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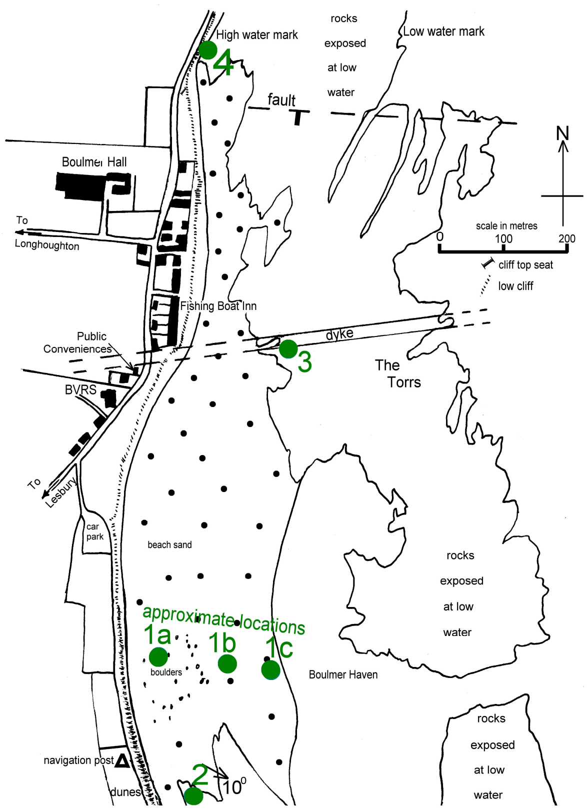
INTRODUCTION

☛ Field groups should time their arrival at Boulmer an hour or two before maximum **low** tide.
Individual groups will need 10x hand lenses, measuring tapes, grain size comparator cards, 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 **BOU12 worksheets**). Completed versions of the worksheets can be found in **BOU13**)
Group Leaders will need a 50M measuring tape, plastic bottle of dilute HCl, a small plastic bottle of water, goggles and a geological hammer. A trowel, a soft brush for sweeping sand from bedding planes, a roll of sticky parcel tape 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.

1a, b, and **c.** Boulmer Haven Beach & Dune Deposits (a study of modern deposits).
2. South Foreshore Wave Cut Platform (a study of an ancient deposit).
3. The Torrs Foreshore (description and measurement of a dyke in sedimentary rocks).
4. North Foreshore Wave Cut Platform (more detailed study of a sedimentary environment.)
5. Summary Of Geological Events.

NOTE: The beach is still active and the depth of sand and level of erosion can vary considerably. It is advisable to make a reconnaissance visit shortly before the field trip to confirm what is visible. 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 pupil small group activity.



NOTE: **The entire beach north of the boulders** is a protected area, and the sand should not be disturbed. For details see the sign at the car park**.**

☛ From the car park at Boulmer walk onto the beach and turn south (right) away from the protected part of the beach.
After 200 metres, just north of the red and white Navigation Post, stop at the boulder field scattered across the beach.

Site 1a: Boulmer Haven Beach Boulders.

NOTE: The exact location of the first 3 sites can vary with the state of the beach. Match the site descriptions here with the beach you have on the day.

This exercise summarises the features of the three main rock types. Remind the group of the main characteristics of igneous, metamorphic and sedimentary rocks and ask them to look carefully at the blocks and see if they can find an example of each type. Also ask the group to measure the diameter of the largest boulder they can see.

☛ After a suitable period (10 minutes or so) bring the group together and summarise their observations.

Worksheet 1: Investigating Beach Sediments.

Suitable questions at this site	**Acceptable responses.**
How are boulders formed?	Physically weathered from an outcrop of rock, along joint (or bedding) surfaces.
The largest boulder is something over half a metre in diameter, i.e. very large. How might it have been moved here?	Either extremely powerful storm waves at some time in the past, or, possibly, by ice during the Ice Age, about 12,000 years ago.
What rock types did you find and how did you recognise them?	**Igneous:** made of interlocking fine – medium crystals. No banding, bedding or fossils. (black dolerite.). **Sedimentary**: Either sandstones, made of grains cemented together **or** grey limestones which effervesce with dilute HCl, with calcite fossils (probably corals & crinoids). There are probably no **metamorphic** examples on this beach as local Northumbrian ice kept the Norwegian ice (and its metamorphic rocks) further east, and there are no local metamorphic outcrops.
Can you recall what the main elements are which make up the lithosphere (rocky crust)?	Si, O and Al (Silica:Si O_2 makes up 59% of the crust and Alumina: Al_2O_3 makes up 15% of the crust.) Essentially we live on a planet with a glass crust (plus 40% of "impurities").
What is the main chemical composition of the sandstone boulders?	SiO_2 (Mineral name Quartz)
What is the main chemical composition of the limestone boulders (assume they are "pure")	$CaCO_3$ (Mineral name Calcite)
What major element of the crust is "missing" from these rocks?	Aluminium.
Why doesn't the composition of these rocks reflect the composition of the crust? NOTE: Dolerite comes from partial melting of the upper mantle, and is made of feldspar (aluminium silicates) and pyroxene (Iron and magnesium silicates). This is the starting material for the rock cycle. All other rocks are recycled (except for the odd piece of meteorite), and in the process become separated into the common rock constituents.	Sedimentary processes can produce beds showing chemical separations. **First** by way of sorting by density and particle size. Hence sandstones are higher in Si and O, whilst clays and shales are high in Si, Al and O. **Second** by chemical (or organic) precipitation from seawater, when elements in solution (e.g. Ca, Na, etc) can become concentrated in the rocks as limestones or evaporites. **Third**, anaerobic decay of organic matter can produce concentrations of (hydro) carbon, or coal and oil.

Site 1b: Boulmer Beach Sands.

☛Tell the group that they are going to concentrate first on the present day rock cycle and its physical, chemical and biological aspects. Remind them that the geological significance of this is the **Principle of Uniformitarianism**, i.e. that chemical, physical and biological processes have operated in the past as they do today. This allows us to use our observations about modern processes to interpret the evidence in rocks for events from millions of years ago.

Figure 2. Ripples and Burrows in Sand.

☛ Move the group to the down-beach side of the boulder field, and on the way choose a suitable place which shows rippling and burrowing of the beach sand. This is **Site 1b**. See **Figure 2.** Ask the group to observe the finer beach material and think about the processes affecting it.

Suitable questions at this site	**Acceptable responses.**
What is the finer beach material made of? Use a strip of parcel sticky tape to take a sample of dry sand grains for observation with a hand lens. What is it made of? How large are the fragments?	Mainly sub angular, colourless sand (SiO_2 quartz) grains, coloured rock fragments and shells about 0.5mm in size, but also, depending on the season, seaweed etc. (N.B. Save the used tape to make comparisons between the sites later).
What **chemical** and **biological** processes can you see evidence for in this beach sand? NOTE: This far south on the beach it is permissible to excavate shallow pits to see what is below the surface.	**Chemical**: decay (of soft parts), smells, brown colour conferred to sand by weathered iron minerals etc. Perhaps crystallisation of salt crystals. Chemical weathering of calcite shells **Biological:** shells, chitinous skeletons of crabs etc. Seaweed, human footprints - and burrows (e.g. lugworms, bivalves.) etc. Note the passing through the digestive tract of worms has a chemical effect on the sediment – by removing nutrients.
What **physical** forces are affecting the sand here? NOTE: Wave energy is derived from winds at sea. It is transmitted great distances through seawater, whilst the water itself moves only in circles. When it breaks onto the beach it is converted into kinetic energy.	**Water waves** and **flows**. NOTE: tidal effects of sun and moon moving wave action up and down the beach. **Wind** action. **Biological** action (humans and burrowing organisms). And **gravity**.
What evidence can you see for the effects of these forces?	Sand grains may actually be moving. Ripple marks. Burrows. And the fact that it is because of gravity that the sand lays on the beach at all.
Material on the beach could have come from below the tide line, above the beach, or along the beach. Where have the different beach materials you can see, come from?	Shells and seaweed are clearly from **below the tide line.** The sand may well have been brought southwards by long-shore drift – i.e. **along the beach**. There may also be material from **above the beach** e.g. litter, building stone etc.
How long have the individual sand grains been in this position?	Since the last tide
How long will they stay like this?	Till the next tide (about 12 hours)
If, on average, a sand grain moves 10m up and 10m down the beach with each tide (assume 2 per day) How far will it travel in a year (assume 300 days). And how far in 10, 000 years (approximately the end of the last Ice Age). [Calculators or a stick in the sand are both permissible.]	20 x 2 x 300 = 12,000 metres per year – or an estimated 12 kilometres. 12 x 10,000 = 120, 000 kilometres (estimated).
What effect would all this movement have on the beach material?	Grains and pebbles would become mechanically broken down. Shells (pebbles and human artefacts) would become broken and smoothed by abrasion with the sand. **NOTE:** sand grains in water do not become well rounded as pebbles do. Well rounded sand grains indicate arid windy conditions.

What would need to happen to this loose sediment in order to turn it into a "solid" rock. (It would probably still have pore spaces in it when cemented, i.e. not fully solid).	The pore spaces between the grains would need to become filled with mineral "cement" (i.e. not Portland - type cement!).
What factors would determine how much mineral cement would be needed to fill the pore spaces?	Grain sorting (smaller grains fit between larger ones, reducing the space) grain shape (angular ones fit closer together, reducing the space). **NOTE:** Grain size on its own does not to affect porosity in well sorted sediments.
What kind of rock would it then be? (NOTE: **Principle Of Uniformitarianism**)	A sedimentary sandstone – with burrows, ripples, fossils etc.

Site 1b continued: Ripples and Burrows.

Draw the pupils' attention to the surface, point out they are walking on the top of a possible future sedimentary rock. Point out that the **Principle Of Uniformitarianism** states that present day processes are the same ones that operated in the past e.g. organisms have been burrowing in beach sand across the world for hundreds of millions of years. This means that ancient features in rocks can be interpreted by understanding present day ones. Focus the group on the ripples and burrows as evidence for activity in the (very recent) past.

Suitable questions at this site	**Acceptable responses.**
What name should we give to this top surface? What name should we give to the "rock" below?	A bedding plane. With a bed of sandstone underneath it. NOTE: Un-cemented sediments are regarded as "rock"
What are the ridges on the top surface of this layer of sand we call a beach?	Ripple marks.
How were they formed?	Wave action (oscillations) during the last tidal cycle.
In what other kind of place can you see ripples in sand?	In flowing water (a river, or a flow across a beach). Also in deserts formed by wind action.
Tell the group that wave ripples are more symmetrical (both side equally steep) whilst running water ripples are more asymmetrical (down-flow side steeper). Ask if these are symmetrical or not?	After very close inspection the conclusion is likely be symmetrical i.e. wave ripples. [NOTE: The flat top to the ripples is caused by the shallowing water as the tide retreats.]
Ask the group to infer the angle between the line of the ripples and the approach of the wave fronts which probably formed them.	The ripples are roughly parallel to the wave fronts. (Unless there is an obstruction close by, causing refraction).
Ask the group what caused the mounds of sand?	Burrowing organisms. There are lugworms and bivalves burrowing in the sand and digesting food filtered from the water or ingested from the sediment.
Dig a small hole in the sand and ask for observations about the sediment. **NOTE:** No digging is permitted on the beach <u>north</u> of the entrance to Boulmer Haven.	You should be able to see burrows, possibly "U" shaped, and black mud which indicates that the oxygen in the sediment has been taken up by chemical reactions (decay and oxidising reduced elements). Point out that at low water mud is allowed to settle out into the sand – i.e. sedimentary rocks are seldom "pure" sandstones etc.
Ask the group what sequence of events might have caused the beach (bedding plane) to look like **figure 2**	1. Tide advances moving sand up & down the beach; 2. Wave action causes sand to ripple.; 3. Tide retreats until the next tide. (Shallowing water flattening the tops of ripples); 4. Organisms living in the sand burrowing up to feed.
Point out they have just used the evidence of their observations to construct a sequence of events. Ask then what happened to the evidence of the tide **before** last?	It was washed away and then re-deposited. Like most geological evidence only fragments of the story become preserved in rocks.

Site 1c: A Boulmer Beach Channel.

Figure 3. Asymmetrical ripples in a beach channel.

☛ Move the group to a point below the boulder field where water from the last high tide is draining out over the sand forming a beach channel. This is **Site 1c**.

NOTE: The precise behaviour of the sand will depend on the velocity of the flow. At low tide most of the water will already have drained from the beach. At higher speeds the grains will move rapidly over a flat surface, at lower velocities ripples will form and migrate downstream.

Suitable questions at this site	Acceptable responses.
Pour some water onto the sand **adjacent** to the channel and let the group see it percolate into the beach. Ask what has happened to the water?	Gravity has drawn the water through the empty pore spaces between the sand grains.
Ask the group why the water is flowing in the channel, but not a metre or so away on the "dry" beach?	Below the channel the pore spaces are filled with water (i.e. below the water table) so the water has nowhere to drain to – except across the surface.
Ask the group to imagine what would happen to the sand if the salts in the water were to precipitate inside the sediment pore spaces?	The precipitation would begin to cement the sand into a solid rock.
Ask the group to observe the bottom of the channel and ask if they can see anything **moving** with the flow? [Remind them of the demonstration they saw in the laboratory]	Depending on water velocity there should be grains of sand rolling along the bottom (traction load). At higher velocity this may occur so fast that the whole ripple can be seen moving downstream, with the steep face being repeatedly buried.
Ask them to observe the floor of the flow and ask is it flat, or is it rippled? Are the ripples symmetrical or asymmetrical (one steep and one gently sloping side)?	It is rippled: asymmetrical ripples. **Note:** The downstream side of the asymmetrical ripples is the steep side. Remind the group that these steep faces become buried to form cross bedding, whilst the beach surface is a true bedding plane.
Ask them to observe closely how the sand grains move through the ripples. **NOTE:** At much higher velocities the surface is washed flat. Move down-channel to find a slower reach of water where ripples are migrating.	If the velocity is high enough, the grains roll up the upstream (gently sloping) side and fall onto the steep (downstream) side where they come to rest. In this way the ripple migrates downstream, burying the previous front faces (and in fossil examples, forming cross bedding).
Use a ruler to estimate the size of the ripples (from trough to crest) and from crest to crest. (Actual measurement is difficult under water!).	About 1 cm. in wave height. About 15 cm or so in wave length.
What scientific investigations might be made into beach sediments?	A large area for investigation would be variation in sediment characteristics up the beach, and the causes of them: **Primary data collection** of variables like sorting, rounding of grains, porosity, composition (silica sand versus other fragments). Current velocities. Ripple studies. Rates of erosion etc. **Secondary sources** could include tide & winds records, newspaper reports, old photographs etc.

☛ Summarise for the group the geological significance of the first three sites: that even a single layer of sandstone can vary greatly from place to place because of the different combinations of physical, chemical and biological processes causing it to be deposited. And that present day processes help us to understand ancient sedimentary rocks.

Site 2: The Southern Wave Cut Platform.

☛ Move the group to the nearest outcrop of rock closest to the dunes. (See **Figure 4**.) This is **site 2**, part of the rock platform, cut by wave action, upon which the beach sands are deposited. These rocks were formed 342 million years ago in the Carboniferous period. The nearly flat surface is close to the original bedding i.e. the rocks are close to the horizontal. The steeply dipping surfaces are cross beds – i.e. the buried and fossilised front faces of asymmetrical ripples. As such they are evidence of events from the remote past – right next to beach deposits which formed in the last few hours.

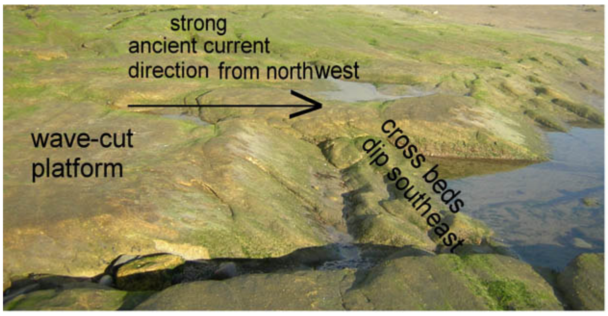


Figure 4. Site 2.

NOTE: The weed covered rock can be very slippery. Caution the group to take care.

Worksheet 2: The Southern Wave-Cut Platform.

Suitable questions at this site	**Acceptable responses.**
Ask the group what has eroded the rock to an almost level surface?	Wave action has cut a wave cut platform.
Ask the group why, given all of 4,500 million years since the crust was formed, the sea hasn't eroded all of the continents almost to sea level?	It would have done, except plate tectonic action keeps elevating parts of the crust into mountain ranges to be eroded down again.
Ask the group to stand with one foot on the rock and the other on the beach. Ask them how far apart are their feet?	Answer: 342 million years: the time gap between the two different sediments.
Look closely at the rock. What features can you see in it?	It is made of medium size sand grains cemented together. There are bedding and cross bedding surfaces.
Is it igneous, metamorphic or sedimentary?	Rocks made up of cemented fragments are Sedimentary rocks. This is a sandstone.
What colour is the surface of the rock? What colour is the broken (inside) of the rock	The outside is yellow whilst the interior is grey sandstone. (Towards the low tide mark it becomes red).
Explain why there is a colour difference.	It is due to the weathering of the rock. The iron is oxidised to yellow and brown hydroxides of iron (rust!)
Can you find any fossils? Hypothesise why might fossils not be present in this rock?	(Almost certainly not): they may not have been able to live in the conditions the rock was deposited in, OR they may have lived here but not been preserved here.
The steeply dipping surfaces are cross beds. What are cross beds evidence for?	The formation of asymmetrical ripples and the direction of the flowing current.
Measure the direction in which the cross beds are dipping. What direction was the current flowing to and form?	The cross beds dip towards the SE, between 140^{o} north and165^{o} north. This suggests a flowing current from the NW.
Judging from the size of the asymmetrical ripples you have seen on the beach, how big would you suggest these ripples would have been? What might that suggest about the strength of the current that formed them?	They are much bigger. Possibly up 40 centimetres in height in places. This suggests that 342 million years ago much stronger currents flowed from the NW. [NB recall the 1cm. high ripples on recent beach sediments and **Principle Of Uniformitarianism**)

Ask the group what they think lies below the sand and dunes to the west?	Rock: the lateral extension of the outcrop (wave cut platform) you have been studying.
Point out to the group that this wave cut platform represents a long period of erosion, followed by much more recent deposition of beach sand on top of the eroded ends of the older beds. Ask how many rock cycles are therefore represented here? [These erosion surfaces are called **unconformities].**	Two: the first ancient one with deposition, tilting uplift and erosion of rocks, and the second modern one with weathering, transport and deposition of loose beach sediment. (In places these beach sediments are already cemented by calcite deposits).
Ask the group to reconstruct the rock cycle story for this exposure. This time the first events should be at the bottom of the list. NB. The rock cycle has the following sequence of events: weathering; transport; deposition & burial; deformation . (e.g. faulting, but not at site 2.); uplift and weathering. **[NOTE:** The age of 342 million years is derived from evidence elsewhere. Here only a relative age (older to younger) can be established]	**3. Uplift and weathering:** The rocks are now tilted and uplifted above sea level and are being chemically weathered (iron hydroxides) and eroded by the sea. The sand grains go to form part of the present day beach. **2. Deposition:** 342 million years ago the sand was deposited in large asymmetrical ripples by powerful water currents. (No evidence of any organisms living in it) and then buried by later rocks. **1. Weathering:** Rocks older than 342 million years were being eroded to form sand grains. They were transported by flowing water currents towards the SE (i.e. here.)

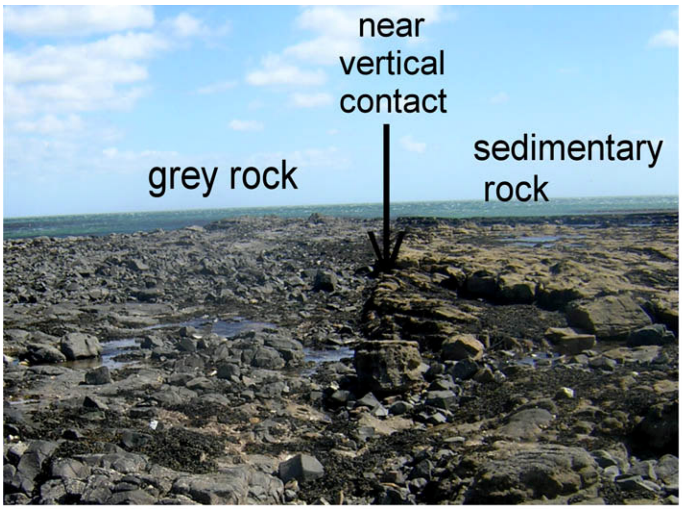


Figure 5. Site 3, The Torrs Dyke / Sedimentary Rock Contact.

☛Continue north up the beach to a point where the rocks change to a uniform dark grey appearance. (See **Figure 1)**

[**NOTE:** The perceived colour of rocks can vary with wetness, degree of weathering and angle of incident light.]

Bring the group to the contact between the two types of rock, with the grey rock to the north. This is **Site 3**, the southern edge of the Boulmer dyke.
Remind the group that when walking on wet and weed encrusted rocks to take care not to slip and fall. Walk seawards for a few metres until the contact can clearly be seen. (See **Figure 5**).

☛ First, direct the group's attention to the rocks to the south. These are sandstones (sedimentary rocks).

Worksheet 3: The Rocks on "The Torrs".

Suitable questions at this site	**Acceptable responses.**
Ask the group why there is no sand on the rocks to the east	The waves have been strong enough to wash the sand further up the beach.
What effect will the waves be having on the rocks here?	Erosion. Breaking pieces off – especially when the waves are larger and have more force.
What has happened to the surface of these rocks?	They have become overgrown by weed and barnacles.
To what kind of weathering will this contribute?	Biological.
What kind of rocks are the ones to the south: igneous, sedimentary or metamorphic?	The rocks show clear beds and bedding planes: this in itself is enough to identify sedimentary rocks. Broken pieces also show grains cemented together. [In fact they are sandstones, deposited about 342 million years ago.]
The beds dip more or less south eastwards, which way would they have to walk in order to walk from younger to older sedimentary rocks?	North westwards. Sedimentary rocks (that have not been turned right over) become younger in the same direction of dip and older in the reverse direction. **Principle Of Superposition**: younger rocks lie on top of older rocks.
Measure the amount of dip of the bedding planes and write it on the map next to the dip arrow.	Around 10^0, depending on exactly where it was taken. NOTE: Use a clipboard to even out the surface for measurement, and measure the steepest angle by first finding the horizontal, and then measuring the dip at right angles to this direction.]

☛ Then direct the group's attention to the dark grey rocks to the north.

Suitable questions at this site	**Acceptable responses.**
What change can they see in the rocks on the wave-cut platform as they look from south to north?	The dipping bedded rocks give way to a grey rock which is well jointed and is broken into many cobble sized pieces.
Which way do the joints run in the grey rock?	They run along the exposure on the beach - north to south
What does the fact that there are cobbles but no sand here tell you about the strength of the waves?	Strong enough to wash the sand up the beach, but not the larger cobbles.
Look at the rounding of the cobbles. How would you describe them? Why are they not well rounded?	Sub rounded. They have not travelled far enough from the outcrop to become well rounded.
What kind of rock is the dark grey rock: igneous, sedimentary or metamorphic? Ask them to pick up pieces and inspect them. They may well recognise them as the same material as found at **site 1a.** Site 3 may well be their origin.	It is made of fine to medium interlocking crystals. Grey in colour. It has no fossils, no bedding, no pore spaces, and is well jointed, especially close to the contact with the sedimentary rocks. On a broken surface the rock can be seen to be made up of interlocking crystals. This is an igneous rock. The dark colour suggests a basaltic (i.e. silica poor, iron and magnesium rich) magma. It is dolerite.
Looking at the contact between the two rocks, can the group suggest which rock type is more resistant to wave erosion here, the grey rock or the bedded rocks? NOTE: Dolerite is intruded at temperatures close to 1000^0 C	The surface of the grey rock is several centimetres lower than the contact with the sediments. The sediments are therefore more resistant, possibly due to baking (metamorphism) by the igneous rock, and because the bedding is dipping towards the sea dissipating wave energy over the sedimentary rocks).

Ask the group to inspect the contact between the two different rock types. Is the contact parallel with the bedding, or does it cut across? **[NOTE:** Pupils may be aware of the name **Whin stone** which is an old term for any particularly resistant rock, and has been applied to the many dolerite intrusions in the area for decades. Not all of them are sills].	The beds dip ESE, but this grey rock has a near vertical contact with the sediments and cuts across them. **Figure 6.** 
What angle to the horizontal is the contact dipping into the ground?	It is vertical - 90°
If this is an igneous rock which cuts across the bedding, what type of intrusion is it likely to be?	It is likely to be a dyke. (Batholiths also cut across bedding, but they tend to be coarse grained igneous rocks: i.e. larger and cooled more slowly.)
Ask the group to search for the opposite contact to the north. Take a tape measure and measure the width in metres. Pupils should draw in the dyke on the section. (Use the baked contact to draw in the southern vertical edge, and the scale to locate the northern vertical edge of the dyke.)	It is almost exactly 30 metres wide, with roughly parallel sides. Depending on where the measurement is taken, 30.10m to 30.50 m. **Take care**, and walk only on weed-free rock!
Ask the group how far, horizontally, the earth's crust on the north side must have moved, or pushed, relative to the south side to let this dyke be emplaced?	Almost exactly 30 metres to the north (or the south side southwards).
Is this evidence for crustal compression or crustal tension?	Tension, resulting in brittle fracture.
What kind of forces are capable of stretching the crust?	Plate tectonics forces (however, this event was **not** part of a crustal rifting episode to form a new ocean.)
How was this large mass of molten magma able to rise up through the crust?	The hot magma was less dense than the crust, and flowed up through pre-existing fractures in the rock (and then out sideways along bedding planes to form sills). [Remind them of the volcano demonstration in the laboratory].
Ask the group to look around and see where the dyke may extend sideways. **(Principle of Lateral Continuity)**	It clearly extends seawards, but it also extends beneath the sand towards the gap between the village buildings. The contact trends at 080° to north i.e. almost E - W
Ask the group what they think about the vertical extent of the dyke?	It can be projected below the surface to an unknown depth. It must once also have extended upwards – but has now been eroded away, along with the sedimentary rocks alongside it, thereby providing many of the dolerite pebbles on the beach.
How can the (absolute) age of igneous rocks be determined?	By radio metric methods. The dolerite is dated at 295 million years old.
Tell the group that **the rocks to the north of the dyke have been downthrown** compared to the rocks to the south of the dyke. How can this be explained?	There is a fault along the line of the dyke.

What kind of behaviour results in faulting of rocks?	Brittle fracture.
Which seems to have come first, the faulting or the dyke intrusion?	Since the fault has not broken up the dyke, it must be **older** than the dyke, which followed the line of the fault during intrusion.
Finally ask the group which is older. The dyke or the sedimentary rocks. NOTE: Here is an example where the relative time scale (older to younger) can be (loosely) tied to an absolute timescale by the age of the dolerite.	The sedimentary rocks have been cut by the dyke: therefore they are older: i.e. older than the age of the dyke: 295 million years. (**Principle of Cross Cutting Relationships)**
Pupils should draw on the map the northern contact of the dyke using the compass heading and buildings to guide them (parallel to the first contact, and through the gap in the houses in the village!). Use dotted lines to indicate the projected line where the contact is not visible.	

Site 4: Boulmer - North Foreshore

Figure 7. Site 4. North Foreshore

☛Proceed northwest wards, diagonally along the sand, making for the low cliffs 200m beyond the last cottage in Boulmer, where the rocks are exposed in the base of the cliff. (See **Figures 1 and 7**).

This is **site 4.** Start by explaining that they are going to interpret the evidence in the rocks using the **Principle of Uniformitarianism**: "The present is the key to the past".

Figure 8a. Tracks.

Figure 8b. Burrows

Figure 8c. *Zoophycos* trails.

☛ Tell the group that these rocks they are studying are **not** believed to have formed on a beach like the modern sediments they have looked at, but the processes that formed them operated in the same way as the ones they have been observing. Ask them to search for pieces of evidence (in outcrop and loose pebbles) that can be used to work out in what kind of place they were deposited.

NOTE: The wider research evidence suggests these rocks were formed in a sea area that was frequently silted up by large deltas building out from the north. (See **BOU4 Briefing** for more details). There are **limestones** formed in the sea, there are **shales** (with burrows and trails) formed in deeper quiet water often in front of the delta, but also in delta top lakes and lagoons, and **sandstones** formed by river currents on top of the delta. There are also **plant fragments** washed in from land areas upstream, (and coal deposits, representing times when the area was built up to swamps just above sea level – but not at site 4!). There are also **cross beds and ripples** as evidence for current directions from the north, and **tracks and trails** as evidence of soft bodied (i.e. no fossilised hard parts) organisms living in the sand and mud. [The "chisel" marks on some bedding planes are the lowest sections of "U" shaped **burrows i**n the overlying shale which has now been eroded away. The "frond" marks are also animal trails, and not plants.

The thin limestone outcrop itself <u>may</u> be exposed just seaward of the concrete blocks below North Cottage, whilst the other evidence, including limestone pebbles, is here, around **site 4.**

Worksheet 4: Boulmer – North Foreshore.

☛ Either discuss the evidence the group has found, and then let them complete **worksheet 4**, or use the worksheet to guide the discussions of the discoveries as they happen. Remind the group to take care when walking on uneven rock surfaces.

Suitable questions at this site	**Acceptable responses.**
Ask what is the evidence that these are beds in the low cliff are of sedimentary rock?	They are layered. They are made of fragments cemented together. (They also contain trace fossils which are evidence of animal movement). They are also rippled and cross bedded, showing they were formed by processes at the Earths surface.
How many different types of sedimentary rocks are there here exposed in the cliff?	Two: black shales, and sandstones
Which rock type is more resistant to weathering?.	The sandstone. (The black shales weather back into the cliff face).
Which is the oldest bed in this exposure?	The lowest one. (**Principle of Superposition**.) At this site it is the sandstone with the dip arrow on **Figure 7**
Ask the group to inspect the bedding planes in the sandstones, **from the lowest upwards**: can they see any ripples? What kind of ripples they are, symmetrical or asymmetrical?	Yes. Symmetrical ripples. NOTE: They are not flattened by shallowing water.
In which direction are the ripple crests aligned? So which way were the wave fronts approaching?	Either north to south, or south to north (some are more NW – SE). Waves approach in one of two directions at right angles to the ripple crests.
Can you see cross bedding? Does this tell you anything about the current?	Yes. It is cross bedded from the north, so the current was flowing to the south.
Can you find any animal trails or burrows? The answer is yes, but they may not recognise them. See **figures 8a, b and c.** How many different types of trail (i.e. evidence for different animals) can you find?	1. Meandering or delicate "frond" like marks on bedding planes are surface trails (see **8c**). (*Zoophycos*). 2. Short (1cm) "chisel" type marks on sandstone bedding planes are the bottom of "U" shaped burrows in the shale above – now eroded away. (see **8b**). 3. Other meandering trails about 1cm across are common.

None of the fossil animals that made any of these marks has ever been found. Why not?	It may be that they are there but have never been found (but absence of evidence is not evidence of absence). More likely they were entirely soft bodied animals and not preserved after death (eaten or decayed).
What might these animals have been doing when they made these marks?	Feeding, hunting, mating, hiding etc. Link this firmly into a grasp of an ancient ecology. Trace fossils (as these are called) are evidence of animal <u>movement</u> (and therefore, purpose) during life.
What has happened to the loose sediments since they were deposited? [Use a clipboard to aid dip measurements]	1. They have been turned into solid rock (the sand by cementation, the shale by compression of de-watering. 2. They have been tilted about 10° to 140° North by plate tectonic forces.
What is now happening to these beds	They are being weathered and eroded away by the sea. The sand is contributing to the beach sand, i.e. part of the present day rock cycle.
Split the group into work parties of 3 (1 to measure, 1 to read off & 1 to record and all to discuss!) and ask them to measure up the top 80 cm or so of sedimentary rock in the low cliff. (See **Figure 9)** NOTE: the "soil" in the upper cliff is slipped weathered material overlying a thick shale bed, otherwise not often seen, and which is at the top of their section. Measure the thickness **at right angles** to the bedding (See **Figure 9)** and plot the information on the worksheet. Add notes to indicate ripples, cross beds or burrows. Point out that they have created a record of a **sequence of changes** of events from 342 million years ago.	
What does this alternating difference in grain size between sand and mud tell you about the changing strength of the current which deposited these beds?	It became weaker, allowing mud to settle out, and then became stronger bringing in sand grains (from a northerly direction again) and washing mud further on in the current. The beds here indicate alternating current strengths.
Summarise the evidence you have seen and how it might be interpreted. Then ask the group in what kind of sedimentary environment these bed might have been deposited?	**Limestone & shelly fossils**: the area was sometimes marine. **Sandstone and shale**: alternating speeds of current. **Cross beds**: stronger currents from the north **Tracks and trails**: enough food and oxygen for animals to survive. **Plant fragments**: close enough to land for plants to be washed in. **Accepted interpretation**: Deltaic area of river channels, marshes and muddy lakes, building out into a sea, - but discuss other sensible options.

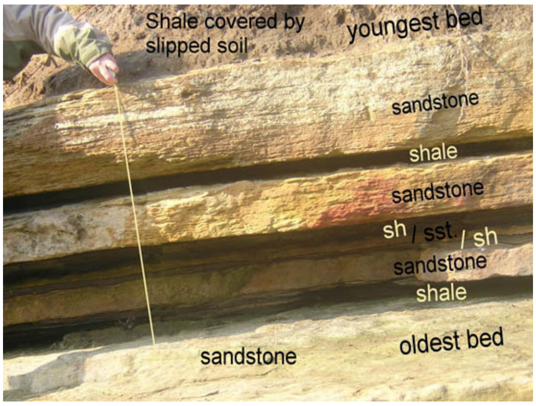


Figure 9. Measuring the Succession at Site 4.

☛ Point out that the log of a succession is an important record of Earth science data. There is one quite simple exercise to be completed on **worksheet 4**. Always measure the thickness of beds at right angles to the bedding planes.

☛ Bring the group's attention to the biological side of these sediments; careful observation will reveal burrows in the shales, as well as small cross beds in the sandstones, indicating a current from the north.

Suitable questions at this site	Acceptable responses.
Tell the group that these rocks were deposited by large river deltas building into a muddy sea area. How would such changes from marine to deltaic affect animals living in the sediments?	Fixed, bottom-living organisms e.g. corals would be buried; changes in salinity would drive any mobile species away. Food webs would change from seawater to brackish water species.
Point out that we have animals and plants living in similar habitats today, but they are **not** the same species, but new ones that do not appear in the Carboniferous fossil record What theory do we use to explain these changes in living things over time. What wards describe the loss of once living species and the arrival of new species in the fossil record.	The theory of evolution. Extinction Evolution
Ask pupils if they can recall any other evolutionary changes in the 342 million years **since** the deposition of these rocks? Point out that this is the basis of the **Principle of Rocks Identified by their Included Fossils,** so Palaeozoic age fossils in a layer of rock mean Palaeozoic age rocks.	The most likely ones are: Extinction of giant Carboniferous insects and amphibians. Dinosaur evolution and final extinction (except for birds); Extinction of large marine reptiles (NOTE: Ichthyosaurs and flying reptiles etc. are **not** dinosaurs, but are extinct). Extinction of ammonites and belemnites; Human evolution. Evolution of grasses and other flowering plants.

☛ Return to the car park along the foreshore.

☛If the building stone exercise from the KS3 trail is to be added to the itinerary, then there are two options: the group may be taken back along the main street towards Boulmer Hall; or, with great care, up the informal and slippery path to the cliff top just north of the large cement blocks at the base of the cliff. (see **BOU6 KS3 Field exercises and BOU7 & 8** for the worksheets and field leaders notes**.**).

☛ 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.