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

Contact: info@ukrigs.org.uk

INTRODUCTION

☛ Field groups will need measuring tapes, compasses and clinometers if dip measurements are to be attempted, as well as clipboards and copies of the relevant field sheets for individual pupils. Callipers for measuring pebble axes are useful, being more accurate than rulers or tapes. (See **MOS12 worksheets.**) Group Leaders will need a plastic bottle of dilute HCl, a small plastic bottle of water; a flexible sheet of foam rubber to demonstrate the shape of folds. A digital camera will also be useful.

☛ Field leaders should have decided which combination of the following exercises they groups are to tackle before they arrive on site: School House Quarry is a study of Ordovician slates; Mosedale Moss is an igneous exposure; Stone Ends Quarry is a scree/moraine deposit; Long Hill Quarry is in a meltwater deposit; Carrock Beck Ford is a modern river sediment (washed out of glacial till); and Howk Gorge is in Carboniferous limestone.

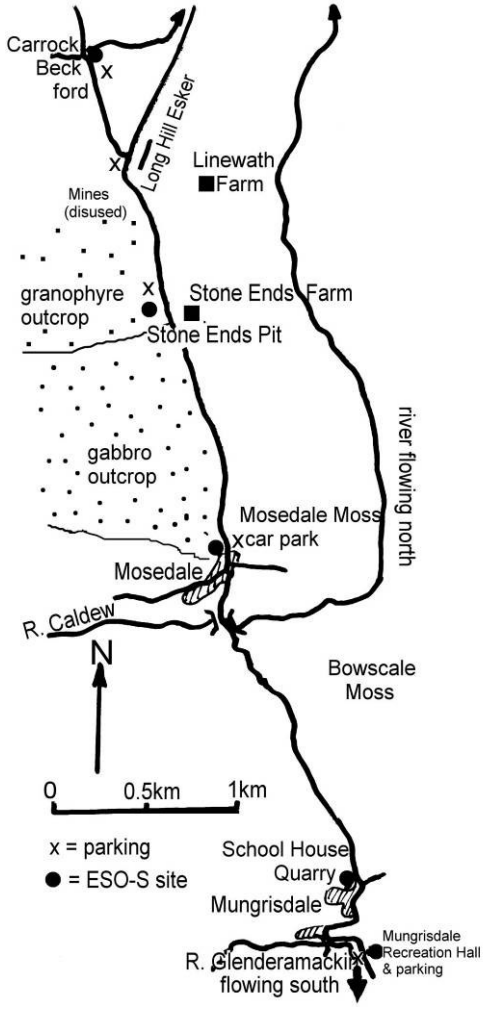

Figure 1. Map of sites in Mosedale.

☛ Park on the left side of the minor road opposite the newly built Mungrisdale Recreation Hall (GR **NY 36353025**). This minor road is quite busy, so take care when crossing. Move the group to the north end of the Recreation Hall where a view of the limekiln can be seen. The signboard gives all the information. There is no need to approach the kiln itself.

Suitable questions at this site	**Acceptable responses.**
When was the limekiln used, and what was the lime used for?	Eighteenth century limekiln. The lime was used for rendering stonework, whitewashing houses and for putting on fields that had acidic soils, weathered from the moraine and slates, to make them more fertile. (Calcium carbonate is an alkali.)
What does this tell you about the chemistry of the rocks from which the soil has been weathered?	Low in alkalis.

☛Take the group along the sign-posted footpath just behind the north end of the village recreation Hall. This cuts across the fields to the road through the village. [The telephone box is 200m away to the left on the roadside]. Continue north along the road, keeping alert for traffic as there are no pavements, past the churchyard on the right and round the right and then left hand bend. At the Bull Fell Water Treatment Works, take the track to the left to the gate. School House Quarry is on the right across the grass behind the Treatment Works.
Go through the gate and assemble the group close to the large block in the centre of the quarry face.
Remind the group that the rock cycle can be thought of in three repeating stages: **i) deposition** of sedimentary rocks; **ii) deformation**, including tilting, folding, metamorphism, igneous intrusion; **iii) uplift, weathering and erosion.**

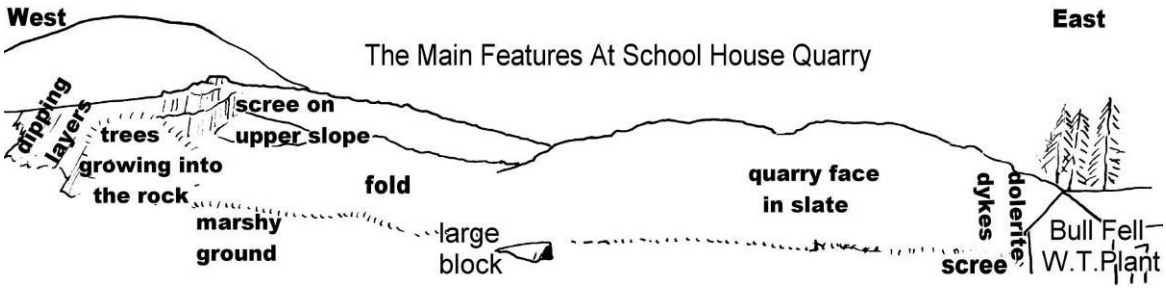

Figure 2. School House Quarry.

Suitable questions at this site	**Acceptable responses.**
Get the group to inspect the rock. Then ask the group to describe the rock and identify it.	It is a fine grained dark coloured rock. It splits into thin plates, but not along bedding planes. It is too resistant to be shale. It is a metamorphic slate.
What was this rock when it was originally deposited?	Fine grained mud. NOTE: the fossils, found (very rarely) here, are graptolites (*Didymograptus diflexus*, an ancient form of marine plankton) indicating that bottom conditions were quiet (and probably deeper-water) marine environment of deposition and an age (dated by other means) of about 470 million years.
What kind of metamorphism has affected it?	Later it was affected by regional metamorphism (i.e. a fold mountain building event which compressed the rocks forming folds and the new splitting direction (cleavage).
What has happened to these rocks since the metamorphism?	Later it has been uplifted to about 240m above sea level.
Can the group see any evidence of tilting or folding?	Just to the west of the large boulder the rock face exhibits a set of cleavages which dip to the south and are curved into a gentle fold. See **Figure 3** [NOTE This "folding" is in fact caused by low angle thrusting visible in the lower face of **Figure 3**.]
Folds (and cleavage) are caused by compression. In which directing was the compression acting? Sheets of foam or paper may be used to demonstrate again the relationship between folds and the direction of compression.	(Remind the group, if necessary about their preparation work on folds.) Compression was at right angles to the cleavage and fold axis: i.e. approximately south - north.
What kind of rock deformation is shown by folding?	Plastic, not brittle.
What kind of forces can create these effects in the Earths crust?	Plate tectonic forces. Fold mountains are interpreted as evidence for a closing plate boundary and the squeezing of sedimentary rocks between two continental pieces of lithosphere.
If regional metamorphism is a sign of fold mountain building, then why aren't there fold mountains (as high as the Alps) here today?	Because they have been eroded completely away (This happened more than 350 million years ago when the limestones at Howk gorge were being deposited below sea level). NOTE: The tiny hills here today have nothing to do with these fold mountains. Their uplift is much more recent.

Figure 3. Cleavages At School House Quarry.

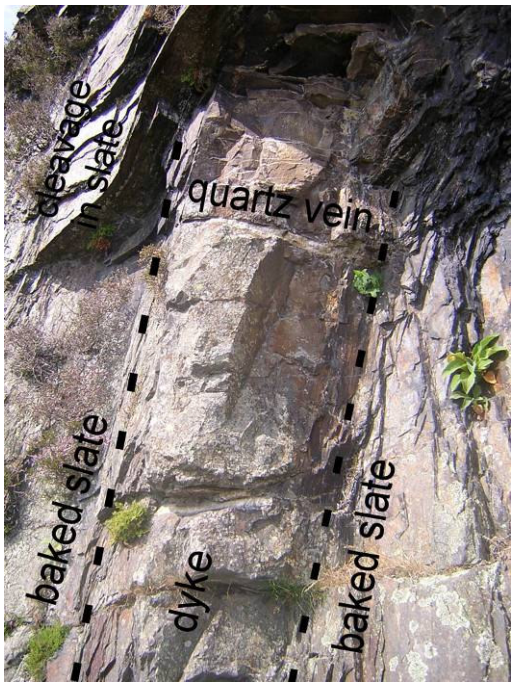

Figure 4. School House Quarry: Dyke, cleavage and quartz veins.

☛Move the group along the face to the east, behind the Bull Fell Water Treatment plant to where the two dykes outcrop. (See **Figure 4.**) Ask the group to investigate the deformation stage of the rock cycle in a little more detail by making observations and deductions.

The sequence of events here can be worked out using the **Principle of Cross Cutting Relationships**. Observe that the quartz veins cut the dyke, and the dyke cuts the slates, therefore the slates are oldest, followed by the dyke and then veining.

NOTE: This exposure is behind the Bull Fell Water Treatment Plant, where there are two dykes. This view is of the westernmost outcrop, with the other dyke to the right.

Suitable questions at this site	Acceptable responses.
There is also evidence of intrusion into these rocks. Guide the search to the east behind the Bull Fell Works. Can you find a dyke, (or two)? How did you recognise them?	The dykes are hard to pick out (See **Figure 4.**) as they weather almost to the same colour as the slates. However, concentrate on the westerly of the two: it is some 30 cm across and doesn't split as finely as the slates and is traversed by joints. It has two, near vertical, margins of baked, darker slate.
What evidence confirms it is igneous and not sedimentary or metamorphic?	It is confirmed by observing the medium sized, dark, interlocking crystals on fresh surfaces. (It is a dolerite intrusion.)
How was this molten magma able to rise through the rocks as it was intruded?	When hot and molten it was less dense than the surrounding rock.
Why are the joints in the dyke roughly horizontal?	The dyke walls are two cooling surfaces and are near-vertical. The contraction during cooling produces tension at right angles to the dyke walls. NOTE: They might also have been caused by brittle fracture during the folding.
Is the dyke older or younger than the slate? How can you tell?	**Principle of Cross Cutting Relationships**: the dyke is younger because it cuts through the slates and bakes them, making them dark.
The white mineral veins in the, near horizontal joint planes is quartz. What is the chemical composition of Quartz?	(SiO_2) Silicon dioxide.
Are the veins older or younger than the dyke?	They are younger. (**Principle of Cross Cutting Relationships**)
Can the group put the events into a time sequence, starting with the first (oldest). Which came first? Dyke, quartz or slate?	First: Slate, cut by dyke and veins. Next: Dyke, cuts slate, but is cut by veins. Last: Veins, cuts dyke and slate.
Move the group onto the last phase of the Rock Cycle. What caused this rock exposure to be here?	It is a quarry face created when the stone was extracted. The hill slope has also been affected by river and ice erosion in the past.
What is the evidence that this rock is being weathered today? What kinds of weathering can you see evidence for?	There are rock fragments at the foot of the upper face of the quarry suggesting physical weathering (by frost or by humans!). Iron staining indicates chemical weathering. To the west there is evidence of trees growing into the joints (and cleavage) in the rock face (biological weathering).
How do we test if this rock porous? [**NOTE:** This simple test can be followed up in the lab by weighing a piece of the slate before and after immersion in water. A piece of porous sandstone could be used as a comparison.] What is the evidence for this in the quarry?	Pour a bead of water onto a flat (horizontal) fragment. It does not sink in. The rock is not porous. This agrees with the observation that the west end of the quarry floor is a little marshy.
If the water and frost cannot get into the rock, why is it so easily attacked by physical weathering?	The (joints) cleavage in the rock divides it up and allows water and frost to attack it over a greater surface area.
Move the group back towards the gate and ask the group to complete and label the field sketch of the dyke on worksheet 1 in **MOS12 worksheets.**	

☛ Return to your parked vehicle by the same route, and drive north through the village of Mungrisdale and on to the village of Mosedale. When crossing Bowscale Moss remind the group the there is a much more recent, glacial, story in the valley. Ice once filled the valley, flowing north and then melting, filling the valley bottom with hummocks of moraine, across which post glacial rivers had to find their way. This is the reason that the River Glenderamackin, south of Mungrisdale, flows south, whilst the River Caldew (to be crossed just south of Mosedale) flows northwards.

In Mosedale the telephone box is on the left as you enter the village. The village roads are narrow and the corners are very tight. After passing through the village of Mosedale you may park in the informal car park area on the right just after the Dalemain Estate sign. (GR NY357325). Mosedale Moss Quarry is the roadside exposure across the road. (See **Figure 5**.) Take care when crossing the road.

Figure 5. Mosedale Moss exposure.

☛ The first exercise at this site is to examine the rock type. This exposure of igneous rock (gabbro) is very variable in colour. Some parts are quite white (more feldspar) and parts are darker (more iron & magnesium silicate minerals). This reflects a difference in chemical composition of the magma during crystallisation. Use the freshly broken pieces lying on the ground to observe the interior of the rock, and contrast with the weathered exterior.

Figure 6. Weathered gabbro (pale coloured).

Suitable questions at this site	Acceptable responses.
Examine the rock pieces on the ground. Describe the rock and suggest what kind of rock it is. (See **Figures 6 & 7**.)	It is made up of black and white crystals, up to a centimetre across. They are interlocking crystals. There is no bedding or fossils. It is an igneous rock.
By the trees, 100 metres to the south, and up the slope, is a baked contact with the same slates you have seen at School House Quarry. (It is very difficult to get to when the vegetation is high). What does this tell you about the age of the igneous rock (gabbro) and the slate.	If it cuts the slates and bakes them then it must be younger **(Principle of Cross Cutting Relationships.)** Dating by radiometric methods gives an age for the gabbro of around 468 million years.
What does the crystal size tell you about the rate of cooling of the magma?	It cooled slowly in a large underground mass (batholith). It is quite large. Most of the hill above is underlain by gabbro).
If the rock was formed deep underground, why is it now found on the fell tops 500 metres above sea level?	The rocks of the lithosphere have been uplifted, and weathering and erosion has removed a large thickness of rock from above. (Although this happened before the deposition of marine limestones about 350 million years ago). Prepare the group for the next exercises by telling them that glaciers have played a part in deeply eroding the rocks in this area.)
What evidence is there here that this rock is being chemically and biologically weathered? What evidence that this rock is being physically weathered?	The outer surface is of a different, brown, colour (See **Figure 6.**) which suggest chemical weathering of iron bearing minerals. The outcrop also has trees and other vegetation which indicate biological weathering with roots growing into the joints. Along the slope there are many large boulders which appear to have fallen from the cliffs above, suggesting physical weathering. (they are also blocks of gabbro). **NOTE**: Beneath the bracken are many concealed scree slopes which are extremely difficult to walk on.

☛The second task at this site is to link the gabbro to the glacial story that will be a feature in the next sites along the valley.

Summarise the glacial context for the group. During a glacial period ice built up into a large "dome" over the tops of the Lake District hills. The pressure (potential energy) from the thick ice at the centre caused the ice to flow outwards, and downwards. However, the ice was up to 1300 metres thick, providing enough force to drive the lower layers of the ice **uphil**l in places. This caused ice to flow north through Mosedale, bringing moraines from the central Lake District, to the south.

Below the ice lumps of rock were frozen into the base of the glacier, and torn from their exposure to become lumps of moraine. When the ice thinned the pressure from the centre decreased, and the ice stopped flowing and melted away. The lumps of moraine were deposited, often being moved again later by meltwater.

Some rocks in the area (including the gabbro) are quite rare and very distinctive and can be found as a trail in the moraine, marking out the path of the ice flow. These distinctive rocks, now lying on top of very different rocks are called **erratics**, and are important evidence when unravelling the story of ice transported moraines. Large erratics can be impossible to distinguish from boulders fallen form a cliff, unless it can be shown that the rock has moved uphill from its geological outcrop (only thick ice can do that).

When this valley lay under more than 1000 metres of ice, what would the physical conditions probably be like at the base of the ice?	Encourage rational hypothesising: **Temperature**: cold. Well below freezing almost all of the time. **Pressure**: higher than atmospheric pressure but less than that caused by the rock removed by erosion. (density of ice is 0.9 grammes per cubic centimetre; density of gabbro around 2.9 grammes per cubic centimetre) **Wet/Dry**: No liquid water (although local pressure melting of small volumes of ice is possible, (as when an ice cube is squeezed between the teeth). When pressure drops the water immediately re-freezes).
What kind of weathering and erosion do you think would happen to the gabbro under these conditions?	Very little chemical weathering (too cold and dry). Very little physical weathering (very few cycles of temperature change above and below freeing). No biological weathering. The group is unlikely to come up with "plucking", the erosional process by which ice freezes onto rock and then plucks out joint block as the ice moves on. (The closest human experience of this is when picking a very cold drinks can from the bottom of a freezer, and having fingers freeze onto the can as the ice melts and then re-freezes.)
The gabbro from this outcrop is very different from the slates in this area. How can it be used now to track the movement of ice over this area thousands of years ago?	The track of the eroded lumps carried by the ice will leave a trail showing the direction of ice movement. (In this location it is to the north, then swinging westwards round the north of the Lake District and then south into what is now the Irish Sea.) Such rocks are called glacial "erratics" i.e. they have a different geology from the rocks they are deposited on.

Figure 7. Gabbro from Mosedale (dark coloured).

☛Return to the vehicle and continue driving north along the road pointing out the screes of very large boulders of gabbro on the left. After 1.5 kilometres, about 200 metres past the well named Stone Ends Farm, park on the left on roadside grass by the unfenced track which leads up the slope to Stone Ends quarry.
Walk upslope for about 250 metres along the unfenced track to the pit, arriving about half way along the exposure.

Pause and focus the group again on the view and the **glacial context.** Remind the group that the superficial deposits seen today in the valley were transported by some combination of ice, water or gravity, or even all three, one after the other. The investigation is to try to work out how the deposits at the next two sites were transported. (See **MOS4 Briefing** for more details.)

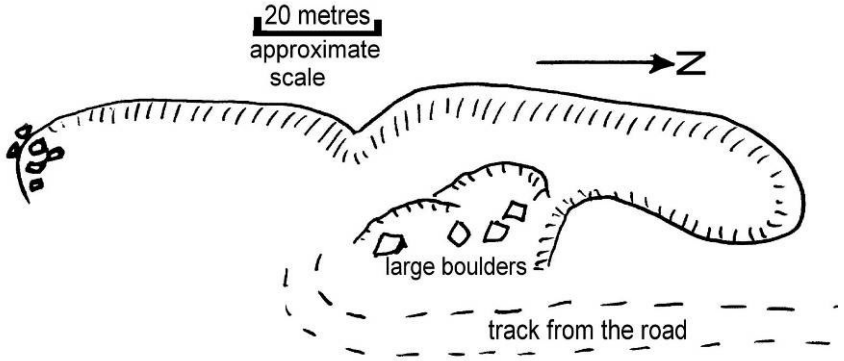

Figure 8. Sketch map of Stone Ends Quarry.

Stone Ends Quarry.

☛ Continue to the southern end of the pit, close to the large boulders. (See **Figure 8**.) Ask the group to investigate the deposit in the quarry. There is no need to climb the slopes.

Suitable questions at this site	**Acceptable responses.**
What is the deposit made of?	Fragments of rock, with some finer sandier material visible, especially near the top of the slope.
Can they tell what rock type the fragments have been weathered from?	Almost all of the boulders and lumps here are igneous made of interlocking black and white minerals: i.e. it is the same gabbro as at Mosedale .
What weathering processes are likely to have been involved in forming theses pieces?	Physical weathering, probably freeze-thaw, followed by falling down the slope under gravity.
Is there evidence that freeze thaw is still happening on the cliffs above?	The currently active scree slopes are higher on the slopes of the fell (they have no vegetation cover). The deposits here, with their grass cover, seem to be much older.
Is this a bedded deposit?	No.
Is this a deposit that has been sorted so that all the same sized fragments are together?	No.
What name do we give to this kind of deposit: Igneous, metamorphic or sedimentary?	Sedimentary. If there is any doubt remind the group that **any** deposit made of weathered fragments of other rocks is called sedimentary.
Ask the group to use **worksheet 2** to describe the deposit, and then go through the significance of the results, as below.	
Ask the group to describe the angularity of the fragments.	They are blocks with sharp edges and corners. Very angular to Sub Angular.
What does this tell them about the amount of transport in water these fragments have experienced?	Very little transport by water.
Ask if all of the pieces are of similar size?	No, the sizes vary from quite large pieces down to sand size. [i.e. it is unsorted].
Ask the group to speculate: Where did these pieces of rock come from?	The likely answers will refer to scree processes, with pieces falling from the cliffs on the fell, above. [NOTE: The crags just to the south west are of gabbro, but it is quite possible that some of these fragments are moraine deposits left over when the (northwards flowing) ice melted and dumped these sediments here – after bringing them from the outcrop to the south.
What has formed this exposure?	The access track and the shape of the faces suggest it is quarried and not a natural face.
To what use does the group think this material was put?	It is probably an aggregate for the repair of farm roads.
What are the characteristics of this sediment which make it suitable for this purpose?	It is made of physically resistant rock fragments with few lines of weakness, and is easy (cheap) to extract.

☛ Walk the group back along the face to the north. Ask them to inspect the fragments at intervals and see if they notice any changes. Stop the group at the point where the track enters the quarry, about at the midpoint of the excavation. (See **Figure 9**.)

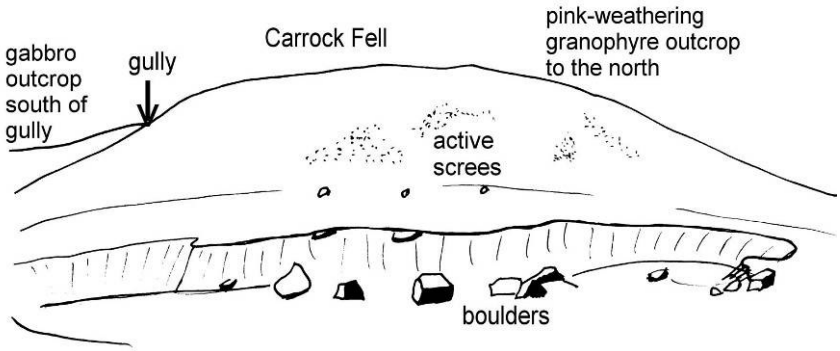

Figure 9. View of the middle of Stone End Quarry from the track.

Figure 10. Stone Ends Quarry.

Figure 11. Active scree slopes.

Suitable questions at this site	**Acceptable responses.**
Ask the group what they have noticed about changes in the fragments making up the quarry?	The proportion of pink weathering rock (granophyre) increases rapidly, although the white and black (gabbro) is still noticeable. (See **Figure 11.)**
What hypotheses can they suggest to explain the changing proportions of the two rock types from south to north?	1) Either the rocks have been moved and mixed up during quarrying operations (some certainly have) or 2) The rock type in the cliffs above changes from south to north (which they do). 3) A further possibility is that this is a moraine deposited as the ice melted from the valley. 4) A combination of all three.
Ask the group to complete **worksheet 2.**	
☛Direct the group's attention to the north to the low ridge lying towards the middle of the valley floor. Point out that this, Long Hill, is also a more recent deposit with some similarities and some differences to Stone Ends Quarry – that need explaining. (See **Figure 12**.)	

Figure 12. Long Hill Esker Viewed From Stone Ends Quarry.

☛ Return to the vehicle and continue north, about 400 metres along the road to the junction with another minor road off to the left (GR NY 353345). Park on the grass at the left hand side of the road. Long Hill Esker is the long low ridge, about 80 metres away to the east. Walk the group across the marshy flat ground (underlain by more impermeable till) to the low ridge, then walk along the crest to the quarry cut into the northern end (See **Figures 13** and **14**).

Suitable questions at this site	**Acceptable responses.**
Ask the group why the ground they have crossed is marshier than the ridge.	Less permeable ground underlain by till (mainly clay), keeping rainwater at the surface.
Why is this exposure here?	Again quarried for aggregate materials used to repair farm roads.
What similarities can they see with the Stone Ends Quarry?	Made up of un-cemented fragments with sand.
Is the deposit bedded?	Yes. On the east side there are traces of bedding, where the deposit is mainly pebbly.
Ask if all of the fragments in the quarry are of similar size?	No, the sizes vary from quite large cobbles down to sand size.
Ask the group to examine the deposit here using **worksheet 3** (**MOS13 KS4 worksheets**) then summarise their findings as indicated below.	
Ask the group to describe the angularity of the pieces.	They are of various shapes, with more rounded edges and corners than at Stone Ends Quarry.
What does this tell them about the amount of transport in water these fragments have experienced?	A significant amount of transport by water.
What does the size of the largest fragment tell them about the speed of the current that deposited these fragments?	Very powerful. The many well rounded cobbles bigger than 100mm suggest currents well over 400 cm per second. (See **Table 1.**)
Point out that Earth Scientists often don't know the answers to questions and have to use observations to create hypotheses they can test. Tell them this is an exercise in observation and hypothesising. Ask the group where the flowing current that deposited these rounded pebbles came from?	They will probably be unsure. Encourage logical observation and hypothesising. The deposit is a ridge not in a channel and lies some distance away from the present drainage channel – which isn't powerful enough to transport this material. If the exercise proves profitable provide a hint: "The sides of the ridge are collapsed. What might have once held them up?" After seeing how far they can get, you will almost certainly need to explain about esker deposits in ice tunnels (See **MOS4 Briefing and Table 1**).

Name of Fragment	Diameter of Fragment in mm.	Approximate Minimum Flow Velocity to Deposit this Sized Fragment
COBBLE	Over 100 mm	400 cm per second (extremely high shooting flow)
COBBLE	Over 64mm	300 cm per second. (extremely high flow)
PEBBLE	4mm to 64 mm	100 cm per second (very strong flow)
GRAVEL	2mm to 4 mm	60cm per second (fast flowing stream)
COARSE SAND	2mm to 0.5 mm	12 to 15 cm per second (more normal stream flow)

Table 1. Depositional threshold velocities for coarse grained fragments in water.

Figure 13. Long Hill Quarry looking south.

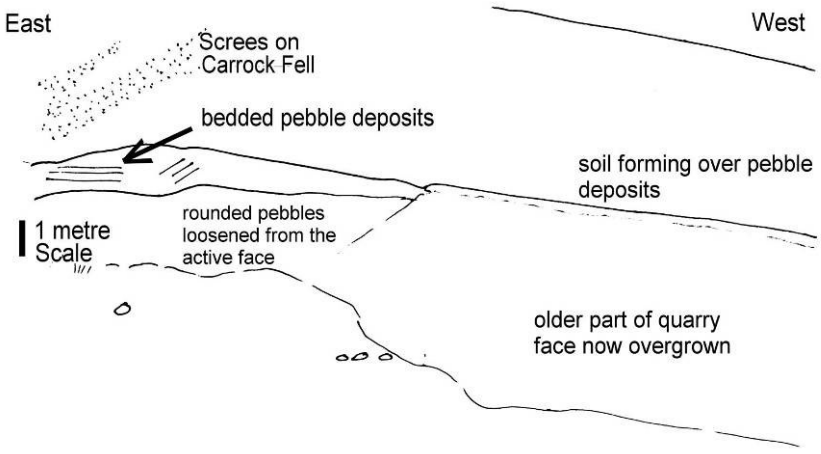

Figure 14. Sketch of Long Hill Esker.

☛ If group leaders do not wish to compare present day river deposits with the esker deposits then omit the next section and follow the directions past Carrock Beck ford to Caldbeck. Alternatively, return to the vehicle and take the left turn up the hill. Park on the grass on the right side of the road about 20 metres before the ford (GR NY34953505), carefully avoiding the rocks in the grass.

Remind the group of the need for suitable and safe behaviour. Also that this is common land and to ignore any horses etc. that might appear to want feeding or petting.
Bring the group to the south bank of the beck. (See **Figure 16.)**

NOTE: After heavy rain the ford may be too dangerous for the next exercise, or to cross in a vehicle. In this case take the alternative route to Caldbeck village and The Howk gorge. (See **Figure 17.)**

Figure 15. Sediment in Carrock Beck Ford.

Figure 16. The Ford at Carrock Beck.

Suitable questions at this site	**Acceptable responses.**
In which direction is the water flowing?	Eastwards
Is the water transporting any sediment? [The answer depends a little on how lucky you have been with the weather].	Probably not, unless there has just been a downpour. However, there may be some fine sand being rolled over the bottom.
What evidence can you see that the stream sometimes flows faster than it is today?	In the stream are banks of gravel with long axes up to 80mm. These would require a current velocity of over 60 cm per second. (See **Table 1**).
Ask the group how far they think the larger boulders have been moved by the river.	They are unlikely to have been brought too far by the river, apart from their size (weight), they tend to be sub angular i.e. they have not had much rolling to round the edges off.
Ask where these boulders might have come from.	They are most likely to have been washed out of the till brought here from the south by the ice during the last 10 to 20,000 years.
Ask where the gravel is likely to have come from.	Westwards, upstream, possibly from the till, or some, weathered from outcrops.
Ask the group to hypothesise which deposit will have more rounded fragments: the stream gravel in Carrock Beck or the deposit at Long Hill, or the deposit at Stone Ends? Set the group the task to make the observations that will allow the comparison between these deposits. (See **Worksheet 4**.)	Be sure to ask for the reasoning behind any suggested hypothesis.
Set the group the task to make the observations that will allow the comparison between these deposits. (See **worksheet 4**.)	
Bring the group together and discuss their findings. (The most angular deposit will be Stone Ends Quarry, whilst the most rounded will be at Long Hill.)	The Stone Ends deposit has many characteristics of scree and few rounded fragments. The choice for most rounded fragments will be between Long Hill and the river gravel. Most of the gravel in Carrock Beck has not been transported far enough to become very rounded, whilst many of the Long Hill fragments have – even though this happened about 10,000 years ago.
Ask the group what changes they think will happen to these fragments in Carrock Fell Beck as they are transported down the river.	Become broken into smaller pieces and become more rounded.
If humans do not interfere, then what will eventually happen to the weathered fragments from this exposure?	Transported to the River Caldew in the main valley and then via the River Eden to the Solway Firth and the sea.
What kind of fossils might be found in these new rocks by geologists millions of years in the future?	Accept most answers that recognise the need for resistant parts: e.g. boats, cars, cans, ipods, shellfish, dolphins, washed – in trees, drowned birds, (and maybe even human skeletons) etc. but not jelly fish etc.

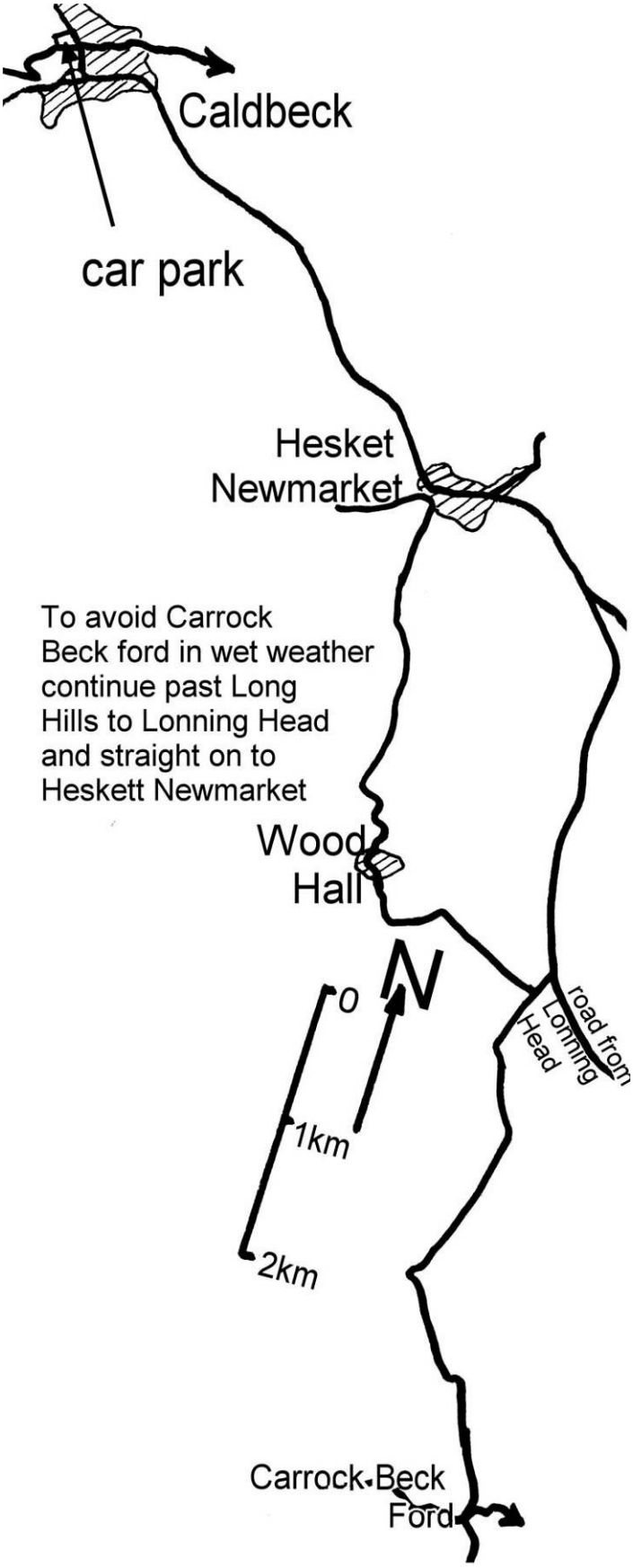

Figure 17. The route to "Howk" Gorge.

☛ Route to The Howk Gorge (grid reference NY 320397)

To go directly to Caldbeck take the minor roads up the hill from Long Hill through the Carrock Beck Ford. Continue past the left turn to Wood Hall and the right turn soon after. Bear left to Hesket Newmarket at the next road junction. Continue through the village on to Caldbeck. The total journey from Carrock Beck Ford is 4 miles (6.5km). In the village, at the Oddfellowes Arms, turn right, and, after crossing the bridge, turn left and park in the free car park. (See **Figure 21.)**

[In very wet weather **avoid the ford** and continue past the Long Hills location, for 1.5 kilometres. Following the signs for Heskett Newmarket turn left over the cattle grid at the first junction, and go through Lonning Head, rejoining the route 2km south of Heskett Newmarket.] (See **Figure 17.**)

On foot, leave the Caldbeck car park along the exit road at the north western corner. At the junction turn left for 50 metres. At the road junction, cross the road and enter the gate Howk Mill footpath, through the cobbled yard.
After about 200 metres the ruins of the Howk Bobbin Mill and the limestone quarry exposures can be seen.

The main limestone exposure is at the north eastern corner of the Howk Mill site, to the right of the path.

Remind the group that the Rock Cycle can be described in three repeating stages: i) deposition of sedimentary rocks; ii) deformation (folding, faulting, metamorphisms, intrusion) followed by iii) uplift and weathering and erosion.

First focus on the rock identification and weathering features of the rocks at this site.

Suitable questions at this site	Acceptable answers
How have these rocks become exposed at this particular site?	River erosion has excavated the gorge, but then the rock has also been quarried by human activity.
Are these grey beds porous? How can we test for porosity? [**NOTE:** This simple test can be followed up in the lab by weighing a piece of the limestone before and after immersion in water. A piece of slate from school House Quarry and a porous sandstone could be used as a comparison.]	Bead a few drops of water into a depression in the grey beds. The water does not sink in. These beds are relatively non porous.
Can you see joints at right angles to bedding planes? Are the bedding planes dipping or near horizontal?	Yes. Near horizontal.
When rain falls onto these grey beds, where will it go?	Either run off to the stream, or flow down the joints underground.
How might these joints affect the rate of weathering of this rock?	It divides the rock into blocks to allow physical weathering (freeze-thaw) and also increases the surface area to acidic rain and chemical weathering of the limestone.
What evidence of weathering of these rocks can you see?	There are signs of soil formation near the top of the face, and evidence of biological weathering with tree roots growing into the joints and bedding in the exposure.
What other observations can you made about these rocks?	They contain fossils (coral and brachiopod).
What does the fossil evidence tell us about the conditions under which these beds were formed?	The corals (by comparison with modern forms i.e. **Principle Of Uniformitarianism**) indicate a warm marine environment of normal salinity, well oxygenated and fairly shallow. Since the corals are found lying on their side, (i.e. not perpendicular to the bedding which indicates the horizontal of the time) they must have been washed around by currents after death.
How did the calcium carbonate get into the sea water to be of use to the organisms?	Mainly as soluble products of chemical weathering, brought to the sea by rivers 245 million years ago.
Do the rocks react with dilute HCl.? (Group leaders should demonstrate using HCl from a small plastic bottle. What do you conclude from this test?	Yes it does. It is a rock made of calcium carbonate.
Are these rocks igneous, metamorphic or sedimentary? Can you name the rock?	Layered rocks with fossils are sedimentary. These contain a large amount of calcite and therefore are limestones.

Next focus on the uplift of these rocks.

Suitable questions at this site	Acceptable answers
Remind the group they have deduced that the grey rocks were formed under the sea: If these grey limestones were formed below sea level, and are now at about 190 metres above sea level, what must have happened to them ?	The rocks have been uplifted and slightly tilted. (Large vertical changes in sea level can be discounted due to the vast amount of water involved in flooding land to this height).
What forces could have done this?	The theory of Plate Tectonics provides the only known explanation for forces strong enough to tilt and uplift large volumes of crustal rocks.
If the rocks of the lithosphere were not being repeatedly uplifted by plate tectonic forces, what would happen to the landscape?	Weathering and erosion would reduce the continental areas to a sea – level plain.
TASK 2: Complete **worksheet 5**	See **MOS8 KS3 worksheets**

Next focus on metamorphism.

Suitable questions at this site	Acceptable answers
What are the main differences between marble and this limestone?	Marble is made of interlocking crystals of calcite, and all fossil remains have been destroyed.
At School House Quarry the rocks had been metamorphosed by heat and pressure into slate. Why have these limestone beds (only 10 kilometres away), also not been metamorphosed?	The metamorphism of the slates must have occurred before the limestones were deposited. These limestones were deposited about 345 million years ago, about 80 million years after the slates at School House Quarry had been metamorphosed.
If there has been metamorphism, uplift and weathering of the slates, but only uplift and weathering of the limestone, then how many Rock Cycles have there been?	Two periods of uplift means two cycles. First the deposition and metamorphism of the slates, uplift and erosion; second the deposition uplift and weathering of the limestone.

Next focus on the uses of the limestone.

What has caused there to be an exposure of limestone here?	The face is at right angles to the gorge face, so it isn't the river. It has been quarried.
What did people want the stone for?	Apart from the possibility of spreading on acid fields, it has clearly been used as a building stone for Howk mill and other buildings in Caldbeck.
Ask the group to complete **worksheet 5**, describing the grey limestones.	See **MOS12 KS4 worksheets**

Another possible focus is to link observations with evolution.

Suitable questions at this site	Acceptable answers
There have been no graptolites (as have been found in the slates at School House Quarry) found in these limstones. Why might that be?	The possibilities are: i) They have not been fossilised here; ii) They lived somewhere else when the limestone was deposited; iii) They had become extinct in the 80 million years or so before the limestone was deposited. The weight of evidence from here and elsewhere, suggests the last theory. (See **MOS4 Briefing** for details).
The species of corals and brachiopods found in these limestones are now also extinct. What other changes have happened to life on earth in the 345 million years since these rocks were formed?	The most likely suggestions will include: i) Evolution and extinction of dinosaurs; ii) Evolution of "popular" Jurassic groups like ammonites etc. iii) Evolution of mammals, (and *Homo sapiens*).

Another possible focus is to link the observations to geochemistry.

Suitable questions at this site	Acceptable answers
What elements make up the mineral calcite (calcium carbonate)?	Ca, C and O.
What are the most common elements in the Earth's crust?	Si, O, Al (Earth has a "glass" lithosphere - with some impurities).
Why doesn't the composition of this rock reflect the average composition of the crust?	Sedimentary processes can produce beds showing chemical separations. First by way of sorting by density and size. Hence sandstones are high in Si and O, whilst finer clays and shales are high in Si, Al and O. Second by chemical (or organic) precipitation from seawater occurs, then 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.

☛ Continue along the footpath through the gorge, up the steps and onto the footbridge over the gorge.

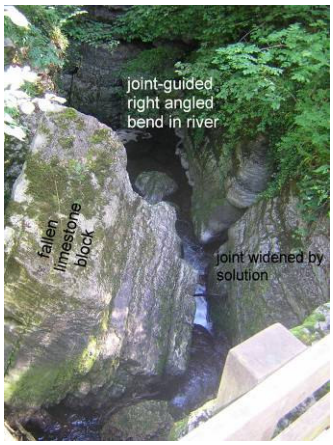

Figure 18. The "Howk" Gorge.

Figure 19. Joints and Pebbles in the Gorge.

Suitable questions at this site	Acceptable answers
Ask the group how do they think this gorge was formed?	Eroded by the down cutting river: chemical processes, and also by eroding limestone fragments. Collapsed block of limestone .
Ask for the evidence they can see for these processes?? Remind them to look down on **both** sides of the bridge. (See **Figures 18 & 19**)	Pebbles in the river bed are evidence of erosion of physically weathered fragments. Solution of joints in the limestone forming the bed is evidence of chemical weathering.
If humans do not interfere, then what will eventually happen to the weathered fragments from this exposure?	They will form new sedimentary rocks in the future (i.e. the next Rock Cycle). Sediment in the River Caldbeck will be taken to the River Eden and then into the Solway Firth.
What kind of fossils might be found in these new rocks by geologists millions of years in the future?	Accept most answers that recognise the need for resistant parts: e.g. boats, cars, cans, ipods, shellfish, dolphins, washed – in trees, drowned birds, (and maybe even human skeletons) etc. But not soft bodied jelly fish etc.
Ask the group to complete **worksheet 6.**	See **MOS8 KS3 worksheets**

☛ Depending on the depth of water which may conceal the stream bed, continue along the river bank for about 40 or 50 metres and view the rock exposed on the stream bed. (See **Figure 20.**)

Suitable questions at this site	Acceptable answers
Ask the group to describe how the rock is being eroded.	The smooth "lumps" (called clints) suggest the rock surface is being lowered, whilst the "grooves" (called grykes) suggest the rock is also being eroded along joint planes.
Ask the group what kind of weathering they think is happening here.	Since there are no sharp edges indicating large pieces being broken away, there is little evidence of physical erosion. Chemical weathering by reaction of the calcium carbonate with acidic water is most likely.
How long has this kind of weathering and erosion been going on in this river bed?	Since the river began to flow at the end of the last glacial period.

Figure 20. Joints widened by solution in Caldbeck river bed.

☛ **Worksheet 7** can be used here to summarise the sequence of events, or be used as a follow-up exercise after the field visit.

There is a circular return walk across the footbridge to the B 5299 and back to the car park in Caldbeck village along the pavement (See **Figure 21.**) or return back the way you came along the footpath through the gorge, to the vehicle.

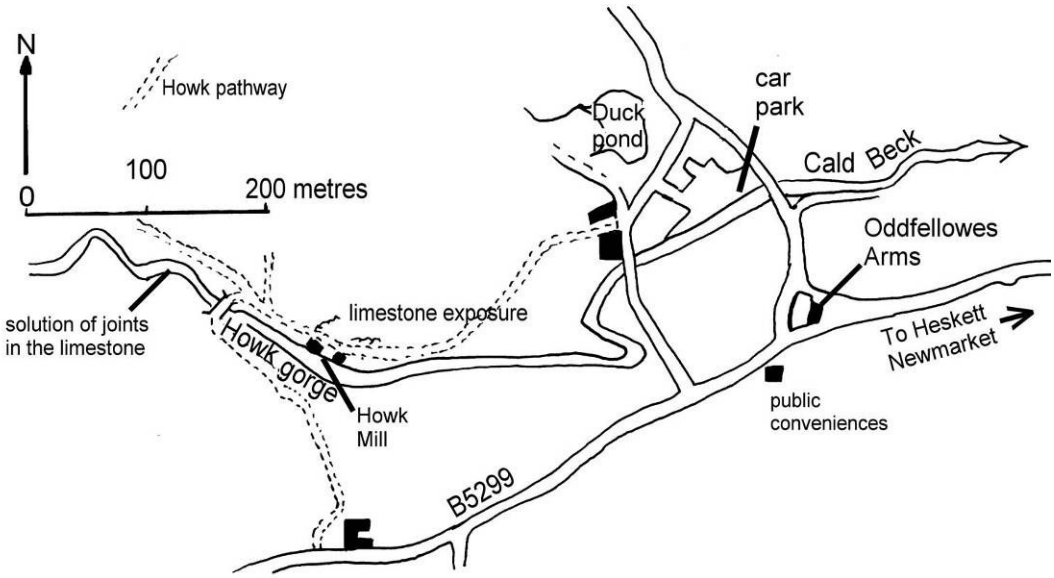

Figure 21. "The Howk" Gorge at Caldbeck.