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EARTH SCIENCE BACKGROUND FOR GROUP LEADERS.
The layers of rocks at South Elmsall Quarry are Magnesian Limestones of the Cadeby Formation deposited during the later part of the Permian period, about 255 million years ago. These rocks are carbonates of calcium and magnesium, chemically, $MgCO_3.CaCO_3$, which forms the mineral dolomite. This is a natural compound, not a mixture.

These beds were deposited in England after a long period of weathering and erosion which left no trace of rocks from the early Permian period. At this time in Earth history the evidence from palaeo-geomagnetic studies tells us that the distribution of the continents looked very different from today's. All of the major landmasses were part of a giant single continent, called Gondwanaland, which stretched from the South Pole, where there was an ice cap similar in size to today's, across the Equator and well into the northern hemisphere (See **Figure 1**). There was no evidence of a northern ice cap at this time. That part of the continent which would later become South Elmsall Quarry was near the northern edge of this large continental land mass, where a long period of erosion had worn away the uplands caused by the folding of the Carboniferous rocks, and left a gently sloping desert landscape, ready to be partially flooded by a shallow sea. This ancient, and now long-gone "sea", is called the "Zechstein Sea" and lay in the subtropical latitudes of the time.

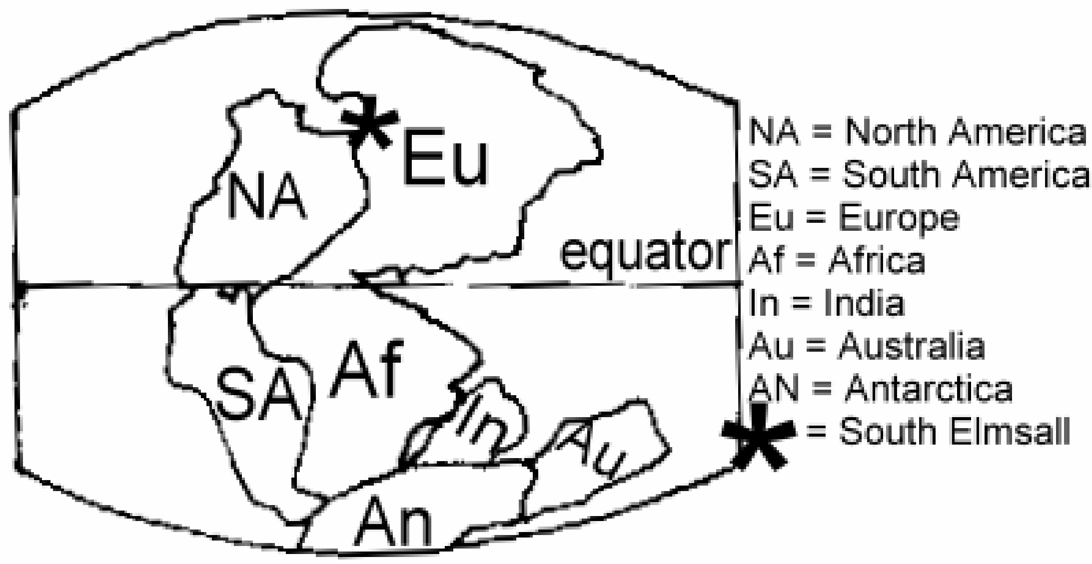

Figure 1 The Distribution of Continents in the Permian period

The layers of rocks deposited by the Zechstein Sea are geologically very unusual. They are mainly evaporite rocks. These are layers of rocks made up of minerals formed by deposition from evaporating seawater, and include dolomite, gypsum, anhydrite, halite (or rock salt) and very rare and valuable potassium and magnesium chloride minerals like sylvite (KCl).

At South Elmsall, (See **Figure 2**) however, only the older, dolomitic, parts of these layers are exposed, and they represent evidence of the conditions close to the western edge of the Zechstein Sea, which extended eastwards into Germany. The younger evaporite beds are found in boreholes further east, and are buried now under later layers of rocks.

The area of South Elmsall seems to have been close to the western coast of the Zechstein Sea, where limestones were being deposited, containing fossil shellfish indicating a marine environment. No marine deposits are found west of Leeds as this was a desert land area at the time (See **Figure 4**). Gentle wave action in the sea, which kept turning over tiny shell fragments, allowed them to be coated with calcium carbonate to form tiny 2mm diameter spherical grains called ooliths. The size of the ooliths are an indication of the amount of wave energy at the time of their formation. Larger waves can roll larger, (and therefore heavier) ooliths, until they become too heavy to move. Layers of rock containing these ooliths can be seen in the South Elmsall Quarry, and indicate very shallow water. (See **Figures 2 and 3**)

Figure 2 Oolitic Specimen at South Elmsall Quarry

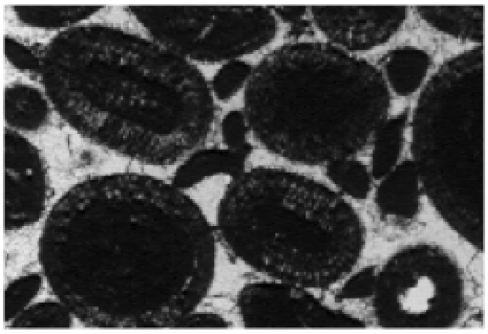

Figure 3 Section through a specimen to show concentric shells of ooliths cemented together. (each oolith is about 1mm diameter)

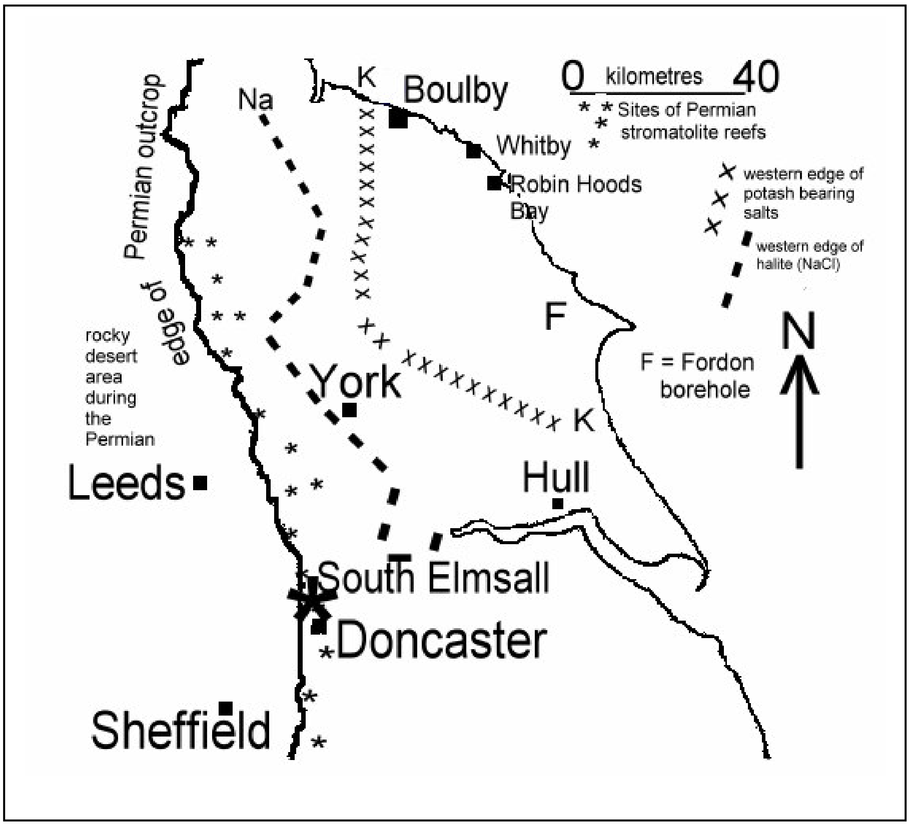

Figure 4 Map Showing the Western Edge of the Zechstein Deposits.

Also living in this sea were small branching organisms called bryozoa which began to form domed mounds, or reefs, about a metre or so across. The water depth was probably no more than 5 metres, and almost without tides. These reefs then died out, but left a suitable platform for mats of photosynthetic blue-green algae to develop, trapping layers of sediment, and slowly building up bigger domes over the tops of closely spaced bryozoan reefs. Reefs of this type can be seen today in Shark Bay, Western Australia. (See **Figure 5**).

NOTE: The term 'blue-green algae' is common in much of the literature, but is no longer regarded as particularly accurate. The modern scientific name for these organisms is 'cyanobacteria', and all occurrences of 'algae' in these documents refer more properly to cyanobacteria. Group leaders may want to point out to pupils that developments in scientific knowledge and understanding often result in important changes of names.

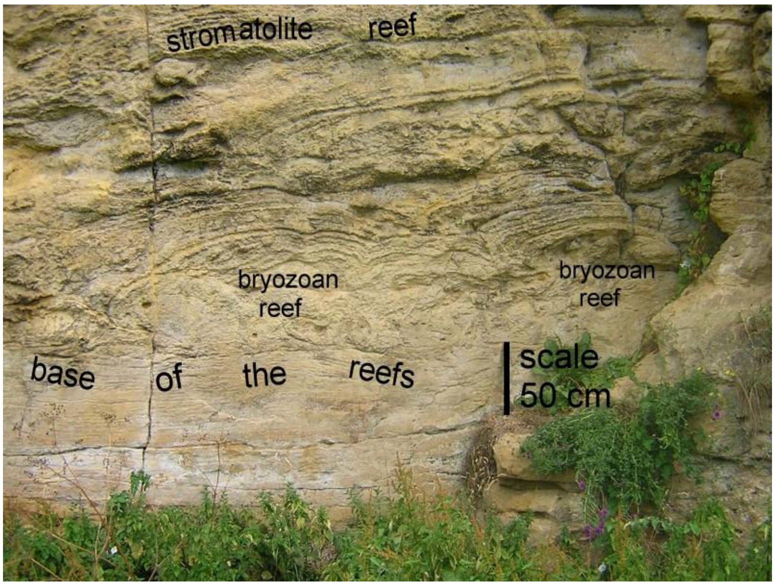

Figure 5 Bryozoan and Stromatolite Reefs at South Elmsall

The reason these bigger, 'algal' (cyanobacteria), reefs called 'stromatolite' reefs (which means layered) survived is probably because the water had become too saline and did not allow gastropods, fish and other animals, to survive there and graze them away. We are fortunate at South Elmsall in that the reefs are revealed by the differential weathering of the layers of sediment trapped by the algae (cyanobacteria) and bryozoans. These are the curving structures easily visible in the eastern face of the quarry. (See **Figure 5**)

The Formation Of Evaporite Layers

Evaporation of the seawater first concentrates the least soluble of the salts it contained. These are calcium and magnesium carbonates, or dolomitic limestone. Some dolomitic limestones may have been deposited originally as the mineral calcite, but altered to dolomite shortly afterwards as the further concentration of the seawater allowed chemical reactions in the sediment to occur.

The salinity of normal seawater is 35 parts per thousand, which means that the evaporation to dryness of a sea 1000m deep would produce only a few centimetres of limestone, less than a metre of anhydrite ($CaSO_4$), and only a little greater thickness of halite ($NaCl$). Evaporating 1000m of open seawater at one time is not feasible and yet there are about 600 metres of mainly evaporite rocks lying on top of the limestones at South Elmsall, buried now, to the east, under younger rocks. This represents the dissolved content of a huge volume of normal seawater, and presents the problem of explaining how it could have happened.

Concentrating such large amounts of salts in seawater by evaporation suggests that the sea area was very shallow and partially enclosed. There must have been a warm climate allowing strong evaporation. The great amount of salt being precipitated in this area means that periodically more (normal salinity) seawater was let into the area, to become evaporated, building up thicker layers than would otherwise be expected. Perhaps this was a seasonal phenomenon: if so the small-scale layering of carbonate, anhydrite and halite found in the Fordon Borehole, about 20 kilometres northwest of Flamborough Head (see **Figure 4**), suggests that 130 m thickness of evaporites might have formed over 25,000 years.

The Sequence of Evaporite Layers.

The sequence of rocks left by evaporating real seawater can be surprisingly complex, with the sequence of layers being influenced by many variables. These include:

i) seawater temperature;
ii) changes in influx of normal seawater (salinity 35 parts per thousand);
iii) salinity of the incoming seawater (which may have been partially concentrated by evaporation elsewhere. For example, salinity in the Red Sea is 40 parts per thousand);
iv) water depth and re-solution of precipitated minerals;
v) whether the precipitated layers are sealed off (e.g. by a layer of mud) from the overlying seawater preventing re-solution of salts;
vi) chemical changes in the layers after burial.

However, under natural conditions the following sequence would be expected from evaporating a body of seawater with progressively increasing salinity:

1) calcite (calcium carbonate) followed by
2) dolomite ($CaC0_3$. Mg CO_3)
3) either gypsum ($CaS0_{4.}2H_2O$) or anhydrite($CaS0_4$) depending on the temperature.
4) after the original water had been reduced to the equivalent of 10% of the original volume, halite (NaCl) is precipitated.
5) last of all, when the water has been reduced to the equivalent of 1.5% of the original volume the rare potassium chlorides, like sylvite (KCl), and potassium and magnesium sulphates, like polyhalite, would be formed. Over geological time, such an occurrence has been extremely infrequent.

This means that the layers of rock formed as the salinity progressively increased would be expected to be in a certain sequence. The thickness of each bed influenced by how much replenishment of seawater had occurred.

Top layer (youngest)
5) Sylvite / polyhalite
4) Halite (or rock salt)
3) Gypsum or anhydrite
2) Dolomite
1) Limestone
Bottom layer (oldest)

If at any time the salinity began to decrease, due to an influx of normal salinity seawater, the order of the layers will be expected to show reversal. Below is the Permian sequence from Yorkshire, (pieced together from many sites) suggesting both increasing and decreasing salinity. Where the order reverses the arrows indicate four periods of influxes of less saline water to explain this. The clay beds at the top helped prevent re-solution of the beds after deposition, and preserved these rocks as evidence of events in the past (See **Figure 6** for a graphical version).

Top layer (youngest)

Muds and clays

Upper Evaporites — halite, potash, halite, anhydrite, dolomite

Muds and clays

Middle Evaporites — halite, potash, halite, anhydrite

Magnesian (dolomitic) limestone

Lower Evaporites — halite, anhydrite, halite, anhydrite

Magnesian (dolomitic) limestone
(as at South Elmsall

Oldest layer resting on folded and eroded Carboniferous rocks

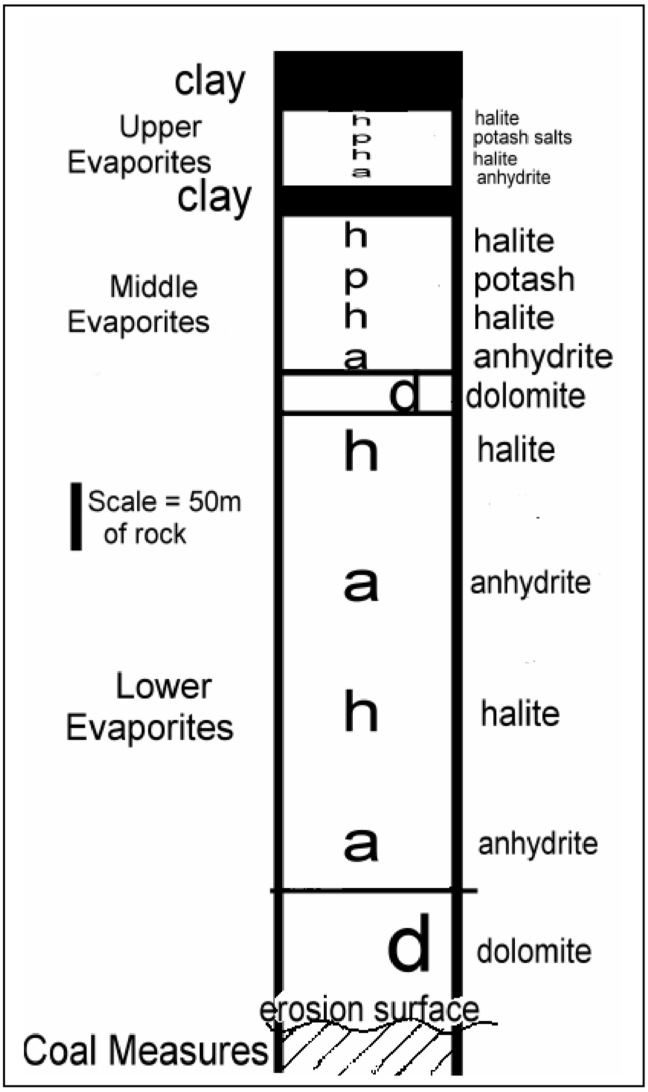

Figure 6 Graphical Representation of the Permian Evaporites In Yorkshire

After deposition, these Permian rocks have been uplifted and gently tilted to the east. Today they extend deep below the North Sea and into Germany. These thick salt beds helped to form many of the oil traps for North Sea oil and gas fields.

Magnesian Limestone was quarried for use as a road aggregate and local building stone, and can be seen in local houses and walls. Dolomite is also used as a lining for refractory furnaces.

The quarry closed in 1955 whilst in the ownership of the Hinchcliff family, but the significance of the exposure was only recognised in 1966 as it was being infilled. The site today is only a fraction of the former extent of the quarry, now a landfill site extending further west towards South Elmsall village.

The site was designated a SSSI in 1977 and opened to the public in 1986.

EARTH SCIENCE PRINCIPLES

In this area it is possible to demonstrate the following Earth Science principles.

1) **The Principle of Uniformitarianism:** The biological, physical and chemical processes we see today, operated in much the same way in the past. “The present is the key to the past”

2) **The Principle of Original Horizontality**: bedding planes represent the original horizontal at the time of deposition of sedimentary rocks. Their current angle shows the accumulated amount of distortion caused by earth movements since deposition. An exception to this principle is the underwater scree slopes at this locality which were deposited at a steep angle.

3) **The Principle of Lateral Continuity of Beds**: this states that sedimentary layers extend in three dimensions and might therefore be found elsewhere.

4) **The Principle of Superposition**: in a bedded sequence of strata, the oldest layers were deposited first, and are found below the younger layers, which were deposited later.

5) **The Principle of Cross-Cutting Relationships:** Structures, like faults and joints, which cut through rocks must be later, and therefore, younger than the structures they cross cut. They must also be older than the ones that cut across them.