# The Sedimentology of Palaeontology: how to accumulate highly fossiliferous deposits

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## Abstract

Macrofossils can be found in almost every sedimentary environment, but the relative abundance and distribution of these fossils varies widely. There are many types of fossil preservation but this paper will focus on permineralization, where ions are precipitated into porous tissue from groundwater. A variety of factors are at work to concentrate fossil deposits, falling into two categories: how the fossils accumulate within any setting; and how fossils are later exposed in outcrop. The fecundity of the environment in which the animals were living will determine the primary density of the populations but other, external factors will then act to concentrate fossils in certain settings.

How concentrated the fossils are depends on necrolysis (processes operating immediately after death) and biostratinomy (what happens after initial burial). Necrolysis includes hydraulic sorting (animal behaviours such as caching will broadly be ignored in this study); deposition rates; and the removal of sediment through winnowing. Anoxic conditions will also favour preservation. These characteristics will all depend on the depositional setting, although eustatic changes may also concentrate fossils at sequence boundaries and on ravinement surfaces, as well as influencing the creation of accommodation space that may dilute fossil density within the sediment. This is particularly true in shallow marine settings.

The (much) later exposure of macrofossils for surface collecting will depend partly on the robustness of the fossils. Thick shelled oysters are much more likely to accumulate than delicate, thin shelled crustaceans, for example. A simple skeleton and infaunal lifestyle will also significantly improve the chances of fossilization. Exposure and resistance to erosion will be enhanced by diagenesis (the most important aspect of biostratinomy when considering concentrated fossil deposits), in particular cementation by silica, calcite, siderite or other minerals. In terms of outcrop geomorphology, the weathering profile and steepness of slope can severely impact how fossils weather out and whether they will accumulate on or at the foot of the outcrop. Climate will also affect the degree and rate of weathering, as will the grain size and lithification or diagenetic cementation of the sediment.

## Theory

Typically, fossils are dispersed through the sediment column. However, fossils can be concentrated in various ways. Work on large datasets of extraordinary fossil accumulations has synthesized these mechanisms into five categories. The first three categories (fecundity, winnowing and low deposition rates) represent mundane conditions; episodic events happen occasionally; while catastrophic events are rare and unexpected.

| *Concentrating mechanism* | *Characteristic environments* |
|---|---|
| Fecundity | • Warm conditions<br>• Abundant food supply<br>• Upwelling |
| Winnowing | • Lag deposits (channel bed or sequence boundary)<br>• Wave action<br>• Storm currents<br>• Ravinement surfaces |
| Low deposition rates | • Terrestrial or marine; low accommodation space<br>• Isolated offshore highs<br>• Maximum flooding surfaces |
| Episodic or periodic events | • Yearly monsoons<br>• Storms<br>• Turbidites<br>• Nearshore slumps |
| Catastrophe | • Flood<br>• Drought<br>• Tar seeps and quicksand; sinkholes<br>• Volcanic eruption<br>• Salinity crises |

*Table 1. Concentrating mechanisms for fossils*

Moving from proximal (upland terrestrial) to distal (deep marine) settings, each depositional environment will be examined in turn to see which of the mechanisms above are operating to concentrate fossils. Several case studies will be presented, including an analysis of 87 fossil rich beds in Cretaceous terrestrial deposits; a Cretaceous shallow marine ammonite assemblage and a Miocene open marine deposit.

The results show that in all settings (fluvial, aeolian, lacustrine, estuarine, shallow marine and open marine), every mechanism can operate to concentrate fossils, but the proportions are very different. A dataset detailing 156 extraordinary fossil accumulations in north America, from a range of depositional settings and ages, is used to map these proportions. The results show that most terrestrial deposits are subject to the same principal mechanisms. However, in marine settings, contrasting mechanisms concentrate fossils.

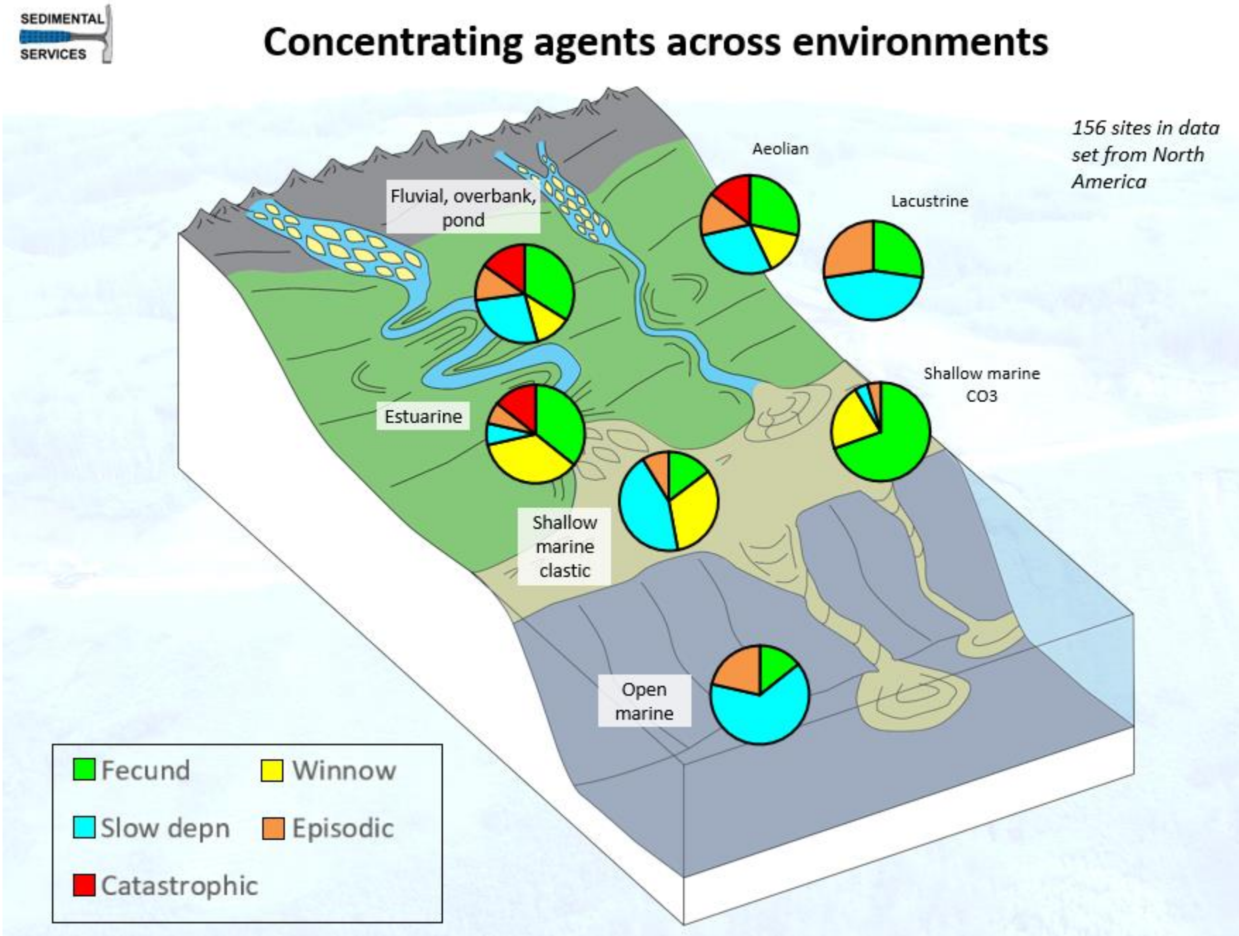


*Figure 1. Concentrating mechanisms across environments*

## A note on deposition rates and other factors

Depositional rates are extremely variable and may be influenced by: sediment supply (and distance from source); water depth; biological processes; precipitation and weathering; topography; sequence stratigraphy; subsequent erosion, resuspension or dissolution. There is also the Sadler Effect to consider, where deposition rates fall with increasing time span. The resulting rate of deposition will obviously affect the fossil concentration at any one horizon, but theoretically fossil concentration can be used as a proxy for deposition rates if everything else is constant.

In terrestrial settings, deposition rates usually decrease away from channels, and may be affected by the presence of tributaries and tie channels, lateral migration rates and erosion of existing deposits. In estuarine settings, deposition rates increase downstream. Marine deposition rates typically decrease from proximal to distal settings. In beach and shallow marine settings, high sedimentation rates are common and invertebrates abundant, although many will be broken. Deep marine settings have slow deposition rates and higher fossil concentrations would be expected.

Fossil abundance is affected by many other factors, which need to be negated before fossil density can be used as a proxy for deposition rates. These include fecundity (upwelling, suitable climate); the energy extant in the environment of deposition, provided by water depth, waves, and storms; preservation potential; the strength of the fossil; the likelihood of entombment; speed of burial and predation and consumption/destruction of hard parts. End members are unfossiliferous rocks (often due to anoxia) and highly fossiliferous rocks, indicating an outside concentrating medium.

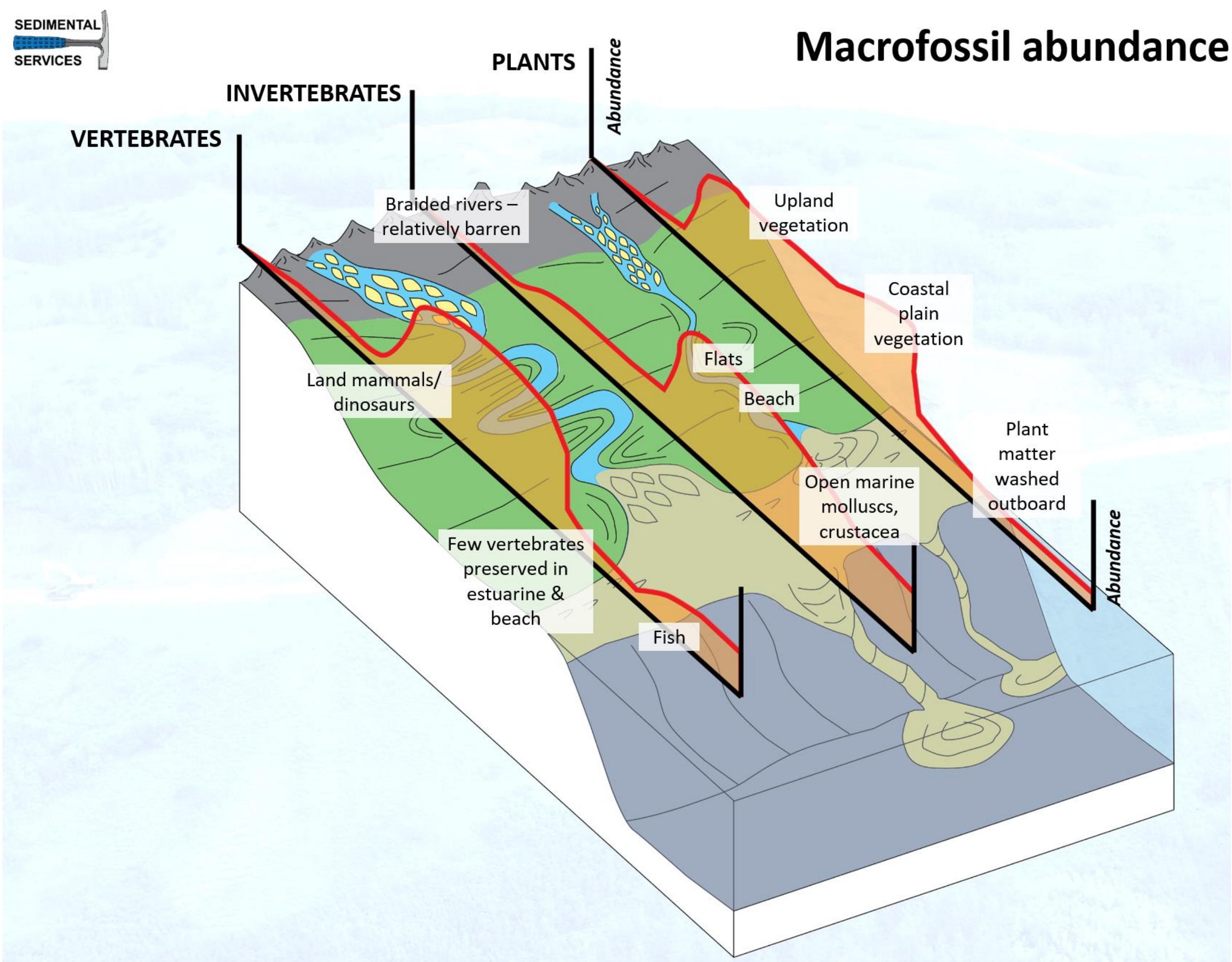


*Figure 2. Macrofossil abundance by setting*

**Taphonomy** is the study of how organisms decay and become fossilized or preserved in the paleontological record. It includes **biostratinomy**, the events that occur between death of the organism and the burial; and **diagenesis**, the events that occur after burial. Taphonomic processes may favour resistant fossils, sort certain types of fossil, or reflect certain behaviours during life, etc. Interpreting the taphonomy correctly will have a huge influence on the sedimentological interpretation of the sediments in which the fossils are preserved. A detailed discussion of taphonomy is beyond the scope of this paper, but it should not be ignored when considering fossil accumulation rates.

**Cements** and nodules can be critical to preserving fossils and tend to form extremely early after deposition. They often preserve fossils in three dimensions, with growth of the nodule nucleating around organic matter, in itself a fossil. Common cements include siderite or $CaCO_3$. The degree of cementation of fossils can create a huge bias as to which fossils are best preserved.

## How to collect fossils

There is an art to collecting fossils. Everyone knows somebody who is particularly adept at finding fossils. A sharp eye is obviously an advantage, but there are other techniques to improve one's success rate when looking for fossils:

| | |
|---|---|
| Background research | Before you head out - do your homework:<br>Geological maps<br>Useful references & books<br>Geologists – talk to local geologists<br>Geological societies – attend talks and talk to other local enthusiasts<br>Museums – look at exhibits and cultivate the curators |
| Reconnoitre | Don't walk straight up to the rock face. Instead walk the outcrop and look out for pockets of fossiliferous material |
| Lithologies | Focus on mudstones where possible. Fossils weather out easily, are often common (so breaking one is not a disaster), can be easily hammered out and are usually very well preserved. Limestones are hard and hence fossils are difficult to extract |
| Weathering profiles and sunlight | Usually, weathered sediments are better with fossils lying on the surface |
| Serendipity | You need some luck |

| | |
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| Pattern recognition | Absolutely key. You need to train your brain to recognize fossils from all angles and from an exposed fragment. Do this by handling fossils, drawing fossils, and studying them in museums or curating them at home |

*Table 2. Techniques to improve success when fossil hunting*

Examination of more than 125 potential fossil sites, catalogued just south of Dinosaur Provincial Park, suggests that outcrops should have low elevation, gentle slopes, high erosion rates and a relatively fine grain size to concentrate material on the surface. Fossil should be abundant, thick shelled or siderite cemented.

## Conclusions

Macrofossils have the potential to provide significant sedimentological data, from aiding the interpretation of depositional settings, understanding the processes operating to concentrate fossils, palaeocurrent interpretation, to diagenetic analysis and much more. A new, fivefold subdivision of mechanisms to concentrate fossils is proposed, comprising **fecundity**; **winnowing**; **low deposition rate**s; **episodic and catastrophic events**. The relative impact of these mechanisms was considered for a range of depositional settings and conclusions drawn. However, this presentation has only scratched the surface, with more work ahead to examine more depositional settings; to collate datasets on extraordinary fossil accumulations form other continents; to look at sorting processes and flow behaviour; to integrate taphonomy and to re-examine the role of diagenesis.


## Acknowledgements

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