HOW DOES THE HURRICANE HARVEY DEPOSITS COMPARE TO PAST BRAZOS SUBAQUEOUS DELTA FLOOD DEPOSITS

An Undergraduate Research Scholars Thesis

by

CHRISTENA HOELSCHER

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ABSTRACT

How does the Hurricane Harvey Deposits Compare to Past Brazos Subaqueous Delta Flood Deposits?

Christena Hoelscher
Department of Marine Science
Texas A&M University

Research Advisor: Dr. Tim Dellapenna
Department of Marine Science
Texas A&M University

Hurricane Harvey brought over 100 cm of rain to the lower drainage basin of the Brazos River and resulted in the highest discharge event in the recorded history of the river. On Sept. 10th, 2017, during the waning phase of the flood, we were able to collect a series of 15 box cores and 14 surface/bottom water samples. We were also able to collect water column profiles of temperature, salinity, turbidity, and dissolved oxygen while participating in a research cruise aboard the R/V Pelican. This data is part of a larger time series that began after the 2015 and 2016 floods and will continue with a follow up coring cruise scheduled for October 28, 2017. By investigating the sediment grain size, flood layer thickness, suspended sediment concentrations, and plume dynamics, we hope to gain a better understanding how and where the initial flood pulse was deposited. For this study, I hypothesize that the Harvey flood layer will have the largest flood deposit compared to past deposits

ACKNOWLEDGEMENTS

I would like to thank my Research Advisor, Dr. Dellapenna, and the members of his lab for the guidance and support in this research. I would also like to thank the crew of the R/V Pelican and the R/V Trident for the assistance when collecting the data needed. I would also like to thank the NSF for funding this project.

NOMENCLATURE

GOM	Gulf of Mexico

CHAPTER I

INTRODUCTION

Rivers have a significant influence on the world's ocean basins and the ecosystem. They are responsible for delivering more than 20 billion tons of dissolved and solid discharge to the world's oceans, which is important because needed nutrients, oxygen, sediment, and fresh water are delivered to these basins help sustain life (Milliman, 2011). These constituents comprise the total discharge of the river. The amount of discharge is a direct result of local/regional climate and the size of the drainage basin, the larger the river basin, the greater the discharge (Milliman, 2011).

There are two factors considered when discussing the climate: evapotranspiration and precipitation. Evapotranspiration is defined by the amount of water lost due to evaporation and plant transpiration, and precipitation is the amount of rain or snow fall in a given area (Milliman, 2011). The amount of precipitation received can change the amount of river runoff produced. Rivers can be categorized based off of this production. Precipitation can range from arid(<100mm/yr) to wet or high-runoff (>750 mm/yr) (Milliman, 2011). In this runoff, sediment can be eroded into the river and delivered to the ocean. The amount of sediment carried in a given amount of time is known as the sediment discharge. The amount of rainfall received has a direct influence on the sediment discharge of the river. For an example, Taiwan experiences a significant amount of sediment erosion due to rains created by typhoons (Milliman, 2011). This sediment is then carried into the ocean basin where it is deposited into layers, each of which can be related to a specific event in time, such as a hurricane or a major flood event.

In 2017, Hurricane Harvey made landfall in Texas and caused historically unprecedented flooding in the Houston area and across much of the lower drainage basins of both the Brazos and Colorado Rivers. This floodwater drained into the Brazos River where it then deposited the runoff sediment and nutrients onto the Brazos Subaqueous Delta. The purpose of this project is to: 1) study the flood layer from Hurricane Harvey deposited by the Brazos River, and compare it to past flood layers deposited by the Brazos and 2) determine the fate of the Hurricane Harvey flood layer. The amount of precipitation received plays a major role in sediment discharge of river systems in the Gulf of Mexico (GOM). This is because during rainfall, not only is the river carrying sediment from eroded surfaces, but is also transporting sediment that drained into the river system through run off (Millman, 2011). This sediment load is mainly controlled by the amount of precipitation received annually (Douglas, 1967). The sediment load can increase drastically if there is a large enough flood event (Fraticelli, 2006).

On September 10, 2017, during a cruise aboard the R/V Pelican, a series of box cores were collected at 15 different sites across and along the Brazos River subaqueous delta (Fig 4). These cores were collected to delineate the flood layer deposited by Hurricane Harvey and to make comparisons to previous flood layers as well as to provide a baseline for future flood layer-mapping efforts. Hurricane Harvey delivered an unparalleled 1.0 to 1.3 m of rain to the lower drainage basin of the Brazos River (Fig. 1 and 2; Ramsey, 2017).

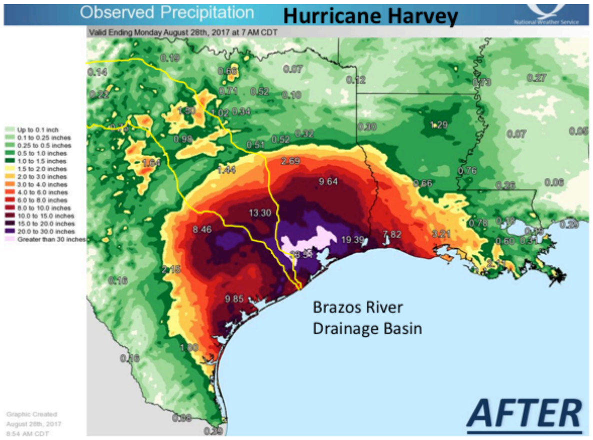


Figure 1. Rain Fall Map of Hurricane Harvey. The total precipitation form Hurricane Harvey, as of 8:45 AM CDT on August 28, 2017. Note, there were three more days of precipitation not depicted in this map. The Brazos River Drainage Basin is outlined in yellow. Note, that the bulk of the precipitation occurred in the lower Brazos River drainage basin.

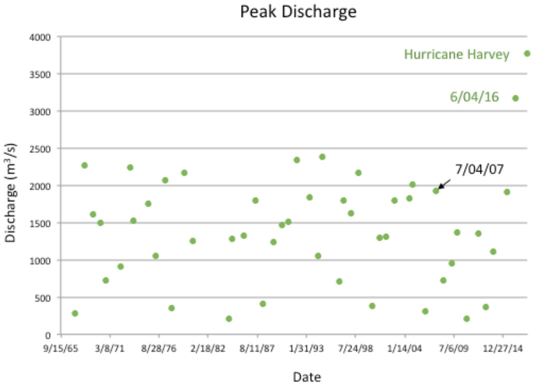


Figure 2. Historical Brazos River Peak Discharges. The last three peak dischargesare noted in this figure, note that the last two peak discharge events, 8/29/17 and 06/04/16 were each record

discharge events. The TAMUG Coastal Geology Laboratory sampled the noted events on this figure

In the GOM, the two main river systems that contribute to the sediment flux are: the Mississippi and the Brazos Rivers. It is estimated that there is about 54 millimeters of sediment being deposited in the GOM every year by the Brazos (Ludwig, 1998).

This runoff depends heavily on the amount of rainfall received that year. Since Hurricane Harvey produced record flooding, record discharge was produced by the Brazos during this time (Figure 3).

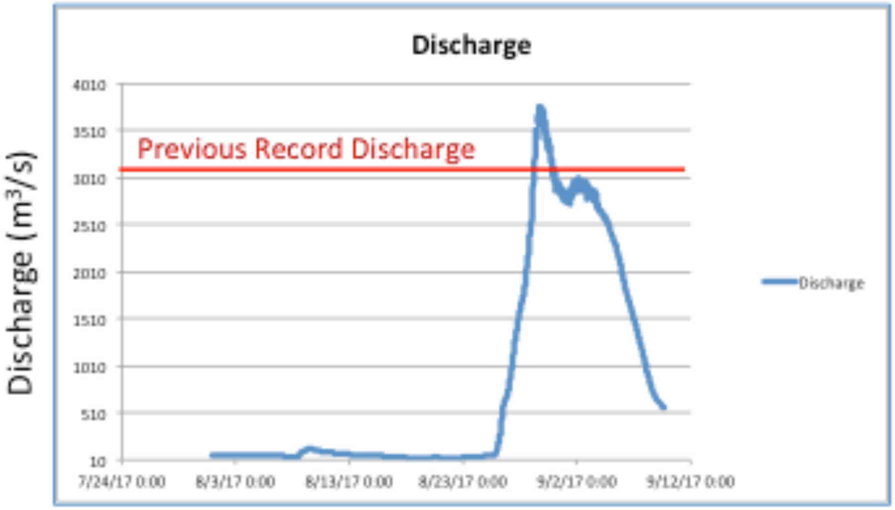


Figure 3. Discharge graph of the Brazos River. The Previous Record Discharge was produced from the June 2016 flood.

Preliminary results from this cruise revealed a 250 mm thick storm layer was deposited as a result of the flood pulse/runoff from Hurricane Harvey. This layer can be differentiated from the GOM sediment by the coloration. The sediment that is deposited from the Brazos has a distinct red-brown color, where as the GOM sediment is a grey color (Carlin, 2014). For this study, I hypothesize that the Harvey flood layer will have the largest flood deposit compared to past deposits since this storm produced record flooding in this region, and that this flood layer will distribute across the GOM throughout the winter.

CHAPTER II

METHODS

Sampling

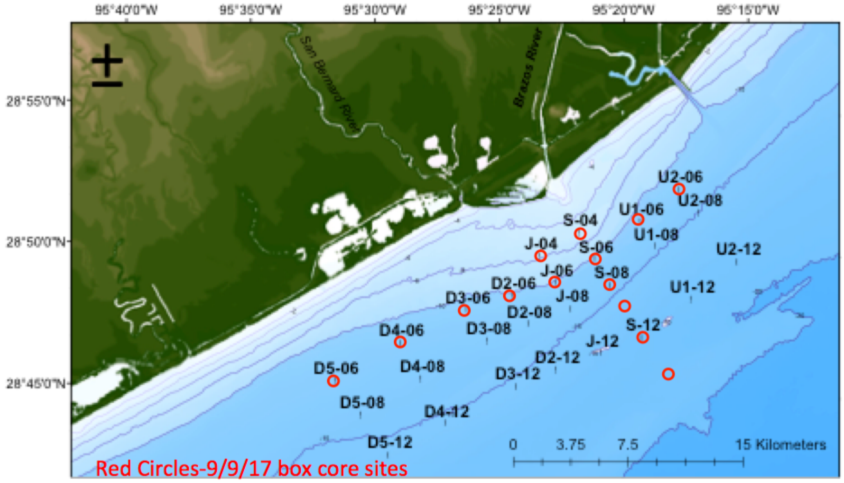
The samples were collected in a grid pattern off of the Brazos Subaqueous Delta on the R/V *Pelican* on September 10, 2017 (Figure 4). The sampling area is about 190 km^2 and consists of 26 total sampling locations. Each sample name is related to the distance it is from the shore in kilometers (i.e. D5-06 is 6 km offshore). On the cruise with the R/V *Pelican,* 15 of the 26 sites were sampled due to lack of time (Table 1). The full 26 locations were sampled on a second cruise aboard the R/V *Trident* in October 29, 2017. They were sampled using a box corer. From these box cores, a series of sub cores were taken.

On the cruise in September 2017, most of the sub cores included a 15.24 cm, a 7.62 cm, and a Plexiglass x-ray tray. Some sights did not get all of the sub cores: Bra-09 only got a small x-ray tray since the box core could not penetrate past the sand, U2-06 and S-04 got an acrylic sub core instead of an aluminum one, and U1-06 did not get an aluminum sub core since the box core was damaged due to unknown causes.

The 15.24 cm diameter subcore was subsectioned into 1 cm thick slices. From each slice, subsamples were collected for water content and grain size analyses. The x-ray trays were used to collect a digital x-ray to analyze sedimentary fabric. The 7.62 cm diameter subcore was archived intact for future analyses

On the October 2017 cruise, most sites got a plexiglass x-ray tray along with a 7.62 cm aluminum sub core. D4-06 and D2-12 did not get a sample because the box core could not penetrate through the sand. Sites U1-08, U1-06, U2-08, and U2-12 used a polycarbonate sub core instead of a x-ray tray since there were limited amount of x-ray trays available.

The x-ray trays and polycarbonate cores were used to get x-ray radiographs to study to sedimentary layers. The aluminum cores were extruded and sub samples of every other centimeter were collected for further analysis on water content and grain size analyses.



Red Circles-9/9/17 box core sites

Figure 4. A map of the coring sites. The red circles are showing the cores taken in September 2017, and the rest of the sites were collected during the October 2017 cruise.

Table 1. Location and water depth for each core collected off of the Brazos Subaqueous Delta and when it was taken.

Date Collected	**Core Name**	**Longitude**	**Latitude**	**Water Depth(m)**
09/10/2017	Bra-04	-95.409563	28.751862	16
09/10/2017	Bra-05	-95.402365	28.789098	13
09/10/2017	Bra-06	-95.397145	28.823235	10

09/10/2017	Bra-07	-95.391292	28.839358	9
09/10/2017	Bra-08	-95.387750	28.858380	3
09/10/2017	Bra-09	-95.386263	28.861372	2.24
09/10/2017	D5-06	-95.520075	28.756257	10
09/10/2017	D4-06	-95.477818	28.777628	11
09/10/2017	D3-06	-95.437852	28.7998692	10.43
09/10/2017	S-04	-95.360052	28.843873	11.02
09/10/2017	U1-06	-95.319775	28.851480	14.09
09/10/2017	U2-06	-95.293473	28.87460	13.26
10/29/17	D5-12	-95.484216	28.712820	16.73
10/29/17	D5-08	-95.503815	28.734887	13.92
10/29/17	D5-06	-95.520612	28.755320	11.61
10/29/17	D4-06	-95.477425	28.777992	11.03
10/29/17	D4-08	-95.463782	28.757408	13.53
10/29/17	D4-12	-95.446407	28.732125	16.5
10/29/17	D3-12	-95.399868	28.753715	17.3
10/29/17	D3-08	-95.418472	28.781573	14.02
10/29/17	D3-06	-95.433590	28.798952	11.31
10/29/17	D2-06	-95.403502	28.807187	12.44
10/29/17	D2-08	-95.39203	28.791233	15.03
10/29/17	D2-12	-95.372355	28.763947	18.41
10/29/17	J-12	-95.34.2942	28.774793	19.63

10/29/17	J-08	-95.360447	28.800293	16.03
10/29/17	J-06	-95.374582	28.816137	13.53
10/29/17	J-04	-95.385530	28.831117	11.03
10/29/17	S-04	-95.358387	28.845352	12.01
10/29/17	S-06	-95.348145	28.829580	14.23
10/29/17	S-08	-95.337572	28.814683	16.31
10/29/17	S-12	-95.317082	28.783562	19.72
10/29/17	U1-12	-95.284127	28.807228	19.63
10/29/17	U1-08	-95.305960	28.837490	16.52
10/29/17	U1-06	-95.318187	28.852517	14.42
10/29/17	U2-06	-95.292305	28.871050	14.42
10/29/17	U2-08	-95.281958	28.859267	16.52
10/29/17	U2-12	-95.254015	28.82.8935	19.72

Longitudes and latitudes are shown in decimal degrees.

Grain Size Analyses

The samples were homogenized and sampled using a Malvern Mastersizer 2000 particle analyzer to determine the grain size distribution of each sample. This device separates the grain sizes (from clay to sand sized particles) using laser diffraction. The samples from the September 2017 cruise were collected at 1 cm intervals (i.e. 0-1cm then 1-2cm) up until the 10cm mark, and then they were collected every other centimeter (i.e. 10-11 cm then 12-13 cm). The samples from the October core were collected every other centimeter.

Water Content

Water content analysis was conducted using the same samples as the Grain Size Analyses. First, aluminum tins were weighed with out sediment. Then, sediment was added until the weight was equal to around 8.00g. The tins were then loaded onto a baking sheet and placed in an oven over night at 148.89°C. The tins were then cooled the next morning and weighed again. The percent water content was then calculated using the equation below:

$$\%Water\ Content = \frac{(('Tin\ \&Wet\ Sample' - Tin) - ('Tin\ \&\ Dry\ Sample' - Tin)}{('Tin\&Dry\ Sample' - Tin)} * 100$$

CHAPTER III

RESULTS

Water Content

Looking at the water content data collected, on average, the sediment through out the core is about 50% water. The average percentage at the surface ranged from 50% to 60%. This range then decreased rapidly to around 35 to 45% with depth and then fluctuated the rest of the way through the core.

Grain Size Analysis

The main sediment size component in these cores was silt followed by clay and then sand (Table 2). The sand was more abundant in the middle of the cores, then decreases toward the surface. This shows that there is a fining upward trend, which can be seen in about 66% of the cores collected (Table 2).

Table 2. Average grain size data for the boxcores collected for both the September 2017 cruise and the October 2017 cruise.

	Sand (%)	**Silt (%)**	**Clay (%)**	**Fining trend**
Min	0.056	12.569	4.359	
Max	78.272	74.447	56.906	
Average	15.9	52.6	33.8	66%

Flood Thickness Comparison

By using the water content, grain size, and the x-radiographs, the thickness of the flood layer was determined. Further details on this can be seen in the next section. When comparing the flood layer results between the cores collected in September, the flood layer is thickest at the mouth of the river then it fans out as it moves out further into the GOM (Figure 5). With the cores collected in October, the thickness seems to be thinner by the mouth and shore, and get thicker toward the GOM (Figure 6). When comparing the layer thickness to past flood layer data, almost 50% of the cores collected both during the September cruise and the October cruise had a larger flood layer than that of the past flood layers (Table 3).

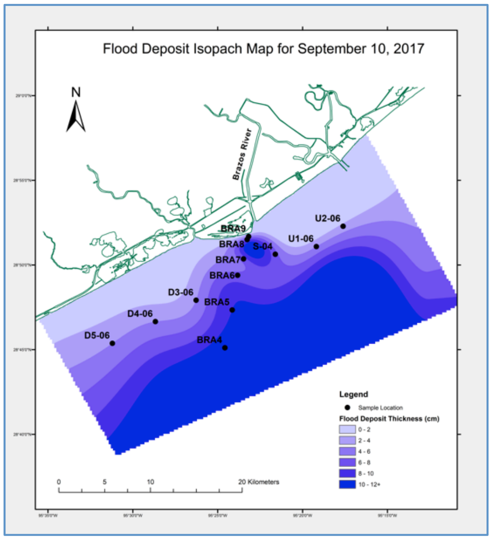


Figure 5. A map showing the Hurricane Harvey flood layer thickness on the Brazos Subaqueous Delta on September 10, 2017.

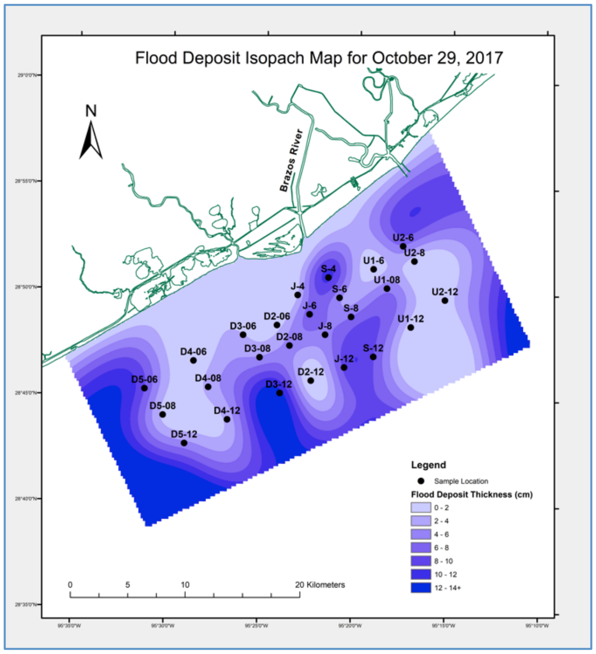


Figure 6. A map showing the Hurricane Harvey flood layer thickness on the Brazos Subaqueous Delta on October 29, 2017.

Table 3. Data of average flood layer thickness of both Hurricane Harvey and Floods in 2016.

	Hurricane Harvey (cm)	**Floods in 2016 (cm)**
Minimum	2.1	3
Maximum	15.5	38.5
Average	September: 7.4 cm October: 5.55 cm Total: 6.19 cm	8.98
Larger than 2016 Flood layers	45.83%	

Discussion

The water content, grain size, and x-radiographs were used to help determining the thickness of the flood layer produced by Hurricane Harvey. In a storm layer, high water content may be observed at the surface because it is deposited quickly, and may decrease throughout time because it is reworked and compacted under other layers (Wheatcroft et al., 1996, Wheatcroft et al., 2006). This is the reason why in most of the cores collected after Hurricane Harvey have a spike of water content on the surface and a sharp decrease. The samples collected post-Harvey did not reach water content of 80% most likely because the main grain size was silt and not mud, which has lower water content.

In flood layers, it is common to see either a coarsening upward or fining upward trend due to the change in energy during the storm. Most of the samples collected had a fining upward trend, which shows there was a large flux of energy, and then it decreased. This can also be seen in the x-radiographs as layers where the lighter sections are coarser material (mainly sand) and the darker sections are finer and denser material (mainly clays or silts).

When studying the flood layer thicknesses between the September and the October cores, there is a decrease between them. This is because the layer is being reworked and remobilized by wave action in the GOM. This also explains why some of the Hurricane Harvey flood layers were not larger than the 2016 flood layer since the majority of them were collected one month after the flood event. Even so, almost half of the cores collected still contained a flood deposit that was larger than the 2016 flood layers, which supports the hypothesis that since Hurricane Harvey had record discharge, record flood layer thicknesses were deposited.

CHAPTER IV

CONCLUSION

This analysis showed the depositional pattern of the Hurricane Harvey flood layer and compared it to other flood deposits such as the 2016 Flood as well as showed the movement of the layer over the span of a month in the late fall. Hurricane Harvey deposits range from 2.1 cm to 15.5 cm on the Brazos Subaqueous Delta. During October, the layer was remobilized further off shore, which can be seen by the thinning of the layer in the near shore deposits. Since the Brazos River had record discharge during Hurricane Harvey due to the amount of flooding, the flood deposits were thicker than the 2016 flood deposits. The Harvey deposits were also reworked and remobilized across the shelf during the winter. Further cores should be taken to see how far the layer has been remobilized since it was deposited.

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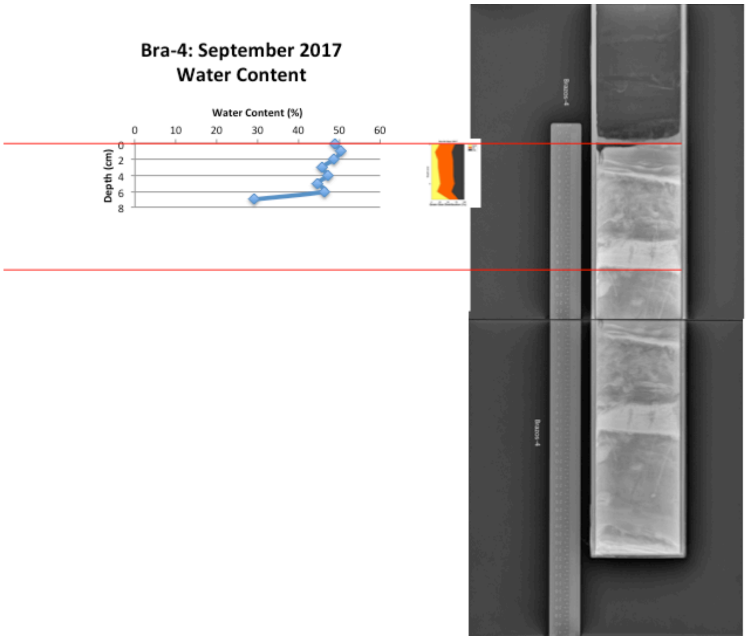
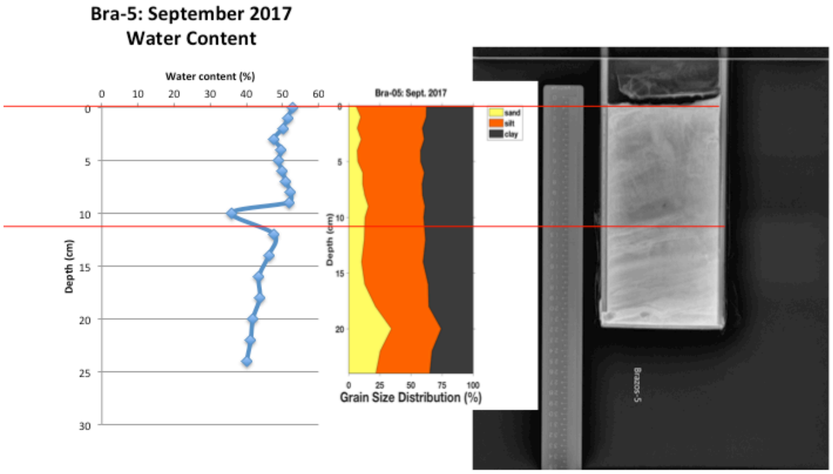
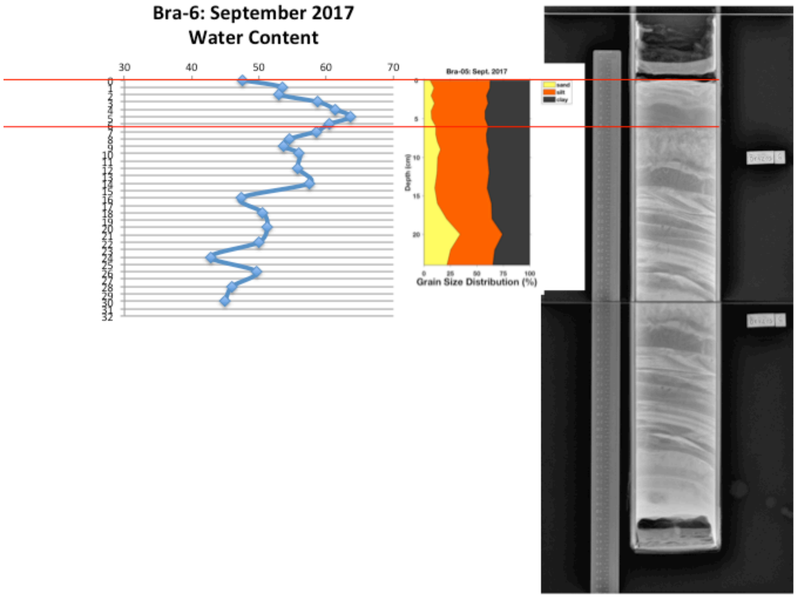
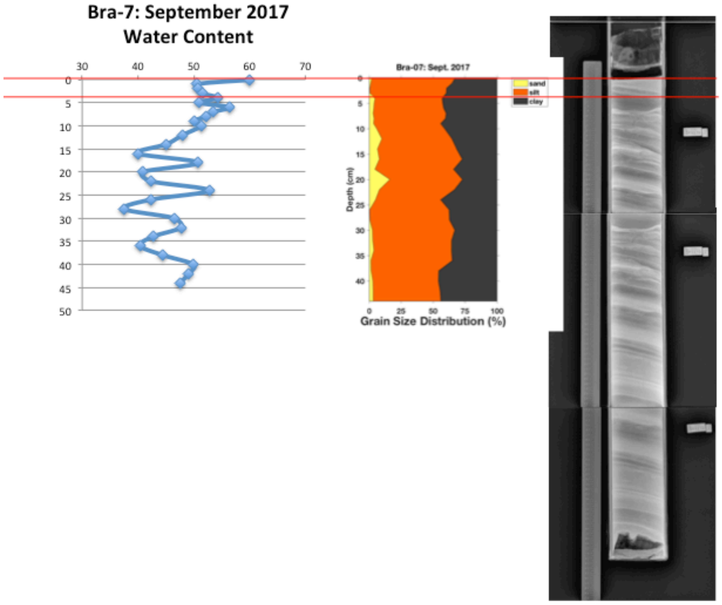
APPENDIX

September 10, 2017

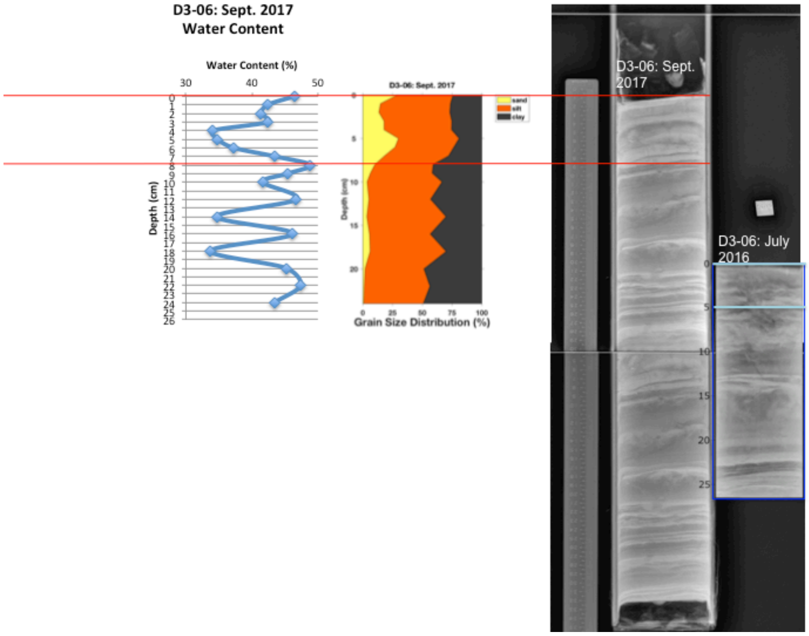


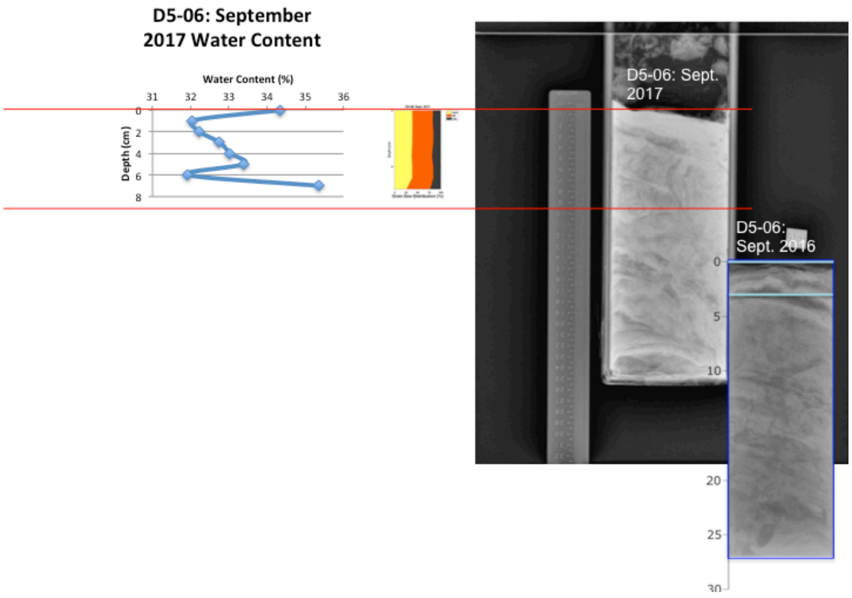


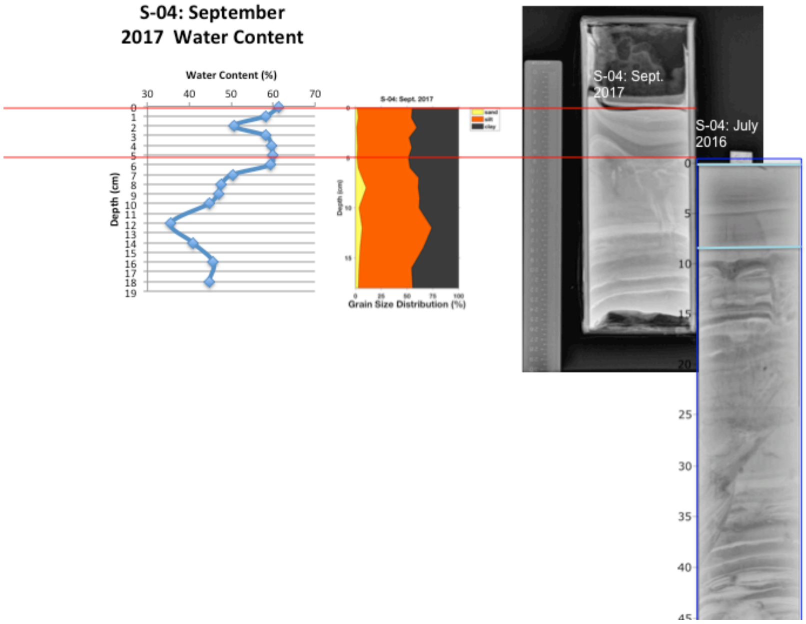

Bra-6: September 2017
Water Content
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
Bra-05: Sept. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
20
0
25
50
75
100
Grain Size Distribution (%)

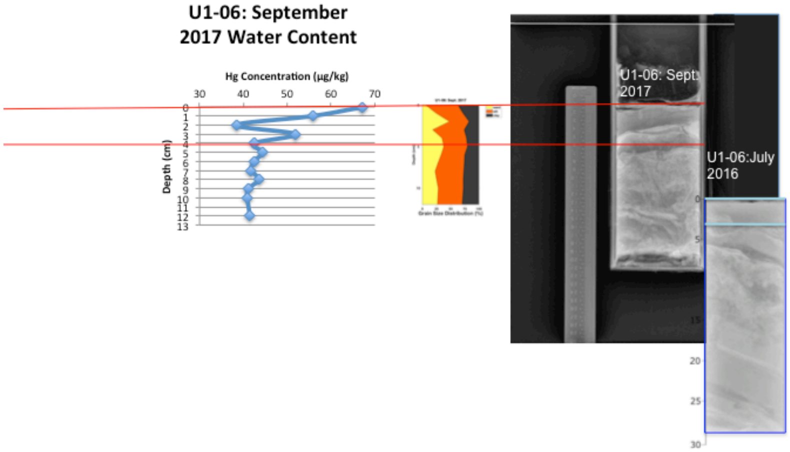

Bra-7: September 2017
Water Content
30
40
50
60
70
0
5
10
15
20
25
30
35
40
45
50
Bra-07: Sept. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
20
25
30
35
40
0
25
50
75
100
Grain Size Distribution (%)

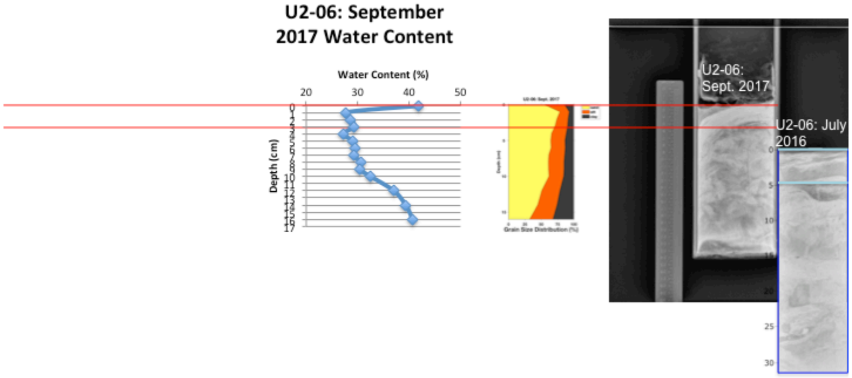

Bra-8: September 2017
Water Content
Water Content (%)
20
30
40
50
60
Depth (cm)
0
2
4
6
Brazos 8


D3-06: Sept. 2017
Water Content
Water Content (%)
30
40
50
Depth (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
D3-06: Sept. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
20
0
25
50
75
100
Grain Size Distribution (%)
D3-06: Sept. 2017
D3-06: July 2016
0
5
10
15
20
25

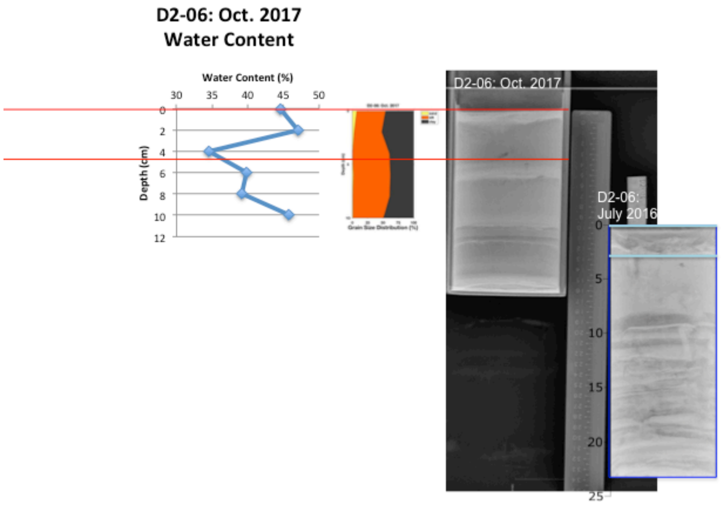

D5-06: September 2017 Water Content
Water Content (%)
31
32
33
34
35
36
0
2
4
6
8
Depth (cm)
D5-06: Sept. 2017
D5-06: Sept. 2016
0
5
10
20
25
30

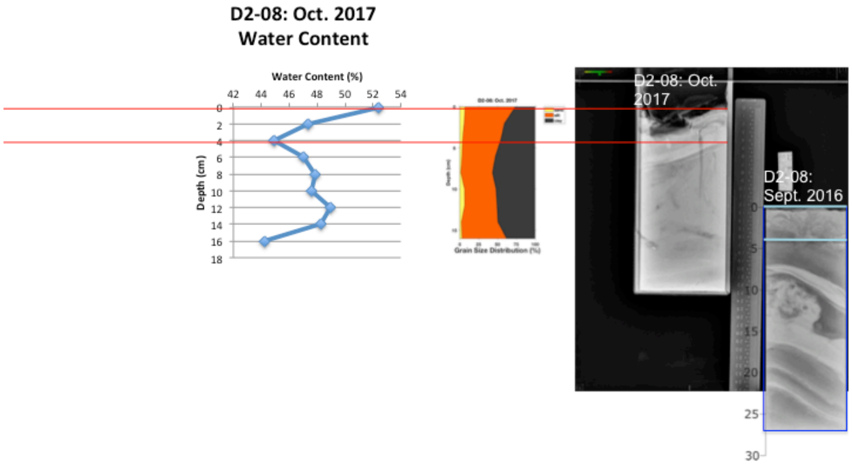

S-04: September 2017 Water Content
Water Content (%)
30
40
50
60
70
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
Depth (cm)
S-04: Sept. 2017
sand
silt
clay
0
5
10
15
Depth (cm)
0
25
50
75
100
Grain Size Distribution (%)
S-04: Sept. 2017
S-04: July 2016
0
5
10
15
20
25
30
35
40
45


U1-06: September 2017 Water Content
Hg Concentration (µg/kg)
30
40
50
60
70
Depth (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Grain Size Distribution (%)
U1-06: Sept. 2017
U1-06:July 2016
0
5
15
20
25
30

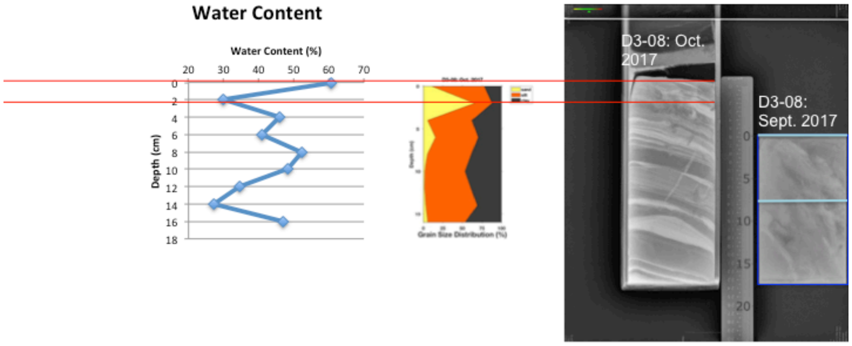

U2-06: September 2017 Water Content
Water Content (%)
20
30
40
50
Depth (cm)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
Grain Size Distribution (%)
U2-06: Sept. 2017
U2-06: July 2016
0
5
10
15
20
25
30

October 29, 2017

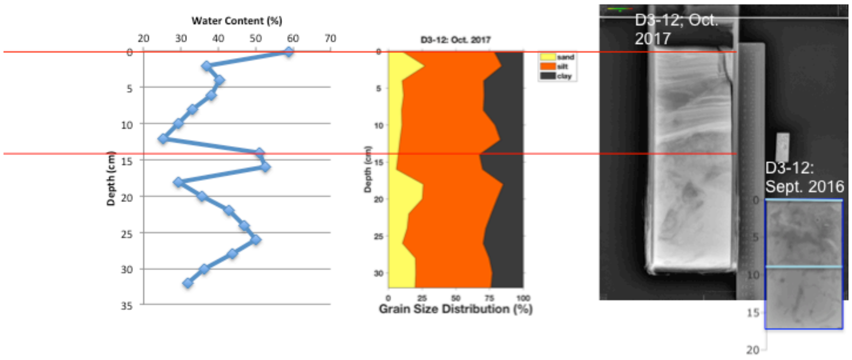


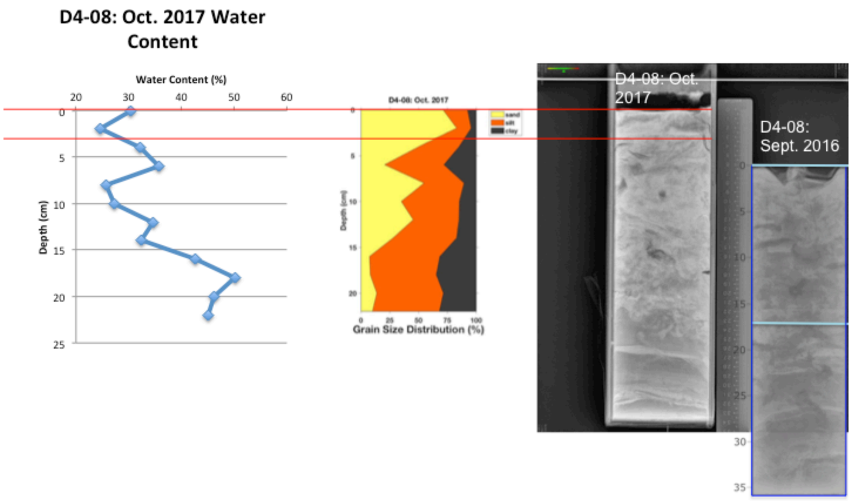


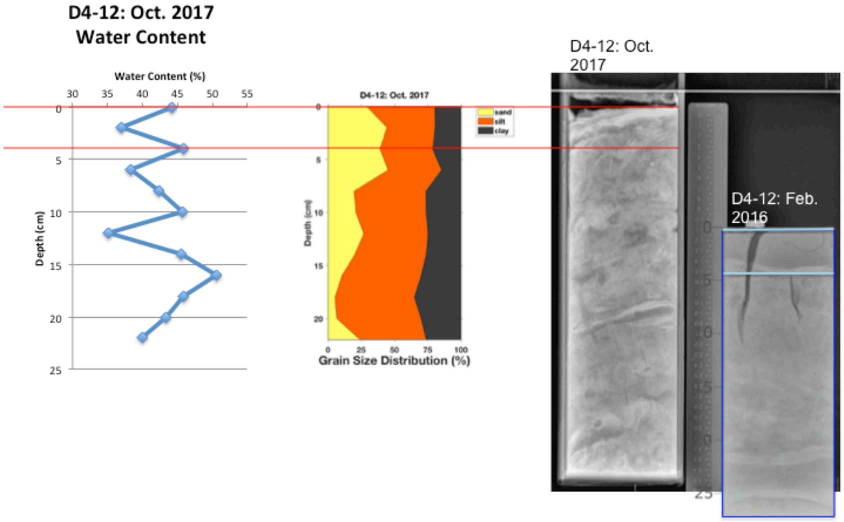
D3-08: Oct. 2017
Water Content

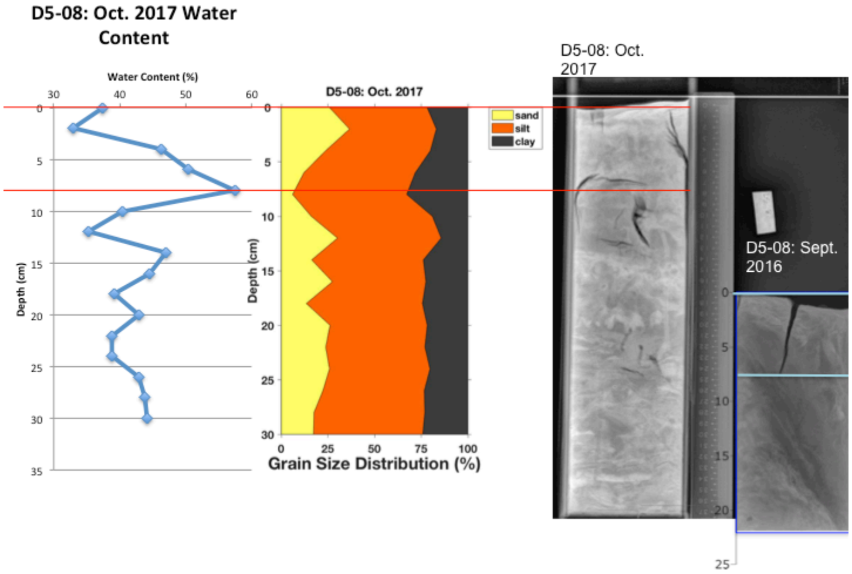


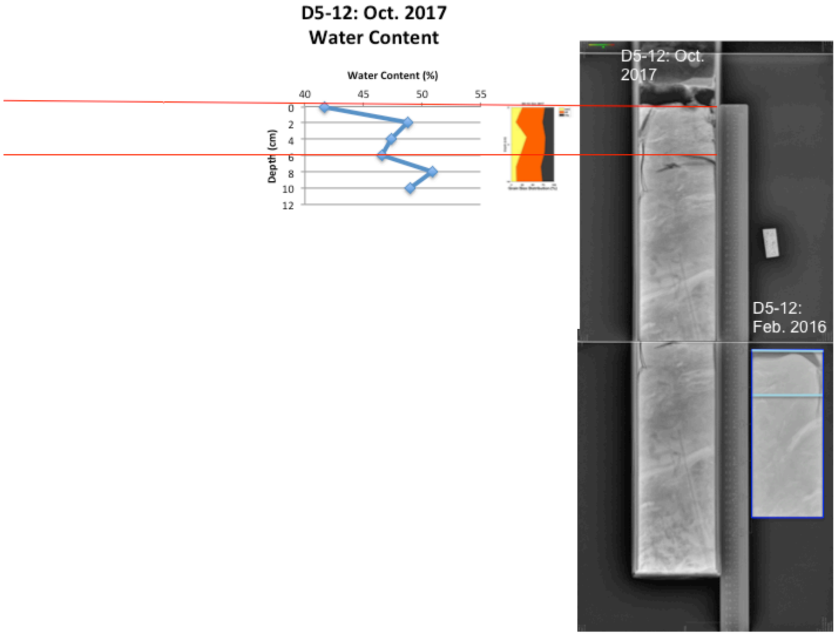
D3-12: Oct. 2017
Water Content

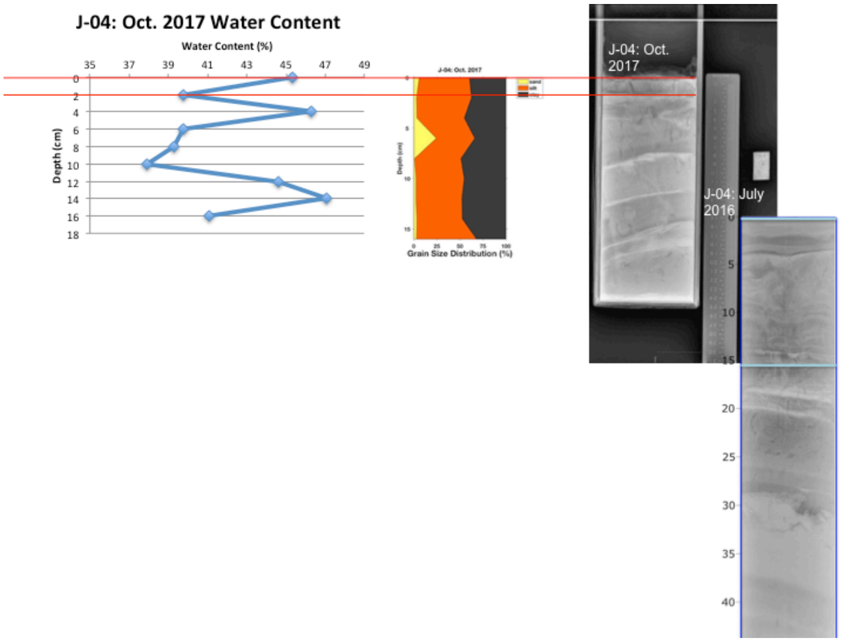


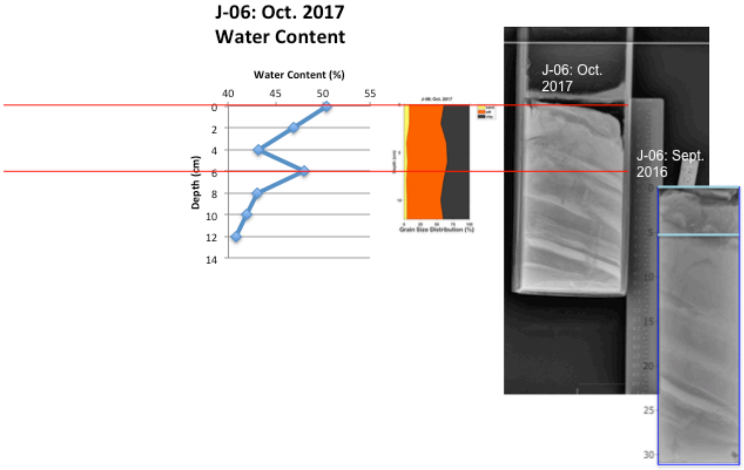

D4-08: Oct. 2017 Water Content
Water Content (%)
20
30
40
50
60
Depth (cm)
0
5
10
15
20
25
D4-08: Oct. 2017
sand
silt
clay
Grain Size Distribution (%)
0
25
50
75
100
D4-08: Oct. 2017
D4-08: Sept. 2016
30
35

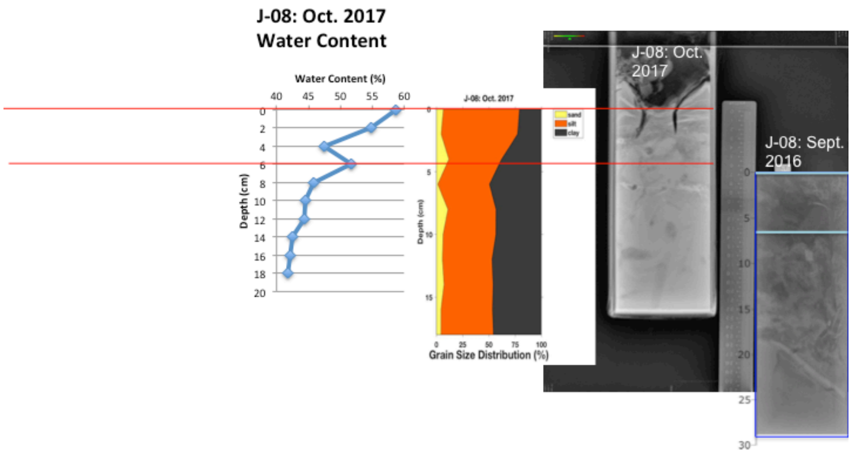

D4-12: Oct. 2017 Water Content
Water Content (%)
30
35
40
45
50
55
Depth (cm)
0
5
10
15
20
25
D4-12: Oct. 2017
sand
silt
clay
Grain Size Distribution (%)
0
25
50
75
100
D4-12: Oct. 2017
D4-12: Feb. 2016

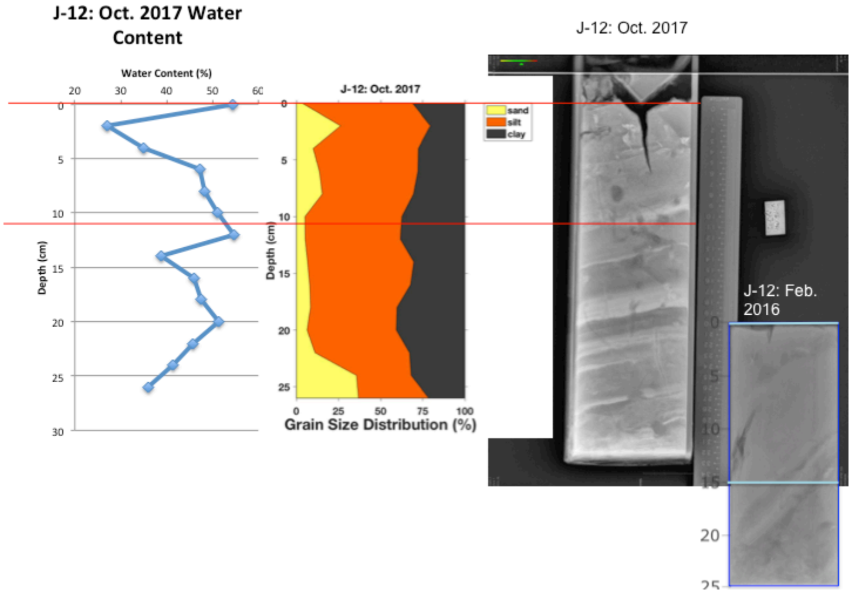

D5-08: Oct. 2017 Water Content
Water Content (%)
30
40
50
60
0
5
10
15
20
25
30
35
Depth (cm)
D5-08: Oct. 2017
sand
silt
clay
0
5
10
15
20
25
30
Depth (cm)
0
25
50
75
100
Grain Size Distribution (%)
D5-08: Oct. 2017
D5-08: Sept. 2016
0
5
10
15
20
25

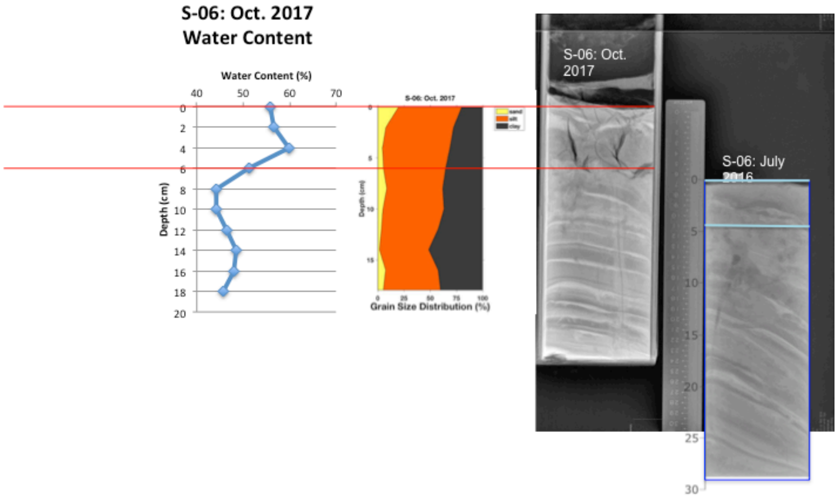

D5-12: Oct. 2017 Water Content
Water Content (%)
40
45
50
55
0
2
4
6
8
10
12
Depth (cm)
D5-12: Oct. 2017
D5-12: Feb. 2016

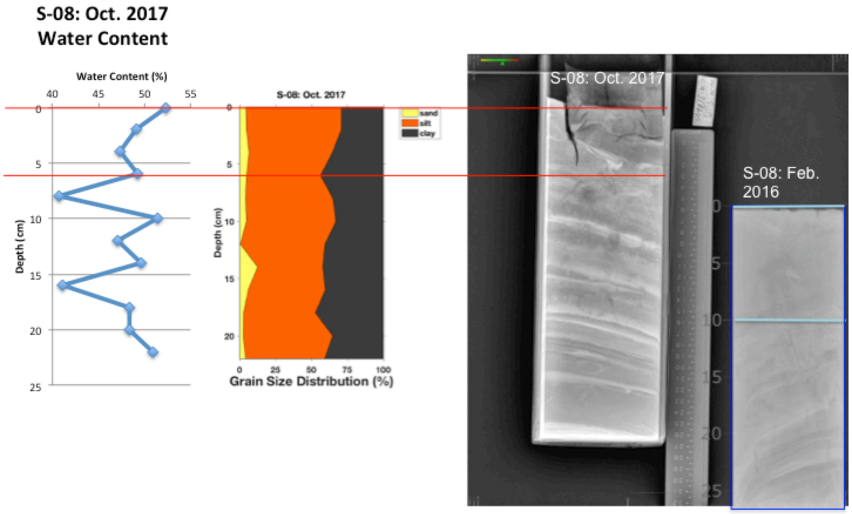

J-04: Oct. 2017 Water Content
Water Content (%)
35
37
39
41
43
45
47
49
Depth (cm)
0
2
4
6
8
10
12
14
16
18
J-04: Oct. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
0
25
50
75
100
Grain Size Distribution (%)
J-04: Oct. 2017
J-04: July 2016
5
10
15
20
25
30
35
40

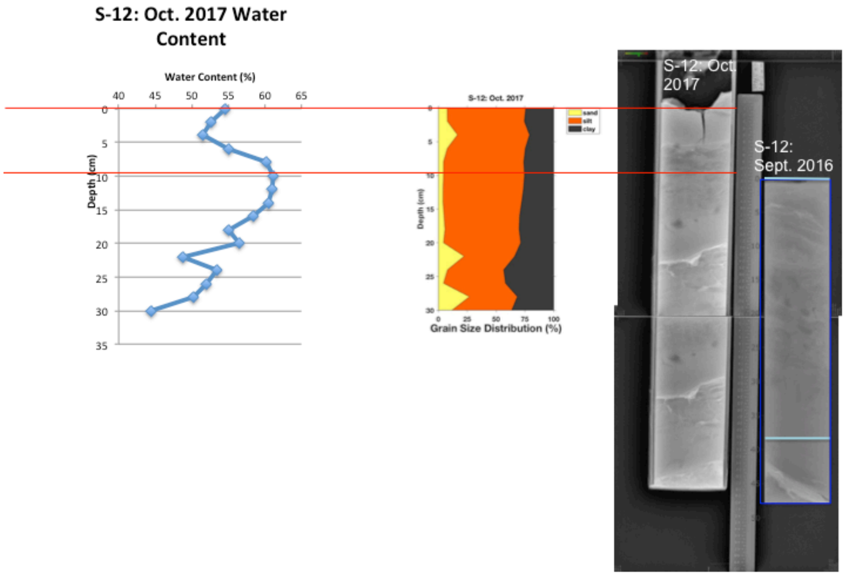

J-06: Oct. 2017 Water Content
Water Content (%)
40
45
50
55
Depth (cm)
0
2
4
6
8
10
12
14
J-06: Oct. 2017
Grain Size Distribution (%)
J-06: Oct. 2017
J-06: Sept. 2016
10
15
20
25
30

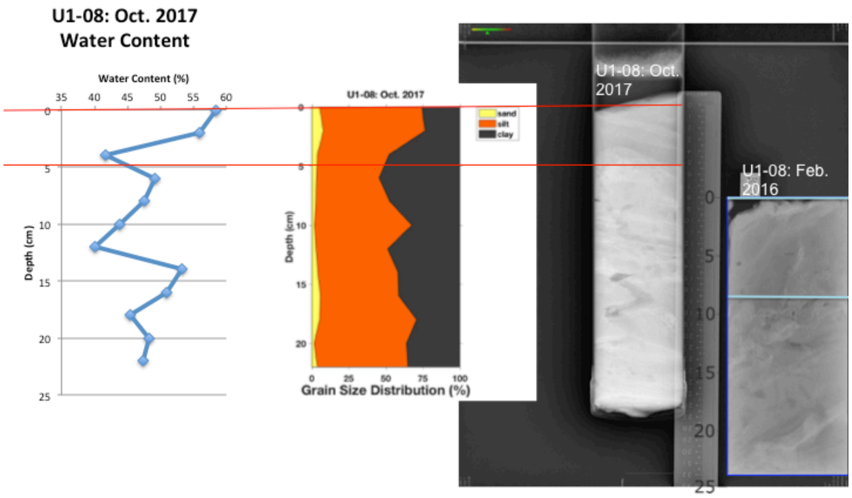

J-08: Oct. 2017
Water Content
Water Content (%)
40
45
50
55
60
0
2
4
6
8
10
12
14
16
18
20
Depth (cm)
J-08: Oct. 2017
sand
silt
clay
Depth (cm)
5
10
15
0
25
50
75
100
Grain Size Distribution (%)
J-08: Oct.
2017
J-08: Sept.
2016
0
5
10
15
20
25
30

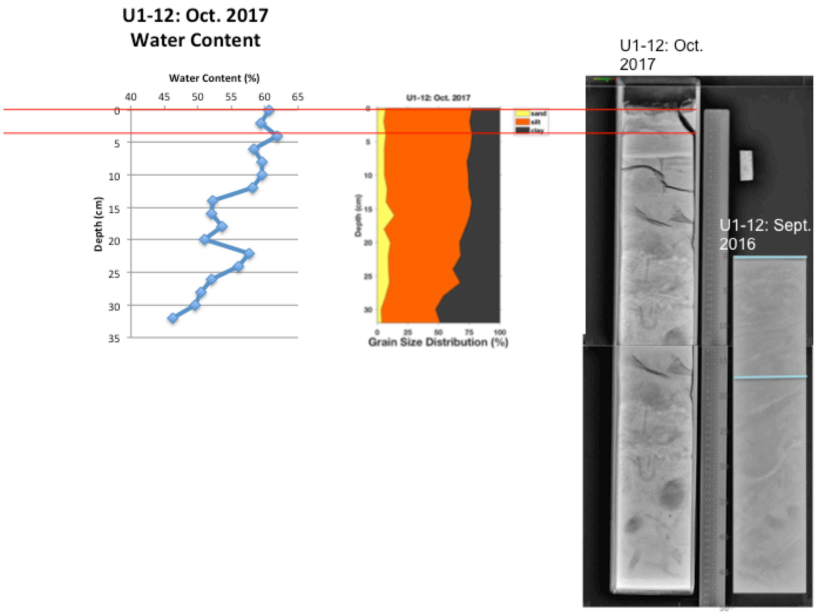

J-12: Oct. 2017 Water
Content
Water Content (%)
20
30
40
50
60
0
5
10
15
20
25
30
Depth (cm)
J-12: Oct. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
20
25
0
25
50
75
100
Grain Size Distribution (%)
J-12: Oct. 2017
J-12: Feb.
2016
0
5
10
15
20
25

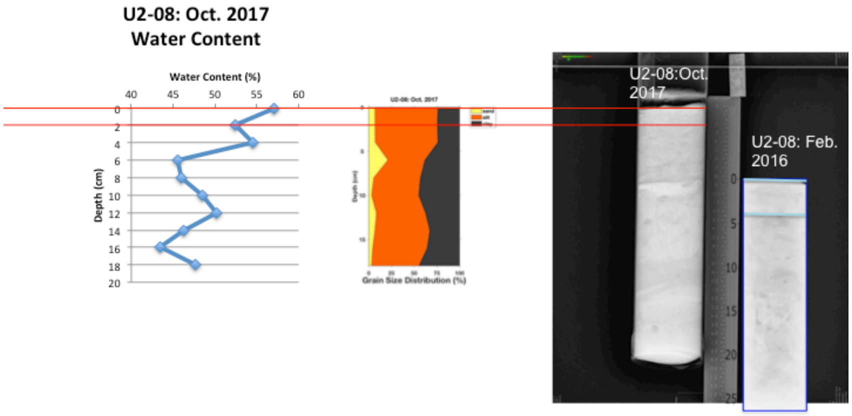

S-06: Oct. 2017
Water Content
Water Content (%)
40
50
60
70
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
S-06: Oct. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
0
25
50
75
100
Grain Size Distribution (%)
S-06: Oct. 2017
S-06: July 2016
0
5
10
15
20
25
30

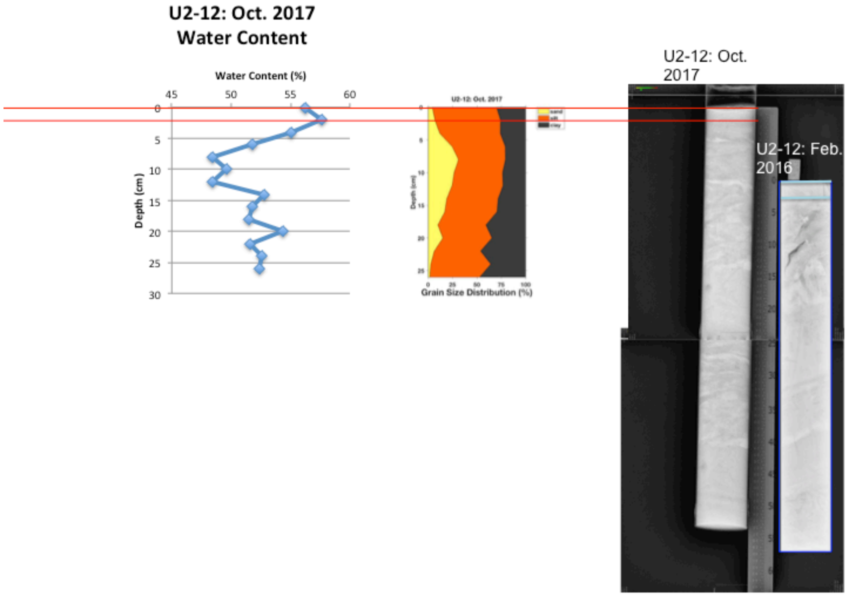

S-08: Oct. 2017
Water Content
Water Content (%)
40
45
50
55
Depth (cm)
0
5
10
15
20
25
S-08: Oct. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
20
0
25
50
75
100
Grain Size Distribution (%)
S-08: Oct. 2017
S-08: Feb. 2016
0
5
10
15
20
25


S-12: Oct. 2017 Water Content
Water Content (%)
40
45
50
55
60
65
Depth (cm)
0
5
10
15
20
25
30
35
S-12: Oct. 2017
sand
silt
clay
Depth (cm)
Grain Size Distribution (%)
0
25
50
75
100
S-12: Oct. 2017
S-12: Sept. 2016


U1-08: Oct. 2017 Water Content
Water Content (%)
35
40
45
50
55
60
Depth (cm)
0
5
10
15
20
25
U1-08: Oct. 2017
sand
silt
clay
Depth (cm)
Grain Size Distribution (%)
0
25
50
75
100
U1-08: Oct. 2017
U1-08: Feb. 2016
0
5
10
15
20
25


U1-12: Oct. 2017
Water Content
Water Content (%)
40
45
50
55
60
65
Depth (cm)
0
5
10
15
20
25
30
35
U1-12: Oct. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
20
25
30
0
25
50
75
100
Grain Size Distribution (%)
U1-12: Oct.
2017
U1-12: Sept.
2016


U2-08: Oct. 2017
Water Content
Water Content (%)
40
45
50
55
60
Depth (cm)
0
2
4
6
8
10
12
14
16
18
20
U2-08: Oct. 2017
sand
silt
clay
Depth (cm)
0
5
10
15
0
25
50
75
100
Grain Size Distribution (%)
U2-08:Oct.
2017
U2-08: Feb.
2016
0
5
10
15
20
25


U2-12: Oct. 2017
Water Content
Water Content (%)
45
50
55
60
Depth (cm)
0
5
10
15
20
25
30
U2-12: Oct. 2017
Depth (cm)
sand
silt
clay
0
25
50
75
100
Grain Size Distribution (%)
U2-12: Oct.
2017
U2-12: Feb.
2016