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An Analysis of Sediment Collected by Pogonomyrmex salinus from the Jurassic Sundance Formation, Bighorn Basin, Wyoming

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Abstract

Pogonomyrmex salinus is a species of harvester ant found in the Bighorn Basin area of Wyoming. Harvester ants are aptly named as they “harvest” seeds for food, but this harvesting behavior is also seen in their collection of sediment particles to build their mounds. For decades, paleontologists have looked to harvester ants for microfossils because the small size of the fossils makes them difficult for human eyes to find. But there are unresolved questions about the data that can be gleaned from the fossils collected by the ants. The mounds collected for this study include material from the Stockade Beaver Shale Member of the Sundance Formation, which dates to the Middle Jurassic Epoch. In this study, harvester ant mounds were collected and examined under microscope and the mounds sorted into their different components. The mounds were sorted into fossil materials, organic materials, and matrix. The fossil material was further sorted into taxa while the organic materials and matrix were loosely grouped according to likeness. For example, seed pods of any kind were grouped together and scat was grouped together. Through this process of sorting, questions of the ants’ collection preferences are explored. Questions include whether the ants exhibit a preference for fossils or non-fossiliferous materials. Further, of the fossils found , is there a specific fossil that they collect more than others, and is that reflective of the abundance of those taxa found from traditional collection methods? This study is novel because previous studies have not included the non-fossil material in the collection analysis. By including non-fossil material, the ants’ gathering biases can be more accurately identified, which will help to more accurately analyze data and glean a more full understanding of the paleo-community make up.

Introduction

Ants have been used by researchers to collect microfossils, or the remains of small animals, for decades (Galbreath, 1959; Johnson, 1966; Shipman and Walker, 1980; Adams, 1984; Matthias and Carpenter, 2004; Wright, 2017). Most microfossils are so small that researchers require microscopes to accurately study them, which makes identifying and collecting these specimens difficult using nested sieves to pick through sediment found scattered on the ground. Instead of collecting the top layer of sediment from a large area, paleontologists let harvester ants do the collecting for them. Though reports of why harvester ants collect microfossils and use them in the construction of their mounds have been largely anecdotal, studies have determined that they are actively transporting and depositing microfossils in their mounds (Schoville et. al, 2009).

The ant genus commonly used as fossil foragers are in the genus *Pogonomyrmex*. There is little research into how *Pogonomyrmex* chooses the material they collect. Experiments designed to examine ant preferences have focused on either fossils, food particles, or rock material, but never any combination (Hooper-Bui et al., 2002; Matthias and Carpenter, 2004; Schoville et al., 2009; Ipser and Gardner, 2019). The lack of research into the fossil foraging behaviors of harvester ants leaves room to wonder how their preferences might bias their collection, which, in turn, would bias the scientific collection of fossils from their mounds. Without knowing what their biases are it is impossible to reliably analyze the data gathered from their collection.

Figure 1. *Pogonomyrmex salinus* photographed by the Virginia Museum of Natural History

This study is focusing on the collection habits, and potential selection preferences, of the ant species *Pogonomyrmex salinus* (Figure 1). This species was chosen for this study because it meets two standards. The first is that this species of ant inhabits the region in which the study area is located. The second standard is that ants in the *Pogonomyrmex* genus have been used to collect microfossils in the past. The study area is in the Bighorn Basin of Wyoming, which is in the northwestern interior part of the United States (Figure 2). The ants live on top of the Stockade Beaver Shale Member of the Sundance Formation. Geologists have used biostratigraphy, which is a dating method based on the known age of fossils found in the rock, to determine that the Stockade Beaver Shale Member is approximately 167 million years old (Kvale et. al., 2001). This puts the Stockade Beaver Shale Member in the Bathonian Age, part of the Middle Jurassic Epoch (Figure 3).

Figure 2. Aerial view of the United States with an arrow pointing to Bighorn Basin, WY. Retrieved from Google Earth.

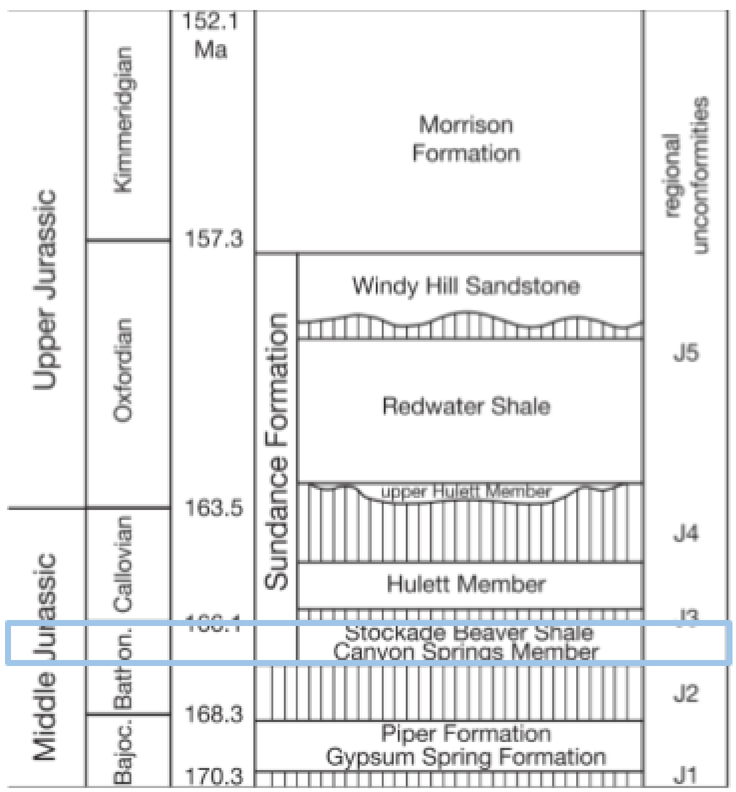

Figure 3. Geologic time scale with associated formations (Kvale et al., 2001).

Figure 4. Illustration of the Sundance Seaway (McMullen et al., 2014).

Geology and Stratigraphy

During the time of deposition, this part of Wyoming was under a shallow sea called the Sundance Seaway (Kvale et. al., 2001; Blakey, 2013; McMullen et. al., 2014.(Figure 4). Because of the volcanic mountain range to the west, the Bighorn Basin was in a rainshadow, which made the climate arid and windy (Kvale et. al., 2001; McMullen et. al., 2014). Because of the movement of tectonic plates, Wyoming was farther south than it is today. The Jurassic Period is when Pangea, the supercontinent, broke apart and the present-day layout of the continents started to take shape. The North American plate moved northward, which brought present-day Wyoming out of a semiarid climate and into a more northern latitude by mid-Jurassic (Kusnerik, 2015).

The seaway's changing shoreline, over geologic time, caused depositional cycles. One cycle of relative sea level, which is the fall and subsequent rise in sea level, is bounded by unconformities, or gaps in the depositional record. There are four cycles of sea-level fall and rise in the Sundance Formation. The cycles in the Sundance Formation are layers of carbonate-based sediment covered by silicate-based sediment, bounded by unconformities, (McMullen et. al., 2014). The Sundance Formation experienced roughly four depositional cycles, but the *P. salinus* mounds from this study are located in rock formed from sediment deposited during the third depositional cycle (Kvale et. al., 2001). Depositional cycles are bounded by subaerial unconformities, which are surfaces marred by erosion. The Stockade Beaver Shale Member is located between the J2 and J3 unconformities, which indicates the ends of the second and third depositional cycles during the Jurassic Epoch (Kvale et. al., 2001; Kusnerik, 2015).

The Stockade Beaver Shale member is mostly carbonate-based rocks, such as limestone, but there are also siliciclastic mudstone deposits (McMullen et. al., 2014; Kusnerik, 2015). Carbonate rocks are sedimentary rocks composed of carbonate-based minerals. The rocks in the study area are limestone, which means that they are made up of calcium carbonate. Calcium carbonate usually originates as a solute in bodies of water. Organisms like clams and oysters provide the calcium when their shells break down, and the carbonate comes from atmospheric carbon dioxide. The rock forms when the calcium carbonate is precipitated out of solution and dries into a hard mass of cemented sediment. Siliciclastic mudstone is another type of sedimentary rock, but this one is composed of silica-based minerals. Mudstone is the cementation of fine-grained particles. A rock is considered mudstone if a third to two thirds of the particles are of clay-sized particles and the rest are silt-sized. The actual rock is formed when the rock is compressed enough to dry out all the moisture from the pore space.

Invertebrate Fossils from the Sundance Formation

Most of the invertebrate fossils found in the Stockade Beaver Shale Member are of the oyster *Gryphaea nebrascensis*, (Wright, 1973; McMullen et. al., 2014; Kusnerik, 2015) (Figure 5). Additional microfauna, or evidence of microfauna, that might be found in the sample include other bivalves, crinoids,

Figure 5. Image of *Gryphaea nebrascensis* from the sorted matrix.

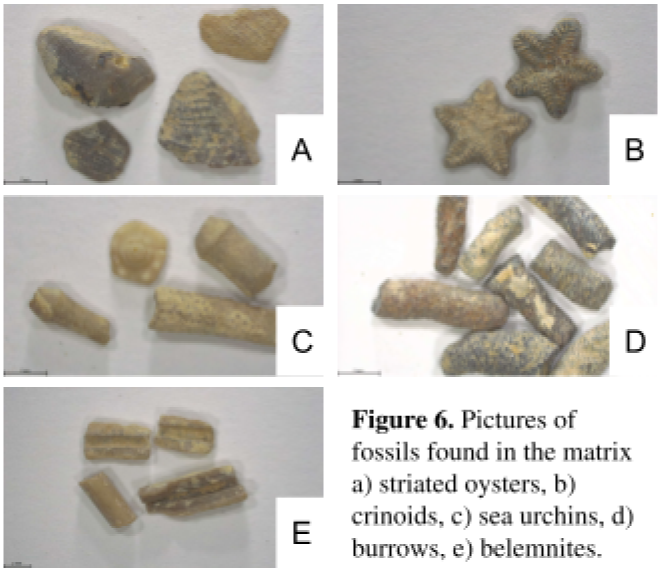

Figure 6. Pictures of fossils found in the matrix a) striated oysters, b) crinoids, c) sea urchins, d) burrows, e) belemnites.

echinoderms, burrows, and belemnites (Figure 6). The presence of these benthic species indicates a near-shore depositional environment (Kusnerik, 2015). What sets this research apart from previous studies is the inclusion of non-fossiliferous material. Therefore, the samples are expected to include plant matter such as leaves, steams, and seeds, as well as scat, dirt clods, dead ants, and rocks (Figure 7).

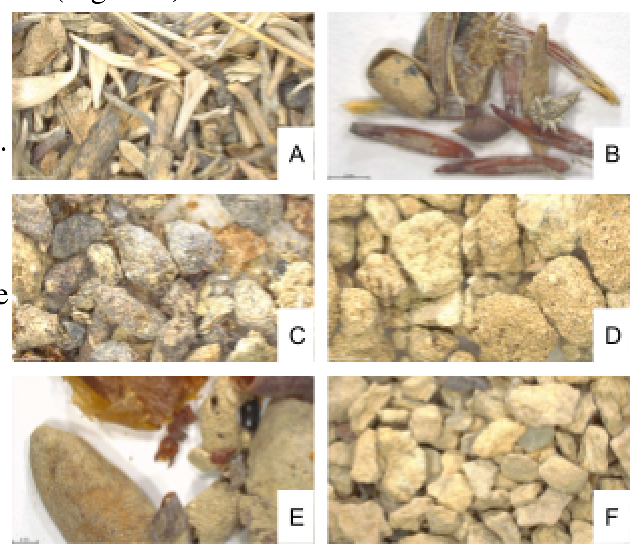

Figure 7. Pictures of a) non-seed plant matter, b) seeds, c) scat, d) dirt clods, e) animal matter, f) rocks.

There are two studies of note that have looked at the abundance of microfossils in the Bighorn Basin. Kusernik (2015) wrote his master's thesis on the community paleoecology of the Sundance Seaway. He collected 15 samples from the Stockade Beaver Shale Member. Sampling methods varied from bulk and surficial sampling to field counts (Kusernik, 2015). McMullen's (2014) research aimed to understand how stratigraphy influenced the distribution of fossils. Her methods included a faunal census, which was described as spending 15 to 20 minutes examining a 1 to 2 square meter area and documenting the taxa found (McMullen et al., 2014). According to Kusernik and McMullen, the most abundant taxa were *Gryphaea* (McMullen et al., 2014; Kusernik, 2015). McMullen actually had to throw out the data point for *Gryphaea* because it was so abundant that they could not get meaningful information about the other data (McMullen et al., 2014).

Ants

Harvester ants are considered pests mostly because of the vegetation disturbance they cause. They are not uncommon visitors to yards and farms within their native range, and the large patch of missing vegetation is unsightly and damaging (Figure 8). Additionally, harvester ants have a painful sting and bite. However, harvester ants are considered a keystone species. Keystone species are organisms that have a disproportionately large impact on their habitat compared to their abundance or size. An example of how much harvester ants influence their environment is in the vegetation that grows on the edge of their mound clearing, which grows well and are often among the first plant species to grow back following a wildfire (Uhey, 2022).

Figure 8. An ant mound with foraging trails in Bighorn Basin, WY. Photo courtesy of Dr. Kal Ivanov.

The species of harvester ant in this study is *Pogonomyrmex salinus.* Harvester ants build mounds with gravel to cover their underground nests, which they establish in soils that they can easily dig into (Schoville et. al, 2009). The mounds often occur in high densities with 6-75 mounds per hectare and anywhere from 12-49m between mounds (Schoville et. al, 2009). Established harvester ant colonies can persist in the environment for 20 years or more, which is one of the reasons they are considered disturbance agents (Schoville et. al, 2009). Harvester ants can forage anywhere from 8-20m away from their mound depending on the amount of vegetation and availability of foragable materials (MacMahon et. al., 2000; Schoville et. al, 2009). Harvester ants establish foraging trails that individuals will routinely use if they are especially successful (Schoville et. al, 2009). However, the ants do not have to stick to those trails and will forage the entire area around the mound (Schoville et. al, 2009). Some experts hypothesize that harvester ants remove vegetation to reduce the obstacles in their way and reduce travel time when foraging, decrease their risk of exposure to grass fires, and increase the amount of solar radiation that hits the area around their mounds to heat them up (Schoville et. al, 2009).

One of the foremost hypotheses that explains why harvester ants build mounds is that the structure helps with thermoregulation (Carlson and Whitford, 1991; Cole, 1994). Ants will choose the largest particles that they can carry because larger particles have low thermal capacity and therefore heat up faster, which means that the inside of the nest heats up faster in the morning, wakes the ants more quickly, and allows for more efficient foraging (Carlson and Whitford, 1991; Espinoza and Santamarina, 2010; Ipser and Gardener, 2019). The particle size that harvester ants can carry is dictated by the size of their mandibles. Males have an average mandible length of 0.95mm and an average width of 0.42mm (Abell et. al., 1999; Espinoza and Santamarina, 2010; Ipser and Gardner, 2019). Female ants are not foragers like the males are, so the size of their mandibles is not as pertinent to this research.

Research on *P. salinus* is limited, so *Pogonomyrmex occidentalis*, which has been used to collect microfossils in the past, is used as a substitute (Galbreath, 1959; Johnson, 1966; Shipman and Walker, 1980; Adams, 1984; Matthias and Carpenter, 2004; Wright, 2017). *P. salinus* and *P. occidentalis* are virtually indistinguishable in the field because the key difference between the two species is the shape of their mandibles. In *P. occidentalis* the basal mandibular tooth curves upward while *P. salinus*' does not. Additionally, both species are found in similar abundance in the study area as they both inhabit areas with deep, sandy soils and avoid poorly-drained soils (MacMahon et. al., 2000). Both ant species are found in the northwestern part of the United States from Wyoming to the West coast and from California into British Columbia. The area that

P. salinus and *P. occidentalis* inhabit is commonly referred to as the Great Basin (MacMahon et. al., 2000).

Figure 9. The difference between the basal mandibular tooth in *P. occidentalis* and *P. salinus*. Highlighted by the white circle. Retrieved from Quinn, 2010.

This Study

The question of the ants' ability to provide a fossil collection that is a statistically valid representation of the fauna of the unit remains unanswered. In order to determine whether the ants have a collecting bias, a sample of fossil invertebrates collected by the ants must be compared to a sample collected using a more traditional screen washing practice. The critical data to be collected is diversity and relative abundance information. The scope of this project must be narrowed due to time constraints, so this project aims to begin understanding the fossil-collecting behaviors of harvester ants. By including non-fossiliferous material in the sample, a more clear understanding of whether the ants prefer fossils or normal sediment can be achieved. Further, if there is an uneven occurrence of materials, the sorted taxa data will provide insight into what specific kind of fossil the ants might prefer.

Understanding fossil-collecting behaviors of *Pogonomyrmex salinus* will open the door to further research. If the ants do exhibit a collection bias, then they will create a fossil record that makes that specific fossil seem dominant even if it isn't true. By understanding how ants influence the study of the fossil record and the biases they might bring to fossil collections, we will be able to describe and understand paleo ecosystems much better.

Methods

The ant mound, which refers to the above-ground collection of sediment that covers the underground nest, was scraped down to the surface to collect a total of 13,185ml of sediment. However the final volume of the total sample that was used in calculations was approximately 991.8ml . The mound that was collected had a diameter of 181 cm from the northernmost point to the southernmost point. However, the shape of the mound was more oblong because the east-west diameter was 149cm. This means that the total area of the mound was roughly 5,295cm^2. The sediment was stored in a plastic bag until it was delivered to the Virginia Museum of Natural History where the sediment was sieved to create samples of certain size ranges. In this paper, the sediment sorted fell in the 5-10mm range. All of the sediment was sorted by particle type. To calculate the relative abundance, the volumes of each of the sorted groups were measured. Because some of the pieces, like dirt clods, would dissolve in water, water displacement was not used. Instead, the volume was estimated by pouring the sorted sample into a graduated cylinder. Relative abundance was determined by dividing the volume of the sorted matrix by the total volume of the sample. Data on the total mass of each of the samples was also collected, though not analyzed in this study (Appendix 1).

Results

Taxon	Volume (ml)
Gryphaea nebrascensis	**612**
Crinoids	**17**
Striated oysters	**5.8**
Belemnites	**2.4**
Sea Urchins	**<1**
Burrow	**<1**
Bryozoans	**<1**
Snails	**<1**
Rocks	**325**
Dirt Clods	**13**
Non-Seed Plant Matter	**7**
Seeds	**2.6**
Scat	**<1**
Animal Matter	**<1**
Unknown/Other	**<1**
Total	**~ 991.8**

Table 1. Volume of each particle group in the matrix. Blue = fossils. Orange = non-fossils.

Shells of *Gryphaea nebrascensis* and rocks are the most abundant materials found from the mound (Figure 10). The sheer number of these two components are overwhelming, so looking at the recovered elements without those two categories is the only way to refine the results. Removing the *Gryphaea* and rocks, more subtle patterns emerge from the data. By volume, crinoids, dirt clods, and non-seed plant matter are the most abundant (Figure 11). There are more fossils in the matrix than non-fossils including the *Gryphaea* (Figure 11). Looking solely at fossils, crinoids and striated oysters are the most abundant (Figure 12). The top three most abundant non-fossil material particles are dirt clods, non-seed plant matter, and seeds (Figure 13).

Discussion

One of the important results of this study was the identification of fossils that were not reported in other research, specifically the bryozoans. Bryozoans were not reported in any of the previous studies examined as part of the literature review for this research. Additionally, I went into this research expecting to find only invertebrate fossils, but I found what is definitely a vertebrate bone. I consulted with Dr. Adam Pritchard, the Assistant Curator of Paleontology at the Virginia Museum of Natural History, to identify this bone. Dr. Pritchard thought that the bone was a fish quadrate, or jaw bone (2023 conversation with A. Pritchard; unreferenced). Since the Sundance Formation is a marine unit, the presence of bryozoans and a fish quadrate, while not expected, makes sense.

<u>Whole Matrix Analysis</u>

In previous studies that examined the fossil composition of ant mounds, *Gryphaea nebrascensis* was the dominant fossil (Wright, 1973; McMullen et. al., 2014; Kusnerik, 2015). Since my methods are similar to the methods employed by previous researchers, I expected to find more *Gryphaea* than anything else. The results of this paper agree with previous research in that *Gryphaea* is the most abundant particle in the ant mound. Because of the overwhelming amount of *Gryphaea* in the sample, the relationships between and importance of other groups might be distorted (McMullen et al., 2014). Therefore, I opted to follow McMullen's example and exclude the *Gryphaea* to ensure that I saw nuances in the rest of the data. Removing the *Gryphaea* data from the sample provided some resolution, but the data were still overwhelmed with the percentage of rocks. Therefore, I followed the same protocol with rocks and removed them from the data as well.

Without the *Gryphaea* and Rocks

With the removal of the rocks, it was revealed that the ants in this mound collected more fossils than non-fossils - specifically crinoids, striated oysters, bryozoans. Crinoids represent over half of the fossil composition once the *Gryphaea* were removed from the matrix. The percent composition that crinoids represent in the sample is roughly double that of the second most abundant particle type, striated oysters. I hypothesize that crinoids are so abundant because they allow for more efficient foraging when building the mound. Crinoids are shaped like stars, which I think plays an important role in their abundance. As previously stated, harvester ants' foraging capabilities are limited by the size of their mandibles (Abell et. al., 1999; Espinoza and Santamarina, 2010; Ipser and Gardner, 2019). I think that the points of the star allow the ants to pick up larger particles because they will be small enough to fit in the ants' mandibles even if the crinoid itself is on the larger side. This hypothesis will be testable in the future.

To attempt to determine if there is a preference among the ants for fossil types, or non-fossil components, the results of this mound must be compared to other data. The two main bodies of data to compare to would be a control sample and to published literature surveys of invertebrates from the formation. I looked for data to establish a baseline for the relative abundance of fossils in the area, but they do not exist yet. However, the Virginia Museum of Natural History collected a control sample at the time that the ant mound I sorted through was collected. In total, the museum collected four ant mounds in pairs. Halfway between each pair, they chose a spot without an ant mound, but that might be a spot the ants would choose to build a mound (Figure 14). They scraped loose sediment off of the surface at this control site, like they would have with an ant mound. The goal is to pick through all four mounds and both control samples to compare results and determine the ants' foraging preferences. Without the control data, it is impossible to make any generalizations or assertions about whatever preference the ants

Figure 14. Map of nests researched by Dr. Kal Ivanov for the Virginia Museum of Natural History. Star denotes the mound collected for use in this research. Circle denotes the other mound collected. Arrow points to the control area. Photo retrieved from Dr. Kal Ivanov.

might show for fossils, non-fossils, or any specific component of either category.

In summary, it came as no surprise that I found more *Gryphaea nebrascensis* and rocks than anything else. However, I also found that, at least in this particular ant mound, the ants collected an equal amount of fossils and non-fossils. Additionally, a closer look at the data found that crinoids were abundant as well. And, though likely not statistically relevant, it is also exciting that unexpected taxa were found in the fossil matrix.

Conclusions

This project aimed to understand the preferences of ants in the collection of particles for their mounds. The focus was two-fold. In addition to understanding whether the ants preferred fossils or non-fossils, this paper sought to determine what kind of fossil the ants might prefer. By including non-fossiliferous material in the sample, a more clear understanding of whether the ants prefer fossils or normal sediment can be achieved. Further, if the ants exhibit a preference for fossils, the sorted taxa data will provide insight into what specific kind of fossil the ants might prefer. If the ants do exhibit a collection bias, then they will create a fossil record that makes that specific fossil seem dominant even if it isn't true. By understanding how ants influence the study of the fossil record and the biases they might bring to fossil collections, we will be able to describe and understand paleoecosystems much better.

There are many opportunities for future researchers to expand on this work. Future researchers can compare the data in this study to other ant mounds and to the control sample, which would be sediment collected from an area close to ant mounds, but unoccupied by ants. To sort through more than what I did would take far more than the year I had to complete this research. Future research should start here.

Though it is speculative in light of the results of my research, ants still may make choices and exhibit preferences for certain forageable materials. As mentioned previously, these choices could be informed by thermal capacity (Carlson and Whitford, 1991; Cole, 1994). It could also be as simple as size restrictions (Espinoza and Santamarina, 2010; Ipser and Gardener, 2019). Perhaps this could be investigated using temperature probes, but first we have to determine whether the ants are acting with preference first. By looking at other ant mounds and control samples, the question of preference can be answered. The resources from the Virginia Museum of Natural History would be a better place to start. My research has gotten the ball rolling and opened the door for future students to write theses adding onto what I’ve found out so far.

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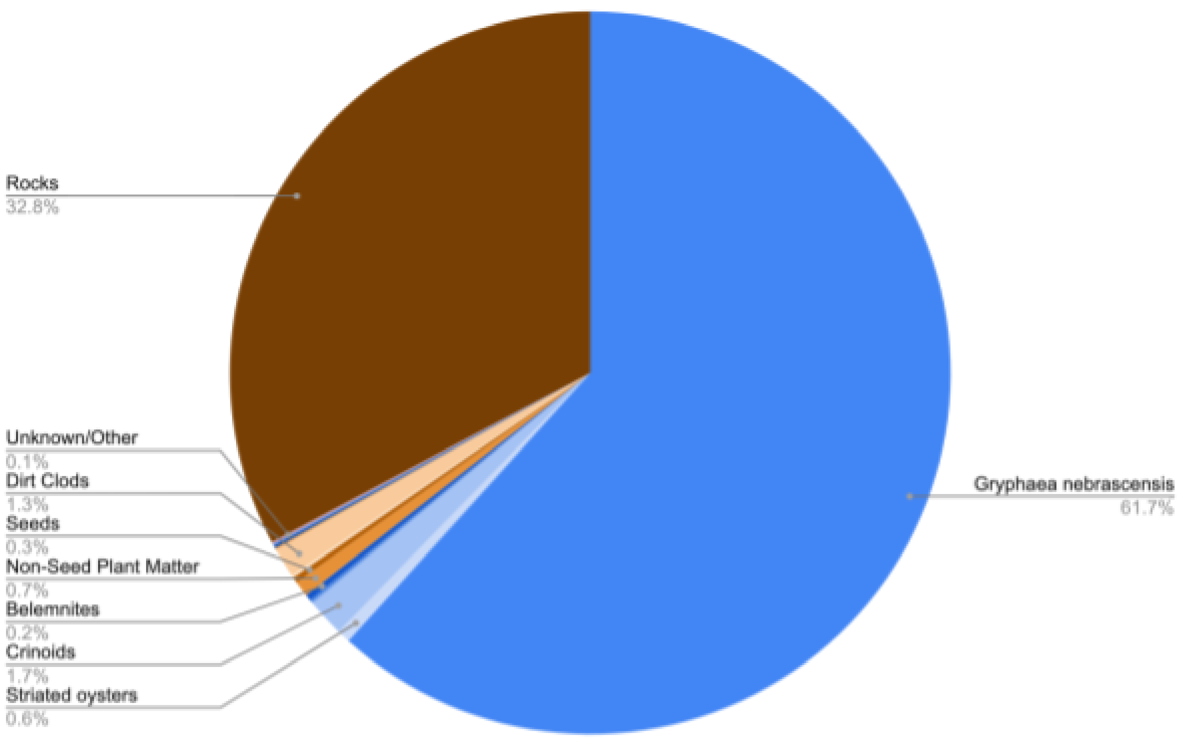

Figure 10. Percent composition of complete matrix by volume. Blue = fossils; Brown/orange = non fossils

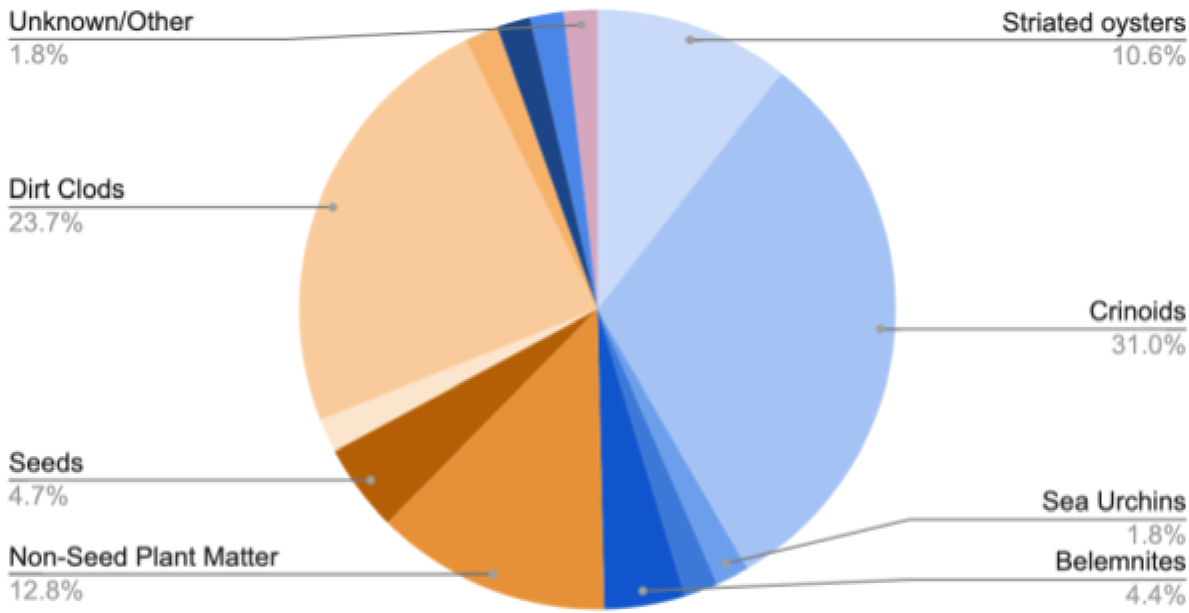

Figure 11. Percent composition of the ant mound by volume without *Gryphaea nebrascensis* or rocks. Blue = fossils. Orange = non-fossils.

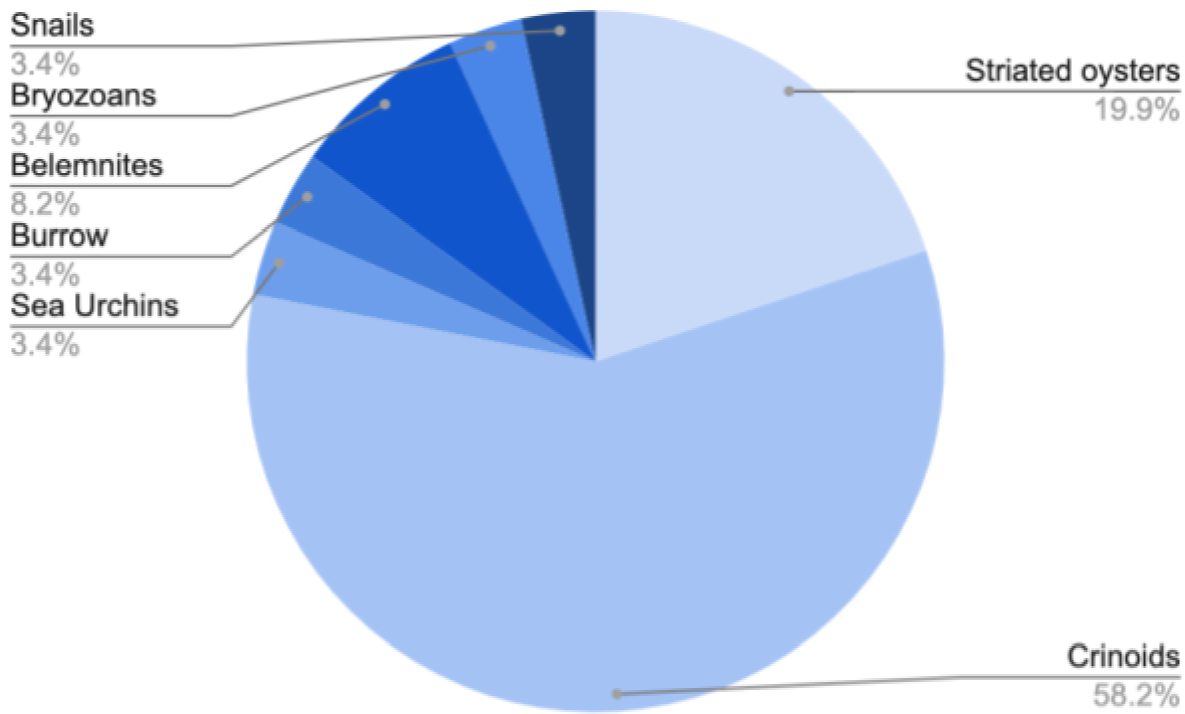

Figure 12. Percent composition of the fossils collected from the ant mound by volume.

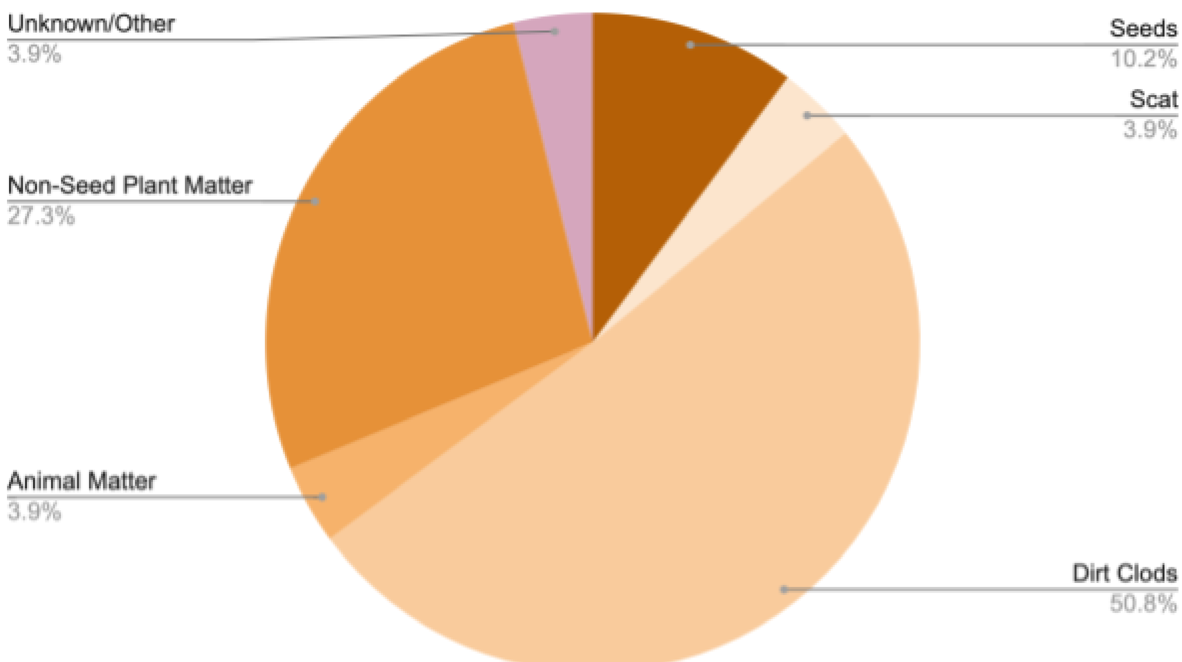

Figure 13. Percent composition of the non-fossil material collected from the ant mound by volume.

Appendix 1. Data on mass of different components of the ant mound.

Taxon	Mass (g)
Gryphaea nebrascensis	**774.0051**
Crinoids	**22.4329**
Striated oysters	**6.3600**
Belemnites	**2.7632**
Sea Urchins	**0.3025**
Burrow	**0.9255**
Bryozoans	**0.3344**
Snails	**0.0408**
Rocks	**412.0244**
Dirt Clods	**15.6826**
Non-Seed Plant Matter	**1.2035**
Seeds	**0.5506**
Scat	**0.2845**
Animal Matter	**0.0058**
Unknown/Other	**0.0745**
Total	**1236.9903**

Table 2. Mass of each particle group in the matrix. Blue = fossils. Orange = non-fossils.

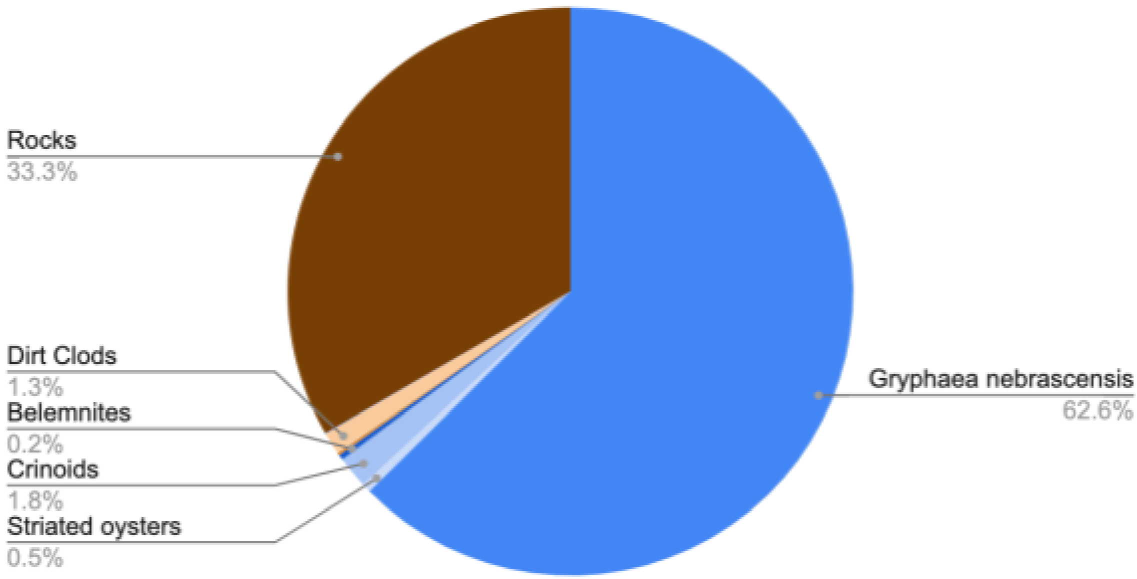

Figure 15. Percent composition of the ant mound by mass. Blue shades indicate fossils. Brown/orange shades indicate non-fossils.

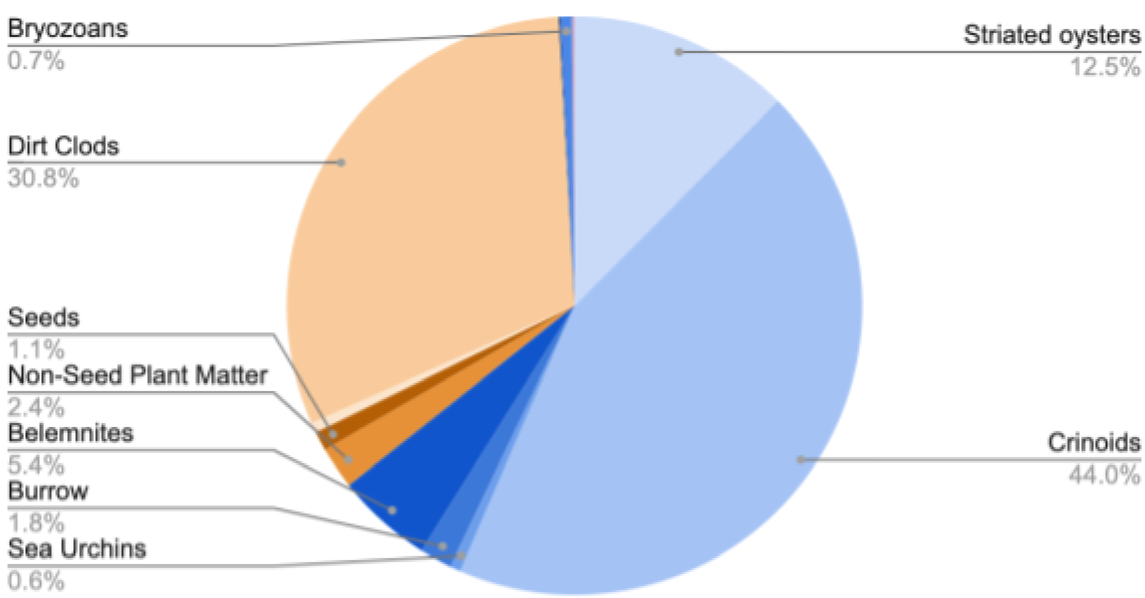

Figure 16. Percent composition of the ant mound by mass without *Gryphaea nebrascensis* or rocks. Blue = fossils. Orange = non-fossils.

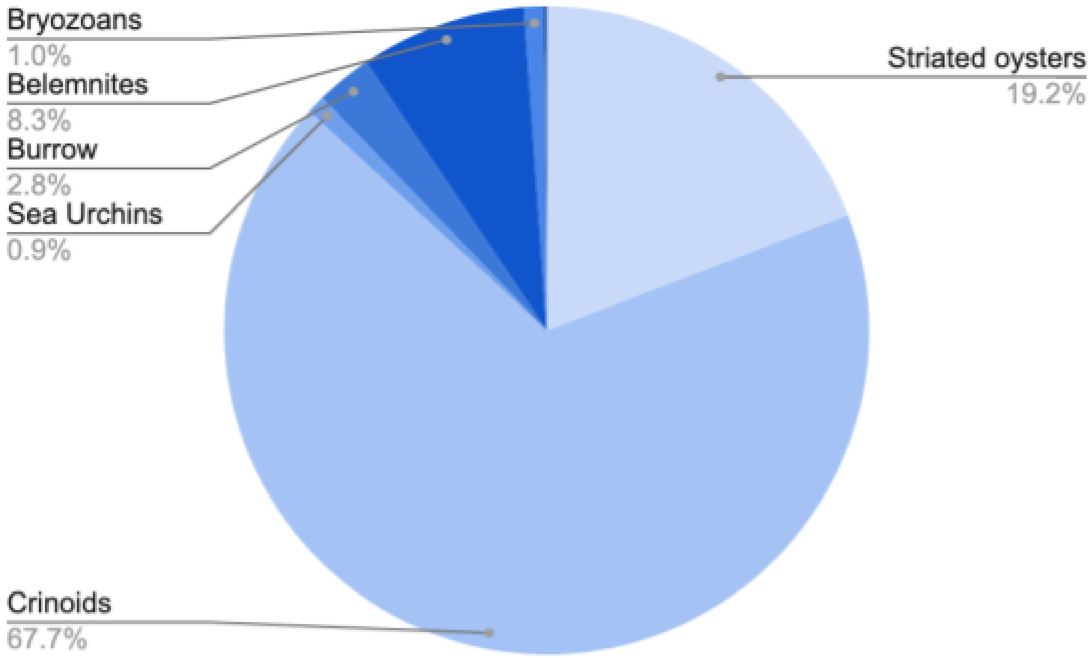

Figure 17. Percent composition of fossils collected from the ant mounds by mass.

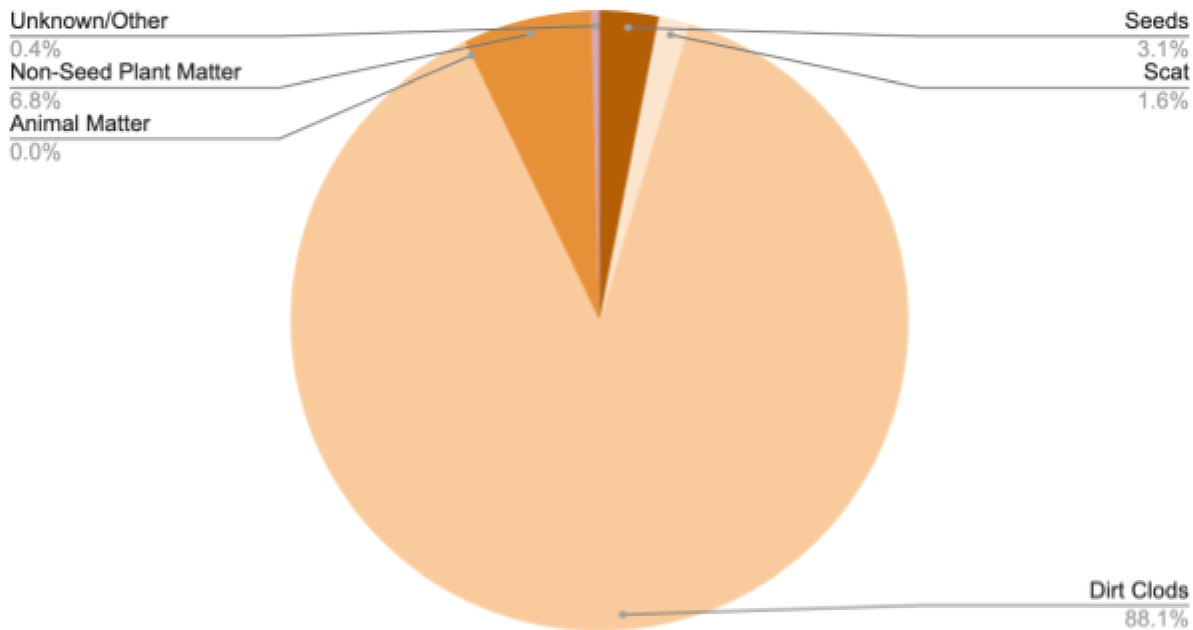

Figure 18. Percent composition of the non-fossil material collected from the ant mound by mass.