The ESO-S materials for the sites at Snableazes Quarry and Cullernose Point may be combined with this visit into an extended field experience, including both dyke and sill exposures.

INTRODUCTION

At any one site it is helpful to think of interpreting the evidence preserved in the rocks as a recurring pattern of events, often referred to as the rock cycle: These events are:

a) Transport and deposition of fragments, forming sedimentary rocks;
b) Deformation (including folding, faulting, intrusion by igneous rocks or metamorphism); and
c) Uplift, weathering and erosion, leading to deposition of sedimentary rocks at the beginning of the next cycle.

The evidence for the events in The Rock Cycle can be "read" from the rocks in any exposure. However, some parts of the story are always missing, because geological evidence has many "gaps" in it caused by a combination of sediments never having been deposited and preserved in the first place, loss by erosion, and the fact that much is still buried and unknown. This means it is important to remember that the "story" at any one site is but fragments of a single Earth Science story that has an "invisible "prologue" and "epilogue" each millions of years long, but for which we cannot see the evidence at any one site, because it is not available to us. This is the story from the Boulmer foreshore and the Snableazes sites and the evidence for two Rock Cycles, with the evidence for any intervening ones having been eroded away.

The First Rock Cycle.

a) Transport and Deposition:

The beds of rock in the area were deposited about 342 million years ago in the "Northumberland Trough", which was a down-faulted area of crust, during the Carboniferous period. This was an elongate area with the sea towards the west and south, and land areas to the north where the Southern Uplands are now located. This land area extended many hundreds of kilometres to the north and west, including what is now Greenland, Canada and the USA. This land area was drained by rivers carrying sand and mud, and forming large swampy delta areas. Occasionally sea level would rise (or land level would fall) and the sea would flood the area depositing very muddy limestones which extend over large areas of what is now northern England. The **calcium** component of calcite ($CaCO_3$) arrived in the sea water as a result of chemical weathering of rocks on land, being transported as ions in solution by rivers. The **carbonate** component arrived partly by the same process in the form of hydrogen carbonate ions and partly by direct solution of carbon dioxide in the sea. Marine animals, like corals and brachiopods, used the material in solution to make their shells. The presence of these fossilised animals indicate that the sea was warm, and of normal salinity and well oxygenated, suggesting that the area was close to the Equator at this time, a position confirmed by palaeomagnetic evidence. In addition there were soft bodied animals, which did not become fossilised, but left traces of their movements in the sediments as trails and burrows.

Sagging of the trough along fault lines allowed the accumulation of a total about 2000 metres of deltaic sands and muds with coals, and muddy marine limestones, although none of it was deposited in particularly deep waters. Burrows and trails of bottom feeding animals, as well as shelly marine fossils, are common in the deposits. On the delta top vegetation grew and soil horizons with rootlets formed. Vegetation which fell into anaerobic, swampy areas failed to oxidise away and became compressed into peat and later formed coal seams. Amphibian footprints can be found indicating vertebrate animal movement from freshwater onto sandbars across the delta top environment, however, very few species of any kind from this time are extant today due to the effects of mass extinctions, periods of rapid reduction in the number of species in the fossil record.

In detail these sediments can appear confusing as the types of deposited sediments vary rapidly across the delta top, but the broad picture of muddy limestones forming in full marine areas, followed by delta front shales and sandstones with coal seams on top is repeated several times in this area. (See **Figures 1 & 2**). All of these beds indicate transport of sand and mud (as well as the dissolved load) by rivers and deposition in a shallow sea area as part of a delta complex which repeatedly built up to sea level. The sands were deposited where the river current slackened, whilst the mud settled out in quiet waters in bays and lagoons, or in delta top lakes, and in front of the delta where water was too deep for the sediment to be disturbed by wave action. The growth of vegetation (with roots into the seat earth below) led to organic deposits of coal when the trees fell into stagnant waters where they could not be oxidised away, and then buried and compacted to form coal.

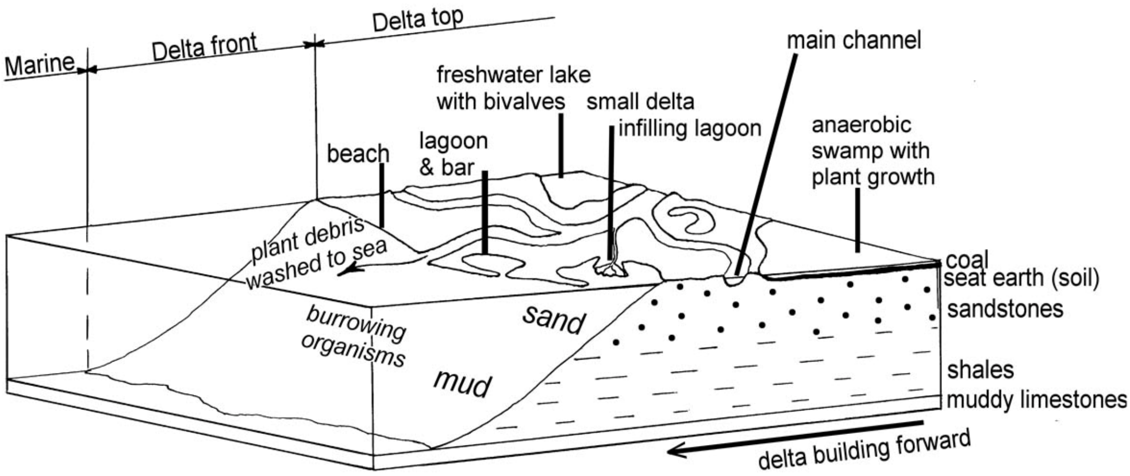


Figure 1. Sketch showing a cycle of delta sediments.

That part of the succession relevant to this visit includes non marine sandstones, shales and coals and marine limestones, which repeat in rough cycles (called cyclothems). None of these beds imply deposition in a depth of water greater than about 50 metres, and the coals suggest the sea area was built up at times to sea level, or slightly above, by delta deposits. Rising sea levels, or down faulting of the basin, then led to a marine transgression and the beginning of a new cycle starting with a marine bed, often a muddy limestone. More widespread transgressions may have been caused by global climatic changes affecting the ice cap at the southern pole, (there was no ice cap in the north polar regions at this time) causing world wide sea level rises. Geological convention takes the limestone as the beginning of the cycle, and the coal seam as marking the end.

From a borehole at Howick, just north of our area a cyclic sequence from bottom to top is as follows:

Youngest bed			
bituminous coal	10 cm	} delta top with vegetation	**END OF CYCLE**
sandstone	300 cm	}	
dark shale	90 cm	} sand and mud delta deposits	
sandstone	360 cm	}	
shale	150 cm	}	
Lickar Limestone (with marine fossils)	30 cm	} marine environment	
shale with corals	90 cm	} muddy marine environment	
bituminous coal	14 cm	} delta top with vegetation	**END OF CYCLE**
seat earth (with rootlets i.e. soil)	120 cm	}	
sandstone	210 cm	} sand and mud delta deposits	
shale	240 cm	}	
Oldest bed			

Along the coast, at Boulmer, lying on top of these beds are slightly younger, cross bedded sandstones and pebbly gritstones that form most of the wave cut platform. These sandstones lie on top of an erosion surface indicating that some uplift and erosion had occurred in the area before they were deposited on top.

b) Deformation: Folding Metamorphism and Igneous Intrusion.

After the deposition of these sediments they became cemented together and then tilted to the east and south east. In the process these earth movements caused brittle fracturing of the rock leaving the beds faulted, mainly in an east – west direction. Some of these faults show one side has dropped compared to the other, but some, such as at Longhoughton and possibly Cullernose Point, suggest that the stresses caused horizontal movement with one side sliding along past the other side of the fault.

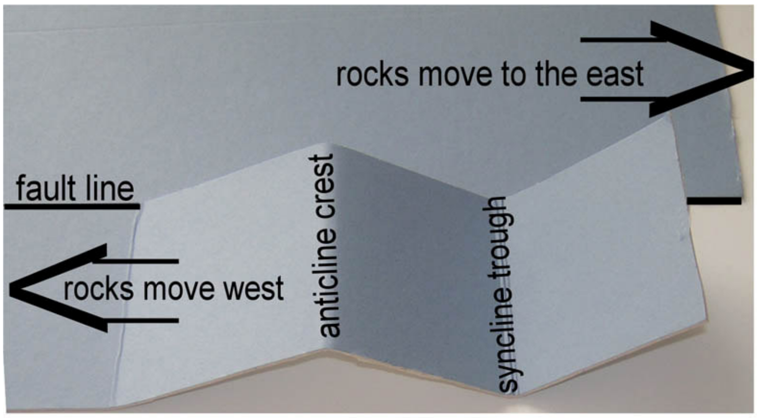
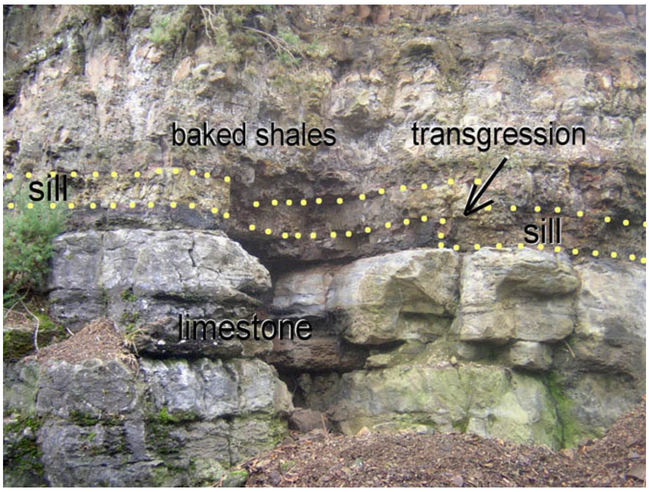


Figure 2. Model of the fault at Cullernose Point.

Plate Tectonic theory suggests that these kinds of earth movements were caused by plate collision. Evidence from many other areas suggests that this Variscan fold mountain building episode (with the South West England right on its northern edge) occurred when southern Europe collided with what is now northern Europe as plate tectonic forces closed the Rheic ocean. This began the uplift of the Armorican fold mountain belt, and by the end of the Carboniferous period this uplift had affected most of what is now England, and had caused the crust to be put into tension across much of the north of the country. This caused faulting (brittle fracture) and thinning of the crust, reducing pressure on the upper mantle and inducing partial melting and the formation of basic magma. Normally the upper crust is solid rock.

Sometime after the folding and some of the faulting, the area was intruded by a basic magma, dated as 295 million years old by radio metric methods. This hot liquid, less dense than the deeply buried rocks it was pushing into, found its way through planes of weakness, such as fault planes and along bedding planes, until it solidified underground, to form dykes and sills of the Whin Sill type. We know that the intrusions came later than the faulting because at Boulmer, the dyke follows a pre existing fault, and just north of Snableazes, the sill crosses from one side of the Longhoughton fault to the other, without being displaced. These intrusions therefore must post date the displacement along some of the faults, according to the **Principle of Cross Cutting Relationships.**



Related lenses of this dolerite occur from the Pennine escarpment and Tessdale across Northumberland to the Farne Islands. Although the sills are mainly within Carboniferous Limestone rocks there are abrupt changes of level, where the magma occasionally "steps" up or down to a different bedding plane. Originally mis-identified as a lava flow these rocks were correctly described as transgressive sill intrusions (by Tate in 1870). Transgressive behaviour is one piece of definitive evidence of an intrusive origin, since lavas on the surface cannot do this.

Figure 3. Transgressive sill at Snableazes Quarry.

This phenomenon can be seen in miniature at Snableazes quarry, where a 20 cm selvage of the main sill steps down 17 cm, across a shale bed, onto the top of the Acre limestone. The evidence for the transgressive nature of these sills is otherwise only revealed by detailed mapping.
Associated with this period of tilting, faulting and intrusion, was a period of uplift, which exposed the rocks to weathering and the beginning of the next rock cycle with deposition of Permian rocks, now eroded from this area.

c) Uplift, Weathering and Erosion.

From other areas of the country we know that there must have been great thicknesses of rock deposited on top of these Carboniferous strata which have now been weathered and eroded away in at least one completely "missing" rock cycle since the Carboniferous period.

The Second Rock Cycle.

d) Transport and Deposition.

Lying in patches on top of the Carboniferous rocks are thin, and poorly exposed glacial deposits from the last Ice Age (about 12,000 years ago), when ice moving from the Cheviot Hills passed over the region and southwards along the edge of the North Sea area. The signs of glacial erosion in the area are muted, mainly restricted to the shaping of the more resistant rocks (notably the dolerite) as small, ice-shaped crags. The presence of local ice seems to have kept ice flows from Scandinavia, further east, so no glacial erratic boulders of Scandinavian origin were deposited here. At this time the North Sea was ice covered land, which began to be flooded by the seas as the ice melted about 12,000 years ago.

The most obvious deposits of this later rock cycle are the beaches and areas of blown sand along the coast. The sand being weathered from glacial deposits and the older Carboniferous rocks and transported by wind and water to the North Sea. On the beach these sediments are moved and re-worked frequently by wind and water, but offshore, North Sea deposition of layers of fined grained present day marine sediments continues with less disturbance by surface processes.

Mass Extinctions.

e) Mass extinction.

There are five recognised mass extinctions in the fossil record since the beginning of the Palaeozoic. This does not include the sixth mass extinction that some scientists think is currently being caused by human activity, and which could prompt useful discussion with groups. (See Figure 4).

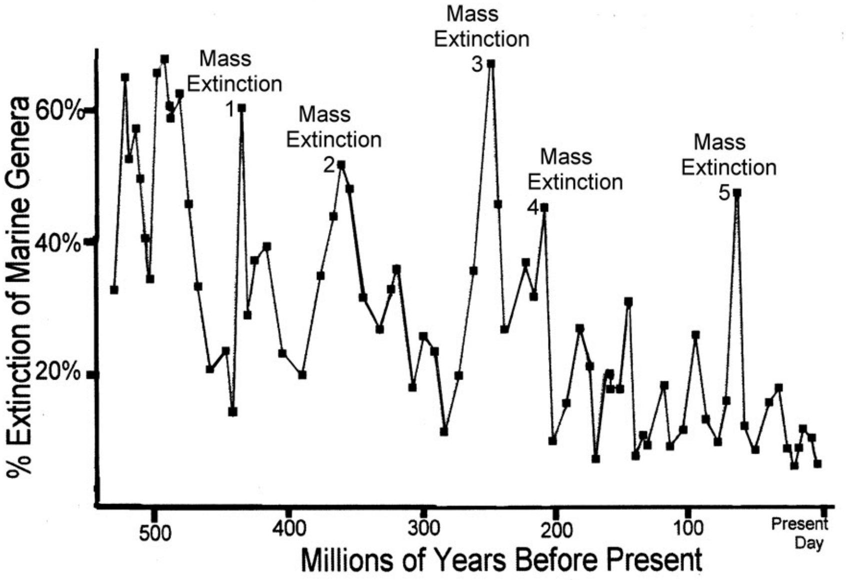
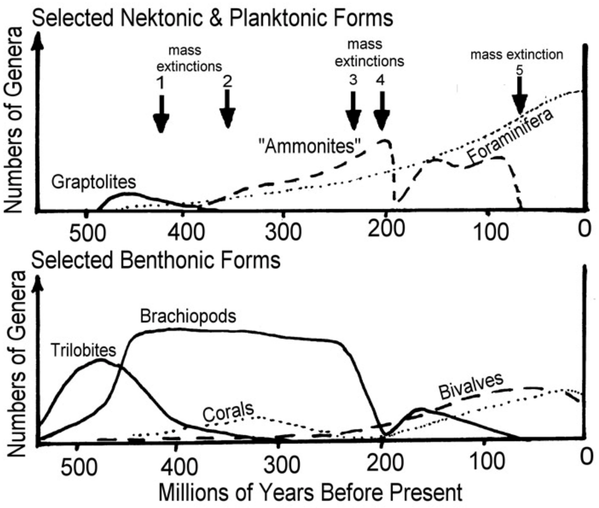


Figure 4. The occurrence of mass extinctions during the last 500 million years.



By the Carboniferous some Lower Palaeozoic genera and groups are already extinct and gone forever, and new ones are present. For example: planktonic graptolites, common in the early Palaeozoic (old life), are gone; corals become common and brachiopods remain abundant, although there are many new species. "Ammonites" including straight forms as well as the more common coiled ones, become common. At this time land living vertebrates appear in the fossil record as amphibians.

Characteristic Mesozoic (middle life) forms, popularly associated with dinosaurs and large marine reptiles, occur in even younger rocks (not seen in this itinerary) as a result of mass extinctions 3, 4 and subsequent evolution.

Figure 5. Examples of changes in fossil genera over the last 500 Ma.

Mass extinction 5 is the one popularised as ending the reign of the dinosaurs at the end of the Cretaceous and may have been the result of a bolide (asteroid) collision at Chicxulub at Yucatan, South America. The following evolution of new species resulted in a further change in life on Earth to the animals we know today, including Homo sapiens. This is called the Cenozoic (seen life) and these changes in fossilised life allow us to identify the relative age of the rocks by the fossils they contain (**Principle of Rocks Identified by their Contained Fossils)**.

Interestingly the numbers of foraminifera, which are marine planktonic (floating) organisms with a mode of life similar to graptolites, continue their steady increase of numbers through all five periods of mass extinctions that have been recognised in the fossil record of the last 500 million years. Many of the plants from the Carboniferous are also extinct, although a close relative of one group, *Equisetum* (horsetail), is still extant.

An important feature of this evidence is that species with very similar habitats show very different responses during these periods of mass extinction. Theories about the possible explanations for mass extinctions has included: planetary collision with an asteroid; reduction of marine shallow water habitats due to continental collision; sudden increases in volcanic activity changing the opacity of the atmosphere and reducing sunlight (and photosynthesis.); increased predation, or competition from other newly evolved species.

Time of Mass Extinction (approx)	% Loss Of Species	Suggestions on Possible / Likely Cause
440 million years ago	-50%	May be linked to changes due to glacial conditions in the southern hemisphere, for which there is good evidence.
380 million years ago	-50%	The decline spreads over a large period and may be linked to drop in sea level reducing circulation and oxygen content.
260 million years ago	-80% to -90%	This huge loss of life, linked in time to massive volcanic eruptions in what is now India which may have blocked out sunlight.
200 million years ago	-50%	Impact by asteroid has been suggested, but the evidence for changes in sea level reducing circulation and oxygen content is perhaps more convincing.
65 million years ago	-50%	Very strong evidence for an impact crater at Chicxulub, Yucatan and related rock deposits around the Caribbean. There were also volcanic eruptions at this time

Table 1. Summary of Mass Extinctions

EARTH SCIENCE PRINCIPLES

Geological Time.
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 accuracy of the absolute timescale, and the match between the two. In this area the radiometric age given for the dolerite intrusions is 295 million years and forms one of many links between the two time scales.

The fundamental geological principle is **The Principle of Uniformitarianism:** which states that the biological, physical and chemical processes we see today, operated in much the same way in the past, i.e. "The present is the key to the past". In establishing the **relative time scale** the following 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. Principle 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. Principle 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. Principle 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: 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.