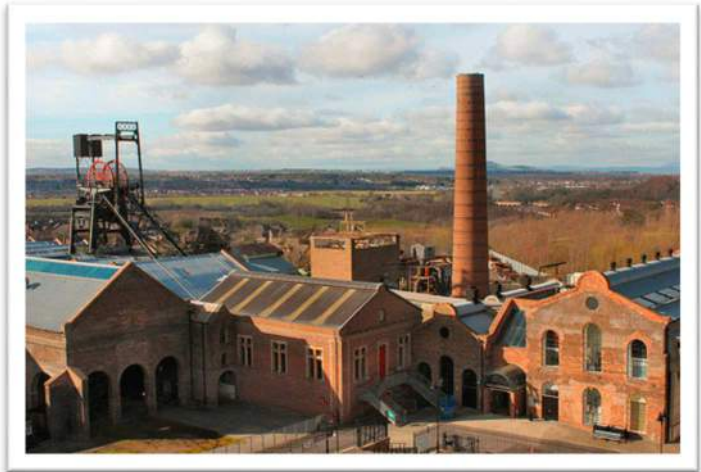


Cycling around the geology and geomorphology of Midlothian



Pictures from www.gorebridge.org.uk

Cycling is probably the best way of appreciating terrain. In this 52-km (32-mile) long trip, mostly on quiet roads and cycle paths, we make the link between terrain, underlying geology and the processes that shape landscapes. The following topics are covered: Carboniferous volcanisms, Carboniferous sediments and the coal industry, the Pentland fault, shaping of the landscape by glaciers and rivers and the influence of contrasts in rock resistance to erosion on landscape morphology. The event takes a whole day and is ideally for people with minimum experience of cycling relatively long distances on hilly terrain.

The trip essentially explores the Esk River basin and includes a ~1:30 hours visit of the National Mining Museum in Newtongrange (Scottish tourist board five-star attraction): <http://nationalminingmuseum.com/>

A map of the itinerary is provided (using OS Map 66 -Edinburgh- as the base map), as well as some information about the geology and geomorphology of the area, including a lovely leaflet about the geology and scenery of the Esk Valley commissioned by Lothian and Borders GeoConservation (visit the Esk Valley Trust website: <http://www.eskvalleytrust.org/>).

Ideal equipment includes: good bike with functioning front and back lights, helmet and high visibility jacket. You may want to bring food and drinks, as well as a lock for your bike and some shoes to walk on a potentially muddy path (the trip includes short walks). **IMPORTANT:** bring warm clothes for the visit of the museum!!! The visit is essentially outdoor or within the mine and it can get VERY cold. Note that Lothian Buses serve many of the towns visited (e.g., service 29 to Newtongrange and Gorebridge, service 40 to Roslin, service 37 to Loanhead, etc...)

Dr Mikael Attal
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Edinburgh, August 2015

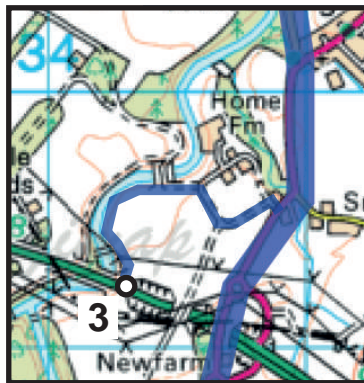


THE UNIVERSITY of EDINBURGH

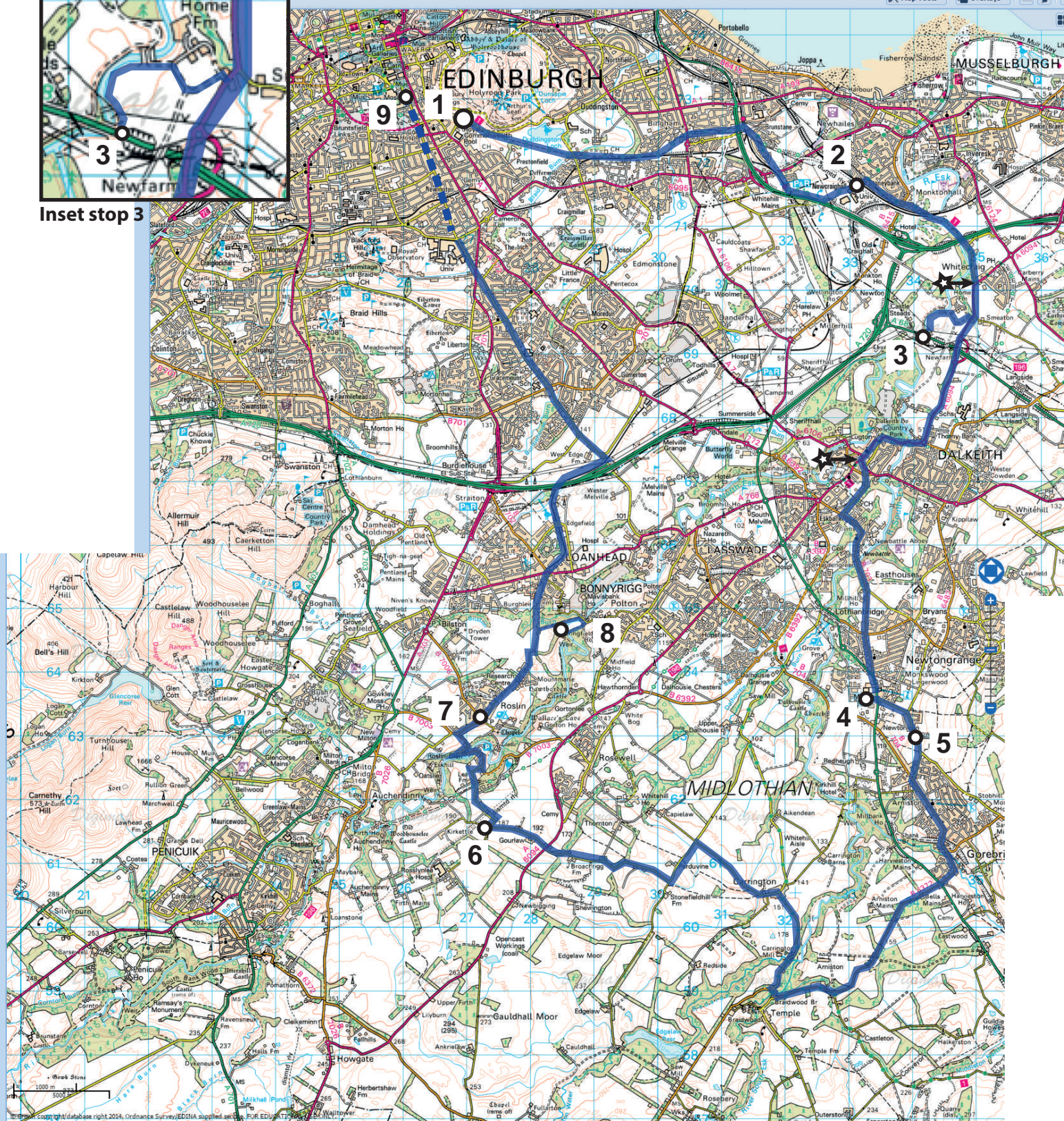
Cycling around the geology and geomorphology of Midlothian

Route map (base map = OS Map 66)

Stars with arrows indicate locations where the route leaves National Cycle Route 1



Inset stop 3



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1 km

Approximate distances: 1 to 4 = 21 km (13 miles)
4 to 7 = 19 km (12 miles)
7 to 9 = 12 km (7.5 miles)

Cycling around the geology and geomorphology of Midlothian

Before starting, make yourself familiar with the geology and geomorphology of the area. The Esk Valley leaflet (page 3-6) gives an excellent introduction to the geological history of the area: the rocks exposed are igneous and sedimentary rocks, Ordovician to Carboniferous in age (380 to 300 million year old, see **Geological timescale** p. 4 and **Scotland's geological history** with geological map p. 5-6). The landscape we see today is essentially the result of shaping by glaciers during the Quaternary; glaciers were covering most of Scotland during the Last Glacial Maximum, which ended only ~20,000 years ago (see **Recent History** p. 4 and **Slipping Slopes** p. 7). The relief of the area is shown on page 8 and 9: high relief is restricted to the Pentland Hills, with the Esk basin contained in a wide trough immediately to the SE of the hills. When geology is superimposed onto the topography (p. 10-12), the importance of the geology appears clearly, with the Pentland Hills being made of volcanic rocks (orange, purple) that are more resistant to erosion than the adjacent sedimentary rocks (grey, yellow, blue). The sharp contact between the two types of rocks, the Pentland Fault, appears as a sharp contact in the topography (hills rise abruptly at the fault). When glaciers were moving over the area, they carved more easily into the sedimentary rocks than into the volcanic rocks, leaving the volcanic rocks in relief (with for example: Arthur's Seat, Corstorphine Hill, the Pentland Hills, North Berwick Law, Bass Rock, to cite only a few). Note that the orientation of the geological structures seems to have influenced the flow direction of the ice: in the area, most geological structures are oriented NE-SW (including the Pentland Hills) and the streamlined NE-SW features in the Esk Basin visible on the hillshade map of the area (p. 9) are evidence that the ice was moving in the same direction (it was actually moving to the NE towards the Firth of Forth, see p. 7); you will look at these features more closely during the trip. Finally, it is interesting to note that the Esk basin sits in a syncline, that is, a fold where the youngest rocks are found in the middle; the cross-section on page 13 will give you an idea of the structure of the different rock units under the surface (the location of the cross-section is shown on the map p. 10). Enjoy the ride!

Description of sites indicated on route map:

- 1-** Starting point on Holyrood Park Road: make yourself familiar with the geological and geomorphological history described in this leaflet and admire the volcanics that make up Arthur's Seat. This is a Carboniferous volcano (~300-350 million year old) and the vertical columns of Salisbury Crags are the result of the cooling of basalt (similar to the famous Giant's Causeway in Ireland). Join Cycle Route 1 through the Innocent Railway Tunnel (most of the cycle paths you will use today were railways in the past).
- 2-** Stop at the Queen Margaret campus by Musselburgh, before going over the railway, and look back at the prominent Arthur's Seat. Prepare to descend into the Esk Valley.
- 3-** Leave the main road and enter an area which is part of Dalkeith Country Park (see inset on map p.1). Down by the river, under the A68, you will find a spectacular coal seam within the Carboniferous fluvial sandstones (p. 6). **DO NOT HAMMER OR EVEN PICK AT ROCKS AT THE EXPOSURE.** The exposure is fragile and there are enough fragments underneath. Note also that there are a lot of horses in this part of the estate and that the horse people don't like cyclists so much (they scare horses): make sure you move slowly and stop if approached by horses. **DO NOT CYCLE ON THE PATH ALONG THE RIVER:** leave your bike at the bridge; ideally, leave your bike at the entrance of the estate (by the main road).

4- Visit the National Mining Museum in Newtongrange. Plan around 1:30 hour for the visit. You will be guided through the mine working, its history and regional significance by ex-miners. Make sure you have very warm clothes, even in summer. And book in advance if you have a big group. This is usually a good place to have lunch and there is a café, restaurant and toilets in the museum if needed.

5- Stop by the school layby in Gorebridge for a great view over the Esk basin. Locate yourself on the hillshade map p. 9. From this point you can see the Pentland Hills and Arthur's Seat in the distance. In front of you, the Esk basin which appears so flat on the map shows quite a bit of relief; a lot of this relief is made of the streamlined features we mentioned earlier. From 5 to 6, you will cycle across these features and across a series of rivers that generally flow towards the NE, towards the Firth of Forth (including the South Esk and the North Esk which join in Dalkeith to form the Esk River). On your way to 6, your legs will make you notice that the area is not flat! Note the smooth appearance of the landscape (rolling hills) and the lack of rock exposures: the landscape is almost entirely blanketed with soft sediment which has been produced, transported and deformed at the bottom of a glacier! Many of the streamlined features are mounds of soft sediment shaped by the movement of the ice as it was moving towards the NE. On your way, note also the deep river valleys, with narrow gorges tens of meters deep. If a 20 m deep gorge had been formed by a river after deglaciation, this would imply erosion rates in excess of 1 mm/yr (to form a 20 m deep gorge in less than 20,000 years). Such erosion rates are typically found in tectonically active places such as the Himalayas, Taiwan or the Alps, so they are quite surprising here in Scotland! Potential explanations include: (1) erosion is essentially in soft sediment so it can be rapid; (2) during deglaciation, rivers may have been much more powerful than now (with higher water discharge) so they could have eroded their bedrock very rapidly; (3) maybe these rivers were sub-glacial streams: the gorges may have been (at least partly) carved by the rivers under the glacier before deglaciation...

6- Nice location for a last panorama over the Pentland Hills to the west and the Esk basin and its hills of soft sediment to the east. Prepare to descend into Roslin Glen (North Esk River).

7- Break in Roslin, with its nice wee pubs and a well-known chapel (since the Da Vinci Code).

8- If time permits, you may want to look at the soft glacial sediment at Hewan Bank. The glacial sediment (or till) is very often covered in vegetation. At Hewan Bank, the meandering river has cut into the hillslope and caused a landslip, offering a rare opportunity to see what the till is made of (see p. 7). To access the site, take a small path to the right BEFORE you pass over a long iron bridge over a deep valley (see map). You will probably have to walk with your bike: the path is rough and relief is high (so a fall may be painful). When you reach the road at the bottom of the hill, cross the river over the small bridge and go back up the river into a small park. Till will appear in many of the scars on the bank opposite (see p. 7), in particular upstream of the dog leg in the river course.

Then, get back onto the cycle path: either go back the way you came or take the very steep winding road that climbs back to Loanhead. The cycle back to Edinburgh (to 9) is essentially downhill.

I hope you enjoyed the ride. Don't hesitate to contact me if you have any suggestion or feedback: mikael.attal@ed.ac.uk.

Introduction

The River Esk has two main tributaries; the North Esk and South Esk. The North Esk rises near East Cairn Hill, in the Pentlands, and passes through the North Esk Reservoir and the village of Carlops.

The South Esk has its source in the Moorfoot Hills near Bowbeat Wind Farm and passes through the Gladhouse and Rosebery Reservoirs as it travels out towards the sea. The rivers converge 2 km northeast of Dalkeith and travel a further 7.8 km to the sea at Musselburgh.

The river has a catchment area of 330 km² covering predominantly farmland and semi-natural woodland.

All the underlying rock is more than 300 million years old. Younger sediments, such as boulder clay, sand and gravel, all less than 100,000 years old, cover about 85% of this bedrock.

Over the last 600 million years, Scotland has progressively moved northwards from south of the equator to its present position in the northern hemisphere today. Along the way, the rocks of Scotland and England, originally on different continents, joined together. The rocks reveal this history.



The globe shows Scotland's journey from south of the equator to the northern hemisphere.

Exploring the Esk Valley



The Esk Valley is easily accessible from Edinburgh, with paths running along the banks of the rivers for most of the route from source to sea.

Acknowledgements:

Text: Nicola Coffin, University of Edinburgh

Photographs: Nicola Coffin. Auchendinny photograph from Robert Gooday, University of Edinburgh.

River Map: Esk Valley Trust (www.eskvalleytrust.org)

Geological Map: Lothian and Borders GeoConservation

Diagram: www.scottishgeology.com

Produced by Lothian and Borders GeoConservation, a committee of the Edinburgh Geological Society, a charity registered in Scotland. Charity No: SC 008011.

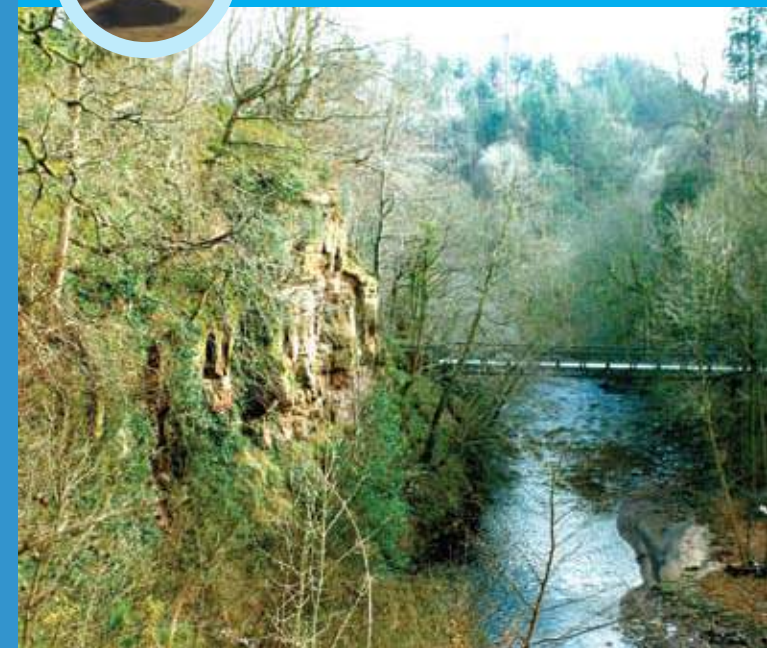
Produced in partnership with the Esk Valley Trust, a charity registered in Scotland. Charity No: SC 031951



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Borders
GeoConservation



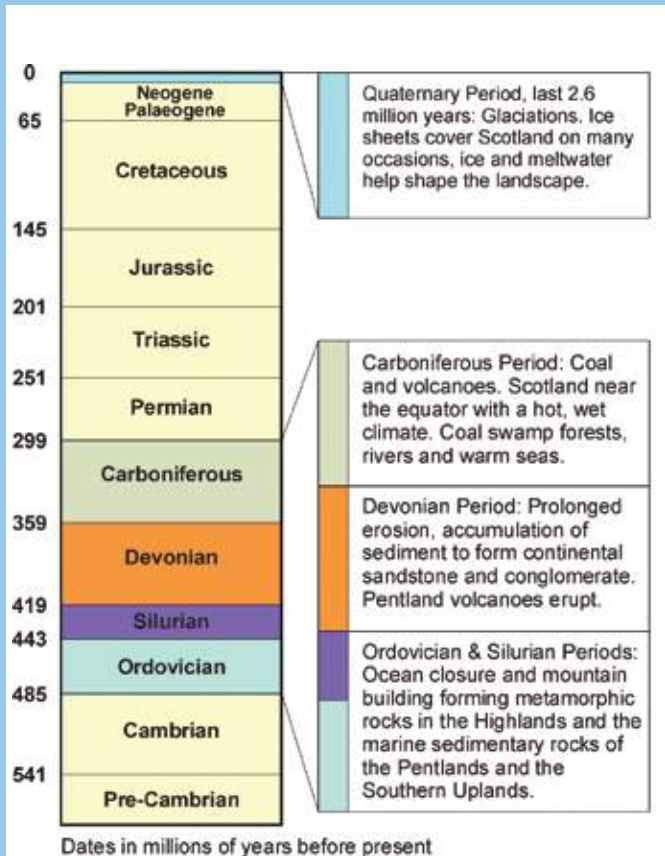
The Esk Valley



Geology and Scenery

Geological Timescale

The geological timescale is measured in millions of years, and is shown below. It is a chronological measurement stretching back to the time when the Earth was formed. The ages are defined by dating rocks and fossils, because certain fossils are only found in particular time periods. The timescale is used to describe the timing and relationships of events in the geological past. Earth formed 4.6 billion years ago, but only rocks younger than 480 million years are seen in the Esk Valley. In this leaflet, the story of Scotland will be told from the Cambrian right up to today by focusing on the rocks seen in the Esk Valley. It includes the recent history of the glaciations and industry within the area.



Recent History

Glaciations

In the Quaternary, ice sheets at least 1km thick covered the area on several occasions, and the last ice sheet began melting around 19,000 years ago. The ice was concentrated between the Pentland and Moorfoot Hills, where the River Esk is situated, and left evidence such as boulder clay, meltwater channels and striations.

As the climate warmed, the ice melted. Initially most of the water flowed within the ice, but eventually found its way to the valley floor and vigorously eroded it. The water finally emerged from the ice as a raging torrent, which continued to cut channels. The picture shows the channel southwest of Carlops, now flooded with debris dumped as the meltwaters subsided. The small hill is Peaked Craig, a volcanic remnant which resisted erosion. The North Esk flows in a southerly direction from its source, but then turns east as it enters this meltwater channel over the waterfall at Carlops. North-east of Carlops the North Esk occupies a river valley present before the ice age. The meltwaters further excavated this to create the present day deep trench.

The meltwaters deposited sand and gravel in many places along the valley. One of these, the Hewan Bank near Polton, is designated as a Site of Special Scientific Interest (SSSI). The river continues to undercut these deposits, resulting in many landslips.

Raised beaches along the coastline of the Firth of Forth resulted from the land rising due to the removal of the mass of the ice, so that the land is now about 10 metres higher than it was around 6,500 years ago. This process, known as isostatic rebound, rejuvenated the rivers, giving them greater erosive power because they were higher above sea level.

Meltwater channels southwest of Carlops.



The many mills along the River Esk are testament to the industrial use of the river. The use of the mills was extensive: gunpowder, paper, cotton, flour, flax and iron. Paper mills were by far the most abundant. The last mill closed in 2004.

There were many coal mines within the Esk Valley, as



Gunpowder Mill in Roslin Glen

it is situated in the Midlothian Coalfield. Sandstone was quarried for building stone, and limestone for agriculture and mortar. Sand and gravel is still quarried from the extensive glacial deposits.

The area was productive enough to warrant a railway being built to transport mill and mine goods out of the area. The disused railway track is now a footpath and cycleway.

The North Esk Reservoir was constructed in 1850 to power the mills along the North Esk. However, the Rosebery and Gladhouse Reservoirs along the South Esk were built to provide freshwater to the Lothians.



North Esk Reservoir

Scotland's geological history

Some of Scotland's geological history can be reconstructed by studying rocks in the Esk Valley.

A Lost Ocean

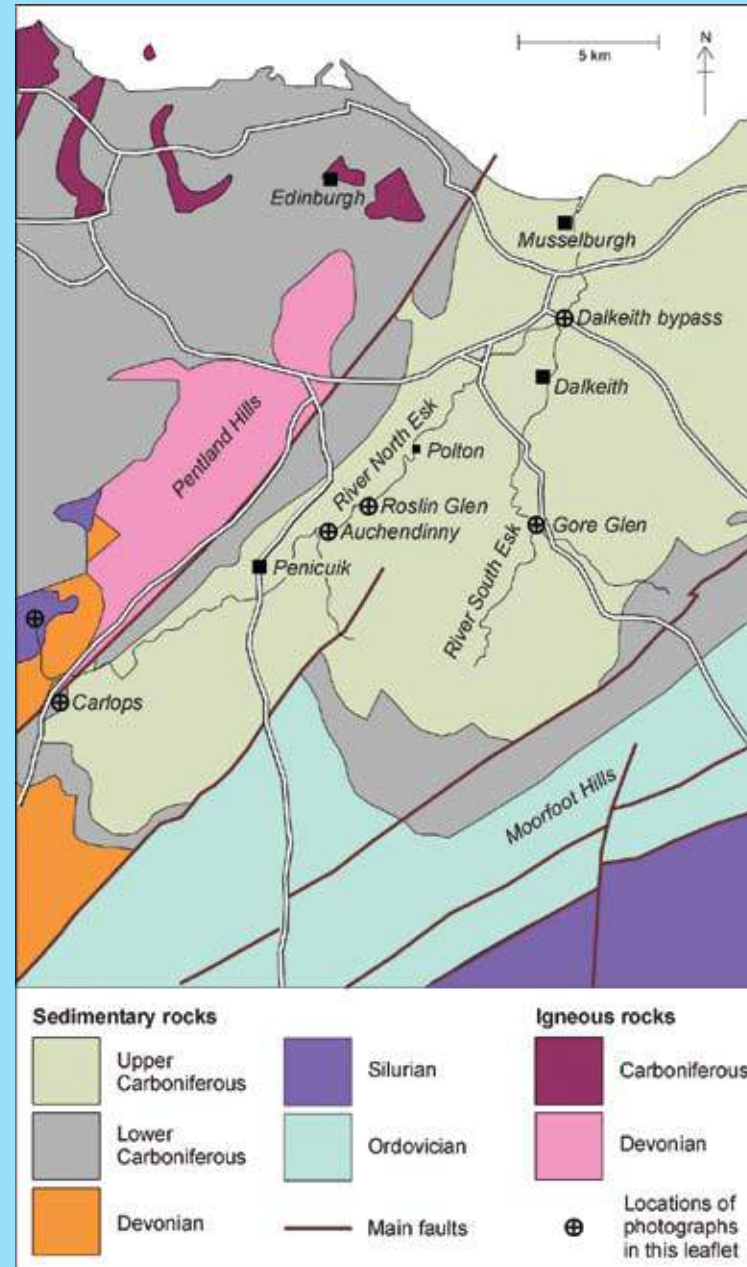
Scotland's geology is intimately linked with the break-up of the supercontinent Rodinia about 590 million years ago. The expanding Iapetus Ocean separated the continents of Laurentia, Baltica and Amazonia. During Proterozoic to Cambrian times marine sands, silts and muds were deposited on the sea floor close to Laurentia, to form the Dalradian rocks of the Grampians. From about 500 million years ago, volcanic activity along the ocean margins heralded the beginning of the closure of Iapetus. Later during the Ordovician and Silurian periods, vast thicknesses of sands and silts formed in deep ocean channels, with black muds accumulating on the ocean floor. Near-shore marine limestones and mudstones were also deposited. Together, these sedimentary rocks now form the Southern Uplands and small outcrops in the Pentland Hills.

Mountain Building

As the Iapetus Ocean closed, the Dalradian rocks of the Grampians were deeply buried, metamorphosed and folded during a period of mountain building. With continued closure the marine sediments to the south, which were to form the South of Scotland, were successively folded and thrust together as the ocean floor was consumed (subducted) by the overriding continent of Laurentia.



Geological Map for the Esk Valley



In the upper reaches of the North Esk, the Silurian rocks record a changing environment from marine and deltaic fossiliferous limestones and mudstones to fluvial sandstones.

Fossils of sea creatures can be seen, such as brachiopods, gastropods, trilobites and fish. In places the sandstone contains igneous intrusions, which in turn are cut by veins made from hot fluids.



Veins in Devonian igneous rock in Carlops.

Prolonged Erosion

The Pentland Hills comprise volcanic and sedimentary rocks from the Devonian period. Studies elsewhere show that Scotland was still located south of the equator. The environment was hilly, volcanic and semiarid. It was a time of seasonal rainfall and poor, patchy vegetation cover. The uplands were being eroded, and sediment transported downhill to accumulate in sedimentary basins.



Sandstone in Auchendinny from the Early Carboniferous showing a boundary between two different sets of sandstone layers deposited by river currents. The upper set shows cross-bedding, where sand is deposited at an angle by moving sand 'ripples'.

Coal and Volcanoes

During the Carboniferous period Scotland was near the equator with a hot and wet climate all year round. Carboniferous generally means coal-bearing, and the Midlothian Coalfield formed during this time. Most large coal seams have been mined, but a coal seam is well exposed by the bridge over the river on the A68. Coal forms from vegetation. At times central Scotland was covered by shallow seas in which limestone and mudstone formed, containing abundant fossils of marine corals and brachiopods, plants, fish and crustaceans. Sometimes freshwater lakes were present, in which mudstone containing bivalves (mussels) formed. At other times river systems dominated the environment and deposited thick layers of sandstone and mudstone with plant roots.

The Carboniferous was a volcanically active time when Arthur's Seat Volcano formed, but in the Esk Valley only



The coal seam in the Upper Carboniferous sandstones in Midlothian Coalfield under the A68.



The base of ancient river channels in Carboniferous sandstone in Roslin Glen, by the Gunpowder Mill, with finer horizontal beds underlying it.

small intrusions called sills and dykes can be seen, with examples between Carlops and the North Esk Reservoir. Faulting occurred in the area, and the major faults trend east-west.

Recent erosion by the River Esk has exposed cross sections through the sandstone in some places, such as in Roslin Glen. This allows us to see the changing nature of the sedimentary rocks, and cross sections of ancient river channels.

Supercontinent Formation

Evidence for most of the rest of Scotland's journey cannot be seen in the Esk Valley. Scotland continued to move northwards, and became part of a supercontinent called Pangaea with an arid environment and covered by deserts. Later, Pangaea started to break up forming the

continents we see today. This caused sea level to rise and Scotland was temporarily plunged under the sea again.

Dinosaurs would have roamed around Scotland, but very few are preserved. Marine reptiles such as Plesiosaurs are more common.

Splitting of Scotland and America

About 65 million years ago, America started moving away from Europe, initiating the Atlantic Ocean. This formed the Mid-Atlantic Ridge. It caused large scale volcanism, forming some of the Western Isles of Scotland, such as parts of Rum, Mull and Skye. Scotland is no longer moving north but the Atlantic Ocean is still opening, with America moving away from Scotland at a rate of 2.5cm per year. The volcanism is concentrated along the Mid-Atlantic Ridge, where new crust is still forming under the ocean and in some places, creating islands like Iceland.



Upper Carboniferous mudstone in Gore Glen, it is interbedded with sandstones along the river.

Glossary

Bedrock - The solid rock beneath unconsolidated material.

Boulder clay - Also known as till. Glacial deposits laid down beneath the ice, with material varying in size from grains of clay to boulders.

Cross-bedding - a common feature in sandstone resulting from accumulation of sand on inclined surfaces such as ripples, sand waves or dunes.

Dyke - A sheet-like igneous intrusion which cuts horizontal or gently dipping rock units at a different angle. Often they are near vertical.

Fault - A discontinuity surface across which the rock has been displaced.

Glaciofluvial - Referring to glacial meltwater activity.

Intrusive igneous body - An igneous body that is pushed into the surrounding rock at depth.

Meltwater channel - A channel cut by glacial meltwater under, along and in front of an ice margin.

Metamorphism - The process of changing the nature of rocks by heat, pressure or fluids.

Mid-Atlantic Ridge - The middle of the Atlantic Ocean where new oceanic plate is created. It rises above and is hotter than the surrounding sea floor.

Sill - A sheet-like igneous intrusion that follows the bedding. They are planar structures.

Striations - Scratch marks on bedrock made by stones embedded in the moving ice.

Slipping Slopes

Hewan Bank is a geological Site of Special Scientific Interest (SSSI) because its glacial deposits record the behaviour of the Scottish Ice Sheet during the last Ice Age.



Diagram 1 right

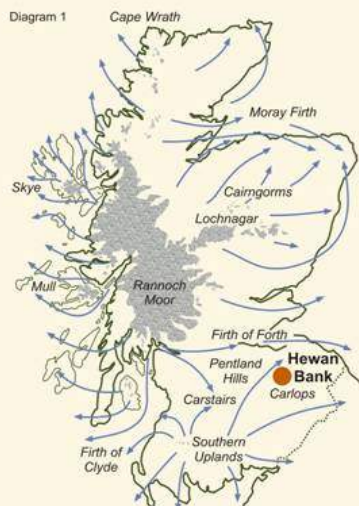
The blue arrows show the direction of ice flow during periods, such as 30,000 - 20,000 years ago, when Scotland was covered by a large ice sheet up to 2 km thick.

Hewan Bank was influenced by flow from the Highlands and Southern Uplands. The shaded area shows the extent of ice during the youngest glaciation of Scotland 11,500 - 12,700 years ago.

Diagram 2 bottom right

The margin of Scotland's main ice sheet retreated up the Esk Valley towards its centre in the Southern Uplands at the end of the last Ice Age.

Huge volumes of meltwater flowed through the rock channels at Carlops and deposited sand and gravel as it flowed towards the coast, rather like the meltwater stream in the Greenland photograph below. The river has excavated the valley subsequently.



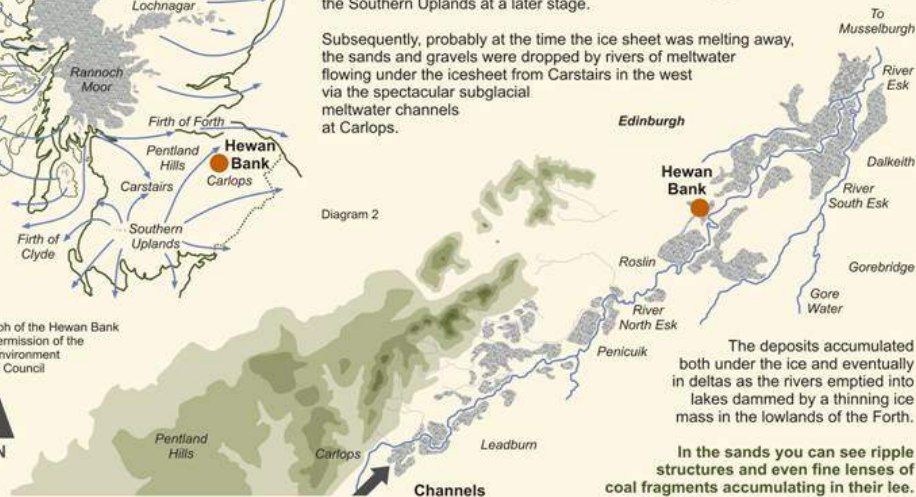
Undercutting by the river has caused landslips, which have disturbed the deposit, but from Springfield Mill we can still see that beds of sand overlies badly drained material called till. The till contains a range of angular-shaped stones that were broken up as they were transported along the glacier bed.

The mix of rock types tells us that the lowest blue-grey till was deposited by the ice from the Highlands. A reddish-brown till above the blue-grey till came from the Southern Uplands at a later stage.

Subsequently, probably at the time the ice sheet was melting away, the sands and gravels were dropped by rivers of meltwater flowing under the icesheet from Carstairs in the west via the spectacular subglacial meltwater channels at Carlops.

Diagram 2

Photograph of the Hewan Bank by kind permission of the Natural Environment Research Council



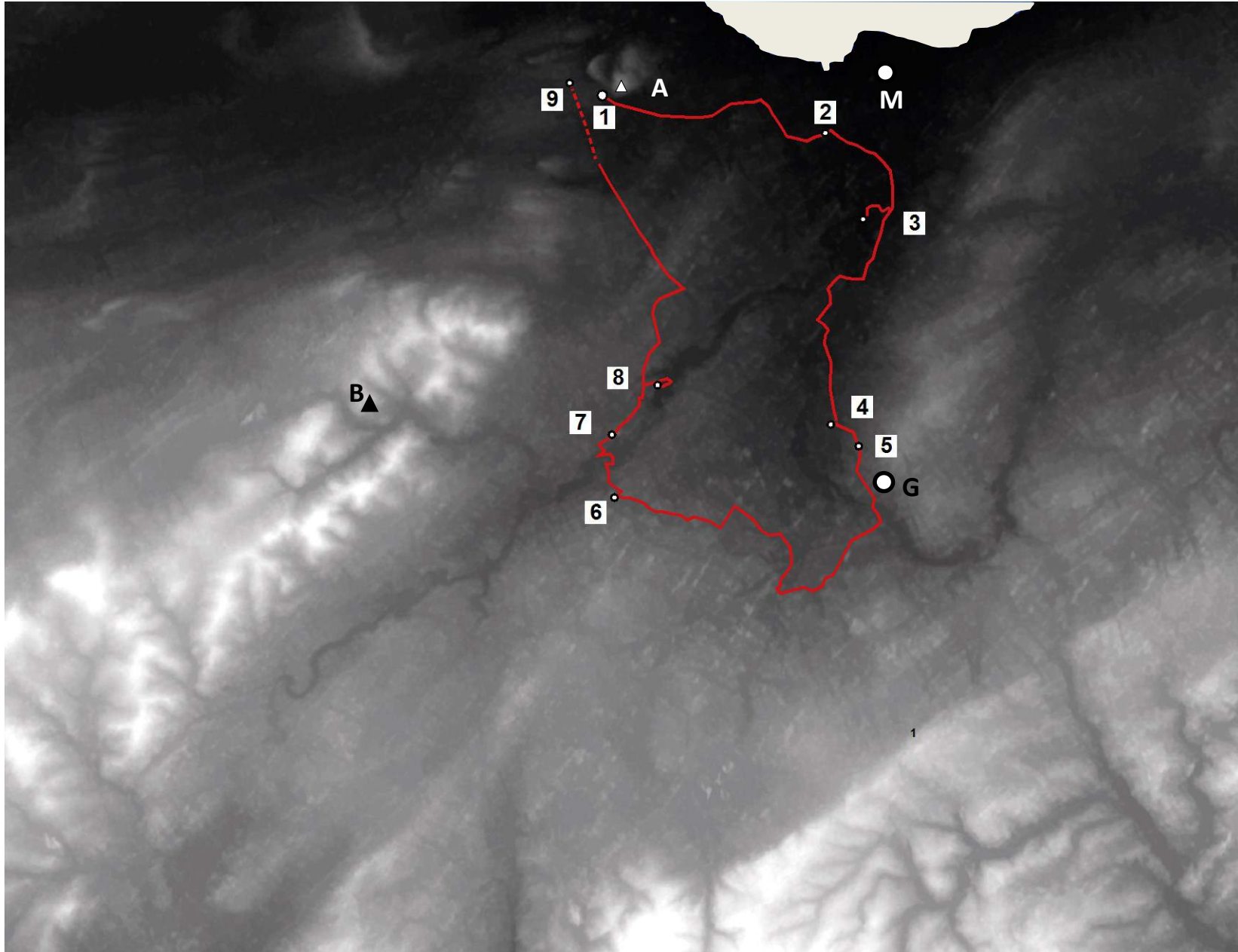
The deposits accumulated both under the ice and eventually in deltas as the rivers emptied into lakes dammed by a thinning ice mass in the lowlands of the Forth.

In the sands you can see ripple structures and even fine lenses of coal fragments accumulating in their lee.

Source of document: Esk Valley Trust (visit their website: <http://www.eskvalleytrust.org/>)

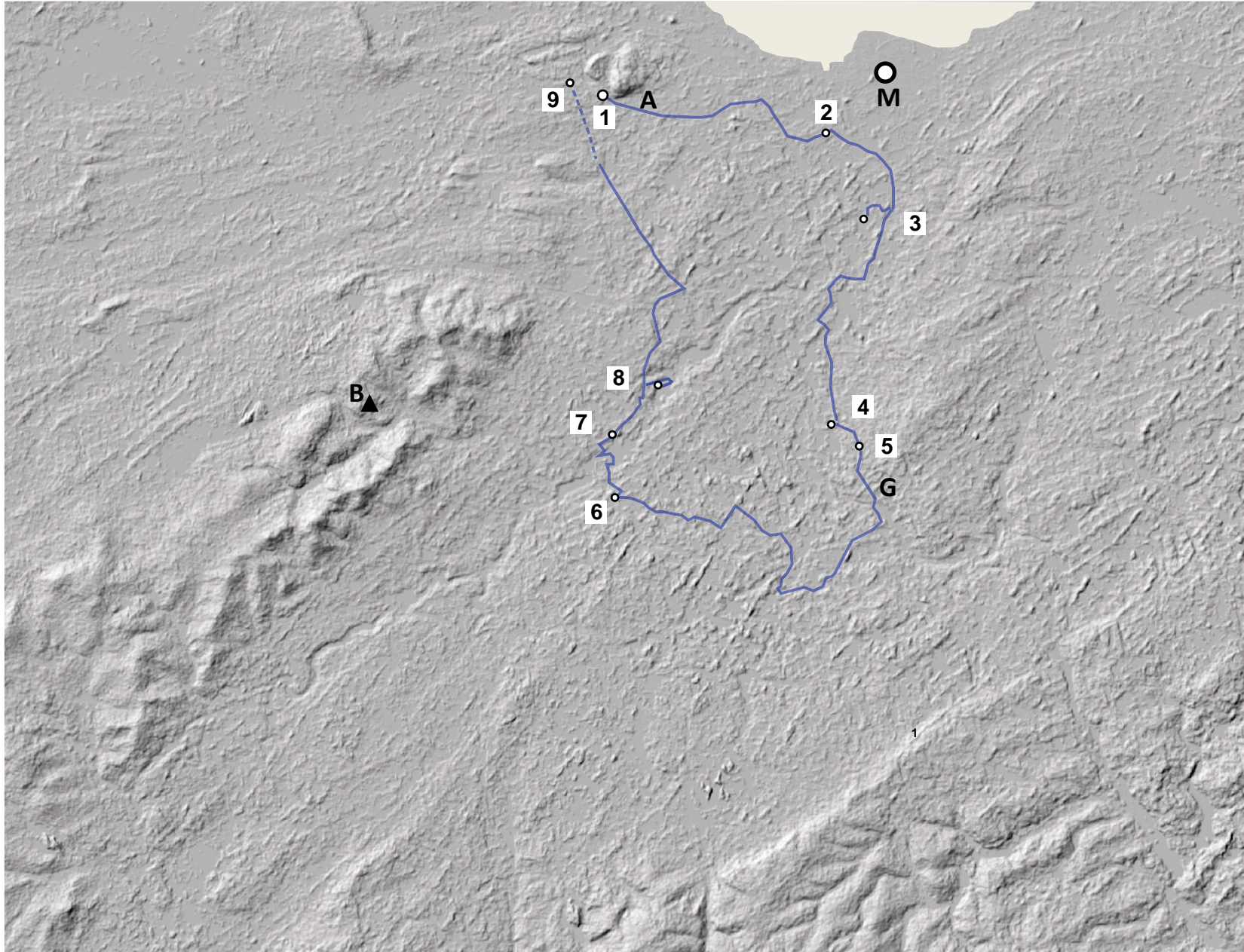
Digital Elevation Model of the Edinburgh area (data from ASTER; ASTER GDEM is a product of METI and NASA).

A = Arthur's Seat, B = Bell's Hill (Pentlands), G = Gorebridge, M = Musselburgh. Cycle route and stops indicated as a guide.



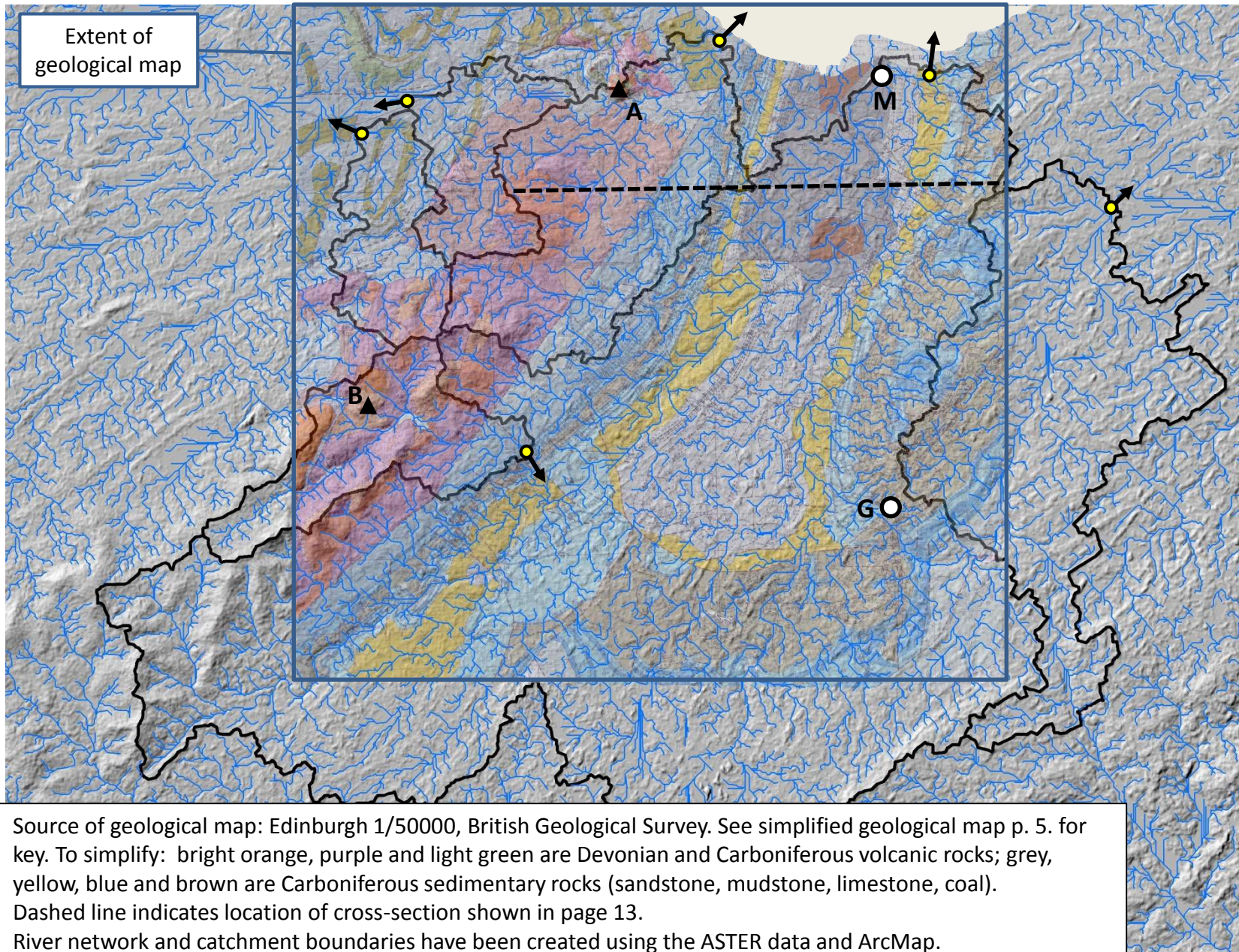
Shaded relief of the Edinburgh area (data from ASTER; ASTER GDEM is a product of METI and NASA).

A = Arthur's Seat, B = Bell's Hill (Pentlands), G = Gorebridge, M = Musselburgh. Cycle route and stops indicated as a guide.

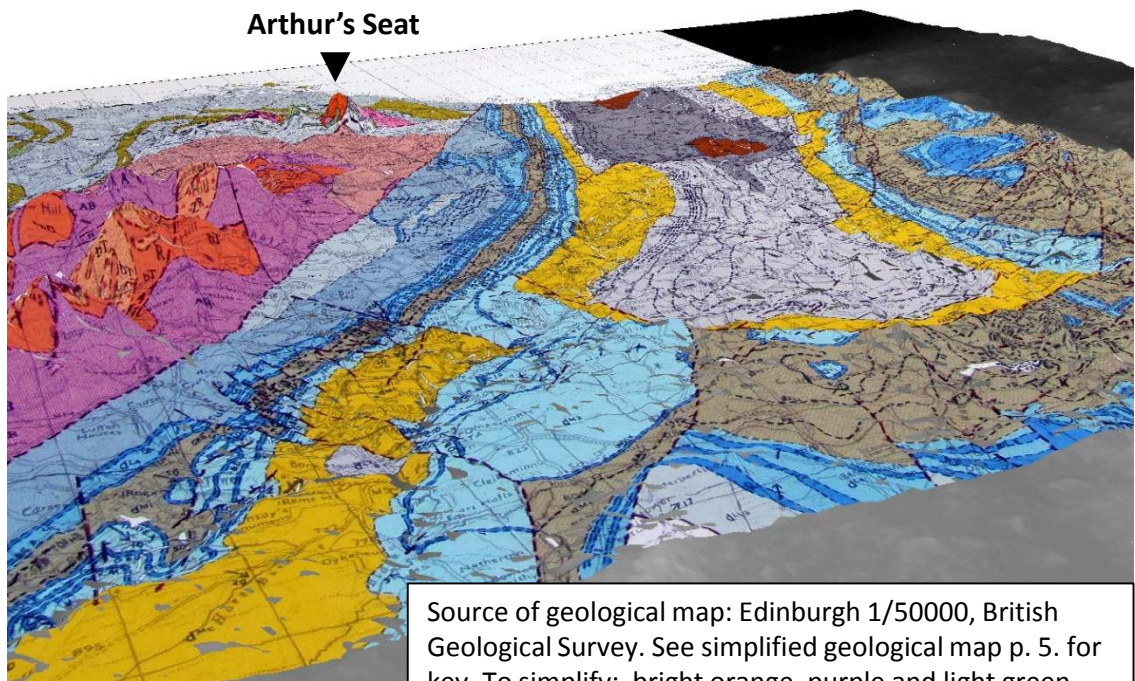
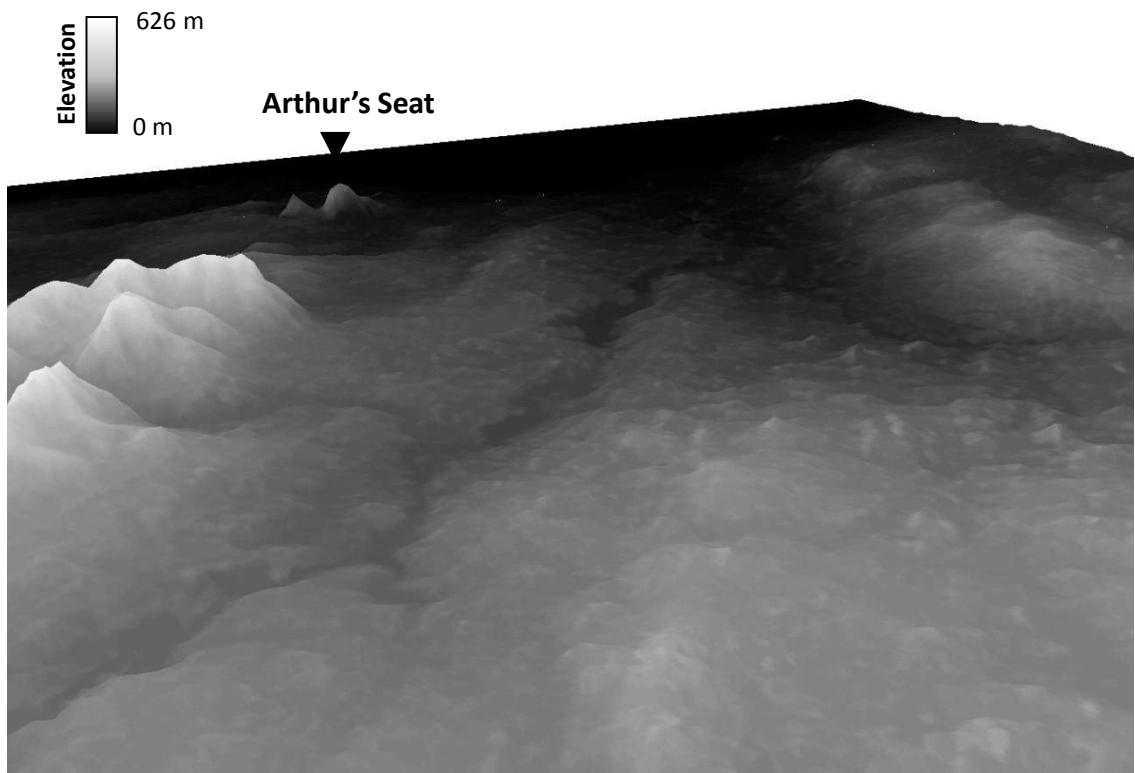


River network and boundaries of a few selected river catchments (including the Esk) + geological map

Yellow dots and arrows show catchment outlets. A = Arthur's Seat, B = Bell's Hill (Pentlands), G = Gorebridge, M = Musselburgh

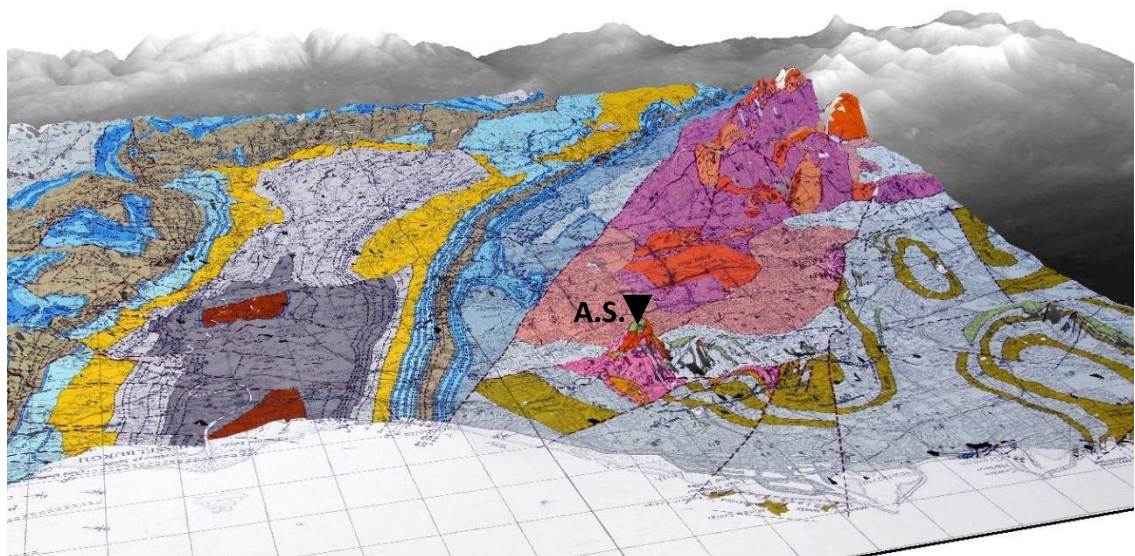
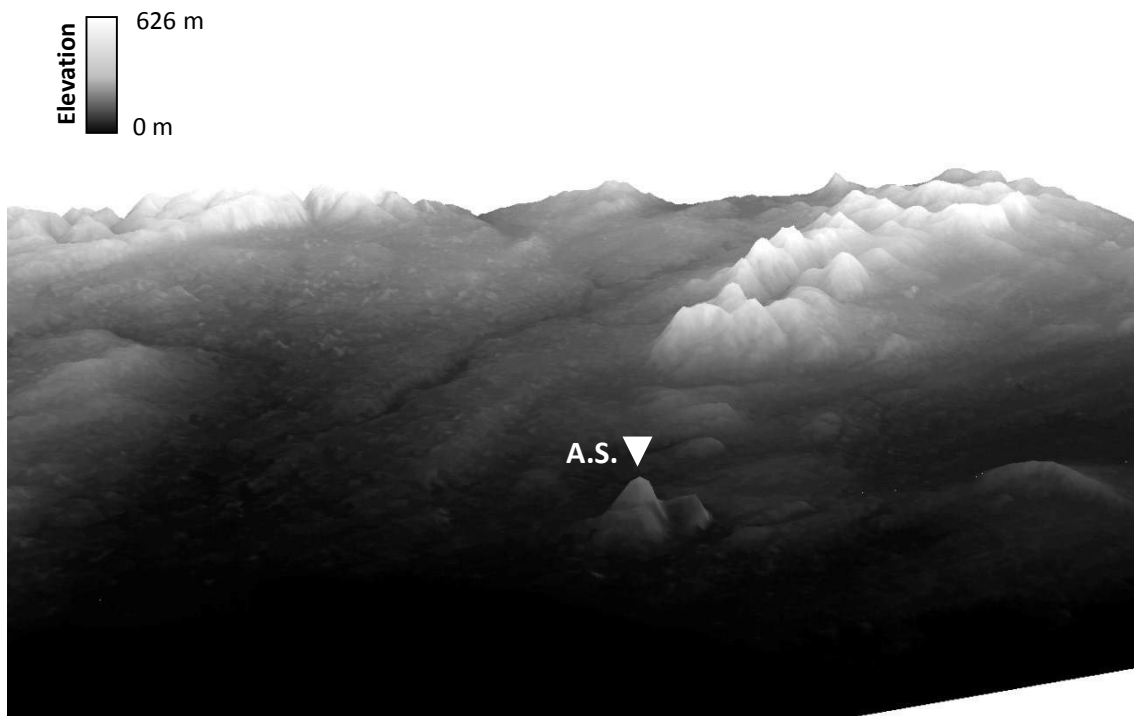


ArcScene representation of topography (top) and geology (bottom). Vertical exaggeration x4. View towards NE.



Source of geological map: Edinburgh 1/50000, British Geological Survey. See simplified geological map p. 5. for key. To simplify: bright orange, purple and light green are Devonian and Carboniferous volcanic rocks; grey, yellow, blue and brown are Carboniferous sedimentary rocks (sandstone, mudstone, limestone, coal).

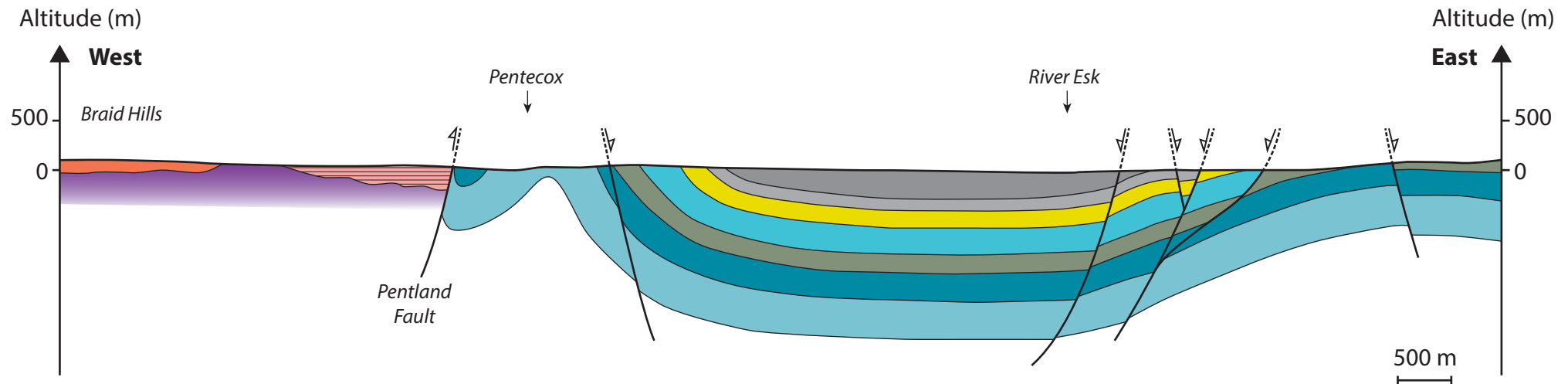
ArcScene representation of topography (top) and geology (bottom). Vertical exaggeration x4. View towards SSW.



A.S. = Arthur's Seat

Source of geological map: Edinburgh 1/50000, British Geological Survey. See simplified geological map p. 5. for key. To simplify: bright orange, purple and light green are Devonian and Carboniferous volcanic rocks; grey, yellow, blue and brown are Carboniferous sedimentary rocks (sandstone, mudstone, limestone, coal).








Cross section on Edinburgh geological map, 1/50000, Br(itish Geological Survey, at latitude grid reference 70



KEY (adapted from geological map):

Sedimentary (approximate thickness indicated in brackets when known):

CARBONIFEROUS

-  **d^{c2}: Middle Coal Measures:** sandstones, siltstones, mudstones, coals (200 - 250 m)
-  **d^{c1}: Lower Coal Measures:** sandstones, siltstones, mudstones, coals (150 m)
-  **d^{MC}: Passage Group:** sandstones pebbly in places, mudstones, coals (175 - 200 m)
-  **d^{M2}: Upper Limestone Group:** cyclic sequence of sandstones, siltstones, mudstones, marine limestones and coals (175 - 300 m)
-  **d^{M1}: Limestone Coal Group:** cyclic sequence of sandstones, siltstones, mudstones and coals + two marine beds (175 - 250 m)
-  **d^{L4}: Lower Limestone Group:** cyclic sequence of sandstones, siltstones, mudstones, marine limestones and coals (175 - 250 m)
-  **d^{L3}: Upper Oil-Shale Group:** sandstones, mudstones, limestones, oil-shale beds, coals (200 - 400 m)



**OLD RED SANDSTONE
(ORS - Devonian)**

Upper ORS

-  **c³: Upper Old Red Sandstone:** sandstones with conglomerate bands and beds of silty mudstone

Lower
ORS

Extrusive igneous (= volcanic):

-  **T: trachyte**
-  **pA: pyroxene-andesite**

