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# Geology of Settle-Carlisle Railway



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# Geology of Settle-Carlisle Railway

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## Introduction

The rocks that form the landscape of Settle-Carlisle Railway cover a vast period of geological time from about 488 million years ago to the present day. They tell a story of the journey of the region as it has drifted north from close to the south pole to its current position. This story includes the opening and closing of oceans, the building and erosion of mountain ranges and the formation and break-up of a vast super-continent. The rocks were laid down in warm, shallow tropical seas, huge delta systems, arid deserts and beneath thick ice sheets.

This booklet details the main rock types and geological features along the railway's route and gives an insight into what it was like when the rocks were deposited. The first few pages give the geological history of the region and put it into a world wide context, the next sections cover the geology seen along the railway line from Settle in the south to Carlisle in the north and on the last pages are explanations of the geological terms and concepts used in the booklet and a short section on the economic geology of the region.



Dentdale – John Peter Buckley

## Geological History

The oldest rocks found along the Settle to Carlisle line are Ordovician in age (about 488 million years old). They were deposited along the edge of a thin continent called Avalonia (which consisted of England and Scandinavia) that lay near the south pole. It was an archipelago similar to Indonesia today. Slowly, during the Ordovician and Silurian (about 488 to 420 million years ago), Avalonia drifted northwards. Sediments were washed from the continent into the sea along its northern margin. These sediments now form the Ordovician and Silurian rocks, outcrops of which can be seen in Ribblesdale, the Fells and the Lake District.

On the far side of the ocean from Avalonia lay the supercontinent of Laurentia (North America and Scotland). As the ocean closed, the edge of Avalonia was subducted beneath Laurentia and partly melted forming magmas. These magmas rose to the surface to erupt from a series of island volcanoes (similar to Japan today). The remains of these volcanoes are the Borrowdale Volcanic Group which form the distinctive landscape of the Lakes.

# Geological History

By the Mid Silurian, Avalonia was welded against Laurentia. However, movement continued along this boundary as continents to the south collided with Laurentia to form the supercontinent Pangaea (all the present day continents). Massive granites were intruded deep underground across what is now northern England. These include the granites that underlie the Askrigg and Alston blocks (see map) and the Lake District. Granite is lighter than the surrounding rocks, which is why these areas have formed high ground during much of the geological history of the region. The Pennine Fault Zone also formed at this time.

During the late Devonian to Early Carboniferous (about 380 to 340 million years ago), the region was stretched to form a low lying area known as the Pennine Basin. This was flooded by a shallow sea. Britain still lay to the south of the equator and the climate was hot and dry. The Askrigg and Alston blocks divided the basin into areas of deeper water and shallower water. Reefs and lagoons formed in the shallow water, much like the Bahamas today. Mudstones were deposited in the deeper water, together with limestone debris washed down from the coast by underwater landslides. These rocks form the Carboniferous Limestone Supergroup.

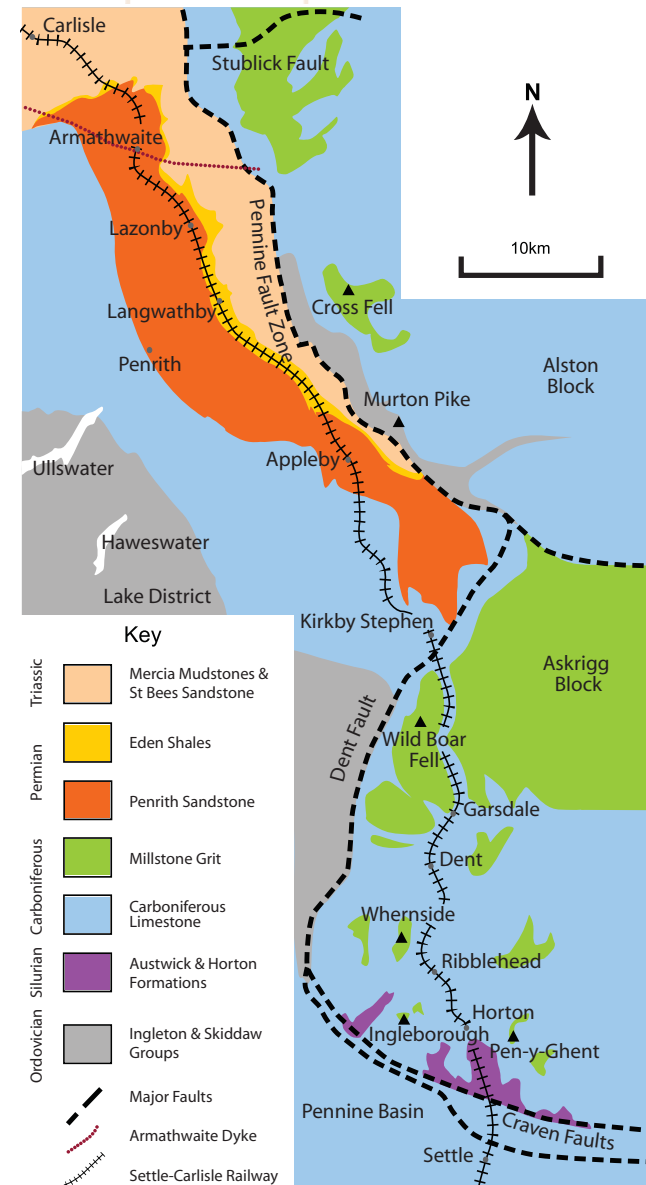
By the Late Carboniferous, rivers had developed across the mountains of the Scottish Southern Uplands and sediments began to be washed down into the Pennine Basin. A series of large deltas formed across the basin and the layers of mudstones, siltstones and sandstones deposited form the Millstone Grit. Britain had continued its drift north and now lay at the equator. The area would have been similar to the Mississippi Delta today with a hot, humid climate and rivers, swamps and lagoons surrounded and filled with lush vegetation. The thin coal seams and soils found in the Millstone Grit are the remains of this vegetation that grew in the delta.

As the Pennine Basin continued to fill, the region became a low lying landscape of swampy jungle, flood plains, lakes and river channels up to 10km wide, only very occasionally invaded by the sea (similar to the Amazon Basin). The Coal Measures have similar rock layers to the Millstone Grit except the coal seams are much thicker.

Towards the end of the Carboniferous, about 295 million years ago, the Whin Sill was formed by molten rock being injected between the layers of sediments. This then cooled and crystallized to form the Sill. It is made of dolerite, a hard wearing igneous rock which forms a ridge across much of northern Britain; Hadrian's Wall is built along part of it.



## Map of the Geology along the Settle-Carlisle Railway





# Geological History

By the early Permian, Britain was at the centre of the Pangaea super-continent. It was now north of the equator and lay within a desert the size of the Sahara. It was a desert of mountains, rocks, huge dune fields blown by trade winds, irregular rainfall, flash floods and extreme temperature changes between night and day. Today, the remains of this ancient desert are found within the Vale of Eden. They were deposited in a basin that formed along the Pennine Fault Zone. The line of this fault is still visible; it forms the escarpment between the Vale of Eden and the Pennines. The earliest desert rocks are the Brockram, which are broken fragments of Carboniferous limestones and sandstones washed down into the growing basin by flash floods. Above these are the brick-red desert Penrith Sandstones. These desert conditions lasted some 30 – 40 million years, before giving way to a hot, arid plain of seasonal rivers, salt flats and lagoons, similar to the Persian Gulf today, in which the Eden Shales were deposited. The Boreal Ocean lay just to the north and occasionally flooded the region depositing limestone layers within the Eden Shales.

The Triassic saw the beginning of the break up of Pangaea and the opening of the Atlantic. The red/yellow St Bees Sandstone was deposited from a river flowing NNW through the region of low lying desert plains. In the Late Triassic the sea repeatedly invaded leaving behind desert lakes in which the shales, gypsum, anhydrite and salt of the Mercia Mudstones were deposited.

There is now a gap of over 140 million years in the age of the rocks along the railway from the Mercia Mudstones (200 million years old) to the Armathwaite Dyke (57 million years old). During which time the region drifted from about 16° north to 40° north (roughly the latitude of the present day Mediterranean). From elsewhere it is known that with the opening of the Atlantic the region was flooded during the Jurassic and Cretaceous when chalk was deposited across much of Britain. These sediments buried the earlier Ordovician to Permian sediments, but at the end of the Cretaceous (about 65 million years ago) northern England was uplifted and the rocks deposited after the Mercia Mudstones were eroded away. The Armathwaite dyke formed during the volcanic activity associated with the opening of the Atlantic. It is part of a swarm of dykes (thin, vertical intrusions of igneous rock) that radiate out from the Isle of Mull.

Britain saw at least three advances and retreats of ice sheets during the last ice age. Evidence for a warmer period before the last advance of the ice sheets was found in the Victoria Cave near Settle where the bones of hippopotamus, straight-tusked elephant, rhinoceros, giant deer, bison and lion were discovered.



As glaciers move, they grind and pluck up rocks and sediment. They carry these, sometimes for great distances, before they lay them down again. These deposits are known as till (a mix of boulders, rock fragments and gravel held together by sandy clay) and are found across much of the region. In places such as the vale of Eden and Ribblesdale, movement of ice over the till has moulded it into drumlins – mounds up to 30m high, which taper in the direction of movement. Movement of the glaciers also scoured the landscape creating open U-shaped valleys and limestone pavements.

Ice is not the only mechanism that has created today's landscape. Limestones consist of calcite and as rain water, which is naturally slightly acidic, percolates down through joints, along faults and between rock layers it dissolves this calcite forming caves and underground passages. Where caves and passages are near the surface, they can collapse into sink holes.

In the cool period following the ice age, hill peat was laid down. It is no longer being deposited as the climate is now too warm. In the last 10,000 years, since the ice age, rivers and streams have created flood plains from the sediments they carry.

0 Ma	Tertiary	Neogene	About 2 million years ago last ice age begins
50 Ma		Palaeogene	England has drifted to 40° north. Region uplifted and eroded as opening of Atlantic continues. Volcanism in Scotland and Ireland
100 Ma	Mesozoic	Cretaceous	Global sea levels reach an all time high. Thick layers of chalk deposited across all of Britain and N. Atlantic opens to west
150 Ma		Jurassic	Super-continent Pangaea begins to break up with rifting along the line of the future Atlantic. Britain in the rift zone subsides below sea level
200 Ma		Triassic	Britain about 16° north of equator Northern hemisphere desert belt. All the continents are joined into the giant super-continent Pangaea. Region is low lying area
250 Ma	Palaeozoic	Permian	of desert lakes and huge sand dune fields, occasionally flooded by sea
300 Ma		Carboniferous	England drifts from southern hemisphere to equator. Shallow, tropical seas and large swampy deltas with lush vegetation.
350 Ma		Devonian	Uplift and erosion of region Ocean to north of Avalonia closes. England collides with Scotland,
400 Ma		Silurian	Lake District volcanoes and Caledonian mountains formed
450 Ma		Ordovician	England 60° south, close to south pole on the continental margin
500 Ma		Cambrian	of a small arc shaped continent called Avalonia

# Settle, Horton & Ribbleshead

As the train pulls out of Settle, Sugar Loaf hill is to the east. It is formed of Carboniferous Limestone and along the bottom of the hill lies the South Craven fault. This fault is part of the system of faults (including the North Craven Fault) which form the boundary between the Pennine basin to the south and higher ground of the Askrigg block to the north. The fault continues across the railway following the line of hills to the northwest.

The valley sides between Settle and the Taitlands Tunnel are formed of the same Carboniferous Limestones as seen at Malham Cove and Goredale Scar to the east. Just north of the Taitlands Tunnel the line crosses the North Craven Fault and the railway runs across some of the older Silurian Austwick and Horton Formations. These are steeply dipping layers of sandstones and siltstones and can be seen as ridges of rocks in the river bed. They contain fossil graptolites (small marine creatures that lived in large colonies that floated in surface waters, sinking to the ocean bottom on death).

To the west, the hills are capped with near horizontal layers of Carboniferous Limestones, which lie unconformably (at a lower angle) to the older rocks beneath. This unconformity represents a long period of time, about 80 million years, in which the older rocks were uplifted, deformed and eroded, before the younger rocks were laid down. The unconformity is particularly clear in the Horton Quarries, with the younger rocks visible along the top of the quarry and the steeply dipping older rocks being quarried away beneath.



Horizontal limestone beds above steeply dipping Ordovician rocks – Anthony Glossop

Where the valley widens out, the flat valley bottom is covered in glacial till and river sediments.

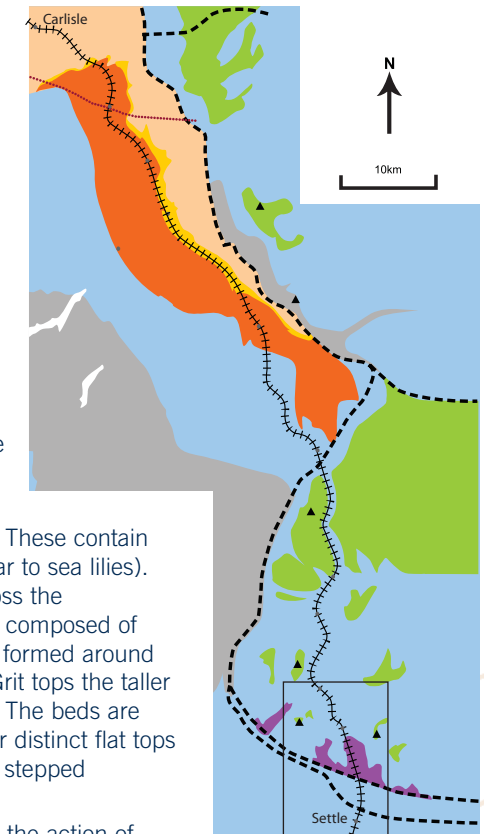
On eastern side of the railway Pen-y-Ghent comes into view. It is made up of layers of Carboniferous Limestone, capped by gritstones and sandstones (and a few thin coal seams) of the Millstone Grit.

Just south of Horton station, the railway goes over the Ordovician Ingleton Group, the oldest rocks on the line. These are mainly hidden by glacial till, but a section can be seen in the cutting just before the station. These are steeply dipping green coloured siltstones and sandstones, which contain fossils of brachiopods (similar in appearance to clams, but unrelated), graptolites and trilobites (marine creatures looking a little like very large woodlice).

Past Horton Station, the landscape is dominated by the Carboniferous Limestones. These contain fossil corals, brachiopods and crinoids (similar to sea lilies). Many of the beds (layers) can be traced across the landscape. One particularly distinctive bed is composed of *Girvanella* – masses of tiny calcite tubes that formed around cyanobacteria (blue-green algae). Millstone Grit tops the taller hills, including Ingleborough and Wharfedale. The beds are roughly horizontal giving the three peaks their distinct flat tops and more resistant layers give the sides their stepped appearance.

The valleys and hills have been smoothed by the action of glaciers during the ice age. Many of the hills are coated in peat formed during the cold period after the last age.

## Map of the Geology along the Settle-Carlisle Railway



Pen-y-ghent – Anthony Glossop



# Ribblehead, Dent & Garsdale

Out from Ribblehead Station, Whernside is up ahead. Around the Ribblehead viaduct the limestone is coated in a thick layer of glacial till, foundations for the viaduct were sunk down through 8m of this to reach bedrock. Drumlins indicate the ice moved southwest across the high ground along the western side of Ingleborough.

From the viaduct, sink holes are visible. These are formed where ground water has dissolved the thick limestone. Many of the becks flowing off Blea Moor and Whernside disappear underground into this cave system. In the valley to the southwest of the viaduct, the River Doe rises, only to disappear underground again after a few hundred metres.



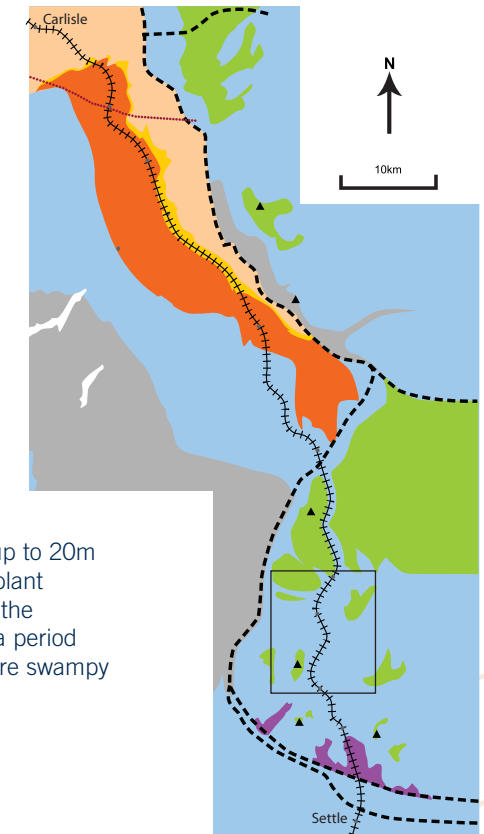
Sink holes at Ribblehead viaduct – Anthony Glossop

The line turns north and runs between Whernside and Blea Moor. Under the steep east face of Whernside are ridges of sandstone debris, the sandstone can be traced to outcrops further up the hill. The ridges are not in the right orientation to have been deposited by ice and the most likely explanation is they may have been formed by 'gill bracks' – snow avalanches which carry debris down hill. A letter from a Thomas Thistlethwaite of Habourgill to his brother and sister in Aysgarth, dated 28th January, 1752 gives an account of farm buildings being destroyed by a gill brack and several people killed. The letter is reproduced in 'The Geology of the country around Ingleborough' (full reference given in references), published in 1890. The author notes that in 1890 no one living remembers sufficient snow in the Dales to cause avalanches. However, it is interesting to note that 1752 is close to the peak of the Little Ice Age (a time of unusually cold weather that lasted several hundred years and ended in the mid nineteenth century).

Blea Moor Tunnel is cut through Carboniferous Limestone. The fossils found in these beds are typical of the warm, shallow, tropical seas in which the limestones were deposited and included *Fenestella* (similar to corals and sponges), bivalves (modern day examples include cockles, molluscs and oysters), corals and giant brachiopods. The line carries on through the same limestones from the tunnel to Dent Station.

Past Dent Station is Risehill Tunnel, in the debris left behind from building the tunnel are the fossils of *Lepidodendron* and *Calamites*. *Lepidodendron* is a club-moss. Today's club-mosses are small herbaceous plants which spread over the ground and grow short erect branches from their stems. The *Lepidodendrons* that grew in the Carboniferous had trunks which could grow up to 35m high and 1m round at the base. *Calamites* was a tree-like plant, which grew up to 20m high and is related to horsetails. Both these plant remains came from a sandstone layer within the Carboniferous Limestone Group, suggesting a period where the sea withdrew from the area and more swampy delta conditions prevailed.

Map of the Geology along the Settle-Carlisle Railway



Horizontal limestone beds near Ribblehead viaduct – Anthony Glossop

# Garsdale, Kirkby Stephen & Appleby

Out of Garsdale Station, the line crosses into the top of the Eden Valley. The Carboniferous Limestone Series has increased in thickness from a few metres just north of Horton Station to over a kilometre thickness north of Garsdale. Between Garsdale and just south of Kirkby Stephen the youngest beds of the Carboniferous rocks are confined to the valley floor and the Millstone Grit series, which has previously only be seen capping the higher hills, is now also seen in the valley sides. Fossils from the Millstone Grit include corals, bivalves, brachiopods, goniatites (similar to a nautilus), nautilus, gastropods (snails, whelks and limpets are all types of gastropods) and sponges.



View down Mallerstang from Ais Gill – Anthony Glossop

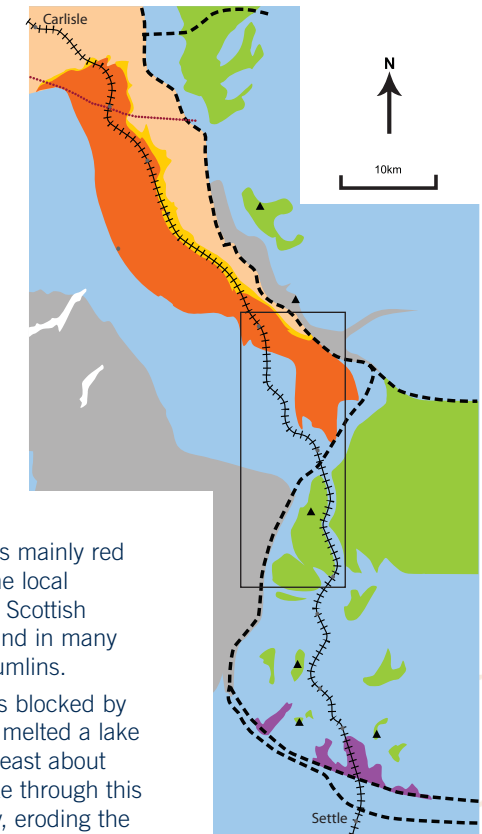
As the railway approaches the Birkett Tunnel the previously near horizontal beds of the Carboniferous Limestone dip more steeply as they approach the Dent Fault. The line crosses the fault about 3km south of Kirkby Stephen, although there is no indication of it in the landscape. The Dent Fault is the western margin of the Askrigg Block which the railway has been crossing since a few miles north of Settle. The rocks on the far side of the fault are the oldest beds of the Carboniferous Limestone series and form the lowest beds of the Eden Valley. They are up to 1.5km thick beneath the centre of the Vale and can be seen in cuttings north of Kirkby Stephen. The Permian aged Penrith Sandstone lie above them. The line crosses the unconformity just after Helm Tunnel, although it is difficult to see as most of the Vale of Eden is covered in glacial till and river sediments. Look out for red soil, this indicates the presence of the Penrith Sandstone beneath.

The Vale of Eden lies between the Fells to the east and the Lake District to the west. It is a sedimentary basin that has a fault on one side only. As the fault moved, it created a low lying area (like a trap door opening) into which Permian to Jurassic aged sediments accumulated. The Pennine Fault Zone separates the Eden Valley from the Ordovician volcanics and Silurian and Carboniferous sediments of the Fells (Alston Block) and forms the clear escarpment to the east. The rocks of the Fells are the same as those found in the Lake District and the same as those that lie beneath the sediments of the Vale of Eden.

The glacial till that covers the Vale consists of rock fragments varying in size from boulders to sand held together by dense, impermeable clay. There are also lenses of gravel and sand from melt-water streams and finely layered clays deposited in small, temporary lakes. The till in the Vale of Eden is mainly red and contains rocks known as erratics from the local sandstones, the Lake District and rarely from Scottish granites. The till varies from 5 to 30m thick and in many places has been sculpted by glaciers into drumlins.

Just after the last ice age, the River Eden was blocked by glacial till near Great Ormside and as the ice melted a lake formed, stretching from Great Ormside southeast about 5km to Warcop. When the waters finally broke through this natural dam the lake drained catastrophically, eroding the gorge between Great Ormside and Appleby.

Map of the Geology along the Settle-Carlisle Railway



Millstone Grit of Mallerstang Edge – Anthony Glossop



# Appleby, Langwathby & Lazonby

From Appleby Station, the conical hill of Murton Pike can be seen to the east. This lies on the far side of the Pennine Fault Zone. The rocks of the Pike are part of the Ordovician Skiddaw Group (Arenig Series). They are grey slates with thin sandstones that were deposited from underwater landslides. Fossils include graptolites, rare trilobites and the microscopic remains of phytoplankton. Beyond this is High Cup Nick, the edge of the Nick is formed by the Whin Sill.

Overlying the Ordovician and Silurian rocks of the Fells are the Carboniferous Limestones and Millstone Grit Series seen earlier in the journey. The Pennine Fault has been active on and off since its formation at the end of the Silurian. Movement on it has folded the Carboniferous and Permo-Triassic sediments of the Vale of Eden into a broad syncline or trough. The fault is still active; the last (small) earthquake on it was in August 1970, with a depth of about 15km.



Murton Pike – Anthony Glossop

From Appleby to Long Marton the railway runs over Lower Permian Penrith Sandstone. This is a red-brown desert dune sandstone, at least 300m thick. The red colour comes from a fine coating of haematite (an iron mineral) around each grain. In places, the bedding is in fine, concave layers known as cross bedding. This forms as the sand is blown up and over the dunes and deposited on the leeside of the dune. As today, the Fells and the Lake District formed higher ground – a dry, rocky desert with the Vale of Eden a sea of sand dunes in between. No fossils have been found in the sandstone – deserts are not good places for animal or plant remains to be preserved. However, there are reptile footprints in the sandstone near Penrith and in rocks of the same age in the Midlands remains of early reptiles and reptile-like amphibians have been found. The Penrith Sandstone is now the main aquifer (water bearing rocks) in the area.

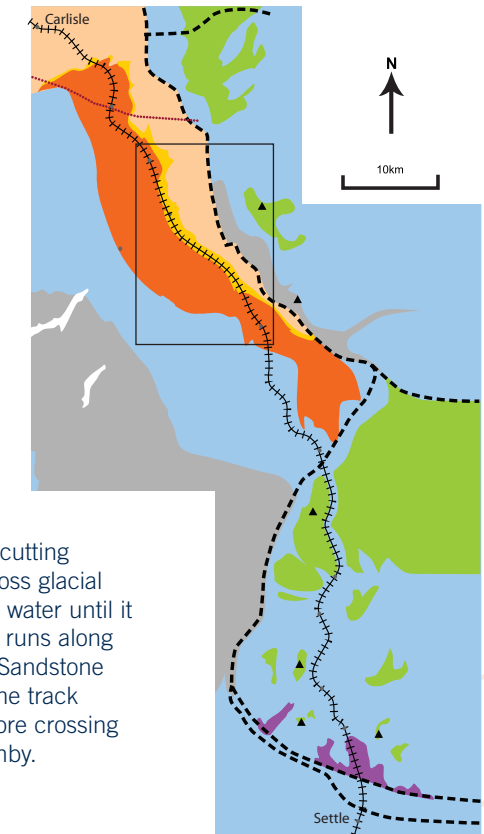
North of Long Marton, on the west side of the line is the covered conveyor belt which connects the Birkhead Mine to the British Gypsum plaster mill at Kirkby Thore. The gypsum mined at Birkhead is from the Eden Shales. The Eden Shales vary in colour from red-brown and purple-red to grey and were laid down in lagoons and when the rivers flooded. Fossils include plants, algal mats and crustaceans similar to water fleas that live in brackish pools today. The arid conditions and the nearby presence of the sea, led to gypsum and anhydrite accumulating. The Eden Shales are poorly exposed and information about them comes mainly from boreholes. They are up to about 160m thick and infill the uneven dune surface of the Penrith Sandstone. The Culgarth Tunnel is through limestone beds in the Eden Shales, laid down when the sea briefly flooded the area.

Just out from Langwathby Station, there is a cutting through glacial till. The railway then runs across glacial sands and gravel deposited from glacial melt water until it crosses the River Eden. Just before it does it runs along the slopes of a small hill capped by St Bees Sandstone with Eden Shales beneath. Across the river the track climbs a gentle hill of Penrith Sandstone before crossing back on to glacial sands and gravels to Lazonby.



Long Meg and daughters – Alan Smith. Long Meg is carved from Penrith Sandstone and the daughters are glacial erratics

Map of the Geology along the Settle-Carlisle Railway





# Lazonby, Armathwaite & Carlisle

A little out of Lazonby, the River Eden runs through the narrow Eden Gorge. The river has eroded away any glacial deposits and the gorge sides are Penrith Sandstone with dune cross bedding. The line runs through Penrith Sandstone virtually all the way from Lazonby to Armathwaite.



Armathwaite Dyke – Joe Cann

In the Baronwood Tunnels area the line crosses glacial sands and gravel deposited by melting ice. About half a kilometre to the southwest of the line (not visible from the train) is the Baronwood sand-pit where thick cross bedded sands are dug out. These sands were deposited as a small delta from a melt-water stream coming from the front of the glacier.

In the river, just before Armathwaite, is a natural weir formed of a layer of hard, erosion resistant rock. This is the 57 million year old Armathwaite Dyke. The dyke runs ESE-WNW along the hill that can be seen in both directions from the railway. It can be traced for 400km from Mull through Cumbria to Durham. It is a long, thin, vertical intrusion of an igneous rock called dolerite (the same rock that forms the Whin Sill, although the two intrusions are unrelated). With the opening of the Atlantic, magma from deep in the Earth was forced along weaknesses in the rocks, it never reached the surface but cooled and crystallized underground.

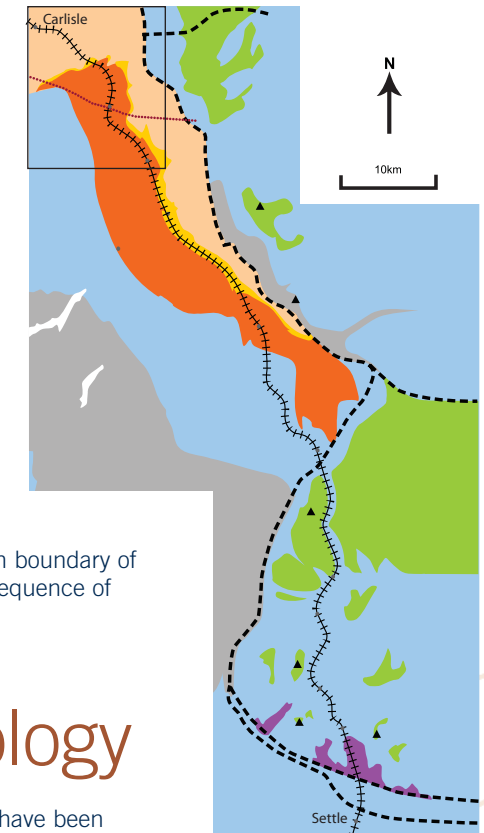
After Armathwaite Station, as the line curves to the northwest towards Carlisle, the landscape opens out into low rolling hills of the Permo-Triassic sediments coated in glacial till and the Pennines become less pronounced.

Beneath the till is the Triassic-aged St Bees Sandstones. Where they can be seen they are dull red sandstones and conglomerates with cross bedded layers. They were deposited in seasonal rivers that migrated across the basin. The cross bedding formed as large sand ripples on the river bed.

Approaching Carlisle, the rocks beneath the till are the Mercia Mudstones. These lie over the St Bees Sandstone. They consist of red, blue and grey shales, green siltstones and layers of gypsum, anhydrite and rock salt deposited in desert lakes (similar to the lake in Death Valley, California today).

An east-west valley through the Pennine hills marks the line of the Stubbs Fault. This separates the Alston Block from the Northumberland Basin that in the Carboniferous had more open marine conditions. This fault also marks the southern boundary of the Carlisle Basin. This is filled with a thick sequence of Upper Permian-Jurassic sedimentary rocks.

Map of the Geology along the Settle-Carlisle Railway



## Economic Geology

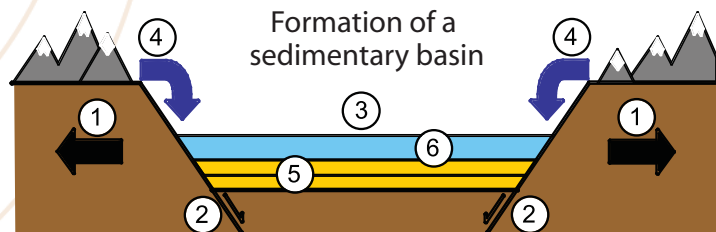
The rocks along the Settle to Carlisle railway have been mined and quarried for centuries. Several quarries are still active today: the quarries at Horton produce crushed rock for the building industry; Baronwood pit near Armathwaite is a source of sand; and gypsum and anhydrite are mined at Birkshead for the British Gypsum plaster mill at Kirkby Thore. Within the Carboniferous Limestones are veins of lead, zinc, fluorspar and barytes, all of which have been mined in the past. Lead mining is known in the area from Roman times. The limestone itself has been quarried to use in the chemical industry, glass manufacture and as agricultural fertilizer. The mudstones and shales of the Millstone Grit have been worked for bricks and tiles and the sandstones for building stone, and of course, as millstones. The coal seams have also been exploited, but are of far less importance than those of the main Coal Measures further south.



# Geological Terms

**Plate Tectonics** The generally accepted theory that the outer layer of the Earth is divided into plates which move relative to each other. The plates can move apart, creating new oceans and depressions in the Earth's surface known as sedimentary basins (see diagram below); one plate can be pushed down (subducted) beneath another, destroying oceans and creating mountain belts; or the plates can grind past each other. The continents are part of the plates and so move, join together and tear apart as the plates interact.

**Sedimentary Basins** These are depressions in the Earth's surface, usually created where the surface is being pulled apart, where sediments (sand, mud etc) are deposited. The edges of sedimentary basins are often formed by faults.



- ① Earth's surface is pulled apart due to movement of the plates
- ② Faults form and a sedimentary basin is created
- ③
- ④ Sediments are washed from the surrounding high ground into the basin where they are deposited in layers
- ⑤
- ⑥ Shallow sea invades the basin also depositing sediments

**Sedimentary Rocks** These form when older rocks are eroded and the grains of sand, silt or mud are transported by wind and water before being deposited again in layers. Limestones are formed in a similar way when the remains of tiny sea creatures settle on the sea bed. New layers of sediments bury and compress older layers squeezing out the water and cementing them together into rocks.

**Igneous Rocks** These form when molten rock (magma) cools and crystallizes. Magma may erupt at the surface from volcanoes or remain below surface forming structures such as dykes and sills.

**Faults** These are cracks in the Earth's surface where the rock layers on either side of the fault have moved relative to each other.



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