9/6-8/05 Types of fossils and taphonomy

Outline:
What’s a fossil?
“Remains of prehistoric life”
Types of fossils: body fossil, molecular fossil, trace fossil
1. Body fossils: Hard parts
   mineralogy and stability: calcite, aragonite, opaline silica, calcium phosphate, chitin, combinations.
   distribution among organisms: mollusks, brachiopods, corals, sponges, arthropods, echinoderms, vertebrates
   Preserved as original material, recrystallized, replaced, permineralized
2. Body fossils: Soft parts
   preserving soft tissues: mummification, freezing, amber, carbon films
   extraordinary fossil deposits: "Fossil-lagerstätten"
3. Molecular fossils – preserved molecules of biological origin
4. Trace fossils: tracks, trails, borings, tooth marks =>fossil behavior

Taphonomy - the study of fossilization and its effects
The fate of hard parts
   governed by their composition, construction, and environment of deposition
   agents of destruction: chemical, physical, biological
   agents of confusion
   transportation - movement within and between habitats
   time averaging- the accumulation of remains over time
   bioturbation - mixing fossils because of burrowing organisms
   recycling - erosion and redeposition of older fossils

Lecture notes
What is a fossil?

Types of fossils:
Body fossil. Hard parts or soft
Molecular fossil biomarkers, fossil dna, etc.
Trace fossils

Body fossils: hard parts and soft parts
Jello, bone, clam, leaf, crab claw

Which is most likely to become a fossil?
What determines the odds of fossilization?

Not all organisms are fossilized, and not all of an organism is fossilized. Those having all or mostly soft parts don't make it. Those with hard parts, most often don't get the soft parts also preserved. Though note the impression of soft parts on hard parts, a theme to be explored as we go through the fossil groups in lecture and in lab.

The sub-discipline of paleontology devoted to studying all the nasty things that happen to a potential fossil between the time it dies and the time it's discovered is:
Taphonomy - the study of how fossils and assemblages of fossils are preserved, altered, or destroyed. The post-mortem life of potential fossils.

From the Greek word taphos, meaning grave. The study of entombment

Since the most common fossils are those that were once the hard parts of some living organism, I want to consider them first.

Note that hard parts can be either internal (as in vertebrates) or external (as with the crab or clam).

Common types of hard parts

1. **Calcium carbonate CaCO₃**. Occurs in two mineral forms:
   - Aragonite: very common. Most mollusks (clams, snails, cephalopods), most living corals. This mineral form of calcium carbonate is not stable; it either dissolves or recrystallizes to the stable mineral form, calcite, over time. It's rare to find original aragonite in rocks older than Triassic.
   - Calcite: very common. The stable form of calcium carbonate. Comes in two chemical varieties:
     - Low magnesium calcite - a relatively pure form, in which Mg makes up less than 4% (Mg substitutes for Ca in the crystal lattice). Common component of brachiopods, bryozoans, oysters (mollusks), two extinct groups of corals.
     - High magnesium calcite. More than 4% Mg substituting for Ca. Echinoderms and a few other groups.

2. **Calcium phosphate** - several varieties of this compound occur as minerals commonly called apatite: a calcium hydroxyl phosphate. Most common is the mineral dahlite. Ca₁₀(PO₄)₆CO₃.H₂O. The major mineral constituent in vertebrate bone.

3. **Opal. Hydrous silica of amorphous structure.** Rather soluble in water, so rarely survives unaltered. Some algae (diatoms), some sponges.

4. **Chitin. An organic material - a polysaccharide that forms long fibers.** Makes up the hard parts of most arthropods - crab shells and the like. Often subject to bacterial decay or even consumption by other organisms. Sometimes all that's left is a carbonized film on the rocks.

5. **Combinations** - some organisms have hard parts of more than one type. Perhaps the most common combination is that of chitin and calcium carbonate. Trilobites, for example, have an exoskeleton made up of chitin that was impregnated with high Mg calcite.
Very often hard parts are not directly preserved. Their original mineralogy may be **recrystallized**
to a more stable form (example: aragonite => calcite).
The original mineralogy may be **replaced** (examples: calcite => silica; calcite => pyrite),
The original hard parts may be **permineralized**: all the open space in the hard parts may be filled in with
a mineral and the original is then dissolved. You are going over these in lab this week.
Casts and molds

### Table 3.1. The original mineralogy of common fossil taxa

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Low-Mg calcite</th>
<th>High-Mg calcite</th>
<th>Aragonite + calcite</th>
<th>Silica</th>
<th>Phosphate</th>
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c, common mineralogy, x, less common.

Body fossils – soft parts
1. Preservation as casts or molds.
2. Preservation of soft part remains, as delicate carbon films or impressions in fine-grained sediments and rocks. These are rare, but often important, because of the opportunity to look at the soft-tissues of fossils.

Deposits which contain a lot of fossils in which soft-tissues are preserved or recorded are sometimes called, in German, *Fossil-Lagerstätten*, or, roughly translated, “fossil bonanzas”.

Some famous ones are:
- Precambrian Ediacaran fauna of Australia (soft-bodied)
- Cambrian Burgess Shale of Canada
- Mazon Creek Fauna of Illinois

The Mazon Creek’s Tully Monster, as seen on a U-Haul Truck

Jurassic Solnhofen Limestone of Germany (first bird)

Solnhofen dragonfly
http://www.ucmp.berkeley.edu/arthropoda/uniramia/odonatoida.html

Solnhofen feather
http://hoopermuseum.earthsci.carleton.ca/solnhofen/archae2.html
2. Molecular fossils. Preserved organic compounds, sometimes (but only rarely) DNA

Atacama Desert, Chile. One of the driest places on earth
Midden has consistency of adobe brick
Has macrofossils of bones, twigs, seeds, pollen, fecal material
Also examined chloroplast and animal mitochondrial DNA

One of three species of rodents of the genus *Phyllotis*, vicuna (a camel relative), a cardinal, other birds, and another rodent – none of which live at the site today – range shift dues to climate shift.

13 plant families – none of which occur at site today; 3 of which not recognized previously as macrofossils. 8 macrofossils not recognized as molecular fossils.

3 plant families found as molecular fossils only
8 plant families found as macrofossils only
2 plant families as both macrofossils and molecular fossils

3. Trace fossils. Many organisms don't just sit there as a lump through their entire lives. Many of them are mobile, or in some other way active, and affect their surroundings. Dinosaur tracks and trails are sometimes preserved; the bore holes of algae and sponges are preserved in shells, the trails of snails across mudflats. Coprolites. Show recent and K example. Fossil behavior. Record of activity and behavior of past life
Some species can leave body fossils, some trace fossils, and some both

Main types of trace fossils
A. Traces on bedding planes
   1. tracks. Discrete footprints (arthropods, vertebrates)
   2. trails. Continuous traces of moving organism (worms, mollusks, arthropod)
B. Structures within the sediment
   1. Burrows – structures formed within soft sediment by moving grains out of the way (vertebrates, mollusks, arthropods, worms).
   2. Borings – structures formed in hard substrates such as shell, coral, limestone, wood, bone. Cutting through the grains mechanically or chemically. Mollusks, sponges, algae, worms.
C. Marks on body fossils
   1. Drillholes - predation usually by snails on other mollusks
   2. Repair scars – from sub-lethal injury (the animal recovered), the injury is repaired in some way. Healed bones, repair scars on shells.
   3. Feeding damage. Marks on bone, shell, leaves, left by herbivores and predators . Munch marks.
D. Excrement
   1. fecal pellets and fecal strings (<10 mm diameter). Crabs, snails, insects
2. coprolites. “Discrete fecal masses” = turds >10 mm in size. Vertebrates

E. Other
1. Root traces
2. Non-fecal pellets - owl pellets, hair balls, excavation pellets of crustaceans

**Naming trace fossils** – after distinctive morphology of the trace; not after the maker of the trace.

Skolithos – vertical tubes
Cruziana – trilobite crawling traces?
Ophiomorpha/Thalassinoides
Zoophycos

*Same trace can be made by different organisms.
Different organisms can make the same trace.*

**Applications of trace fossils**

A. Paleoenvironmental reconstruction

“ichnofacies” (Overhead and figure in lab handout and below): groups/assemblages of trace fossils that are indicative of particular environments.
Records of behaviors that are typical of certain environments (even though the maker of the trace may be different at different times)

![Image of trace fossils]


Prothero, 2004

**Applications of trace fossils, continued…**

B. Paleobiology

1. Paleodiet: Analysis of contents of fecal pellets Dietary preferences from drillholes in prey
Compare relative abundance of species (potential prey) with relative abundance of drilled individuals. Prey is being selected if the proportions differ.

2. Posture, relative speed, absolute speed in vertebrates. From trackways (a series of footprints). Trackways: step (right foot to left foot); and stride (right foot to next impression made by right foot)

   a. Posture in dinosaurs. Sprawling (feet wide apart) vs upright (feet directly beneath). Bipedal and quadrupedal

   b. Relative speed. Within a trackway, an increase in stride length indicates an increase in speed.

   c. Absolute speeds. But we can’t use stride length to compare different speed in different species of dinosaurs. Why not? Because smaller animals moving at the same speed as a larger animal need to take more strides. Their stride length will be smaller only because their legs are shorter. – more in lab later in the semester.

http://www.open2.net/naturalhistory/palaeobiology/main/traces.html

**Taphonomy**

The fates of hard parts

What then happens to hard parts after death; what controls their fate; why are some things preserved and
not others?

1. original composition (chemistry, mineralogy)
2. mode of construction (how hard part is built - sturdy or fragile?)
3. environment of deposition (physical, chemical and biological activity affecting the hard part)

Agents of destruction - processes that destroy hard parts

1. Chemical destruction. Some hard parts are simply dissolved away when the organism dies and the organic matrix within which the hard parts were secreted decays.

   Three things control a hard part's susceptibility to chemical destruction:
   a. original mineralogy: opal, high mg calcite, aragonite, calcite, calcium phosphate; in decreasing order of solubility.
   b. hard part construction. Hard parts that are porous, or thin and delicate, present a large surface area to any dissolving fluids. Dense, compact ones will last longer than lacy, flimsy ones. Here's an example from a real simple lab study:
      Case study: “The Cholla Bay Weight Loss Plan”
      -we put several different shells from the Gulf of California in acid (calcium carbonate dissolves in acid) baths and pulled them out at different intervals and measured how much weight had been lost.

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   dissolution rate (%original wt per hour)

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   surface area/weight

The point here is not only that fossils are being destroyed (through solution), the destruction is selective. Dense, compact shells dissolve more slowly than thin shells.

c. environment of preservation. The ground water in acid soils and swamps may dissolve potential fossils. Weathering on the outcrop (acid rain) may dissolve fossils made of calcium carbonate. For example, the solubility of calcium carbonate increases with increasing pressure and decreasing temperature. Watch what happened to calcite microfossils (foraminifera) at different depths in the Pacific Ocean.

Pre-weighed samples were placed at different depths along a buoy cable in the central Pacific.

The colder, deeper water dissolved more microfossils. These microfossils live, in fact, in the upper 100 meters of the water column, whether the water is in the deep ocean or in the shallows near shore. Where would you expect to find microfossils more frequently?
2. Physical destruction. This is perhaps the most obvious type of hard part destruction. Shells being tossed around in the surf and all that. Abrasion can destroy surface details and breakage can be so extensive that the hard parts are no longer recognizable.
   a. Hard part mineralogy - little or no effect
   b. hard part construction. Very important. Well-constructed hard parts will survive longer than flimsy ones.
   c. environment of preservation. Quiet water environments (deep water, swamps, lagoons) are more likely to protect against physical destruction than high-energy environments (surf zone beaches, river channels, etc.)

Chave's experiment with shells in a tumbling barrel. (Figure from today’s reading) Hard parts, quartz sand or chert pebbles, water. Rotate the barrel, inspect frequently
Doesn't just demonstrate the obvious, that hard parts get destroyed, but that physical destruction is also selective. What if you only found *Nertia*. Would that be an unbiased assemblage? How could you tell?

3. Biological destruction. Rather common. Lots of animals bore away or gnaw at the remains of once-living organisms. Hyenas crushing bones, sponges or algae boring into shells (pass around *Dosinia*).
   a. Effect of original mineralogy not well studied. I expect little biol. destruction of opal, calcium carbonate is probably equally probable. Calcium phosphate has organic goodies in it, so prob often consumed. Chitin all organic, so prob, very freq. consumed. All based on hardness and palatability, not on experiment.
   b. hard part architecture. Probably plays a role again. Hard parts with a lot of exposed surface are get lots of borers, those with sturdy shells probably don't. Again, little study
   c. environment of preservation. Potential fossils that are removed from a biologically active zone will stand a better chance - quick burial, or low oxygen conditions.

An example: Neumann's experiments in Bermuda took slabs of the coral limestone that make up the island, weighed `em wired onto these "carpets" of the boring sponge *Cliona* set them out in the harbor for 33 to 100 days removed the *Cliona* carpets (with hydrogen peroxide) weighed the slabs recorded weight loss of 1000 to 6000 g/m²/100 days approx equal to -1.4 cm/yr; 1 m per 70 yrs (counteracted by continued production)
---of course, chemical, physical and biological destruction may not act alone. Breaking up a shell exposes more surface area for biological or chemical destruction. Biological destruction may weaken a shell, making it more liable for physical destruction.

Classroom experiment

**Summary**

*Destruction occurs, its rate may depend on three factors (mineralogy, environment, architecture), and destruction is selective.*

**Other biasing agents in taphonomy are:**

**Agents of confusion.**

Even if the hard parts are preserved, they may still be affected by processes that can move them from their original place or preserve them with other species that lived several generations or thousands of years apart. I call these agents of confusion.

1. **Transportation.** One of the first that probably comes to mind. Tidal currents, streams, oceanic currents, mudflows, etc., can all cause transportation of hard parts away from where they lived. The result:
   a. unnatural assemblages of species (Logs and clams preserved together)
   b. size sorting. smaller remains more likely to be removed, bigger stuff can stay behind as a lag (placer). Selective removal of juveniles or of small-bodied species
   c. physical destruction during transportation.

2. **Time averaging.**

   Peterson's study: Mugu Lagoon and Tijuana Slough
   sampled living molluscs and sampled dead remains
   Mugu 35 live over ten months of study, 49 dead
   Tijuana 28 live over ten months, 39 dead

   What gives? The collection of hard parts represents the accumulation of species, remains over some period of time. Thus, species may not have lived at exactly the same time, even if they are found together. Environments fluctuate over time. These are, in some crude sense, averaged together in the deposit of fossils.

   The amount of time-averaging probably varies a lot. Some collections of fossils may represent "instants" in time; others may represent thousands of years. Cholla Bay time-averaging of 4,000 years.
3. **Bioturbation.** Hard parts can be displaced after their death by other organisms. Bioturbation refers to the churning about of sediment by burrowing organisms. This is usually only local displacement from life position to some other posture, or moving up or down in the sediment.

4. **Recycling.** Some hard parts are eroded and deposited several times before final burial. This recycling can mix together hard parts of very different ages and environments. Chesapeake Group (Miocene) fossils washing out with Recent shells along the coast of Maryland/Virginia. Age diffs of 15 MY, shark's teeth and other open continental shelf species together with living species of the bay.

**Taphonomy - Case study: “Bones on the beach”**

A common approach to see how well the fossil record reflects the animals that were alive at that time is to look at Recent habitats and faunas, and to compare the diversity and composition of the living faunal with that of the accumulating dead remains:

**Live : Dead studies**

The Mugu Lagoon and Tijuana Slough studies mentioned earlier, for example.
Another example: marine mammals in the northern Gulf of California (reading #2; see also: http://www.sciencenews.org/20030719/toc.asp on web)

Live fauna known from boat and aerial surveys
Skeletal remains from the beaches on the Colorado River delta – bones on the beach

Examined about 4 km of beaches,
Found 470 individual bones plus three carcasses
Identified species from skulls: 28 skulls found

  Found 8 of the 18 species known in northern Gulf. Why so few?

Some bones more common than others in living marine mammals
  Skull:vertebrae:ribs:phlanges:girdle/limbs ratio is 1:74:30:68:16 (the expected ratio if everything preserved)
  Among the dead (the observed ratio): 1:12:3:1:1. Which bones are not well-represented? Why?

![Graph of bone distribution](image)

**FIGURE 3**—Number of bones found by type (solid), number of bone types expected based on 26 individuals and a minimum skeletal ratio (stippled), and number of bone types expected based on a maximum skeletal ratio (white).

Multi-part specimens and the minimum number of individuals: Which bone to use? (same issue with all multi-part skeletons: bivalves, for example; others?)