Lecture 4: Fossilization
(Why do we only find the bones?)

Skeleton of the ankylosaur *Euoplocephalus* (source)

Big question: why do we only find the bones of dinosaurs?

- Why don’t other parts get recovered?
- Is this always the case?
- If not, when might we expect to find more than bones?

Hall of Dinosaurs at the American Museum of Natural History (source)

Dinosaur remains are a type of fossil

- Extinct organisms occasionally get preserved in the geologic (rock) record as **fossils**
- **Fossil:** the preserved remains of a prehistoric organism

Paleontologist Kathleen Ritterbush standing in front of a fossil ammonite (source)

Major kinds of fossils: body fossils

- **Body fossil**: physical remains of an organism

- Very rare to find whole, intact skeletons

- Typically fragmented, damaged,

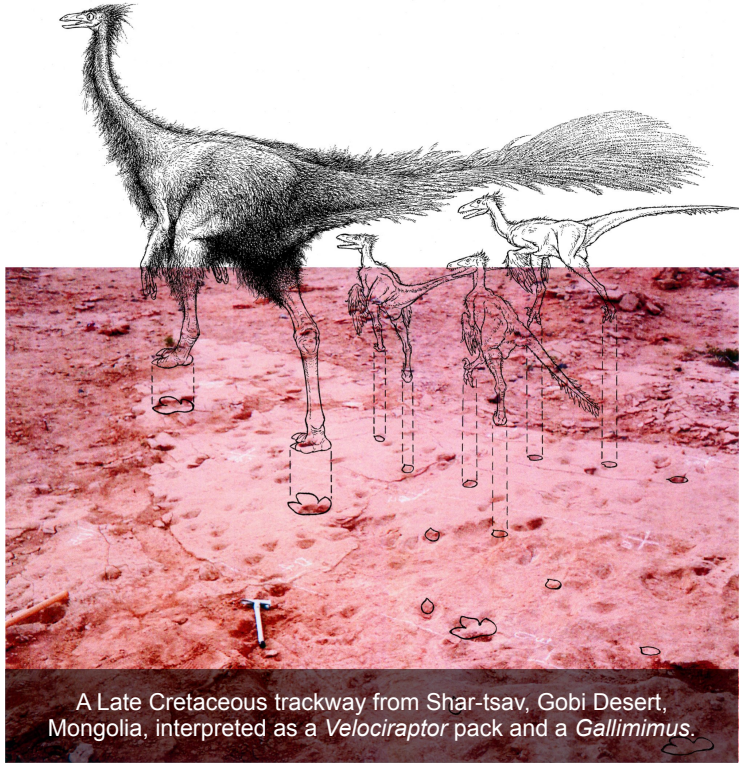
Dinosaur bones from the Morrison formation (source)

Major kinds of fossils: trace fossils

- **Trace fossil** (ichnofossil): remains of an organism but not the organism itself

- Examples include trackways, coprolites (fossil poop), and bite marks

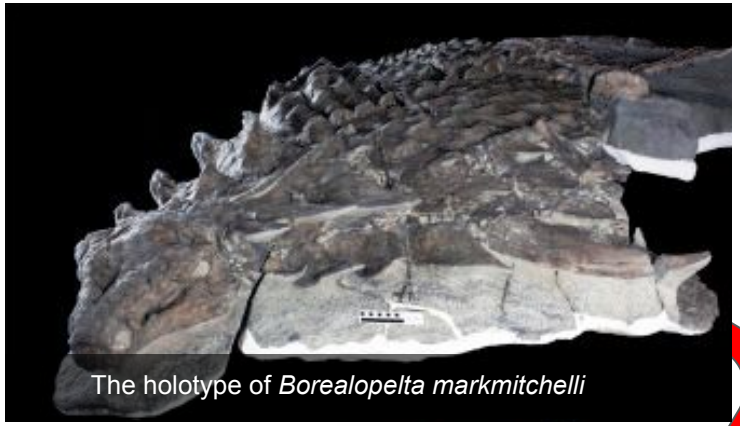
- Trace fossils provide evidence of a prehistoric organism's behavior



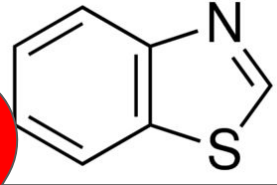
A Late Cretaceous trackway from Shar-tsav, Gobi Desert, Mongolia, interpreted as a *Velociraptor* pack and a *Gallimimus*.

Fastovsky, David E., and David B. Weishampel. *Dinosaurs: a concise natural history*. Cambridge University Press, 2016.

Major kinds of fossils: molecular fossils



The holotype of *Borealopelta markmitchelli*



Isolation of benzothiazole, implying pheomelanin-rich melanin

Reconstruction of *Borealopelta* coloration by Davide Bonadonna (source)

- In exceptional cases, molecules can be preserved and extracted from fossils

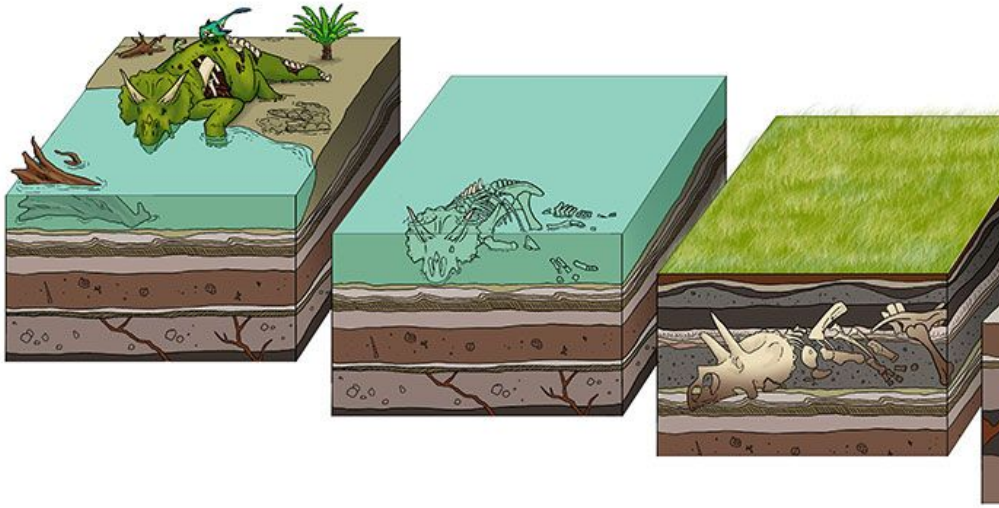
- Examples of these **molecular fossils** include ancient DNA, proteins, and lipids (fats)

Brown, Caleb M., et al. "An exceptionally preserved three-dimensional armored dinosaur reveals insights into coloration and Cretaceous predator-prey dynamics." *Current Biology* 27.16 (2017): 2514-2521.

How does fossilization occur?

- An organism must be buried under sediment to become a fossil

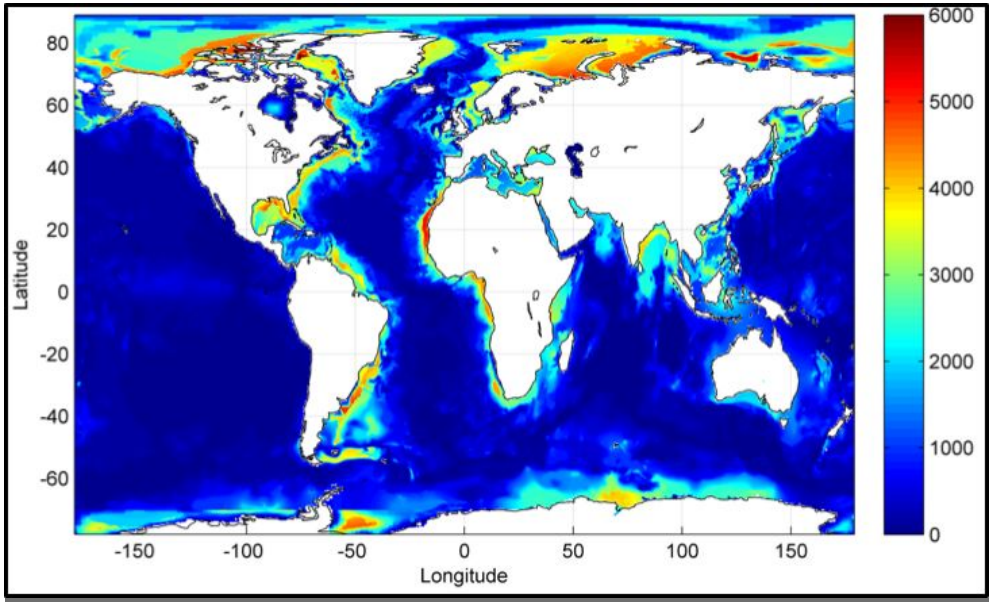
- On land, **erosion** (the loss of sediment) is more common than **sedimentation** (the accumulation of sediment)



Visual representation of the fossilization process (source)

How does fossilization occur?

- Most sedimentation occurs along coastal regions
- We have a much better fossil record of shallow-water marine organisms than we do of dinosaurs

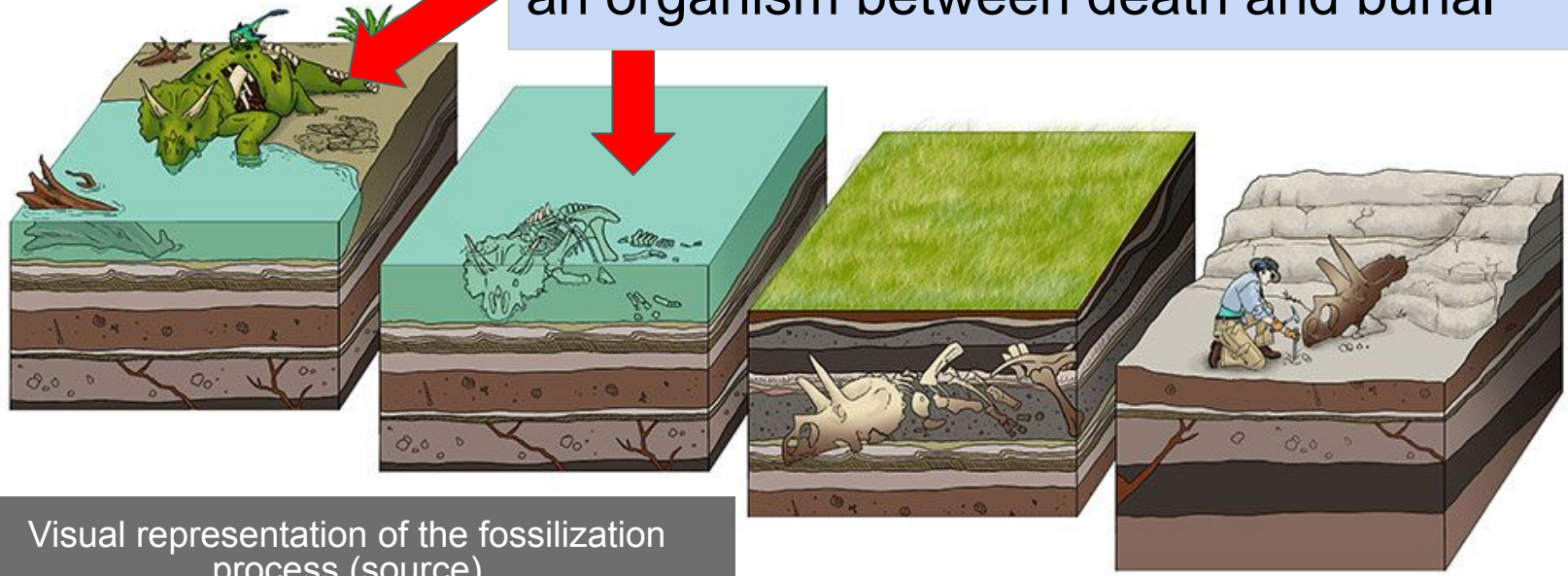


Map of global sedimentation

LaRowe, Douglas E., et al. "Temperature and volume of global marine sediments." *Geology* 45.3 (2017): 275-278.

The fossilization process: biostratinomy

Biostratinomy: everything that happens to an organism between death and burial



Visual representation of the fossilization process (source)

Most parts of an organism will not survive the biostratinomy process

- Damage before burial
  - **Disarticulation** from predators and scavengers
  - **Boring** from insects
  - **Decomposition** from microbes
  - **Weathering** from wind and rain

Decaying corpse of a donkey (source)

Mineralized bones, teeth, and shells (skeletons) are unusually resistant to destruction and decay

Donkey skeletons inside The House of Chaste Lovers in Pompeii (source)

- Many skeletons are a mixture or organic material and inorganic minerals
- This is why most fossils represent the “hard parts” (bones, teeth, and shells)

Hard parts that are not mineralized are less likely to fossilize

Triceratops skull (source)

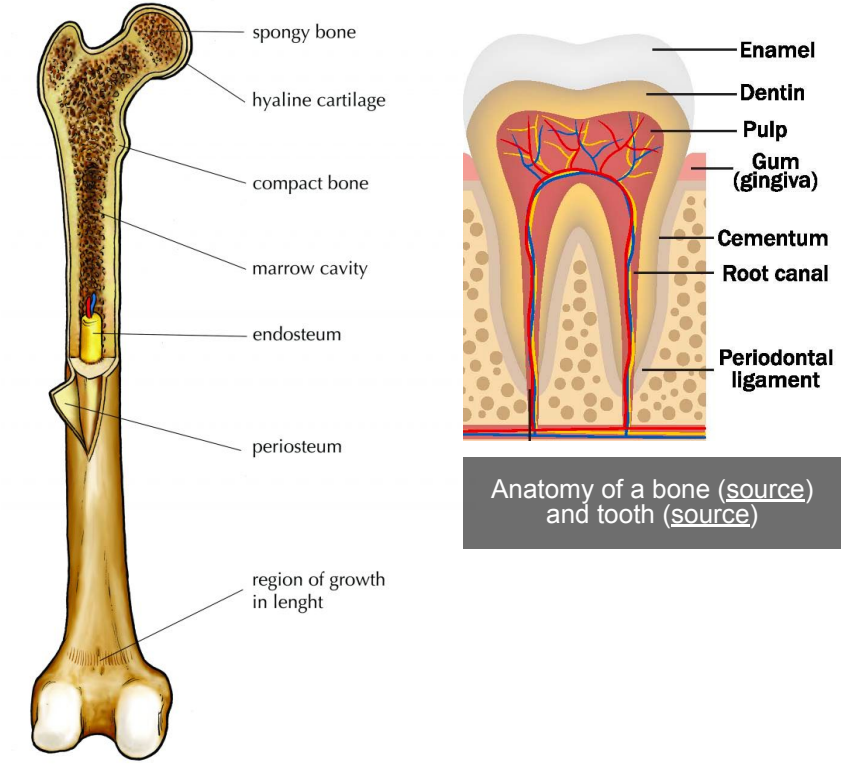
Triceratops by Sergey Krasovskiy (source)

Pachyrhinosaurus skull (source)

Pachyrhinosaurus at the Royal Ontario Museum (source)

Pachyrhinosaurus by Fabrizio De Rossi (source)

The mineralogy of bones

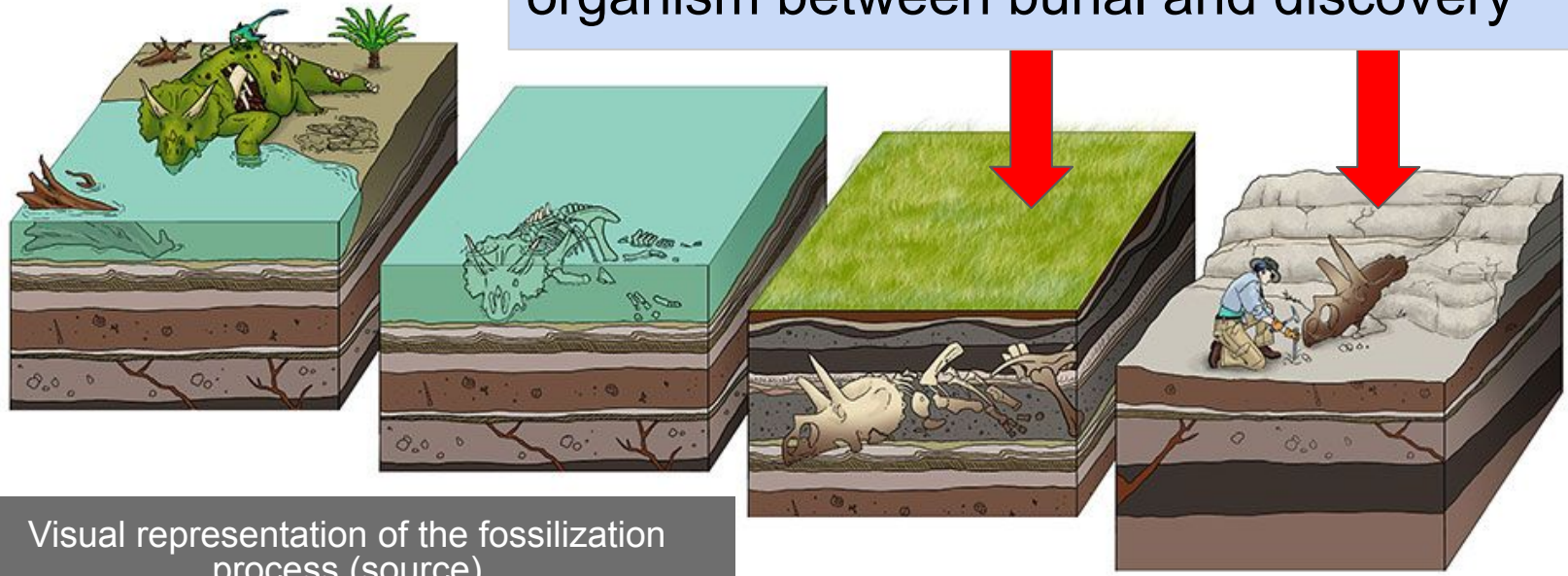


Anatomy of a bone (source) and tooth (source)

- In vertebrates, the main mineral in bones is **hydroxyapatite**
- The enamel of teeth have an even higher mineral concentration, and are more likely to be preserved than bone

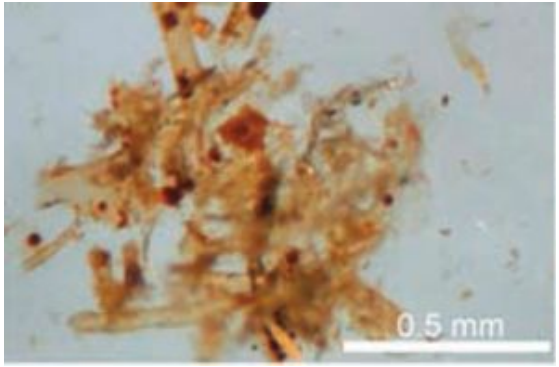
The fossilization process: biostratinomy

Diagenesis: everything that happens to an organism between burial and discovery



Visual representation of the fossilization process (source)

Diagenesis typically involves the loss of any remaining organic matter



Putative collagen from the dinosaur *Brachylophosaurus*

- Organic matter in bones includes blood cells, bone-building cells (osteoblasts), and structural proteins like **collagen**
- Most of this decays away in the fossilization process, although collagen is tough and can survive in fossils

Schweitzer, Mary H., et al. "Soft-tissue vessels and cellular preservation in Tyrannosaurus rex." *Science* 307.5717 (2005): 1952-1955.
Schweitzer, Mary H., et al. "Biomolecular characterization and protein sequences of the Campanian hadrosaur B. canadensis." *Science* 324.5927 (2009): 626-631.

Diagenesis typically involves the loss of any remaining organic matter

- Bones are an “open system”
- Lichen and other fungi can contaminate bones and produce collagen
- Some dinosaur bones have unique bacterial communities living inside of them

Lichen growing in and on an Eocene-age penguin fossil (source)

Saitta, Evan T., et al. "Cretaceous dinosaur bone contains recent organic material and provides an environment conducive to microbial communities." *Elife* 8 (2019): e46205.

The minerals of bones are chemically reactive and can be lost too

- Hydroxyapatite reacts with other minerals in the earth, particularly if there's water
- This can lead to **dissolution** of the original material and **replacement** by inorganic minerals
- The older a fossil, the more likely it is to exhibit complete replacement

A toe from *Fostoria*, with hydroxyapatite replaced by opal

Fastovsky, David E., and David B. Weishampel. *Dinosaurs: a concise natural history*. Cambridge University Press, 2016.

Exceptional modes of preservation can occur

Mummified *Edmontosaurus* (source)

- Impressions of soft tissue can be associated with fossils
- This is more likely in arid or anoxic conditions, where decay is slower

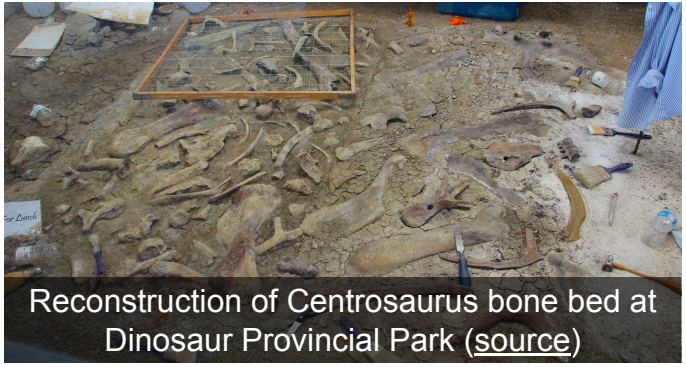
Exceptional deposits: bone beds

- Hundreds or thousands of bones preserved in one site
- Sometimes all members of the same species, sometimes a mixture

Disarticulated dinosaur bones from Upper Jurassic Morrison Formation (source)

Some important dinosaur bone beds

A herd of *Centrosaurus* caught by a storm by Michael Skrepnick (source)



Reconstruction of Centrosaurus bone bed at Dinosaur Provincial Park (source)

- Triassic-age *Metoposaurus* bone bed from Portugal
- Jurassic-age Cleveland-Lloyd Dinosaur Quarry of Utah
- Jurassic-age Dinosaur National Monument in Utah / Colorado
- Cretaceous-age *Mapusaurus* bone bed at Cañadón del Gato, Argentina
- Cretaceous-age *Albertosaurus* bone bed from Alberta, Candara
- Cretaceous-age *Daspletosaurus* bone bed from Montana

Exceptional deposits: lagerstätte

- **Lagerstätte**: a fossil deposit with exceptional preservation

- Anoxic environments that preserve many individuals with evidence of soft tissue

- The Jurassic-age **Solnhofen Limestone** is a lagerstätte that includes dinosaurs

Archaeopteryx from the Solnhofen lagerstätte in Germany (source)

Additional lagerstätte that contain dinosaurs

- Cretaceous-age Santana and Yixian formations
- Cretaceous-age Myanmar (Burmese) amber

The turtle *Ordosemys* and dinosaur *Psittacosaurus* preserved together (Link)

Conclusion

- Hard parts of organisms resist decay and are therefore more likely to be preserved as fossils
- **Biostratinomy** and **diagenesis** impact what gets preserved
- Prehistoric animals can leave **body fossils**, **trace fossils**, and/or **molecular fossils**
- In exceptional cases of preservation, soft tissues and the original organic matter can be preserved