

Research Article

# Geology's Grip on Baseball: Investigating the Sedimentology, Mineralogy, and Physical Properties of Baseball Rubbing Mud

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Keywords: Mud, Sedimentology, Baseball, Geology, Delaware River, XRD, SEM

<https://doi.org/10.2110/001c.144870>

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## The Sedimentary Record

Vol. 23, Issue 1, 2025

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Major League Baseball (MLB) prepares a minimum of 156 baseballs for each game by rubbing them with mud, sourced from the same company since the 1950's (Baseball Rubbing Mud, n.d.). This mud is intended to add grip and color to the baseball in a way that ensures competitive consistency across the league. Despite its long-standing use, the geologic characteristics of this mud and its precise effects on the baseball are still poorly understood. In this study, we analyze the mineralogy and physical properties of the baseball rubbing mud in the context of its depositional environment in a tributary of the Delaware River near Philadelphia.

Samples of game-used and new baseballs were analyzed with Scanning Electron Microscopy (SEM), along with SEM analysis of the un-applied mud. These data were supplemented with X-Ray Diffraction (XRD), Particle Size Distribution (PSD), and Rock-Eval of the mud itself. Results show that the mud is composed primarily of non-swelling clays (Kaolinite, Chlorite, and Illite/Mica) and quartz, with minor amounts of other components. SEM images show that the clays primarily accumulate in the pores, adding the desired color to the baseball, while the coarser quartz grains serve as a scouring material, inducing scratches, micro-cracks, patches of erosion, and occasional flaking of the leather. This provides minor grip enhancement to the ball without significantly altering ball aerodynamics. The lack of swelling clays also prevent overly slippery or inconsistent grip in the presence of moisture. While muds could be sourced from different locations, changing the location of mud collection would result in variations in composition, grain size, and color that could alter the grip and color uniformity in ways that could provide competitive inconsistencies.

### 1. Introduction

In baseball, the friction between a pitcher's fingers and the surface of the leather ball is a critical factor that significantly influences pitching performance. At the moment of release, the tangential force reaches its maximum and affects both spin rate and the translational direction of the ball (Kinoshita et al., 2017 and Yamaguchi et al., 2022). Stronger grip on the ball generally leads to increased pitching accuracy and performance. As such, discrepancies between balls can create unfair competitive advantages. To enhance grip even further, pitchers have occasionally used foreign (i.e., sticky) substances such as pine tar and rosin on baseballs. In June of 2021, Major League Baseball (MLB) announced efforts on prohibiting foreign substances that alter the ball's grip. In the wake of these changes, the average spin rate of fastballs fell by approximately 4% (Katz et al., 2021).

Along with eliminating foreign substances, MLB also standardized the methods of pre-game baseball preparation to prevent unfair competitive advantages. According to

MLB regulation, prior to each baseball game, 13 dozen balls are prepared in advance for gameplay. Baseballs used in MLB games have traditionally been prepared with a specific rubbing mud to remove gloss from the surface of newly manufactured balls, intended to increase friction and improve grip (Yamaguchi et al., 2022). This specific and MLB sanctioned mud is the Lena Blackburne Baseball Rubbing Mud, which is sourced from a single company that has been supplying the MLB with rubbing mud since the 1950's (Baseball Rubbing Mud, n.d.), instituting an important tradition in MLB. The company describes the mud as odorless, with a consistency that is a "cross between chocolate pudding and whipped cold cream" (Baseball Rubbing Mud, n.d.).

Past studies have focused on the physics of the rubbed baseballs, including the impact of the mud on grip (Pradeep et al., 2024), airflow (Smith, 2019), and physical interactions between fingers and baseballs (Kinoshita et al., 2017; Matsuo et al., 2018; Yamaguchi et al., 2022). However, these studies have not sufficiently investigated the geological properties of the mud or how the rubbing mud alters the

surface of the ball. Pradeep et al. (2024) described some basic geological properties such as grain size and XRD-derived mineralogy, but failed to characterize the clay mineralogy and organic components. In addition, their mud application on the baseball itself did not follow standard MLB practices, having over-applied mud to the ball. As a result, the characteristics of the mud, and its effect when applied to baseballs require further evaluation.

In this study, we investigate geological properties of the rubbing mud and examine topologic variances on baseball surfaces prior to and subsequent to applying the mud on the baseball. Primary datasets include results from X-Ray diffraction (XRD), Scanning Electron Microscopy (SEM), and Particle Size Distribution (PSD) analyses, in addition to identifying the range of colors of both the baseballs and the mud itself. We further explore the prevailing depositional environment and stratigraphic framework of the mud source location as well as discuss the uniqueness of this particular mud, exclusively authorized to be used in MLB.

There are two main questions that can be addressed with these data. These include: 1) What are the geologic properties of this mud? 2) What effect does the mud have on the surface of the baseball? With these answers, we can deduce if mud collected from different locations would be equally effective when applied to a baseball, and which geologic properties are most impactful to use as baseball rubbing mud.

## Geologic Background

The Lena Blackburne Baseball Rubbing Mud Company keeps the precise mud collection site confidential, but states that it harvests the mud each July in a tributary of the Delaware River in Burlington County, NJ (Baseball Rubbing Mud, n.d.). Additional public information suggests that the mud collection site is near the Tacony-Palmyra Bridge on the Delaware River (WHYY, 2011) (Figure 1). These sources suggest that the collection site is most likely near the confluence of the Delaware River with either Pennsauken Creek, Pompeston Creek, or Rancocas Creek (Figure 1).

The overall mineral composition and constituents of the mud collected from the riverbanks is a product of the mineralogy of the area's exposed bedrock within reach of the watershed as well as the geomorphologic expression of the depositional system in this area (Figure 1). In the vicinity of the estimated collection site, the Delaware River is eroding into a succession of relatively unconsolidated Holocene estuarine muds and marsh deposits (Cape May Formation), underlain by Pleistocene fluvial quartzose gravels and arkosic sands (Pensauken Formation) and ultimately into Cretaceous coastal plain sediments (Potomac and Magothy Formations) at depth (Hammond & Fleming, 2021; Stanford et al., 2016). Overall, the stratigraphy in this location reflects a history of river incision, glacial outwash deposition, sea-level rise, and estuarine backfilling, overprinted by modern tidal and anthropogenic modifications (Dalton et al., 2014; Stanford et al., 2016).

The described collection location in New Jersey is within a low-sinuosity portion of the Delaware Bay estuary, and within the tidally influenced estuarine reach (tidal range

~1.5 - 2 m ("Station ID: 8545240, NOAA")) which extends upstream through Philadelphia with the ultimate tidal limit near Trenton, NJ. As such, the collection site experiences regular semidiurnal tides that may have an impact on sediment transport, bank stability, salinity, biological habitats conditions and can also modulate water level and flow dynamics of the river at this location, especially during low-flow conditions (Stanford et al., 2016).

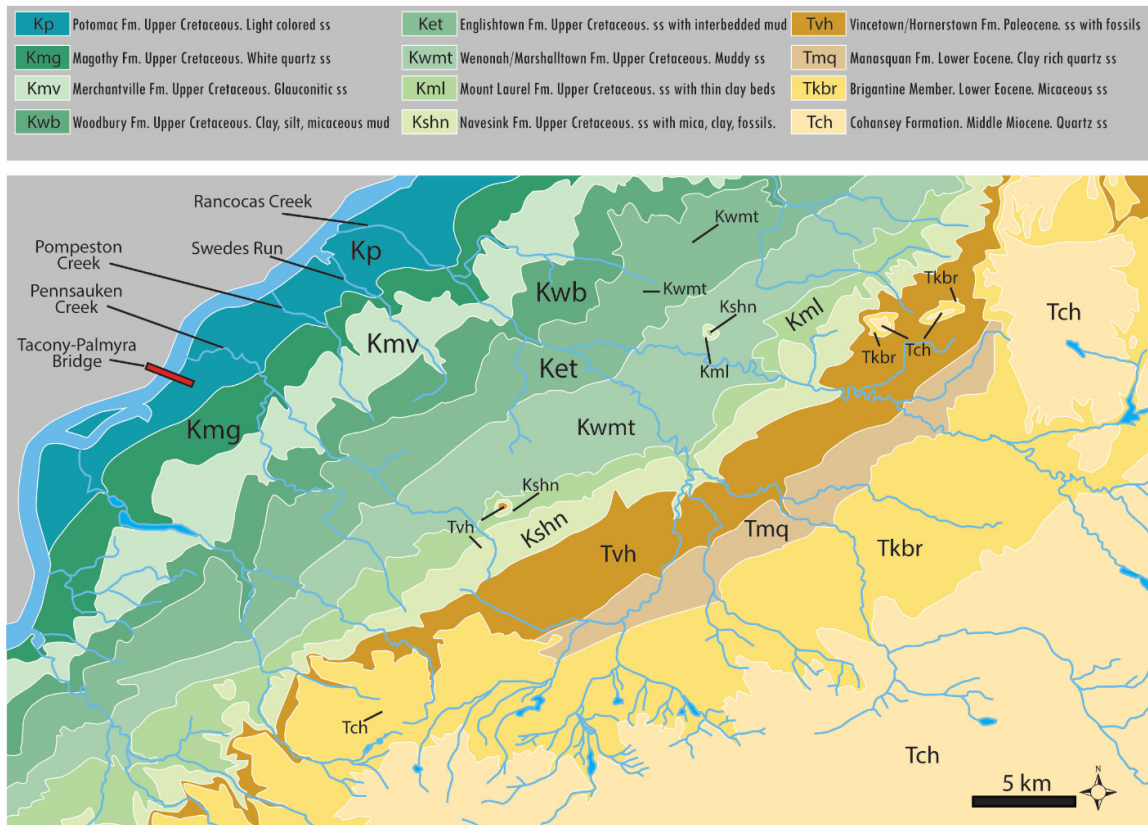
## 2. Methods

Two jars of the Lena Blackburne Baseball Rubbing Mud were purchased directly from the company in the fall of 2024 and spring of 2025, which were presumably harvested during the July 2024 mud harvesting cycle. The two rubbing muds were examined and compared to verify the consistency in geologic properties, including (1) mineralogical assemblage with XRD analysis, (2) characterization of organic matter with Rock-Eval Pyrolysis, and (3) distribution of grain sizes with PSD analysis, that may affect the mud-applied surface of baseballs (S1 - S3).

New Rawlings baseballs were prepared following MLB standards (Tracy, 2022), to investigate their properties both before and after being mudded with Lena Blackburne Baseball Rubbing Mud. This method includes rubbing the balls with a small amount of mud for 30 seconds per ball to remove the gloss, while avoiding directly rubbing the mud into the laces, which would over-darken them. MLB provides teams with a reference chart illustrating acceptable color ranges for mudded baseballs, enabling team staff to assess whether the amount of mud applied is within prescribed limits. These balls are then inspected by umpires prior to the start of the game. In the absence of this official chart, we compared the color of our freshly mudded ball to an official MLB game-used ball, purchased after its use in the first inning of the Washington Nationals versus Philadelphia Phillies game on April 7, 2024 (Figure 2). Additionally, we use the Munsell soil chart to quantify the variance in colors of the freshly mudded (wet and dry) and the game-used baseball (Figure 2).

The game-used baseball was involved in two pitches, the second resulting in a foul ball. Following its initial pre-game mud application, the ball experienced a moderate amount of handling, brief gameplay, and an unknown history of subsequent handling and shipping before being analyzed in the laboratory. We assume that most changes to the mudded surface occurred during gameplay, particularly from bat impact, with minimal additional handling and no reapplication of mud.

In order to examine the effect of baseball mud on baseball surfaces and its relation to game performance, baseball samples were prepared by cutting the stitches using a scalpel, allowing for the removal of small pieces of leather (approximately 3 cm in diameter). The collected samples were then examined through detailed imaging in high resolution using the SEM analysis to identify (1) surface morphology, (2) microstructure, and (3) pore-filling particles (Figures 3 and 4). Detailed description of all analytical methods above is provided in the supplementary material (S1 - S4). Additional leather samples were prepared and



**Figure 1. Geologic map of the New Jersey side of the Delaware River.**

The region shown on this map likely contains the collection location of the Lena Blackburne Baseball Rubbing Mud and shows the geologic context for the depositional environment. Modified from Dalton et al. (2014).

used for color matching via Munsell soil color charts for determining color changes of the mudded baseballs. Supplementary material also includes results from X-ray fluorescence (XRF) analysis and geochemical characterization of interstitial water extracted from the Lena Blackburne Baseball Rubbing Mud. These datasets were non-essential to the primary interpretations and are provided for completeness.

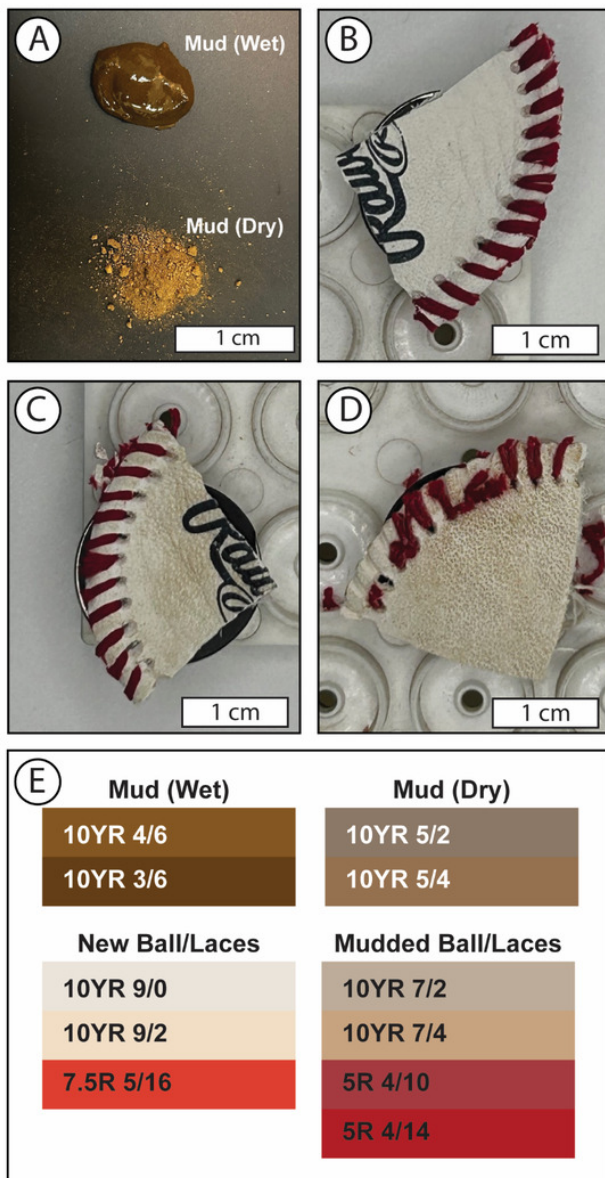
### 3. Results and Discussion

#### Mud Composition and Depositional Environment

The presumed sampling location is located within the Delaware River watershed, collecting mineralogy from the exposed geology within that area (Figure 1). The tributaries of the Delaware River shown in Figure 1 are located within the Bridgeton fluvial plain (Stanford et al., 2016), and flow within Upper Cretaceous to Miocene strata, primarily composed of siliciclastic sediment (Figure 1). This is reflected in the mineralogy of the rubbing mud (Table 1), collected from one of these tributaries near the confluence with the Delaware River (exact location proprietary). A detailed sampling of sediment from the area is beyond the scope of this paper, but given the uniform stratigraphy across the study area, it is reasonable to suspect that the bulk composition of mud between tributaries does not vary greatly and would have similar mineralogical properties.

The mineralogy and grain size of the sediment in this river system is also a product of the depositional environment, as higher flow regimes result in winnowing of clays and finer particles. As such, changing the location of the mud collection site could result in different relative abundances of the minerals identified in Table 1. Thus, it is logical that the Lena Blackburne Baseball Rubbing Mud Company has harvested mud from the same location since their company's inception. Changing the location to a part of the river system with higher or lower flow rates would affect the relative amounts of sand to clay, and possibly even the types of clay if they moved to a different tributary. In addition, the composition of the mud would also be sensitive to upstream anthropogenic alterations such as dam construction that might limit sediment delivery. The company also harvests the mud during each July, protecting the mud from interannual changes in stream flow rates that could affect sediment sorting (Hammond & Fleming, 2021).

The results from the XRD analysis are summarized in Table 1. Results indicate that the largest constituent by weight is clay at 59% of the total weight of the sample. The clay comprised of mostly non-swelling illite, kaolinite, and chlorite (Bleam, 2012; and Civan, 2007). Due to overlapping peaks of illite and mica in diffractogram reflection patterns, these crystalline phases are quantified together within the data table. Vermiculite, which has a range of swelling properties, is present in small amounts, and no smectite was recorded. Aside from the clays, quartz was the most com-



**Figure 2. Photographs of leather samples from each of the 3 baseballs analyzed in this study.**

A) Photograph of a small amount of the baseball rubbing mud wet and dry. B) Leather sample from a new baseball. C) Leather sample from a new baseball rubbed with the rubbing mud. D) Leather sample from an official game-used MLB baseball. E) Range of colors for the mud, leather, and laces, following a Munsell soil color matching chart.

mon constituent, accounting for 36% of the total weight, and only 2% of the clay fraction. Minor amounts of plagioclase, potassium feldspar, and hornblende are also present in the sample.

Also documented in [Table 1](#) is the Total Organic Carbon (TOC) of 2.54%. Consistent with the low TOC, the material does not exude the scent of rotting organic matter, nor is it odorless as the supplier claims, but instead has a faint earthy scent similar to soil.

### Ball Roughness, Color, and Texture

A ball with rougher leather will produce more turbulent flow while in flight (Smith, 2019). Smith (2019) showed that

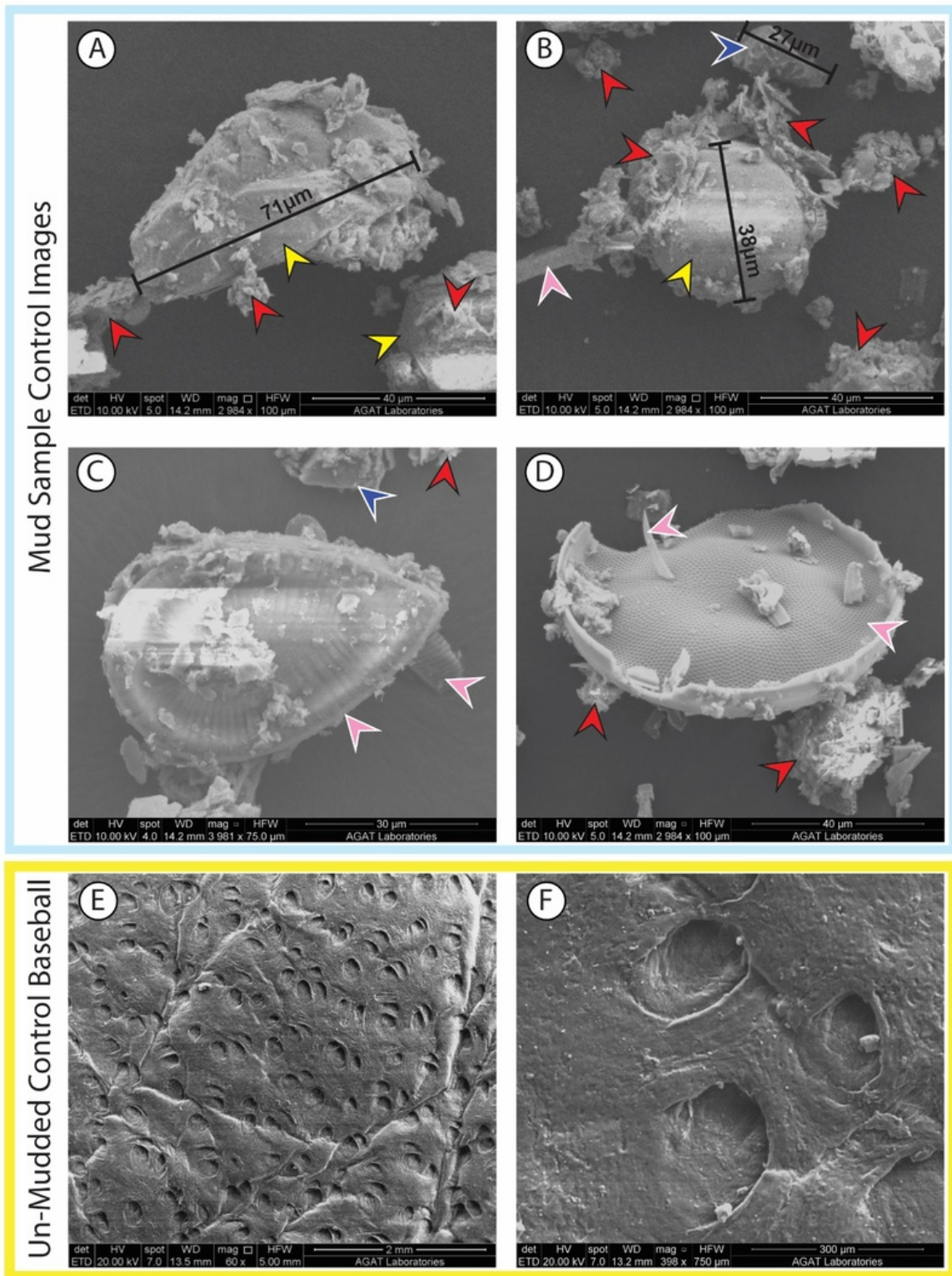
rubbing baseballs with mud only adds approximately 0.45g of weight, and did not change the roughness enough to have a significant effect on the boundary separation layer when thrown at 75 mph. Yamaguchi et al. (2022) showed that the friction between the ball and finger only experiences a small change before and after applying rubbing mud to the ball. Therefore, if the apparent roughness is not enough to change the flight of the ball, and the friction is not significantly changed, what is the mud actually doing to the surface of the ball?

Pradeep et al. (2024) imaged the surface of a baseball after a coating of mud, but their methodology applied far too much mud to be indicative of a baseball during game-play. They hypothesize that the fingers do not contact the leather directly, and their imaging captures a layer of mud on the outside of the ball, thus failing to demonstrate what the mud does to the leather. Our results show that the mud primarily accumulates in the pores of the leather. Despite what was reported in Pradeep et al. (2024), the fingers of a baseball player would indeed make contact with the leather of the baseball, as well as the mud that is filling the pores, and to a lesser degree any small grains adhering to the outer surface of the leather.

[Table 1](#) shows that the main components of the mud are quartz and non-swelling clays. These provide the mud's primary functions of pore-filling and scouring. Mud-filled pores also create many small dots of color on the ball that contribute to the desired off-white color of a mud-rubbed ball. As summarized in [Figure 2](#), color matching via Munsell soil color charts show that the baseball mud itself ranges from 10YR 4/6 to 10YR 3/6 wet and 10YR 5/2 to 10YR 5/4 dry. New baseballs range in color between 10YR 9/0 to 10YR 9/2 with the laces of the new ball being 7.5R 5/16. Mud rubbed baseballs range from 10YR 7/2 to 10YR 7/4 with the laces now 5R 4/10 to 5R 4/14. In effect the mud decreases the Munsell Value or Lightness and increases the Munsell Chroma for both the ball and laces.

While the laces of the ball are not the focus of this study, it has been noted that the laces do accumulate mud during the application process ([Figures 2](#) and [4](#)) and are also darkened with the leather. As previously described, the mud decreases the Munsell value (lightness) and increases the Munsell chroma (saturation) for both the ball and laces. These changes in the color of the baseball make it more difficult for the hitters to pick up the exchange from the pitcher's hand to the flight path of the ball towards them. While the change in the Munsell value for the laces makes it more difficult for the batter to pick up the spin of the baseball that determines the type of pitch and the break from the normal plane as it moves towards the batter (Fogt & Terry, 2006; and Sarris, 2016).

Only those sedimentary particles smaller than the diameter of a pore can serve as pore-filling material. With the average diameter of the pores being in the range of 50-150  $\mu\text{m}$ , the pore filling material is primarily clay minerals and other particles smaller than 150  $\mu\text{m}$ , as shown in [Figure 5](#). Pores are occasionally completely filled, partially filled, or poorly filled, as seen in [Figure 4](#). Given that the mud preferentially accumulates in the pores, this could explain why

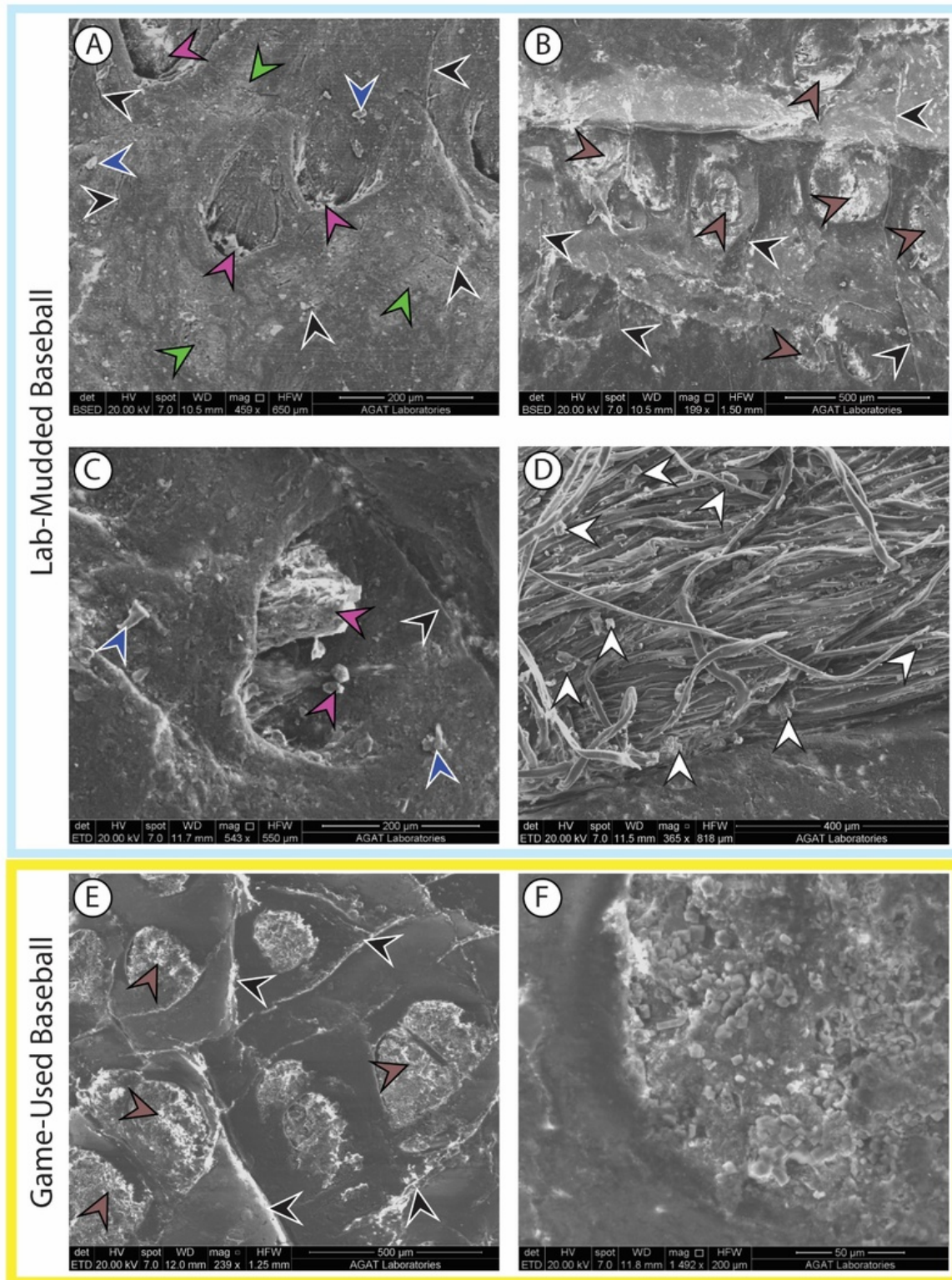


**Figure 3. SEM images from a smear sample of the Lena Blackburne Baseball Rubbing Mud (images A-D).**

And images of new un-mudded baseball leather (images E and F). All images have undergone minor brightness and contrast adjustments. A) Quartz grain (yellow arrow) measuring 71 μm along its long axis, classifying it as very-fine sand. Red arrows indicate clay particles or floccules. B) Quartz grain (yellow arrow) measuring 38 μm along its long axis, classifying it as a silt size grain. Red arrows indicate clay particles or floccules. Blue arrow indicates a diatom fragment. C) Pink arrow in the center of the image shows an external view of a *Surirella* diatom. Pink arrow to the right of the image shows an obscured view of an additional unidentified diatom fragment. Blue arrow shows the edge of a feldspar grain. D) Diatom fragments (pink arrows), with the large fragment in the center of the image being an internal view of a broken valve of *Stephanodiscus*. Red arrows indicate clay particles or floccules. E) Shows the surface of the leather with the pores visible throughout the image. Folds in the leather induced by removing the leather from the ball. F) Magnified view of two pores, showing minor amounts of pore-filling particles.

the mud applied to the baseball does not significantly alter the boundary separation layer of a ball mid-flight (Smith,

2019). If the mud were creating additional relief on the surface of the ball, the effect on aerodynamics could be more



**Figure 4. SEM images of the newly mudded baseball leather (images A-D), and the game-used baseball (images E and F), examining the effect of rubbing mud on the surface of the baseballs.**

All images have undergone minor brightness and contrast adjustments. A) Purple arrows show pores partially filled with clay minerals. Green arrows show areas of eroded leather. Black arrows show micro-cracks. Blue arrows show feldspar grains. B) Brown arrows show completely filled pores. Black arrows show micro-cracks. C) Purple arrows show a pore that is partially filled by a larger grain lodged within it. Blue arrows show feldspar grains outside of the pore. D) Shows the edge of the laces of the ball. White arrows indicate small grains lodged within the laces. E) Black arrows show micro-cracks. Brown arrows show completely filled pores. F) The right side of the image shows that the mud-filled pores are covered with a mat of salt crystals, as suggested by their cubic crystal structure.

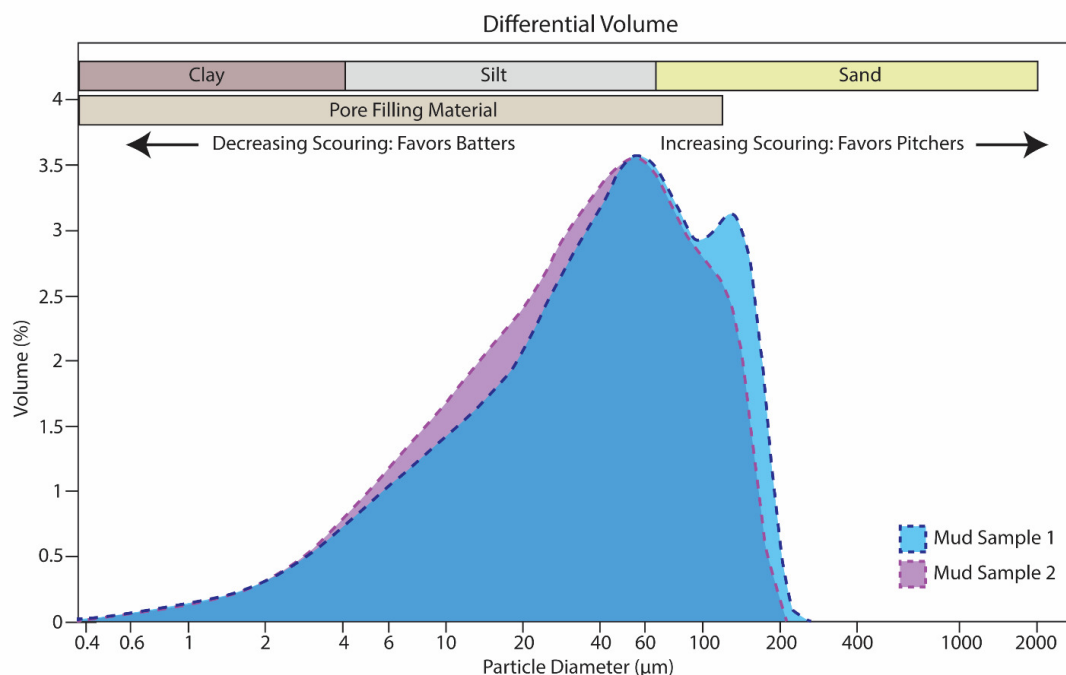
significant. Perhaps the most impactful feature of the mud is the minor amount of swelling clays (Table 1). If the pore-filling muds were primarily composed of swelling clays, any

moisture from rain, humidity, or sweat could make the ball slippery.

Summary of XRD Analysis															Rock-Eval						
SAMPLE ID:	TYPE OF ANALYSIS	WEIGHT %	Quartz	Plagioclase	K-Feldspar	Calcite	Dolomite	Hornblende	Pyrite	Muscovite	Hematite	Siderite	CLAYS					Total Clay	TOC %	HI	OI
													Kaolinite	Chlorite	Illite/Mica	Vermiculite	Smectite				
Lena Blackburne Baseball Rubbing Mud	BULK FRACTION:	86.11	42	3	1	0	0	1	0	0	0	0	10	7	35	1	0	53			
	CLAY FRACTION:	13.89	2	1	1	0	0	0	0	0	0	0	21	20	51	4	0	96			
	<b>BULK &amp; CLAY</b>	<b>100</b>	<b>36</b>	<b>3</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>1</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>0</b>	<b>11</b>	<b>9</b>	<b>37</b>	<b>2</b>	<b>0</b>	<b>59</b>	<b>2.54</b>	<b>191</b>

**Table 1. XRD results from the Lena Blackburne Baseball Rubbing Mud.**

Displays both the results of the bulk fraction as well as clay speciation. Also shown is key data from Rock-Eval Pyrolysis. Additional rock-eval data is available in the appendix.



**Figure 5. PSD results from the two samples of Lena Blackburne Rubbing Mud.**

Shows an overall positively skewed grain size distribution. The sand, silt, and clay size ranges are shown, along with the range of grains that could serve as pore-filling material, falling below the upper range of leather pore diameters.

In addition to pore-filling, the other primary function of the mud is to provide scouring to the outer surface of the ball to enhance grip. Figure 4 shows that there is a significant impact to the texture of the leather itself. Figure 4 shows scratches, flaking, erosion, and micro-cracks in the leather. It is difficult to estimate how much material has been removed from the leather, but clearly displays a rougher texture, which would contribute to changing the feel of the ball without significantly damaging the leather. Given that the pores are recessed, the pore-filling mud is likely not a major contributor to the texture of the ball. However, quartz and feldspar grains were occasionally observed on the outside of the freshly mudded ball. These would serve to increase the grip on the ball. These feldspar and quartz grains were rarely detected on the outside of the game used ball, and it is hypothesized that the bat strike and subsequent handling could knock any loose grains off the ball.

The game-used baseball also displayed growth of salt crystals on top of pore-filling clays (Figure 4f). It is unclear

why these salt crystals have developed. It could be salt from the brackish water of the source creek, precipitating after application of the mud to the baseball. It could also be residual sweat from baseball players. It should also be noted that the baseball was obtained 8 months after its use in a game, and the storage and handling conditions during that time are unknown.

In summary, the examination of the baseballs under the SEM yields 4 key observations about its effects on the surface of a baseball and the associated grip or feel of the ball: 1) the mud acts as a gentle abrasive that creates a rougher texture on the leather, generating scratches, flaking, erosion, and micro-cracks; 2) the mud adds occasional sand and silt size sediment grains on the surface of the leather that would increase the grip of the ball; 3) the mud adds a consistent color by preferentially accumulating mud in the pores of the leather; 5) game use does not remove clays from the pores of the baseball, but other grains on the outer surface of the leather are rarely observed.

## How “Magic” is this Mud?

It is worth considering whether there is anything geologically unique about this mud, or if similar materials from other regions could perform just as well. The individual components—common detrital minerals and widespread diatoms—are not rare, and the depositional environment itself is not particularly distinctive. What makes this mud effective is the specific combination and relative proportions of its constituents. This rubbing mud reliably delivers the grip and subtle darkening that MLB requires. A higher sand content would increase abrasiveness and grip, potentially giving pitchers an advantage. On the other hand, a finer-grained, less abrasive mud would reduce grip and favor hitters.

The absence of certain minerals is also important. For instance, if the clay fraction included a higher proportion of swelling clays (such as smectite), the mud could dry out and crack the leather, swell unpredictably in humid or wet conditions, or become slippery when wet. Similarly, excess organic material could lead to spoilage during storage, unpleasant odors, or microbial growth. In short, it’s not any single component that makes this mud unique, but rather the specific balance of mineralogy, grain size, and low organic content that gives it consistent and functional performance.

Changes in mineralogy could also change the color of the mud. Muds from different locations could also have a slightly different color when either wet or dry. Small color variations might seem insignificant to a layperson but could affect how a skilled batter tracks the ball while in flight, as they rely on the color of the spinning ball to read pitches. If muds were collected locally to each ballpark, there would likely be inconsistencies in the color of the balls, the amount of abrasion to each ball, as well as the possibility of swelling clays being present. Although the mud imparts only minor changes in friction (Yamaguchi et al., 2022), skilled pitchers can discern the effect, making consistent application important for fair competition. This is evidenced by the fact that during gameplay, a ball is often discarded once it comes in contact with the ballpark dirt.

Recent efforts by MLB to standardize the mud application process stem from a desire to ensure fair competition across the league, with consistency between balls and ballparks being crucial. While there is not a specific magic ingredient to the Lena Blackburne Baseball Rubbing Mud, our interpretation is that the consistent color, abrasive properties, and minor amount of swelling clays makes it an ideal choice for consistency. Locally sourced muds would induce too much variability to the color and feel of the ball.

## 4. Conclusions

Lena Blackburne Baseball Rubbing Mud has been an important part of baseball tradition for decades, but the characteristics of the mud, along with its effect on the surface of

a baseball have been poorly understood. Using mineralogical, sedimentological, and SEM analyses, we have characterized this mud as being dominated by low-swelling clays, with secondary components comprised of detrital quartz and feldspar, with small amounts of swelling clays, diatoms, and organic carbon.

When applied to the surface of the ball, the clays fill pores in the leather, adding color to the ball that does not fall off during aggressive gameplay. The other components of the mud, along with the clay, also serve as a gentle abrasive, exfoliating the outer surface of the leather. This would serve to remove the glossy outer surface of a new baseball and add additional texture for enhanced grip.

Using mud or sediment from different sources would also be effective at either adding color to the ball or exfoliating the leather. However, different mud sources would have different effects on the surface of a baseball. An increase in the amount of swelling clays, or coarser material, could cause too much damage to the leather. A decrease in the amount of clay could impact how well the mud adheres to the ball. A change in the color of the mud could affect a batters’ ability to read pitches, as they rely on the color of the spinning ball as it is thrown.

We even recognize that the collection site is a product of the depositional environment, and moving to an area of the creek with different flow rates could change the relative sorting and grain size of the sediment. The mud would be very sensitive to changing locations, as well as external factors such as the building or removal of dams in the area. Thus, while the individual components of this mud may not be unique, their combination creates distinct properties that justify its continued use as the standard for baseball preparation. Future research could examine whether these minor variations in collection location or alternative mud sources would produce comparable effects.

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## Acknowledgements

We would like to thank AGAT laboratories for providing laboratory support to this project. We would also like to thank Ethan Penner for doing field reconnaissance that aided our geologic context. Finally, we would be remiss if we did not acknowledge the helpful reviews we received that greatly improved the clarity and readability of this work.

Submitted: August 06, 2025 CDT. Accepted: September 26, 2025 CDT. Published: September 30, 2025 CDT.



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## Supplementary Materials

### Supplementary Material- Figs and Text combined

Download: <https://thesedimentaryrecord.scholasticahq.com/article/144870-geology-s-grip-on-baseball-investigating-the-sedimentology-mineralogy-and-physical-properties-of-baseball-rubbing-mud/attachment/303965.docx>

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