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

INTRODUCTION

☛Field groups should time their arrival at Boulmer an hour or so before maximum **low** tide. 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 **BOU8 worksheets**). 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. The first 5 sites are around Boulmer. Apart from a theme of human use of geological materials, the main linking theme is that of the **Principle of Uniformitarianism,** using present day processes to help us interpret ancient rock cycles.

1a, b, c, and **d.** Investigating Boulmer Beach & Dune Sands.
2. The Rocks Of the Wave-Cut Platform.
3a.Torrs Foreshore I.
3b.The Torrs Foreshore II.
4. Boulmer Coastal Defences.
5. Boulmer Wall Stone Exercise.
6. Sumary 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 pupils in small group activity.

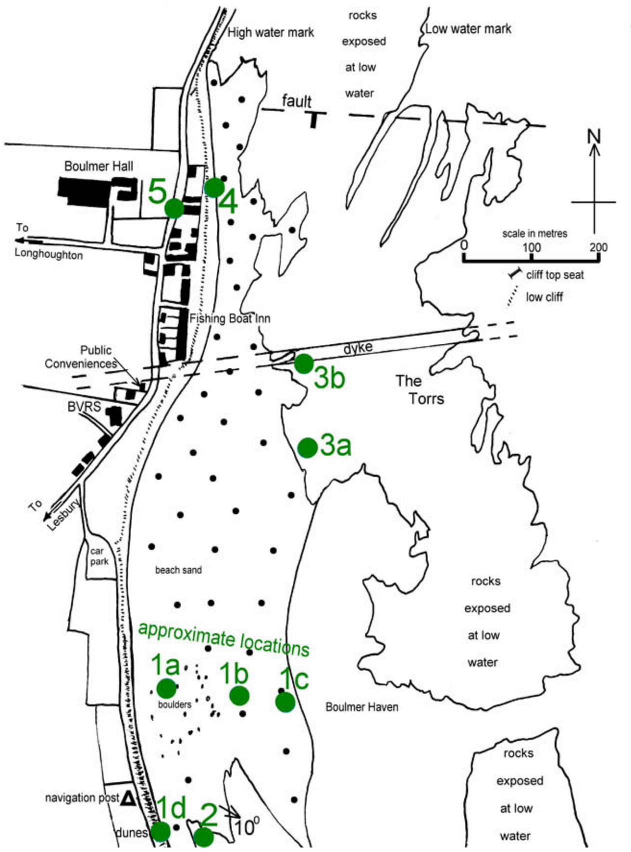


Figure 1. The Sites at Boulmer.

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.

NOTE: The exact location of **sites 1a 1b & 1c** can vary with the state of the beach. Match the site descriptions here with the beach you have on the day.

Site 1a: Boulmer Haven Beach Boulders.

☛ 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.

Remind the group of the main characteristics of the three main rock types 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 Boulmer Beach Sands.

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, which ended 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.
What would you expect to happen to the boulders on this beach over time?	They would be further abraded by the sand being washed over them and eventually broken up in to smaller pieces of sand size.

Site 1b: Boulmer Beach Sands

☛ Tell the group that they are going to concentrate first on the present day rock cycle and today's physical, chemical and biological aspects. Move the group's attention to a suitable piece of sand down-beach from the boulders (See **Figure 2**), and focus on the finer beach constituents. Ask the group to observe the other beach material and think about the processes affecting it.

Suitable questions at this site.	Acceptable responses.
Apart from the boulders, 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.	Mainly coarse to medium sized sand grains, but depending on the season: shells, seaweed etc. (N.B. Save the used tape to make comparisons with dune sand later)
Where has the beach material 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.
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 the burrows below 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?	**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 are evidence of recent movement. Burrows and animal casts. Also the fact that gravity is holding the sand on the beach.
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.
How long has there been a beach here?	Roughly since the last Ice Age about 12,000 years ago (although it gradually moved westwards with the rising sea level due to ice melting).
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 kind of rock would it then be? (NOTE: **Principle Of Uniformitarianism**)	A sedimentary sandstone.

Site 1b: continued.

Figure 2. Ripples and burrows in sand.

☛ 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 i.e. organisms have been burrowing in beach sand 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 present rock cycle that may become preserved in the future

Suitable questions at this site.	**Acceptable responses.**
What would we call this top surface? What kind of rock lies just below it?	A bedding plane. With a bed of sedimentary sandstone underneath it. (Un-cemented sediments are still regarded as "rocks".)
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 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 deserts.
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 should 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 a nearby obstruction causing refraction).
Ask the group what caused the mounds of sand?	Burrowing organisms. There are probably lugworms and bivalves burrowing in the sand and digesting food from the water or sediment.
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 relative sequence of events. [Remind them that these processes have been going on for millions of years, so we can do the same thing with ancient rocks.] Then ask then what happened to the evidence of the tide **before** last?	Bedding planes are pauses in deposition (gaps in evidence). Previous deposits were 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.

NOTE: The behaviour of the sand will depend on the velocity of the flow. At high speeds grains will move over a flat surface, at slower velocities ripples will form and migrate downstream.

Suitable questions at this site.	Acceptable responses.
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.
What differences are there between the beach deposit above and below the channel waterline?	Below the waterline: the pore spaces are filled with water containing dissolved salts, (above they are filled with air); the grains may be moving with the flow.
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).

Site 1d: The Dunes.

☛ Move the group up the beach to the edge of the dune belt, just west of the rock outcrop on the beach. Here the exercise is to emphasise why sedimentary rocks are so variable in grain size, fossil composition and structures. Use the sticky tape to take another sample and compare the description with the sand from lower down the beach. **This is a conservation area so do not damage the vegetation cover or dig in the sand.**

Worksheet 2. Investigating dune sands

Suitable questions at this site.	**Acceptable responses.**
This sand is a continuation of the sand on the beach, but how is this sand different from the sand down the beach?	Again use sticky tape to take a sample for examination by hand lens. It is finer grained but it has no mud. It has a mixture of types of rock types and silica grains. On a larger scale it has snail shells (terrestrial species) and plants with rootlets in it. It is also piled up into 4 metre high dunes.
What forces moved the sand here?	By wind action – when the beach sand was dried out at low tide. i.e. with an easterly wind.
Why did the sand get deposited here?	As the wind blew through the vegetation it slowed down and dropped the sand it was carrying.
What is holding the sand together and preventing it from being blown away?	The vegetation and its roots.
Can you see how the next dune will form seaward of the present one?	Early salt-loving coloniser plants, like sea rocket, have established themselves on the beach in front of the dunes. Soon marram grass will establish and grow deep binding roots and start another line of dunes in front of the main one. Older dunes behind have shrubs and more mature vegetation.
If this dune sand was cemented into a rock, how would it be different from the sandstone down the beach if that was cemented into a rock?	The dune sand would have terrestrial species (e.g. of snails), finer grains, and very little mud. (NOTE: The vegetation and roots would probably oxidise away and not be preserved.

☛ Summarise the geological significance of the first four sites: that a single layer of sandstone can vary greatly from place to place because of the different combinations of processes causing it to be deposited.

Site 2: The Rock Platform.

☛ Move the group a few metres southeast to the nearest outcrop of rock. This is part of the rock platform, cut by wave action, upon which the beach sands are deposited.

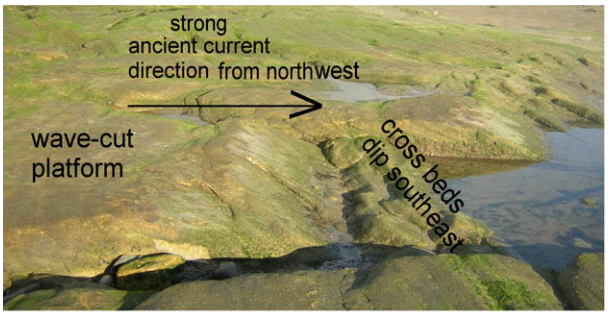


Figure 4. Site 2. The Rock Platform.

These rocks were formed 340 million years ago in the Carboniferous period. The nearly flat, wave-eroded surface is close to the original bedding i.e. the rocks are close to the horizontal.
[NOTE: The steeply dipping surfaces are cross beds – i.e. the buried and fossilised front faces of large asymmetrical ripples. As such they are evidence of depositional events from the remote past.]

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

Worksheet 2. The Wave Cut Platform.

Suitable questions at this site.	**Acceptable responses.**
Look closely at the rock. What features can you see in it?	It is made of 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.
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? For what reasons 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. [Compare with the beach ripples seen earlier.]
In what direction do these cross beds indicate that the ancient current was flowing?	Towards the southeast. (The cross beds dip in a down-current direction (as on the beach earlier).
Ask the group to put one foot on the rock and one foot on the sand and ask them how far apart their feet are?	Answer 340 million years (the time gap between the deposition of the rock and the deposition of the sand by the last tide).
Ask the group what is happening to the rock at the present day?	The weathering has already been recognised. It is also being eroded – and contributing sand grains to the beach in the modern rock cycle.
Ask the group how the flat surface on the rock was formed?	Erosion by wave action as tides move the waves up and down the beach.
Ask the group what lies below the sand on either side of this rocky outcrop?	Rock. This exposure is just a high point on a platform that extends laterally underneath the dunes and out to the sea.
Ask the group to reconstruct the **sequence of rock cycle events** for the beach features they have seen (follow convention with first event at the bottom of the list). NOTE: Point out that weathering and erosion would have reduced the Earth's surface to sea level millions of years ago if Plate Tectonic forces hadn't repeatedly uplifted it to start a new cycle.	**3. Deposition:** Of sand beach materials (boulders and sand). Colonisation by burrowing animals etc. **2. Weathering and erosion**: Weathering attacks the rocks and waves erode them releasing sand grains onto the beach. **Deformation:** Uplift of the beds above sea-level. **1. Deposition**: of the grey sandstone by a flowing current in (large) asymmetrical ripples, 340 million years ago, and deep burial below thicknesses of other rock.

Site 3a: The Torrs Foreshore.

☛Take the group northwards and continue towards The Torrs, along the margin between the sand and rock platform to the east. At a suitable point at the edge of the rock platform, stop the group and draw their attention to the change in the beach.

Worksheet 3. The Rocks on "The Torrs."

Suitable questions at this site.	**Acceptable responses.**
Ask the group why there is not much sand on the rocks to the east.	The waves have washed 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 they: 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 340 million years ago.]
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?	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 sediment.
Ask the group to measure the dip amount of one bedding plane. NOTE: Dip amount is best found by using a clinometer to find the horizontal direction on the sloping bed. Then measure the dip amount at right angles to this direction.	Answers should be around 10°. [If group leaders also want pupils to measure and plot the dip direction, then the dip arrow should be removed from **worksheet 3.]**
If 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?	More or less NW. Sedimentary rocks (that have not been turned right over) become younger in the same direction of dip, and vice versa. **Principle of Superposition**: younger rocks lie on top of older rocks.

☛Continue a few metres north up the beach to a point where the rocks change to a dark grey appearance. [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 dark grey rock to the north. This is **Site 3b**, 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 vertical contact can clearly be seen. (**Figure 5**).

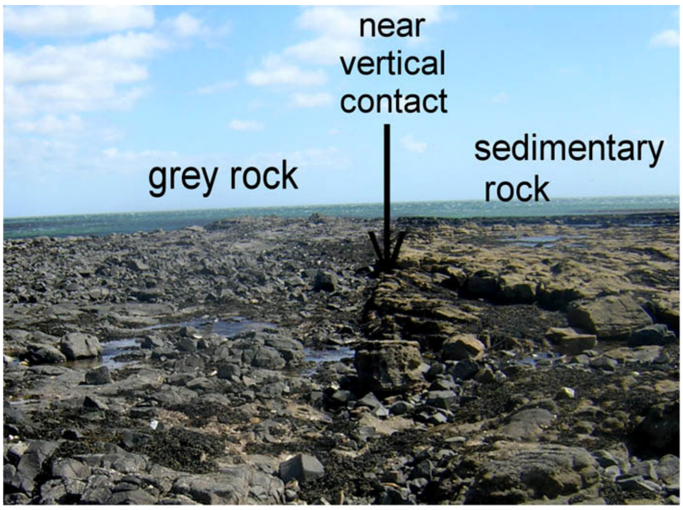
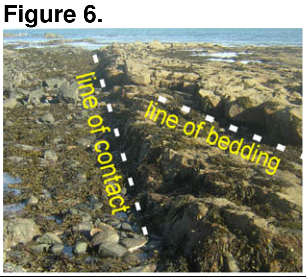


Figure 5. Site 3b. The Torrs, Dyke / Sedimentary Rock Contact.

Worksheet 3. The Rocks on "The Torrs."

Suitable questions at this site.	**Acceptable responses.**
What change can they see in the rocks on the wave-cut platform 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 across the exposure on the beach - north to south. i.e. at right angles to the vertical cooling surfaces. (although there are also some other joints which run E-W.)
What does the fact that there is no sand here tell you about the strength of the waves recently affecting the beach?	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 grey rock: igneous, sedimentary or metamorphic? Ask them to pick up pieces and inspect them.	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.]
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 have heard of the term **Whin stone.** It is an old name 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.** 
At what angle to the horizontal does the contact dip into the ground?	Almost 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. cooled much more slowly.)
Ask the group to search for the opposite contact to the north. Take a tape measure and measure the width in metres.	It is almost exactly 30 metres wide. Depending on where the measurement is taken 30.10m to 30.50 m.
Ask the group how far the earth's crust on the north side must have moved to let this dyke be emplaced?	Almost exactly 30 metres to the north (or the south side southwards). i.e. Northumberland was being stretched.
Ask the group to look around and see where the dyke may extend. **(Principle of Lateral Continuity)**	It extends seawards, but it also extends beneath the sand towards the gap between the buildings in the village. The contact trends at 080^0 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.
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.
Which seems to have come first, the faulting or the dyke intrusion?	Since the fault has not broken 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	The sedimentary rocks have been cut by the dyke: therefore they are older. (**Principle of Cross Cutting Relationships)** [NOTE: The dolerite has been dated be radiometric methods at 295 million years].

Site 4: The North Foreshore.

☛Proceed northwest wards, diagonally along the sand, making for the low cliffs between the last two cottages in Boulmer. This is **Site 4**. Start by focussing on present day processes of weathering, erosion and transport.

Figure 7. Site 4. The North Foreshore.

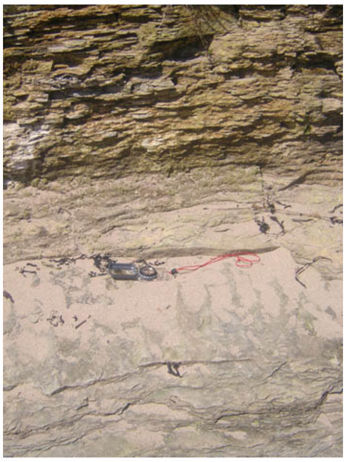


Figure 8. Ripple-Bedded Sandstone.

Worksheet 4. Boulmer Coastal Defences.

Suitable questions at this site.	**Acceptable responses.**
Ask what the large cubic blocks have been made from.	Cement and beach material (shells are visible) plus angular dark fragments of hard dolerite.
Ask why these materials have been used.	Suitable by being local, and cheap to obtain, and resistant to weathering when cemented into a block.
Ask why the concrete blocks have been put here.	To protect the cliff from wave erosion. (Originally, probably wartime defences).
What is the evidence that this piece of cliff is being attacked by waves?	The lower part of the cliff has rocks washed clean. The upper part is covered with vegetation.
Where has the material washed from the cliff gone to?	Onto the beach.
Investigate the pebbles on the beach. Find an example of igneous, metamorphic and sedimentary rocks, (and human-made). Dilute HCl. will test for limestones which will be dark grey and impure rocks, but will still effervesce. **Observe the usual safety precautions with acid.**	There will be many sedimentary rocks, and some human material, e.g. red brick, and maybe an igneous example (grey dolerite). There are unlikely to be any metamorphic rocks, so keep the hunt short!
Describe the shape of the pebbles on the beach.	Most of them are sub rounded.
Why are they not well rounded?	They have not been transported on the beach long enough to become more rounded.

☛Then bring the group closer to the base of the low cliff, just north of the last concrete cube, and draw their attention to the rock exposure. Here we are focussing on the evidence for an ancient rock cycle from 340 million years ago when these beds were deposited as part of a large delta building out from the north into a marine area. Give them a few moments to inspect the rocks and pebbles.

Suitable questions at this site.	Acceptable responses.
Ask what is the evidence that these are beds of sedimentary rock?	They are layered. They are made of fragments cemented together. (They also contain fossils). They are also rippled, showing they were formed by processes at the Earths surface.
Ask what kind of ripples they are, symmetrical or asymmetrical?	Symmetrical. NOTE: They are not flattened by shallowing water.
Which way were the wave fronts approaching?	Either north - south, or south – north
Can you see cross bedding? Does this tell you anything about the current?	Yes. It is from the north, however, depending on the state of the beach you may have to go 200m north to the rock platform under the low cliff to see it.
Which is the oldest bed in this exposure?	The lowest one. (**Principle of Superposition**.)
In what ways are the lowest bed different from the ones above?	The lower beds are (rippled) sandstone. The upper beds are shales (with more mud).
What does this difference in grain size (sand to mud) tell you about the changing strength of the current which deposited these beds?	It became weaker as time passed, allowing mud to settle out.
What has happened to these 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 and de-watering. 2. They have been tilted to 16^0 at 140^0 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 the present day rock cycle.

☛ Finally, tell the group that these rocks they are studying were **not** formed on a beach like the modern sediments. Ask them to search the beach for pieces of evidence (pebbles and cobbles) that can be used to work out where they were deposited.

[NOTE: The evidence suggests they were formed in a sea area that was frequently silted up by large deltas building out from the north and northeast. There are **limestones** formed in the sea, there are **shales** formed in front of the delta, and **sandstones** formed by rivers on top of the delta. And there are **plant fragments** and coal deposits, representing times when the area was built up to swamps just above sea level. There are also **cross beds and ripples** as evidence for current directions from the north. The limestones may be exposed just seaward of Site 4, but if not the beach pebbles are full of other evidence.]

Site 5: Building Stones in Boulmer.

Worksheet 5. Boulmer Wall Stones.

☛Either retrace your steps along the beach and return north along Boulmer main street, or you may decide the group is equipped to take the informal (steep and slippery) path up the low cliff to the road just east of Boulmer Hall.

Take the group to the line of cottages just south of North Cottage, where the wall exercise is located. Here the exercise is to recognise the features of the materials used by humans to construct these walls. A “treasure hunt” strategy in small teams can work well, but please caution the groups not to touch the walls or cause offence to the occupants. Observations can best be made a little distance away from the walls.

Also look out for traffic.

The answers to the wall stones exercises are summarised in **BOU5 Group Leader’s Notes.**

☛ After this exercise, walk the group down the main street (observing more examples of deeply weathered building stone on the way) to the car park at the south end of the village.

☛ 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 exposures of dolerite sills.