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Temporal Stability of Cave Sediments

Kevin Hughes
Eric Wade Peterson

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Temporal Stability of Cave Sediments

By Eric W. Peterson, and Kevin Hughes
Illinois State University, Department of Geography-Geology, Campus Box 4400, Normal, IL 61790

Abstract

Sediments within cave systems have been examined concerning source, mineralogy, and transport potential. While sediments in the thalweg are very mobile, the entrainment potential of the sediment piles has not been examined. Over the course of nine months, sediment piles in a Missouri cave were sampled to determine the stability of the piles and of the sediment properties. Sediment cores were analyzed for dry bulk density ($\rho_d$), porosity ($n$), volumetric wetness ($\theta$), organic content (O.C.), hydraulic conductivity (K), and sediment particle size distribution. Observational evidence, deposited sediment and deformation of previous sample holes, suggests that despite elevated flows, the sediment piles were not mobilized over the course of the nine months. Physical properties remained constant at each location, but varied among the various locations. Dry bulk density values ranged between 1.2 g/cm$^3$ to 1.5 g/cm$^3$. Porosity values were 0.42 to 0.57. Volumetric wetness showed similar variation ranging from 0.38 to 0.53. Organic content had the highest variation among the parameters ranging from 1.24 percent at one site to 4.84 percent at another. Hydraulic conductivity ranged from $2.13 \times 10^{-7}$ m/s to $3.10 \times 10^{-7}$ m/s.

INTRODUCTION

Cave sediment work has focused on many different themes. White (1977) focused on finding the source of sediment. Herman and others (2007) examined the sediment mineralogy of the suspended sediment. Murray and others (1993) determined the sediment age and rate of accumulation. Granger and others (2001) and Anthony and Granger (2004) employed the dating of cave sediments to develop histories of cave systems. Krekeler and others (1997) examined the role of sediment in landscape evolution and what the sediments can reveal about surface-weathering conditions. Engel and others (1997) analyzed cave sediments to gain information about reversals of the geomagnetic field. Springer (2002) used cave sediments for paleoflood reconstruction.

Examining the mobility of sediment within the thalweg facies, Dogwiler and Wicks (2004) reported that fluviokarst systems can transport up to 85 percent of the substrate during bankfull conditions. In the systems they investigated, flows capable of transporting the $d_{50}$ and $d_{85}$ sized particles occurred at intervals of 2.4 and 11.7 months, respectively. Whereas Dogwiler and Wicks (2004) examined the sediment within the channel, they did not examine the sediment piles adjacent to the cave streams.

Sediment piles serve as zones of low discharge and high storage, for water, solutes, and bacteria. Peterson and Wicks (2003) analyzed the physical and hydraulic properties concluding that the sediment possessed hydraulic properties similar to the matrix and that the cave sediments were an extension of the bedrock for modeling purposes. Lines of evidence exist suggesting that the sediment piles are periodically entrained. White (1988) states that if cave streams were incapable of flushing sediment from the conduits, then the conduits would quickly clog. The large number of caves with traversable passages stands as a testament to the fact that flushing occurs. Herman and others (2008) reported that flow thresholds had to be exceeded to mobilize the sediment in the sediment piles. Thus, the sediment is mobile and can be reworked.

Hence, the question of frequency of entrainment for sediment piles needs to be examined. This work examines the stability, both temporally and spatially, of cave sediments. While, the work done by Peterson and Wicks (2003) examined the sediment piles, their work was a one-time sampling and did not examine the potential temporal changes. This work examines the role of high-flow events and the possibility that the hydraulic properties could change after the sediments are disturbed.

FIELD AREA

The investigation centered on Berome Moore Cave of the Moore Cave System of the
Perryville Karst Area located in Perry County, Missouri (fig. 1) The strata of the Perryville Karst Area are comprised of three stratigraphic units of Middle Ordovician age. The basal unit is the St. Peter Sandstone, a well-sorted quartz arenite, marking the lower limit of karstification (Panno and others, 1999). Unconformably overlying the St. Peter Sandstone is the Joachim Dolomite; a yellow-brown, silty dolomite containing limestone interbeds and minor shale (Panno and others, 1999) with intense cavern development. The Joachim Dolomite is about 76 meters thick in the study area (Panno and others, 1999). Overlying the Joachim Dolomite, the Plattin Formation is even bedded, fine-grained to sublithographic limestone that has intervals of chert nodules and thin beds of shale (Dean, 1977; Martin and Wells, 1966). This formation is about 106 meters thick and forms most of the bedrock of the eastern portion of the Perryville Karst Area (Panno and others, 1999). The Plattin Formation forms a geomorphic surface where there is intense sinkhole formation. Overlying the Plattin Formation, are thick loess deposits (Panno and others, 1999). Geochemical analysis of the cave sediment reveals that the sediment composition is primarily silicates and are loess derived (unpublished data); entering the conduit system through the many sinkholes.

Figure 1: Location of the Moore Cave System, Perry County Missouri

Sinkholes of the Plattin Formation serve as discrete groundwater recharge points, allowing surface runoff and transported sediments to enter the cave system. After penetrating the Plattin Formation, the water and sediments enter the karst aquifer. Flow through the Moore Cave system is dominated by conduit flow that has been steady as indicated by small scallops along the main cave stream.

METHODS AND PROCEDURES

Sediment collection

Sediment piles from four sites were chosen within Berome Moore Cave for sampling. The Waterfall Passage site was located at the edge of a shallow plunge pool below a perennial waterfall. After entering the plunge pool, the water flows out to two small streams that eventually merge into a single stream. Collection was from a sediment pile between the two streams emerging from the plunge pool. Hydraulically, the site represented a waterfall. The Middle Main Stream Passage occurred within a conduit with a constant flow of water. In many places, the channel facies was almost non-existent; existing only as a laminated clay layer on top of bedrock. Collection occurred from a point bar along the main channel. Hydraulically, the site represented steady flows of moderate to high discharge. The Drum Passage has water pools and a small stream that was only centimeters across and millimeters deep. During high flow events, the main cave stream has the ability to overflow its banks and backflood the Drum Passage area. Sediment was collected from a point bar. Hydraulically, the site represented a point of stagnation with occasional high flows and backflooding. The No Name Passage was located in a small side conduit with a diameter of less than two meters. The roof of the conduit had fine sediment and plant debris deposited on the edges and along the apexes of dome structures. The deposits indicated that the conduit experienced pipe-full conditions and that the water source carried surface materials into the system. The collection site was a sediment pile on the edge of the conduit. Hydraulically, the site represented pipe-full flow conditions.

During each sampling trip, three cores were collected from each location to determine dry bulk density ($\rho_d$), porosity ($n$), volumetric wetness ($\theta$), and organic content ($O.C.$). A bulk density sampler was used to collect individual sediment cores of known volume. Each core was wrapped in aluminum foil, placed in a collection...
bag, and stored in a cooler with ice to preserve water content. Three additional sediment cores were collected in 1.4 cm internal diameter collection tubes to determine hydraulic conductivity (K). Finally, sediment for grain-size analyses was collected with a hand-trowel and placed into sample bags. The sample size was small, six cores per site, to accommodate the small area and immobility of the sediment piles. If more samples were collected, then the integrity of sediment piles would have been destroyed and the temporal objectives of this study would have been lost.

**Sediment Properties**

Dry bulk density values were determined using the procedure presented by Blake (1986). Porosity ($n$) was determined from the formula:

$$n = \frac{1 - \frac{\rho_d}{\rho_p}}$$

where $\rho_d$ is the dry bulk density and $\rho_p$ is the sediment particle density, which for this work a value of 2.65 g/cm$^3$ was used. A sediment particle density of 2.65 g/cm$^3$ represents clays and quartz (Blake, 1986), which is the dominant mineralogical composition of the sediment as determined by SEM analysis. The volumetric wetness ($\theta$) was determined for each core using the method presented by Gardner (1986). The organic content ($O.C.$) of the sediment was determined following the method presented by Schulte and Hopkins (1996).

**Determination of Grain size distribution**

For each sample, the grain-size distribution was determined using a combination of sieve and hydrometer analysis (ASTM D 422). The sieve and hydrometer data were used to generate a cumulative frequency curve.

**Determination of Hydraulic Conductivity**

Hydraulic conductivity (K) was determined by conducting a falling head test on the intact sediment cores that were collected using a plastic tube with a known cross-sectional area. Hydraulic conductivity was found using the method presented by Lee and Fetter (1994).

**RESULTS**

Six sampling events occurred over a nine month period from February to October 2006 (fig. 2). With the exception of the first sampling trip, all cores were successfully collected and analyzed. During the first sampling trip, all of the cores collected for the sediment property analyses from the Drum Passage were destroyed during transport out of the cave.

![Figure 2: Distribution of daily rainfall (black bars) in Perry County (National Climatic Data Center, 2011). Gray dashed lines indicate sample collection dates.](image)

Over the course of this study, the sediment piles appeared to be permanent fixtures of the cave. During each consecutive sampling trip, a thin layer of sediment, primarily clay, had been deposited in past sampling holes, indicating that deposition was active at each of these sites. High flow events occurred as a result of rain events (fig. 2). The presence of turbid pools of water located on shelves between three to five meters above the cave stream base level attests to the elevated flows. Even with the higher flows, the only noticeable alteration to the sediment piles was plastic deformation, as indicated by the elongation of past sampling points along the axis parallel to stream flow.

Each sediment pile was underlain by gravel sized particles. Overlying the gravel were layers of varying lithologies, but primarily fine grained, silt and clay sized, particles. One layer of note was an organic rich layer composed largely of forest litter from a conifer forest, predominant land-use for the area is agriculture. This layer was another indicator that the sediment piles had been immobile for quite
some time. The top layer of all piles was a clay layer. This top clay layer would, with its strong electrostatic attraction, armor the sediment piles and make them hard to move. Sampling was conducted on the layers overlying the gravel. Although multiple layers were present, the collection methods for analysis of the physical properties and hydraulic conductivity did not allow for individual analysis of the layers. Thus, the results are representative of the material overlying the gravel as whole.

Sediment Properties

**Bulk Density Porosity, Volumetric Water Content, and Organic Carbon Content**

Waterfall Passage (fig. 3a) had a $\rho_d$ that ranged from 1.16 g/cm$^3$ to 1.25 g/cm$^3$ over the course of this study. Dry bulk density standard deviations ranged from 0.01 g/cm$^3$ to 0.08 g/cm$^3$. The Middle Main Stream Passage (fig. 3a) has $\rho_d$ values that ranged from 1.46 g/cm$^3$ to 1.53 g/cm$^3$ with a standard deviation that ranged from 0.01 g/cm$^3$ to 0.06 g/cm$^3$. The $\rho_d$ for sediment at the Drum Passage ranged from 1.32 g/cm$^3$ to 1.38 g/cm$^3$, with a standard deviation that ranged from 0.02 g/cm$^3$ to 0.22 g/cm$^3$ (fig. 3a). Dry bulk density for the No Name Passage ranged from 1.15 g/cm$^3$ to 1.29 g/cm$^3$ with a standard deviation ranging from 0.01 g/cm$^3$ to 0.23 g/cm$^3$ (fig. 3a).

Porosity of the sediment at the Waterfall Passage (fig. 3b) ranged from 0.53 to 0.56 with a standard deviation range from 0.00 to 0.02. Middle Main Stream Passage (fig. 3b) had porosity ranging from 0.42 to 0.45 with a standard deviation ranging from 0.00 to 0.02. Drum Passage sediments had a porosity range of 0.48 to 0.49 with a standard deviation ranging from 0.00 to 0.08 (fig. 3b). At No Name Passage, porosity ranged from 0.51 to 0.57 with a standard deviation ranging from 0.01 to 0.09 (fig. 3b).

Volumetric wetness at the Waterfall Passage (fig. 3c) ranged from 0.50 to 0.53 with the standard deviations ranging from 0.01 to 0.03. Middle Main Stream Passage had a $\theta$, ranging from 0.38 to 0.43, with standard deviations ranging from 0.00 to 0.02 (fig. 3c). For Drum Passage, $\theta$ ranged from 0.43 to 0.47 with a standard deviation ranging from 0.01 to 0.06 (fig. 3c). The $\theta$ at No Name Passage ranged from 0.46 to 0.49 with a standard deviation ranging from 0.00 to 0.03 (fig. 3c).

Compared to the other properties, the organic carbon content exhibited a greater range of values at each site (fig. 3d). At the Waterfall Passage, O.C. ranged from 3.12 to 3.53 percent with a standard deviation range of 0.07 to 0.52 percent. O.C. for the Middle Main Passage ranged from 1.24 to 1.61 percent with a standard deviation range of 0.07 to 1.11 percent. The Drum Passage experienced the greatest range in O.C. with values from 2.45 to 4.84 percent and a standard deviation range of 0.11 to 0.62 percent. No Name Passage exhibited some of the highest O.C. values ranging from 3.28 to 4.84 percent with standard deviation values ranging from 0.05 to 0.73 percent.

For each site and each sediment property an ANOVA was performed to test whether the values of the sediment properties changed from sampling event to sampling event (Table 1). A quick examination of figure 3 would suggest that the individual sediment property values are rather stable at each location. This is confirmed by the ANOVA analyses (Table 1). With the exception of the $\theta$ at the Water Fall Passage and Middle Main Passage, and the O.C. at the Drum Passage and No-Name Passage, the values were
statistically similar for all sampling events. Note that the $\rho_d$ and $n$ values did not statistically vary over the duration of the study for each location.

The values for the individual sediment properties vary among the sample locations (figs. 3 and 4). Waterfall Passage had the lowest $\rho_d$ value with the Main Middle Passage having the highest $\rho_d$ value. Given the relationship between $\rho_d$ and porosity, Waterfall Passage had the highest porosity value with the Main Middle Passage having the lowest porosity value. The $\theta$ values had a similar relationship as porosity. The $O.C.$ values exhibited some of the larger differences among the sites. Drum Passage and No Name Passage had higher $O.C.$ than Waterfall Passage and Middle Main Passage. Middle Main Passage had considerably less $O.C.$ than the other three locations. To test whether the variation in the individual properties were statistically different among the locations, an ANOVA was performed for each property. Among the locations, there is significant variation for each of the sediment properties (Table 2).

**Grain Analysis**

Sediment particle size distributions reveal similar distributions among the four sites and show relatively stable particle size distributions at the sites over time (fig. 5). A noticeable exception is that the Drum passage has a smaller percentage of sand size particles, 12 percent as compared to the other sites that have between 17 percent at Middle Main to 21 percent at No Name. At all locations clay sized particles comprised 2.5 percent or less of the overall material. No Name had the highest amount at 2.5 percent, followed by Middle Main (2 percent), Waterfall (1.8 percent), and Drum (1.6 percent).

Sieving of sediment samples revealed that more than geosediments composed the sediment piles. Plant debris, pine needles, and the shells of small mollusks were observed with the sediment. These materials account for the higher $O.C.$ values measured for the sediments.

Figure 4: Comparison of the sediment properties among the four passages. The ends of the boxes represent the 25th and 75th percentiles with the solid line at the median; the error bars depict the 10th and 90th percentiles and the points represent the 5th and 95th percentiles.

Figure 5: Grain size distribution curves for the sediment particles at the four sampling locations. The points represent the mean value over the course of the sampling and the error bars represent the standard deviation over the course of the sampling.

**Hydraulic Conductivity (K)**

The cores collected at each location during each sampling event provided statistically similar $K$ values for each location (Table 1 and fig. 6). The Waterfall Passage had the highest $K$ values, which ranged from $3.04 \times 10^{-7}$ m/s to $3.28 \times 10^{-7}$ m/s, with a standard deviation range of $1.65 \times 10^{-9}$ m/s to $1.63 \times 10^{-8}$ m/s. Middle Main Passage had the lowest $K$ values that ranged from $2.01 \times 10^{-7}$ m/s to $2.17 \times 10^{-7}$ m/s, with a standard deviation range of $2.45 \times 10^{-10}$ m/s to $1.02 \times 10^{-8}$ m/s. The Drum Passage had $K$ values that ranged from $2.31 \times 10^{-7}$ m/s to $2.45 \times 10^{-7}$
m/s, with a standard deviation range of $4.12 \times 10^{-10}$ m/s to $1.49 \times 10^{-8}$ m/s. K values at No Name Passage ranged from $3.03 \times 10^{-7}$ m/s to $3.16 \times 10^{-7}$ m/s, with a standard deviation range of $9.12 \times 10^{-10}$ m/s to $2.10 \times 10^{-8}$ m/s.

**DISCUSSION**

During the nine-month period of sampling, the sediment properties remained stable, resulting in consistent values among the various sediment properties (Table 1 and fig. 3). Exceptions to the stable properties include $\theta$ for the sediments at Waterfall Passage and Middle Main Passage and O.C. at Drum Passage and No Name Passage. A noticeable difference in the $\theta$ occurs in the May sampling event, which followed a precipitation event. Both Waterfall and Middle Main sediments had higher $\theta$ values, which may be a direct result of the wetter conditions. For the variations in O.C. values two possible reasons exist. First, there was a large vertical heterogeneity as dictated by the different beds that make up the sediment profile. If each sample did not capture the exact same beds, then a difference would result even if the individual beds were homogenous. Second, there was a large horizontal heterogeneity, meaning that as the sample points moved along the sediment pile, the heterogeneity caused deviation in the data points and could be interpreted as a temporal shift. Small variation in the $\rho_d$, $n$, particle size distributions, and K values existed, but since the sediment piles were immobile, there is reduced likelihood that these properties were changing.

A previous study reports that organic carbon content of karst sediments are less than 1.5 percent (Peterson and Wicks, 2003). The only site that was in-line with the reported data is the Middle Main Stream Passage. The common trait that the Middle Main Stream Passage has compared to the previous study is that there is a large volume of water constantly moving by the sediment pile. The less than 1.5 percent organic carbon content may be due to the washing effect of this moving water. Organic debris caught in this swift water may not have the opportunity to deposit with the sediment. This is further supported by the lack of the forest-litter rich layer that was found at the other sites. Compared to the Middle Main Stream Passage and previous studies mentioned, the Waterfall...
Passage, Drum Passage, and No Name Passage have more than twice the organic content (fig. 3). The Waterfall Passage had a very strong presence of the forest litter rich layer. Some core samples had a simple black layer while other cores were rich in recognizable pine needle remains. It is likely that the waterfall feeds in from a sinkhole. Forest litter at the bottom of the sinkhole was washed in and deposited around the plunge pool. The Drum Passage showed greater variation in organic carbon content, which may be related to the back flooding and presence of water pools. Near the pools, more organic carbon has been deposited. Away from the pools, less organic material is deposited. The most revealing part of the organic carbon content was revealed in the No Name Passage. Here, a lot of insect activity was observed in the form of beetles and crickets. Earth worms crawl through the sediment piles and fresh plant debris, including tree seeds that attempt to germinate in the dark cave environment, is carried in. The rich organic nature of the sediment, almost 5 percent, is likely due to the fresh inputs.

The clay armor seems to make the sediment piles a somewhat permanent feature of the cave streams and only very high flow events are capable of altering them. The permanence of the sediment piles was demonstrated in August when high flow conditions only caused plastic deformation of previous sampling points. Although the sediment piles are composed of grains that should become mobile according to the study done by Dogwiler and Wicks (2004), the finer sized particles make the sediment piles behave like larger particles.

The controlling factor on the hydraulic conductivity of the sediment piles is likely the hydraulic conductivity of the silt. Silt tends to have a hydraulic conductivity that ranges from 1x10^{-9} m/s to 1x10^{-5} m/s. The K values measured for the sediments, on the order of 10^{-7} m/s, at each location were within this range and were similar to those measured by Peterson and Wicks (2003). The data presented here further support the claim by Peterson and Wicks (2003) that the cave sediments can be modeled as an extension of the matrix rock because the hydraulic conductivity of the sediment piles are similar to the hydraulic conductivity of limestone. A limitation to this claim would be if the sediment piles are highly mobile.

Compared to other published work, the sediment piles appear to be less mobile than the sediment within the karst streams. Dogwiler and Wicks (2004) observed movement of the d_{50} particle on a 2.4 month interval; over the nine months, there was no movement of the sediment pile in Berome Moore Cave. While comparison is made between the studies, caution must be exercised. Dogwiler and Wicks (2004) were examining larger bedload particles, the d_{50} particle was 70 mm, located in the thalweg of the stream. The sediment piles are finer grained, d_{50} particle ~0.04 mm, but require similar stream velocities to become entrained as the larger particles. Additionally, the sediment piles are located along the banks of the stream where velocities are lower than in the thalweg. Thus, erosion is limited as a result of the need for higher velocities to entrain the sediment and the lower velocities that occur along the edges of the stream.

Finer sized particles do move through systems. Herman and others (2008) indentified flow thresholds that needed to be exceeded before deposited sediment in the conduits would be entrained and moved through the system. For the systems examined by Herman and others (2008), the entrainment thresholds were reached as a consequence of extremely high flows, greater than two orders of magnitude above baseflow, associated with precipitation from remnant hurricanes. During the nine months, the Berome Moore system did not experience extreme flows remotely close to the levels observed by Herman and others (2008). This work was not able to address the point when the flow threshold for entrainment was exceeded.

CONCLUSIONS

Over the course of the nine-month sampling period, the sediment piles within Berome Moore Cave did not move. The hydrologic properties, n and K, did not change over the study, confirming the stability of the piles. While the sediment was not entrained and the properties remained stable at the individual sampling locations, the locations behaved differently. Particle size distributions were similar among
the sites, but $\rho_d$, n, $\theta$, $O.C.$, K., statistically varied among the sites. This variability appears to be a result of the difference in flow regime among the sampling locations.

Table 1. ANOVA results examining temporal variation of the sediment properties at the four locations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Waterfall Passage</th>
<th>Main Middle Passage</th>
<th>Drum Passage</th>
<th>No-Name Passage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Bulk Density</td>
<td>$F(5, 12) = 2.12, p = .13$</td>
<td>$F(5, 12) = 2.03, p = .15$</td>
<td>$F(4, 10) = 0.14, p = .96$</td>
<td>$F(5, 12) = 0.10, p = .99$</td>
</tr>
<tr>
<td>Porosity</td>
<td>$F(5, 12) = 2.44, p = .09$</td>
<td>$F(5, 12) = 2.02, p = .15$</td>
<td>$F(4, 10) = 0.15, p = .97$</td>
<td>$F(5, 12) = 0.11, p = .99$</td>
</tr>
<tr>
<td>Volumetric wetness</td>
<td>$F(5, 12) = 3.61, p = .04$</td>
<td>$F(5, 12) = 5.20, p = .01$</td>
<td>$F(4, 10) = 1.31, p = .33$</td>
<td>$F(5, 12) = 0.71, p = .99$</td>
</tr>
<tr>
<td>Organic Carbon Content</td>
<td>$F(5, 12) = 0.55, p = .73$</td>
<td>$F(5, 12) = 0.25, p = .93$</td>
<td>$F(5, 12) = 22.32, p &lt; .01$</td>
<td>$F(5, 12) = 6.74, p &lt; .01$</td>
</tr>
<tr>
<td>Hydraulic Conductivity</td>
<td>$F(5, 12) = 3.09, p = .06$</td>
<td>$F(5, 12) = 2.03, p = .17$</td>
<td>$F(5, 12) = 0.95, p = .49$</td>
<td>$F(5, 12) = 0.45, p = .80$</td>
</tr>
</tbody>
</table>

1Data were subjected to a logarithmic transformation

Table 2. ANOVA results examining the spatial variation of the sediment properties among the four locations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Waterfall Passage</th>
<th>Main Middle Passage</th>
<th>Drum Passage</th>
<th>No-Name Passage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Bulk Density</td>
<td>$F(3, 65) = 53.04, p &lt; 0.01$</td>
<td>$F(3, 65) = 52.16, p &lt; 0.01$</td>
<td>$F(5, 12) = 58.61, p &lt; 0.01$</td>
<td>$F(5, 12) = 68.66, p &lt; 0.01$</td>
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<tr>
<td>Porosity</td>
<td>$F(3, 65) = 53.04, p &lt; 0.01$</td>
<td>$F(3, 65) = 52.16, p &lt; 0.01$</td>
<td>$F(5, 12) = 58.61, p &lt; 0.01$</td>
<td>$F(5, 12) = 68.66, p &lt; 0.01$</td>
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<tr>
<td>Volumetric wetness</td>
<td>$F(3, 65) = 53.04, p &lt; 0.01$</td>
<td>$F(3, 65) = 52.16, p &lt; 0.01$</td>
<td>$F(5, 12) = 58.61, p &lt; 0.01$</td>
<td>$F(5, 12) = 68.66, p &lt; 0.01$</td>
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<tr>
<td>Organic Carbon Content</td>
<td>$F(3, 68) = 68.66, p &lt; 0.01$</td>
<td>$F(3, 68) = 68.66, p &lt; 0.01$</td>
<td>$F(5, 12) = 68.66, p &lt; 0.01$</td>
<td>$F(5, 12) = 68.66, p &lt; 0.01$</td>
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<td>$F(3, 68) = 449.69, p &lt; 0.01$</td>
<td>$F(5, 12) = 449.69, p &lt; 0.01$</td>
<td>$F(5, 12) = 449.69, p &lt; 0.01$</td>
</tr>
</tbody>
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REFERENCES


