MORTAR ANALYSIS

PREPARED FOR:

JVA, INC

1319 SPRUCE STREET

BOULDER, CO 80302

PROJECT:

FALL RIVER ENTRANCE STATION

ROCKY MOUNTAIN NATIONAL PARK

PREPARED BY:

PHILLIP BARLOW, HISTORIC PRESERVATION SPECIALIST

BARLOW CULTURAL RESOURCE CONSULTING, LLC

4576 TANGLEWOOD TRAIL, BOULDER, CO 80301

303-746-1602 : BARLOWPL@GMAIL.COM

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EXECUTIVE SUMMARY

Three mortar samples from site elements at the Fall River Entrance Station to Rocky Mountain National Park were collected by Tom Soell of JVA, Inc. and delivered to BCRC on September 16, 2021. The Fall River Entrance Station was built ca.1930 as a Civilian Conservation Corps (CCC) project in conjunction with the National Park Service. The three samples were labeled as follows:

1: Low on the west end of the upper headwall
2: Under top course of the low headwall
3: Curb at parking lot

This intent of this report is to provide the necessary information that will allow a mason to create a mortar mix that will match the existing in a historically appropriate manner. The specifications include a mortar mix ratio, a detail of aggregate grain size and color, and a methodology for creating an accurate mortar color match.

Aggregate sieve analysis of sample 3 aligned well with ASTM C144, standard for masonry mortar aggregate. Samples 1 and 2 were skewed slightly towards larger aggregate. A high percentage of fine material was present in all samples, likely indigestible components of the cement binder, clays, and pigments. The aggregate in all four samples appear to be native to Colorado and include clear quartz, cloudy white quartz, orange and green quartz, and granite. Aggregate shape is primarily sub-angular.

Standards published by the American Society for Testing and Materials (ASTM C270) specifies that cement/lime/sand mortars should have a sand content of at least **2.25** times the lime/cement mix (31% binder), and not more than **3** times the binder mix (25% binder). All three samples were within, or very close to, the standard.

The mortar samples were taken from stone construction, with the stone likely being predominantly granite. Due to the durable nature of granite and the exposed location, a type O mortar is recommended for areas represented by samples 1 and 2. Sample 3 was more difficult to crush and resisted acid digestion significantly more than the other samples, indicating that it had a higher strength and percentage of Portland cement. Compression testing of sample 3 suggests that this mortar was closest to the type N category.

Sample #	Sample Name	% Dissolved	Portland Cement	Hydrated Lime	Sand	Mortar Type
1	Low on the west end of the upper headwall	28%	1	2	8	O
2	Under top course of the low headwall	25%	1	2	9	O
3	Curb at parking lot	24%	1	1	6	N

COMPOSITION ANALYSIS

Before acid digestion a qualitative hardness test is performed to determine the presence of cement. A pure lime mortar, which is just lime and sand, will typically crush with minimal effort. If a significant effort is required to fracture the sample then it is safe to assume that Portland cement is part of the mortar mix.

Samples 1, 2, and 3 could not be crushed with finger strength, indicating that cement was present.

A digestive mortar analysis was conducted on the material, the full procedure for which is available in the appendix. Acid digestion is the process of using acid to dissolve lime and cement. By measuring the weight of the sample before and after digestion it is possible to determine the ratio of binder to aggregate.

Following digestion the aggregate is washed, filtered, and sieved. This determines the gradation of aggregate sizes.

A U.S. Standard sieve set was used to calculate the proportion of grain sizes. The sieve sizes used were:

No. 4 – opening of .187”
No. 8 – opening of .09”
No. 16 – opening of .046”
No. 30 – opening of .023”
No. 60 – opening of .0098”
No. 100 – opening of .0055”
No. 200 – opening of .0029”

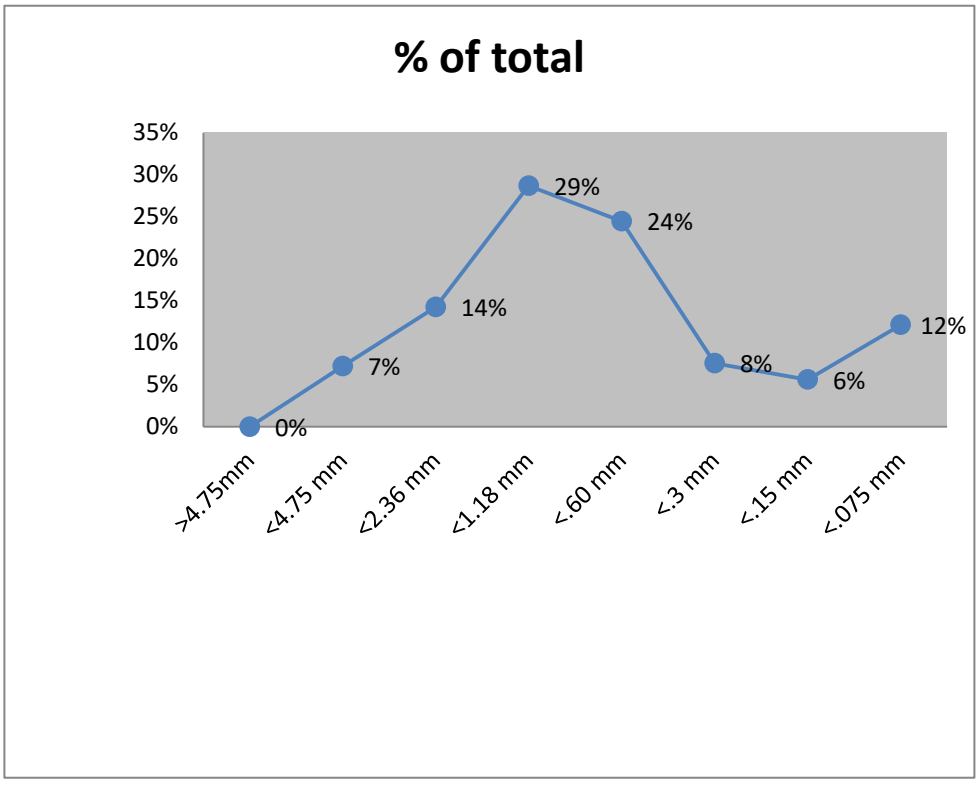
Pan - This is the material that was small enough to pass through the 200 sieve. Fines are generally clay or very fine aggregate material, including pigment that is smaller than .0029”.

AGGREGATE SIZE DISTRIBUTION

Sample #	**1**
Sample Location	**Low on the west end of the upper headwall**
Name	**Fall River Entrance Station**
Date	**09.17.2021**

Sieve	With Sand	Without Sand	Sand	Particle sizes	% of total	
4	61.72	61.72	0	>4.75mm	**0%**	gravel
8	58.22	57.81	0.41	<4.75 mm	**7%**	very coarse sand
16	57.52	56.71	0.81	<2.36 mm	**14%**	coarse sand
30	55.23	53.6	1.63	<1.18 mm	**29%**	medium coarse sand
60	56.01	54.62	1.39	<.60 mm	**24%**	medium fine sand
100	53.57	53.14	0.43	<.3 mm	**8%**	fine sand
200	53.14	52.82	0.32	<.15 mm	**6%**	very fine sand
Pan	14.36	13.67	0.69	<.075 mm	**12%**	silt
Total	**409.77**	**404.09**	**5.68**			

Weight of sample	7.87	grams	**% dissolved**	**28%**
Wt filter paper for sand	1.43	grams		
Wt sand & paper	7.11	grams		
Wt sand	**5.68**			
% sand	**72%**			



The following table compares this data to the ASTM C 144 standard for masonry mortar aggregate. Red indicates that the sample does not match the standard.

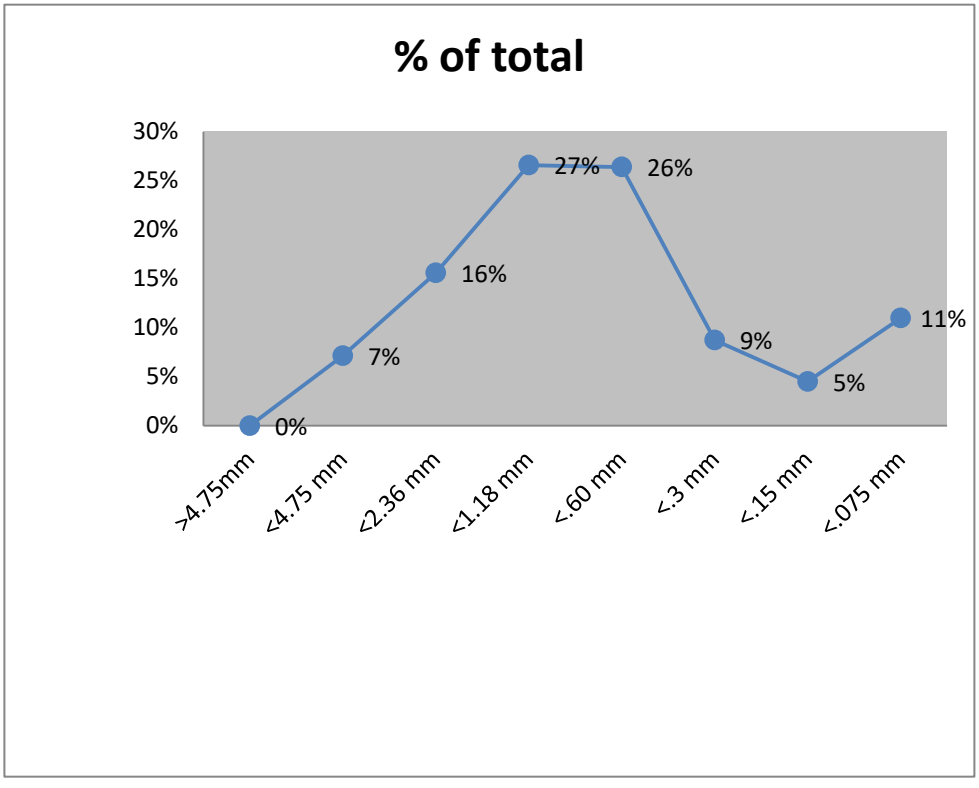
Sieve Size	Percent Passing, SAMPLE #1	ASTM C 144, Natural Sand
No. 4	**100**	100%
No. 8	**93**	95-100%
No. 16	**79**	70-100%
No. 30	**50**	40-75%
No. 40	**26**	10-35%
No. 100	**18**	2-15%
No. 200	**12**	0%

While it is included here for accuracy, please note that the percentage that passes sieve 200 is primarily clays, pigments, and indigestible portions of Portland cement and not considered part of the aggregate.

Sample # **2**
Sample Location **Under top course of the low headwall**
Name **Fall River Entrance Station**
Date **09.17.2021**

Sieve	With Sand	Without Sand	Sand	Particle sizes	% of total	
4	61.71	61.71	0	>4.75mm	**0%**	gravel
8	58.57	57.81	0.76	<4.75 mm	**7%**	very coarse sand
16	58.38	56.72	1.66	<2.36 mm	**16%**	coarse sand
30	56.43	53.6	2.83	<1.18 mm	**27%**	medium coarse sand
60	57.42	54.61	2.81	<.60 mm	**26%**	medium fine sand
100	54.07	53.14	0.93	<.3 mm	**9%**	fine sand
200	53.3	52.82	0.48	<.15 mm	**5%**	very fine sand
Pan	14.88	13.71	1.17	<.075 mm	**11%**	silt
Total	**414.76**	**404.12**	**10.64**			

Weight of sample	14.16	grams	**% dissolved**	**25%**
Wt filter paper for sand	1.39	grams		
Wt sand & paper	12.03	grams		
Wt sand	**10.64**			
% sand	**75%**			



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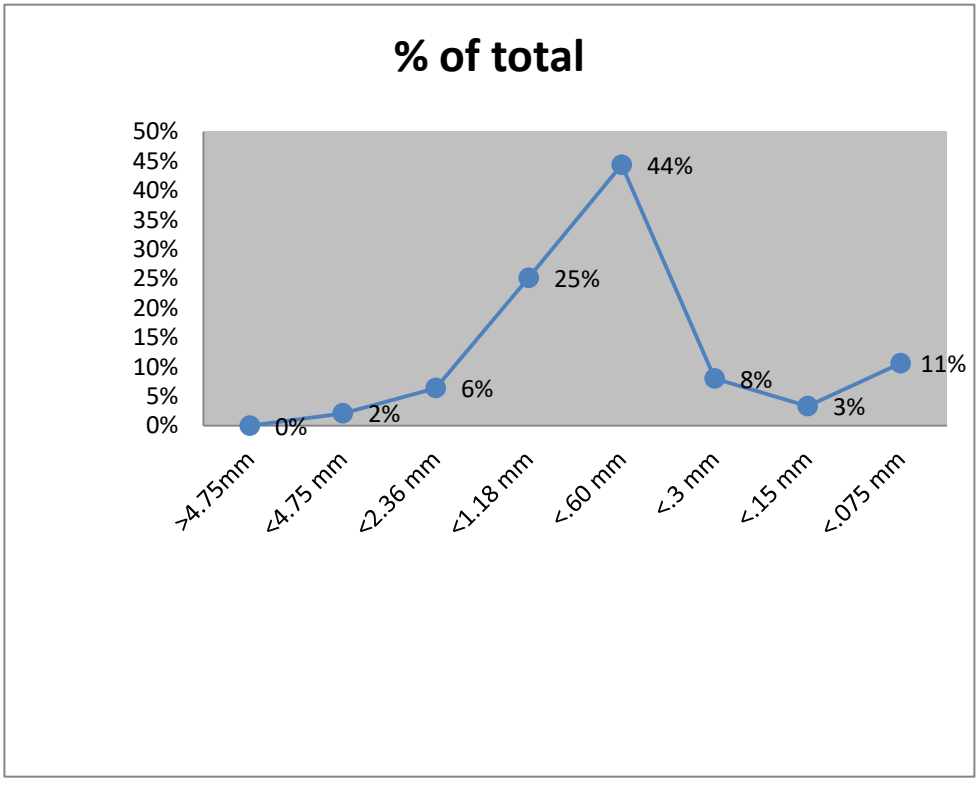
No. 16	**77**	70-100%
No. 30	**50**	40-75%
No. 40	**24**	10-35%
No. 100	**15**	2-15%
No. 200	**11**	0%

While it is included here for accuracy, please note that the percentage that passes sieve 200 is primarily clays, pigments, and indigestible portions of Portland cement and not considered part of the aggregate.

Sample #	**3**
Sample Location	**Curb at parking lot**
Name	**Fall River Entrance Station**
Date	**09.17.2021**

Sieve	With Sand	Without Sand	Sand	Particle sizes	% of total	
4	61.71	61.71	0	>4.75mm	**0%**	gravel
8	58.06	57.8	0.26	<4.75 mm	**2%**	very coarse sand
16	57.51	56.72	0.79	<2.36 mm	**6%**	coarse sand
30	56.7	53.6	3.1	<1.18 mm	**25%**	medium coarse sand
60	60.08	54.61	5.47	<.60 mm	**44%**	medium fine sand
100	54.14	53.15	0.99	<.3 mm	**8%**	fine sand
200	53.22	52.81	0.41	<.15 mm	**3%**	very fine sand
Pan	14.97	13.66	1.31	<.075 mm	**11%**	silt
Total	**416.39**	**404.06**	**12.33**			

Weight of sample	16.13	grams	**% dissolved**	**24%**
Wt filter paper for sand	1.4	grams		
Wt sand & paper	13.73	grams		
Wt sand	**12.33**			
% sand	**76%**			



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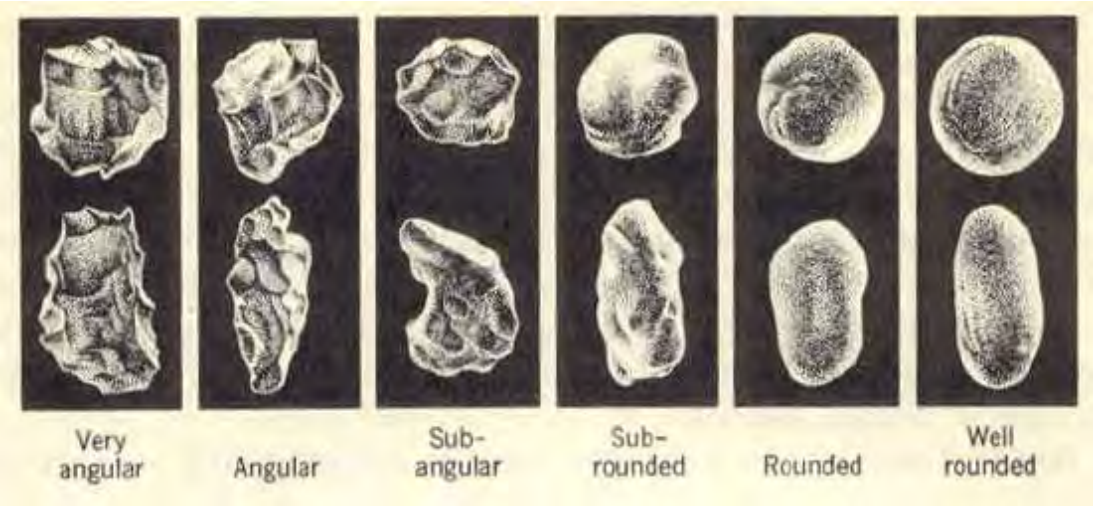
Sieve Size	Percent Passing, SAMPLE #1	ASTM C 144, Natural Sand
No. 4	**100**	100%
No. 8	**98**	95-100%
No. 16	**92**	70-100%
No. 30	**67**	40-75%
No. 40	**23**	10-35%
No. 100	**15**	2-15%
No. 200	**11**	0%

While it is included here for accuracy, please note that the percentage that passes sieve 200 is primarily clays, pigments, and indigestible portions of Portland cement and not considered part of the aggregate.

MICROSCOPIC ANALYSIS

The aggregate from all three samples is similar and composed of sub-angular clear and cloudy white quartz throughout the size gradations with a small mix of various colored inclusions, including orange and green quartz, and granite. The overall hue of the aggregates is beige. All of the minerals are local to this region of Colorado. Images of the aggregate from each sample are included in the appendix for reference.



[1]

Image 1: Representative image of aggregate.

[1] Powers, M.C., 1953, Journal of Sedimentary Petrology, v.23, p. 116

COMPRESSION ANALYSIS

Test procedure:

- A portion of each supplied sample was selected for testing and the dimensions for each were recorded
- The sample was placed on a 56Kn point load tester equipped with a ball-seated flat platen to allow for proper seating
- The sample was compressed until failure and the peak pressure recorded
- The compressive strength was determined and converted to the PSI standard

NOTE: Sample 3 (Curb) was the only sample of sufficient size to conduct compression testing.

Sample #	**3**
Sample Location	**Curb at parking lot**
Name	**Fall River Entrance Station**
Date	**09.17.2021**

Sample Height (mm)	14.45
Sample Width (mm)	23.46
Sample Depth (mm)	27.43
Max Kn at failure	2.654
Kn/sectional area	0.005088598
PSI	**738.0387235**

Mortar Type Per ASTM C270	Min. Compressive Strength
M	2500 psi
S	1800 psi
N	750 psi
O	350 psi
K	75 psi

MORTAR MIX RATIOS

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The mortar samples were taken from stone construction, with the stone likely being predominantly granite. Due to the durable nature of granite and the exposed location, a type O mortar is recommended for areas represented by samples 1 and 2. Sample 3 was more difficult to crush and resisted acid digestion significantly more than the other samples, indicating that it had a higher strength and percentage of Portland cement. Compression testing of sample 3 suggests that this mortar was closest to the type N category.

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Mortar Types
(Measured by volume)

Designation	Cement	Hydrated Lime or Lime Putty	Sand
M	1	1/4	3 - 3 ¾
S	1	1/2	4 - 4 ½
N	1	1	5 – 6
O	1	2	8 – 9
K	1	3	10 – 12
"L"	0	1	2 1/4 – 3

Suggested Mortar Types for Different Exposures

	Exposure		
Masonry Material	Sheltered	Moderate	Severe
Very durable: granite, hard-cored brick, etc.	O	N	S
Moderately durable: limestone, durable stone, molded brick	K	O	N
Minimally durable: soft hand-made brick	"L"	K	O

2

[2] Technical Preservation Services, National Park Service. "Repointing Mortar Joints in Historic Masonry Buildings" 1980 http://www.cr.nps.gov/hps/tps/briefs/brief02.htm

COLOR MATCHING

Once an aggregate has been selected several small (roughly 1 cup) test batches should be mixed in the prescribed ratios. Matching the color as closely as possible with the aggregate is the best approach, but this testing period is when various pigments and additives can be tried to determine how best to match the existing color. Volcanic pumice, lamp black, and bone black are all chemically stable coloring agents that resist fading in the sun.

Using a masonry specific pigment, each test batch should be mixed with varying quantities and combinations of pigment to produce a palette of choices. It is important that each batch be labeled, and that precise notes are kept of the pigment recipe. Once allowed to dry the building owner or project manager should inspect the samples and select the one that best matches the remainder of the wall. The recipe for that sample should then become the master recipe for the project. It is important to note that mortar color can be different from one part of the wall to another, so if a discernible difference in color is noted as work progresses than the recipe should be altered to maintain uniformity.

Matching the new mortar to the existing will be a challenge because of the discoloration of the original mortar from dirt and plant growth. Options to address this include:

- Match the new mortar to the original and let the discoloration occur naturally
- Match the new mortar to the existing, keeping in mind that the pigments might weather differently
- Clean the masonry to remove the discoloration

APPENDIX

Mortar Analysis for Ratio and Aggregate Distribution Procedure

Goals

To identify the proportions and characteristics of the three main components of historic mortars; the binder, the fines and the aggregate. The binder, principally calcium carbonate ($CaCO_3$), is dissolved in acid. The fines (clay and other fine particles) are separated while in solution from the aggregate (typically sand). The procedure is designed mainly for historic lime and sand mortars. To determine proportions of cement in mortars, the calcimeter mortar analysis should be followed, however this simple mortar analysis may provide some useful information on the character of cement mortars.

Equipment and supplies

400 ml beakers, 250 ml Erlenmeyer flasks, steel mortar and pestle, funnels, filter paper (fast), sieve set, 20% solution hydrochloric acid, water, analytical balance, Petri dishes, stereomicroscope, wash bottle with water, safety eye wear

Procedure

1. Collect 3 samples (at least 10 grams)
2. Examine the samples and record the characteristics: color, texture, hardness, inclusions
3. Powder 2 samples for analysis with mortar and pestle. Save the third for future reference.
4. Weigh each sample on a balance to .01 g precision. (If not dry, dry in oven first.) Record the weight on the data sheet.
5. Place each sample in a 250 ml flask and dampen with water.
6. Add enough HCl solution to cover sample. Avoid inhaling fumes. Observe and record reaction.
7. Add a drop of HCl solution to determine if reaction is complete. If fizzing occurs, add more acid. Repeat drop test until reaction is complete.
8. Label the filter papers to be used with pencil with your name and sample number.
9. Weigh each filter paper and record on the data sheet.
10. Fold the papers into quarters in place in the funnels with a 400 ml beaker below each.
11. Slowly add water to the sample flask.
12. Swirl to suspend the fines.
13. Slowly pour the liquid with the suspended fines into the filter paper, keeping the aggregate in the flask.
14. Repeat 11 through 13 until the water runs clear.
15. After the water has completely drained, carefully remove the filter paper and dry it in the oven.
16. Label and weigh another set of filter papers and record the weights in the data sheet.
17. Wash all the aggregate from the flask into the filter papers.
18. After the water has completely drained, carefully remove the filter papers and dry them in the oven.
19. Weight the filter papers with the dry fines. Record the weights.
20. Subtract the weight of the filter paper to determine the weight of the fines.
21. Weight the filter papers with the aggregate. Record the weights.
22. Subtract the weight of the filter paper to determine the weight of the aggregate.
23. Express the amount of fines and the amount of sand as percentages of the whole initial sample weight. The amount of the dissolved binder is determined by adding the weights of the sand and the fines and subtracting from the total initial sample weight.
24. Examine the aggregate under a stereomicroscope. Record the characteristics (color, shape, size) of the particles and their relative distribution.
25. Sieve the aggregate in a standard sieve set. First weight each sieve. Then add sample and carefully shake. Reweigh each sieve. Then clean each sieve. Express the weight of each particle size as a percentage of the whole.

AGGREGATE DOCUMENTATION

Image 2: Sample 1, representative aggregate

Image 3: Sample 1, , representative aggregate

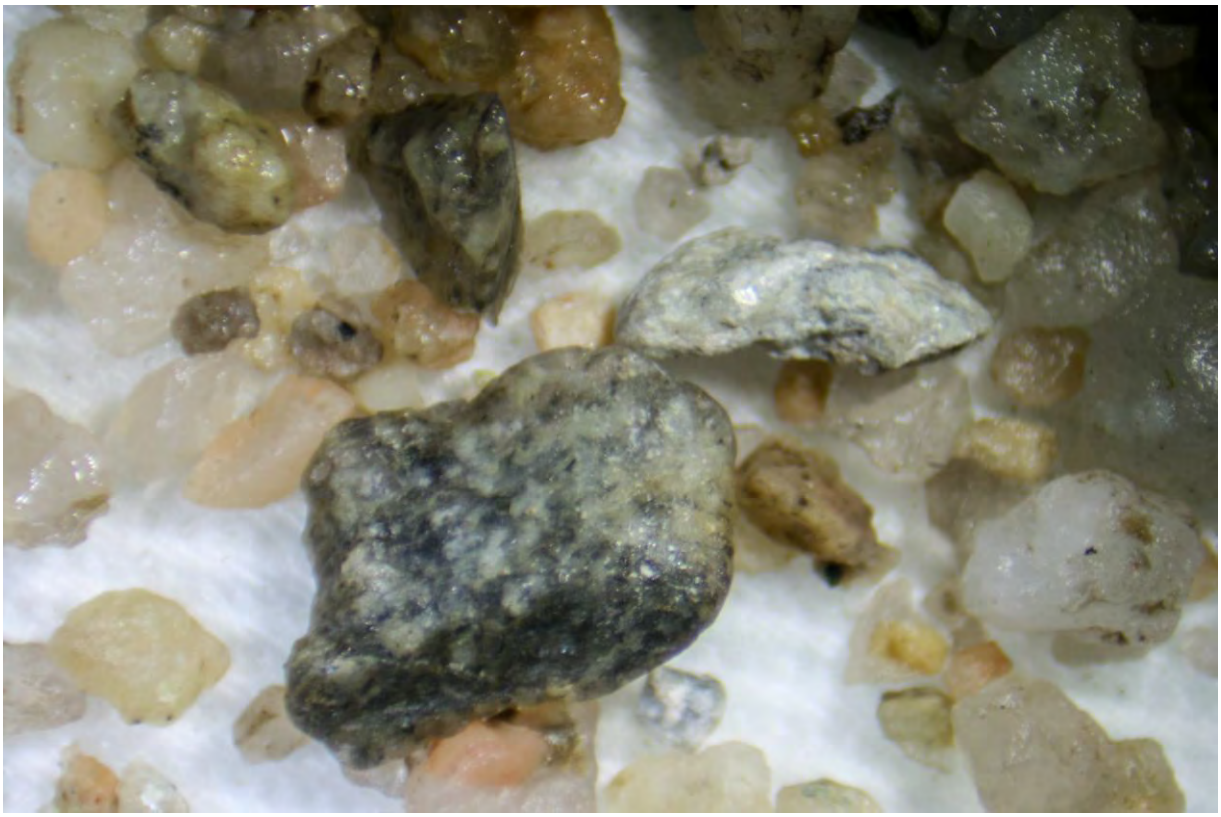

Image 4: Sample 2, representative aggregate

Image 5: Sample 2, representative aggregate

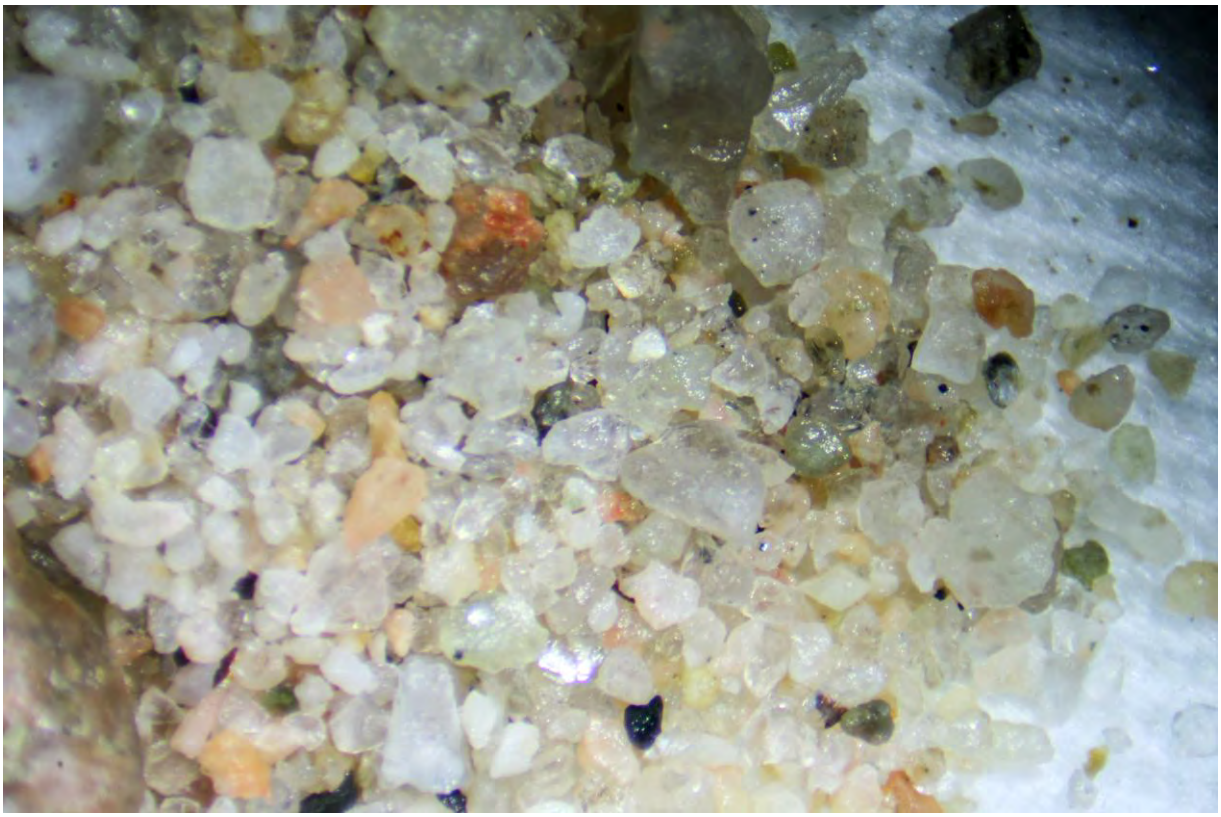

Image 6: Sample 3, representative aggregate

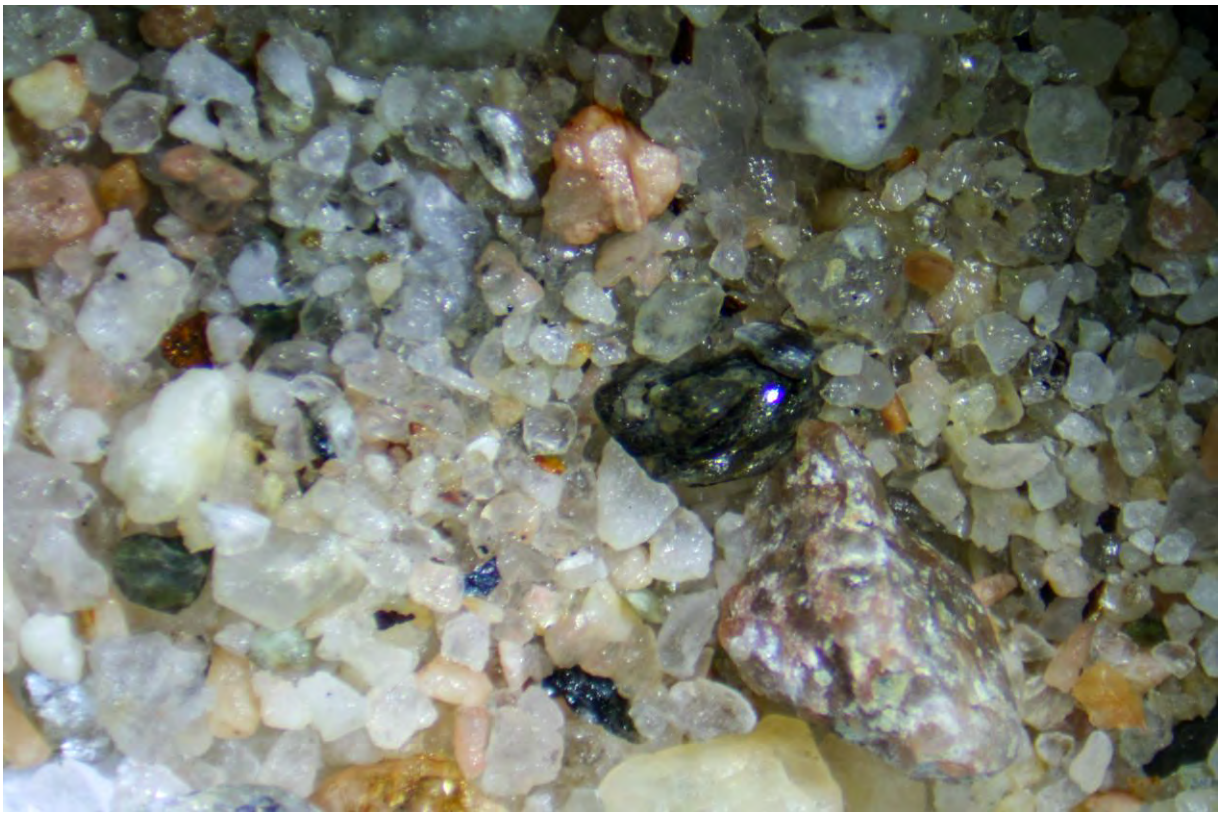

Image 7: Sample 3, representative aggregate