Funded by Defra's Aggregates Levy Sustainability Fund, administered by English Nature.

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INTRODUCTION

☛ Individual groups will need 10x hand lenses, measuring tapes, compasses and clinometers if dip measurements are to be attempted, as well as clipboards, pencils, rulers and copies of the relevant field sheets for individual pupils. (See **SNA12 KS4 worksheets**).
Group Leaders will need a plastic bottle of dilute HCl, a small plastic bottle of water, goggles a geological hammer and a digital camera will also be useful.

☛ Field leaders should have decided which combination of the following exercises the groups are to tackle before they arrive on site.

1. Snableazes Quarry
2. Snableazes Quarry In Section
3. Snableazes Quarry, West Crag
4. The Rock Succession At Snableazes.
5. Cullernose Point
6. Cullernose Point Dolerite and Columnar joints.
7. View Of Long Heugh Crag
8. Summary Of Geological Events

NOTE: Worksheets may be used as appropriate to help pupils summarise the activities at any location, or to guide the discussions, or as a guide for pupils in small group activity.

☛ Follow the directions to Snableazes Quarry given below. Due to the angle of the driveway to the quarry, it is advisable to approach from the north. **NOTE:** Access to this site is **only by prior permission**. (See **SNA3 locaccess** for details).

Site 1: Snableazes Quarry.

NOTE: Access to this site is **only by prior permission**. (See **SNA3 locaccess** for details).

☛ Take the A1 towards the north eastern outskirts of Alnwick. Leave the A1 north of Alnwick at Denwick, and turn right onto the minor road eastwards, towards RAF Boumer, after passing through Denwick village. Continue 4.5 km on to Longhoughton. Take the left turn along the minor road signposted to Lesbury and Alnmouth. After 1 km the narrow, (and hard to spot), gated driveway to Snableazes quarry is on the left just before a slight dip in the road. It is immediately after Snableazes farm, which is on the right. Minibuses and cars may drive in and park **only by prior arrangement**. Coaches will need to drop off the group and return to pick them up after an hour.

Take the group along the drive to **site 1a**, the earth bank at the edge of the open area in the east of the quarry. **Under no circumstances** should you allow pupils to proceed past this point.

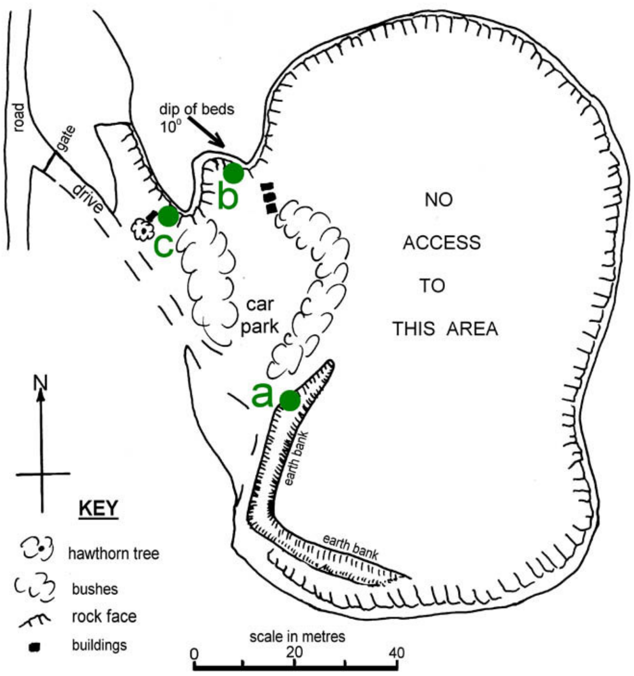


Figure 1. Map of Snableazes Quarry.

Site 1a. The East face of the Quarry

☛ The tasks here are: to orientate the group in the vertical dimension by using the section on **worksheet 1** (See also **Figure 3**); to describe the main sill exposure and the modern weathering processes affecting it.

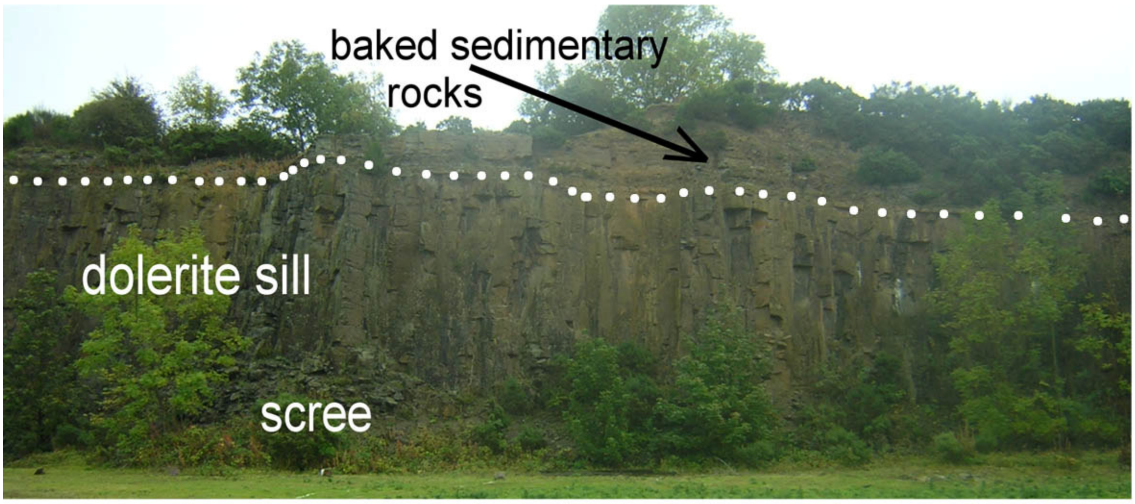


Figure 2. The East face of Snableazes Quarry

Worksheet 1: Snableazes Quarry, East Face.

Here the emphasis is on careful observation and the application of recalled knowledge.

Suitable questions at this site	Acceptable responses.
Look at the lower two thirds of the quarry face opposite. Can you see jointing?	Yes. Near vertical jointing over most of the face.
Is it likely to be igneous or sedimentary?	In the absence of bedding it is likely to be igneous
Confirm to the group that the rock is igneous (dolerite) How were the joints formed? If the joints are near vertical where would you expect the cooling surfaces to be?	They were formed as the magma cooled, solidified, and then continued to contract as it cooled further, causing brittle fractures to occur at right angles to the cooling surfaces. Cooling surfaces would be approximately horizontal above and below.
Do the joints continue right to the top of the face?	No, the top couple of metres at the top are not jointed in the same way.
Describe the top part of the face. Trace the top contact of the igneous rock near the top of the face from right to left.	The top part is bedded. These are sedimentary rocks lying on top of the igneous rock. They appear to be horizontal
Tell the group that in fact the beds are dipping away from them, and only appear horizontal. (Imagine looking at the edges of pages in a book, or on a clipboard, held so as to be dipping away from you. The closest edge appears horizontal, but the page surface is dipping. See **Figure 3**). Refer them to the section on **worksheet 2**. which illustrates this	
Tell the group that the two options for a name for this igneous feature are a **sill** (intrusion) or **lava flow** (extrusion). What evidence would we need to be sure it was a sill and not a lava flow?	We would need to investigate the top contact and see that it had baked the overlying rock – something that a lava flow at the surface cannot do (since the overlying beds would not have been deposited.).
Give the group the information that the beds above the igneous rock are shales and fine sandstones, which have been baked hard. What name would they give to the igneous feature?	It's a sill – not a lava flow.

Does this mean the sill is older or younger than the beds above **and below** it?	Younger. It was intruded into the layers a long time after they were deposited and buried. (**Principle of Cross-Cutting Relationships.)** **NOTE:** This appears to reverse the more usual **Principle Of Superposition,** which does not apply in these circumstances.
How can we date igneous rocks? This dolerite gives a date of 295 million years old, i.e. very similar to the dyke at Boulmer?	By using radio metric methods.
Where did the magma come from? **NOTE:** basic magmas originate by partial melting of the upper mantle – which otherwise behaves as a **solid**.	Deep below ground, (probably intruded along the fault which links this sill with the dyke at Boulmer, although this cannot be confirmed from this outcrop.) The magma then spread out sideways between the bedding planes here at Snableazes. (and in many other sites across northern England from Teesdale to the Farne Islands).
What force caused the molten magma to be intruded upwards through the rocks	Hydrostatic pressure. Liquid hot magma is less dense than the surrounding rock.
Where would you expect the bottom of the sill to be found?	Underneath: below the ground at the base of the quarry face.
Estimate the thickness of the visible part of the sill.	About 15 – 20 metres
What does this mean for the rocks above the dyke during the intrusion?	They would be baked and altered (metamorphosed) **but also** lifted by the same amount 15 – 20 metres. [i.e. parts of Northumberland were not only stretched to allow dolerite dykes, but also uplifted in places by hydraulic pressure from dolerite sills, about 295 million years ago.]
How was the scree formed?	Physical weathering of the jointed rocks on the face
So is the scree material forming an igneous, sedimentary or metamorphic rock?	No matter what kind of rock the "lumps" are, it is a sedimentary rock because it is made up of weathered blocks – just like the sand on the beach. It just hasn't been cemented together yet.
Ask the group to sketch and label the outcrop using **worksheet 1**. Then use the section to help guide their interpretation of the rest of the quarry.	

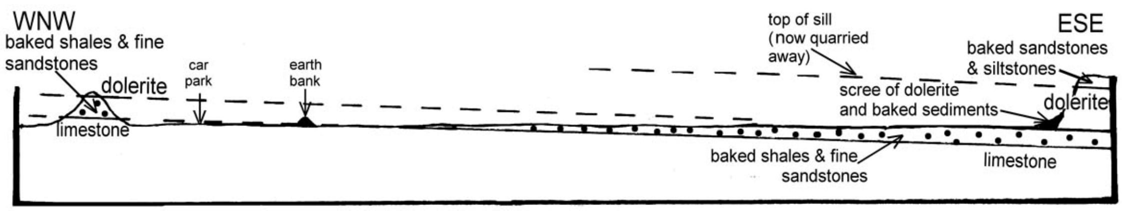


Figure 3. Section across Snableazes Quarry

Site 1b. Snableazes Car Park.

☛ Bring the group back to the car park and to the face at the northern end. This is **site 1b.** Here the sedimentary rock below the dolerite is exposed in a three dimensional outcrop i.e. two faces at right angles.

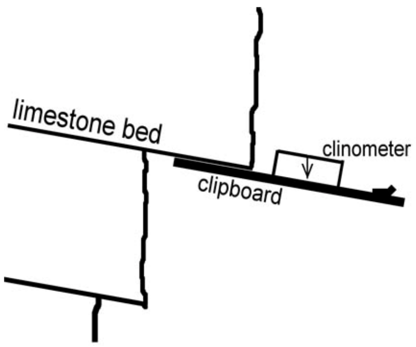


Figure 4: Taking a dip reading at Site 1b.

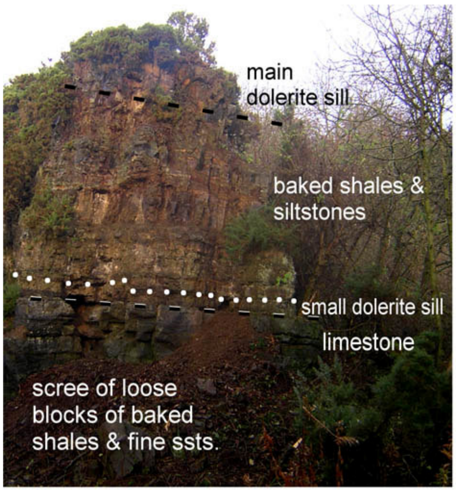
Very few top bedding planes are exposed here, so if a dip reading is to be taken, use a clipboard held to the bottom bedding surface, as shown.

NOTE: The dip arrow is already drawn on the pupil map of the quarry and the dip amount could be recorded there. However, if the dip arrow is to be measured and plotted by pupils this should be removed from the worksheet.

Worksheet 2: Snableazes Quarry in section.

<table>
<tr><th>Suitable questions at this site</th><th>Acceptable responses.</th></tr>
<tr><td>Ask the group to describe the rock in the exposure.</td><td>Grey. It has bedding running across the face and some jointing.</td></tr>
<tr><td>What kind of a rock might it be, igneous, sedimentary or metamorphic?</td><td>Bedded rocks are sedimentary.</td></tr>
<tr><td>Ask them to approach the exposure and describe the rock type.</td><td>An impure (contains a lot of clay) limestone (effervesces slightly with dilute HCl).</td></tr>
<tr><td>Ask them to estimate its visible thickness (top and bottom are not seen</td><td>About 3 metres thick.
(Don’t climb the exposure.)</td></tr>
<tr><td>Are the beds horizontal?</td><td>No, they appear to be dipping towards the main quarry face to the right (SE)</td></tr>
<tr><td>Were the beds deposited at this angle?</td><td>No, originally they would have been deposited horizontal. (Principle Of Original Horizontality)</td></tr>
<tr><td>What forces can tilt large sections of rock in the earth’s crust?</td><td>Plate tectonic forces.</td></tr>
<tr><td colspan="2">The best place to get a good idea of the true dip is in the NW corner of the car park where apparent dips in the faces are to the left and to the right. In fact the true dip is directly out of the corner, towards the SE. (See the map on the worksheet). Ask the group to measure the dip of the sedimentary rocks (Use a clipboard as a proxy for the more uneven bedding plane. Remember the dip is measured in the direction of steepest gradient, i.e. the direction a drop of water would roll down the clipboard surface. In this situation hold the clipboard tightly against the lower bedding plane of a conveniently overhanging block. (See Figure 4)). The dip should be 10^0 to 15^0 in the direction of 130^0 to the north. Record it on the worksheet.</td></tr>
<tr><td>Ask the group to work out if this limestone is above or below the dolerite sill?</td><td>The angle of the dip carries it below the quarry floor, so it is below the dyke.</td></tr>
<tr><td>Can the contact of the limestone with the bottom of the dolerite be seen?</td><td>No it can’t, at least, not at this location, because of the vegetation. (And the fact that there are a few metres of sediments between the limestone and the base of the sill).</td></tr>
<tr><td colspan="2">☛ Tell the group there is a way to see the base of the sill. Ask the group to trace by eye the top of the limestone as they walk to site 1c. The contact is almost horizontal along the west face of the car park – and around the corner and along the drive (not through the trees) to site 1c.

Worksheet 2: Snableazes Quarry in section
As they walk out of the car park and round to site 1c pupils should complete the table on worksheet 2 using their observations and the Principle of Lateral Continuity to help them.
NOTE: Locations “v”, “x” and “z” form the crag at site 1c. Location “w” is the lateral continuation of layer “v”.</td></tr>
</table>



☛ Bring the group round towards the entrance driveway and stop by the face just east of the large hawthorn tree. (See **Figure 5**). This is **Site 1c.**

The lower part of the exposure is of 3 metres of grey muddy limestone with 6 metres of baked and altered sediments lying on top.

The lower 1 metre or so of dolerite sill is visible right at the top. However, only the lowest beds are directly observable from the ground.

Figure 5. Site 1c: The Western Exposure at Snableazes Quarry.

Worksheet 2: Snableazes Quarry In Section

☛ On arrival at site **1c** group Leaders may want to explore some aspects of quarrying with the group. Using the map on **worksheet 1** and section on **worksheet 2**.

Suitable questions at this site	Acceptable answers
Ask the group to describe the material accumulated at the base of the crag. How has it got there?	It is loose material forming scree. It has weathered and fallen from the face above (and will therefore contain samples of material out of reach from the ground.).
Tarmac finished quarrying here in 1987. How many years has it taken this scree to form?	About 20 years.
Why is there a quarry here? What was worth quarrying?	Road stone (whinstone) quarried for its physical and chemical resistance for road stone. It also bonds well with bitumen hence its use in Tarmac surfaces. [The other rocks in this quarry fracture easily]
Using a thickness of 20 metres, estimate the area of the main quarry (use round numbers) and then calculate the volume of dolerite quarried from here.	Volume = w **x** l **x** thickness V = 40m **x** 100 m **x** 20m = 80,000 cubic m.
Using a **very approximate** market figure of £2 per cubic metre, ask the group to calculate the value of the quarried road stone, over the lifetime of the quarry	80,000 **x** 2 = £160,000 total value
Ask the group to consider the cost – benefit aspects of this quarrying operation. On one side is the noise, dust, large hole in the ground, disturbance to wildlife, and heavy traffic on the roads. On the other side are jobs in a largely rural area, raw materials for construction, and the wider contribution of better transport to the economy, both locally and nationally.	
Ask the group to identify the factors which would increase the costs of this roadstone to a buyer.	Distance to transport the stone; anything that would increase the costs of extraction.
Then ask for possible geological reasons why this quarry was not extended further eastwards? (HINT: Look at the section on the worksheet)	The overlying (and useless) baked shales get thicker and therefore more expensive to move if the quarrying went further eastwards.

Site 1c: Overview Of West Crag.

☛ Assemble the group on the drive where they can see the whole crag. (as in **Figure 5**). Larger groups may be split and one small group conduct this exercise and the following one in reverse order.

Worksheet 3 Snableazes Quarry, West Crag.

Suitable questions at this site	Acceptable answers
Ask the group to describe the material accumulated at the base of the crag. How has it got there?	It is loose material forming scree. It has weathered and fallen from the face above (and will therefore contain samples of material out of reach from the ground.).
Ask the group to describe the lowest rock exposed at the base of the exposure.	Grey. It has bedding running across the face and some jointing. It is likely to be sedimentary. (It may be predicted that it is the same limestone as the one traced round from the car park)
Ask the group to describe what they can of the higher beds in the middle part of the crag.	Brown stained (chemical weathering), with traces of bedding running through it. Jointed and breaking into small blocks. Again, likely to be sedimentary. (In fact they are fine sandstones and shales, baked by the sill and also weathered)
Ask the group to describe what they can "see" of the rock right at the top of the crag.	It is brown coloured (iron weathering) and jointed into blocks. Bedding is not obvious
Ask the group to use the **Principle of Lateral Continuity of Beds** and predict what the top layer might be. HINT: Use the section on **worksheet 2**.	Projection from the section of the worksheet suggests it is the base of the sill. Other observations do not contradict this: it has a contact parallel with the bedding in the sedimentary rock below; it has strong jointing and no sign of bedding.
Ask the group if this is the top contact of the sill or the bottom one?	Clearly it's the bottom contact. (Use the sketch section on **worksheet 2** to demonstrate the relationship to the top of sill seen at **site 1a**.)
Ask the group why the full thickness of the dolerite sill is no longer present here?	It has been quarried away for roadstone.
Ask the group to predict what rock types might be found on the scree slope?	Dolerite, baked shales and fine sandstones, and maybe limestone are the ones possible.
Ask the group to examine the material on the scree slope to see what it is made of. **SAFETY NOTE**: When breaking clean surfaces of rock fragments, teachers should wear goggles and use only a special geological hammer. Hammer pieces away from other members of the group.	It is made of a fine sandy soil, plus examples of baked sedimentary rocks, often showing "spots" of newly formed metamorphic minerals. (The joints in the baked shales allow it to be easily weathered. Dolerite and limestone pieces are quite rare).
Ask how this material got here?	Physical and biological weathering of lumps of rock from the vegetated face above, but also chemical weathering to produce the clays.

Site 1c: Inspecting the face.

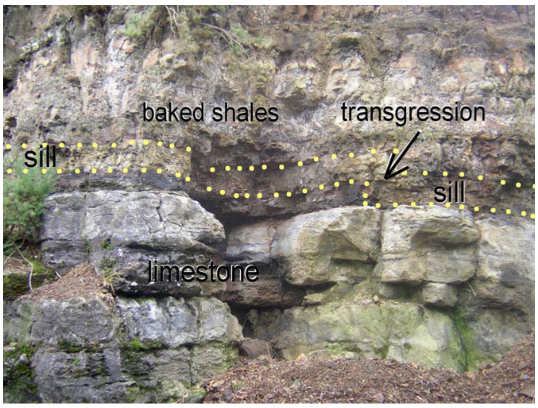


Figure 6. The centre lower face at Site 1c.

☛ The space on the scree is limited and individuals should take care not to lose their footing, or cause anyone else to do so. Here the task is to describe and interpret a small transgressive sill just above the limestone. It is an offshoot of the main sill, and is weathered to a yellowy colour. It has not been folded.

Apart from the field sketch on **worksheet 3**, the rest of the worksheet should, for safety reasons, be completed on the flat area by the drive, not on the scree. Divide the small group into two and approach the crag face, one group to the left and the other to the right of the group leader. (Keep the number of pupils on the scree at any one time to a manageable 6 or so).

Worksheet 3. Snableazes Quarry, West Crag.

Suitable questions at this site	Acceptable answers
Ask the group to describe and identify the lowest bed (If this is a group which has already done the overview, ask "What test will confirm it's a limestone? Answer: effervescence with dilute HCl. Group Leaders should take the usual precautions when using acid))	It is grey, fine grained, with joints and clear bedding planes running across the face. It is therefore sedimentary. It effervesces with dilute HCl. (but not a great deal due to clay impurities) It is therefore a limestone.
Ask the group what would have happened to this rock if the heat from the intrusion had been greater?	It would have been metamorphosed into a marble. (In fact, in places, some slight re-crystallisation can be seen).
Ask what rock is immediately above the limestone?	The group on the left will report a 17cm layer of hard red and black fine grained rock. This is a baked (metamorphosed) shale. The one on the right will report a 20cm "layer" of yellowy rock with joints. (This is a thin leaf of the dolerite sill, about 6m below the main mass.)
Ask the groups to trace "their layer" into the centre of the face and describe what happens.	The red and black shale suddenly stops, whilst the yellowy (dolerite) suddenly steps up over the shale and continues to the left above the shale. This is called transgressive behaviour. (See **Figure 6)**. It has not been folded.
Ask the group to explain their observations, using geological principles. [Or "How can a "bed " be at two different positions (i.e. older and younger than the shale) at the same time?"] [The suggestion of a liquid intrusive sill, emplaced along lines of weakness, crossing from one bed to another whilst the beds were deep underground should be suggested to the group, if it is not forthcoming.]	Focus on hypotheses which refer to geological principles. One layer (yellow) clearly **cuts across** another (shale) and therefore must be later in origin**. (Principle Of Cross Cutting Relationships).** This suggests the "yellowy bed" is later and has displaced part of the shale bed upwards during intrusion.
Find a small piece of the dolerite and inspect a broken surface. (There are many loose pieces. There is no need to damage the face). Ask why the inside is a dark blue colour whilst the outside is yellowy.	Chemical weathering of the minerals in the exposed surface of the rock. **SAFETY NOTE:** Only use a special geological hammer when trimming rock fragments, and wear goggles. Always hammer away from the rest of the group.
Ask the groups if the crystal size of this dolerite would be smaller or larger than the crystals in the large sill they saw at **site 1a?**	Smaller, because being a thin sill (with larger surface area to volume) it would have cooled more quickly.
Draw the attention to the baked sediments and the difference between them and the un-altered specimens of sandstone and shale they have seen in the laboratory, prior to the visit (which showed grains cemented together). Here the "greasy" look, slightly reminiscent of porcelain is indicative of baking of clay minerals, and is caused by heat leaking from the intrusion as it cooled. Also notice the dark "spots" in freshly broken pieces of the baked sediments. These are the crystals which began to form under the new conditions imposed on the minerals by the heat of intrusion (metamorphism).	

☛ Bring the group together on the flat area by the drive and summarise the events they have been investigating as a geological history. Use the section on **worksheet 2** to help the group orientate themselves in three dimensions, and use the rock cycle to help them sort out the sequence of events in time (the fourth dimension):

1. Deposition (oldest bed first), **2. Deformation** (including intrusions), **3. Uplift, weathering & erosion.**

Suitable questions at this site	Acceptable answers
Ask the group to summarise the geological events that they have seen evidence for at Snableazes. Geological convention is oldest event is listed at the bottom (1), to youngest at the top (5).	5. quarrying for roadstone. 4. **uplift weathering** and **erosion** 3. **intrusion** of dolerite sill, (both large and small) baking the rocks top and bottom 2. **deposition** of fine sandstones & shales in delta conditions 1. **deposition** of limestone in marine conditions (oldest bed).

☛ Group leaders who are linking this ESO-S visit with the sites at Boulmer may want to complete the visit here by linking the sedimentary rocks seen at this exposure, back to the rocks seen on the beach at Boulmer, using the model of repeated delta build-up. See **Figure 7** and also **SNA4 Briefing**.

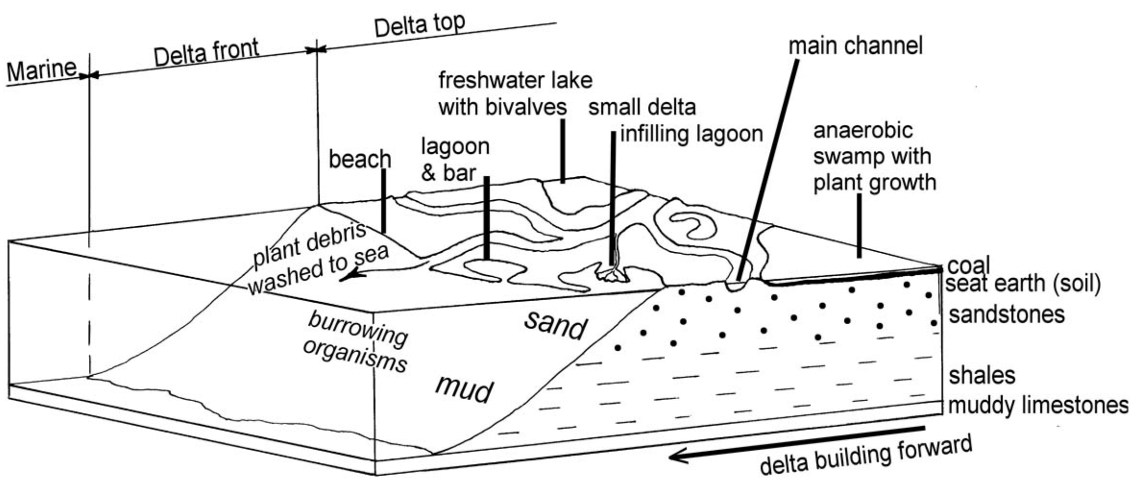


Figure 7. Delta and marine deposits.

☛The sandier Boulmer deposits were formed closer to the delta top than the (now baked) shales at Snableazes – but not in the same cycle (See **SNA4 briefing** for more details). The Shilbottle coal (below the Acre limestone at Snableazes) represents a previous delta top deposit, again, from a different, and older, cycle.

Worksheet 4 The rock succession at Snableazes Quarry

Suitable questions at this site	Acceptable answers
Ask the group to think back to the sedimentary rocks at the north foreshore at Boulmer and compare them with these. What is different about these beds here?	There is a thick limestone here, and there are no thick beds of sandstone, but, instead, many more finer grained beds of shale sandstone.
Ask the group what kind of place the impure limestone at the base of the crag, was formed?	A marine area (where a lot of mud was being washed in as well).
If the other beds are finer grained, what does this tell us about the energy of the currents when they were deposited, compared with the north foreshore at Boulmer?	The currents must have been slower and weaker to deposit these shales. [The beds at Snableazes were formed offshore from a delta, (as indicated by the limestone below) rather than near powerful river currents on the delta top, as at Boulmer. (See **Figure 7**

Since the beds are dipping roughly towards the SE in this area, are these beds older or younger than the beds at Boulmer?	At the surface beds become younger in the direction of dip. So these are older than those on the coast. (ie they are west of Boulmer).
Tell the group that by measuring sections of rock in various places (as they did at Boulmer) a (more or less) complete section for the whole area can be built up. (See the section on **worksheet 4**. Ask what rocks lay just below their feet?	The column on **worksheet 4** indicates sandstone and shale, with a coal seam below.
Ask where that coal seam would outcrop at the surface?	It would outcrop across the road, by Snableazes farm. (Remember, younger rocks outcrop in the direction of dip, older ones in the opposite direction).
Ask the group to recall how coal seams were formed.	In swampy conditions (on a delta top) where vegetation accumulates in mud, sealed away from oxygen. (i.e. a land area, just above sea level.)
What do these beds tell us about changes in sea level during this time (342 million years ago)?	Sea level must have risen in order to replace a land deposit with a marine deposit.
What might cause a rise in sea level compared with land level?	**Sea level might rise** due to: melting ice (at this time there was an icecap, but only at the south pole); **Land level might fall** due to: down-faulting of the crust (creating a sag, into which sediments become deposited.)
In either case, how might sea floor level rise to sea level or just above?	By the build up of sedimentary rocks filling up the sea area, e.g. by delta deposits. [Or by up-faulting, however, in this case it is delta sediment build up.]

Site 2: Directions To Cullernose Point

☛Leave the quarry at Snableazes and continue northwards to the crossroads. (Ratcheugh Crag, on the right is the same sill of dolerite, but is not easily seen due to vegetation). At the cross roads turn right to Longhoughton. At the crossroads at Longhoughton turn left onto the B1339 to Embleton. After 1.25 km, on a sharp left bend, take the right turn onto the minor road to Dunstan, which has a low bridge of 12 ft 6 inches across it. After 2km the road bends sharply left, and after a further 1km begins to diverge from the cliff top. The pathway to Cullernose Point is on the right where the emergency telephone is sited, and the lay by is on the left.

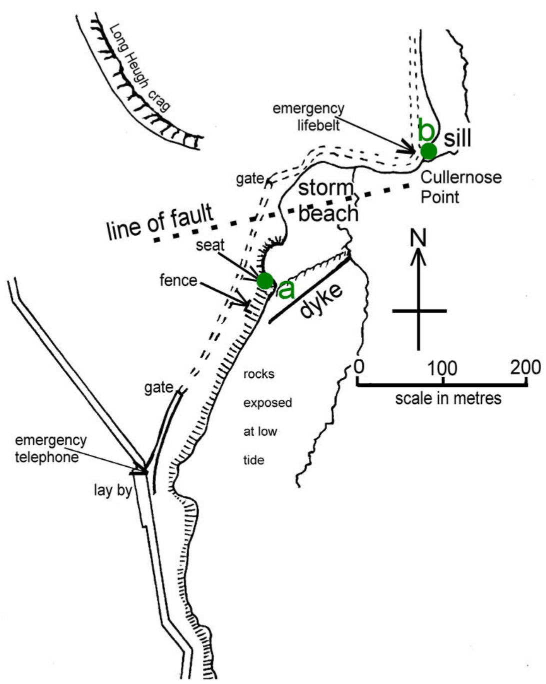


Figure 8: Sites 2a, b and c: Cullernose Point.

Roadside parking is possible here on the left, but coaches should drop off their party and return to pick up the group after an hour and a half. The descent to the beach is steep and often slippery. Stay on the cliff top. Take the footpath northwards along the top of the cliff.

The site is a nesting site for seabirds, so do not stray from the footpath and disturb them during the breeding season.

Take the footpath from the road northwards for about 300 metres, to the seat with a view of a small crag to the north. This is **site 6a**.

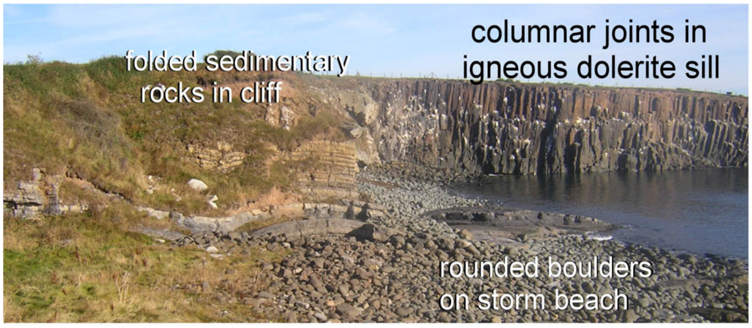


Figure 9. Cullernose Point from Site 2a.

☛ The small crag to the north of **site 2a** is of sedimentary rocks down faulted in front of the dolerite of Cullernose Point. The rocks on the foreshore to your right and behind are sedimentary with a dyke running through them, visible at lower water when looking back along the shore to the south.

Worksheet 5 View Of Cullernose Point.

Suitable questions at this site	**Acceptable answers**
What present day weathering and erosion processes are affecting the exposure **on the headland** in the distance?	Weathering – chemical weathering of iron minerals in it to hydoxides (brown) and physical weathering (using the joints) and biological weathering (bird guano, and vegetation growing into it). Marine erosion by wave action.
Ask for a description of the rocks in the headland.	Lack of bedding and strong vertical jointing. Dark coloured. Iron stained due to weathering.
What kind of rocks are they likely to be igneous, sedimentary or metamorphic?	Igneous. It is the dolerite, of which they have already seen so much.
Ask how the joints were formed in this igneous rock	As the liquid magma cooled it became solid (at about 600^0 - 800^0 C) As it continued to cool it contracted setting up stresses which caused brittle fracture in the solid rock.
Ask the group where the cooling surfaces would be to give those cooling joints?	Since the joints form at right angles to the cooling surfaces, they must have been almost horizontal, dipping slightly seawards. (i.e. approximately the same as the bedding planes)
What name should be given to this igneous feature.	It is a sill since it does not cut (significantly) across the bedding planes.
Why can't we see the top surface of the sill?	It has been eroded away.
Estimate the thickness of the sill (and therefore how much the rocks have been uplifted by the intrusion.)	Close to 20 metres.

☛ Then move the group's attention to the beach and nearer cliff face

Describe the beach material bellow the cliff, and explain how it got there	Well rounded and large boulders. They have been broken off from the outcrop and moved up the beach by powerful storm waves.
Ask why there is no sand on this beach?	The waves are too powerful. Any sand will be washed away.
Ask the group to describe the rocks in the cliff in front of them.	Layered and folded rocks in the lower two thirds. Brown crumbly material with large boulders on top.
What kind of rocks are they likely to be igneous, sedimentary or metamorphic?	Sedimentary (they are layered).
Point out the crumbly brown material with the large blocks above the bedded rocks. Is this material older or younger than the bedded rocks below?	Younger. **Principle of Superposition**.

How might this layer have been formed? Hints might include the "boulders" and "clay". i.e. deposited by a medium strong enough to carry the boulders, but not able to sort into sizes.	Glacial material only 12,000 years old from the end of the Ice Age, and about 340 million years younger than the Carboniferous beds below.
Direct attention to the beds below: ask the group which way the sedimentary rocks are dipping in the cliff in front of them.	Generally towards the sea, although they are also folded (and faulted).
What kinds of folds can be seen?	Anticlinal folds.
Of what kind of deformation are folds evidence?	Plastic deformation
Using the trend of the folds as a guide, suggest which way the compressive forces were directed when these beds were folded.	More or less east to west.
Between this cliff and the headland (i.e. underwater, and not visible on this visit) is a fault. For what kind of rock deformation is this evidence?	Brittle failure.

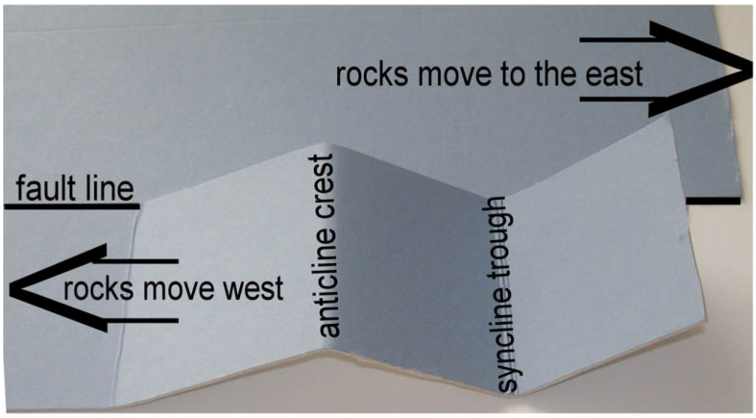


Figure 10. Model of faults and folds at Cullernose Point.

☛ There is strong suspicion that at least some faults in the area are transcurrent faults (i.e. with a horizontal displacement).

The folding here might be caused by strong sideways east – west displacement along the fault, causing the bedding to "ruck up" either side of the fault. The evidence from the outcrop is inconclusive in these respects, an important point about "available evidence" to introduce to pupils who might ask about these features.

In any case the N – S trend of the folds at Cullernose suggest plastic deformation as a result of an east-west compression.The intrusion of the sill is later than the faulting, and follows the layers on the north side of the fault, perhaps changing to a lower layer just offshore, accounting for the seaward slope of the dyke surface.

Figure 11. Site 2b.

☛Walk on along the Coastal Footpath and cross the line of the fault marked on **Figure 8**.

Tell the group that the fault plane has a sheet of dolerite intruded along it.

Continue along the path on to the top of the sill and on to the foreshore exposure of dolerite. This is **site 2b**. Do not get too close to the sea, especially if the waves are running high.

Worksheet 6: Cullernose Point. Dolerite and Columnar Joints.

Suitable questions at this site	Acceptable answers
Remind the group that igneous intrusions rise because they are less dense than the surrounding rock. Ask them to explain why the fault they have just crossed has a vertical sheet of dolerite along it?	The magma was following a line of weakness through the solid rocks. (And later spread out along a weak bedding plane to form the sill – and lift the rocks above by about 20 metres here at Cullernose!).
Does this indicate that the fault occurred before the intrusion, or afterwards?	It occurred before. **Principle of Cross Cutting Relationships.**
Ask the group if they are standing on the sedimentary rocks above the sill, or on the sill itself? (**NOTE**: They are not on the top of the sill itself – that has been eroded away here.)	They are standing on dark, un-bedded, fine grained igneous rock – i.e. on the sill
Ask the group what has happened to the hundreds of metres of rock that was once on top of the sill?	It has all been eroded away.
Ask the group how all of the cracks (joints) in the sill were formed?	The sill was intruded at a temperature close to 1000^0 C. as it cooled it crystallised and became solid, whilst still very hot. As it cooled further it contracted and the stresses caused brittle fracture – the cracks or joints.
Tell the group that cooling stresses theoretically produce regular joint patterns. Ask the group to describe the shapes marked out by these joints.	Polygonal: ideally hexagonal (6 sides), but here varies from 3 to at least 7 sides.
Ask the group to envisage what each joint block would look like in 3 dimensions?	A polygonal column at right angles to the cooling surfaces.
Select a column by placing a marker on it, and sketch the adjacent columns. Count the sides to each column. Measure the distance between the centres of each adjacent column.	The number of sides varies between 3 (triangular) and 7 (heptagonal) with the majority at 4 (rectangular). Although many are clearly cooling joints, some are quite possibly superimposed fractures caused by fracture during uplift and tilting.

Figure 12. Joints in the Sill.

Figure 13. Vesicles in Dolerite.

Suitable questions at this site	Acceptable answers
Find a broken surface of the dolerite and ask the group to describe it.	Made of fine to medium grained interlocking black crystals and having low porosity. No bedding, or fossils.
What does the crystal size tell you about the rate of cooling?	Medium to quite quick (probably many thousands of years, rather than the few days in a lava flow.)
Point out the small holes, sometimes filled with minerals, in the dolerite. Ask for hypotheses on how they may have formed. **NOTE**: Observe the usual safety precautions when hammering rock.	Hypotheses will fall into two groups: those suggesting the holes formed **during** the formation of the rock, and those suggesting they formed **afterwards** e.g. by boring organisms. The way to confirm they formed at the same time as the rock is to find one with no demonstrable connection to the outside by breaking it open. [**NOTE**: They are bubbles of gases left over when the magma crystallised, probably condensing to very watery solutions.
If there were volatile gaseous substances in the magma as it crystallised, what would happen to the bubbles?	They would be less dense than the magma and would tend to rise towards the top surface of the sill, **depending on the viscosity of the liquid magma**. (Here, however, there are vesicles throughout the sill).

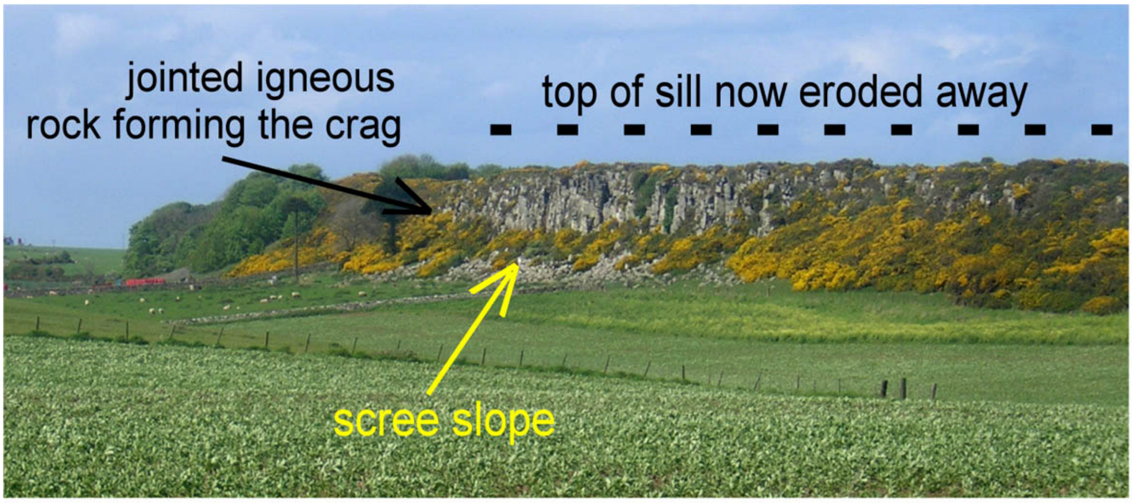


Figure 14. Site 6c: Long Heugh Crag.

☛Walk back along the cliff top and towards the road. About 100 metres past **site 2a** stop on the coastal path and look back towards the northern skyline.
(See **Figure 14**). This is **site 2c.**

Worksheet 6: View Of Long Heugh Crag.

Suitable questions at this site	**Acceptable answers**
Ask the group to look back at Cullernose Point and explain why there is a headland at this point on the coast	The dolerite is more resistant to the erosion by waves than the sedimentary rocks carved out to form the bay.
Ask the group to look at Cullernose Point and then ask “Can you work out to where this sill extends inland”?	To Long Heugh Crag to the west. (and probably some way out under the sea)
Why is there a (Long Heugh) crag at this location to the west?	It is made of more resistant rock, with the less resistant rock in front having been eroded away (mainly by glaciers during the last ice age).
What has formed at the base of the crag to the west?	A scree slope.
What factors have encouraged the formation of this scree	The rock is well jointed allowing physical weathering processes to beak pieces off. These processes include ancient (peri-glacial conditions **after** the ice age) and modern freeze thaw, as well as the effect of roots (biological weathering).
Why isn’t there a scree slope in front of Cullernose Point?	It has been washed away by the waves into the storm beach of rounded boulders.
What differences in vegetation can be seen on the crag, compared with the fields?	More bushes and gorse bushes along the crag
Why this difference?	The farmer hasn’t needed to clear the bushes, but the gorse is growing on the acid soil weathered from the dolerite, rather than the soil from the limestones and shale under the fields.

☛ Finally ask the group to summarise the sequence of geological events they have seen evidence for today, using **worksheet 8.**

The final **worksheet 9** could be used as a follow-up homework exercise.

Return along the coastal footpath route to meet your transport on the road.

☛ The ESO-S materials for the sites at Boulmer Foreshore may be combined with this visit into an extended field experience, including modern sedimentary processes.