1. The North Face (worksheet 1)

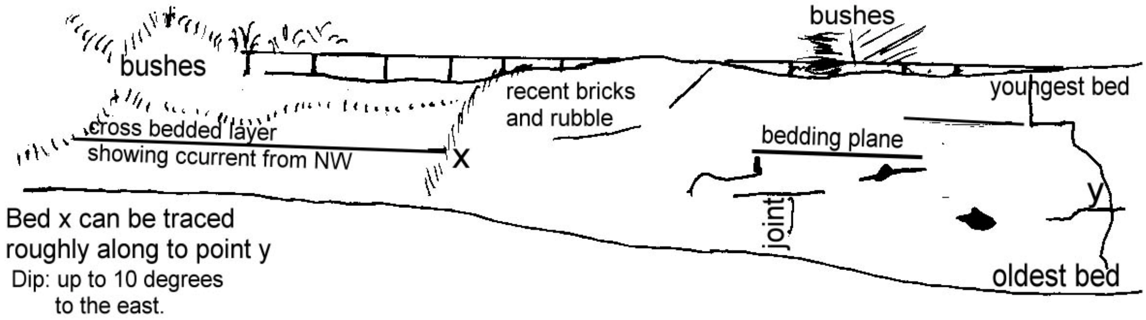

Figure 1 Field sketch of the North Face

The rocks exposed in this quarry are Magnesian Limestones, formed in the Permian geological period, about 255 million years ago. These are limestones with a lot of magnesium present as the mineral dolomite, and they effervesce only slightly in dilute HCl, when compared with pure calcitic limestone. A hand lens may be necessary to see the reaction, but do not breathe in the fumes. There are few if any signs of fossils (apart from the algal reefs referred to later). Many fossils may have been destroyed after burial by reactions between the calcite and very saline solutions formed by evaporating seawater.

The small (less than 1mm), spherical, bodies in the rock are ooliths. These are inorganic grains formed by the rolling of small shell fragments by wave action in shallow warm water, allowing calcite or dolomite to crystallise around the nucleus in a series of concentric cases as water evaporates. The weight of the oolith, a function of its size, indicates the minimum strength of the wave needed to move it. Small ooliths suggest gentle wave action. These are often more easily seen in dry specimens found at the foot of the face. See document **SE4 Briefing** for full details and photographs). A grain size comparator card is useful to help pupils to estimate the size of ooliths.

The beds become thinner towards the top, (See **Figure 1**) indicating more frequent breaks between the deposition of one bed and the next. Depending on the exact site of any dip measurement, the dip of the beds here is of less than 10 degrees to the east. Pupils should record information on the base map as well as the section.

This easterly dip means that the beds in the area will get younger to the east, and be older to the west. Less than 0.5km away in South Elmsall village, a small exposure of older Carboniferous sandstones can be seen by the roadside. The overlying evaporites are buried by younger rocks to the east).

One bed in the NW corner of the quarry clearly shows cross bedding of the ooliths in the rock, indicating a current flowing from the northwest. (see **Figure 2).** Mainly these beds are fine grained, indicating gentle currents, of fairly low energy.

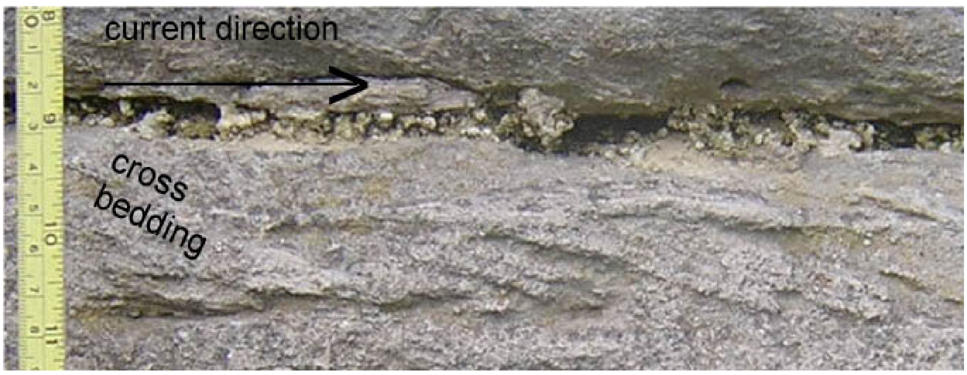

Figure 2 Cross Bedding in the North Face

2. The North East Face (worksheet 2)

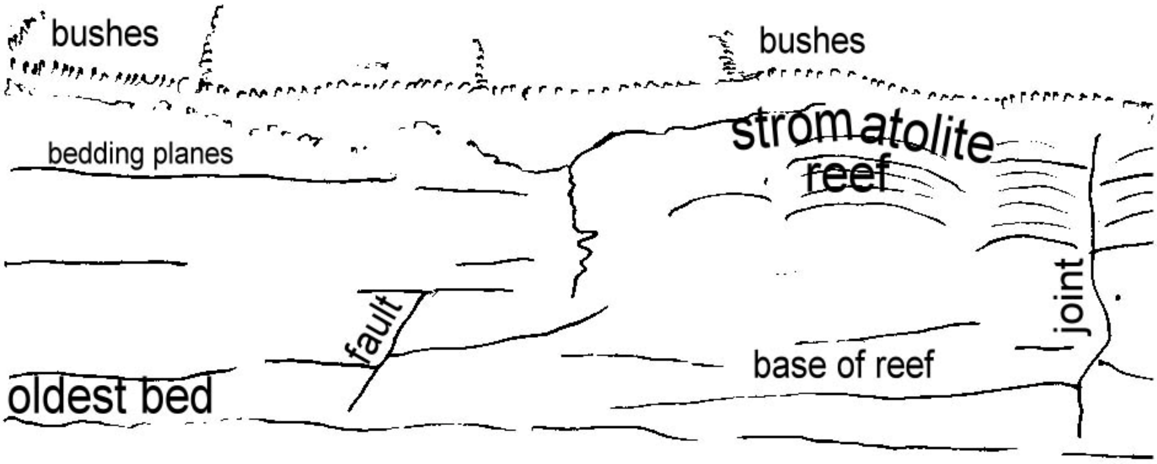

Figure 3 Field Sketch of the North East Face

On the left side of the north east face is the contact between the bedded Magnesian Limestones and the curving layers of the reefs, now weathered out on the rock face. (See **Figures 3 and 5** below). Pupils should also mark this junction on their map of the quarry (worksheet 3), as well as the sites of their other observations.

There is a small fault in the NE face, down throwing the beds to the north (See **Figure 4**). We can tell this is later than the beds of rock because it cuts across them. It was caused by movements of the rock after deposition. (Principle of Cross Cutting Relationships)

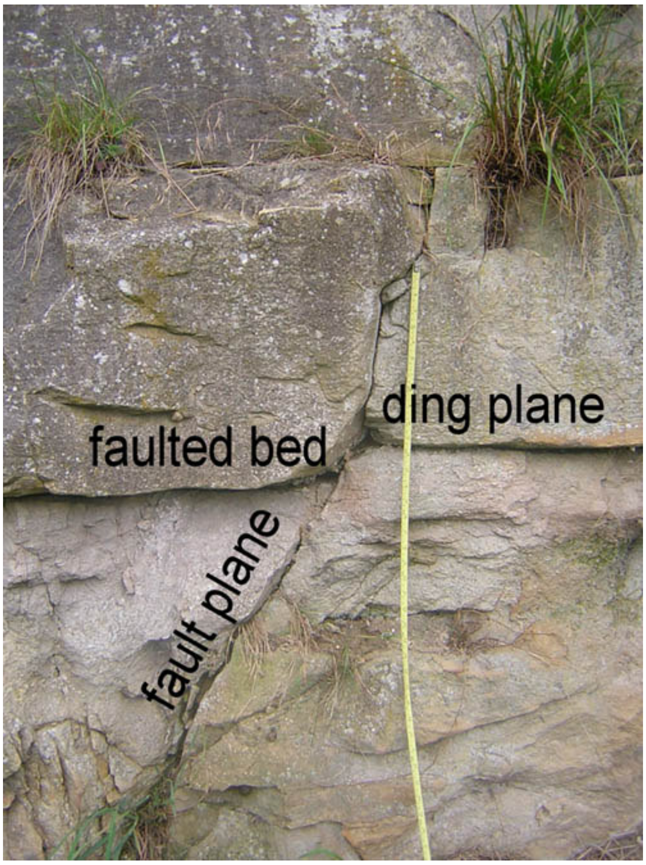

Figure 4 Fault in the Magnesian Limestone.

The reef structure makes up most of this face. It is visible mainly because the different layers of sediment trapped by the bryozoans and the blue-green algae, (nowadays more properly called '**cyanobacteria**'. See the note in **SE4 briefing**, p3) have different resistances to weathering – the softer parts of the layers weathering out and giving a 3D relief to the shapes. There is very little visible trace of organic remains as fossil evidence. Unless pupils already know these structures are organic in origin and can recall that information, then the exercise here is to allow reasoned speculation, followed by asking pupils if they can give reasons for, or test any of their ideas from the evidence of the face.

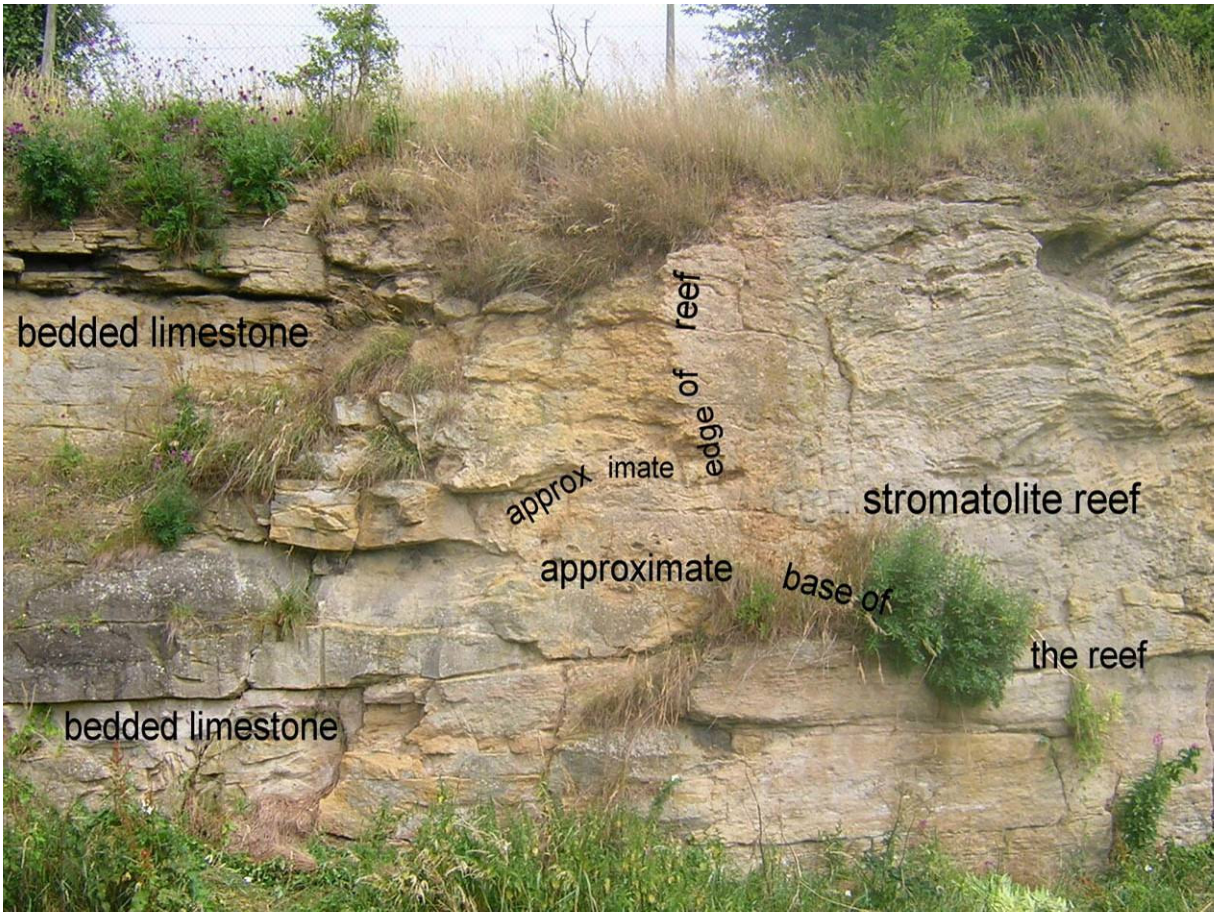

Figure 5 The Contact Between the Reef and the Bedded Limestone

There are two groups of possible explanations: those for events occurring after deposition, and those for events occurring during deposition. Suggestions of post-depositional changes (e.g. folding) have to explain why the beds below the reef are **not** folded (See **Figure 5**). Suggestions of events during deposition have to explain why the beds weren't laid down horizontally. The domed layers (they are curved only when seen in two dimensions) are ascribed to the growth of mats of organisms which trapped the sediment in this way and built up the reef structure. Establish with the group that the structure is a stromatolite reef.

Interpretation of these reefs is made by comparison with modern day examples of stromatolite reefs, found today in Western Australia, at Shark Bay, where they are occasionally exposed at very low tides. This is an application of the **Principle of Uniformitarianism** (biological, chemical and physical processes in the past operated in the same way as in present day). See section 3 below for more details.

These reefs, in three dimensions, are small mounds a metre or so across and up to 60 centimetres high. This means that the deposition of limestone sediment and the height of the reef increased more or less together. By applying the Principle of Uniformitarianism water depth at their formation is thought to have been no more than about 5 metres, and the climate, tropical, as with similar structures today.

The best view of this relationship between the two reef types is further along this face to the right, the site of the final exercise on worksheet 4. At this point give out worksheet 4, which directly names the structure as a reef, and move the group to the south east corner of the quarry.

3. The South East Face

Ask pupils to observe and then sketch the features in the rock face (See **Figures 6 and 7**). Encourage pupils to record this information on their base map and to search out, and mark on, the "other edge" of the reef, where the bedded Magnesian Limestone can again be found.

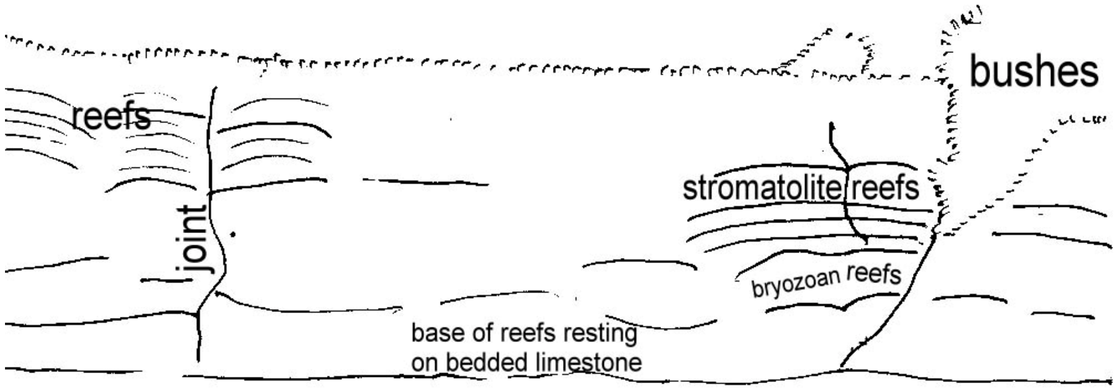

Figure 6. Field Sketch of SE Face

This "other edge" of the reef is towards the top of the grassy slope in the SW corner, although there are some "false alarms" along the way (See **Figure 2 in SE7 Field exercises**). These false alarms can be used to encourage pupils to "check" their conclusions and observations by asking for confirmation that the reef can't be found further along the face.

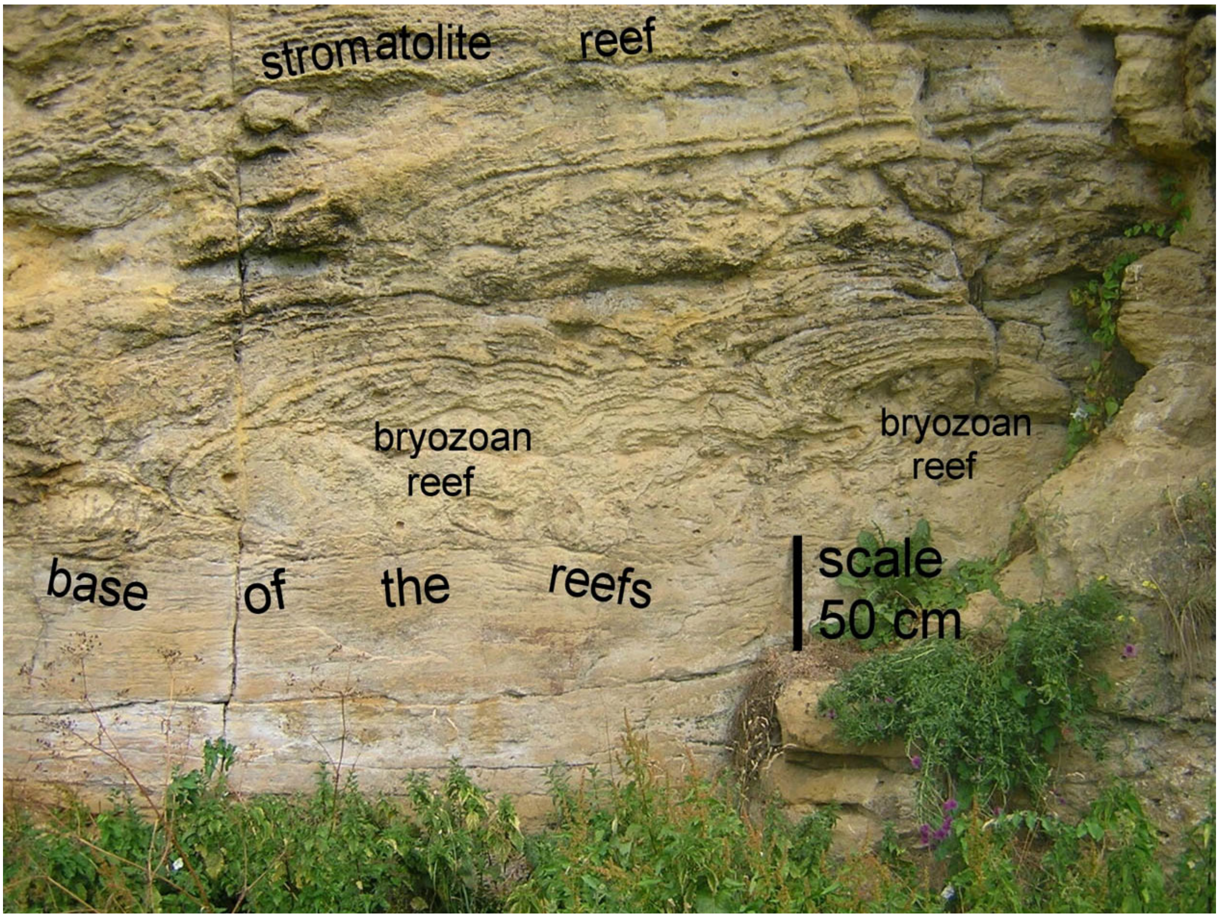

Figure 7 Photograph of the Reefs at South Elmsall

Fragments of the fossil bryozoan *Acanthocladia* (now extinct) have been found here at South Elmsall, along with marine bivalve fragments. Bryozoa are filter feeders made up of branches 1mm in length, but linked up into large mat-like colonies up to 1 metre across. These colonies can provide shelter for other animals, such as bivalves, and build up mounds by trapping sediment.

Animals such as flatworms, fish and gastropods graze these bryozoan colonies, and may be one reason that they eventually died out here. Another possibility is that the seawater became too saline for the bryozoans to survive.

The interpretation of the reefs at South Elmsall is that earlier bryozoan reefs, eventually died out but formed the base for larger mats of cyanobacteria, (previously called blue-green algae) which trapped sediment to form larger stromatolite (meaning sheet-shaped) reefs draped over the top of the earlier reefs (See **Figure 6**). The reason the reefs were not grazed away and destroyed is interpreted as a sign of high salinity, caused by evaporation, which prevented gastropods and other grazing animals from surviving there.

The "other" edge of the reef is best found by walking along to the upper edge of the south western corner of the quarry where the bedded Magnesian Limestones can again be found against the reef, although the reef is more difficult to see here. Pupils can make additional notes on their base map to show the two edges of the reef, (with the quarry taking a "corner" out of it).

Asking pupils to "join up" the two observed reef edges on their map to mark the continuous edge of the reef can lead to a useful discussion about the difficulties of interpolating between points of discrete observations and the kind of further evidence needed to do the exercise reliably. [There isn't any. It has been quarried away. Earth Scientists are often in the position of not having conclusive evidence either because it is buried, eroded way, or was never preserved or deposited in the first place].

4. Summary of Evidence from the Quarry

Bring the group back to the centre of the quarry, a suitable place to summarise the evidence found in the quarry about the origin of the beds and their subsequent history. The discussion of these points should bring out the issues related to the difficulties inherent in the interpretation of evidence.

STATEMENT ABOUT THE ROCKS IN THE QUARRY	EVIDENCE WHICH SUPPORTS THE STATEMENT
These rocks were formed in a shallow sea, not a deep ocean.	Limestones form in shallow seas, especially dolomitic ones associated with evaporites. (Remind the group of the preparation activities)
The currents in this sea were gentle and some flowed from the north west.	The grains in these beds are mainly small ooliths with limy mud between, indicating slack currents. (Size related to wave strength) The cross bedded layer near the top of the quarry, gives a direction from the NW.
Patch reefs and stromatolite reefs formed in these waters.	The structures observed in the quarry face and interpreted using the Principle of Uniformitarianism.
The sea lay in a hot tropical region.	Dolomitic limestones (those rich in magnesium) form where salinities are high, implying strong evaporation in shallow water. Also associated sediments above these limestones include thick evaporates.
The rocks were later uplifted and tilted to the east.	They are now exposed at about 60 metres above sea level and we measured the dip direction to the east.
These rocks were discovered to be economically useful.	The rocks were quarried, and so must have been useful. Main uses of dolomitic limestones are: road aggregate, building stone (see the villages nearby) and for making refractory furnace linings.
The site was scientifically important enough to protect.	Instead of completely infilling the site with domestic refuse, this face was preserved with public access.

5. Earth History at South Elmsall

The follow-up work to this Earth-Science On-Site excursion (found in **SE6 KS4 Prep**) is to deduce the sequence of events in Earth history which led to the formation of the quarry as it is today. The eight statements of the events are:

A conservation of the site as an SSSI
B infilling of the quarry
C faulting uplift and tilting to the east by plate tectonic forces
D weathering and erosion revealing the dolomitic limestone at the surface
E quarrying of the rock for refractory furnace linings
F growth of bryozoan and stromatolite reefs in the shallow water
G deposition in a shallow tropical sea of dolomitic limestone in beds
H Burial by evaporite rocks being deposited on top

The explanations of the sequences given should be based on the Earth Science principles of **Superposition** (younger beds lie on top of older beds) and **Cross Cutting Relationships** (features which cut across other features are younger) where appropriate.

YOUNGEST EVENT AT THE TOP	EXPLANATION
8 A	The site then protected as an SSSI.
7 B	The quarry was then infilled.
6 E	The quarry was dug down through the erosion surface (Principle of Cross-Cutting Relationships).
5 D	The younger beds were removed by erosion, with the erosion surface cutting across the beds (Principle of Cross-Cutting Relationships).
4 C	The beds were later affected by uplift and faulting (Principle of Cross Cutting Relationships).
3 H	The later rocks deposited on top must also be younger (Principle of Superposition).
2 F	The reefs formed above the first beds, and therefore must be younger (Principle of Superposition.)
1 G	Deposition of the oldest bed begins the evidence of earth history for the site.
OLDEST EVENT AT THE BOTTOM	

TEACHER'S NOTE:
It is only possible to get an **absolute age** in millions of years, for a geological event if it is possible to use radiometric dating techniques. The most usual form of dating for geological events is to establish a **relative age**: i.e. which order the events in a sequence occurred. Thus geologists use two concepts of time, an **absolute time scale**, and a **relative time scale**. Research is constantly attempting to improve the match between the two.

In establishing the **relative time scale** six laws and principles are used:

1 **Law of Original Horizontality:** all sedimentary rocks were originally laid down in a more or less horizontal attitude.
2 **Principle of Lateral Continuity**: In principle, a sedimentary rock is laid down in a layer (or bed) that extends sideways (originally horizontally) and a bed may therefore be found in other places.
3 **Law of Superposition**: In any sequence of strata that has not been overturned, the topmost layer is always the youngest and the lowermost layer the oldest.
4 **Law of Faunal and Floral Succession**: Fossil organisms have succeeded one another in a definite recognisable order over geological time. It follows that the same combinations of fossils in rocks have a similar (relative, not absolute) age, as do the rocks that contain them. This means that the relative age of sedimentary rocks may be identified by the fossils they contain.
5 **Law of Cross-cutting Relationships:** Any structure (fold, fault, weathering surface, igneous rock intrusion, etc.) which cuts across or otherwise deforms strata must be younger than the rocks and structures it cuts across or deforms.
6 **Principle of included fragments:** In principle particles are older than rock masses in which they are included. So the pebbles in a conglomerate are from rocks older than the conglomerate itself.