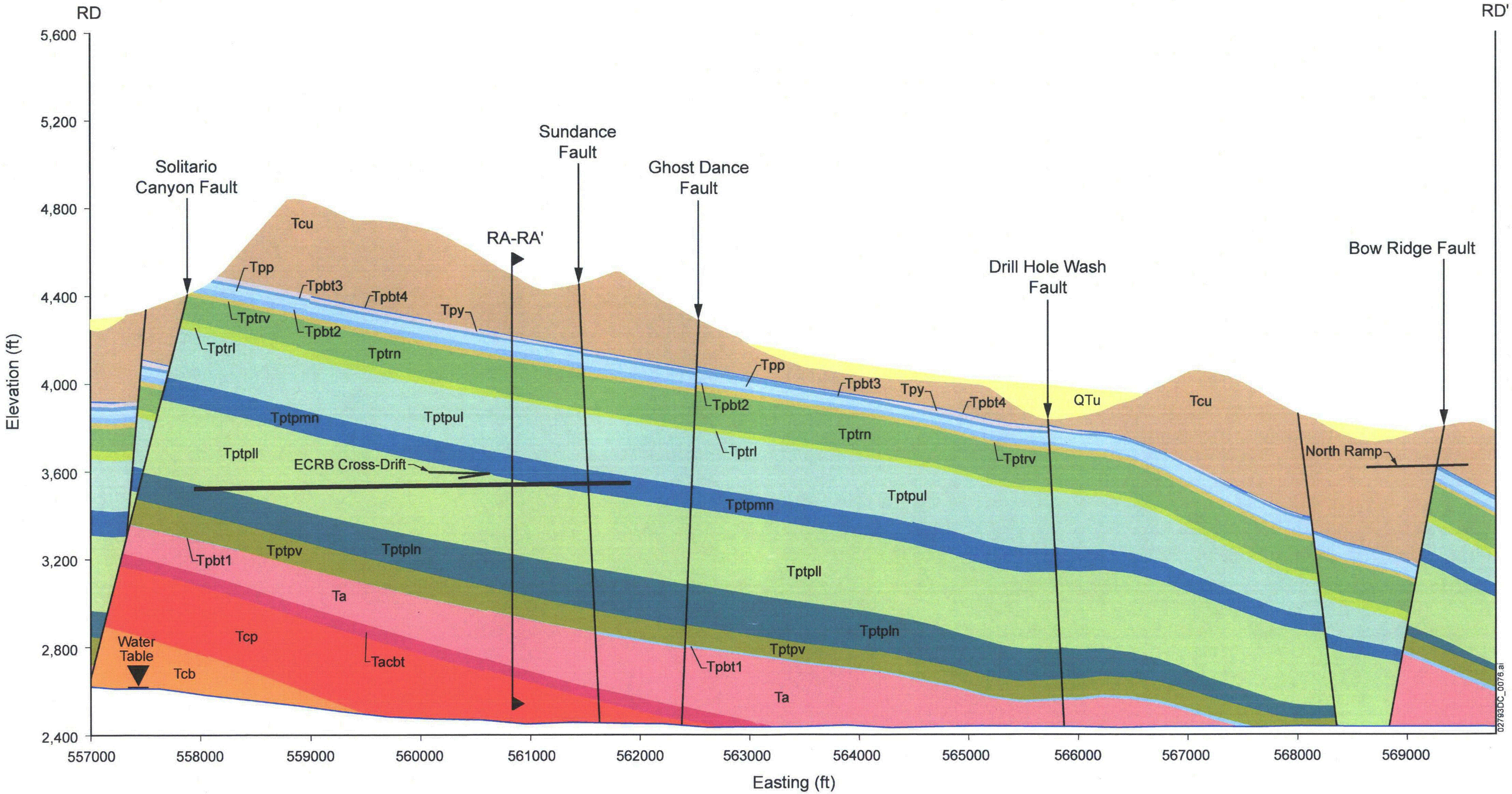

NOTE: Location of section RD–RD' is shown on Figure 1. Section extends from the surface to the top of the water table. Easting coordinates are Nevada State Plane (NAD27) in feet. The extent of subsurface geologic repository excavations is indicated by the black region within Tptpmn, Tptpll, and Tptpln. The North Construction Ramp location is shown within Tcu. Cross section RA–RA' is shown in Figure 5.
Vertical exaggeration of the cross section is 2:1. Vertical scale of the cross section is 1:7,200. Horizontal scale of the cross section is 1:14,400.

Stratigraphic unit abbreviations are provided with Figure 5.

Figure 8. Subsurface Geologic Repository Operations Area Geologic Cross Section RD–RD', Looking North

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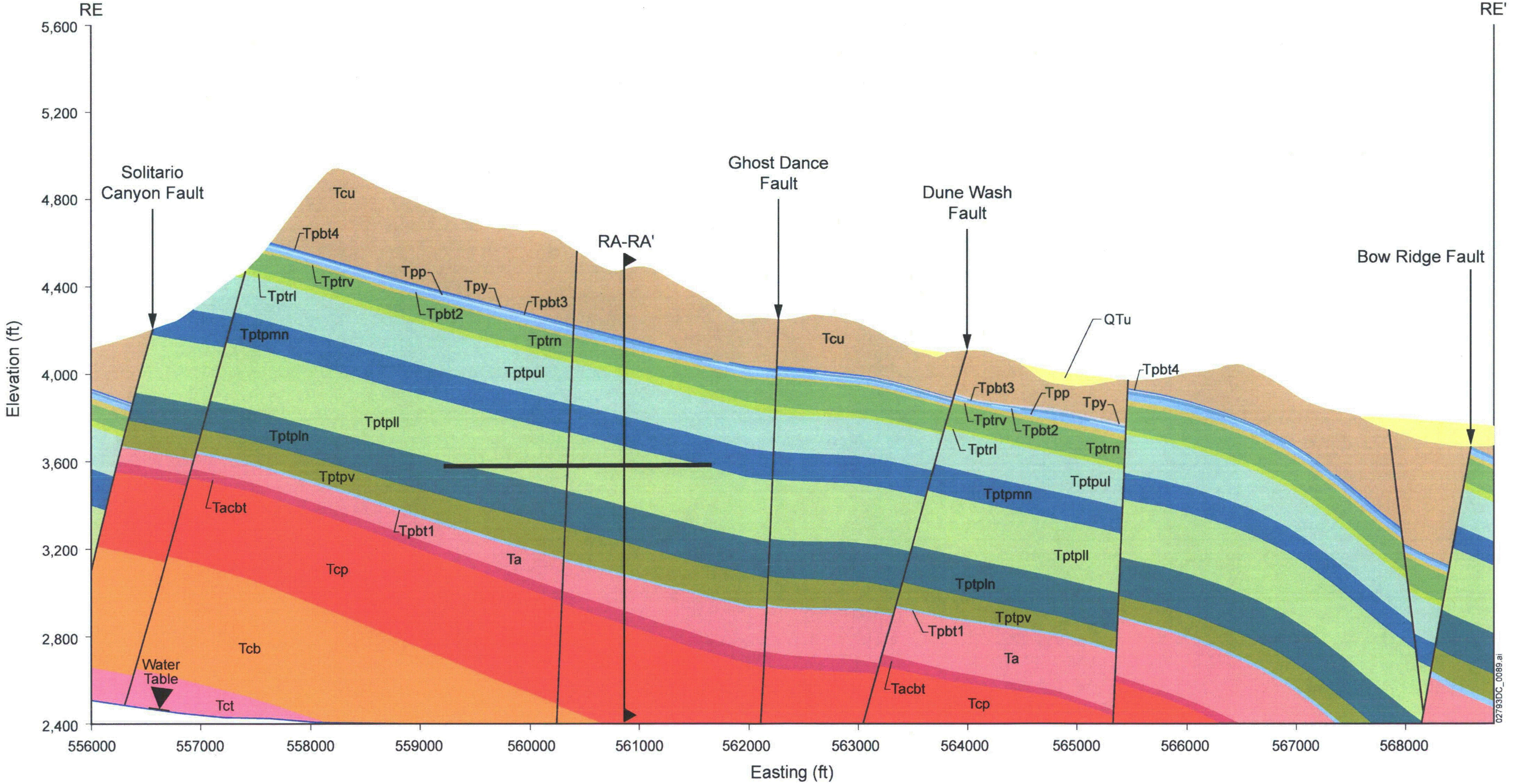

NOTE: Location of section RE–RE' is shown on Figure 1. Section extends from the surface to the top of the water table or to the intersection of 2,400 ft elevation. Easting coordinates are Nevada State Plane (NAD27) in feet. The extent of subsurface geologic repository excavations is indicated by the black region within Tptpmn, Tptpll, and Tptpln. Cross section RA–RA' is shown in Figure 5. Vertical exaggeration of the cross section is 2:1. Vertical scale of the cross section is 1:7,200. Horizontal scale of the cross section is 1:14,400.

Stratigraphic unit abbreviations are provided with Figure 5.

Figure 9. Subsurface Geologic Repository Operations Area Geologic Cross Section RE–RE', Looking North

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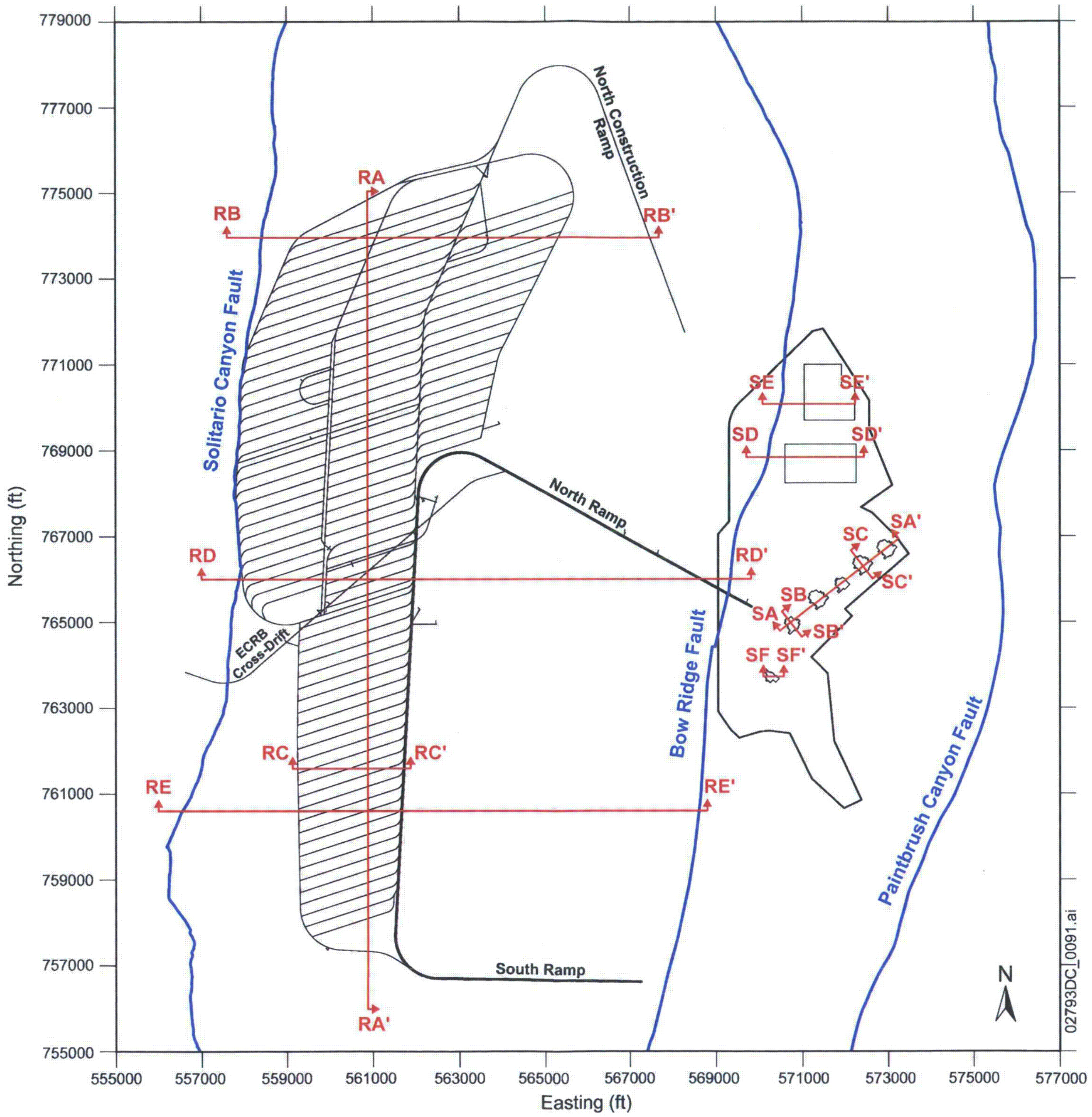

Figure 10. Current Index Map of the GROA Showing Quaternary Fault Traces with the Potential for Significant Displacement in Close Proximity to the GROA

NOTE: Fault traces are from the bedrock/alluvium interface projected on dip to the surface.

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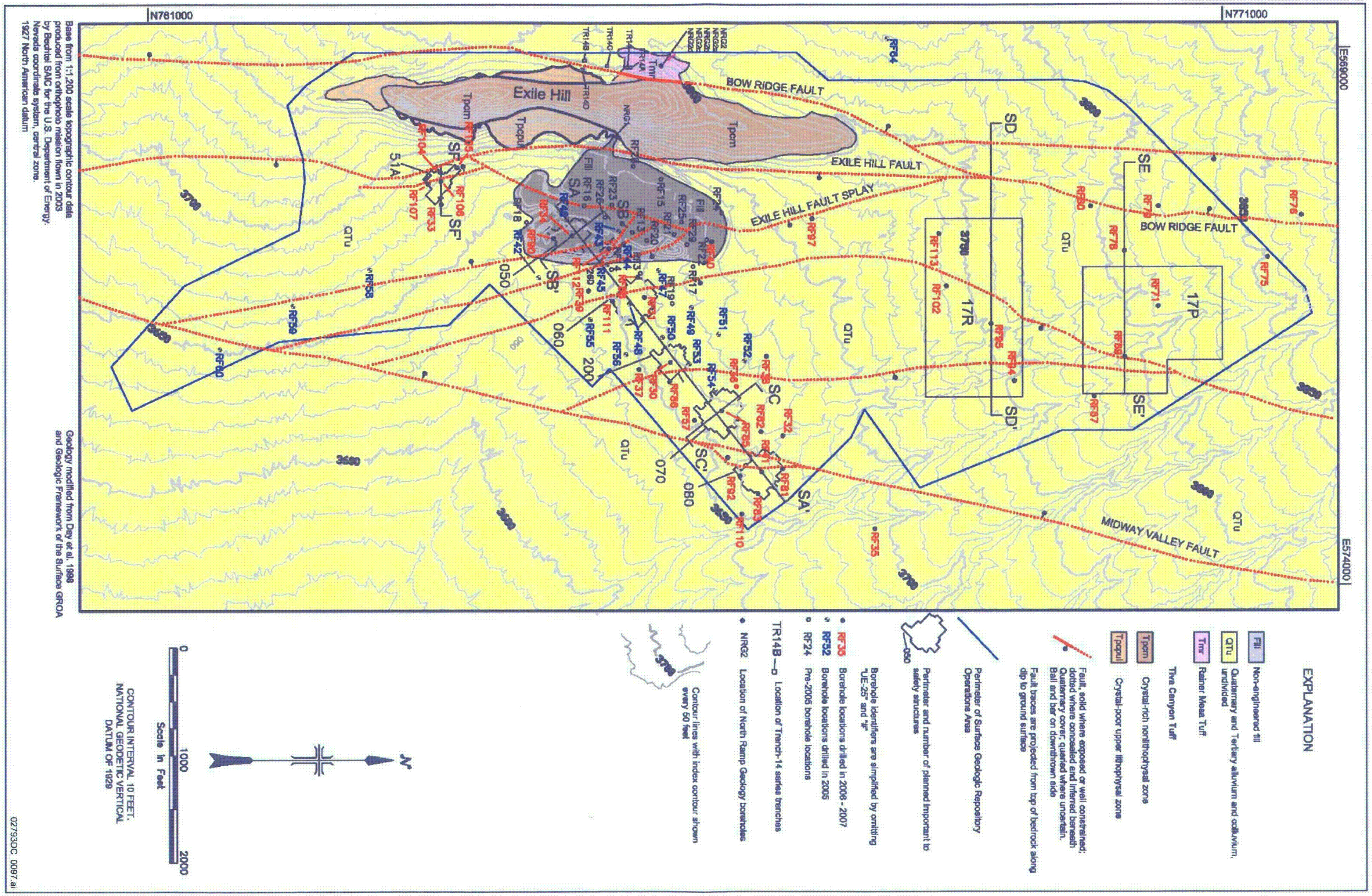

Figure 11. Geologic Map of the Surface Geologic Repository Operations Area with the Location of Six Geologic Cross Sections, Boreholes, and Planned ITS Structures

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