National Park Service

GCLA Bullfrog Launch Ramp
GLCA-220829

Preliminary Geotechnical Exploration
Final

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Prepared by:

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Acronyms and Abbreviations

Acronym	Definition
~	approximately
>	greater than
bgs	below ground surface
ID	identifier
Jacobs	Jacobs Government Services Company
NPS	National Park Service
pcf	pound(s) per cubic foot
psi	pound(s) per square inch
RQD	Rock Quality Designation
UCS	unconfined compressive strength

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Chapter 1 – Introduction

This report summarizes the preliminary geotechnical exploration that was conducted for the Glen Canyon Launch Ramp project. The National Park Service proposes to modify or relocate launch ramps at four visitor use areas within Glen Canyon National Recreation Area due to unprecedented low water conditions at Lake Powell in order to develop a rapid response plan to maintain boater access with resilient, long-term, engineered solutions. Users must continue to have access to Lake Powell for recreational activities. The launch ramps serve a public health and safety need to provide safe access to the water as well as protect impacts to natural resources by providing designated access points to the water. The original water elevation for Lake Powell was 3,700 feet. At the time of this report in early 2023, the water level has fallen to 3,522 feet. The Bullfrog Launch Ramp is being relocated from its existing location to the Stanton Creek Area due to low water.

This geotechnical exploration gathered geological and subsurface information at the proposed launch ramp site for the conceptual design and provides geotechnical data to the design-build contractors to assist in their response to the request for proposals for the Bullfrog Launch Ramp.

The exploration was conducted between December 10 and 13, 2022, and supervised by a Jacobs Government Services Company (Jacobs) geologist.

1.01 Project Scope

The Jacobs scope of this investigation included the following:

- Conduct a geotechnical exploration along the proposed launch ramp alignment where rock cuts are anticipated, to the approximate depth of the rock cut. This included advancing two rock core boreholes and collecting continuous rock cores to evaluate subsurface conditions.
- Install a standpipe piezometer to measure groundwater levels.
- Perform laboratory tests on selected rock core samples to measure the strength and stiffness properties of the rock.
- Conduct limited geologic mapping based on observations of outcrops to develop a conceptual geologic site model.
- Provide a summary of geologic observations, subsurface conditions, rock properties, and water levels observed on the site in a summary report.

Figures 1 and 2 show the current launch ramp concept in plan and section.

1.02 Limitations

The recommendations presented in this report are based on data obtained from surface observations of the geology, and borings that indicate subsurface conditions only at specific locations and times, and only to the depths penetrated. They do not necessarily reflect strata and water level variations that may exist between exploration locations or over time. If variations in subsurface conditions from those described are noted during construction, Jacobs should be notified and given an opportunity to review the design assumptions. In the event that any changes in the nature, design, or location of the components of this project are planned, the findings contained in this report should be reevaluated, and the recommendations of this report modified or verified in writing by Jacobs.

Figure 1. Launch Ramp Layout

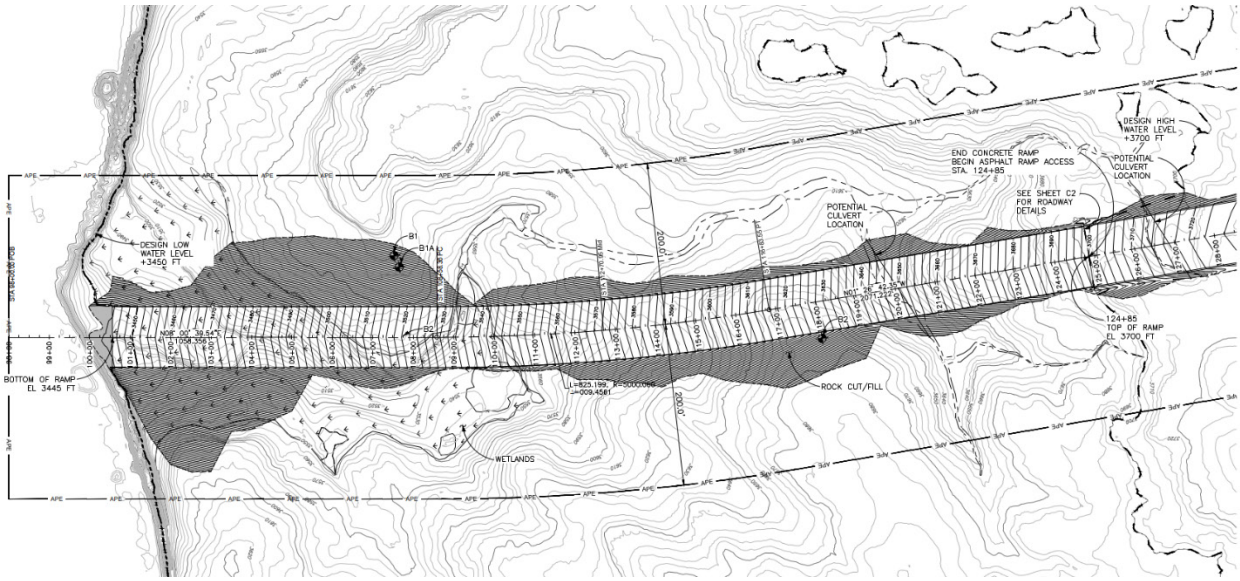
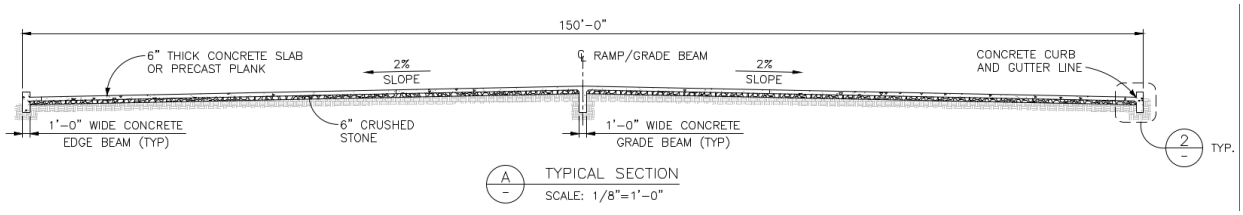


Figure 2. Launch Ramp Section



Chapter 2 – Geotechnical Exploration

2.01 Rock Core Holes

The drilling program consisted of advancing two rock core borings and installing one standpipe piezometer. The borings were located approximately in the deepest part of proposed rock cuts.

Appendix A shows the locations of the borings. The borings were advanced by Salisbury Associates, Inc. of Spokane, Washington. Borings were advanced using portable, componentized drilling equipment moved into place using an A-Star helicopter (Photographs 1, 2, 3, 4 in Appendix B). The drill was equipped with a triple-tube coring system to collect HQ-sized (2.4-inch-diameter) core samples. Where soil overburden was encountered (BH-01 only), an HWT casing advancer (5-inch-diameter) was used to advance a protective casing through the soil to the rock surface. The borings were advanced to depths ranging from 49.8 to 60 feet below ground surface (bgs). Table 1 summarizes the boring details.

Table 1. Borehole Summary

Boring ID	Latitude[a]	Longitude 1	Elevation (feet)	Total Depth (feet bgs)	Depth to Groundwater/ Elevation and Date[b]
GCLA BH-01	37.483613	-110.692905	3,585	40.0[c]	(not measured)
GCLA BH-01A	37.483634	-110.692822	3,582	60.0	~30'/3,552 (12/12/22)
GCLA BH-02	37.486390	-110.691858	3,672	49.8	(Not measured)

[a] Latitude, longitude, and ground surface elevations at boring locations were approximated and located using handheld Global Positioning System instrument.

[b] Measured after drilling on December 12, 2022.

[c] Drill rods became stuck in borehole and were abandoned in place.

~ = approximately

ID = identifier

A Jacobs professional geologist logged the borings. The rock core boring logs include lithology, Rock Quality Designation (RQD), rock hardness estimates, weathering, discontinuity descriptions, and other observations pertinent to the drilling and interpretation of the subsurface conditions. Appendix A provides the rock core logs, and Appendix C provides the rock core photographic log.

RQD and rock strength/ and hardness were measured for each core sample recovered. The RQD is calculated as the ratio of the sum of the length of core fragments longer than 4 inches to the total drilled footage per run, expressed as a percentage. Table 2 summarizes the rock mass classification based on RQD.

Table 2. Rock Quality Designation and Corresponding Rock Mass Classification

RQD (%)	Rock Mass Classification
0 to 25	Very Poor
25 to 50	Poor
50 to 75	Fair
75 to 90	Good
90 to 100	Excellent

Source: Deere and Deere 1989

Rock hardness is subjectively assessed in the field during drilling, based on qualitative parameters a series of field tests, and is used to estimate unconfined compressive strength (Table 3).

Table 3. Rock Hardness Scale

Grade	Description	Field Identification	Approximate Range of Unconfined Compressive Strength, (psi)
R0	Extremely weak rock	Specimen can be indented by thumbnail.	30 to 150
R1	Very weak rock	Specimen crumbles under firm blows with point of geologic pick; can be peeled by a pocket knife.	150 to 750
R2	Weak rock	Specimen can be peeled by a pocket knife with difficulty; shallow indentations made by firm blow of geological pick.	750 to 3,500
R3	Medium strong rock	Specimen cannot be scraped or peeled with a pocket knife; specimen can be fractured with single firm blow of hammer end of geological pick.	3,500 to 7,500
R4	Strong rock	Specimen required more than one blow with hammer end of pick to fracture it.	7,500 to 15,000
R5	Very strong rock	Specimen required many blows of hammer end of geological pick to fracture it.	15,000 to 35,000
R6	Extremely strong rock	Specimen can only be chipped with geological pick.	>35,000

Source: ISRM 1981
> = greater than
psi = pound(s) per square inch

2.02 Laboratory Testing

The geotechnical laboratory testing program consisted of measuring unconfined compressive strength and unit weight of the rock cores. GeoTek Inc. of Meridian, Idaho, conducted the laboratory testing. The laboratory testing program included the following:

- ASTM International D7012 (2017): Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures
- The dry unit weight of the cores was determined during the preparation of the cores for the unconfined compression testing

Core specimens for unconfined compression testing were selected to represent a range of rock types observed during the subsurface investigation. Appendix D provides the lab data sheets and stress-strain curves. Section 3 discusses the results of the unconfined compression testing.

Chapter 3 – Geologic Interpretations

3.01 Geologic Setting

The site is located in the Colorado Plateau geologic province, which is characterized by a thick sequence of sedimentary rock formations. In the project area, two rock formations are mapped: The Upper Carmel Formation, which overlies the Navajo Sandstone (Doelling and Willis 2007; Doelling et al. 1989) and the Navajo Sandstone:

- The Upper Carmel Formation is exposed along the access road alignment and down to the launch ramp vicinity. It is described as “reddish or brown slope-forming and earthy weathering silty sandstone or siltstone intercalated with sporadic irregular beds of white, calcareous fine-grained sandstone.” The thickness of this unit is approximately 50 to 70 feet. This description is consistent with the exposures in the project area.
- The Navajo Sandstone is the predominant rock type near the proposed launch ramp and is easily identified as the bare rock “slickrock” and forms the cliffs in Glen Canyon. This unit is described as “white, pink, and brown, highly cross-bedded sandstone that forms cliffs, domes, and bare rock outcrops.” This unit ranges from 950 to 2,000 feet thick and is considered an excellent aquifer.

Other geologic deposits in the vicinity of the launch ramp and access road include alluvial gravels (silt, sand, gravel, and cobble), scattered eolian deposits (windblown fine sand) and lacustrine sediments (clay, silt, and sand deposited in Lake Powell during high water levels; recently exposed on slopes and in drainage bottoms.

Structurally, the geologic units are relatively flat, but rest on the eastern limb of the northwest-trending Rock Spring Syncline; and thus the layers have a slight west-southwest dip. Field observations indicate the dip of the Upper Carmel Formation ranges from approximately 2 to 5 degrees in the area.

3.02 Local Geologic Mapping

Geologic mapping was conducted to supplement the information from the rock core borings, and gain an understanding of local geologic conditions that could influence slope stability and construction of access road and launch ramp. Appendix E provides a site geologic map of the BH-01/BH-01A and BH-02 areas. Appendix B provides a photolog that illustrates some of the geologic observations.

Key geologic features observed in the area of BH-01/BH-01A (Figure BH-01 in Appendix E) include:

1. The most notable geologic feature of this area is the smooth cross-bedded outcrops of Navajo Sandstone (Photograph 5 in Appendix B). This unit is fine-grained quartz sandstone formed from “cemented” sand dunes. Cross-beds are oriented in several directions and are truncated where the dunes migrated across

each other. The cross-beds dip from less than 10 degrees to 30 degrees. Some of the cross-beds with more degree of “cementation” form resistant ridges.

2. No predominant joint set or faults were observed in the vicinity that would influence rock slope stability. The Navajo Sandstone typically is a cliff-forming unit where eroded by streams and exposed in rock cuts. However, some vertical joints were observed in aerial photographs in the area that likely facilitate cliff formation. No steep joints were observed that would reduce the stability of the east-facing rock cut slope.

3. The Navajo Sandstone is considered an “excellent aquifer” due to its primary porosity, sandstone lithology, and fracturing. While the primary permeability through the intergranular porosity of the sandstone is significant, secondary fracturing greatly enhances this permeability by more than an order of magnitude. Numerous zones of seepage from the sandstone were observed. This feature is interpreted to be a function of decades of saturation from inundation by Lake Powell. As the lake level has receded over the years, the water is slowly discharging from the sandstone. A few very distinct “springs” were observed, and in general, the sandstone appears to be saturated all along the present lake shoreline and wet, crumbly rock was evident. A rock cut slope in this material will be subjected to wave erosion as lake levels fluctuate, and also seasonal freeze-thaw. The saturated lower portions of the slope thus may weather more rapidly, resulting in “undermining” of the rock cut.

Key geologic features observed near BH-02 (Figure BH-02 in Appendix E) include:

1. BH-02 was located on a flat shelf, which is below the reservoir’s high pool elevation The predominant geologic feature near BH-02 is the contact of the Navajo Sandstone and the Upper Carmel Formation (Photograph 7 in Appendix A). These two units have very different geologic characteristics. The Navajo Sandstone, as described previously, typically weathers to smooth outcrops and domes. The Upper Carmel, however, contains interbedded sandstone, siltstone, and claystone with different hardness and weathering rates. This formation thus forms distinctive benches in the topography, where the resistant sandstone layers form ledges, and the weaker siltstone and claystone weather more rapidly into flatter slopes (Photograph 8 in Appendix A).

2. In the BH-02 area, the sandstone layers show on the aerial photographs as lighter tan-colored whereas the siltstones and claystones are dark reddish. Note that the reddish, weaker layers are flatter because of more rapid weathering, and the tan sandstones are ledge-forming. Also, layers reddish sediment from weathering of siltstone and claystone and redeposition underwater mantle the slopes.

3. The flat stratigraphic layering allowed field-based dip estimates of the layers. The layers dip approximately 2 to 5 degrees to the west-southwest (toward the axis of the Rock Springs syncline). The weaker claystones will hence “daylight” out of the west-facing cut slope. At such a low angle (e.g., less than 5 degrees), it does not appear that these would be a major factor in planar failure. However, the strength properties of weak layers should be evaluated in cut slope design.

4. Because the weaker claystone and thinly bedded siltstone layers weather more rapidly than the resistant sandstone layers, large rockfalls of sandstone blocks are prevalent in the vicinity (Photographs 9 and 10 in Appendix A). These rockfalls are easily visible on the geologic map. The size of the rockfall blocks varies due to the spacing and intersections of vertical joints in the sandstone. Most notably, some of these fallen blocks are 6 feet by 6 feet by 3 feet in dimension and could weigh 8 tons or more. However, even 1 foot by 2 feet rock blocks would pose a severe safety hazard. Rockfall is anticipated to be a concern, as 25 to 30 feet of the Upper Carmel Formation will be exposed in the west-facing rock cut slope. This cut slope will be under water at high lake levels, which will exacerbate the differential erosion and resultant rockfalls (Photographs 11 and 12 in Appendix B).

3.03 Subsurface Conditions

3.03.1 Rock Core Characteristics

General subsurface conditions at the project site consist of a interbedded sandstone and siltstone with occasional claystone layers (Upper Carmel Formation) overlying massive cross-bedded quartz sandstone (Navajo Formation). Borings BH-01 and BH-01A were drilled entirely within the Navajo Sandstone. Boring BH-02 was drilled at a higher elevation, and the contact between the bottom of the Upper Carmel and the top of the Navajo Sandstone was encountered within the lower portion of this boring.

Rock Core Boring BH-01

Boring BH-01 was drilled to a depth of 40 feet bgs in a proposed east-facing rock cut in the Navajo Sandstone at approximately Station 107+75, 135 feet left. At a depth of 40 feet bgs, the rods became “sanded in” and thus had to be abandoned in place. The drill rig was moved approximately 20 feet to the northeast, where borehole BH-01A was advanced to a depth of 60 feet bgs.

Rock in boring BH-01/BH-01A consisted primarily of pink to tan, fine-grained, quartz sandstone (Appendix C). The RQD in the upper 40 feet ranged from 0 to 16 percent, which indicates very poor rock mass. The natural fractures were often parallel to the cross-bedded surfaces that dipped 5 to 30 degrees. The predominant “discontinuity,” however, was horizontal mechanical breaks (often several mechanical breaks per foot), which reduced the RQD.

From 40 to 60 feet in depth, RQD ranged from 30 to 54 percent, which indicated poor rock mass. Again, numerous horizontal mechanical breaks were observed, along with 10 to 15 degree dipping fractures on cross-bedding.

Rock hardness was field estimated to be predominantly R2, which equates to “weak rock” with an estimated compressive strength between 1,000 and 3,500 psi. The field measurements largely correlated with the lab test results (see Rock Core Boring BH-02 section).

Occasional fractured or rubbleized zones were observed in this rock, but overall the Navajo Sandstone is weak to medium strong, poor to fair quality rock mass.

Rock Core Boring BH-02

Boring BH-02 was drilled to a depth of 49.8 feet bgs in a proposed west-facing rock cut at approximately Station 117+50, 75 feet right. The drill was set on a flat weathered rock and sediment surface. Depth to hard rock was approximately 1 foot. The lithology of the upper 40 feet in this borehole consisted primarily of a sequence of interbedded muddy sandstone, dark red laminated and thinly bedded siltstone, dark red silty claystone, tan to pink sandstone of the Upper Carmel Formation (Appendix C). A layer of dark red claystone was observed at 39.2 to 40 feet—this is interpreted to be the contact of the Carmel Formation with the underlying Navajo Sandstone.

Because of the interbedding in the stratigraphy, the RQD varied accordingly. In the thinly bedded weaker siltstone layers, the RQD typically indicated very poor rock mass, However, in the more resistant sandstone beds, RQD ranged from 60 to 90 percent, indicating fair to good rock mass.

Also, accordingly, the rock hardness varied with lithology. The silty claystone was estimated to be R1 to R2 hardness (very weak to weak rock), whereas the siltstone and sandstone were estimated to be generally in the R2 to R3 range (weak to medium strong rock).

Below 40 feet, the lithology was primarily tan to pink, fine-grained quartz sandstone (contact of the Navajo Sandstone at elevation approximately 3,632 feet in this boring). This rock was poor to very poor rock mass, with several horizontal drill breaks, a hardness estimated to be mostly R2, with a few crumbly to rubbly zones observed.

3.03.2 Unconfined Compressive Strength

Table 4 shows the results of the unconfined compressive strength (UCS) testing on the rock cores. A total of six core specimens were tested, three from each borehole. Overall the samples suitable for core testing were quite uniform, and as such the range of UCS is relatively small. Rock core holes BH-01/BH-01A consisted entirely of uniform Navajo Sandstone, with cores selected based on minor lithologic variations and long enough to meet the 2:1 length:width ratio (L=2D) for testing (numerous mechanical breaks were present in the cores, as such the number of cores available for testing was low).

The upper 25 feet of BH-02 was advanced in the Upper Carmel Formation, which consisted of interbedded sandstone and thinly bedded siltstone. As such, numerous bedding-plane separations resulted in very few core samples with appropriate L=2D ratio. Only one sample of relatively strong siltstone was tested in the upper 25 feet in BH-02.

The compressive strength the sandstone/siltstone ranged from 1,420 to 3,495 pounds per square inch (psi), which indicates “weak rock” with a hardness of R2. These results are consistent with the field estimates of rock hardness. The construction considerations of the rock strength are described below.

The moist unit weights of the core specimens ranged from 137.9 to 164.1 pounds per cubic foot (pcf), which is within the range of typical sandstone and siltstone; although any values greater than 150 pcf would be considered on the dense side. The unit weight is influenced by degree of weathering, porosity, secondary mineralization, depositional characteristics, and saturation. Considering all of these rock samples were under high water for decades, it is conceivable they contain relic saturation that resulted in higher unit weight values than would be anticipated above the groundwater table.

Table 4. Summary of Laboratory Strength Test Results

Boring	HQ-Run	Depth (feet)	Rock Classification	UCS (psi)	Moist Unit Weight (pcf)
BH-01	HQ-8A	35	Quartz sandstone	2,405	137.9
BH-01A	HQ-11	53	Quartz sandstone	1,885	146.0
BH-01A	HQ-12	58	Quartz sandstone	2,630	153.3
BH-02	HQ-10	22	Muddy sandstone	3,495	149.9
BH-02	HQ-12	33	Siltstone	2,685	164.1
BH-02	HQ-15	44	Weak sandstone	1,420	157.2

3.03.3 Groundwater Conditions

After the completion of rock core boring BH-01A, a 1-inch polyvinyl chloride standpipe piezometer with a pre-packed screen was installed in order to measure groundwater levels. A sandpack consisting of 10-20 Colorado Silica Sand was placed to 2 feet above the screen interval, and the remainder of the annular space was backfilled with bentonite pellets. The piezometer was completed with an aboveground steel monument for protection.

The depth to water was approximately 30 feet below ground surface (approximate elevation of 3,552 feet). At the time of drilling, Lake Powell was at an elevation of 3,528.78 (December 12, 2022). Note that the water level was measured immediately after drilling and piezometer installation; and therefore the water needs to be remeasured after it has had time to stabilize; and also to observe how the water levels change with seasons and respond to fluctuating reservoir levels.

Chapter 4 – Recommendations and Construction Considerations

Based on the results of the preliminary investigation, the following list outlines recommendations and construction considerations. The selected Design-Build Contractor will ultimately be the engineer of record for this project and will evaluate the findings and recommendations of this report and conduct additional investigations as needed to develop the final design.

1. ***Rock cut slopes:*** Rock cuts should be able to be excavated steeper than 2H:1V, based on the results of the preliminary geologic mapping and rock core borings. The upper rock cut slopes at BH-02 will expose interbedded sandstone and siltstone with claystone layers dipping less than 5 degrees. Existing slopes in similar material in the area are cut at approximately 0.5H:1V. However, slopes near the reservoir pool elevation may exhibit large variations in erosional rates due to changing levels of saturation. It is recommended that rock catch ditches will be implemented into the design to retain surficial rockfall and erosion (Photographs 11 and 13 in Appendix B).

   Rock cut slopes along the lower part of the proposed ramp from approximately Stations 118+50 to 0+00 will expose primarily massive sandstone. The Navajo Sandstone was formed as ancient migrating dune fields and is not densely jointed in the area (Photograph 14 and 15). Based on existing slopes in Navajo Sandstone, slopes can be cut steeply (for example, local vertical-walled “slot canyons” and vertical to overhanging cliffs several hundred feet high that form the heart of Glen Canyon are eroded in the Navajo Sandstone). However, any rock cut slopes below ultimate high water mark that will be subjected to wetting or drying as the reservoir level fluctuates, wave erosion from rigs or boats going in and out of the ramp, and freezing or thawing cycles, could be subject to accelerated erosion and weathering.

   In addition to rock catch ditches, erosion protection such as shotcrete, rock bolts, anchored mesh, or similar may be required to minimize excessive erosion in both the Navajo and Carmel Formations. Given the fluctuations in water levels, surface protection methods should include considerations of drainage.

   Rock anchors are not anticipated to be required for global stability, given that the bedrock formation is massive to roughly horizontally layered strata. However, accelerated erosion and undermining on the parts of slopes that will be subjected to the listed elements may require rock anchor stabilization. Erosion will trigger rockfalls local toppling failures, and during the excavation for the launch ramp rock instability should be evaluated by a geologist and unstable blocks may need to be removed or anchored.

   Springs were observed to emanate from the Navajo Sandstone along launch ramp centerline near the reservoir (Photographs 16, 17, and 18 in Appendix B). In addition, the Navajo Sandstone close to the reservoir appears to be saturated and weeping to actively draining. Slope drainage where seepage is observed will be required, and can use the rock catch ditch, but may also require the installation of drains to relieve pore pressure for design of a stable final cut slope.

2. ***Rippability:*** Field and laboratory testing of rock specimens and exposures indicates UCS ranging from around 2,000 to 4,000 psi, with occasional stronger rock and also "crumbly" zones weathered to more sandy material. The samples that are tested are generally the more competent material, so these are close to the upper bound strength values that are anticipated. This material should be readily rippable, based on estimated UCS and published rippability charts. Note that the Navajo Sandstone exposed below elevation approximately 3,640 feet is not jointed (joints generally help with ripping), but the rock should still be rippable based on strength.

3. ***Utility Trenches:*** The terrain along the proposed access road consists of upland areas of eolian (windblown) sand, alluvial gravel, and general soil cover along beginning of the road to about Station 197. The thickness of this sand and gravel will be highly variable, and is expected to be thin (less than 1 foot) to absent in some areas, and thus shallow rock is exposed. As the road approaches the more eroded areas and former inundated zones past approximately Station 197 down to the lake, the terrain consists of primarily stratified sandstone and siltstone with little (maybe 1 or 2 feet) to no soil cover, and numerous areas of exposed rock. The drainage bottoms generally have alluvial soils deposited in them.
   - For preliminary engineering estimates, from Station 302 to 197, consider 75% conventional trenching (soil or overburden) and 25% rock trenching.
   - For preliminary engineering estimates, from Station 197 to the end of the launch ramp, consider 90% rock trenching and 10% soil or overburden excavation.

Figure 3. Rock Trenching along Road Alignment

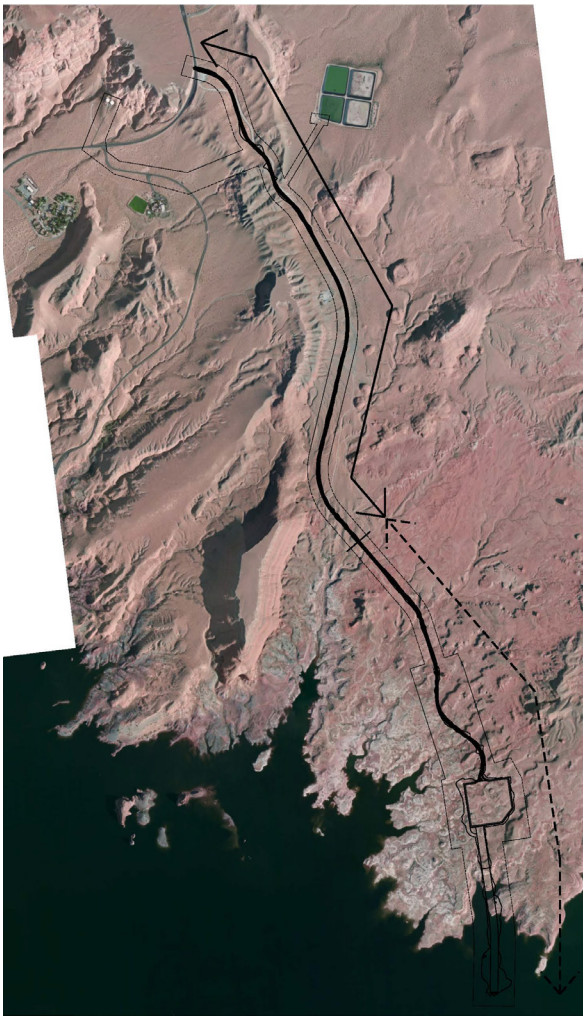


Figure 3 shows the road alignment adjacent to solid line arrow primarily soil-covered; and along dashed line arrow is primarily rock exposure.

4. ***Base rock and concrete aggregate:*** The onsite bedrock consists of weak sandstone and siltstone that is erodible and exhibits very low durability characteristics. Any processing of this material in an attempt to make aggregate or crushed stone will result in a silt/sand mixture. As such, the onsite bedrock is not suitable for U.S. Department of Transportation specifications or an aggregate source for base rock or concrete aggregate.

5. ***Recommendations for future explorations.***

   Future explorations may be needed to support the Design-Build designer, and may consist of the following, or other explorations:

   - Excavation of test pits along the access road to evaluate overburden thickness and material types. Collect soil samples for laboratory testing of soils to evaluate suitability for general fill materials.
   - Depending on the rock cut slope design, additional rock coring and rock discontinuity mapping may be required to evaluate suitable rock cut slope angles.
   - Depending on the cut slope erosion protection design, durability testing on rock cores and samples to evaluate erosion rates may be needed for the erosion protection design for the slopes.
   - Continued groundwater level measurements to obtain groundwater data and correlate changes in groundwater levels with seasons and changes in reservoir level.
   - Material source investigation to locate appropriate aggregate sources with sufficient volumes of durable rock to be used for road mix, ballast, or concrete aggregate.

Chapter 5 – References

ASTM International. 2017. ASTM D7012-14e1, Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures. August 14. https://www.astm.org/d7012-14e01.html.

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Doelling, H.H., and G.C. Willis. 2007. Geologic map of the lower Escalante River area, Glen Canyon National Recreation Area, eastern Kane County, Utah: Utah Geological Survey, Miscellaneous Publication 06-3DM, scale 1:100,000.

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Appendix A – Rock Core Boring Logs

PROJECT NUMBER:	BORING NUMBER:	SHEET:
D3167645 A.P3.OE.S1	BH-01/1A	1 of 3

ROCK CORE LOG

PROJECT : Glen Canyon Lake Access
LOCATION : Bullfrog Marina
ELEVATION : 3,582 ft asl
DRILLING CONTRACTOR : Salisbury and Associates (SAI)
DRILLING METHOD AND EQUIPMENT :
WATER LEVELS : 30 ft bgs (12/12/22)
START : 12/12/22
END : 12/13/22
LOGGER : G. Warren, P. G.

DEPTH BELOW SURFACE (FT)	CORE RUN, LENGTH, AND RECOVERY (%)	DISCONTINUITIES: R Q D (%)	DISCONTINUITIES: FRACTURES PER FT	DISCONTINUITIES: DESCRIPTION (DEPTH, TYPE, ORIENTATION, ROUGHNESS, PLANARITY, INFILLING MATERIAL AND THICKNESS, SURFACE STAINING, AND TIGHTNESS)	GRAPHIC LOG	LITHOLOGY (ROCK TYPE, COLOR, MINERALOGY, TEXTURE, WEATHERING, HARDNESS, AND ROCK MASS CHARACTERISTICS)	COMMENTS (SIZE AND DEPTH OF CASING, FLUID LOSS, CORING RATE AND SMOOTHNESS, CAVING ROD DROPS, TEST RESULTS, ETC.)
	HQ-1 40% 5.0	0				Sandstone, pink, fine-grained, quartz (Navajo Formation), H = R0 to R1, some areas completely weathered to sand, very poor rock mass quality	HQ CORE
5	HQ-2 86% 10.0	0		Fractures 5-10/ft, some horizontal, some on cross-bedding at 25 - 30 degrees Fracture zone at 7.8'		Sandstone, pink, cross-bedded, fine-grained, quartz (Navajo Formation), H = R1 to R2, moderately to highly weathered very poor rock mass quality	
10	HQ-3 86% 15.0	0		4 Fractures/ft, most are horizontal mechanical breaks, some on cross-bedding at 5 degrees		continued Sandstone, pink, cross-bedded, fine-grained, quartz (Navajo Formation), H = R2, moderately to highly weathered very poor rock mass quality	
15	HQ-4 92% 20.0	8		4-7 fractures/ft, mostly horizontal drill/mechanical breaks, others 20 - 45 degrees, undulating, smooth, sandy to clean coating Rubble zone at 17.4'		continued Sandstone, pink, fine-grained, quartz (Navajo Formation), H = R2, moderately weathered, very poor rock mass quality	
20	HQ-5 96% 25.0	16		20.8': 45 degrees, planar, smooth, clean 3-5 fractures/ft, mostly horizontal drill/mechanical breaks		continued Sandstone, pink, fine-grained, quartz, H = R1 to R2, slightly to moderately weathered, very poor rock mass quality	

PROJECT NUMBER:	BORING NUMBER:	SHEET:
D3167645 A.P3.OE.S1	BH-01/1A	2 of 3

ROCK CORE LOG

PROJECT : Glen Canyon Lake Access
LOCATION : Bullfrog Marina
ELEVATION : 3,582 ft asl
DRILLING CONTRACTOR : Salisbury and Associates (SAI)
DRILLING METHOD AND EQUIPMENT :
WATER LEVELS : 30 ft bgs (12/12/22)
START : 12/12/22
END : 12/13/22
LOGGER : G. Warren, P. G.

DEPTH BELOW SURFACE (FT)	CORE RUN, LENGTH, AND RECOVERY (%)	DISCONTINUITIES: R Q D (%)	DISCONTINUITIES: FRACTURES PER FT	DISCONTINUITIES: DESCRIPTION (DEPTH, TYPE, ORIENTATION, ROUGHNESS, PLANARITY, INFILLING MATERIAL AND THICKNESS, SURFACE STAINING, AND TIGHTNESS)	GRAPHIC LOG	LITHOLOGY (ROCK TYPE, COLOR, MINERALOGY, TEXTURE, WEATHERING, HARDNESS, AND ROCK MASS CHARACTERISTICS)	COMMENTS (SIZE AND DEPTH OF CASING, FLUID LOSS, CORING RATE AND SMOOTHNESS, CAVING ROD DROPS, TEST RESULTS, ETC.)
	HQ-6 68%	0		6-7 Fractures/ft, cont. horizontal mechanical breaks, surfaces are planar, rough, clean with some sand filling Fractured 28 - 30'		cont. Sandstone, like above More broken/fractured from 28 to 30 ft	HQ CORE
30.0							
30	HQ-7 90%	0		Fracture zone at 31.3 4-5 Fractures /ft, drill breaks, rough/undulating, clean to sandy		cont. Sandstone, like above, H = R1 to R2, moderately to highly weathered very poor rock mass quality	UCS Sample BH-01B Q_u = 2,405 psi γ = 137.9 pcf
35.0							
35	HQ-8 100%	81		0-3 Fractures/ft, some on cross-bedding at 15 degrees, horiz breaks at 37.5, 37.8, 38.2, 38.5, 38.8, 39.6		Sandstone, pink, fine-grained, quartz (Navajo Formation), H = R2, fresh to slightly weathered, good rock mass quality	
40.0							
40	HQ-9 98%	40		horizontal drill/mechanical breaks, 10 - 15 degrees on cross bedding, planar, smooth, clean		cont. Sandstone, pink, cross bedded, fine-grained, quartz (Navajo Formation), H = R2, fresh to slightly weathered, poor rock mass quality (probably because of mechanical breaks)	
45.0							
45	HQ-10 90%	38		horizontal drill/mechanical breaks throughout, core pieces spinning		cont. Sandstone, pink, cross bedded, fine-grained, quartz (Navajo Formation), H = R2, fresh to slightly weathered, poor rock mass quality (probably because of mechanical breaks)	
50.0							

PROJECT NUMBER:	BORING NUMBER:	SHEET:
D3167645 A.P3.OE.S1	BH-01/1A	3 of 3

ROCK CORE LOG

PROJECT : Glen Canyon Lake Access
LOCATION : Bullfrog Marina
ELEVATION : 3,582 ft asl
DRILLING CONTRACTOR : Salisbury and Associates (SAI)
DRILLING METHOD AND EQUIPMENT :
WATER LEVELS : 30 ft bgs (12/12/22)
START : 12/12/22
END : 12/13/22
LOGGER : G. Warren, P. G.

DEPTH BELOW SURFACE (FT)	CORE RUN, LENGTH, AND RECOVERY (%)	DISCONTINUITIES: R Q D (%)	DISCONTINUITIES: FRACTURES PER FT	DISCONTINUITIES: DESCRIPTION (DEPTH, TYPE, ORIENTATION, ROUGHNESS, PLANARITY, INFILLING MATERIAL AND THICKNESS, SURFACE STAINING, AND TIGHTNESS)	GRAPHIC LOG	LITHOLOGY (ROCK TYPE, COLOR, MINERALOGY, TEXTURE, WEATHERING, HARDNESS, AND ROCK MASS CHARACTERISTICS)	COMMENTS (SIZE AND DEPTH OF CASING, FLUID LOSS, CORING RATE AND SMOOTHNESS, CAVING ROD DROPS, TEST RESULTS, ETC.)
	HQ-11 100%	30		cont. horizontal mechanical breaks, evenly distributed, occ. 10 to 15 degree fractures on cross bedding, planar, smooth to undulating		cont. Sandstone, like above, pink, fine-grained, quartz, H = R2, fresh to slightly weathered, poor rock mass quality	HQ CORE UCS Sample BH-01A Q_u = 1,885 psi γ = 146.0 pcf
55	55.0						
	HQ-12 98%	54		57.2': 10 degrees, planar rough clean Rubble zone at 58' (0.2 feet thick) Rubble zone at 59.1' (0.2 feet thick)		cont. Sandstone, like above, pink, fine-grained, quartz, H = R2, fresh to slightly weathered, poor rock mass quality	T. D. = 60 feet, install 1" standpipe piezometer with screen from 40-60 feet
60	60.0						
65							
70							

PROJECT NUMBER:	BORING NUMBER:	SHEET:
D3167645 A.P3.OE.S1	BH-02	1 of 2

ROCK CORE LOG

PROJECT : Glen Canyon Lake Access
LOCATION : Bullfrog Marina
ELEVATION : 3,672 ft asl
DRILLING CONTRACTOR : Salisbury and Associates (SAI)
DRILLING METHOD AND EQUIPMENT :
WATER LEVELS : not measured
START : 12/10/22
END : 12/11/22
LOGGER : G. Warren, P. G.

DEPTH BELOW SURFACE (FT)	CORE RUN, LENGTH, AND RECOVERY (%)	DISCONTINUITIES: R Q D (%)	DISCONTINUITIES: FRACTURES PER FT	DISCONTINUITIES: DESCRIPTION (DEPTH, TYPE, ORIENTATION, ROUGHNESS, PLANARITY, INFILLING MATERIAL AND THICKNESS, SURFACE STAINING, AND TIGHTNESS)	GRAPHIC LOG	LITHOLOGY (ROCK TYPE, COLOR, MINERALOGY, TEXTURE, WEATHERING, HARDNESS, AND ROCK MASS CHARACTERISTICS)	COMMENTS (SIZE AND DEPTH OF CASING, FLUID LOSS, CORING RATE AND SMOOTHNESS, CAVING ROD DROPS, TEST RESULTS, ETC.)
	HQ-1 50%	15		2': 55 deg, planar, smooth, clean to silty coat 2.5': 65 deg, planar, rough, clean Fracture zone/mech. breaks		Soil (silt/clay, fine sandy lake sediments Muddy sandstone, dark red to gray, quartz fine-grained, slightly weathered, H=R3, very poor rock mass; some core missing	HQ CORE
5	5.0					Gradation to siltstone at 6'	
	HQ-2 50%	20		Clayey seam/rubble zone 0-10 deg. bedding planes, undulating smooth minor silty coat From 7.5' to 9.8', 5 degree, silty bedding planes, undulating, smooth to rough		Laminated siltstone, dark red, H=R3, slightly weathered, very poor rock mass 7.5' muddy Sandstone, red with gray nodules, H=R4, slightly weathered very poor rock mass	Clayey material plugging up core bit
10	10.0					10' siltstone, dark red, not well bedded, H=R2 - R3, slightly weathered, poor rock mass	
	HQ-3 76%	34		2-3 fractures/ft, mostly horizontal drill to 10 degress/ mechanical breaks rough, minor silt coat, roughed up by drilling 13.8 to 14.2' clayey fracture zone clayey rubble at 14.5, redrilled pieces		12.3' sandstone, gray hard (R4) 13.3' cont. siltstone, dark red, not well bedded, H=R2 - R3, slightly weathered, poor rock mass	
15	15.0					14.5' Silty Claystone, dark red, massive, H=R2, fresh, very poor rock mass	
	HQ-4 66%	0		mechanical breaks/bedding plane partings mechanical breaks, core pieces spun in core barrel rubble zone with some clay 18-19.5'		continue Silty Claystone, dark red, massive, H=R2 with some zones of R1, very poor rock mass some bedding visible; appears horizontal, very thin layers of claystone	Clayey material plugging up core bit, core broken up
20	20.0			Mostly fractured into 2" long pieces, mechanical breaks on planes, possibly vertical joints			
	HQ-5 92%	30		23.4' horizontal, planar rough clean 24.3': 30 degrees, undulating, smooth fresh surface 24.8 horizontal mech. break		Muddy sandstone, pink-tan, fine-grained, crystalline, H=R3, fresh, fair rock mass; dark red siltstone seam at 24'	UCS Sample BH-02A Q_u = 3,495 psi γ = 149.9 pcf
	25.0						

PROJECT NUMBER:	BORING NUMBER:	SHEET:
D3167645 A.P3.OE.S1	BH-02	2 of 2

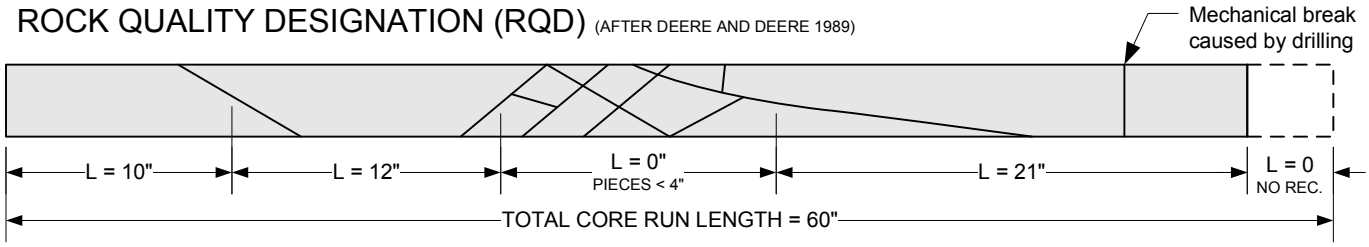
ROCK CORE LOG

PROJECT : Glen Canyon Lake Access
LOCATION : Bullfrog Marina
ELEVATION : 3,672 ft asl
DRILLING CONTRACTOR : Salisbury and Associates (SAI)
DRILLING METHOD AND EQUIPMENT :
WATER LEVELS : not measured
START : 12/10/22
END : 12/11/22
LOGGER : G. Warren, P. G.

DEPTH BELOW SURFACE (FT)	CORE RUN, LENGTH, AND RECOVERY (%)	DISCONTINUITIES: R Q D (%)	DISCONTINUITIES: FRACTURES PER FT	DISCONTINUITIES: DESCRIPTION (DEPTH, TYPE, ORIENTATION, ROUGHNESS, PLANARITY, INFILLING MATERIAL AND THICKNESS, SURFACE STAINING, AND TIGHTNESS)	GRAPHIC LOG	LITHOLOGY (ROCK TYPE, COLOR, MINERALOGY, TEXTURE, WEATHERING, HARDNESS, AND ROCK MASS CHARACTERISTICS)	COMMENTS (SIZE AND DEPTH OF CASING, FLUID LOSS, CORING RATE AND SMOOTHNESS, CAVING ROD DROPS, TEST RESULTS, ETC.)
	HQ-6 100% 30.0	86		25.6' to 29.8': horizontal mechanical breaks, 27.5', 28.9': 0 - 5 degrees, planar, stepped, clean		Sandstone, pink, quartz, fine-grained, some manganese (?) nodules, H = R3, fresh, good rock mass	HQ CORE
30	HQ-7 100% 35.0	90		30.6': 5 degrees, planar rough clean 31.5': 2 degrees, undulating, smooth clean mechanical breaks (horiz) 33.8', 28.9': 2 degrees, planar, smooth, clean 35': vertical fracture		Siltstone, dark red, laminated/very thinly bedded, H = R3, fresh, good to excellent rock mass	UCS Sample BH-02B Q_u = 2,685 psi γ = 164.1 pcf
35	HQ-8 100% 40.0	56		35.4: 10 degrees, planar rough clean 35.8' to 39.2': 0 to 5 degree mechanical breaks, planar rough stepped clean 39.2-40': clayey rubble zone		Claystone, dark red, H=R1 - R2, moderately weathered, clayey, broken up in to rubble	
40	HQ-9 86% 45.0	34		41.1 - 42.8': 3 fractures/ft; 0 - 5 degrees, planar rough clean 43.1': broken up 45': crumbled in shoe		Sandstone, tan to pink, non-bedded, fine-grained, quartz (Navajo Formation), H = R2, moderately weathered, very poor rock mass quality; 3 mm manganese (?) nodules	UCS Sample BH-02 Q_u = 1,420 psi γ = 157.2 pcf
45	HQ-10 100% 49.8	10		4-5 fractures/ft; evenly distributed (mechanical breaks), horizontal to 10 degrees, rough, planar to undulating, clean		pink in color below 45' some core forms sandy material 49' - greenish white bedding	TD - 49.8' bgs; backfill with holeplug chips

ROCK CORE LOG LEGEND

ROCK QUALITY DESIGNATION (RQD) (AFTER DEERE AND DEERE 1989)

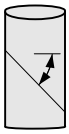


$$RQD = \frac{\sum \text{LENGTH OF SOUND CORE PIECES LONGER THAN 4" (100mm)}}{\text{TOTAL CORE RUN LENGTH}} = \frac{10+12+21}{60} = 72\%$$

RQD	DESCRIPTION OF ROCK QUALITY
0-25%	VERY POOR
25-50%	POOR
50-75%	FAIR
75-90%	GOOD
90-100%	EXCELLENT

DISCONTINUITY ORIENTATION

DISCONTINUITY ANGLES ARE MEASURED FROM THE HORIZONTAL.



TEXTURE OR GRAIN SIZE

(AFTER CORE LOGGING COMMITTEE 1978)

DESCRIPTIVE TERM	DEFINING CHARACTERISTICS
FINE-GRAIN	AVG GRAIN SIZE UP TO 0.05 INCH
MEDIUM-GRAIN	AVG GRAIN SIZE FROM 0.05 TO 0.2 INCH
COARSE-GRAIN	AVG GRAIN SIZE GREATER THAN 0.2 INCH

WEATHERING (AFTER ASCE 1976)

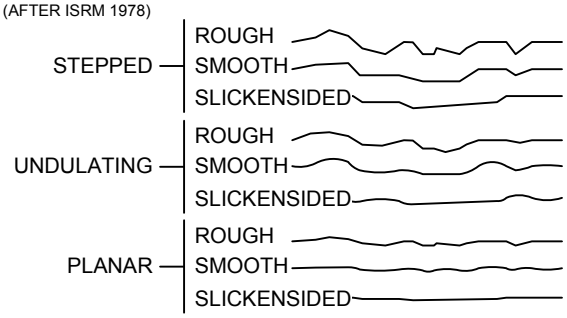
DESCRIPTIVE TERM	DEFINING CHARACTERISTICS
FRESH	ROCK AND DISCONTINUITIES ARE UNSTAINED.
SLIGHTLY	DISCONTINUITIES SHOW SOME STAINING ON SURFACE, BUT DISCOLORATION DOES NOT PENETRATE INTO THE MASS.
MODERATE	DISCONTINUITY SURFACES ARE STAINED AND DISCOLORATION EXTENDS INTO THE ROCK MASS.
HIGHLY	INDIVIDUAL ROCK FRAGMENTS ARE THOROUGHLY STAINED. FELDSPARS HAVE MOSTLY ALTERED TO CLAYS. ROCK IS BEGINNING TO TAKE ON SOIL CHARACTERISTICS.

JOINT AND BEDDING SPACING (AFTER ASCE 1976)

SPACING	JOINTS	BEDDING/FOLIATION
< 0.5 IN		LAMINATED
0.5 IN - 2 IN	VERY CLOSE	VERY THIN
2 IN - 1 FT	CLOSE	THIN
1 FT - 3 FT	MODERATELY CLOSE	MEDIUM
3 FT - 10 FT	WIDE	THICK
> 10 FT	VERY WIDE	VERY THICK (MASSIVE)

ROUGHNESS AND PLANARITY

(AFTER ISRM 1978)



HARDNESS RATING (AFTER ASCE 1976 AND ISRM 1981)

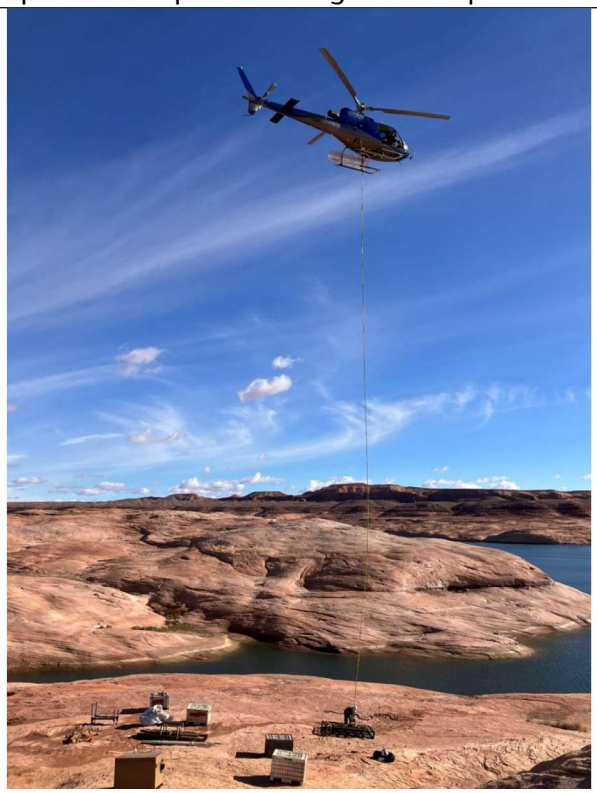
GRADE	DESCRIPTION	FIELD IDENTIFICATION
R0	EXTREMELY SOFT	CAN BE INDENTED BY FINGERNAIL.
R1	VERY SOFT	CRUMBLES UNDER FIRM BLOWS OF GEOLOGIC PICK, CAN BE PEELED BY A POCKET KNIFE, SCRATCHED WITH A FINGERNAIL.
R2	SOFT	SHALLOW INDENTATIONS MADE BY FIRM BLOW OF GEOLOGIC PICK, CAN BE PEELED WITH DIFFICULTY AND SCRATCHED BY A KNIFE.
R3	MEDIUM HARD	CAN BE FRACTURED WITH A SINGLE FIRM BLOW OF GEOLOGIC PICK HAMMER END, CANNOT BE PEELED AND DIFFICULT TO SCRATCH WITH A KNIFE.
R4	HARD	REQUIRES MORE THAN ONE BLOW WITH GEOLOGIC PICK HAMMER END TO FRACTURE, DIFFICULT TO SCRATCH WITH KNIFE.
R5	VERY HARD	REQUIRES MANY BLOWS WITH GEOLOGIC PICK HAMMER END TO FRACTURE, CANNOT BE SCRATCHED WITH KNIFE.
R6	EXTREMELY HARD	CAN ONLY BE CHIPPED WITH GEOLOGIC PICK.

ASCE, 1976. "Subsurface Investigation for Design and Construction of Foundations and Buildings." *ASCE Manual on Engineering Practice*. No. 56, p. 53.
Core Logging Committee (South Africa Section, AEG), 1978. "A Guide to Core Logging for Rock Engineering." *Bull. of the Assoc. of Engr. Geologists*. Vol. 15, No. 3. pp. 295-328.
Deere, D.U. and Deere, D.W., 1989. *Rock Quality Designation (RQD) after Twenty Years*. US Army Corp of Engr, Waterway Experiment Station. Contract Report GL-89-1.
ISRM, 1978. "Commission on Standardization of Laboratory and Field Tests." ISRM. *Inter. Jour. of Rock Mech. and Mineral Sciences and Geomech. Abstracts*. Vol. 15, pp 319-368.
ISRM, 1981. *Rock Characterization, Testing, and Monitoring: Suggested Method for Determination of Uniaxial Compressive Strength of Rock Materials*. International Society for Rock Mechanics. Pregamon Press, London, U.K.

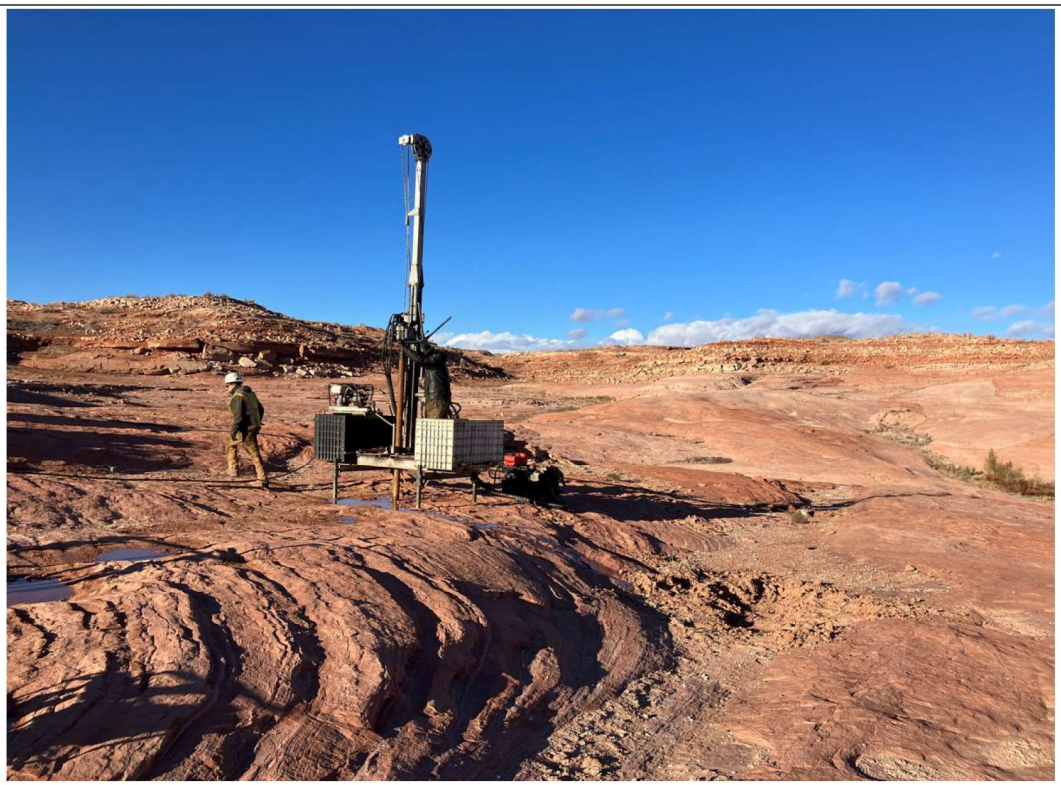
JACOBS

Appendix B – Photolog

Photograph 1: Helicopter lowering drill components at BH-01



Photograph 2: Helicopter lowering drill components at BH-01



Photograph 3: Drill rig setup at BH-01 on Navajo Sandstone

Photograph 4: Drill rig setup at BH-01 on Navajo Sandstone

Photograph 5: Drill rig setup at BH-01 on clean rock surface of Navajo Sandstone

Photograph 6: Drill rig setup at BH-02. Note soil and vegetation at surface – this is below high-water mark.

Photograph 7: Contact of Upper Carmel Formation overlying Navajo Sandstone (black line). Note vast difference in weathering styles and rock characteristics between the two.

Photograph 8: Upper Carmel Formation overlying Navajo Sandstone. Note numerous rockfalls.

Photograph 9: Rockfalls in Upper Carmel Formation below BH-02.

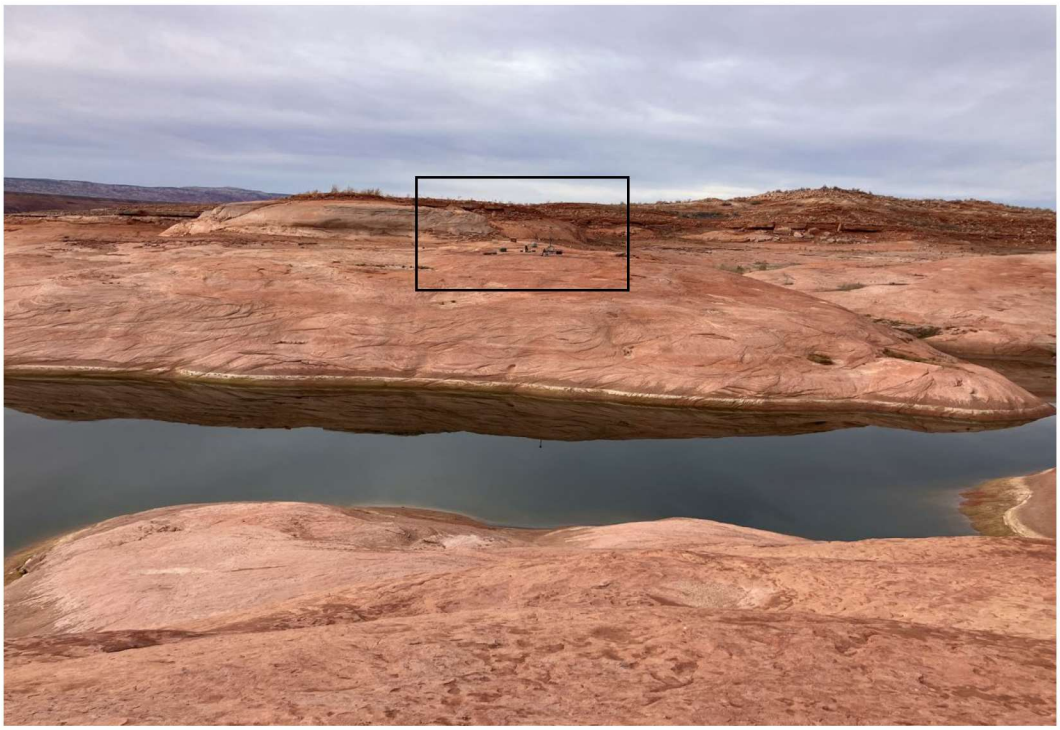
Photograph 10: Rockfalls of multi-ton sandstone blocks where weak siltstone/claystone differentially erodes. This is looking “up-alignment from BH-02 location.

Photograph 11: Differential erosion rates of dark red weak siltstone and more resistant sandstone blocks, which leads to rockfalls. This in near rock cut in BH-02 vicinity.

Photograph 12: Significant erosion of dark red weak siltstone and resistant sandstone blocks.

Photograph 13: Excellent view of vertical jointing in overhanging resistant sandstone blocks, resulting in large rockfalls.

Photograph 14: Large crossbeds in Navajo Sandstone show evidence of ancient migrating dune field. Note erosional surface (blue arrow)



Photograph 15: Navajo Sandstone exposed in vicinity of proposed lower boat ramp. Note drill equipment set up at BH-01 location.

Photograph 16: Spring emanating from Navajo Sandstone. This is near road centerline.

Photograph 17: Seepage and saturated sandstone near reservoir waterline in December 2022.

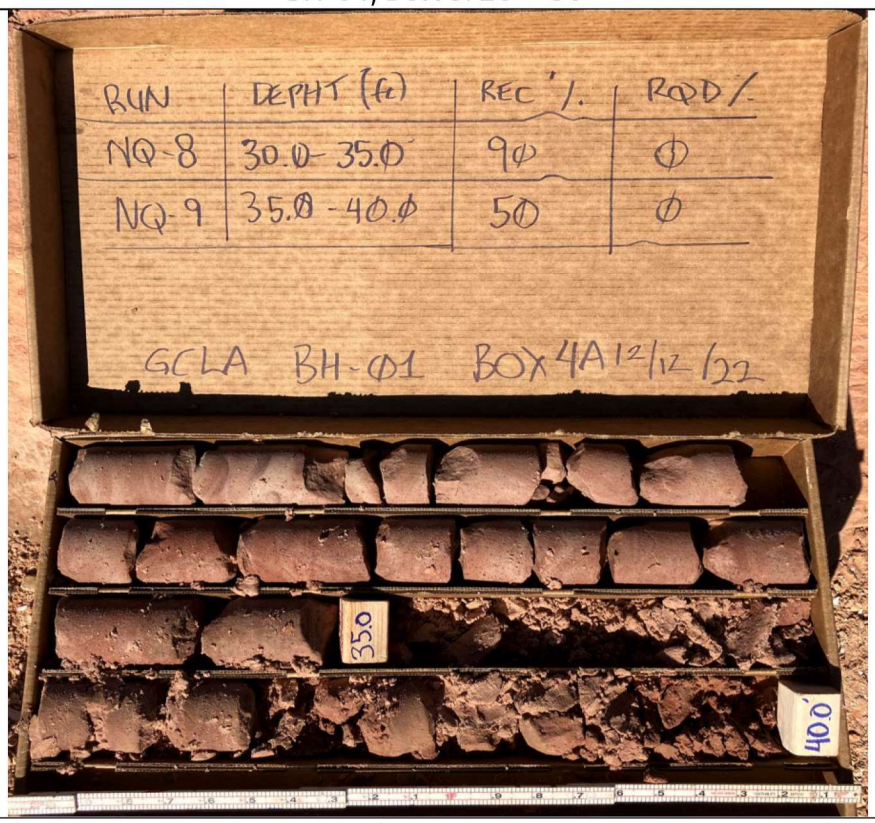
Photograph 18: Springs emanating from Navajo Sandstone in lower boat ramp vicinity.

Appendix C – Rock Core Photologs

BH-01, BOX 1: 0′ – 11.5′

BH-01, BOX 2: 11.5′ – 20′

BH-01, BOX 3: 20′ – 30′

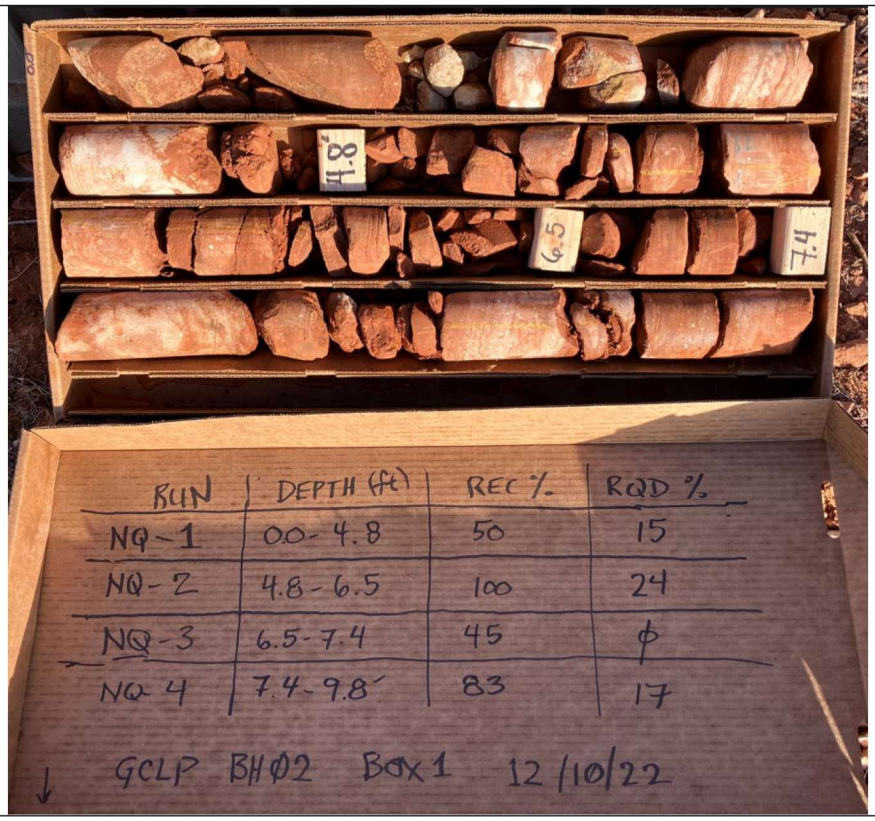


BH-01, BOX 4A: 30′ – 35′ (NOTE THAT 35-40 HERE IS SLUFF)

BH-01, BOX 4B: 35′ – 45′

BH-01, BOX 5: 45′ – 55′

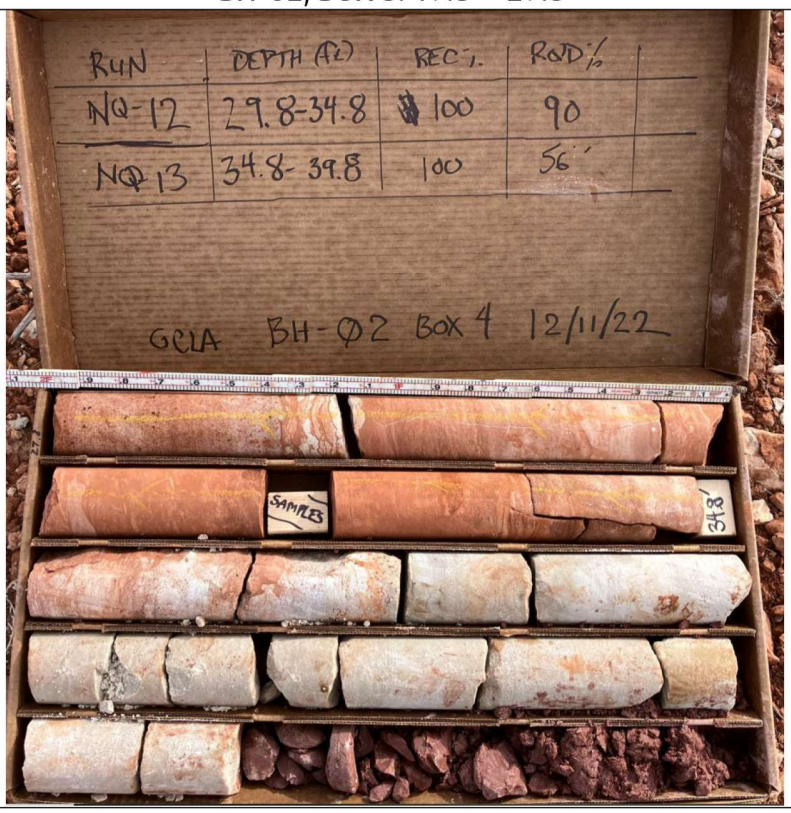
BH-01, BOX 6: 55’ – 60’



BH-02, BOX 1: 0′ – 9.8′

BH-02, BOX 2: 9.8′ – 19.8′

BH-02, BOX 3: 19.8′ – 29.8′



BH-02, BOX 4: 29.8′ – 39.8′

BH-02, BOX 4: 39.8′ – 49.8′

Appendix D – Laboratory Data Sheets

Rock Core Compressive Strength
ASTM D 7012

GeoTek, Inc.
320 East Corporate Drive Suite 300 Meridian, ID 83642-3511
(208) 888-7010 Office (208) 888-7924 Fax www.geotekusa.com

Project: Jacobs - Lake Powell
Client: Jacobs
Location: Lake Powell - Boat Ramps

WO #: 2106-ID
Date: 12/29/2022
Sample ID# BH-01-A-B; BH-02-A-B
GeoTek Lab# 23-00020-C01-C06

Sample Location	Sample Depth(ft)	Dia (in.)	Length (in.)	L to D Ratio	X-sec Area (sq. in.)	Mass of Core (lbs)	Unit Wght (pcf)	Load (lbs)	Comp. Strght (psi)
BH-01	58	2.39	5.00	2.09	4.49	1.99	153.3	11,810	2,630
BH-01A	53	2.38	5.00	2.10	4.45	1.88	146.0	8,375	1,885
BH-01B	35	2.39	5.00	2.09	4.49	1.79	137.9	10,800	2,405
BH-02	44	2.39	5.00	2.09	4.49	2.04	157.2	6,370	1,420
BH-02A	22	2.38	5.00	2.10	4.45	1.93	149.9	15,540	3,495
BH-02B	33	2.39	5.00	2.09	4.49	2.13	164.1	12,855	2,865

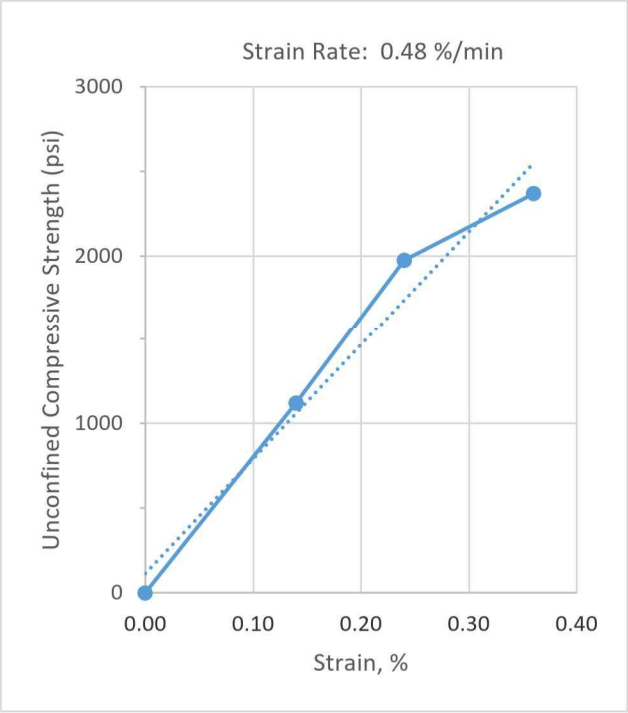
Rock Core Compressive Strength
ASTM D 7012

GeoTek, Inc.
320 East Corporate Drive Suite 300 Meridian, ID 83642-3511
(208) 888-7010 Office (208) 888-7924 Fax www.geotekusa.com

Project: 2106-ID - Jacobs - Lake Powell Rock Cores
Client: Jacobs
Location(L/L): Lake Powel Boat Ramp
Sample Depth: 58'
Sample Desciption: Red Sandstone

WO #: 2106-ID
Date: 12/29/2022
Sample ID: BH-01
GeoTek Lab #: 23-00020-C01

Sample	Dai (in)	Length (in)	L to D Ratio	X-sec Area (sq. in.)	Unit Wght (lbs)	Load (lbs)	CS (psi)
BH-01	2.39	5.00	2.09	4.49	153.3	11810	2632

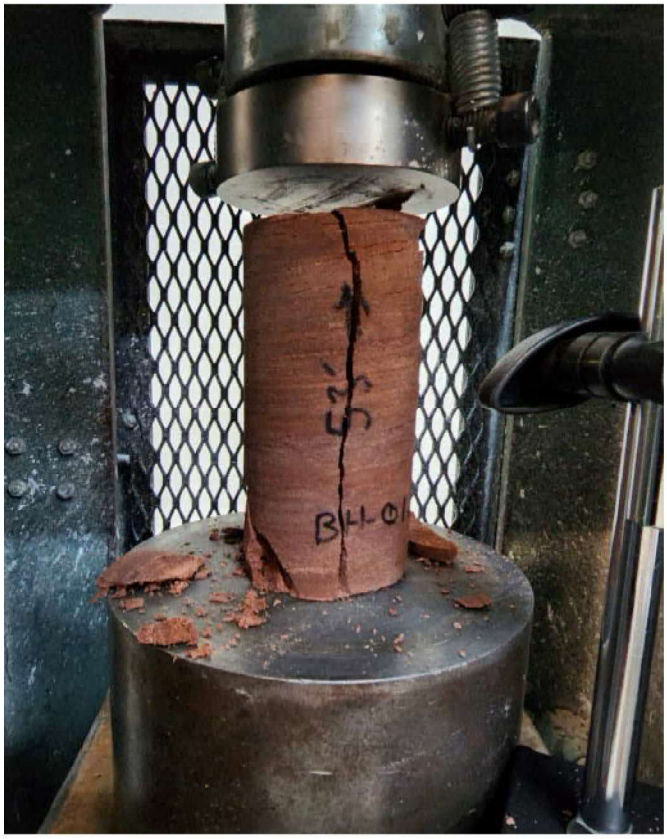


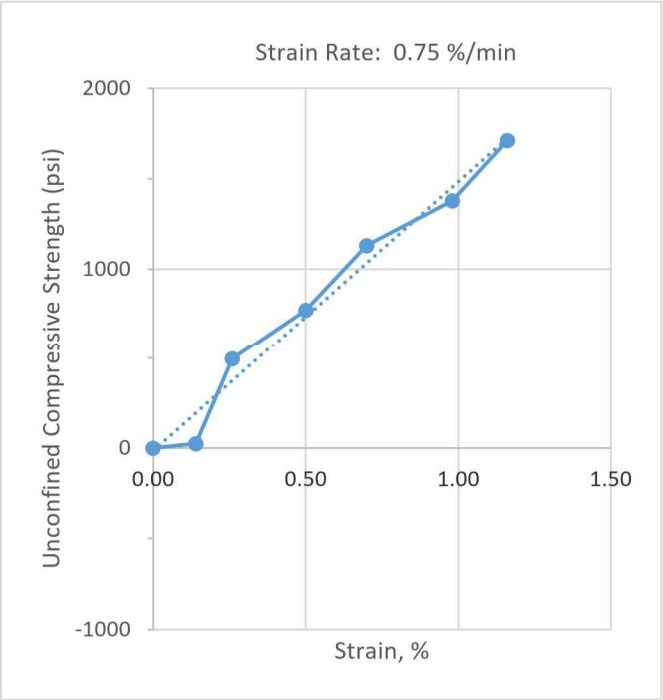
Rock Core Compressive Strength
ASTM D 7012

GeoTek, Inc.
320 East Corporate Drive Suite 300 Meridian, ID 83642-3511
(208) 888-7010 Office (208) 888-7924 Fax www.geotekusa.com

Project: 2106-ID - Jacobs - Lake Powell Rock Cores
WO #: 2106-ID
Client: Jacobs
Date: 12/29/2022
Location: Lake Powell - Boat Ramps
Sample ID: BH-01A
Sample Depth: 53'
GeoTek Lab #: 23-00020-C02
Sample Desciption: Red Sandstone

Sample	Dai (in)	Length (in)	L to D Ratio	X-sec Area (sq. in.)	Unit Wght (lbs)	Load (lbs)	CS (psi)
BH-01A	2.38	5.00	2.10	4.45	146.0	8375	1885





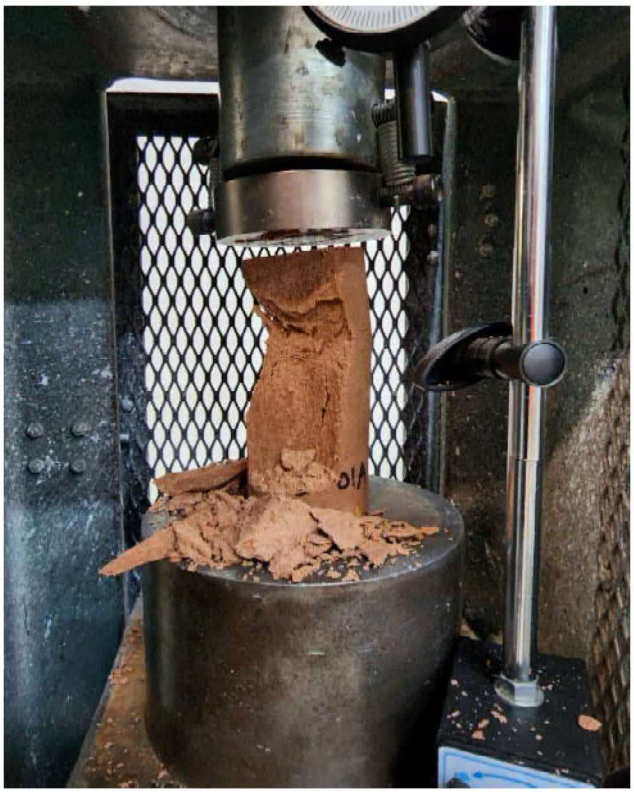
Rock Core Compressive Strength
ASTM D 7012

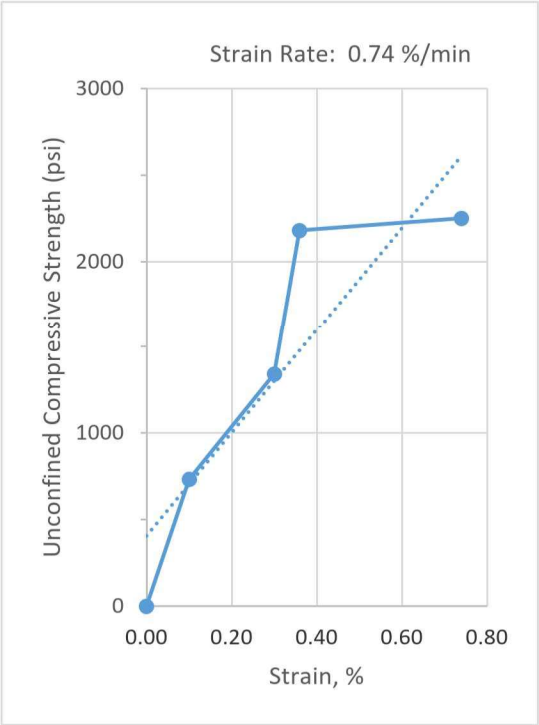
GeoTek, Inc.
320 East Corporate Drive Suite 300 Meridian, ID 83642-3511
(208) 888-7010 Office (208) 888-7924 Fax www.geotekusa.com

Project: 2106-ID - Jacobs - Lake Powell Rock Cores
Client: Jacobs
Location: Lake Powell - Boat Ramp
Sample Depth: 32'
Sample Desciption: Red Sandstone

WO #: 2106-ID
Date: 12/29/2022
Sample ID: BH-01B
GeoTek Lab #: 23-00020-C03

Sample	Dai (in)	Length (in)	L to D Ratio	X-sec Area (sq. in.)	Unit Wght (lbs)	Load (lbs)	CS (psi)
BH-01B	2.39	5.00	2.09	4.49	137.9	10800	2405





Rock Core Compressive Strength
ASTM D 7012

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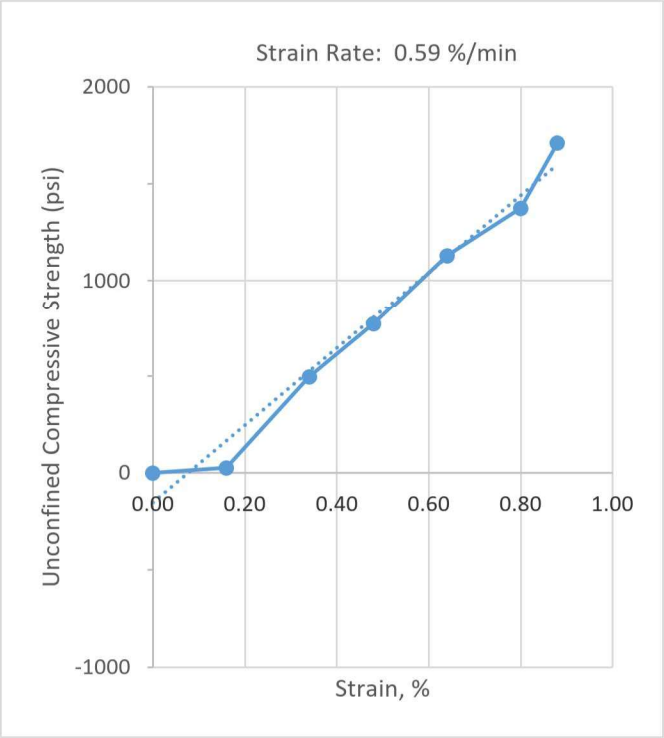
(208) 888-7010 Office (208) 888-7924 Fax www.geotekusa.com

Project: 2106-ID - Jacobs - Lake Powell Rock Cores
WO #: 2106-ID
Client: Jacobs
Date: 12/29/2022
Location:
Sample ID: BH-02
Sample Depth: 44'
GeoTek Lab #: 23-00020-C04
Sample Desciption: Red Sandstone

Sample	Dai (in)	Length (in)	L to D Ratio	X-sec Area (sq. in.)	Unit Wght (lbs)	Load (lbs)	CS (psi)
BH-02	2.39	5.00	2.09	4.49	157.2	6370	1420

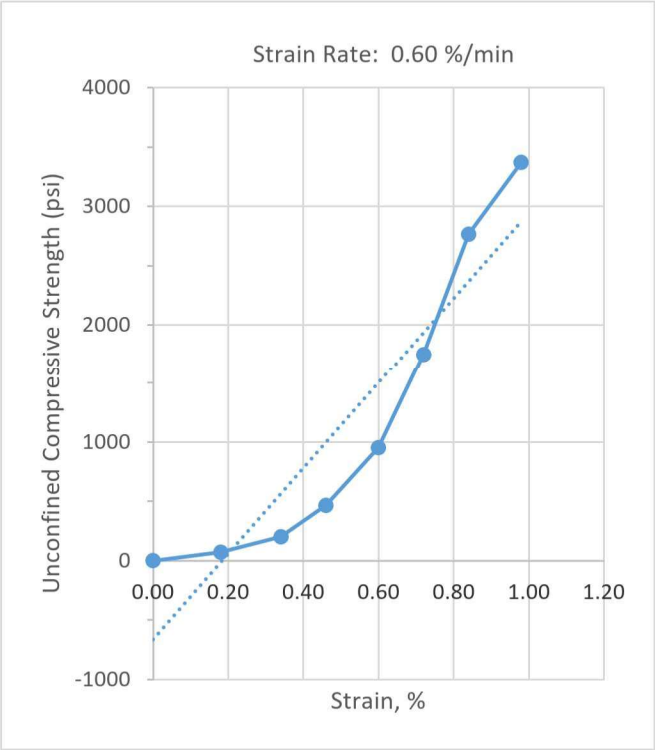


Rock Core Compressive Strength
ASTM D 7012

GeoTek, Inc.
320 East Corporate Drive Suite 300 Meridian, ID 83642-3511
(208) 888-7010 Office (208) 888-7924 Fax www.geotekusa.com

Project: 2106-ID - Jacobs - Lake Powell Rock Cores
WO #: 2106-ID
Client: Jacobs
Date: 12/29/2022
Location: Lake Powell - Boat Ramp
Sample ID: BH-02A
Sample Depth: 20'
GeoTek Lab #: 23-00020-C05
Sample Desciption:

Sample	Dai (in)	Length (in)	L to D Ratio	X-sec Area (sq. in.)	Unit Wght (lbs)	Load (lbs)	CS (psi)
BH-02A	2.38	5.00	2.10	4.45	149.9	15540	3495

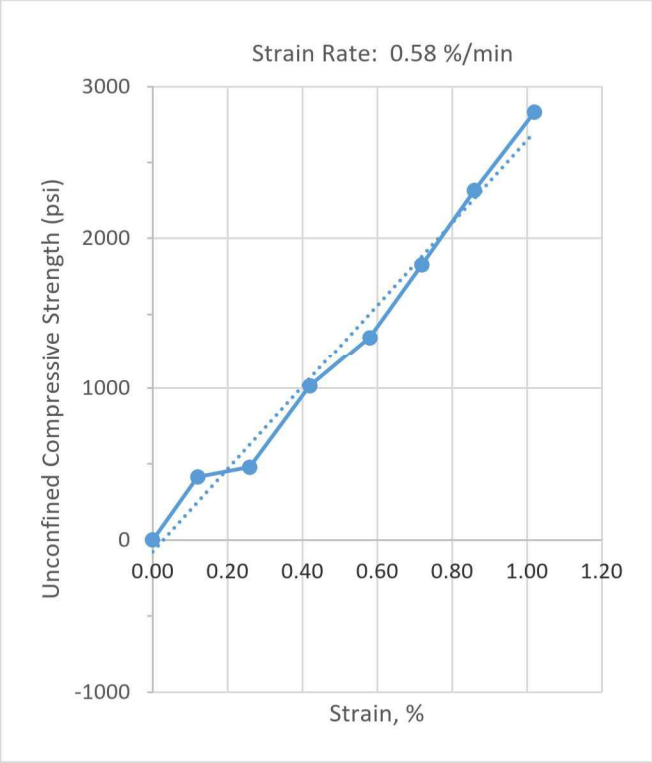


Rock Core Compressive Strength
ASTM D 7012

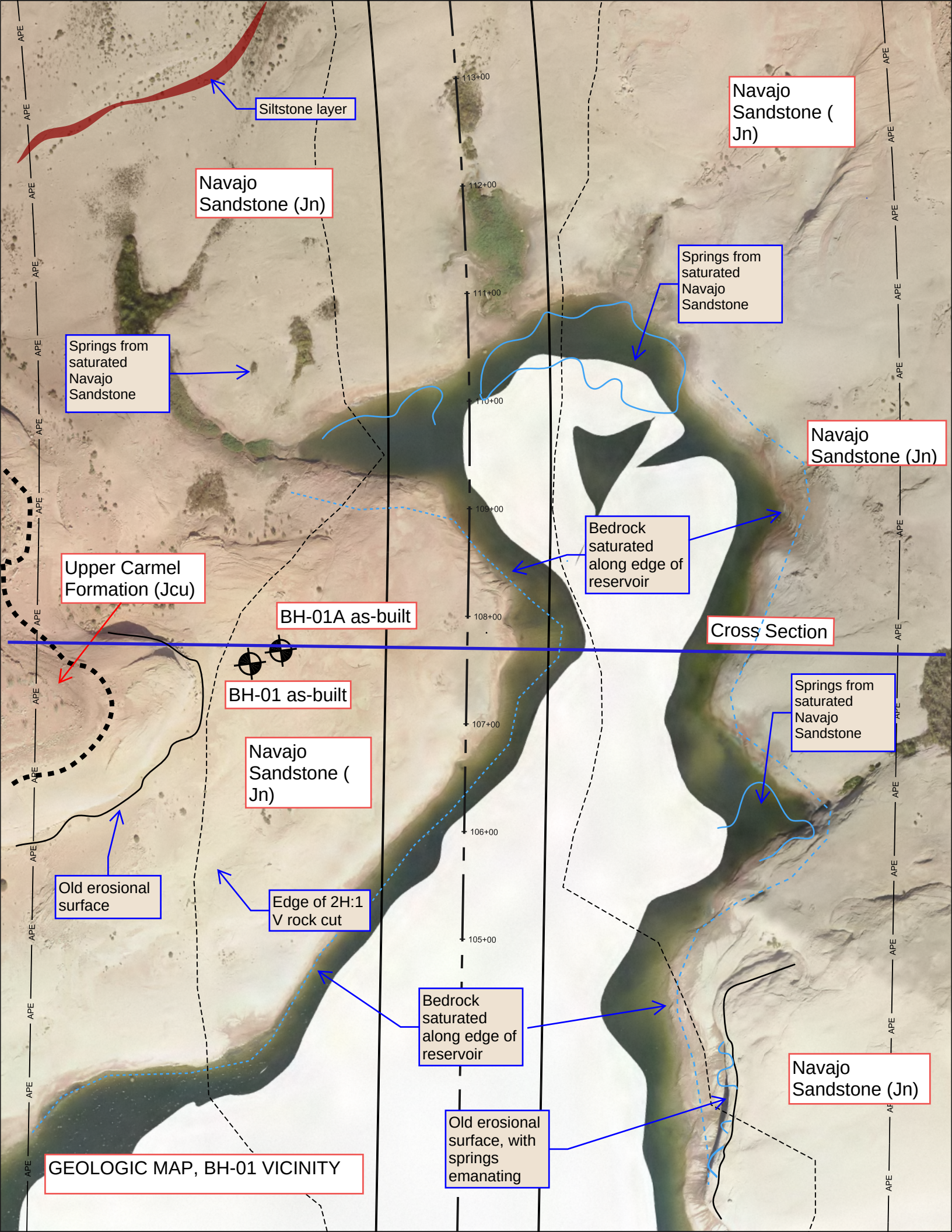
GeoTek, Inc.
320 East Corporate Drive Suite 300 Meridian, ID 83642-3511
(208) 888-7010 Office (208) 888-7924 Fax www.geotekusa.com

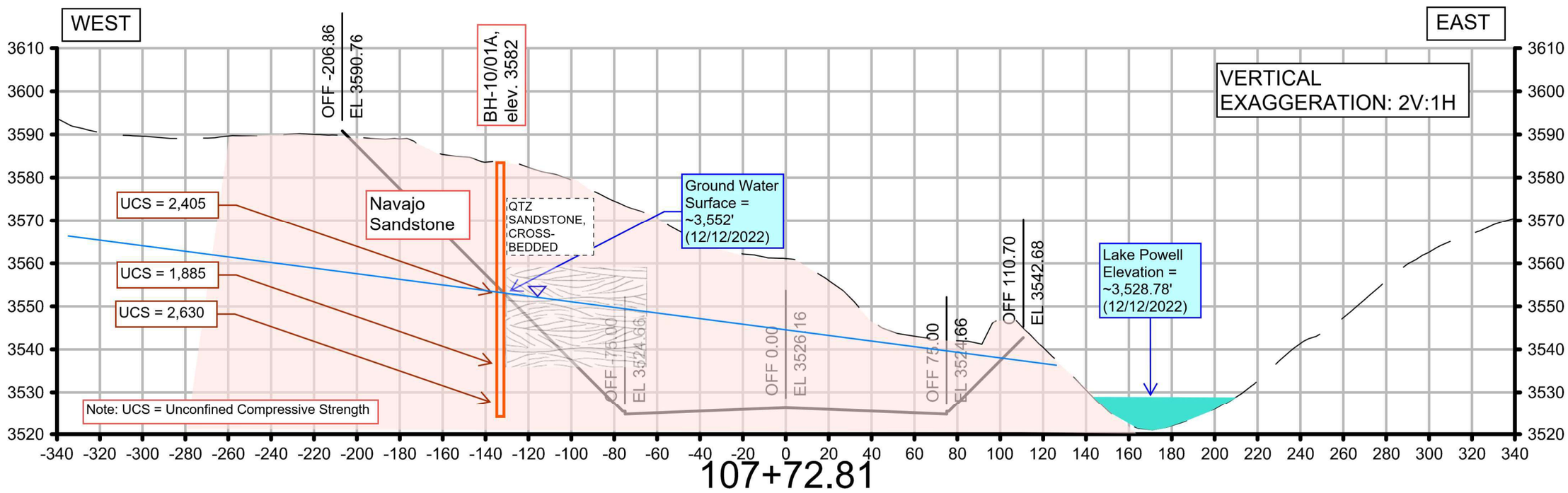
Project: 2106-ID - Jacobs - Lake Powell Rock Cores
WO #: 2106-ID
Client: Jacobs
Date: 12/29/2022
Location: Lake Powell - Boat Ramp
Sample ID: BH-02B
Sample Depth: 33'
GeoTek Lab #: 23-00020-C06
Sample Desciption: Red Sandstone

Sample	Dai (in)	Length (in)	L to D Ratio	X-sec Area (sq. in.)	Unit Wght (lbs)	Load (lbs)	CS (psi)
BH-02B	2.39	5.00	2.09	4.49	164.1	12855	2865

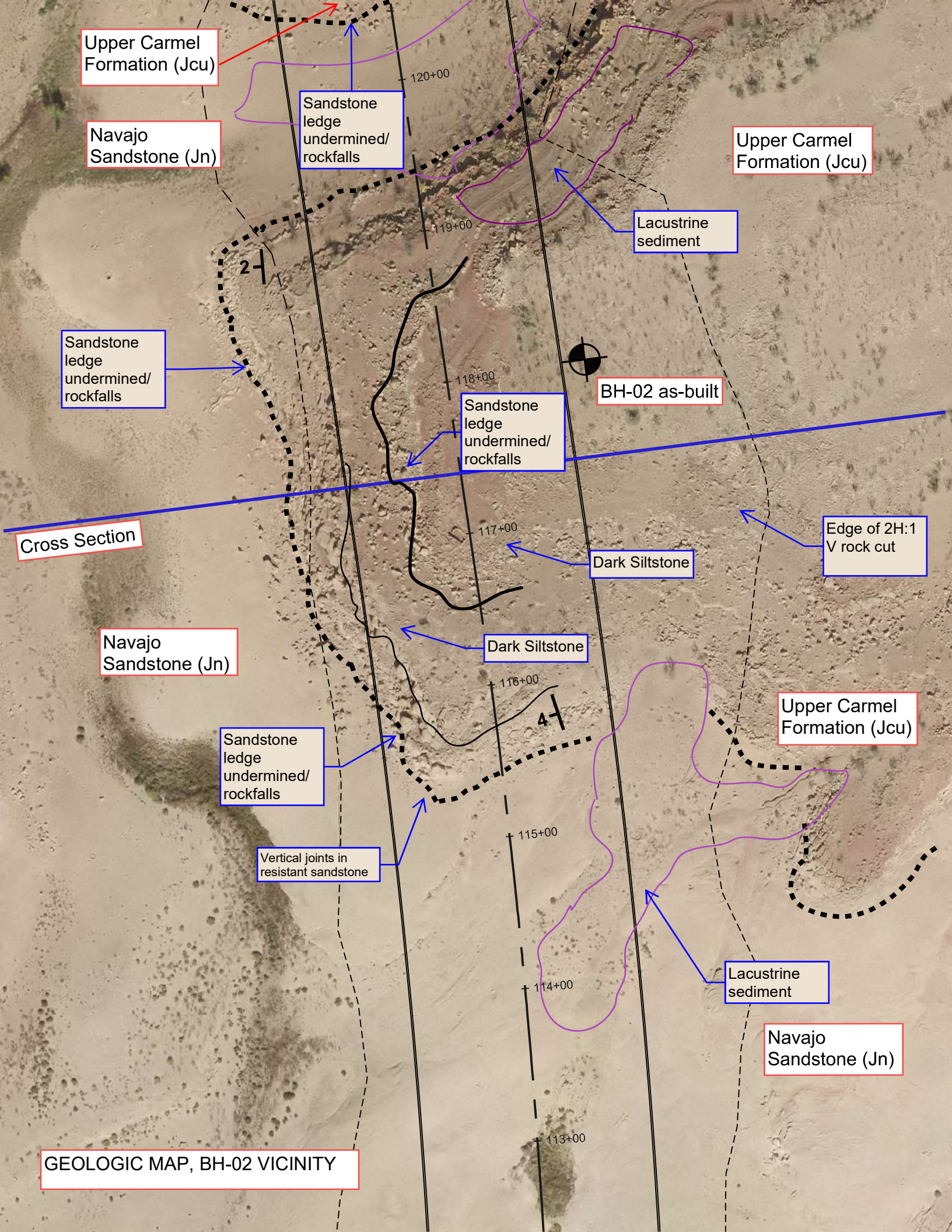


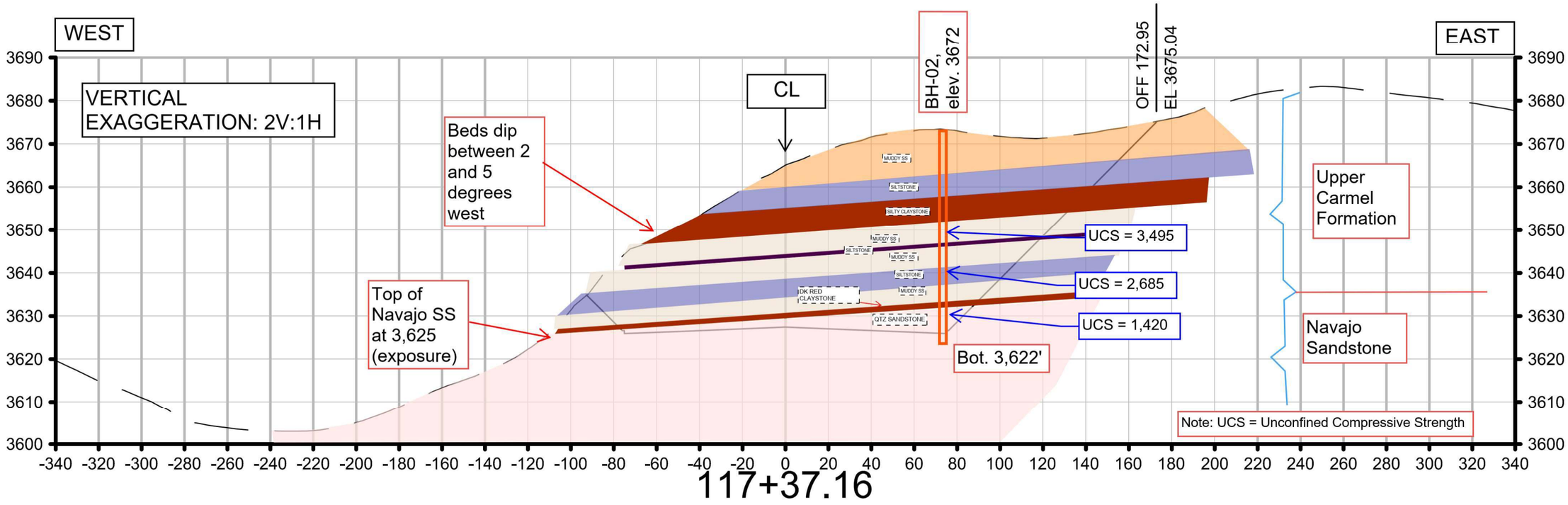
Appendix E – Geologic Maps and Cross-sections


Siltstone layer
Navajo Sandstone (Jn)
Navajo Sandstone (Jn)
Springs from saturated Navajo Sandstone
Springs from saturated Navajo Sandstone
Navajo Sandstone (Jn)
Bedrock saturated along edge of reservoir
Upper Carmel Formation (Jcu)
BH-01A as-built
Cross Section
BH-01 as-built
Springs from saturated Navajo Sandstone
Navajo Sandstone (Jn)
Old erosional surface
Edge of 2H:1 V rock cut
Bedrock saturated along edge of reservoir
Navajo Sandstone (Jn)
Old erosional surface, with springs emanating
GEOLOGIC MAP, BH-01 VICINITY
113+00
112+00
111+00
110+00
109+00
108+00
107+00
106+00
105+00
APE



BH-01 GEOLOGIC CROSS SECTION


Upper Carmel Formation (Jcu)
Navajo Sandstone (Jn)
Sandstone ledge undermined/ rockfalls
120+00
119+00
118+00
117+00
116+00
115+00
114+00
113+00
Upper Carmel Formation (Jcu)
Lacustrine sediment
2
Sandstone ledge undermined/ rockfalls
BH-02 as-built
Sandstone ledge undermined/ rockfalls
Cross Section
Edge of 2H:1 V rock cut
Dark Siltstone
Navajo Sandstone (Jn)
Dark Siltstone
4
Upper Carmel Formation (Jcu)
Sandstone ledge undermined/ rockfalls
Vertical joints in resistant sandstone
Lacustrine sediment
Navajo Sandstone (Jn)
GEOLOGIC MAP, BH-02 VICINITY



BH-02 GEOLOGIC CROSS SECTION