THE PRESERVATION OF FOSSILS

WHAT ARE FOSSILS?

Fossils are the remains of living organisms. Most fossils are the hard parts of whole or fragmented organisms, such as shells of a bivalve or the skeleton of a dinosaur. These are called body fossils as they represent the skeletal remains or `hard parts' of the organism. The other main types of fossils are trace fossils including tracks, trails and burrows.

Key Definitions

- **An organism** = something that was once alive. This may be single-celled or multicellular.
- **A body fossil** = the hard parts of an organism, such as the skeleton or shell.
- **Dissolution** = the process whereby minerals that make up the fossils are dissolved away and removed in solution by groundwater.
- **Replacement** = the atom by atom substitution of one mineral for another.
- **A mould** is the impression of the outside or inside of a fossil
- **A cast** is an infilled fossil void, usually with another mineral.

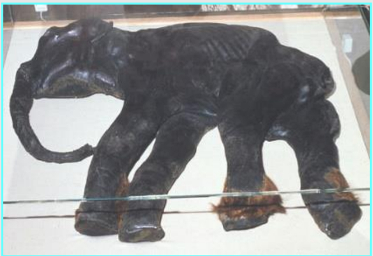
MODES OF EXCEPTIONAL PRESERVATION

1. Organisms may be entombed in amber. Amber is the sticky, transparent **exudate** emitted from certain species of **conifer.**
   Exudate = a substance secreted by a plant or insect.

   This results in near-perfect preservation of organisms covered by it.

   It is mainly important for preserving insects, but also very small vertebrates like frogs and lizards.

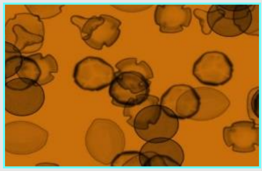
2. Refrigeration is the process that effectively entombs organisms in ice sheets and glaciers. This is relatively recent in terms of age (10,000 to 2 million years old). Extreme conditions slow down the rate of decay by slowing down enzyme action.
   E.g. Wooly mammoths



3. Dehydration (mummification) involves drying out of an organism within a hot, dry climate. This was practised in ancient Egypt. If dehydration occurs prior to burial then enormous amounts of detail are preserved, including delicate soft parts.

4. Entombment in peat bogs. Peat bogs slow down the rate of decay. Anaerobic cold conditions with the antiseptic properties of the tannins present in peat and tar can preserve great detail.
   Pollen grains, seeds and spores trapped in peat bogs have been used to reconstruct climate change through time.

Peat forms in wetland conditions, where decaying vegetation becomes submerged in water and so flooding obstructs the flow of oxygen from the atmosphere, slowing the rate of decomposition. Peat is the accumulation of partially decayed organic matter.



5. Entombment in tar pits. Tar pits occur where hydrocarbons seep upwards from deeper strata and reach the Earth's surface to form discrete pools. The material is actually crude oil (a mixture of dark bituminous hydrocarbons) rather than tar.

TYPES OF PRESERVATION: REPLACEMENT

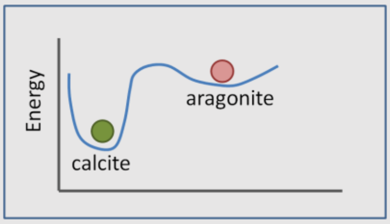
Replacement occurs when the **original mineral** making up a fossil is **dissolved atom by atom** and **substituted with another mineral.** A common example is the conversion of the less stable **aragonite to calcite**.

Aragonite and calcite are **polymorphs** of one another, with the same formula $CaCO_3$
This means they are isocheimal; have the same chemical composition but vary in their **structural arrangements**. It is the **bonds within the minerals** that differ. Some (mainly more **recent deposits**) shells of **bivalves, gastropods and corals** are made of aragonite, which is less stable than calcite. Aragonite rearranges its chemical formula to alter to calcite over time.

Equally, replacement could be with another mineral present in the groundwater such as **hematite, an iron oxide.**

Another good example is in the process of Dolomitization: when magnesium ions (from groundwater) replace calcium ions in the carbonate mineral calcite. This is what forms the carbonate mineral dolomite found in the Dolostone and dolomitic marble of the Dolomite mountain range, Italy.

$2\ CaCO_3 + Mg^{2+} \rightleftharpoons CaMg(CO_3)_2 + Ca^{2+}$



TYPES OF PRESERVATION: SILICIFICATION

The process by which organic matter becomes **saturated with silica** or groundwater rich in silica moves through a rock and the **silica precipitates within pore spaces and voids.** The minerals in the groundwater **crystallise out** of solution within pores and voids.
Groundwater needs to be rich in silica = **Silicon dioxide (SiO_2)**.
If bone, wood or shell is present then the pores become filled with the mineral, **increasing the density** of the rock. **Petrified wood** is a classic example.

Petrification means literally turning to stone. Silicification is an example of petrification where silica is the mineral precipitating out into voids.

In some cases during petrification, **the remains of organisms are dissolved** away by percolating **acidic waters**, then the space created is infilled by minerals precipitated from solution by subsequent **percolating** waters.

Common petrifying minerals: **Quartz (silicification), Calcite (calcification), Iron Pyrite (pyritisation).**

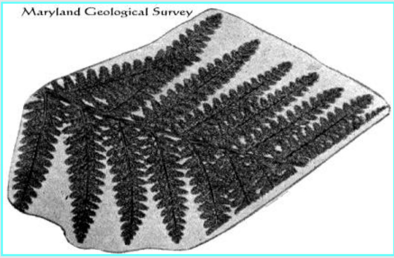
TYPES OF PRESERVATION: PYRITISATION

This is the **replacement of the original mineral by iron pyrites**. It took place when the **environment was devoid of oxygen** (anaerobic) and the only living organisms were **sulfur bacteria**. The bacteria required sulfur to respire, **reducing it to bisulfate**. This **bisulfate** then **reacts with any iron** in the environment to form iron pyrites. This then replaces the fossil material. Pyritisation commonly occurs in deep**-sea environments** with an **anoxic seabed,** or in **shallow swamps.**

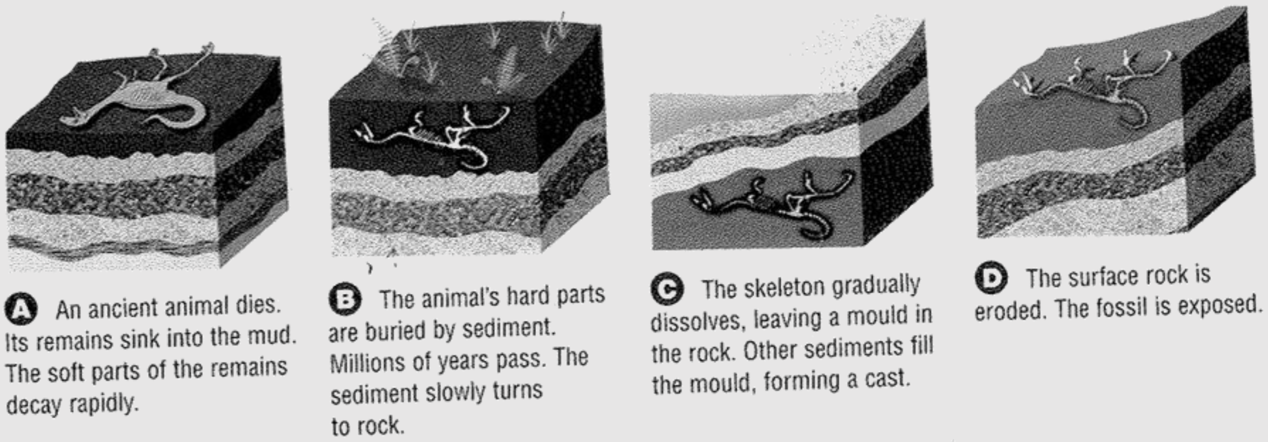
TYPES OF PRESERVATION: CARBONISATION

This process occurs during burial as the overlying mass of rocks increases, so does the temperature and pressure. This expels volatiles or gases within the organic matter. The oxygen, methane, carbon dioxide and water content decreases and so carbon content increases.

This preserves plants, animals (like graptolites) as a thin film of carbon within shale or mudstone.



TYPES OF PRESERVATION: MOULD AND CAST FORMATION



Molds are formed when **fossils are dissolved out** of the rock they are in. These fossils are therefore usually made of $CaCO_3$ and the groundwater dissolving them may be slightly acidic. This leaves a **void or hole** in the rock (the mould). Breaking this rock open will reveal an **external mould** of the fossil.

If the fossil **was filled with sediment before complete burial**, the sediment may reveal an **internal mould** showing the **internal structures** along with any **impressions of soft tissues within**.

Internal moulds are fossilized replicas of the internal structure of an organism. The best examples of this type of fossil are **brachiopods** (clams). When the organism dies, over time the soft parts of the animal decay. The shell is left empty and this may be filled by sediment. Eventually, the shell dissolves away, but the sediments have hardened and remain as a fossil.

The difference in internal and external moulds lies in what happens when the shell dissolves away. If the shell dissolves before its empty cavity is filled, it leaves a void in the surrounding rock, which then becomes filled with sediment (**another mineral like iron pyrite or silica**) to form an **external mould** with a **cast fossil** in the cavity, which shows signs of the **outer shell features**. Whereas, an internal mould fossil will only show signs of the shell's internal features. Casts are seen as the counterparts to external moulds. Equally, casts are made in labs by infilling moulds with latex or modelling clay.

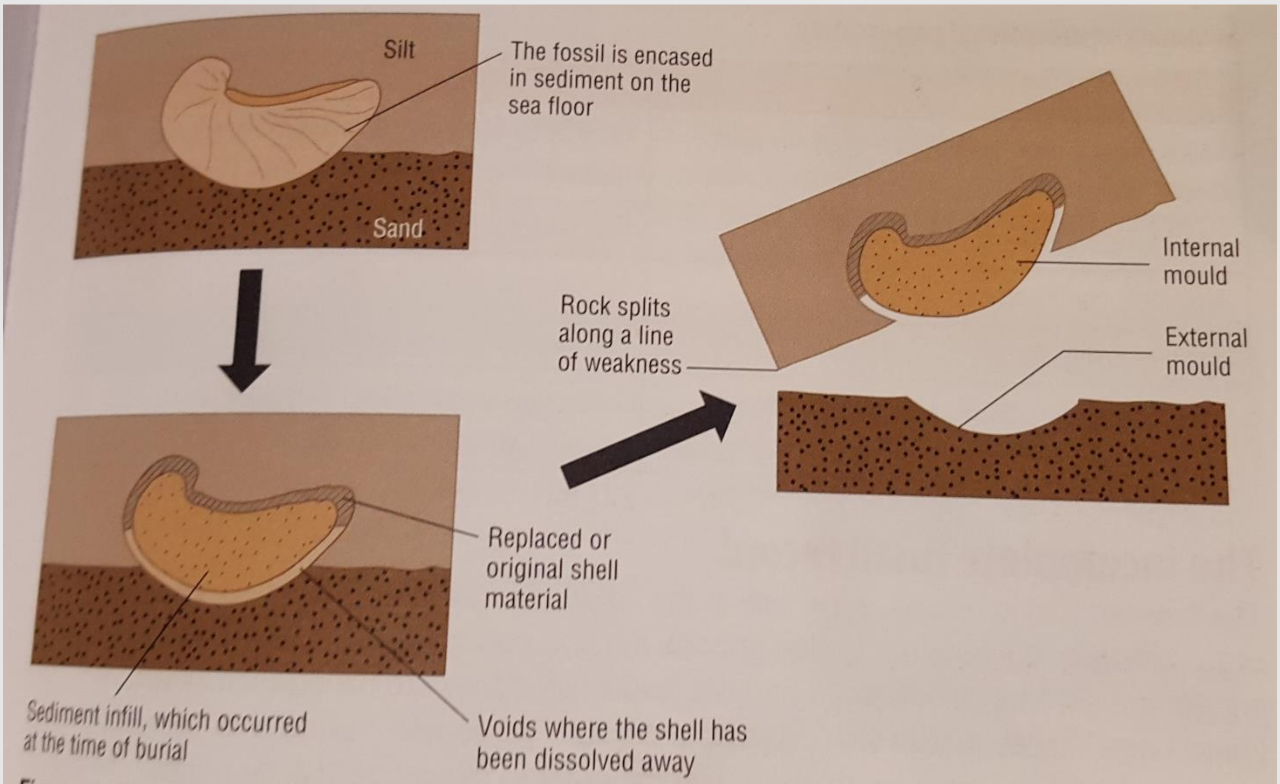


Figure 4 Diagram to show fossil mould and cast formation

Exceptional preservation is when there is an extraordinarily fine detail of an organism or the remains of soft tissue being preserved in a fossil.

Soft tissues can mean the **whole animal** (a worm or jellyfish) or maybe **only a certain part** (such as the gills or muscle), preserved along with other hard parts.

Commonly, only hard parts are preserved due to the effects of scavengers and decay processes that act to remove soft tissue before preservation. **Terrestrial animals** have comparatively little chance of preservation unless they are washed into lakes, since the **land surface is largely an area of erosion**.

The ideal conditions required for exceptional preservation are:

- **Rapid burial** in a **protective medium** such as a soft, fine clay, to protect hard and soft parts from the destructive action of scavengers and the weather.
- **Burial in low-energy** conditions to prevent breakup or fragmentation and for the best chance of fossilisation.
- **Anaerobic (anoxic)** conditions greatly reduce decay chance
- **The acidity or alkalinity** of the water – high acidity slows decay conditions as in peat swamps.

Too much modification of hard tissue by **early diagenesis** can **destroy detail**. This could be **compaction or replacement** of the original shell. Even after the fossil has formed, **physical processes** cause **disarticulation** of shells or **abrasion (folding/faulting)**. **Chemical processes** mean that weakly acidic ground waters can dissolve calcium carbonate shells.

Conditions that must occur	Reasons
Rapid burial in a **protective sediment**, shortly after death	No time for **breakage, scavenging or decay** of the material.
Fine-grained sediment	Fine particles preserve the **best detail**
Anaerobic conditions	Prevents the **chance of decay** of soft tissue (difficult for **bacteria/detritus feeders** to survive)
No **scavenging** animals	No fragmented, or eaten parts
Original material replaced **early in diagenesis**	**Less detail is lost** since there is **little alteration** of the original material.
Burial in **low energy** conditions	Reduces the chance of damage, fragmentation or transport.

#Low-energy = the **velocity** of the water is slow or still during deposition. Examples include: swamps, deep-sea environments, lakes or ponds.

Anaerobic means without oxygen, this condition is used to determine **conditions within a sediment**.

Anoxic is used to describe **conditions within water** that is lacking in oxygen**. Standard scavengers or decomposing bacteria cannot survive** in such environments.

The fossil record is biased, especially with respect to the **organism type being preserved**.

When an organism dies, bacteria act to decompose the soft parts leaving only hard tissue such as skeletal features.

Skeletal structures survive best if they are **naturally mineralised** with **impregnates of calcium carbonate** (**calcite or aragonite**), **calcium phosphate or silica**.
Such animals with mineralised skeletons include: **brachiopods, molluscs, echinoderms, corals and many chordates.**

For this reason, the fossil record is particularly biased to these types of organisms, whilst groups lacking a mineralised skeleton like worms, jellyfish and insects, are poorly preserved.