Skiddaw U3A Geology Group

A Beginner's Introduction to Geology in and around KESWICK

Chris Wilson June 2020

If you live in Keswick or the surrounding area you will be familiar with the local landscapes and the character of the buildings in the town. These features reflect not only the human history of the area over the past few thousand years but also its geological history that extends over nearly five hundred million years.

https://de.wikipedia.org/wiki/Datei:Keswick_panorama_-_oct_2009.jpg

This presentation is just a taster of some of the topics covered during the Skiddaw U3A Geology Course. If you would like to work your way through the main menu then consider joining us. Go to https://u3asites.org.uk/skiddaw/page/32891 for more information

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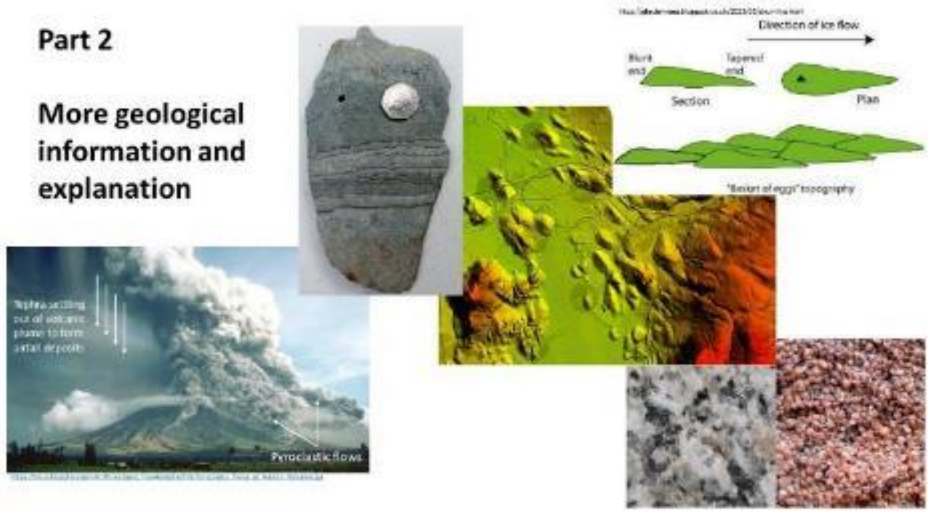

Part 1 In and around Keswick

Part 2 More geological information and explanation

Introduction

The presentation is a compilation of material used in the Skiddaw U3A two-year introductory geology course.

In Part One a series of views of townscapes and local scenery provide starting points for introducing various geological features and aspects of the geological history of the Keswick area. These explanations refer to introductory descriptions and explanations of geological features that are given in Part Two.

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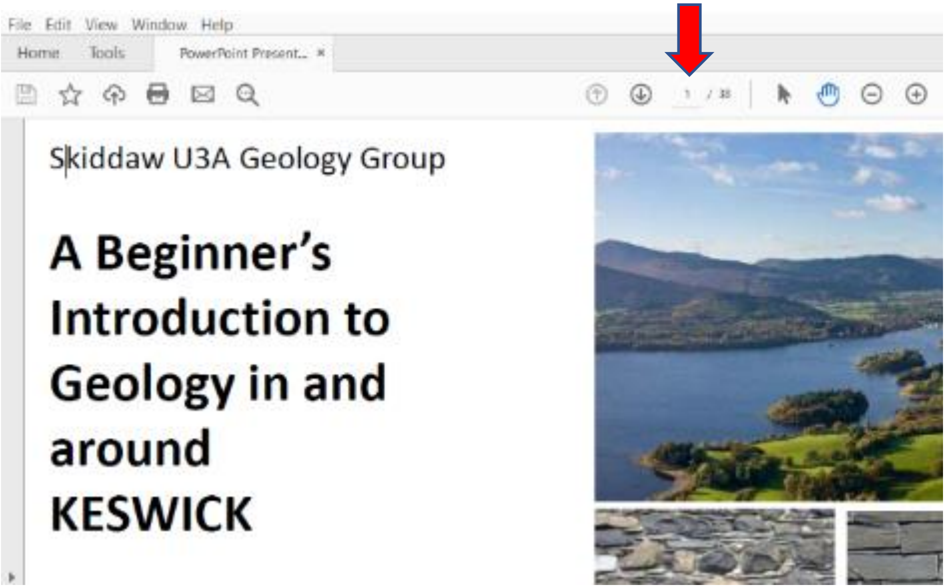


Chris Wilson

Emeritus Professor of Earth Sciences, The Open University

Most of my professional life was spent at the Open University having joined as a founder member of staff in 1969.

I moved to Sherborne in Dorset in 2003 and retired from the Open University the following year. In 2005 I started leading a U3A geology group the focus of which was visiting key sites along the Jurassic Coast World Heritage Site in Dorset and East Devon.

Soon after moving to Keswick in 2015 I started a two year geology programme for Skiddaw U3A and so had to learn about Lake District geology in order to stay one step ahead of the group. I would like to thank Clive Boulter, John Rodgers and Alan Smith* for their invaluable help during this rapid learning process. I am still learning.

*Alan's publications about the geology of the Lake District have been invaluable (see page 43) as were his comments on a draft of this presentation.

Part 1

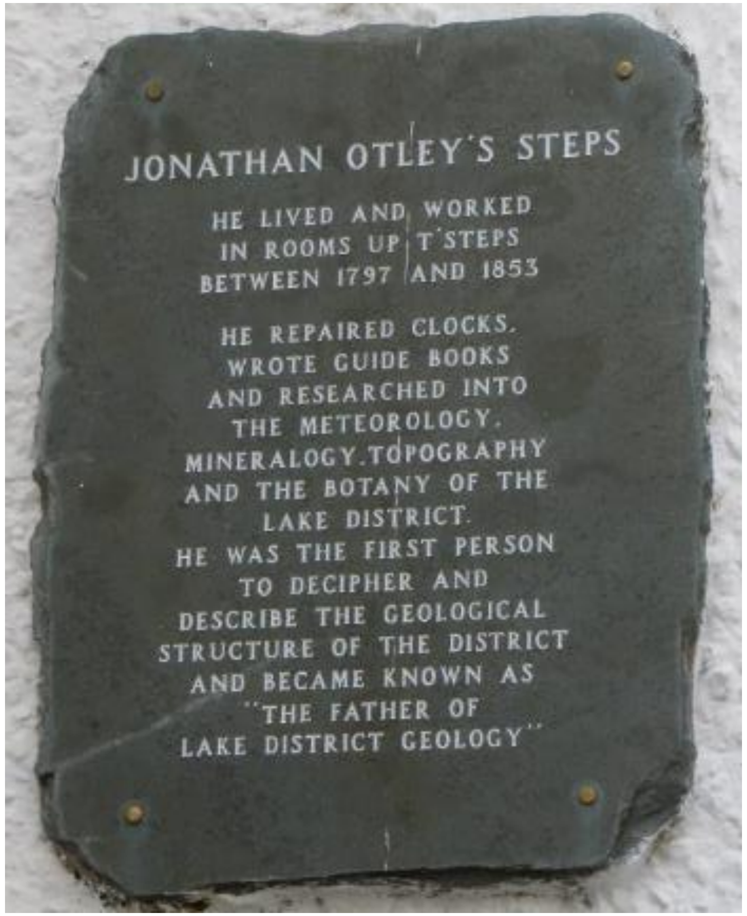
In and around Keswick

Jonathan Otley 1766 – 1856
Father of Lakeland geology

A good place to start a geological tour of Keswick is at Jonathan Otley's house. His contribution to understanding the geology of the Lake District is summarised on the next page.

Keswick Museum & Art Gallery

Jonathan Otley's house in Kings Head Yard
Reached by walking down the alley opposite Moot Hall on the right side of the Cotswold shop.

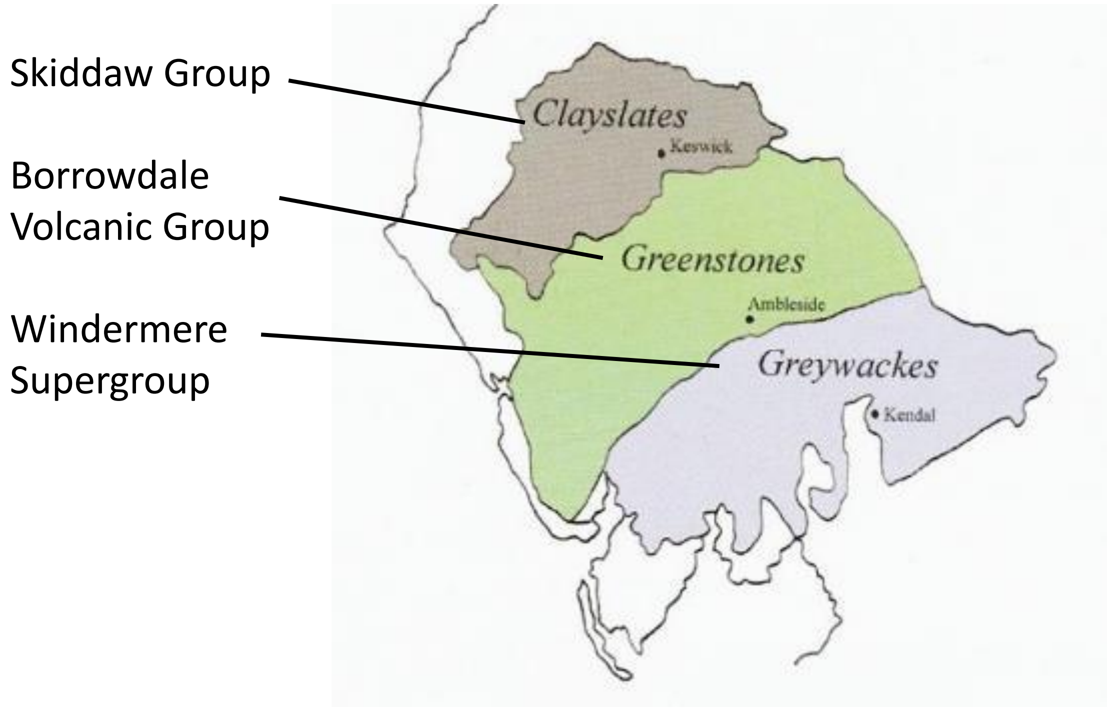


In 1820 Jonathan Otley published a description of the geological structure of the Lake District:
The greater part of the central region of the Lake Mountains is occupied by three distinct groups of stratified rocks of slatey texture.

He named these the **Clayslate, Greenstone** and **Greywacke**.

The modern map to the right shows the distribution of Otley's units and beside it the modern names for them are shown.

He recognised that the *Clayslate* is the oldest of the three units and that the *Greenstones* contain lavas and volcanic ash deposits. The *Greywackes* contain alternating layers of slate and hard sandstones. The term is a German word for 'grey earth' which was adopted by early geologists in several parts of Europe to name hard dark coloured poorly sorted sandstones.



These three inclined books lying on top of one another provide a very simplified model of the structure of the Lake District.

The map is from 'Lakeland Rocks' by Alan Smith, Riggside Publications, Keswick, 2010. A new edition of this book was published in 2019 by The Crowood Press. Marlborough (see page 43).

Geology and scenery around Keswick

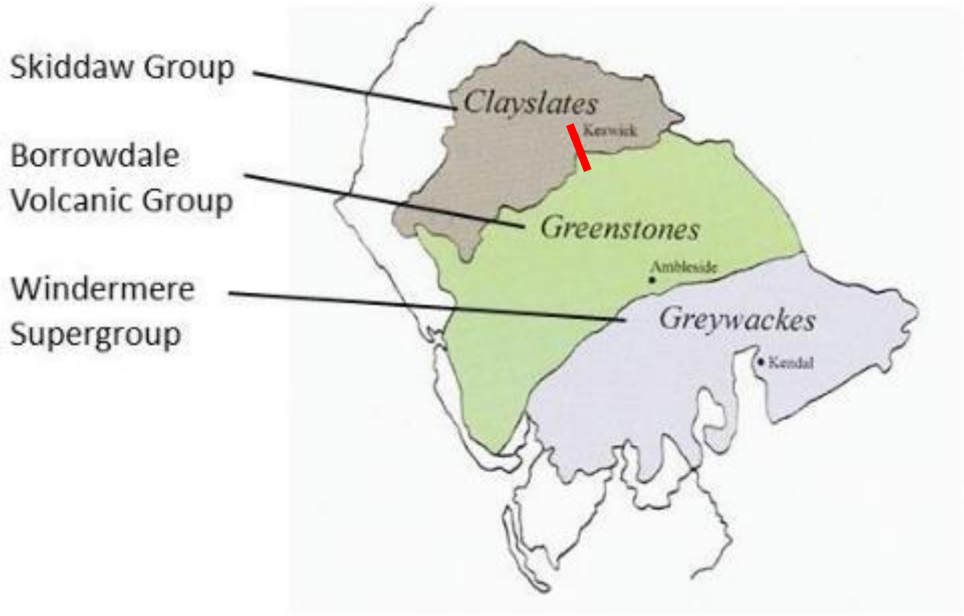
The contrasting landscapes to the north and west of Keswick, and those to the south, reflect the different types of the rocks beneath them.

The smooth slopes of the fells to the north and west of the town are underlain by Skiddaw Group rocks These were deposited on a deep sea floor as muds and fine grained sands between 480 and 460 million years ago. Later these sediments were altered to slates (see page 35) and sandstones when they were buried beneath the younger units and then caught up in a major mountain building episode that culminated about 400 million years ago.

The harder, erosion resistant, volcanic rocks of the Borrowdale Volcanic Group underlie the more rugged Central Fells to the south of Keswick. This volcanic episode occurred between 460 and 450 million years ago.

The lower rolling hills of the South Lakes are underlain by slates and fine grained sandstones deposited between 450 and 420 million years ago.

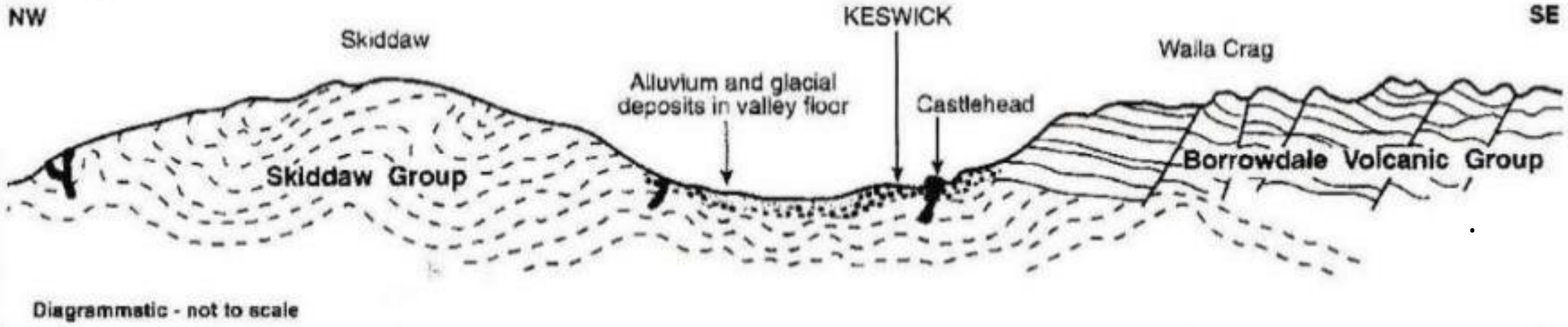
See pages 32 and 33 for an explanation of the geological time scale.



The red line shows the location of the geological cross section.

The wavy dashed lines on the cross section show the complex folding produced by compressive forces during mountain building. The more rigid volcanic rocks were less susceptible to this deformation. The small black areas show rocks that formed as liquid rock (magma) was intruded into the Skiddaw Group at the same time that volcanic activity formed the Borrowdale Volcanic Group (see page 21).

Geological cross section across the Keswick area



From Alan Smith (2004) *Landscapes around Keswick*, Rigg Side Publications.

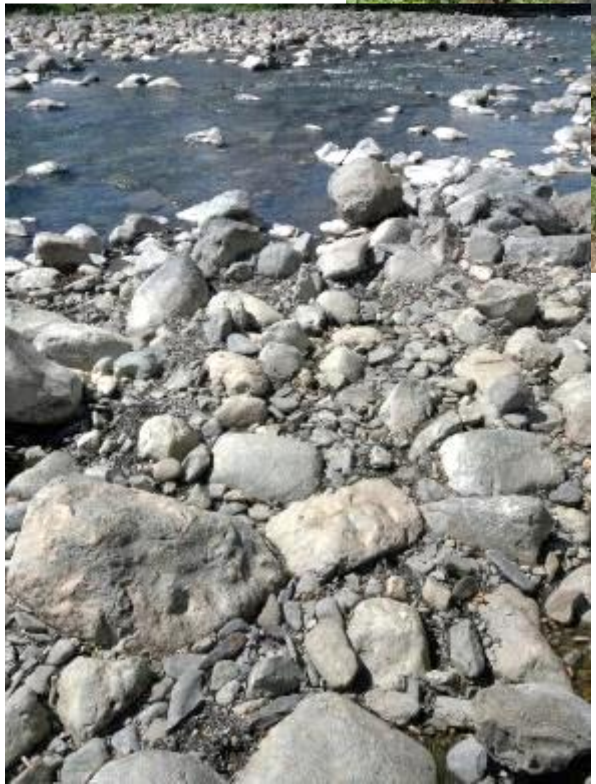
Keswick building stones: gathered stone

The Skiddaw Group on which parts of the town are built consists predominantly of slates that are susceptible to weathering and so are not suitable as building stones apart from being used in dry stone walls. Although not ideal building material cobbles and boulders from river and glacial deposits around Keswick are seen in some buildings around the town. Materials from this source are referred to as *gathered stone**.

Gathered stone in the front wall of St Herbert's Centre, High Hill

Prior to the mid -19th century most buildings in Keswick were constructed of material gathered from easily accessible local river and glacial deposits. These cobbles were ultimately derived from the Borrowdale Volcanic Group. Flat pieces of slaty volcanic ash and occasionally Skiddaw slate are used to level the courses of irregular cobbles. Many gathered stone buildings have been rough cast, rendered and painted.

* I found the information published by Alan and Kath Smith was invaluable in planning geological walks around the town: R.A. & K. Smith, 1998. The Building Stones of Keswick, *Proceedings of the Cumberland Geological Society* vol. 6 pages 233-252.



Pebbles and cobbles in the bed of the River Greta next to Keswick Youth Hostel: a former source of gathered stone. Almost all this material is composed of rock types that occur in the Borrowdale Volcanic Group.

Examples of gathered stone buildings

South east side of Derwent Close.

North east side of Standish Street.
The red lintels are Penrith sandstone.

South west side of Moot Hall.

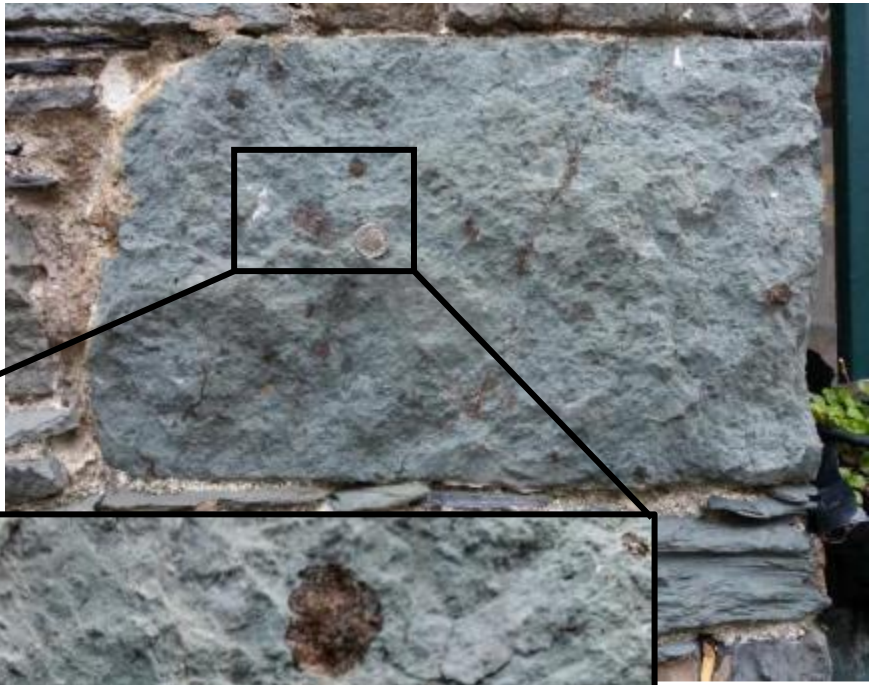
Red volcanic breccia.
A breccia is a poorly sorted accumulation of angular shaped volcanic or sedimentary fragments.

Hand trimmed blocks of volcanic ash containing irregular fragments or eruptive material.

See next two pages for explanations of the origin of these blocks of gathered stone originating from the Borrowdale Volcanic Group.

Volcanic rocks at Moot Hall

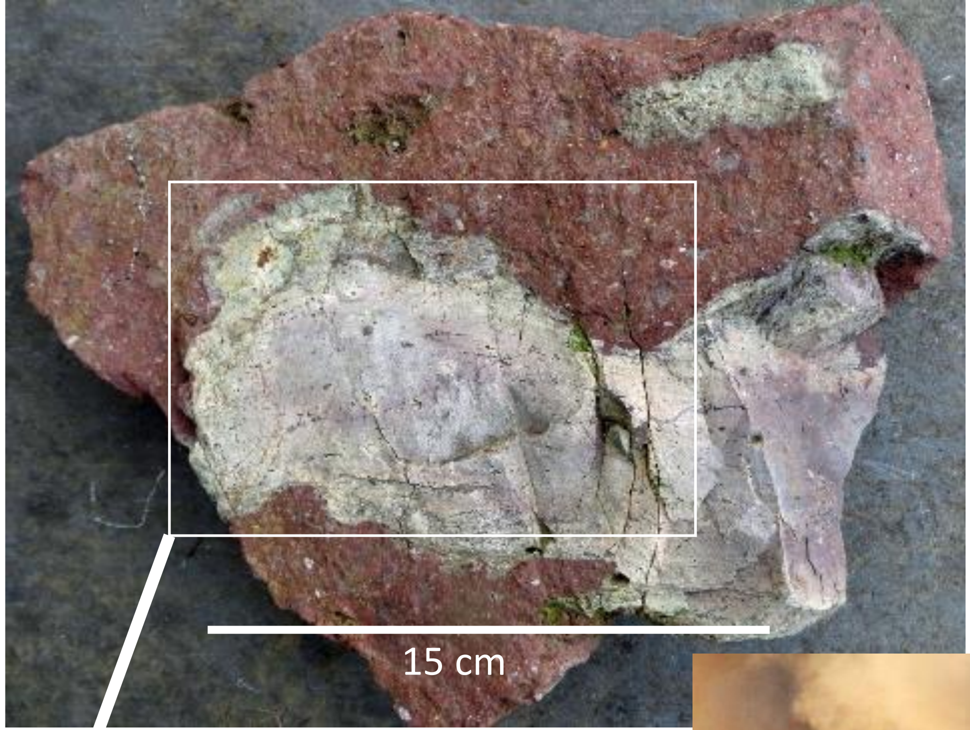
A boulder of a red volcanic deposit derived from near the base of the Borrowdale Volcanic Group.
Some of the fragments were weathered away leaving angular holes. The origin of this rock type is explained on the next page.



Right photos: block of grey green volcanic ash containing irregular dark brown blobs of lava.
The blobs of lava were thrown out by volcanic explosions that also produced the volcanic ash. The blobs were still molten when they landed but quickly cooled so that gas bubbles were preserved. The green spots within the blobs are bubbles filled with volcanic ash .

Sample collected the eastern shore of Derwentwater from near the base Borrowdale Volcanic Group

It is probable that the red deposit resulted from explosive volcanism caused by molten rock (magma) coming into contact with water. The resultant volcanic fragments may have fallen into water and the finer grained material was possibly transported short distances by currents.



The upper photo shows an irregular shaped fragment of lava encased in red volcanic material. The enlarged view (bottom left) shows lines of gas bubbles trending roughly parallel to the longer edge of the lava fragment. It was formed as pieces of red hot lava were flung out of a volcanic vent (bottom right).

Keswick building stones: 'Lakeland Green Slate'

This grey-green rock typifies the town. Despite being used as roofing slate for centuries its common use as a building stone only began in the 1850s when the town began to grow to accommodate increased numbers of tourist especially when the railway station opened in 1865.

Lakeland green slate started life as a volcanic ash often referred to as *tuff*. There are two thick intervals of tuff in the Borrowdale Volcanic Group: an older one in Borrowdale and a younger one to the south between Kentmere and Coniston. They were deposited as ash from nearby eruptions fell into lakes. As they were buried under thousands of metres of younger deposits they slowly changed into hard rocks. Compression of these rocks during Earth movements associated with a major mountain building episode about 400 million years caused minerals within the tuffs to become aligned parallel to one another. It is easy to split the tuffs along *cleavage planes* that follow this alignment. These planes are not related to the original layering of the tuffs that developed as they were deposited on the floors of lakes. A full explanation of the relationship between depositional layering and cleavage is given on page 36.

Some intervals of the tuffs can be split very thinly along cleavage planes to produce roof tiles and or buildings stones. More massive tuffs are split along cleavage planes to produce blocks thick enough to be used in the construction of walls. It is unusual to be able to produce blocks of building stone thicker that 30 cm and 15 cm is the more common thickness. The blocks can be trimmed manually along natural vertical weaknesses called joint planes that are perpendicular to the cleavage direction (A below; see also photo at bottom left of page 16). A more expensive option is to cut them using masonry saws to produce very regular blocks that fit closely together (B). Modern buildings usually use the tuffs as facing material using blocks formed by manual splitting along cleavage and joint planes plus vertical saw cuts (C).


A


B


C

Guest houses on St John's Street opposite the church.

The contrasting appearance of the houses in this terrace reflects the budgets available to build them.

'Greystones' on the right was built in 1863 using machine cut blocks bonded with thin amounts of mortar. The door jambs, window sills and lintels were made from very large and expensive blocks of tuff obtained from Quayfoot Quarry in Borrowdale (passed when walking to the Bowder Stone from the nearby car park).

'Strathmore' on the left was built in 1868 using cheaper iron stained tuffs (see photo below) that were hand trimmed and laid dry. Sandstone was used for jambs (now painted over), sills and lintels instead of more expensive large blocks of tuff.

Left photo: the flat faces of two of the blocks are coated with a thin veneer of iron hydroxide. This mineral, which is similar to rust, was precipitated from ground waters long after the tuffs were formed. The flat faces are known as joint planes. They occur in all types of hard consolidated rocks and are the result of tensional forces that usually produce two sets of joints trending at right angles to one another.

‘Rainspot slate’ steps outside The Edwardine B&B on Southey Street

‘Rainspot slate’ is a local term that is misleading because there are no rainspots in the rock. It is a volcanic deposit with larger fragments produced during explosive activity enclosed in a finer matrix of tuff.

Imported stone in Market Square

This view shows building material imported from beyond the Keswick area.

Barclays Bank
Red Penrith sandstone plus Borrowdale slate blocks in the upper floors. The sandstone was deposited in desert sand dunes 280 million years ago when Britain was situated at the same latitude as the Sahara desert is today.

Seasalt
Lighter coloured Carboniferous sandstone the origin of which is not known but likely to be from within Cumbria.

Paving stones
These were imported from Lancashire, Italy and China – see next page.

Paving stones in Market Square (and in nearby streets)

These materials were laid in 2003. Thanks to Alan Smith for letting me have information he obtained from the contractors undertaking the work.

1: the setts are a Carboniferous sandstone from Whinney Hill Quarry, Accrington, Lancashire.

2: the curb stones are granite imported from China. See close up view on page 19.

3: these pavement areas are described by the contractors as 'a red/brown porphyry' sourced from the Atesina platform near to Bolzano Northern Italy (see close up view on next page). The website* of one of the major quarry companies in the area gives an age of 260 million years and states that the rock is an ignimbrite. *Ignimbrites* are deposits formed from a pyroclastic flow which is a hot chaotic mixture of rock fragments, gas, and ash that travels rapidly (tens of meters per second) away from a volcanic vent (see page 36). So whereas the rock is foreign its origin is similar to parts of the Borrowdale Volcanic Group.

* http://www.porfidotrentino.com/en/porphyry/

Ignimbrite paving slabs

The pink flecks are small crystals of the mineral feldspar. They are set in a fine grained matrix of volcanic ash. The irregular orange pieces are possibly fragments of lava expelled during the violent eruption that caused the formation of the pyroclastic flow.

Granite in Keswick

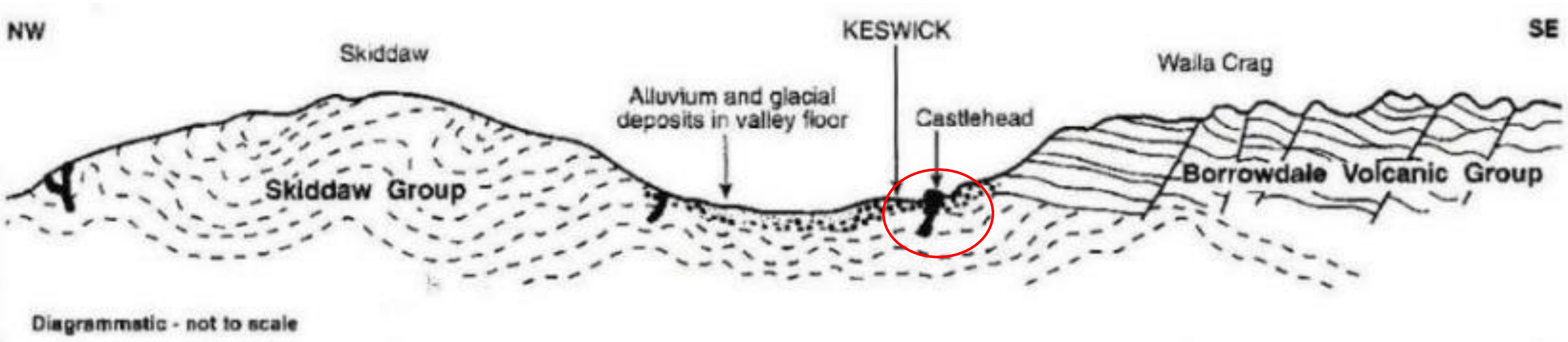
Granites are coarsely crystalline light coloured igneous rocks.

Right: the entrance to the Methodist Church Hall in Keswick is flanked by columns of Peterhead granite. This igneous rock consists of tightly interlocking minerals and exhibits a crystalline texture (see pages 40 & 41) that formed as liquid rock (magma) cooled slowly at least five kilometers below the Earth's surface. Four types of mineral occur: white, dark grey, pink and black.

Left: granite curb stones in Market Square. This rock does not contain the pink mineral. *Right:* more granites can be seen in headstones around St Johns Church.

Castlehead dolerite

The Castlehead dolerite is another igneous rock. The crystals within it are very small because, unlike coarsely crystalline granite, it cooled rapidly at shallow depths within the Earth's crust. It is a very dark grey to black rock as all the minerals within it are dark coloured. It was quarried for only about 20 years from around 1840.



The rock was extracted from several quarries around Castlehead (see page 30). The magma from which it cooled rose through an irregular shaped pipe that penetrated the surrounding Skiddaw Group to form a plug shaped igneous intrusion that extends from Castlehead westwards to Friar's Crag on the shore of Derwentwater. The rising magma was a source of some of the lava flows in the Borrowdale Volcanic Group.

Most of the blocks used to build Vergers Cottage on St John's Street are Castlehead dolerite.

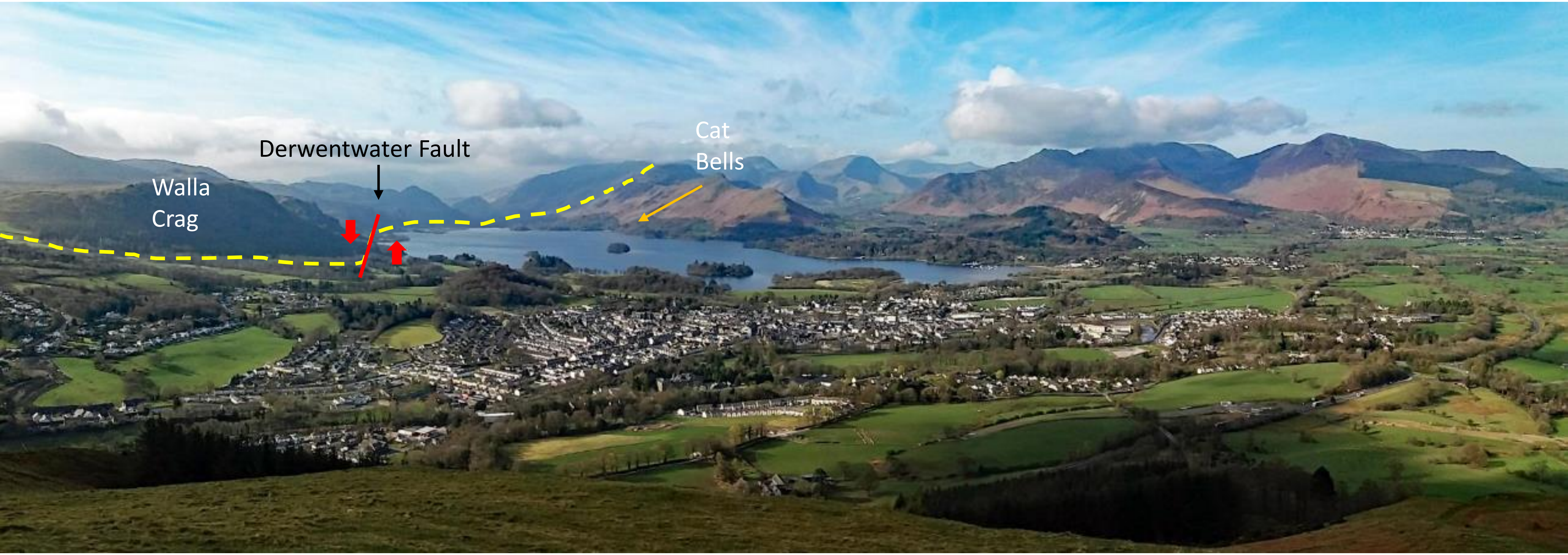
The darker blocks in this wall are Castlehead dolerite that have slightly irregular surfaces in contrast to the lighter coloured blocks with flatter faces of material from the Borrowdale Volcanic Group.

Scenic views around Keswick

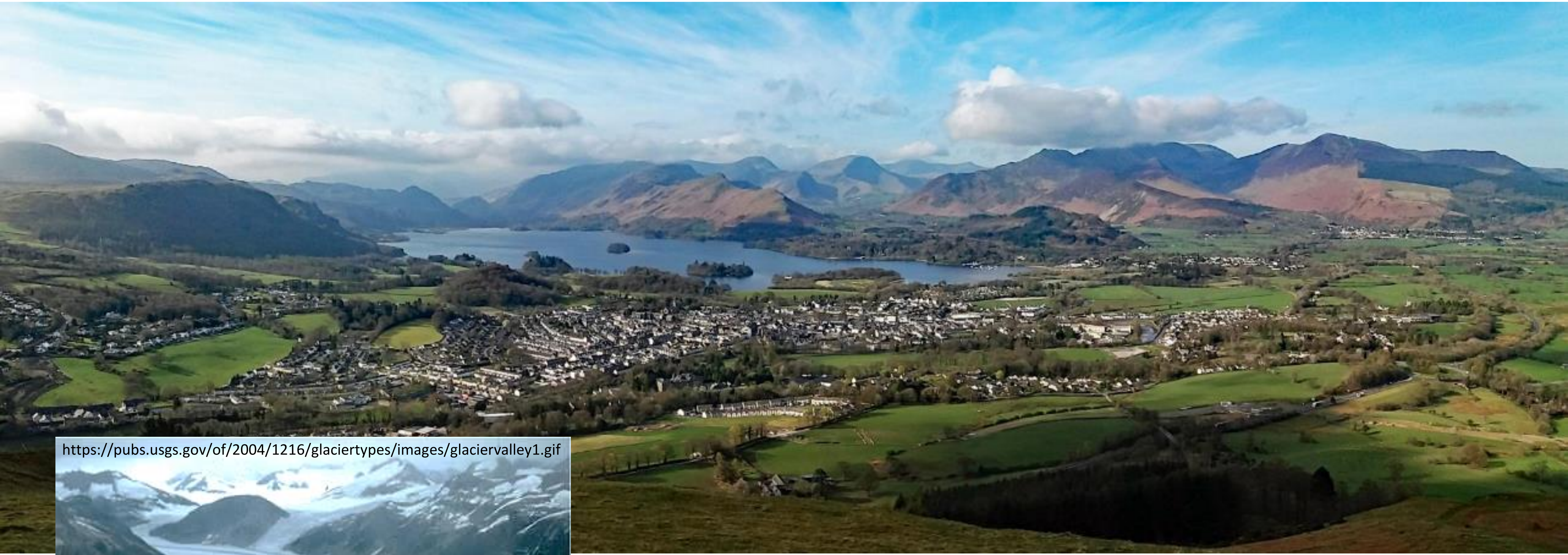
View south from Crow Park

Looking south s down Derwentwater the sprinkling of snow makes it easier to pick out the south easterly inclination of the rocks underlying the fells along the west side of the lake. The arrows show the inclination of lines across which vegetation changes occur; these follow layers within the Skiddaw Group rocks. The slope on the SE side of Cat Bells also follows this direction. The yellow dashed line indicates the boundary between the Skiddaw Group on the right and the Borrowdale Volcanic Group on the left.

View south from Latrigg



The orange arrow indicates the southeasterly inclination of the Skiddaw Group strata. The yellow dashed line shows the boundary between the Skiddaw and Borrowdale Volcanic Groups. This boundary is displaced about five kilometers to the north by the Derwentwater Fault which runs along the eastern shore of the lake. This explains why the Borrowdale Volcanic Group is exposed on Walla Crag but the Skiddaw Group occurs on the opposite side of the lake. The approximate position of the fault is shown as a red line and the relative displacement across it by the red arrows. The displacement is probably a combination of vertical and sideways movements.



https://pubs.usgs.gov/of/2004/1216/glaciertypes/images/glaciervalley1.gif

This view of a glacier in Alaska gives a general impression of what Borrowdale would have looked like when the area was glaciated.

Twenty thousand years ago this view would have looked very different. Major glaciers would have flowed up Borrowdale towards Keswick, eastwards and northeastwards along the Newlands valley and eastwards along the Greta valley on the left of the photo. These glaciers merged and flowed northwestwards across what is now Bassenthwaite lake.

View north across from Crow Park

The elongate mound shaped topography of the meadow is typical of glacial features known as *drumlins*. The name is based on the Gaelic word *druim* which means a rounded hill or mound.
The distribution of these features around Keswick and their glacial origin are explained on pages 27-30.

https://de.wikipedia.org/wiki/Datei:Keswick_panorama_-_oct_2009.jpg

Derwentwater and Skiddaw viewed from Walla Crag.
CH: Castlehead; CP: Crow Park.
The islands in Derwentwater are drumlins as are the low hills to the east (right) of them except for Castlehead which is a crag and tail feature (see pages 29 & 30).

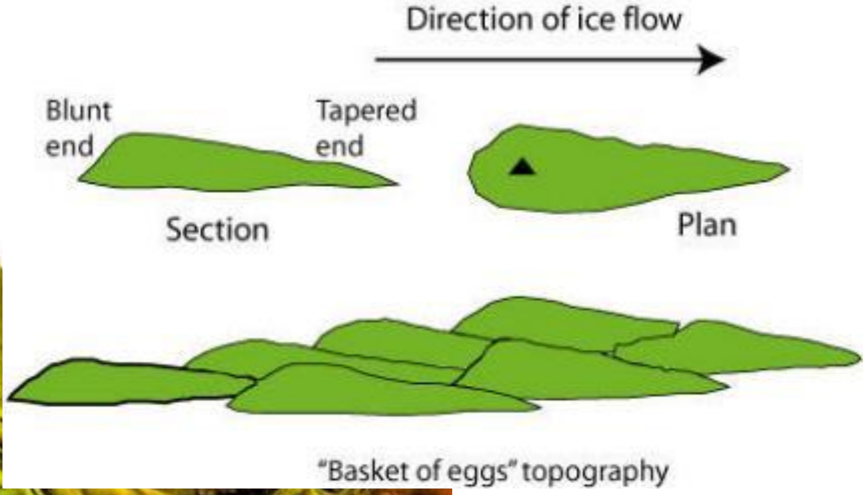
View from Latrigg looking towards Thornthwaite taken in winter an hour or so before sunset. The low elongate hills along the valley floor are drumlins.

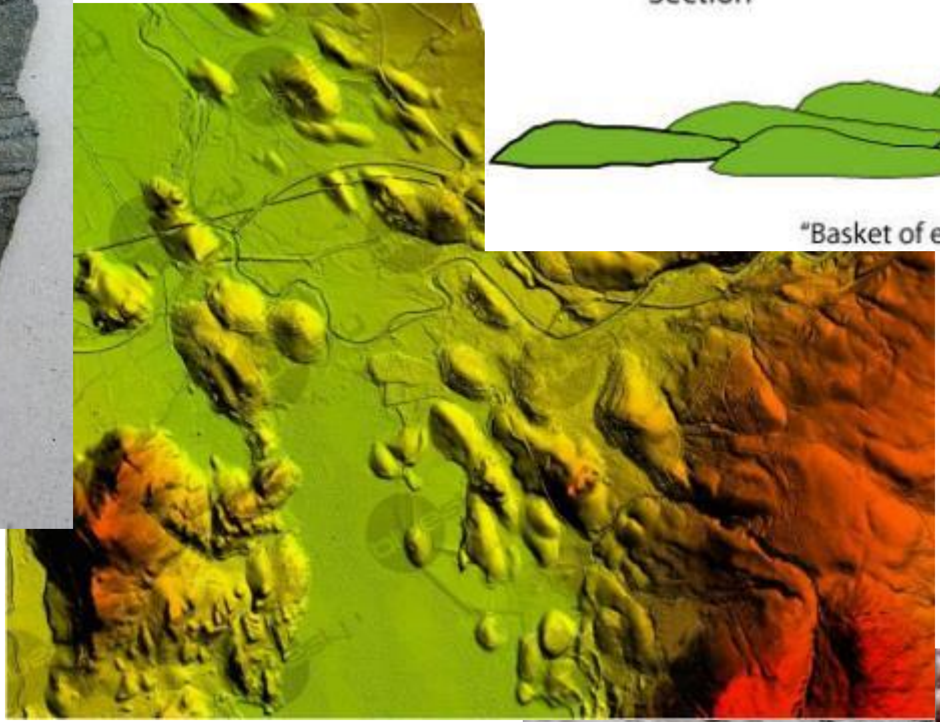
Part 2

More geological information and explanation

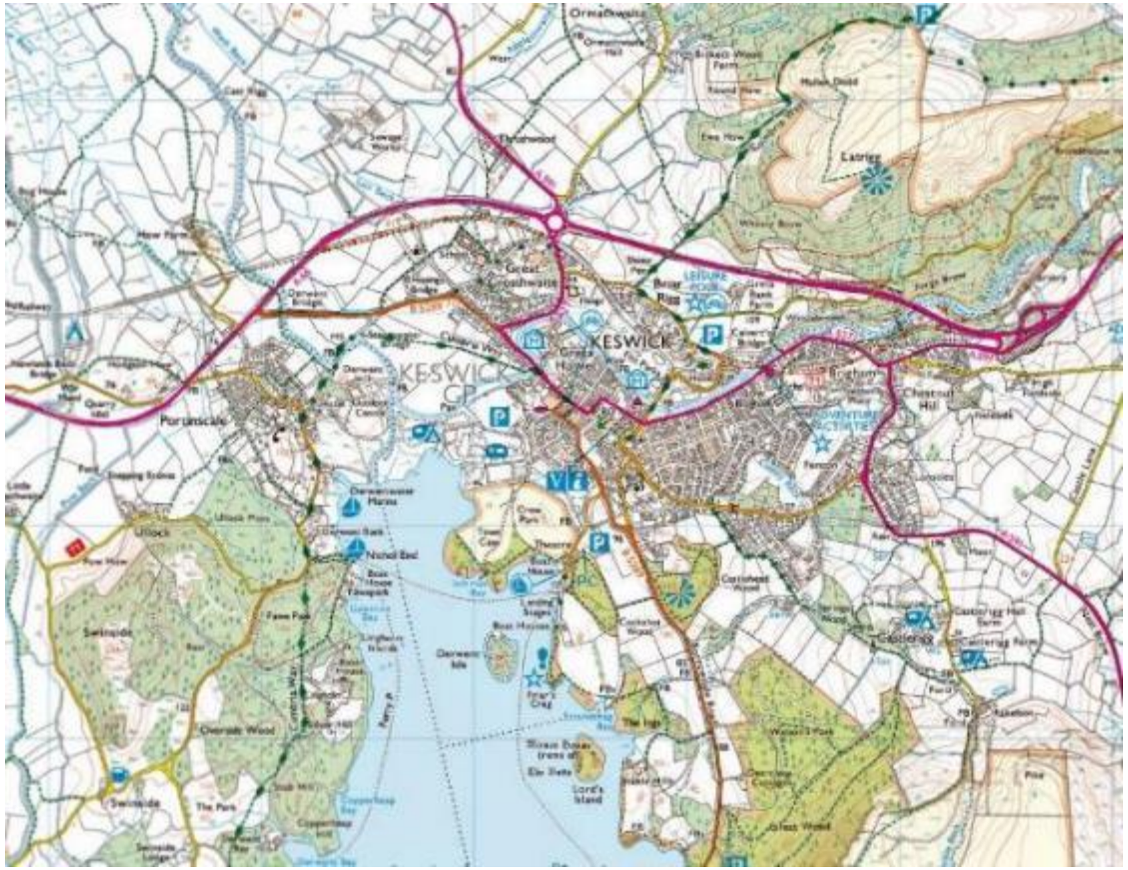
https://en.wikipedia.org/wiki/Pyroclastic_flow#/media/File:Pyroclastic_flows_at_Mayon_Volcano.jpg

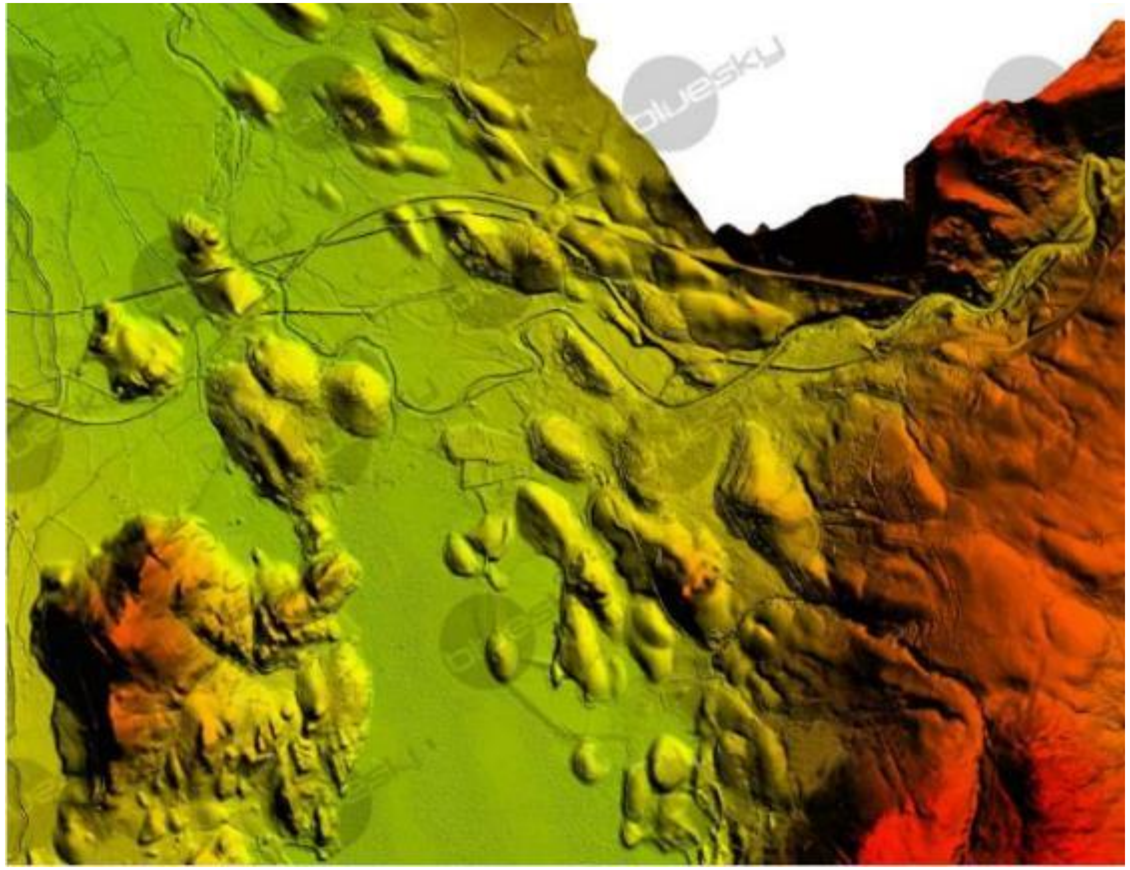
http://glacialmass.blogspot.co.uk/2013/05/drumlins.html





Glacial features around Keswick: drumlins and crag and tail

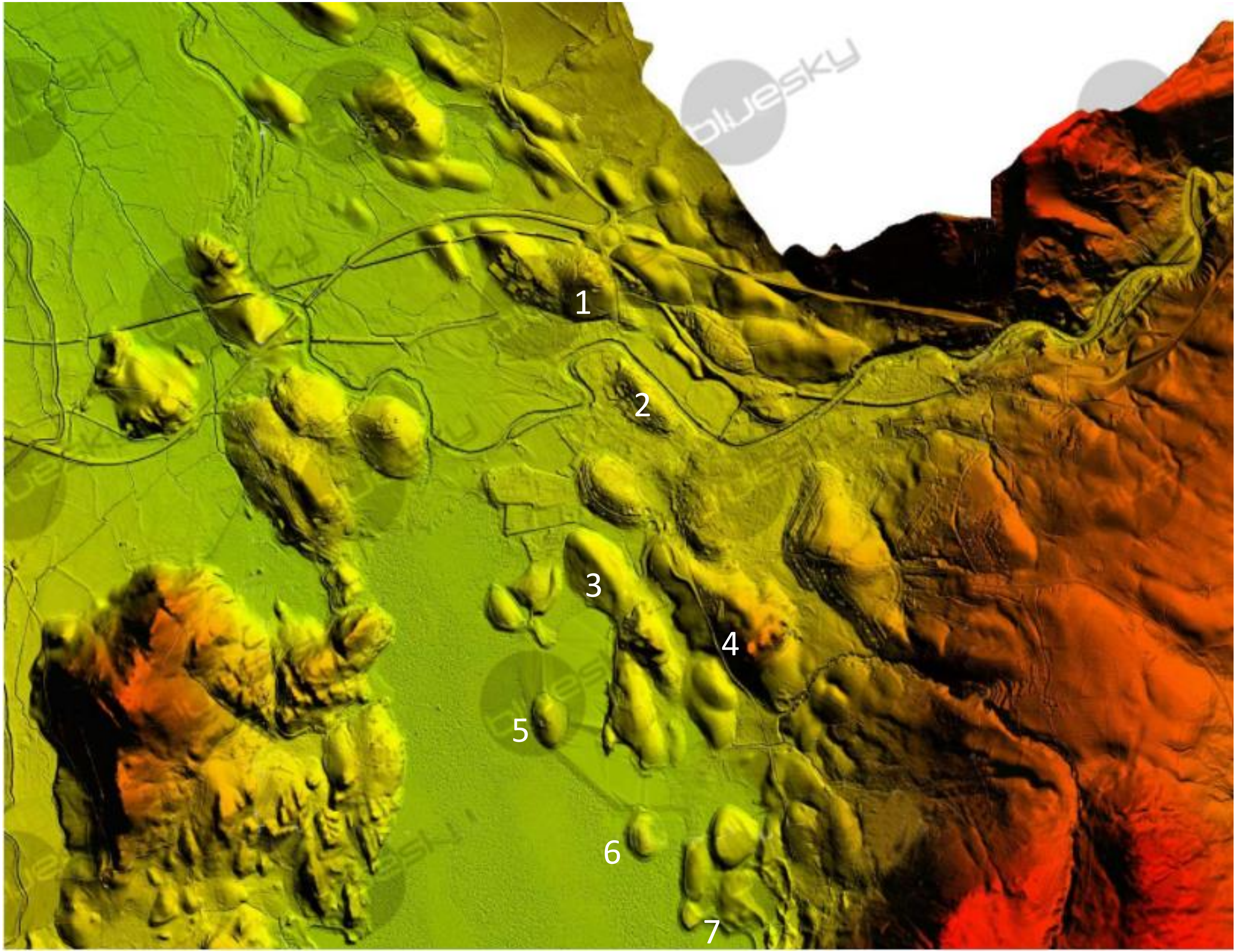




Ordnance Survey Explorer map of the area around Keswick and a LiDAR image of the same area

LiDAR is an acronym for Light Detection And Ranging. LiDAR technology uses light sensors to measure the distance between the sensor and the target object. From an aircraft this includes objects such as the ground, buildings and vegetation. The data collected is used to build a digital 3D model of an area that can be illuminated from any direction – from the north east in this example. This enables topographic features to be graphically revealed in a way not possible on maps or aerial photos. The drumlins around Keswick stand out clearly on the LiDAR image.

The LiDAR images shown in this presentation are from http://lidar-uk.com/. The images available on this site show a white dashed line square which I have removed. All the images are overprinted by a circle and the word 'Bluesky' which I have not attempted to edit out. Lower ground on the images is shown in green grading through yellow to red for higher elevations.



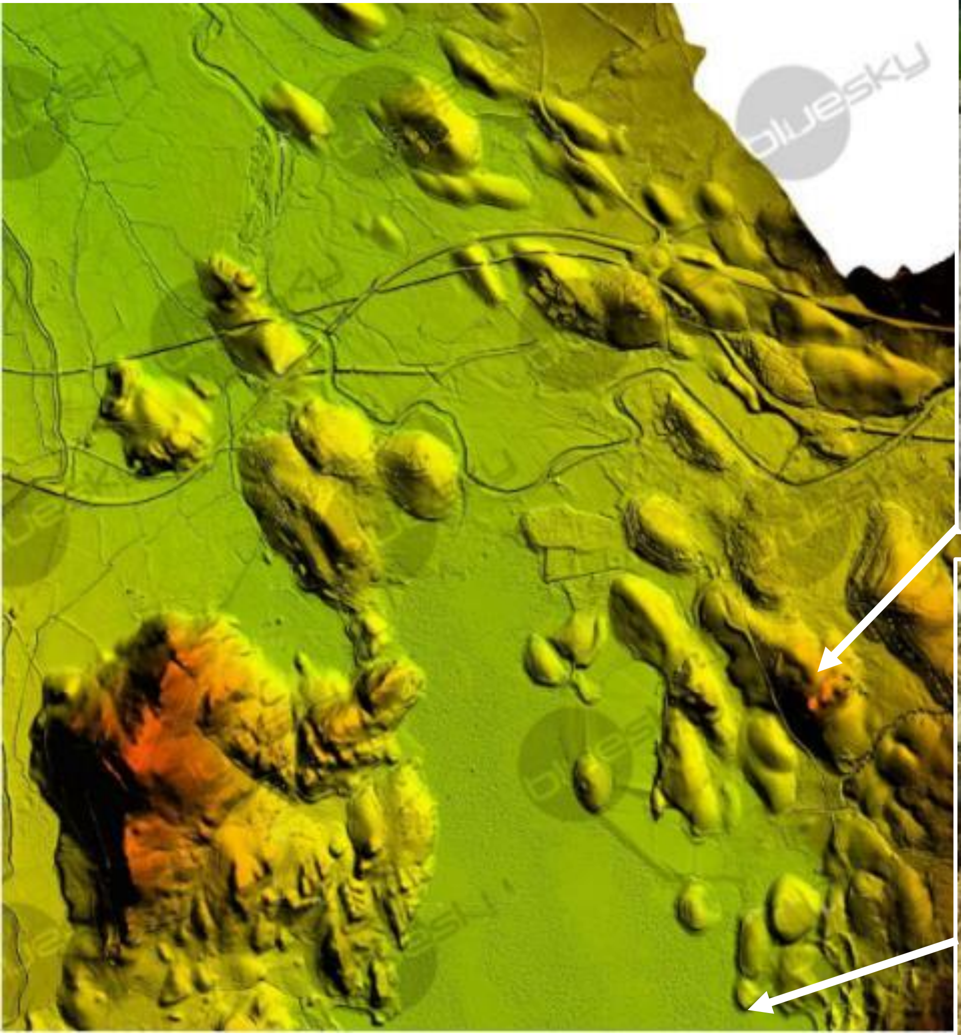
Drumlins around Keswick

Most of the elongate hills on the LiDAR image are drumlins. Their long axes indicate the *trend* of ice flow which changes from south to north around Derwentwater to southeast to northwest to the north of the town. Boulders of Borrowdale Volcanic Group rocks must have originated from areas to south of the town. This, together with the trend of orientation of the long axes of the drumlins, indicates that the ice flow direction was towards the north and northwest.

1: Great Crossthwaite
2: Greta Hamlet
3: Crow Park
4: Castlehead (see next page)
5: Derwent Isle
6: Lord's Island
7: Calf Close Bay (see next page)

Drumlins: 1, 2, 3, 5, 6, 7.
Crag and tail: 4 (see page 30).

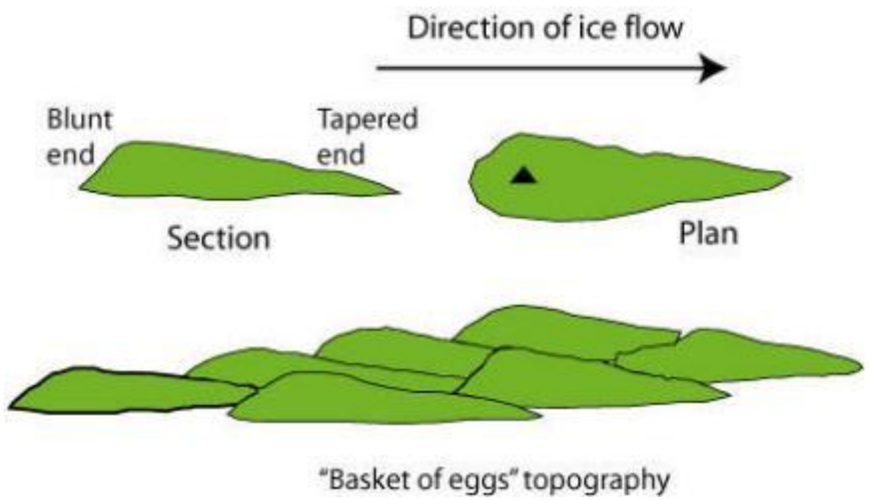
Castlehead and Calf Close Bay



Glacially smoothed and striated dolerite at the summit of Castlehead indicates that the hill was completely covered by the glacier flowing north out of Borrowdale. It is probable that this hill is an example of a crag and tail feature (see next page). The quarries on the flanks of Castlehead are visible of the LiDAR image.

Boulder clay exposed in a low cliff at the northern end of Calf Close Bay. This poorly sorted mixture of pebbles, rock fragments and clay is typical of sediments deposited by melting ice at the base of glaciers. This exposure is located at the southern end of a drumlin.

Drumlins



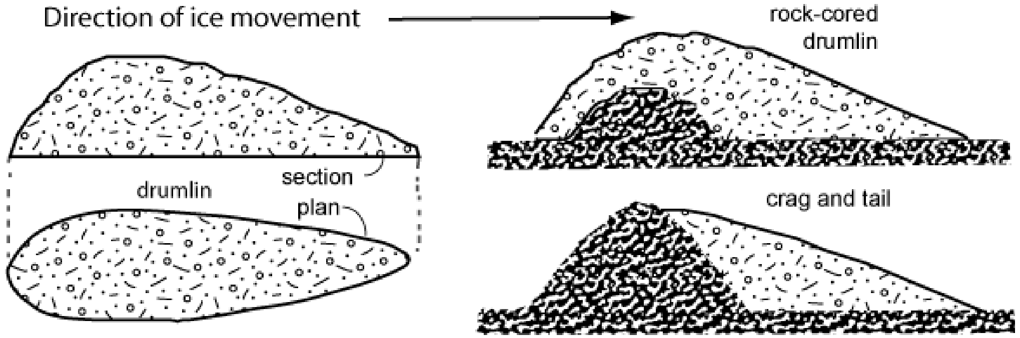
http://glacialmass.blogspot.co.uk/2013/05/drumlins.html

The name is based on the Gaelic word *druim* which means a rounded hill or mound.

Drumlins typically have one very steep side and one more gradually sloping side which is inclined in the direction that the glacier moved. They often occur in groups. They were deposited and sculpted at the base of moving glaciers. Drumlins are composed of *till* or *boulder clay.* The latter term is a good shorthand description of poorly sorted sediment, ranging in grain size from clay particles to boulders, that is deposited adjacent to or under glaciers as they melt. The lower right photo on the previous page shows a typical exposure of this type of sediment.

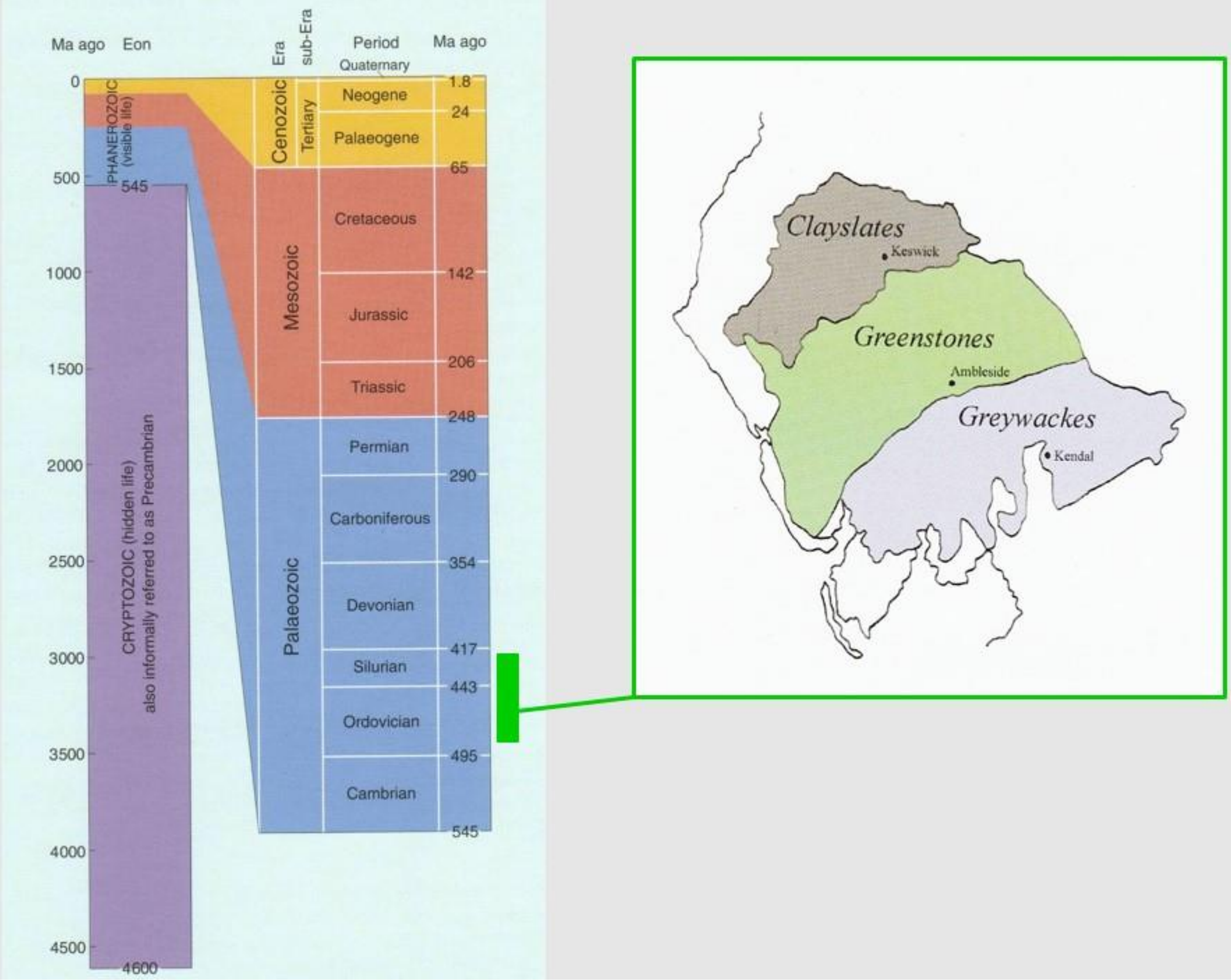
Crag and tails

These form when ice flows over and around a more resistant mass of rock such as a volcanic vent. The more resistant rock withstands glacial erosion better than surrounding softer rocks so remains as a topographic high. Glacial till is deposited downstream of the feature producing the tail. Castle Rock and the Royal Mile in Edinburgh is perhaps the most famous example of this feature. Castlehead is a local example (see previous two pages).



Drumlin Crag and tail

http://www.bianoti.com/gallery-glacial-landforms.html

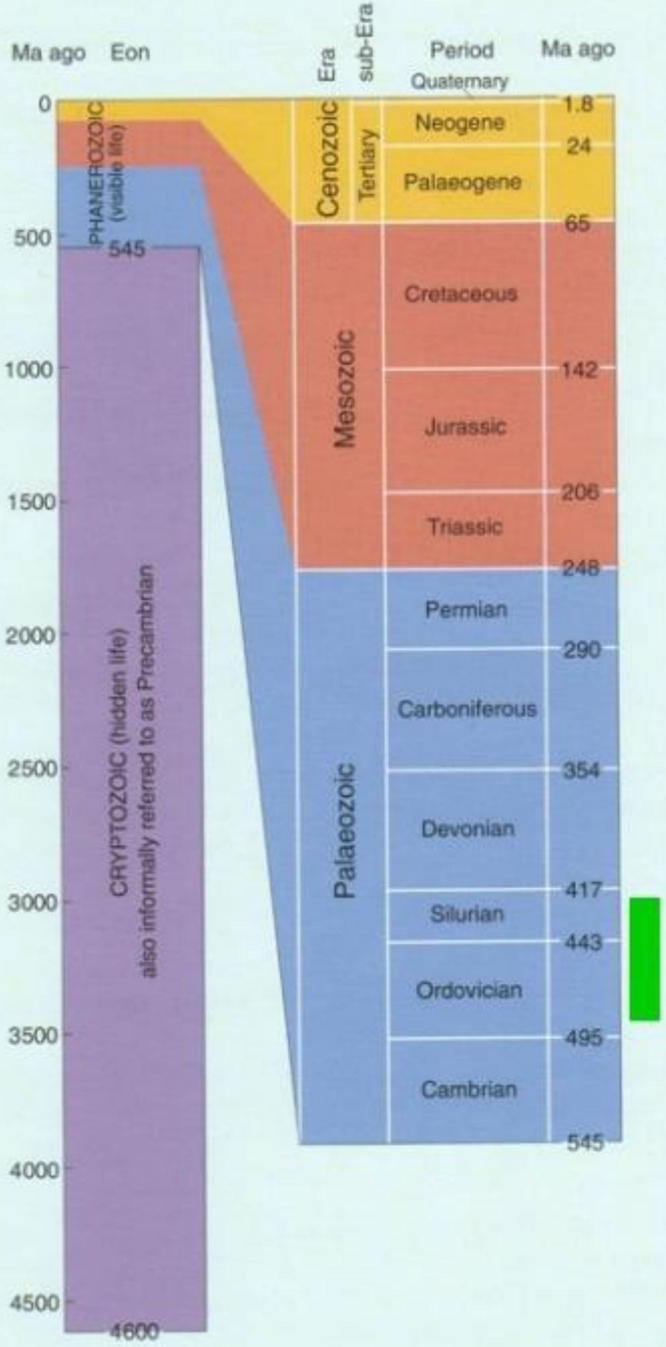


The Geological Time Scale

The diagram on the left shows the terms used to divide geological time. The age range of Otley's three rock divisions is shown.

The 'Clayslates' and 'Greenstones' were formed during the Ordovician Period, and the 'Greywackes' during the Silurian Period.

See next page for more explanation of the divisions of geological time.



Eon Phanerozoic (visible life)
Cryptozoic (hidden life)
or Precambrian

Era Cenozoic (recent life)
Mesozoic (middle life)
Palaeozoic (ancient life)

Period e.g. Ordovician,
Carboniferous

The Cryptozoic Eon is characterised by the occurrence of fossils of single celled life. The start of the Phanerozoic Eon (and the base of the Cambrian Period) is marked by the appearance of fossils of animals with hard shells. Most of the Periods were defined by British geologists. The Cambrian, Ordovician and Silurian Periods were first recognised in Wales with the two younger Periods named after Roman names for Welsh tribes.

The diagram summarises how geological time is divided and named. Today we know that the Earth was formed 4.6 billion (4 600 000 000) years ago and modern methods enable the duration of the divisions shown on the diagram to be determined. However the names used in the diagram were recognised long before it was possible to determine the absolute ages of rocks. The divisions and their age order from oldest to youngest were established nearly 200 years ago by regional studies defining successions of sedimentary rocks and studying the fossil assemblages found in different parts of these successions.

From mud and volcanic ash to slate

Mud to shale via compaction

Most slates originated from muddy sediments deposited on ancient sea floors.

The photos illustrate the compaction of sedimentary mud to form clay, mudstone and shale as the original deposits were buried to deeper and deeper levels and water was progressively expelled from them.

Mud

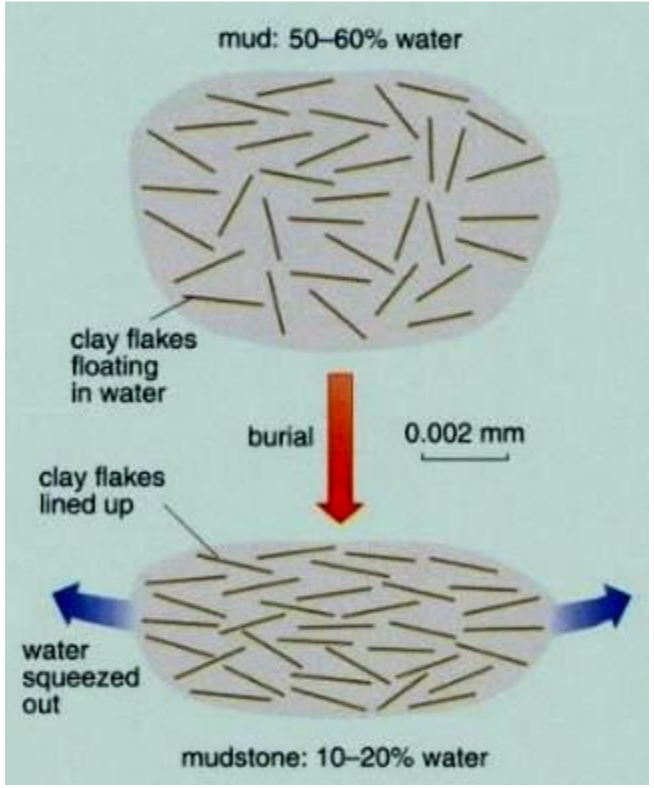
https://canilearntopaint.files.wordpress.com/2015/08/mud-face.jpg

Clay

https://4.bp.blogspot.com/-iNOCqEc4S3I/Va-IlszONOI/AAAAAAAAEPU/xgS_Ptnw3og/s1600/potter_clay2.jpg

Mudstone

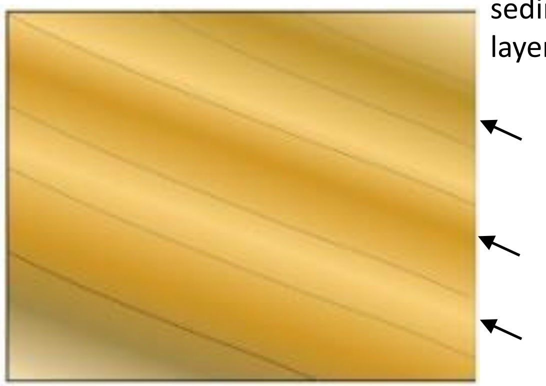
Shale



Muds consist of randomly orientated microscopic flakes of clay minerals that are held apart by water. This type of sediment contains between 50 and 60% water. As muds are buried beneath overlying sediments water is expelled and the clay minerals become progressively more aligned.
Clays have a water content of around 30% which means that they can be molded easily. Further reduction in water content to between 10 and 20% results in mudstones which show an irregular fracture pattern as the mineral alignment within them is only poorly developed. Shales contain even less water than mudstones and the clay mineral alignment within them is well developed so that they spilt easily along planes parallel to the original layering of the sediment.

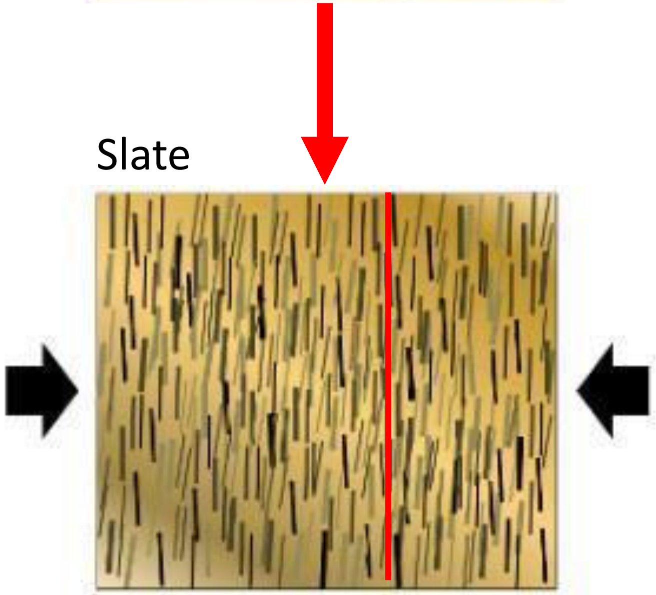
Compressional Earth movements and cleavage

Mudstone or shale



Arrows show sedimentary layering

Slate



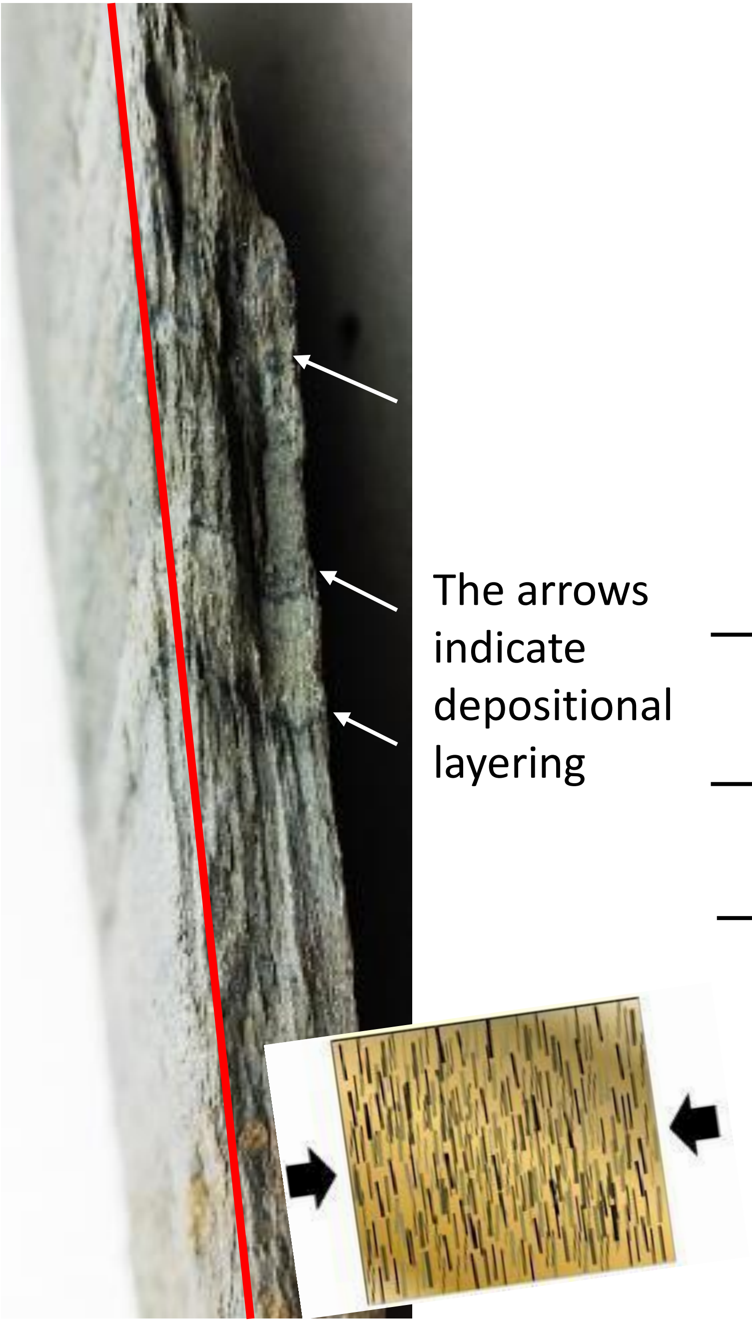
http://opentextbc.ca/geology/wp-content/uploads/sites/110/2015/07/image007.png

The large black arrows in the lower diagram show compressional Earth movements occurring several kilometres beneath the Earth's surface. These movements caused the formation of new types of flake shaped minerals the parallel orientation of which produces the cleavage direction in slates. These new minerals grow perpendicular to the direction of maximum compression so that the cleavage direction (the red line on the diagram) cuts across the original depositional layering. The original sedimentary layering is faintly visible – the cleavage cuts across these layers.

The bricks and slates used to build this house (it is not in Keswick) were made from mud deposits. They are examples of natural and artificial *metamorphic* rocks. This type of rock formed from pre-existing rocks in response to heating and changes in pressure within the Earth's crust. Metamorphism does not significantly change chemical compositions but often results in the growth of new minerals which are often aligned resulting in a characteristic banded appearance.

Bricks are artificial metamorphic rocks. The heat of the brick kiln drives off water from the clay and alters the clay minerals.

The Welsh roof slates are natural metamorphic rocks formed by heat and pressure as clay sediments were buried and deformed deep under mountain belts.



The arrows indicate depositional layering

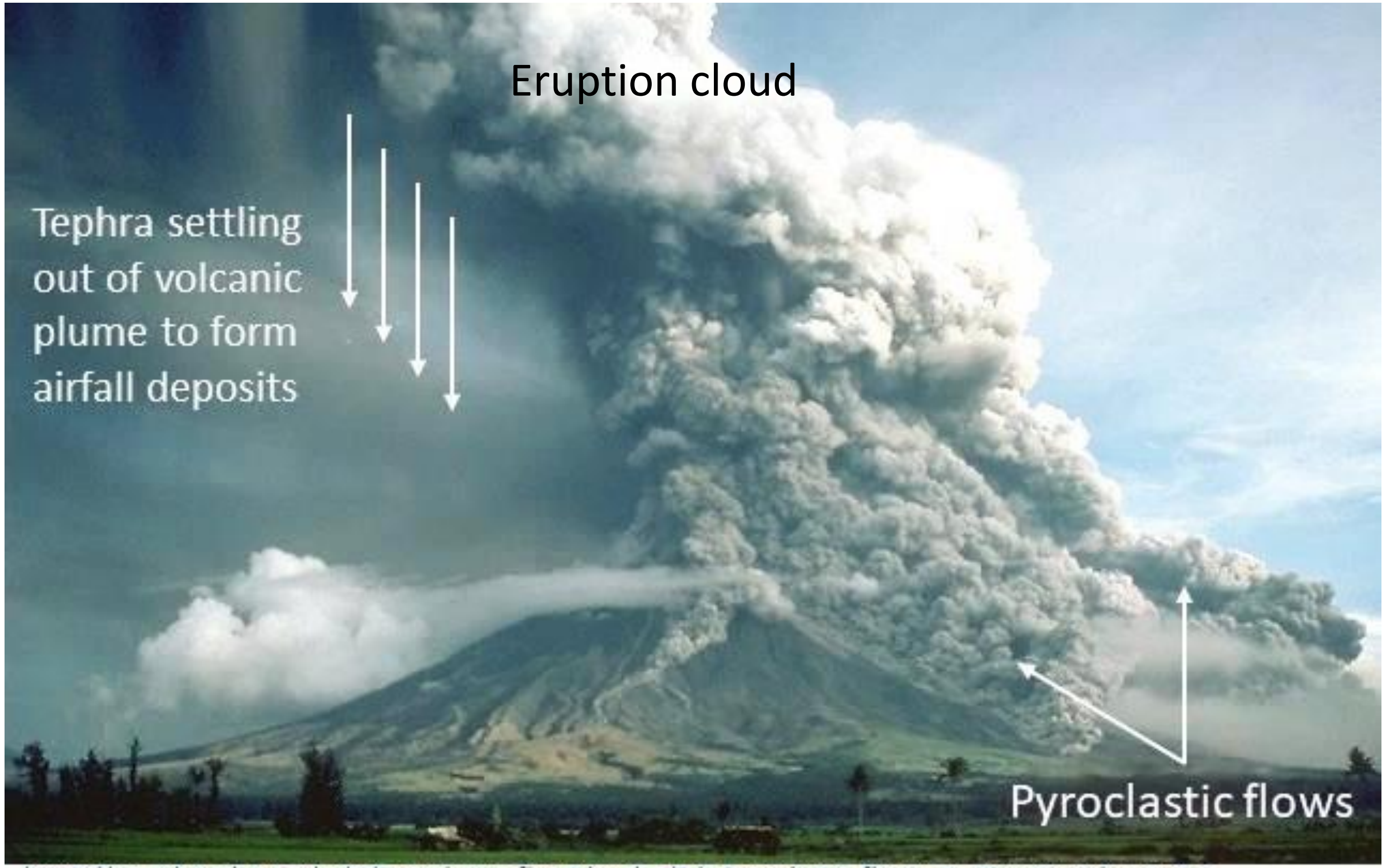
Cleavage and depositional layers in Lakeland green slate

Lakeland green slate was formed by the metamorphism of volcanic ash falls (see next page) that were deposited in a lake. Like mud sediments this ash contained microscopic flake-shaped minerals.

The right photo was taken looking down on a broken piece of roofing slate that I found in my garden. The flat surface on which the coin rests is a cleavage plane. The layers running across this plane were produced as successive ash falls accumulated. The left-hand photo shows one edge of the piece of roof slate. The red line indicates the cleavage direction along which the rock is easily split. Note how the cleavage direction cuts across the depositional layering.

The inset diagram at the bottom left shows how flake shaped minerals were formed and aligned during metamorphism of this rock. The large black arrows indicate the direction of compressive stress involved. The mineral alignment cuts across the original depositional layering.

Volcanic rocks in Keswick explained



https://en.wikipedia.org/wiki/Pyroclastic_flow#/media/File:Pyroclastic_flows_at_Mayon_Volcano.jpg

Tephra is a term used by volcanologists for fragmental material produced by a volcanic eruption including volcanic bombs (> 64 mm), lapillae (64 – 2 mm) and ash (< 2 mm).

The photo shows two types of clouds produced by a violent explosive eruption.

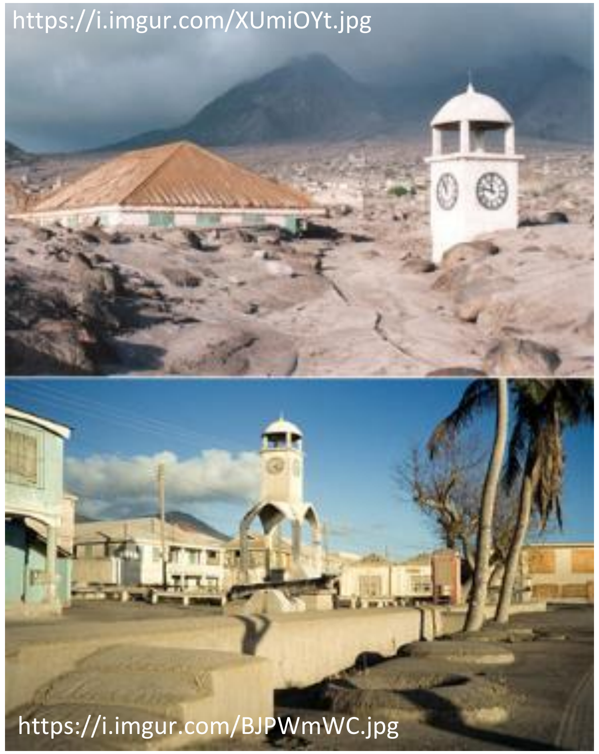
Material is thrown upwards to produce a cloud that may rise many kilometres into the atmosphere. Fragmental material from this cloud eventually falls out of suspension to form *airfall deposits* on the ground, in lakes or in the sea.

Pyroclastic flows are high density turbulent clouds of hot ash and lapillae that flow down the sides of volcanoes at speeds between 30 and 200 meters per second. The temperature within flows may exceed 1000^{o} C, hot enough to cause partial re-melting of lapillae when material settles out of the flow as it slows. The deposits from these flows are known as *ignimbrites*.

Photos on the next page illustrate the volcanic products and processes described above.

Above: **airfall tuffs** buries car and buildings after the 1984 eruption of Rabaul, Papua New Guinea.

Right: **pyroclastic flows**.
A: after and before images of Plymouth (the capital of Montserrat) showing how it was buried by a pyroclastic flow deposit in July 1995.
B: Casts of bodies engulfed by a pyroclastic flow during the eruption of Vesuvius in AD79.
C: Remains of a building destroyed by pyroclastic flows during eruption of El Chichon volcano in Mexico 1982. Reinforcement rods in concrete are bent in direction of flow.



A

https://i.pinimg.com/originals/3f/c9/94/3fc994eb90f05c2df819e7d294ac3b25.jpg

B

C

Ashfall deposits

The Lakeland green slate building blocks and roof tiles were deposited as tuffs fell into a lake. The banding in the roof tile fragment could have been caused by successive pulses of eruptive activity and or changes in wind direction. The fragments in the 'rainspot slate' are lapillae encased in tuff indicating a more violent explosion of a volcanic vent closer to the place where the tuffs were accumulating.

Pyroclastic flow deposits (ignimbrites)

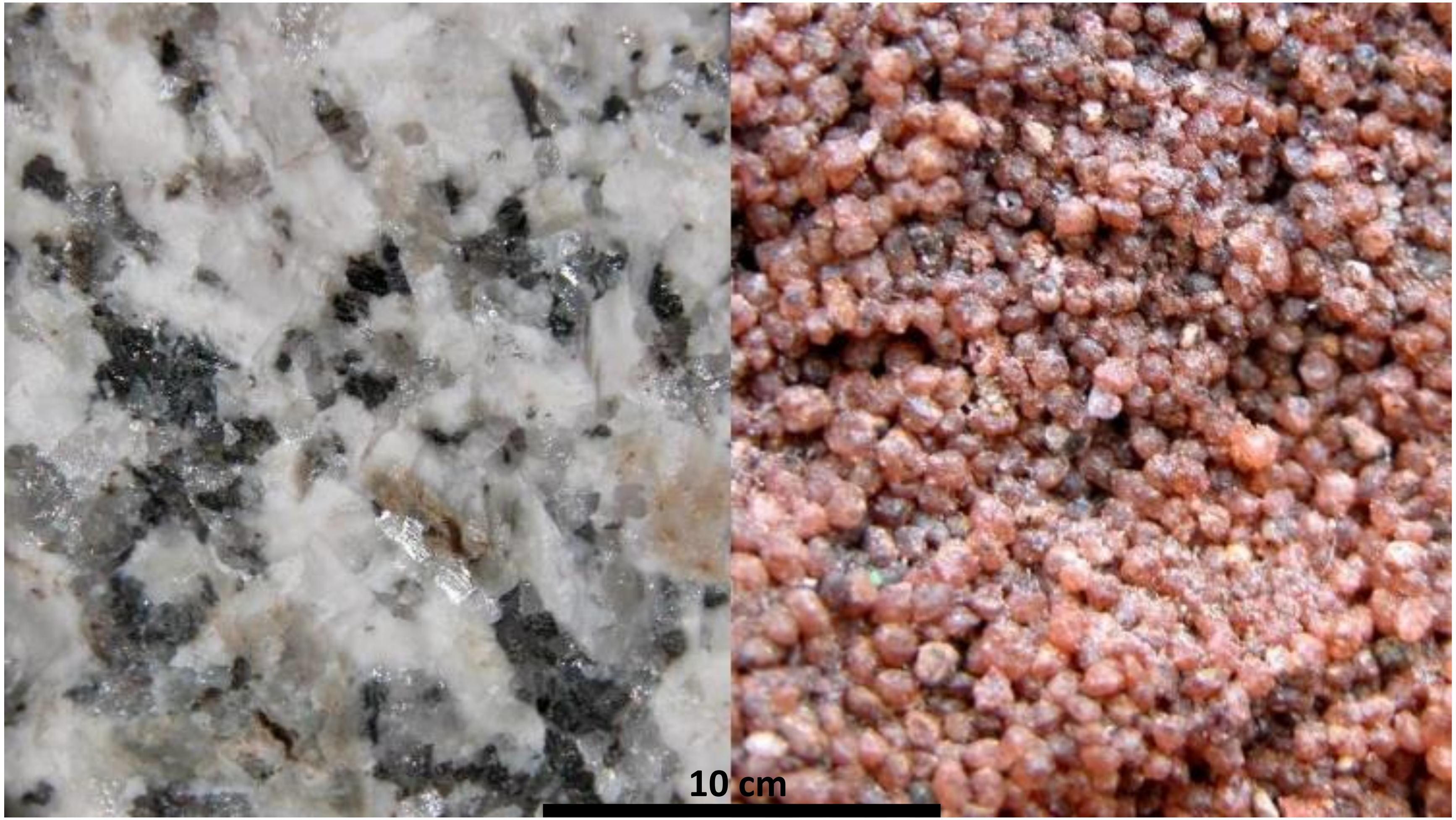
The photo above shows an ignimbrite paving slab in Market Square (see pages 18 & 19). This flow was not hot enough to melt the lapillae but many flow deposits within the Borrowdale Volcanic Group show lapillae that were remelted, squashed and flattened The photo below shows a pebble of this rock type collected in Borrowdale. Similar rock types can occasionally be seen in gathered stone walls in Keswick.

Looking at rocks

At the first session of the Skiddaw U3A Geology Course we examine two contrasting rock specimens and make observations that provide clues about how they were formed. We start by observing – *thinking about how the rocks forms comes later. Here is a taster of what we do.*

Look at the close -up views of the two rock types and answer two questions:

1 What is the relationship between the bits that make up the rock?
2 How many different types of bits are there?



Answers to questions on previous page:

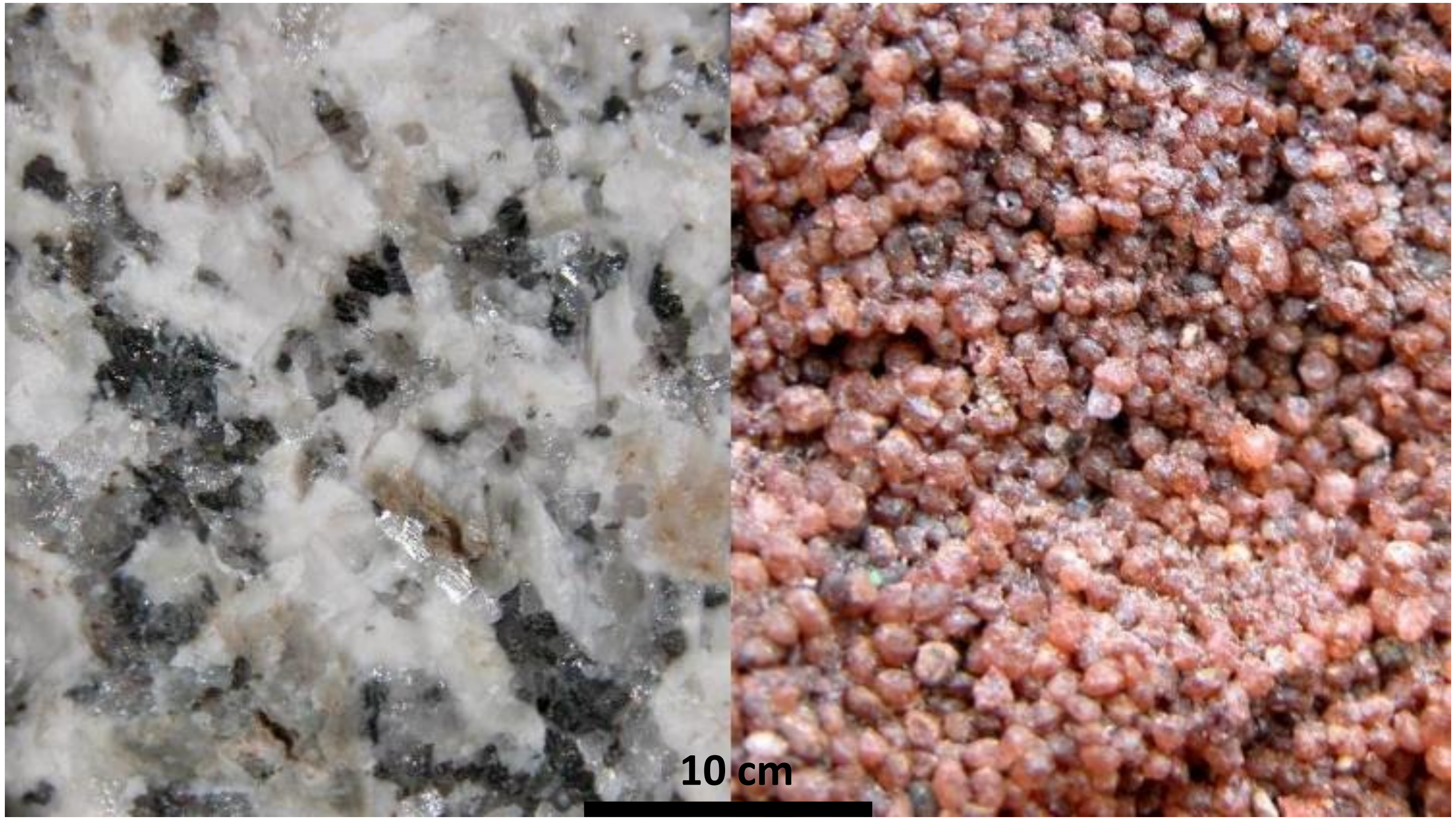
1: Left photo shows angular bits;
Right photo shows rounded bits.

2: Left photo shows interlocking bits with no spaces between them (like a jigsaw with angular pieces);
Right photo shows bits resting against each other and with spaces between them.

The left photo shows a *crystalline* texture and the right one a *fragmental* texture. *Texture* is a term that encompasses the *sizes* and shapes of particles in rocks and their relationship to one another.

As far as texture is concerned there are just two types of rock: *crystalline and fragmental*. Crystalline rocks contain an interlocking meshwork of angular crystals with no spaces between them.
In fragmental textures particles (crystals and/or fragments of other rocks) are sub-angular to rounded, do not interlock, and there are spaces between them occupied by air or water, or mineral cement.

Crystalline rock | Fragmental rock



The ‘bits’ in the rocks are minerals.
The left photo shows Dartmoor Granite which contains three minerals (white, glassy grey and black). The Skiddaw granite shows comparable features.
The right photo shows Penrith sandstone which was deposited in a desert dune. The reddish bits are sand grains coated with iron oxide.

The three types of rock

Igneous rocks crystallised from molten rock (magma). *Extrusive* igneous rocks formed from magmas that reached the surface of the Earth to form lavas or debris produced by beneath the Earth's surface within pre-existing rocks.

Metamorphic rocks formed in response to heating and changes in pressure within the Earth's crust. Metamorphism does not significantly change chemical compositions but often results in the growth of new minerals which are often aligned resulting in a banded appearance. Metamorphism of sedimentary muds and volcanic tuffs results in the development of cleavage planes along which the rocks can be split to produce roof tiles and building stones. More intense metamorphism produces coarser crystalline rocks.

Sedimentary rocks formed by deposition in water or air. They may consist of fragments of pre-existing rocks, or the remains of organisms, or chemical precipitates formed in the sea and lakes.


Rainspot slate (p. 15)


Tuff layers in tile fragment (p. 31)


Dartmoor granite (p. 36)

Splitting Lakeland green slate along a cleavage plane (p. 31)


Lakeland green slate building stone (p. 13 & 14)


Penrith sandstone (p. 36)

Further reading

If you would like to learn more about Lakeland geology I recommend the following publications.

Publications by Alan Smith

Lakeland Rocks
Crowood Press, 2019. 160 pages. ISBN 978 1 78500 651 7
An excellent lavishly illustrated introduction to rocks of the Lake District including its building stones.

The Ice Age in the Lake District
Rigg Side Publications, 2008. 60 pages ISBN 0 9544679 2 2
A very good overview of the features of glacial features and their origins.

Landscapes around Keswick
Rigg Side Publications, 2004. 24 pages. ISBN 0 9544679 1 4

The Geology of the Lake District

There are no books that give a good beginners guide to the geology of the Lake District. Here are two books that are field oriented and require some prior understanding of geology.

Geology in the Lake District National Park
Phil Davies
Published by Otley's Steps, 2018. ISBN 978 1 5272 2888 7

Exploring Lakeland Rocks & Landscapes
Edited by Susan Beale and Mervyn Dodd
Cumberland Geological Society, 2008. 163 pages. ISBN 978 0 9558453

GLOSSARY

Airfall deposits: volcanic debris material from volcanic eruptive clouds that falls out of suspension to form *tuffs* on the ground, in lakes or in the sea.
Borrowdale Volcanic Group consists of lavas and volcanic ash deposits that formed between 460 and 450 million years ago during the Ordovician Period. It is at least 6000 m thick.
Boulder clay is a poorly sorted mixture of pebbles, rock fragments and clay. This type of sediment, also known as *till*, is deposited by melting ice at the base of glaciers.
Breccia is a poorly sorted accumulation of angular shaped volcanic or sedimentary fragments.
Carboniferous: the geological Period between 354 and 290 million years ago. The name means 'coal-bearing' and was coined because in many parts of the world rocks of this age contain deposits of coal.
Clay results from the compaction so that their water content is reduced to around 30% from the 50-60% present in the mud sediment from which they were derived.
Clayslate is the oldest of the three rock units defined by Jonathan Otley in 1820. The modern name for this unit is the Skiddaw Group.
Cleavage in rocks is the result of compressional Earth movements occurring several kilometres beneath the Earth's surface. These movements cause the formation of new types of flake shaped minerals the parallel orientation of which produces the cleavage direction in slates. These new minerals grow perpendicular to the direction of maximum compression so that the cleavage direction cuts across the original depositional layering.
Compaction is caused by increasing pressure as sediments and sedimentary rocks are progressively buried to deeper levels. Compaction results in tighter packing of sedimentary particles as water is expelled from the spaces between them.
Crag and tails form when ice flows over and around a more resistant mass of rock such as a volcanic vent. The more resistant rock withstands glacial erosion better than surrounding softer rocks so remains as a topographic high. Glacial till is deposited downstream of the feature producing the tail.
Crystalline texture. Texture is a term that encompasses the sizes and shapes of particles in rocks and their relationship to one another. Crystalline texture is characterised by an interlocking meshwork of angular crystals with no spaces between them.
Dolerite is an igneous rock. The crystals within it are very small because, unlike coarsely crystalline granite, it cooled rapidly at shallow depths within the Earth's crust. It is very dark grey to black rock as all the minerals within it are dark coloured.
Drumlin. The name is based on the Gaelic word *druim* which means a rounded hill or mound. Drumlins typically have one very steep side and one more gradually sloping side which is inclined in the direction that the glacier moved. They often occur in groups. They were deposited and sculpted at the base of moving glaciers. Drumlins are composed of *till* or *boulder clay.*
Earth movements: movements of the Earth's crust that are caused by stretching (tension) or squeezing (compression).
Fault: a surface, often planar across which rocks are displaced vertically, sideways or a combination of both types of Earth movement.

Fragmental texture. c Fragmental textures are characterised by particles (crystals and/or fragments of other rocks) that are sub-angular to rounded, do not interlock, and the spaces between them are occupied by air or water, or mineral cement.

Gathered stone was the predominant building material used in Keswick before the mid-19th Century. It consists of cobbles and boulders that occur in river and glacial deposits.
Geological timescale. Today we know that the Earth was formed 4.6 billion (4 600 000 000) years ago and modern methods enable the duration of geological *Periods* to be determined. However, the names used to define intervals of geological time were recognised long before it was possible to determine the absolute ages of rocks. The divisions and their age order from oldest to youngest were established nearly 200 years ago by regional studies defining successions of sedimentary rocks and studying the fossil assemblages found in different parts of these successions
Glaciers are masses of moving ice that occupy valleys in mountainous regions or form large ice sheets such as in Antarctica and Greenland.
Granites are coarsely crystalline light coloured igneous rocks that formed as liquid rock (magma) cooled slowly at least five kilometers below the Earth's surface.
Greenstone was recognized by Jonathan Otley in 1820. It is the second oldest of his three rock units and consists of lavas and volcanic ash deposits. The modern name of this unit is the Borrowdale Volcanic Group.
Greywacke is the youngest of the three units recognized by Jonathan Otley in 1820. It consists of alternating layers of slate and hard sandstones. The 'greywacke' is a German word for 'grey earth' which was adopted by early geologists in several parts of Europe to name hard dark coloured poorly sorted sandstones. The modern name for this unit is the Windermere Supergroup.
Igneous rock crystallised from molten rock (magma). *Extrusive* igneous rocks formed from magmas that reached the surface of the Earth to form lavas or debris produced by explosive volcanic activity. *Intrusive* igneous rocks were emplaced beneath the Earth's surface within pre-existing rocks.
Joints are planar surfaces that occur in all types of hard consolidated rocks and are the result of tensional forces that usually produce two sets of joints trending at right angles to one another.
Lakeland green slate started life as a volcanic ash, often referred to as *tuff*, from nearby eruptions fell into lakes. As the tuffs were buried under thousands of meters of younger deposits they slowly changed into hard rocks. Compression of these rocks during Earth movements associated with a major mountain building episode about 400 million years caused minerals within the tuffs to become aligned parallel to one another. It is easy to split the tuffs along *cleavage planes* that follow this alignment. These planes are not related to the original layering of the tuffs that developed as they were deposited on the floors of lakes.
Metamorphic rocks form from pre-existing rocks in response to heating and changes in pressure within the Earth's crust. Metamorphism does not significantly change chemical compositions but often results in the growth of new minerals which are often aligned resulting in a characteristic banded appearance.
Mud consist of randomly orientated microscopic flakes of clay minerals that are held apart by water. This type of sediment contains between 50 and 60% water.
Mudstones result from the compaction of mud sediments so that they contain only 10 – 20% water. Unlike clays they are not malleable but can be broken.
Ordovician is a geological Period named after the 'Ordovices' which is the Roman name for a Welsh tribe
Penrith sandstone was deposited in desert sand dunes 280 million years ago when Britain was situated at the same latitude as the Sahara desert is today.
Period. A geological Period is one of the key time intervals in the geological time scale. Almost all the names used are based on the geographic names of the regions where they were first defined.
Pyroclastic flow: a hot chaotic mixture of rock fragments, gas, and ash that travels rapidly (tens of meters per second) away from a volcanic vent

Rainspot slate is a local term that is misleading because there are no rainspots in the rock. It is a volcanic deposit with larger fragments produced during explosive activity enclosed in a finer matrix of tuff.
Sedimentary rocks formed by deposition in water or air. They may consist of fragments of pre-existing rocks, or the remains of organisms, or chemical precipitates formed in the sea and lakes.**Shales** contain even less water than mudstones and the clay mineral alignment within them is well developed so that they spilt easily along planes parallel to the original layering of the sediments.
Silurian is a geological Period named after the ‘Silures’ which is the Roman name for a Welsh tribe.
Skiddaw Group rocks were deposited on a deep-sea floor as muds and fine-grained sands between 480 and 460 million years ago. Later these sediments were altered to slates and sandstones when they were buried beneath the younger units and then caught up in a major mountain building episode that culminated about 400 million years ago. The Group is 5000 m thick.
Slate results from the metamorphism of mudstones, shales or volcanic ash during compressional Earth movements so that flake shaped minerals become aligned parallel to one another. Slates are split easily along this direction of alignment (see cleavage).
Tephra is a term used by volcanologists for fragmental material produced by a volcanic eruption including volcanic bombs (> 64 mm), lapillae (64 – 2 mm) and ash (< 2 mm).
Till: see boulder clay.
Tuff is a volcanic deposits that contains more than 755 of volcanic ash (see tephra).
Windermere Supergroup consists of slates and fine-grained sandstones deposited at the end of the Ordovician Period and during the entire Silurian Period between 450 and 420 million years ago. Its thickness varies across the southern Lake District from 5000 m to 8000 m.