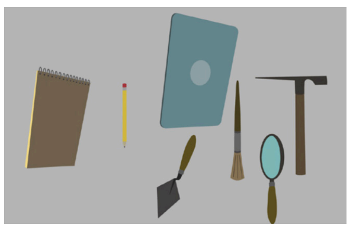
BONEBED

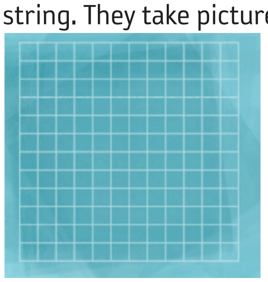
Developing a Plan

Paleontologists don't dig just anywhere. Careful planning is involved when deciding where to dig. To start, paleontologist look for rock that comes from the same time period they want to study using a "geologic map." This is a map that tells scientists how old exposed rock is in different locations. For example, if a paleontologist wants to find *Tyrannosaurus rex fossils*, they would use a geologic map to look for rock from the Cretaceous period, the time when *T.rex* lived.

After they find a place to dig, paleontologists decide on what tools they will use to uncover the fossils. They think about the size of the quarry and the type of rocks found there. Large tools, like jackhammers, picks, shovels, and rock saws may be used to remove the "overburden"- the layer of dirt and rock above the fossils. As they get closer to the layer where the bones are, paleontologists put their large tools aside and reach for smaller tools such as dental picks and paintbrushes. They use these tools to slowly uncover the fossil being very careful not to damage it in the process.



Once they have exposed all of the fossils, the bone bed (layers of rock where fossils are most densely concentrated) must be mapped. Mapping a bone bed takes some time. To map a bone bed, paleontologists create a meter grid square over the dig site using a compass, end posts, and string. They take pictures and make notes of where fossils are located within the grid. This is a very important step because once the site has been dug up, paleontologists will need to remember where all the different fossils were located. For instance, it will be important to remember if a certain fossil was located right next to another fossil, or if it was found many feet away. It is also helpful to know whether a fossil was found high or low in the bone bed. These details will help the original scientists and their colleagues (like you!) to form hypotheses about the fossils they find even after everything has been excavated and brought back to the museum for closer examination.



Examining the Bone Bed

The study of what has happened to an organism from the time of its death up until the time of its discovery as a fossil is called taphonomy. When conducting a taphonomic study of dinosaurs, or any fossil, there are many observations that scientists make and record. These include examining the sediment in and around the bone bed, noting how the bones are arranged, which bones are missing, looking for clues from the condition of the bones, any markings on the surface of the bones, and more. All of this information will help scientists develop hypotheses about why these animals died and what happened to their bodies after they died.

The sediment in the bone bed provides a lot of information for paleontologists. Sediment is made up of particles from Earth's pre-existing rocks. Often, sedimentary rock is formed as these particles accumulate, compact, and become cemented together. Because sedimentary rock is made up of the sediment that was in an area at a given time, it can tell scientists a lot about the history of an area. Some of the main rocks that make up bone beds are claystone, siltstone, limestone, and sandstone. Here are some general descriptions:

- **Claystone** is made up of very small clay particles that have been compacted over time. It feels smooth because the particles are so small. It is a type of mudstone, which means that the particles were at one point wet and muddy.

- **Siltstone** is another type of mudstone. It is made up of silt-sized particles (particles that are smaller than a grain of sand) that were deposited by water, wind, or ice and then cemented into rock over time.

- **Limestone** can range from smooth to rough textures, depending on how it was formed and what it is made of. Limestone is classified as having more than 50% calcium carbonate and is most often formed through water precipitations, secretions of marine animals like coral and algae, or the build up of shells from marine species.

- **Sandstone** is characterized by the sand-sized grains that are cemented together in sedimentary rock. It usually feels gritty, like sandpaper.

The way that the fossils are laid out can provide valuable insight into how they came to be deposited there. One thing that paleontologists look for is whether the bones are articulated or disarticulated. If the bones are articulated, that means the bones were found in the same arrangement as when the animal was alive. Think of your spine. If it is found articulated then it is found with each vertebrae lined up next to one another the way it is in your body now. If bones are found disarticulated, it means that the bones were not found arranged as they were in life. For example, an arm bone might be separated from the shoulder bones and hand bones. This could be due to water or wind moving the bones around, or scavenging animals that scatter body parts.

Bone beds can represent millions of years, so it is also important to note how fossils are positioned in relation to other fossils. Scientists can usually assume that fossils found higher up died more recently in time than fossils found lower in the bone bed. Sometimes there is strong evidence that a carnivorous dinosaur was scavenging or killing another dinosaur, such as a tooth from one dinosaur stuck in the bones of another, or bite marks on the surface of a fossil. If scientists uncover bones from an adult animal next to a smaller version of those same bones, they may hypothesize that they have found a mother and baby.

There are many other clues paleontologists look for to help them make sense of a bone bed. A large concentration of bones from a variety of ages of animals often represents some type of catastrophic event that resulted in the death of the animals at or near the site. Bones arranged in a circular pattern could record deaths in or around a small pond or watering hole. A pattern of long bones (such as arm or leg bones) that are all parallel to each other suggests that a stream of water pushed the bones into this orientation.

Skeletal Data

There is a lot of important information to be gained from the surface of fossilized bones themselves. When paleontologists examine fossils from the bone bed, they take note of the shape, surface, and size of the fossils. Some of the signs they are looking for when examining bones are evidence of weathering, abrasion, and surface tracings.

Weathering is the breaking down of materials through contact with wind, water, radiation from the sun, heat, cold, or other natural forces. Evidence of damage from weathering provides clues about how long a bone was exposed to the surface of the Earth. In fossils, weathering can be hypothesized if the fossil has longitudinal cracks in the bone and flakiness of the outside layer. Heavy weathering means that bones sat on the surface for a while before being buried. These bones may be split apart longitudinally and the surface layer of the bone could be completely flaked off. Light weathering means a fossil was buried soon after death. These bones may show some signs of longitudinal splitting and some surface flaking. No weathering means that a bone was buried immediately or very soon after death. These bones will not appear to be split longitudinally or have any signs of flaking.

Abrasion refers to scraping that happens when two surfaces are rubbed against each other. Abrasion could be caused by bones being moved from their original location by natural means (such as a flood or landslide), from water moving over the bones, sand grains continuously pelting the surface, digestion in the stomach of another animal, and many other situations. Patterns of abrasion on fossils can help scientists form hypotheses about what caused the abrasion. For instance, if a bone was buried with just a small part sticking out of earth, that part that was exposed might become abraded by wind and sediment. If a scientist discovers this fossilized bone millions of years later, they may observe that the abrasion only affected a small part of the bone and hypothesize that the bone was partially buried soon after the animal died.

Fracturing means that part of a bone was partially or entirely broken. Paleontologists look at fractured bones and tried to determine whether they were broken before or after death. Why do you think it is important to know whether a bone was broken before or after death? If it was before death, it provides evidence that can help scientists develop hypotheses about the animal's life. Evidence of healed bones includes bones that are fused together or extra bony material where the bone was healed over. If a bone was broken after death, it won't show any signs of healing and provides evidence of what happened to the animal's body after it died. Scavenging(feeding on animals that are dead or dying) and trampling of the bones by animals are two common causes of fractures that happen after the animal has died. Physical, chemical, or biological changes to sediment can also causes fractures after death.

Surface traces are marks on the bone made by other organisms. This includes tooth marks from predators or scavengers, trample marks from other dinosaurs walking over the bones, small holes and grooves made by insects like beetles that bore into the surface, or evidence of rotting seen on the surface of bones that have been soaked in water for a long time.

Scientists look for evidence of all these clues and record their observations. They use their observations and their knowledge of dinosaur anatomy, modern animal interactions, and patterns found in nature to help them form an evidence-based hypothesis about what kind of bone they have found, how the animal lived and died, and what happened to its bones after the animal's death.

ANIMAL INTERACTIONS

Think about how many different organisms you interact with on a daily basis. You interact with other people, with animals, bugs, plants, soil, and so much more. These interactions are part of every organism's daily life. Understanding interactions helps us to understand how an organism may have lived and died.

When we are thinking about dinosaurs, we look at behaviors of animals living today to explain how dinosaurs might have interacted with other organisms in their environments in the past. With this information in mind, we can find clues that explain why fossils are arranged in a particular way in the bone bed. We can also look at the condition of the fossils to figure out what role interactions with other organisms might have played in the dinosaur's life and death.

Predators and Prey

Predators are organisms that hunt other organisms. Prey is the organism that is hunted. For example, when a lion eats a zebra, the lion is the predator and the zebra is the prey. During the time dinosaurs roamed the Earth, carnivorous dinosaurs such as theropods, were predators of other dinosaurs. Their prey might have been herbivores or other carnivores that were smaller or slower than they were.

Scientists believe that some dinosaurs were social predators, and some were solitary hunters, just like we see in modern day animals. What examples of social and solitary hunters can you think of?

Predator traps are naturally occurring environments, such as tar pits or thick mud that trap prey and make it easier for predators to kill the animals. However, this doesn't always work out so well for the predators. In California, the La Brea Tar pits are a famous example of this phenomenon. Over one million bones have been excavated from the tar pits, representing dire wolves, saber-toothed cats, coyotes, mammoths and many other creatures that died when they became stuck in the sticky tar. Scientists believe that animals that are often prey, such as mammoths, may have gotten stuck first, drawing the attention of predators, like dire wolves, which in turn may have gotten caught themselves, drawing the attention of even more predators.

Scavengers

Scavengers are also carnivores but they do not primarily hunt. They eat animals that have already died or are dying. One example of this today is vultures, which eat the remains of animals like zebras that have already been killed by a predator like a lion. Scavengers existed at the time of dinosaurs, too. There is an ongoing debate about whether *Tyrannosaurus Rex* was a scavenger or a predator because some scientists believe that a *T. rex* would move too slowly to be a successful predator. Other scientists argue that it was a predator because a fossil of a plant-eating dinosaur was found with a *T. rex* tooth lodged inside a bone in the tail. The bone was healed around the tooth, suggesting that the *T. rex* attacked the animal when it was alive—something predators do, not scavengers. Whether or not *T. rex* was a scavenger or predator, it probably wouldn't leave a perfectly good meal on the side of the road. Predators can act as scavengers too.

Competition

Competition is when individuals or groups have to compete for the same resources, such as food, water, mates or shelter. Competition happens between individuals of the same species, as well as between two different species. For example, different species of birds that both have the same beak size might be in competition with each other for the same food sources because they both like to eat the same size of seed. When resources such as land, mates, or food are limited, members of the same species will compete for the resource they need. This could include fighting, stealing, or even combat. Scientists believe that organisms have been competing with each other since life on Earth began.

NATURAL DISASTERS

Natural disasters are events in nature that cause widespread destruction of life. Sometimes the loss of life is direct, such as when an animal is crushed by falling debris in an earthquake or drowned in a flood. Sometimes the loss of life occurs more slowly, after animals' shelter or food sources have been destroyed. Some natural disasters cause other natural disasters to happen. For example, the force from an earthquake could set off a landslide that blocks a river, causing a flood when the water from the river can't get around the blockage and overflows its banks. Natural disasters leave behind widespread damage and death of plants and animals. Understanding how different types of natural disasters effect the environment and animal life in modern times can provide clues about what may have caused mass mortality sites from the past.

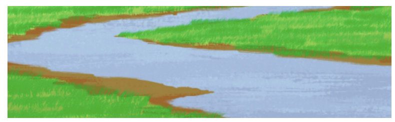
Drought

Drought is an extended period of time when an area's water supply is below normal levels. There are many causes for drought. One common reason is due to decreased precipitation - when an area doesn't receive as much rain or snow as it usually does. Some droughts last for months or even years. Drought can cause significant problems for plants and animals that rely on predictable water supplies.

Earthquakes

Earthquakes are the result of a sudden release of energy in the Earth's crust that creates surface waves, moving the ground. Scientists measure earthquake intensity on scale of 1-10, with 1 being the smallest amount of motion and 10 being the most intense. There are hundreds of small earthquakes (level 2 or less) every day around the world that most people don't even notice, but especially large earthquakes (level 8 or higher) cause great devastation for people and animals and can trigger other catastrophic events such as volcanic activity, landslides, and tsunamis.

Floods



A flood is when water covers land that is usually dry. It can be caused by an overflow of water from lakes and rivers, a build up of rainwater, or melting snow. Some floods develop slowly while others, like flash floods, can develop in just a few minutes and without warning. Floods can be very small or very large. Large floods are very powerful and can be deadly to anything in their path. When floodwaters recede, the area is often blanketed in silt, mud, and debris carried by the water.

Landslides

Landslides happen when rock, earth, and other debris move down a slope. They can happen when heavy rains, droughts, earthquakes, or volcanic eruptions have made the ground on the slope unstable. Most landslides are small and cause little damage, traveling at an average of 10 miles per hour. Other landslides are huge and can travel at speeds of up to 200 miles per hour. The largest landslide that scientists are aware of happened almost 50 million years ago in present day Wyoming. A an area about 500 square miles broke off of a plateau and slid about 24 miles into a basin. What remains of this landslide is now called Heart Mountain.

Mudslides are a common type of fast-moving landslide that occurs when sediment is full of water and there is not enough vegetation or other material to hold the sediment in place. Areas where wildfires, erosion, or other events have destroyed vegetation on steep slopes are at high-risk for a mudslide after heavy rains.

Volcanoes

A volcano is an opening in the crust of Earth that allows magma, ash, and gases to escape. Once magma reaches Earth's surface, it is called lava. Lava, ash, and gases from volcanoes create many hazards for life on the surface of the earth and their influence can be wide spread. The longest lava flow recorded was 47 miles, but lava ash has been known to travel up to 1,000 miles. The destruction caused by lava flows and ash can contribute to other natural disasters, such as landslides, floods, and wildfires.

Wildfires

Wildfires are uncontrolled fires that are most often caused by lighting, volcanic eruptions, and humans. The size of these fires and the speed at which a wildfire spreads makes them highly destructive. Other disaster events, such as drought, can increase the chances of a wildfire happening because the vegetation is dried out and catches fire more easily. The impact of a wildfire can also lead to natural disasters like mudslides.

MODERN EXAMPLES OF MASS MORTALITY EVENTS

Case Study: Hwange National Park, Zimbabwe: Predation

Hwange National Park in Zimbabwe is home to many different animals including buffalo, zebra, giraffe, wild dog, warthog, ostrich, and elephant. Throughout the park there are many water holes in the wet season, but by June most have dried up. The few that continue to have water attract many animals. Predation at the water holes is very common and mostly occurs at night. Scientists monitoring the water holes observe many skeletons from animals that have fallen prey to nearby predators.

Case Study: Hwange National Park, Zimbabwe: Drought and Competition

At Hwange National Park in Zimbabwe the only known water sources in the late dry season are "seeps." Seeps are dried up water holes where elephants dig into the ground to find water that is in the ground, creating a well. A series of unusually dry wet seasons between 1978-1984 did not fill the water holes enough to last as long as usual, creating a drought for the many elephants. Some elephants gathered at the seeps and competed for access to the wells. The smaller and weaker animals died due to heat, stress, dehydration, and starvation. In 1982, 145 elephants died near the seeps. In 1993, 45 more elephants died there.

Case Study: Wood Buffalo National Park, Canada: Flood

Wood Buffalo, a wilderness area in north-central Canada, is one of the largest national parks in the world. Many animals live in the park, including moose, deer, caribou, Northern Gray Wolves, and bison. In 1974, an enormous flood killed at least 3,000 bison when the animals got trapped on low-lying ground. Their carcasses became bloated with gas and this allowed the bodies to float in the current and pile up on the sides of the river. In some areas, there were as many as 49 carcasses that had been pushed together into a space only 100 feet wide.

Case Study: Piedras Moras Reservoir, Argentina: Poison

Algae is an organism that is often found in water, but sometimes an algae population grows so rapidly that it upsets the natural order of the environment it is in and becomes toxic (poisonous) to animals that live in or nearby the water. When this happens, it is called an algae bloom. Algae blooms have been known to cause sudden mass death in marine wildlife and the animals that feed on those creatures. Common victims are birds, fish, dolphins, whales, and even sea urchins.

In March 2009, scientists studying the Piedras Moras Reservoir in Argentina noticed that more animals than normal were being found dead in the areas around the reservoir. Animals that died included horses, dogs, iguanas, and a large number of birds. After examining the dead animals and the reservoir water, scientists were able to conclude that the deaths were caused by an algae bloom that made the water poisonous.

Case Study: Betpak-Dala, Kazakhstan: Disease

Saiga are a type of critically endangered antelope that are found in the grasslands and steppes of central Asia. In June of 2015, 160,000 Saiga antelope died off suddenly in northern Kazhakastan. Scientists are still trying to figure out what happened, but clues point to a bacteria that normally lives harmlessly in the animals stomachs but was able to multiply rapidly and cause illness when the Saigas' immune system was compromised. Those studying the situation think that environmental factors, such as an increase in the growth of grass that is toxic in high amounts, must have played a role in lowering the animals' immunities so that the bacteria could thrive and kill off its host. This species of antelope has had several similar mass death events in the last century, but this is the largest by far.

Case Study: Yellowstone National Park, Montana: Wildfire

In June of 1988, several small fires started in the park.

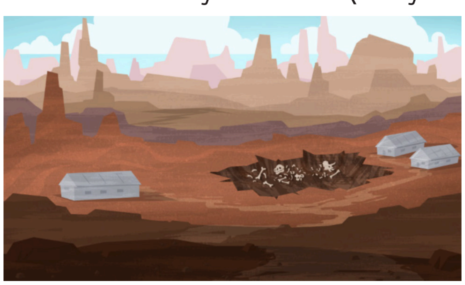
Park staff didn't think too much of them at first because fires happen every summer when the vegetation dries out. However, drought and weather made these fires unpredictable and they continued all the way until September 11 when rain and snow finally fell and helped relieve weary firefighters. Nine of the fires were started by humans and 42 were caused by lightning. 36% of the park (793,880 acres) burned and many animals were killed, including 246 elk, 9 bison, 4 mule deer, and 2 moose.

Case Study: Mount St. Helens, Washington: Earthquake, Volcano, Landslide, Flood

Earthquakes starting in March of 1980 signaled to scientists that Mount St. Helens was active again after 123 years of rest. Small eruptions of steam and gas began escaping from the volcano as earthquakes continued, destabilizing the mountain slowly through the spring. On May 18, a 5.1 magnitude earthquake triggered an enormous landslide that traveled 24 miles at speeds of 110-155 miles per hour. The landslide completely displaced the water in Spirit Lake, creating 600-foot waves and raising the water level by 200 feet. All life in the direct blast zone, an area of about 8-mile radius, was killed. Scientists estimate that 7,000 deer, elk and bears were killed, along with many birds, small mammals and nearly 12 million salmon fingerlings.

FIELD NOTES FROM CLEVELAND-LLOYD DINOSAUR QUARRY

The Cleveland-Lloyd Dinosaur Quarry is a U.S. National Natural Landmark Site located in Emery County, Utah. It has the densest concentration of Jurassic period dinosaur fossils ever found in the world, and one of the densest concentrations of dinosaur fossils of all time.



Scientists first became aware of the Cleveland-Lloyd Dinosaur Quarry in the late 1920's, but exploration of the site was irregular until 1960. Record-keeping of the fossils have not been very consistent until recently so we are unsure of exactly how many fossils have been found and removed from the site. We do know that at least 12,000 fossil fragments have been excavated so far, and scientists are still excavating this site today.

The area that we are focusing on in this Research Quest is about 50 by 100 feet wide and 3 feet thick. Scientists are still debating how much time this area covers—we know it took less than 5 million years and probably more than one year to accumulate, a huge range! More recently, experts have been hypothesizing that whatever caused this large collection of bones happened more than once. The bone bed map and Carrie's field notes represent excavation efforts between 1960-1990. Even though that was more than 20 years ago, scientists are still studying those fossils in order to try and understand these animals' lives and deaths.

Bone Bed

Hint: Read the "Bone Bed" section and use the information about dinosaur taphonomy to interpret this data.

- The bone bed at the Cleveland-Lloyd Dinosaur Quarry is about 3 feet thick and is made up of siltstone and claystone--smooth, dark mudstones. Scientists are unsure how much time this 3 feet layer represents because sediment can accumulate at different speeds depending on environmental conditions. A layer of ash about 10 feet below the bottom of the bone bed was dated at about 152 million years ago. Another layer of ash about 1 foot above the bone bed was dated at about 147 million years ago. This means that between these 15 feet, 5 million years passed. Consequently, scientists know that the 3-foot layer of bone bed that exists between the layers of ash represents less than 5 million years.

- Limestone, a sedimentary rock made up of the remains of marine species such as coral and shells, was found above the bone bed. Some of the bones in the bone bed are even sticking up into the limestone. This means that immediately after the bone bed formed, the area was covered by water.

- There is no evidence of charcoal in the bone bed, which means that fire was probably not involved in the death of the animals found in the bone bed.

- Fossils were found throughout the entire thickness of the bone bed but some scientists have categorized them into three different horizontal sections where the fossils are pointing different directions. This provides evidence that there may have been at least 3 different events.

- Most fossils were found disarticulated (disconnected), with the exception of a few vertebrae sections that included up to 10 vertebrae in a row.

- Allosaurus fragilis fossils were packed together throughout the bone bed, making it difficult to identify individuals. Scientists counted the number of left femora (upper leg bones) to get an estimate of how many are there.

- The remains of two turtles were found. This could mean that a turtle lived there, or was in a carnivore's stomach at the time that it died.

- One crocodile tooth and piece of osteoderm (the bony external armor) was found. This could mean that a crocodile was there, or was just someone's meal.

Skeletal Data

Hint: Read the "Bone Bed" section and use the information about dinosaur taphonomy to interpret this data.

- Only 4% of all the bones at Cleveland-Lloyd showed any signs of weathering. Of these bones, the highest level of weathering (which was only for 1 bone fragment), showed that it had been lightly exposed for 0-3 years above the surface.

- 37% of the bones showed signs of abrasion on the bone. Of those bones, 92% of those abrasions were very light. Based on the areas of the bones that are abraded, some scientists think that the bones were only partly sticking up out of the ground.

- 30% of the bones had fractures that formed after death.

- Only 4% of the bones had surface traces, and all but one of these surface tracings were tooth marks. The exception appears to be the work of a type of beetle. Most of the bones with surface tracings were from herbivorous dinosaurs. This is interesting because the majority of bones that have been found are from Allosaurus, which are carnivorous dinosaurs.

General Patterns

Hint: Read the "Animal Interaction" section and use the information about how modern animals interact to interpret this data.

- Approximately 75% of the animals found were carnivorous. Since 5-10% of modern animals are predators, that is the percentage that scientists would expect to find in a bone bed. Having such a high number of carnivores here makes scientists think that something unusual happened.

- Pieces of 46 different Allosaurus have been found, identified by counting the number of left femur bones. This means that 66% of all of the dinosaurs found are Allosaurus.

- 80% of Allosaurus skeletons are juveniles but all the rest of the Allosaurus skeletons belong to adults. Scientists are unsure whether this is unusual or not since this many Allosaurus have never been found in one place before.

Environmental Data

Hint: Read the "Animal Interactions," "Natural Disasters," and "Case Studies" sections and use that information to interpret this data.

- Sediment samples from nearby areas, from this same Jurassic period, show that ponds, lakes, and rivers existed nearby.

- Scientific reconstructions of the environment show that this area probably received ½ the rain that other areas on the continent received. This means that on average, it was a drier habitat than other areas nearby.

- There was no evidence of fish or amphibians in the bone bed, which means that any water in the area was probably either from a flood, only existed seasonally, and/or was possibly poisonous.

- One dinosaur egg was discovered in the area. The egg had an extra layer of eggshell, which happens in modern animals that lay eggs when the mother is under stress from the environment (doesn't have enough food, predation, etc.) and does not lay the egg right away.

- On top of the bone bed is a layer of limestone that is 1-3 feet thick. Limestone usually forms when water is present, which means that there is evidence that a lake or pond occupied the area after the bones were buried by sediment.

- The closest active volcanoes in this time period were located several hundred miles away in the area that is now Nevada.