LOCH LOMOND TO STIRLING

A LANDSCAPE FASHIONED BY GEOLOGY

SCOTTISH NATURAL HERITAGE

BGS 1835

British Geological Survey

Contents

Cover: Loch Lomond from above Duncryne.

View of the Ochil Hills.

The area between Loch Lomond and Stirling encompasses some of the most diverse landscapes in Central Scotland. It ranges from the flat agricultural land of the Carse, east and west of Stirling, the volcanic hills of the Ochils, Gargunnocks and Campsies to the rugged Highlands with their lochs and glaciated rocky summits.

In this booklet we attempt to show how this diversity reflects the underlying geology and how this complex foundation developed over many millions of years. In the recent geological past ice has played an important role in shaping the scenery and this is a classic area to view its dramatic effects.

Stirling Castle, the Wallace Monument and the Ochil Hills.

View over Stirling

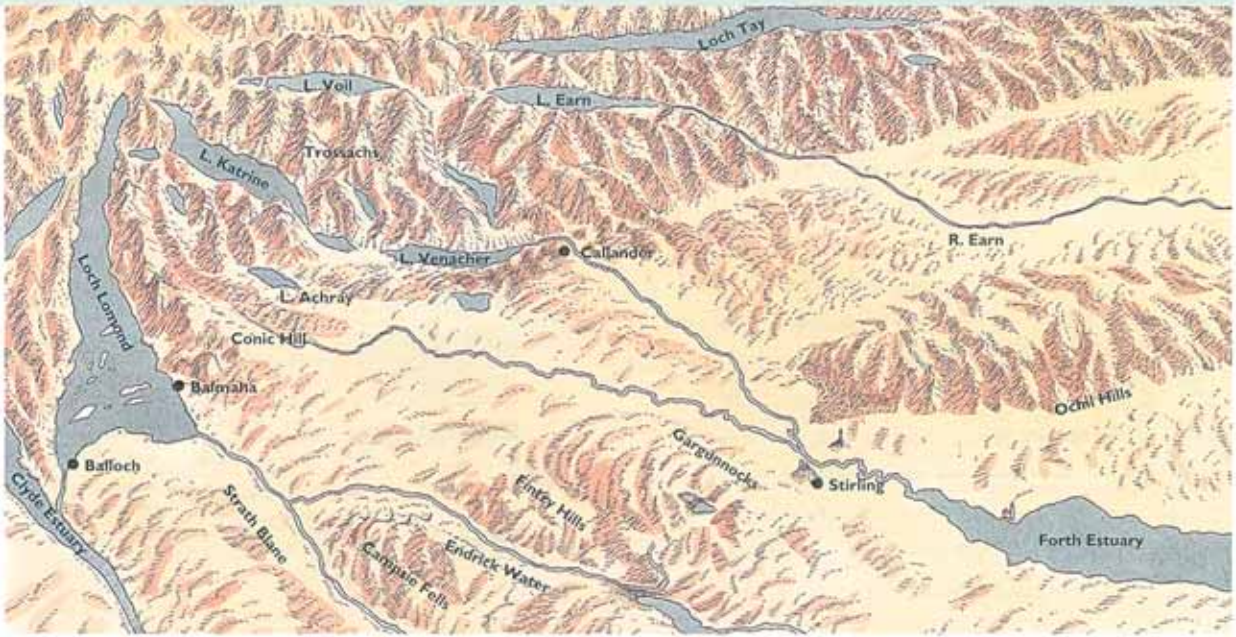
Stirling Castle has been a pivotal place in Scottish history, guarding the only safe crossing of the River Forth and the adjacent treacherous boggy ground. The Castle overlooks the surrounding lowlands and is within sight of the Highland Line. On a clear day many of the significant landscape features of Central Scotland can be viewed from its battlements. To the east lies the estuary of the Forth with the distant chimney of Longannet Power station, a living monument to the Scottish coal mining industry. Much of this low lying area is underlain by the Central Coalfield, now covered by thick glacial deposits laid down as the last major ice sheet to cover Scotland melted about 13,500 years ago. When the ice retreated, the sea once extended as far inland as Aberfoyle.

It was only 6,500 years ago that the Carselands to the west of Stirling were formed by the silting up of the Forth estuary. Remains of whales up to 25m long were found in the clays when the bogs of the Carse were drained in the 18th and 19th centuries. Other remains show that Mesolithic people found plentiful food supplies of shellfish, wildfowl and deer.

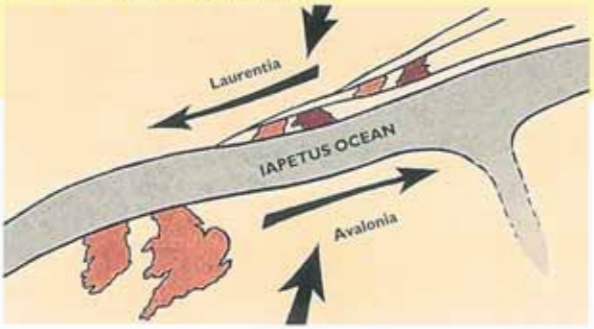
Above these formerly wet and forested lowlands rise a number of upland areas all made of hard volcanic rocks of various ages. The Ochil Hills are made of a series of andesitic lava flows which are some 410 million years old. Their steep southern slope reflects the line of the large Ochil Fault, separating the hard, massive volcanic rocks from the softer coal-bearing

Carboniferous sedimentary rocks. Weathering and erosion have stripped away the softer sedimentary rocks leaving the harder igneous rocks standing proud. The Gargunnock Hills, to the west, are a series of basaltic lava flows and volcanic ash layers which were erupted onto a tropical coastal plain some 340 million years ago. Later the hills were gently tilted to the south and their northern slopes were sculpted by Highland glaciers to form the tiered hills we see now. Stirling Castle and the Wallace Monument sit on natural ramparts, created when a thick sheet of molten rock was forced between the Carboniferous sedimentary strata and along existing faults about 295 million years ago. This rock cooled and crystallised to form a continuous layer of dolerite which now lies under much of the Forth estuary.

Deep below the Carselands and peat mosses in the lower parts of the Forth and Teith valleys to the west of Stirling we find red-brown sandstones, mudstones and pebbly conglomerates. These rocks link at depth to the upstanding ridges of the Menteith Hills in the distance – formed by almost vertical strata of the same rocks. The strata were formed under tropical conditions about 400 million years ago in the Devonian age. Behind the Menteith Hills is the craggy backcloth of the Highlands with the prominent peaks of Ben Ledi, Ben Venue and farther west Ben Lomond. These much older rocks have suffered a longer and more complex history and formed part of the Caledonian Mountains which stretched from Norway to the Appalachians.



The coming together of Scotland.



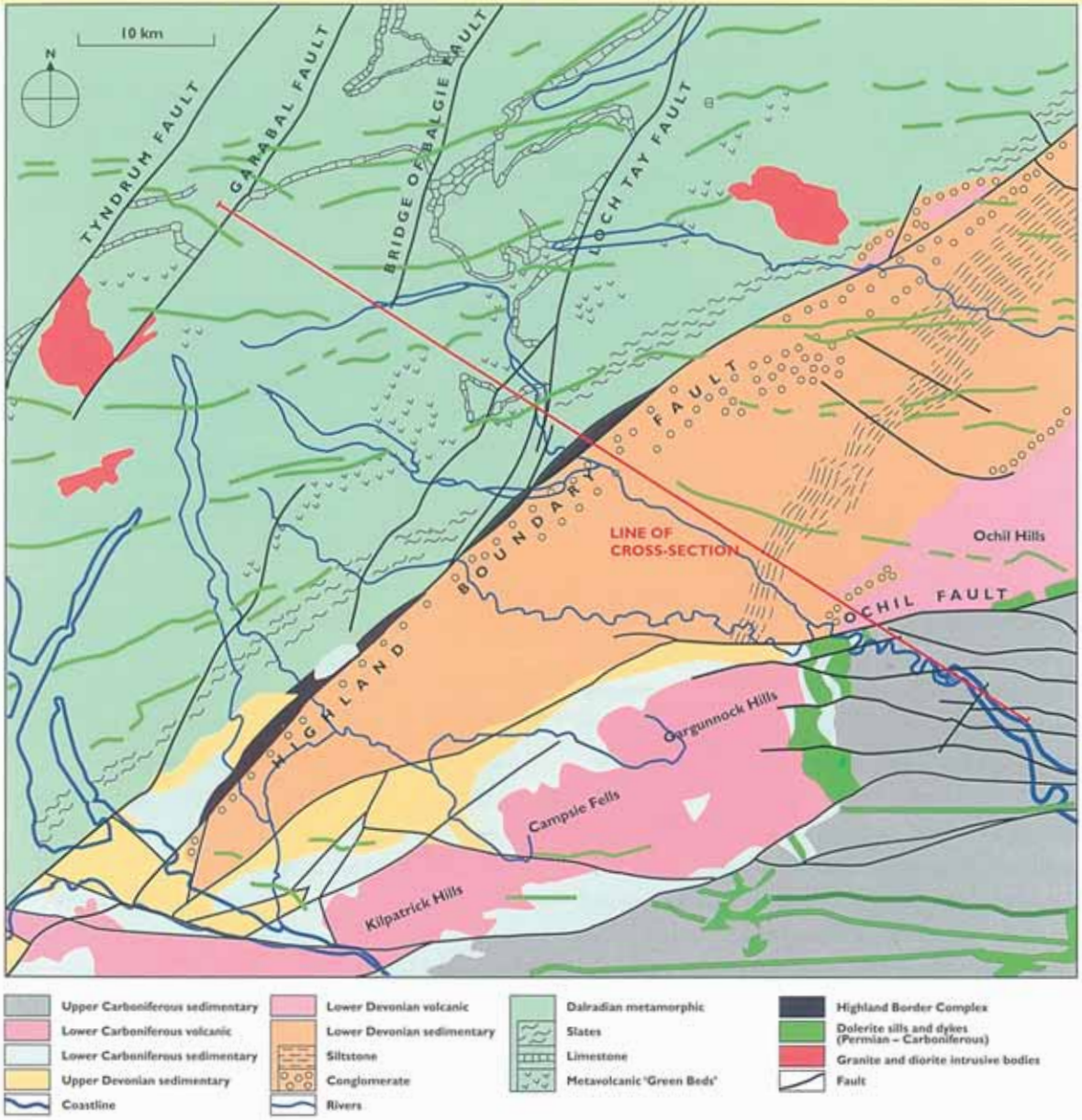
The basic geological framework of Scotland represents a union of different fragments of the earth's crust. The earth's surface comprises a series of plates which are constantly on the move, a process known as plate tectonics. This movement of plates is similar to pack ice, breaking and reforming and eventually creating large icebergs which go their separate ways dictated by currents beneath. Because continental crust 'floats' on viscous fluid 'rock' about 120km below the earth's surface, it can be broken up by prevailing earth forces and directions of flow in the 'fluid' rock layer and then reassembled. Volcanoes and earthquakes occur commonly in areas which are tectonically active.

The Loch Lomond – Stirling area sits astride a major boundary between two blocks, brought together between 450 and 420 million years ago. The Highlands and Lowlands are separated by the near-vertical Highland Boundary Fault, a large fracture that penetrates deep into the earth's crust separating different crustal blocks. The rocks we see in the Highlands form part of an older block of 'twisted, cooked and stewed' altered rocks, which had already formed when the rocks of the lowland Midland Valley were deposited. The Midland Valley formed as a large basin or series of basins bounded by faults within which thick layers of Devonian and then Carboniferous sedimentary and volcanic rocks were laid down.

Years ago	Geological Period and Palaeolatitude	Events in Stirling and Loch Lomond area
60		Peak of coal mining
200		Major clearance of surface peat in Forth valley begins
500		Coal mining starts
		Clearance of forests
5,000		Sea level at present level
6,800		Loch Lomond – sea loch 5000 – 6500 yrs. ago Sea level 16m above present. Carse clay deposition in Forth valley
		Loch Lomond mainly freshwater lake
10,000		End of Loch Lomond Re-advance
11,000	QUATERNARY	Start of Loch Lomond Re-advance Loch Lomond – sea loch 12000 – 11000 years ago Late Devensian Ice Age ends
13,500		
27,000		Late Devensian Ice Age begins Build up of ice on Rannoch Moor
		Several Ice Ages Ice sheets and glacial meltwaters erode deep depressions into bedrock
2 M		Corries develop in Highlands Scottish climate cold enough for start of Ice Ages
	46°N NEOGENE AND PALAEOGENE (TERTIARY)	Present day drainage initiated Uplift and erosion
65 M		Basaltic magma injected as dykes Opening of NE Atlantic
	45°N CRETACEOUS	Shallow sea chalk deposited
135 M	43°N	
	JURASSIC	Warm, temperate seas around Scotland
205 M	33°N	Opening of North Atlantic
	TRIASSIC	Arid climate, desert
250 M	10°N	
	PERMIAN	Minor volcanic activity
300 M		Intrusion of dolerite sills and dykes Earth movements, folding, faulting, uplift
	0°N	
	CARBONIFEROUS	Tropical shallow seas and wide, low, coastal plains. Rain forests decay to form coal. Mudstones and limestones deposited. Local uplift, continuing volcanism.
		Volcanoes erupt basalt lavas and ashes
360 M	0°S	Tropical muddy coastal plain, sometimes flooded by sea water during storms
		Desert with sand dunes, large alluvial plains draining east
	DEVONIAN	Earth movements: folding, faulting, uplift and erosion Very large river system flowing SW deposits sandstones and conglomerates
	10°S	Large volcanoes produce lavas and debris flows
410 M		Lateral faulting in Highlands Intrusion of granites, diorites. Uplift
	SILURIAN	Emplacement of Highland Border Complex Highland and Midland Valley crustal blocks joined
435 M	22°S	
	ORDOVICIAN	Main Caledonian Mountain Building Periodic uplift Thrusting, folding, metamorphism of Dalradian rocks
495 M		Deposition and formation of Highland Border Complex components
	CAMBRIAN	
570 M		
600 M		Start of Caledonian Mountain Building
	PRECAMBRIAN	Low grade metamorphism
800 M		Deposition of Dalradian sedimentary and volcanic rocks

Geological Framework

Map showing the bedrock geology of the Loch Lomond – Stirling area.



The Highlands – a part of North America?

View from the Gargunnock Hills across the Carse to the Highlands.

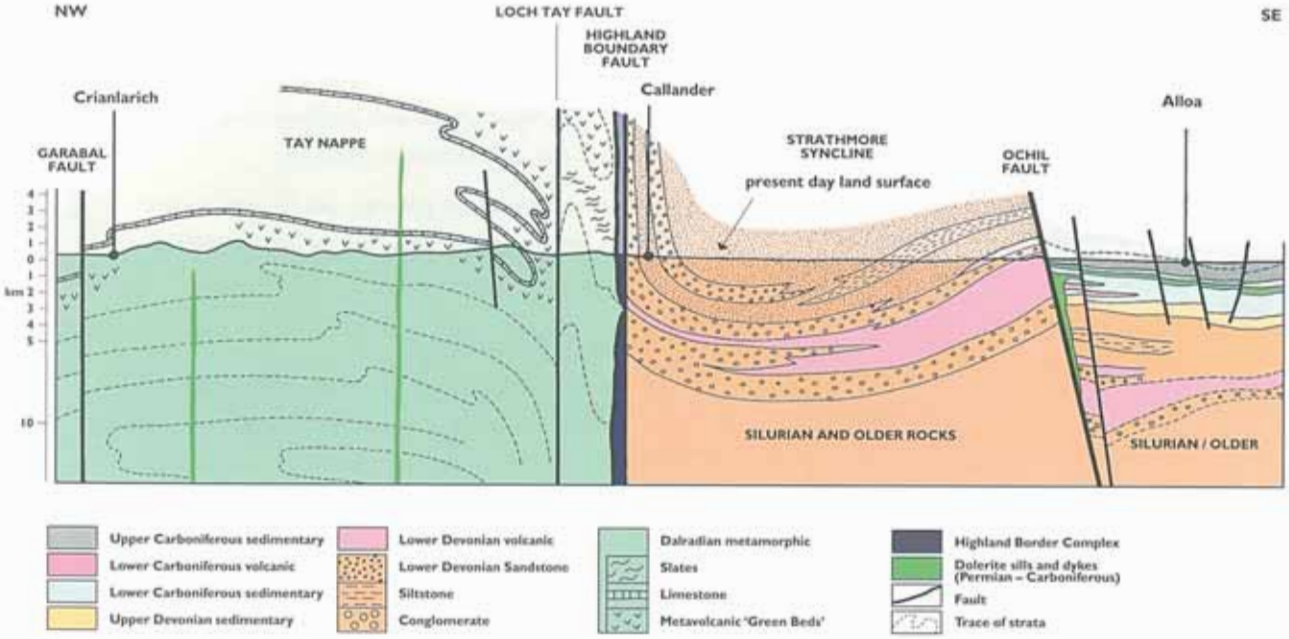
The abrupt change in the landscape as the Highlands are approached from the Lowlands reflects major changes in the type and age of bedrocks and their differing geological histories. The heather-clad mountains and wooded glens so distinctive of the Highlands were carved out of hard rock, known as Dalradian after the ancient Scots kingdom of Dalriada. These were originally marine sands, muds, lime-rich deposits and layers of volcanic ash. They were subsequently altered by heat and pressure, resulting from burial to depths of around 15 to 20 kilometres below the earth's surface. Folding and metamorphism of the rocks, brought about by the increased pressure, and temperatures of 500 to 600 degrees Celsius, 'cooked and stewed' the minerals in the sedimentary rocks and crumpled the original pattern of sedimentary and volcanic strata.

New minerals were formed and sands and muds were transformed into hard cleaved rocks such as slates, phyllites and schists. The earth movements responsible for these upheavals are known as the Caledonian Orogeny or mountain building event. More recently the Alps and Himalayas were formed in a similar way. At the time these rocks were formed, the area we now recognise as Scotland lay south of the equator and formed part of Laurentia; a large continent subsequently fragmented to form eastern North America, Greenland and Scotland. This area was separated from England by the Iapetus Ocean, which has long since disappeared.

At the end of the Caledonian Orogeny uplift accompanied by faulting occurred. Molten granitic magmas were also created at this time which rose towards the surface and crystallised to form ovoid bodies up to 10 km across such as those near Arrochar and in Glen Fyne. Smaller pulses of magma crystallised to form sheets and dykes. Weathering and erosion by wind and water tried to keep pace with the uplifting mountain chain and by about 400 million years ago a balance was reached with the area remaining as undulating hills. Although innumerable modifications to the landscape have occurred since, the basic division into Highlands and Lowlands was complete by the end of the Caledonian Orogeny.

Ben Lui – carved by ice from hard Dalradian rocks.

Geological cross-section from the Highlands to the Forth Estuary.



The Highland Line

The sharp change in topography, weather, vegetation, and wildlife, marked by the Highland Line, from Helensburgh via Balmaha, Aberfoyle and Callander and continuing northwards to Stonehaven, is reflected in the culture and population density. The Line has played an important role in the colourful history of Scotland, dividing the Highland Clans from their wealthier Lowland neighbours. It is no surprise that disparities in the fertility of agricultural land, the climate and the living conditions historically resulted in regular raids from Highlanders on their southern neighbours.

The Highland-Lowland boundary reflects the major geological change from hard Dalradian metamorphic rocks in the north west to pebbly conglomerates and softer sandstones of Devonian age immediately to the south east. Between the two there is a sequence of lavas, conglomerates, limestones, black mudstones and sandstones which are different to both Highland and Lowland rocks, called the Highland Border Complex. They form a zone up to 1.2 kilometres wide which is found between Balmaha and Callander. These rocks came from both deep and shallow waters and once formed part of the floor of a small ocean basin. We know this because of the marine fossils found in the limestones, although these are very small and difficult to find. The rocks range in age from about 550 million to 445 million years old. They became attached to the Highland block by lateral faulting as a result of plate tectonic movements.

Highland Boundary Fault from above Conic Hill, Loch Lomond.

Highland Border Complex rocks form hilly ground, which near Callander lies between the higher ridges of the Menteith Hills and Callander Craig to the southeast, and the rocky crags of the Dalradian which overlook them to the northwest.

Immediately southeast of the Highland Boundary Fault at Balmaha Pier, pebbles in the Devonian conglomerates have open vertical cracks which show that the rocks were stretched as lateral movements occurred between the two blocks separated by the fault. We know that these movements happened about 420 to 390 million years ago.

Much of the above geology can be seen on the Highland Boundary Fault trail at David Marshall Lodge near Aberfoyle.

The Trossachs

The Trossachs, literally translated from the Gaelic as 'bristled territory', is strictly defined as the narrow rocky, wooded valley between Loch Achray and Loch Katrine, but it is now used for the wider area between Callander, Loch Katrine and Aberfoyle. It lies mainly within the Highlands and the complex pattern of the underlying geology is partly reflected in the landscape.

In the 17th to 19th centuries trade in cattle reared in the Northwest Highlands was important, and drove routes were established to the fairs or 'trysts', at Crieff and later at Falkirk. One of the major routes led via Tyndrum to Crianlarich, Glen Gyle and Loch Katrine. It crossed volcanic 'Green Beds' on the north shoulder of Ben Venue via Bealach nam Bo (Pass of the cattle). This particularly steep part of the route attests to the nimbler cattle of former times.

The accessible but wild beauty of the Trossachs was first publicised by the Reverend Dr Robertson who reported on the parish of Callander in 1768. He described the Loch Achray – Loch Katrine valley as 'a tumultuous confusion of little rocky eminences, all of the most fantastic and extraordinary forms, everywhere shagged by trees and shrubs'.

In the following 50 years, several well-known writers, including Wordsworth, Coleridge and Walter Scott, visited the Trossachs. It was Scott, in the poem Lady of the Lake (1810), who encapsulated the romantic wildness of the area in the style favoured at the time. This led to a great increase in the numbers of tourists visiting the area in the 19th century. The use of Loch Katrine for Glasgow's water supply and the adjacent hills for coniferous forestry have tamed parts of the area, but the oak woods, glaciated rocky eminences and backcloth of ice-moulded craggy hills still remain.

Tropical Rivers and Deserts

Devonian – Early Carboniferous (415 to 345 million years ago)

By early Devonian times, Scotland was situated just to the south of the equator. The climate was hot, with wet and dry seasons. The Caledonian Mountains had been eroded and as this burden was reduced, so the land rose to expose the rocks we see today which were originally several kilometres deep in the earth. The landscape consisted of eroded mountains to the north and alluvial fans along the Highland Border. Farther south was an alluvial plain which stretched from Scandinavia to Wales where it met the sea. The rivers were large and braided with channels as wide and deep as the Mississippi. The finer silty floodplain deposits were usually eroded and carried away so that the Devonian rocks are mostly sandstone and conglomerate. Plants were only just beginning to colonise the land and were probably found in isolated damp places on the floodplains and in marshes. Large armoured fish, with life cycles

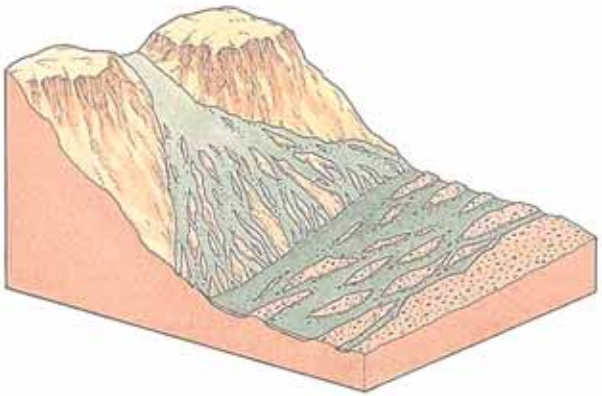
similar to those of salmon, lived in the rivers and lakes. Evaporation of groundwater in drier times caused the chalky compound calcium carbonate to harden in the soils as nodules and hard ground known as calcrete.

Volcanic processes were also at work. Andesitic and basaltic lava flows were erupted from large volcanoes similar to those in the Andes today. Volcanic mudflow conglomerates and some airfall ash deposits are interbedded with the lava. These rocks now form the Ochil Hills.

Following earth movements during Middle Devonian times, when the older rocks were folded, uplifted as mountains and eroded, the landscape was low-lying near sea level, with only a few low hills in the Highlands. In the late Devonian, the area was part of a central Scottish alluvial plain in which braided rivers mainly drained eastwards to the sea. Initially, there was little vegetation, and windblown sand dunes formed when the rivers periodically dried up. As groundwaters evaporated in the dry seasons calcium carbonate again hardened the soils as calcrete.

For a while in early Carboniferous times, muddy deposits were laid down on a coastal floodplain, with storms bringing seawater well inland to mix with the groundwater. In the dry seasons, surface and groundwater evaporated, drawing up and depositing gypsum, anhydryite and salt (which later dissolved) in the sun-cracked muds, and also transforming beds of limestone to dolomite (cementstone) in lakes or lagoons.

Schematic diagram of a braided river and alluvial fan



Upper Devonian desert sandstone at Finnich Glen, lower Strathblane.

Rivers later returned to the plains, but these flowed into the area from higher ground to the north depositing mainly sandstones. Vegetation was probably patchy with only limited stands of trees.

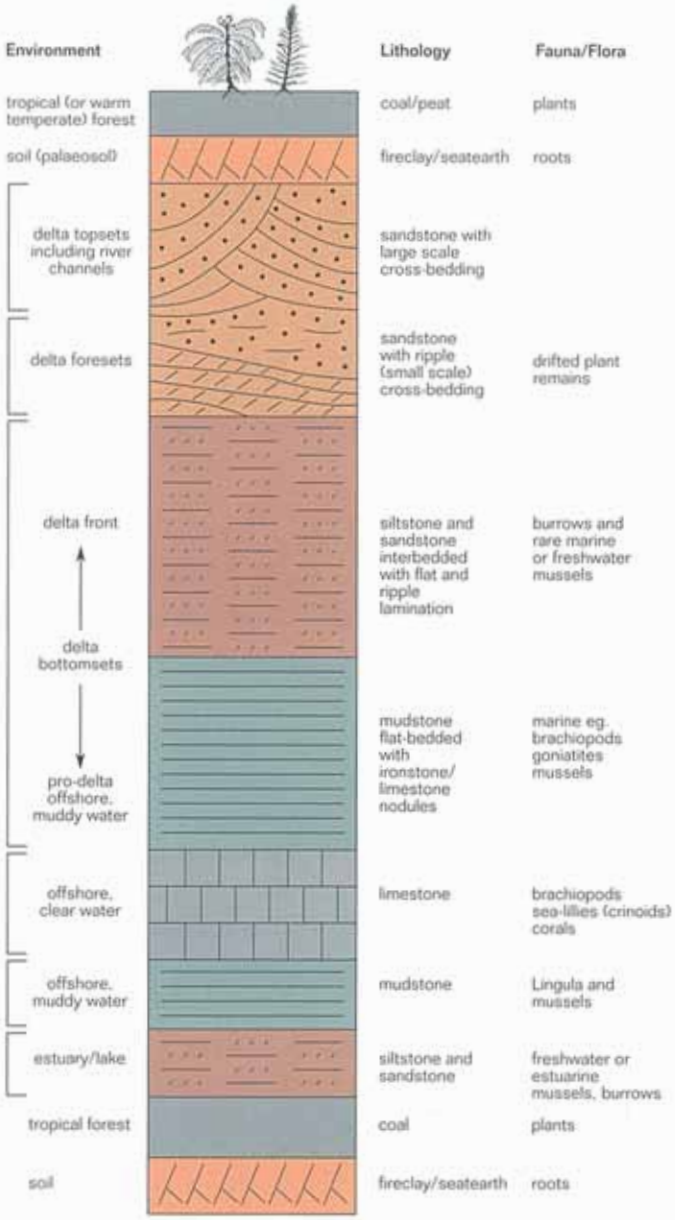
Volcanoes were also active at this time. The 340 million years old basaltic lava flows and volcanic ashes of the Campsie Fells and the Kilpatrick and Gargunnock hills were erupted from fissures and small volcanic cones which were often grouped along fault lines. The individual flows form bold scarp or 'trap' features on the northern face of the Gargunnock Hills and southern face of the Kilpatricks. The eroded roots of the volcanoes, now hard plugs of basalt, form characteristic isolated hills like Dumgoyne and Dumbarton Rock. The volcanic activity on Iceland, where new ocean floor is currently being generated causing the European and North American plates to drift farther apart, shows how this area might have been in Carboniferous volcanic times. However volcanic activity in Scotland ended before actual rifts were created.

Tropical Forests and Seas

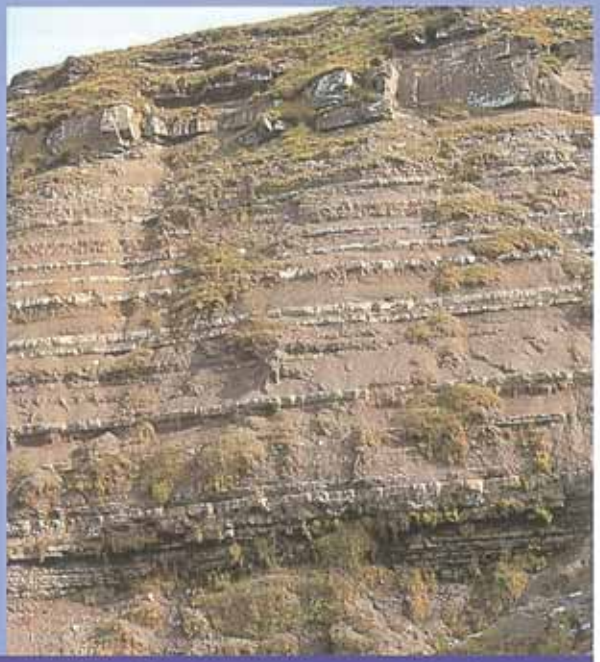
Early – Late Carboniferous (335 to 300 million years ago)

Scotland remained in equatorial latitudes, and the Midland Valley was a very small part of a huge, continental-scale, low-lying coastal plain which had a range of constantly changing landscapes. Usually, it was almost completely covered with luxuriant tropical rainforests. The trees of this time were very different to their modern relatives and only a few were woody, but many were buttressed by having tough bark. Carboniferous trees were simply constructed, small and rapidly growing. As this vegetation died and began to rot it formed thick layers of peat which are now preserved as coal seams.

These Carboniferous peats were like modern blanket bog and raised peat bogs which need regular rainfall to grow. Whereas the more recently formed East and West Flanders raised peat mosses are up to six metres in height, their Carboniferous cousins reached 10 – 22 metres. Between peat bogs, meandering rivers deposited sand in their channels and silt on their floodplains. Organic-rich muds and bog iron ores formed in some small lakes.



Cycle of coal formation.



Lower Carboniferous bedded cementstones and mudstones in Ballagan Glen.

Peat accumulation stopped when the coastal plain became submerged under the sea or by large lakes, which drowned the bogs. We know about these floodings because of the many marine and non-marine shell beds preserved in the rock record. Limestones were deposited in clear tropical seas where corals and sea lilies thrived. The drowning was sometimes caused by a global rise in sea-level or climate change, and at other times by land subsidence created by tectonic processes such as earthquakes. Other causes such as wild fires also stopped peat from forming. Over time, delta plains extended out into the sea with wide interlinking channels and lagoons. As the new delta surface emerged as dry land, soils developed as vegetation established anew.

And on to the Tertiary (300 to 2.4 million years ago)

Earth movements at the end of the Carboniferous caused uplift, folding and faulting and halted the sedimentary record in the Lomond area. From the Permian some 250 million years ago to the beginning of the Quaternary around 2.4 million years ago Scotland was carried northwards, from equatorial to temperate latitudes, by continental drift. During the Permian and Trias, the landscape formed under desert conditions with sandstorms. A few volcanoes remained active. In the Jurassic, the climate became humid and warm and later Cretaceous sea probably flooded the area to lay down a veneer of Chalk, which was later completely dissolved and eroded. In the Paleogene and Neogene (60 – 2 million years ago), the climate cooled and extensive weathering and erosion took place. The framework of the present river systems was also established, only to be changed later by the erosive power of ice.

Lava flows in the Fintry Hills.

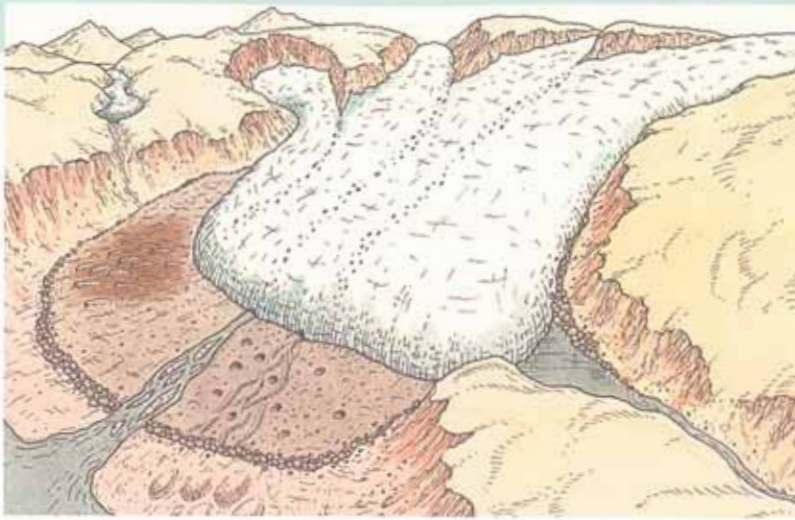
The Coming of Ice

The gradual drift of Scotland northwards from its equatorial position in Carboniferous times 300 million years ago, made climatic changes inevitable. Thus when the cooling climate heralded the ice age over two million years ago, the northerly latitude and predominantly wet southwesterly airstream that still dominates our weather today made Scotland a ready target for glaciation. Corries formed by annual freeze-thaw action breaking up the bedrock as snow patches became thicker on the steeper hill slopes. Excellent examples of corries occur on the north side of the Campsie Hills, and on Ben Lui and Ben Lomond. Small ice sheets developed on the higher and wetter areas, joining to form a larger ice cap which eventually covered the whole of Scotland and at times extended much farther south. High mountain tops sometimes stood proud of the ice sheet and frost shattered the upstanding rock to form fields of angular boulders. Corries were accentuated on the flanks of the higher peaks. Ice sheet development took around 3,000 years. Numerous cycles have occurred in the last two million years with ice sheets developing, only to melt in warmer interglacial periods.

The flowing ice picked up rock fragments from the bedrock and acted like sandpaper, scouring and polishing the upland and lowland topography. Bedrock was ground down and carried away by the ice, much of it to be deposited beneath the ice to form till, especially in the lowlands. Till is a stiff clayey to sandy mixture of rock particles, which range from flour to large boulders. In many areas the till was sculpted by the overlying flowing ice to form streamlined mounds up to 20 or 30 metres high called drumlins. Drumlin swarms are seen around Gartocharn and near Drymen and Killearn. In the lowlands small upstanding hills

Corrie of Balglass, north side of the Campsie Fells.

Schematic diagram of landforms produced at the edge of a melting glacier.



were scoured by the ice on their upstream side and till deposited on the lee side giving crag and tail features such as Duncryne and Dunglass. Stirling Castle and the Wallace Monument both perch on ice-scoured crags.

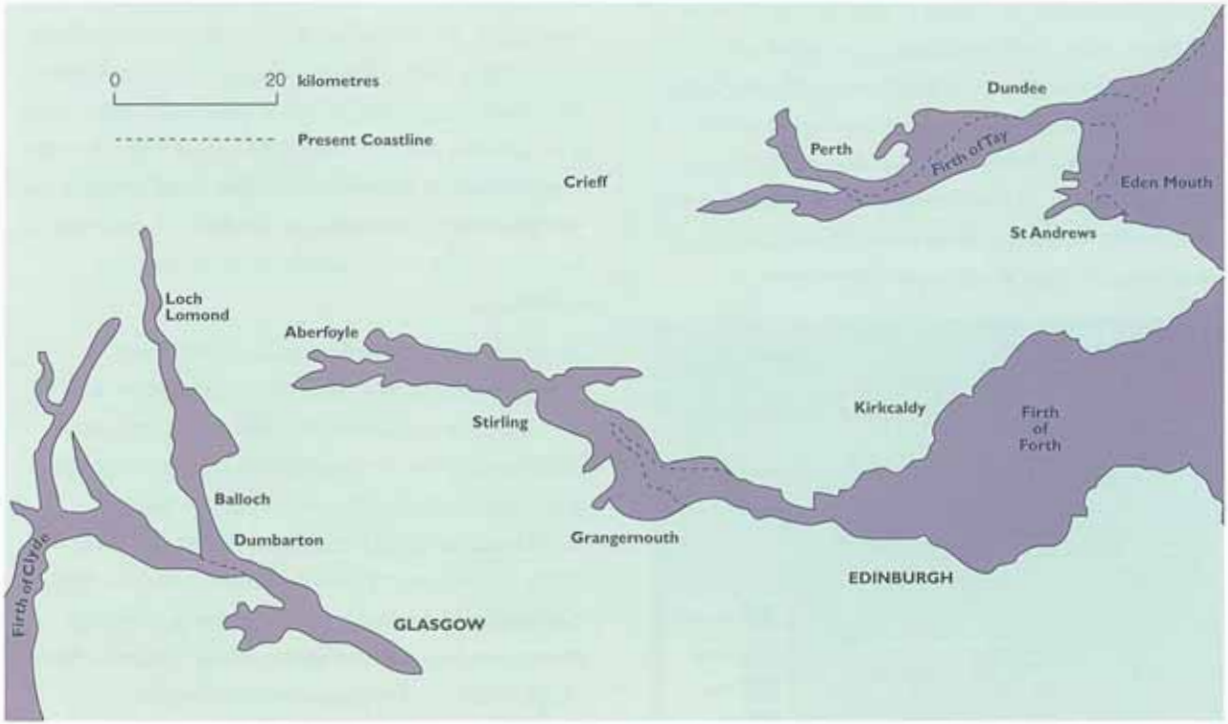
Beneath the thick ice sheet existing shallow river valleys were deeply excavated by rapidly moving ice to form smooth U-shaped valleys with only gently sloping floors. For example, Loch Voil drains to Loch Lubnaig some eight kilometres away, but their water levels differ by only three metres – a slope of 0.02 degrees. Where this erosion was magnified by narrow valleys deep hollows were formed and became lochs when the ice melted. Many of the larger lochs extend to depths well below sea level, for example Loch Lomond (183 metres) and Loch Katrine (38 metres). The confluence of ice streams had a similar effect; those from Glen Dochart and Glen Lochay joined resulting in the deep scoured basin (over 150 metres deep) now occupied by Loch Tay. In other areas tributary ice streams lacked the cutting power of the major stream and when the ice retreated 'hanging' valleys remained, such as those seen in Glen Falloch and above the northern part of Loch Lomond.

The landscape prior to the onset of glaciation was subdued after millions of years of erosion in a warm temperate climate. The main drainage pattern was imposed on the geology probably less than 60 million years ago following early Tertiary uplift. The drainage of Central Scotland was dominated by the River Forth whose headwaters lay in Glen Luss and Glen Douglas and flowed eastwards via an ancestor of the Endrick Water. Loch Arklet, and possibly the Loch Lomond valley itself above Inversnaid, may also have flowed east to the Teith or Forth valleys. This drainage pattern was radically altered by the ice. The rapid flow of ice from centres in the Southwest Highlands deepened valleys such as that now occupied by Loch Lomond. The former headwaters of the River Forth were diverted to the Clyde and the flow of the Endrick Water reversed.

The last widespread ice sheet to cover most of Scotland, the Late Devensian Ice Sheet, existed between about 27,000 and 13,500 years ago, and it removed most of the evidence of earlier glaciations. The bones of woolly rhinoceros dated at 27,500 years old, found in sand and gravel pockets from beneath the ice sheet in the Kelvin valley, provide evidence of the onset of the ice age. The main ice centre lay on Rannoch Moor, and from there ice generally flowed outwards as shown by the distribution of distinctive erratics, large blocks of rock transported by the ice from their original bedrock sites. The maximum extent of this ice sheet was reached around 18,000 years ago. Models of the maximum ice thickness give varying estimates but in the Midland Valley it was at least a kilometre, sufficient to bury the Ochil Hills.

The Leaving of Ice

The ice sheet began to recede around 16,000 years ago and Scotland was largely free of ice by 13,000 years ago. Between 13,000 and 12,000 years ago the weather was like today, but warmer in summer and cooler in winter. As the ice melted local sea level was high flooding the lower parts of the Forth and Clyde valleys and Loch Lomond. Where ice retreat slowed, for example in the Kincardine Bridge area and around Stirling, large deltas and terraces built out into the sea. Relics of these features can still be seen around Falkirk and Stirling. Marine sediments are found at 40 to 45 metres above sea level east of Stirling and up to 34 metres above sea level west of Stirling. Conditions were still arctic in the winters, as shown by the fossils found in the marine clays laid down during this period. Following removal of the ice, the land rose and by 11,000 years ago sea levels dropped to below present level. These rapidly changing sea levels left a series of raised beach features that can still be recognised in places.



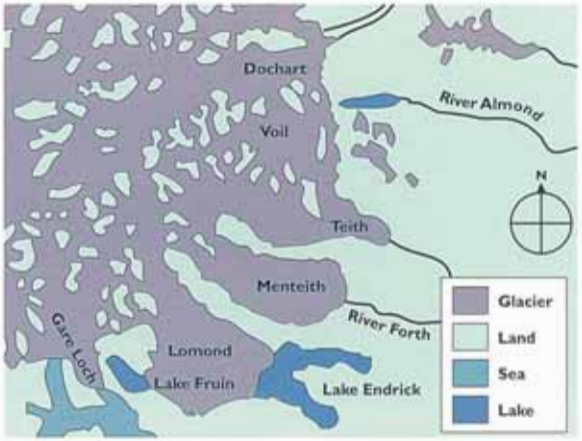
The coastline as it would have appeared 6,500 years ago.

The Loch Lomond Re-advance

The climate deteriorated and between 11,000 and 10,000 years ago arctic conditions prevailed. Ice built up in the Southwest Highlands and advanced once more into the Lowlands. This Loch Lomond Re-advance is well documented, with the related landscape features and deposits being little altered in many areas. Ice reached Callander, the Lake of Menteith, Drymen and Alexandria.

The Holocene stage

About 10,000 years ago the weather began to get gradually warmer up to around 6,500 years ago. Woodland developed until about 5,000 years ago when man started to remove it. At first after the ice had gone, rising land levels again competed with the overall rising sea level, but the lower Forth and Clyde valleys were eventually flooded to a level of some 16 metres above current sea level at about 6,500 years ago. The position of the shoreline which existed at this time can be recognised from east of Grangemouth to Aberfoyle, and also in the lower Clyde valley.



Limit of the ice sheet during the Loch Lomond Re-advance

Erratic of conglomerate dumped in sands and gravels near Callander.

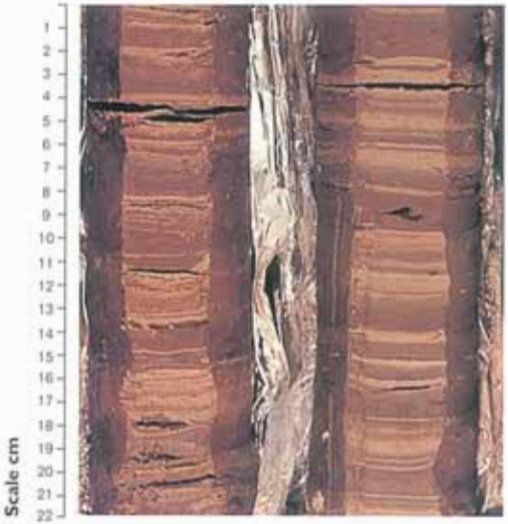
In the enlarged Forth estuary peat began to develop soon after the ice had gone but was stopped by the rising sea level and grey tidal Carse clays and silts were widely deposited. Peat continued to form locally on Flanders Moss where coastal bogs persisted. Only sands and gravels and peat deposits were laid down in the Clyde valley. The sea entered Loch Lomond for two short periods before 6,800 years ago, after which it remained a sea loch until 5,500 years ago. The falls in sea level and the warmer, wetter weather since the last glaciation have seen the formation of river and stream gorges and waterfalls such as the Falls of Leny.

Landform development continues to this day. Rivers continued to develop their floodplains during the Holocene and slopes readjusted to post glacial conditions. In the unconsolidated sediments on the low-angled valley floors, river meander belts developed, as along the Endrick Water and River Forth. The meanders on the Endrick, near to where it enters Loch Lomond, are still actively migrating across the floodplain as banks erode. The reworking of the floodplain sediments and the long history of changes in the river course are clearly seen in the old channels and cutoffs abandoned on the floodplain.

Loch Lomond from Craigie Fort, Balmaha.

Loch Lomond

With a surface area of 70 kilometres, Loch Lomond is the largest and most accessible of all Scottish lochs and has a great diversity of environments and fish species. It lies only 7.9 metres above sea level and is used for water supply and for recreation. The present size of Loch Lomond is testimony to the erosive power of the glacial ice sheets that covered Scotland. It formed one of the main corridors for movement of ice away from the centres farther north down to the Clyde, and the ice excavated a trench probably involving removal of up to 600 metres of bedrock. In its northern part where the ice eroded more powerfully, the loch is narrow and deep (153m). Smoothed bedrock surfaces, 'hanging' valleys and steep landslipped valley sides can be seen around Inveruglas. In its wide, southern, lowland part where deposition of glacially-derived till, sands and gravels and clays has been dominant, the loch rarely exceeds 30 metres in depth. The geology is strongly reflected in the scenery found along its length. The softer Devonian conglomerates and sandstones at the south end have been weathered, eroded and scoured by the ice more easily than the harder metamorphic Dalradian rocks farther north.



Borehole cores of glacial lake clays from near Killearn.

The Highland margin is marked by steeply dipping Devonian conglomerates and the Highland Boundary Fault zone on Conic Hill above Balmaha and on the elongate islands of Inchmurrin, Creinch and Inchcailloch. Dalradian rocks are dominant north of the Highland Boundary Fault and consist of metamorphosed sandstones, grits and mudstones with minor volcanic ash.

Around 13,000 years ago, as the ice melted, Loch Lomond became an arm of the sea. Borehole cores taken from the lower part of the Endrick valley show that laminated clays and silts were first deposited followed by massive, silty clays with marine shells and dropstones derived from ice rafts. They indicate that although the climate had become warmer, the winter conditions were still colder than those today. As overall uplift of the land continued, following ice removal, sea level fell rapidly and by 11,000 years ago lay at around the present level or below. With the onset of glaciation again between 11,000 and 10,000 years ago, a 20 to 50 metre thick sequence of marine muds was deposited ahead of the advancing ice.

This ice 'bulldozed' the existing deposits in the loch to form a prominent moraine that can be traced easily around the Loch Lomond area. It forms a prominent ridge up to 25 metres high stretching from Shantron Muir and Glen Fruin to Alexandria and then eastwards to near Killearn and north to Drymen. Glacial meltwater flowed down the River Leven depositing sand and gravel which effectively raised the outlet of the loch and are partly responsible for it being freshwater today. Beneath the ice a moundy lodgement till consisting of clayey and sandy material with many stones and boulders was laid down. The ice also dammed up the valleys of the Fruin, Endrick and Blane waters causing the formation of lakes. The sandy deposits of the terminal moraine southeast of Drymen pass southeastwards into the varved clays and silts of the former glacial lake of Strath Blane.

Terminal moraine at the south end of Loch Lomond.

Satellite image of the Firth of Clyde, Glasgow, Loch Lomond and the Trossachs.

Mugwort (Artemesia Norvegica)

Around 10,000 years ago a rapid change to warmer but wet climatic conditions occurred and the ice disappeared from Scotland. In the succeeding period until 6,500 years ago temperatures rose to be warmer than at present and sea levels around Loch Lomond oscillated with marine conditions only prevailing at greater than 9,500 years ago and briefly around 7,900 years ago. Between 6,800 and 5,500 years ago a longer marine phase occurred and the remains of a series of old shorelines have been recognised at 13, 12 and 9 metres above sea level. Generally muddy sediments were deposited except at river mouths where sandy deltas formed. The Loch Lomond 'herring' or powan, is a char more typical of colder water today – a reminder of the loch's recent glacial history.

The sediments on the bed of Loch Lomond together with other lochs in this area, and the local peat bogs, contain pollen grains and other plant remains that provide evidence of changing vegetation during the last 13,500 years. At the end of the Late Devensian glaciation initial vegetation was of open habitat, with grasses, sedges and mosses taking hold on the bare soil. In some areas heath, dwarf shrub and some birch, willow and juniper grew but the general tree line did not reach the area. During the Loch Lomond Re-advance vegetation was open tundra and soils were destroyed as the plant cover broke up under the intense cold and dry conditions. Mugwort was an important plant along with some sedges and grasses. Ten thousand years ago at the end of the Ice Age heath and birch woodland spread rapidly, followed by pinewoods, with hazel and oak well established by 6,500 years ago.

Man-made modifications

Raised peat bog – Offerance Moss, by Buchlyvie, upper Forth valley.

Jules Verne visited the Trossachs area in 1859 and was undoubtedly impressed by the 19th century coal mining industry of Central Scotland and the Highland scenery. In his little known novel 'Black Diamonds', written in 1875, an abandoned coal mine, the Dochart Pit, extending beneath Aberfoyle is re-opened. The story ends with Loch Katrine emptying down the Yarrow shaft into the mine. Stretching fact and credibility, it was never one of Jules Verne's best selling novels, but it does touch upon the more obvious activities of this area in the 19th century. Loch Katrine does indeed empty down a man-made shaft, but it leads to Glasgow to provide water supply and was not built until the 1920s. Jules Verne added to the already sizeable reputation of the area as a tourist destination and this remains today.

Man's greatest changes on the area have been its deforestation, which commenced some 5,000 years ago, and the draining and clearing of land with development of agriculture and commercial afforestation in the past two centuries. Major 'improvements' started in 1766 when Sir John Sinclair began reclamation of the Carse. In the following century the peat was removed and the land drained to provide rich agricultural land. Most of the peat was flushed away, causing tremendous pollution farther down the Forth Estuary and ruining the oyster beds and salmon fishing. The modern clashes between 'improvement', agriculture and conservation are more balanced than those a century or more ago, but are still a subject of current debate.

Road cut at Rubha Mhór, Loch Lomond.

Traditional routes through the area avoided the lower wet ground in the Lowlands and followed the droving routes in the Highlands. General Wade's roads built in the 18th century fixed some of the Highland routes but it was the construction of the railways in the 19th and early 20th centuries that established the main routes. The road routes generally followed the rail network, expanding when the rail network contracted. Apart from the Glasgow – Fort William, Glasgow – Stirling – Perth, and Edinburgh – Glasgow lines the once dominant rail network is now dismantled. In contrast the A82 and A84 road improvements continue apace, with new road cuts and even causeways on Loch Lomondside speeding visitors north with greater ease. Motorways and dual carriageways now criss-cross Central Scotland in some abundance.

Loch Sloy – one of the earliest hydro-electric schemes in the Highlands.

A former limestone mine at Linn of Baldernock, Blairskaith Muir, east of Milngavie.

In the Highlands, Loch Lomond and Loch Katrine, and Glen Finglas Reservoir, are important water supply reservoirs and water has also been harnessed to provide Hydro-electric power. The Loch Sloy – Glen Shira scheme was built between 1946 and 1950, one of the first to be developed in the post-war expansion of hydro electric power. Its main generating station at Inveruglas is readily visible. The later Breadalbane Scheme developed the generating potential of Glen Lochay, Glen Lyon and Lochan na Lairige on the north side of Loch Tay and Loch Earn and Loch Lednock farther south. These developments all result in controlled water levels and alteration of the natural water flows in many of the nearby stream courses.

Mining has left its mark in numerous parts of the area. The effects of coal mining, with its bings and former mining communities dominate east of Stirling. Old ironstone mines were also common in this area in the 19th century. Fireclay mines also existed but this is now only quarried near Bonnybridge. Small mines for baryte, copper and silver were worked in the Ochil Hills and baryte was worked near Aberfoyle. At Tyndrum lead and zinc were mined and recently discovered gold reserves exist at Cononish nearby.

Rock has been quarried and locally mined for building stone, as at Bishopbriggs, though only a small operation near Airth remains today. Slates were obtained from near Aberfoyle and Luss. Rock is required for aggregate and large quarries can be found near Tillicoultry, Denny, Kilsyth and Stirling, mainly in the Permo-Carboniferous dolerite sill. Sand and gravel is quarried from fluvioglacial deposits near Callander, and by Drymen. It is also obtained by crushing Carboniferous quartz conglomerate at Blanefield.

Human impact on the landscape can also be seen in extensive tree plantations. As well as direct impacts through the concealment of geological features and landforms, runoff patterns have been altered and accelerated and sediments have been deposited in some river courses. Soil erosion, too, has followed from other land management activities, recreational pressures, and from natural causes. The geomorphological sensitivity of the environment, be it in relation to soil erosion, flooding or slope instability, is thus an important consideration in land management and planning.

Tourism has a long history in Stirling and the Trossachs and the variety of scenery and contrast of highland and lowland attracts people as much today as it did 200 years ago when Walter Scott crossed the area during his legal work and made the detailed notes for his novels which sparked an explosion of interest in the area. Unlike Jules Verne, Scott's imagination took good account of the geology and scenery of the area.

Tracks, road and rail routes crossing morainic mounds of sand and gravel, Cononish Glen by Tyndrum.

Scottish Natural Heritage is an independent government agency established by Parliament in April 1992 and responsible to the Secretary of State for Scotland. It was formed by the merger of the Countryside Commission for Scotland and the Nature Conservancy Council for Scotland. Its task is to secure the conservation and enhancement of Scotland's unique and precious natural heritage – the landscape, habitats and wildlife which have evolved through the long partnership between people and nature. SNH advises on policies and promote projects that aim to improve the natural heritage and support its sustainable use. SNH's aim is to help people to enjoy Scotland's heritage responsibly, understand it more fully and use it wisely so that it can be sustained for future generations.

Scottish Natural Heritage

The aims of SNH are:

To safeguard and enhance Scotland's natural heritage, particularly its genetic and scenic diversity;
To foster awareness and understanding of the natural heritage;
To encourage enjoyment of the natural heritage and to promote responsible access to it, in a way which does not damage it;
To encourage public support and harness voluntary effort for the benefit of the environment;
To encourage environmental sustainability in all forms of economic development.

Rowardennan, Loch Lomond.

SNH has two key principles:

To work in a partnership with others to achieve our aims;
To devolve decision making to the local level where our staff are accessible to local needs and circumstances.

The need to conserve geological and landform features is, perhaps, less obvious than, for example, protecting a rare species of butterfly or an endangered wildlife habitat. However geological and landform sites are often just as vulnerable to changes in land use.

British Geological Survey

Founded in 1835 as the first Geological Survey in the world, the Survey has worked in Scotland since 1854, and had an office in Edinburgh since 1857.

The primary objectives of BGS are:

To maintain an up-to-date knowledge of the geology of the UK landmass and its adjacent continental shelf by means of systematic surveys;
To publish results as maps and reports;
To maintain a UK geoscience database;
To provide an information and advisory service;
To undertake technical co-operation and aid overseas;
To carry out geological research.

The Scottish office of BGS is sited at Murchison House on the Edinburgh University Kings Buildings Campus. All aspects of Land and Offshore Surveys are dealt with, as well as Hydrocarbons, Seismology and Geomagnetism. The office runs an advisory and information service, a geological library and has a well-stocked geological bookshop.

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