This topic provides descriptions of the rock types appearing on the British Geological Survey 1:625 000 scale map of the UK North and gives a brief explanation of their origins.

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542 to 416 million years ago

Broad outcrops of Lower Palaeozoic rocks, both sedimentary and igneous, are ranged across northern Britain and Ireland. The older of these rocks accumulated as the Iapetus Ocean grew to its maximum width, achieved towards the end of the Cambrian, and reflect conditions at its extending and subsiding margins. The younger of the rocks were deposited in compressive tectonic regimes as the ocean began to close, a process that was completed by the mid Silurian.

In the north-west of mainland Scotland a Cambro-Ordovician sequence of shallow-marine quartzite and limestone rests unconformably on Torridonian or Lewisian rocks. Distinctive assemblages of Cambrian to Ordovician volcanic lavas and ultramafic rocks known as ophiolite-complexes — remnants of ancient oceanic crust — are seen in Shetland, within the Highland Boundary Fault Zone, at Ballantrae in south-west Scotland, and in County Tyrone, Northern Ireland. Ordovician to Silurian sedimentary sequences unconformably overlie the Ballantrae and Tyrone complexes, and several inliers of Silurian clastic strata occur elsewhere in the Midland Valley of Scotland. To the south, the Southern Uplands terrane continues into Ireland as the Longford-Down inlier; it comprises a vast and structurally complicated thickness of Ordovician to Silurian deep-sea...
sandstone. In northern England, in the large Lake District inlier and several smaller inliers, a thick accumulation of Ordovician volcanic rocks separates older Ordovician deep-sea sandstone and mudstone from a younger, more variable sedimentary sequence of Ordovician to Silurian age.

**Lower Palaeozoic rocks in the north-west Highlands of Scotland**

Smoo Cave near Durness, eroded into the Cambro-Ordovician limestone of the Durness Group. P506771.

The topographic ridge created by the rocks of the Highland Border Complex running westwards across Loch Lomond. P001225.

Cambro-Ordovician rocks form a narrow, linear outcrop stretching about 250 km from Loch Eriboll on the north coast of Scotland, south-westward to southern Skye. The western margin of the outcrop is the basal unconformity, overlying Torridonian and Lewisian rocks ([Plate P000857](#)), but in the east the Cambro-Ordovician sequence has been overthrust by Moine strata. The most complete and least deformed succession, ranging in age from early Cambrian to Llanvirn, is seen in the north around Durness where as much as 1000 m of strata may be present. Elsewhere, and particularly at the eastern margin of the outcrop and within the adjacent Moine Thrust Belt, the succession is disrupted and repeated within imbricate thrust slices. It can be divided into a lower clastic sequence, the Cambrian Ardvreck Group ([Plate P571791](#)),
and an upper limestone sequence, the Cambro-Ordovician Durness Group (Plate P506771). This episode of mainly marine deposition took place along the tropical and shallow-water, near-shore zone of an extensive shelf that formed the northern, passive margin of the Iapetus Ocean.

**The lower part of the Ardvreck Group** (E1–2) consists of about 150 to 200 m of quartzite (the Eriboll Formation (ERSA) | Eriboll Formation) divided into a lower unit with current cross-bedding, and an upper unit known as the Pipe Rock because of its abundant tube-like fossil burrows. These rocks were deposited as tidal sands in a shallow marine environment. The quartzites are conformably overlain by a thin layer of ferruginous brown dolomitic siltstone with abundant burrows (known as the Fucoid Beds) that originated in muddy lagoons. Above the siltstone lies a unit of grey quartz-arenite (20 to 50 m thick and known as the Salterella Grit) that records a return to higher energy open marine conditions. The rocks contain a variety of fossils including trilobites.

**The Salterella Grit is conformably** overlain by the Durness Group (E3), which consists of at least 750 m of mainly dolomitic limestone, with sporadic associated units of chert. There are abundant stromatolites (the fossil remains of algal encrustations) and the limestone contains a sparse shelly fauna. Deposition was largely in a shallow marine environment, but periodically sabkha and tidal flat conditions were established and the exposed limestone surfaces were weathered into karst topography. The boundary between the Cambrian and Ordovician systems lies within the Durness Group, and is conventionally taken at a relict karst surface. Fossils recovered about 200 m below this surface indicate an early Cambrian age, while above it only Ordovician fossils have been recovered.

**Ordovician ophiolite-complexes**

**As the Iapetus Ocean closed**, from the early Ordovician onwards, most of its oceanic crust was destroyed by subduction beneath the opposing continental margins. Continental suturing was complete by the late Silurian. Along the length of the resulting Caledonian fold belt vestiges of the original ocean are preserved in the form of ophiolite-complexes, assemblages variously comprising mafic lava and sheeted dykes, gabbros and ultramafic plutonic rocks. The ultramafic rocks are relics of the oceanic upper mantle, whilst the gabbroic rocks, sheeted dykes and lava represent an upward section through the overlying oceanic crust. An origin through sea floor spreading is implicit but, in reality, many ophiolites are atypical of oceanic crust and were generated above subduction zones, that is at a destructive plate margin rather than at a constructive mid-ocean ridge. The Caledonian examples of Shetland, the Highland Border and Ballantrae in Scotland, and Tyrone in Northern Ireland are typical in that respect. During their Cambro-Ordovician generation, the margins of the Iapetus Ocean were probably similar in character to the modern west Pacific Ocean with a complicated pattern of inter-related volcanic island arcs and back-arc basins.

**The Shetland Ophiolite-complex** (EO) forms a large part of the islands of Unst and Fetlar in the north-east of the archipelago. Its rocks are most probably of Cambrian age and were thrust onto the Laurentian continental margin (a process known as obduction see Figure P785798) towards the end of that period, as the Iapetus Ocean began to close. The gneissosse metasedimentary rocks of the Shetland Dalradian form the basement to the complex and crop out on its western margin. Only the lower parts of the ophiolite sequence — ultramafic rock, gabbro and sheeted dolerite dykes — are preserved in two thrust sheets separated and underlain by imbricate zones. The imbricate zones are composed of sedimentary material eroded from the ophiolite as it was obducted, together with metavolcanic rocks and hornblende schist. This tectonised assemblage — the Unst Phyllite Group —
also extends beyond the imbricate zones of the ophiolite-complex.

**The Highland Border Complex** (O1–2), comprises a series of about ten, structurally isolated slivers containing various combinations of serpentinised ultramafic rock, mafic lava, and sedimentary lithologies. The outcrops are contained within the various strands of the Highland Boundary Fault Zone, from Stonehaven on the east coast of Scotland to Arran in the west (Plate P001225). The oldest components are early Cambrian or possibly late Neoproterozoic amphibolites derived from obducted ultramafic rock; they are spatially associated with gabbro, pillow lava and black mudstone of uncertain age. Younger sequences (though structurally beneath the obducted ophiolite rocks) comprise either conglomerate and limestone with early Ordovician fossils, or mafic lava and black mudstone, or sandstone, limestone and mudstone. The structural complexity allows alternative interpretations of the original relationships.

![Pillow lavas from the Ballantrae Complex.](image)

The characteristic appearance was acquired during rapid submarine cooling of the lava. P005992.

**Between Girvan and Ballantrae**, on the south-west coast of Scotland, the structurally complicated Ballantrae Complex consists mainly of serpentinised ultramafic rocks (EO) and basalt lavas (O). Pillow lavas (Plate P005992) that indicate submarine eruption are common, and together with abundant volcaniclastic breccia form the Cambrian to Ordovician Balcreuchan Group. Graptolites of Arenig age have been recovered from sedimentary interbeds, but the lavas were erupted during both the Tremadoc and Arenig in disparate volcanic arcs and oceanic islands. All were tectonically juxtaposed and obducted onto the continental margin of Laurentia at about 478 Ma (the age of a dynamothermal amphibolite produced during obduction). The youngest graptolite fauna found in the complex is of late Arenig age (about 480 Ma), and this dates the sediments that were contemporaneous with obduction.

**The tectonic position of the Tyrone Complex** (O & OS), Northern Ireland, is analogous to that of the Highland Border Complex in that it is contained between major fault zones and bordered to the north by Dalradian rocks. There are two distinct parts: a lower assemblage of gabbro and dolerite and an upper sequence of volcaniclastic rocks and lavas (Tyrone Volcanic Group). Within the upper sequence at least three volcanic cycles can be identified, each commencing with basaltic pillow lavas, passing up through various volcaniclastic rock types and culminating in a sedimentary layer of chert and mudstone; some of the mudstone beds contain Arenig to Llanvirn graptolites. Younger, arc-related felsic intrusions cut both the volcanic and gabbroic parts of the complex and an inlier of Moine-like rocks. The felsic intrusions are late Arenig or early Llanvirn in age, which suggests that obduction of the ophiolite occurred in the mid Arenig.
Ordovician to Silurian sedimentary inliers of the Midland Valley

**Sequences of mid Ordovician to Silurian sedimentary strata** (O3–5) unconformably overlie the ophiolite-complexes of Ballantrae and County Tyrone, whilst several other inliers of Silurian strata (S1–2) crop out across the Midland Valley terrane in Scotland and its extension into Northern Ireland. The maximum stratigraphical range is seen at Girvan, on the northern side of the Ballantrae Complex where, in two closely adjacent inliers, the succession records a marine transgression across the obducted ophiolite; it ranges from the Llanvirn, more-or-less continuously upwards into the Wenlock. At Pomeroy the base of the sequence resting unconformably on the Tyrone Complex is of Caradoc age, whence the stratigraphy ranges upwards to the high Llandovery. The remaining Midland Valley inliers, and the small Lisbellaw inlier in Northern Ireland span various parts of the Llandovery–Wenlock interval.

![Thinly bedded late Ordovician turbidites from the Ardmillan Group forming the Ayrshire coast south of Girvan (seen in background)](P005864).

**At Girvan, Ordovician sedimentation** on the eroded Ballantrae Complex was controlled by a series of major extensional faults throwing down to the south. At the base of the sequence, late Llanvirn conglomerate beds fine southwards into wacke sandstone; mudstone and limestone are interbedded with the conglomerates. The limestone contains an abundant shelly fauna and the calcareous alga *Girvanella*. This relatively proximal, northwards transgressive sequence forms the Barr and Albany groups. Above it, deeper water, turbiditic strata dominate the Ardmillan Group ([Plate P005864](#)). There is a minor, low-angle unconformity at the top of the Ardmillan Group, above which the base of the Silurian Girvan Group is diachronous, although at its minimum the stratigraphical break is very small. Above the unconformity, marine sandstone, conglomerate and turbiditic strata (many of which are carbonate-rich) contain both shelly and graptolitic fossil faunas that prove at least one stratigraphical hiatus. The overlying Wenlock strata were deposited in an environment that became progressively shallower, so that marine beds at the base of the sequence are succeeded by deltaic and intertidal sandstone.

**In Northern Ireland, Caradoc and Ashgill strata** of the Desertcreat Group unconformably overlie the ophiolitic rocks of the Tyrone Complex; they are now exposed in the Pomeroy inlier. A conglomerate at the base of the sequence is succeeded by Caradocian sandstone and mudstone containing brachiopods and trilobites. Above that, a finer grained Ashgill succession of mostly siltstone and mudstone contains a varied fossil fauna—brachiopods, trilobites, bivalves, gastropods, nautiloids — that is indicative of a marine, continental-slope environment. The overlying Silurian sequence, the Little River Group, spans much of the Llandovery. Graptolitic mudstone predominates with sporadic bentonite layers in places, although the highest strata preserved consist of quartz-pebble conglomerate interbedded with sparsely graptolitic sandstone.
Interbedded sandstone and mudstone of mid-Silurian age (Waterhead Group) exposed in the banks of the Dippal Burn, Lesmahagow. P219790.

**Several inliers spaced along the southern margin of the Midland Valley** — Lesmahagow, Hagshaw Hills, Carmichael, Pentland Hills — contain a Silurian sequence spanning the mid Llandovery to Wenlock interval (Plate P219790). Marine, deep-water turbidites and graptolitic mudstones dominate the lower part of the sequences, passing upwards into shelf lithofacies, intertidal deposits and finely laminated lacustrine strata by the early Wenlock. In places the lacustrine mudstone contains a fossil fauna of fish and eurypterids. In most of the inliers, during the Wenlock, there was a final transition into terrestrial deposition — fluvial, red-bed sequences of sandstone, mudstone and sporadic conglomerate. The conglomerates have distinctive compositions that allow correlation between the inliers: an ‘igneous’ conglomerate (mostly fine-grained alkaline and calc-alkaline volcanic rocks) marks the base of the Wenlock, with a ‘quartz’ conglomerate (mostly quartzite clasts) a little higher in the Wenlock. A thick and extensive ‘greywacke’ conglomerate (with clasts of wacke-type sandstone) is taken as the formal base of the Old Red Sandstone lithofacies, though it is most likely of late Silurian age.

A broadly mid-Llandovery succession of mainly graptolitic mudstone forms the Lisbellaw inlier, south-east of Enniskillen in Northern Ireland. Near the middle of the formation a distinctive member is made up of a series of conglomeratic beds each grading up into coarse sandstone; the conglomerate consists mostly of quartzite pebbles.

**Southern Uplands—an Ordovician–Silurian accretionary complex**

**The Southern Uplands geological terrane** forms the southern part of Scotland and extends westward to form the Longford–Down inlier, part of which lies within Northern Ireland. The terrane formed as an accretionary thrust complex (Figure P785798) at the Laurentian continental margin during late Ordovician to mid Silurian subduction of the Iapetus Ocean. It was built up by a series of southward-propagating, imbricate thrusts that structurally repeat an oceanic sequence. At the base of this sequence, the Moffat Shale Group (OS), consists of a thin assemblage of black, graptolitic mudstone with interbeds of volcanic ash. It is underlain in a few places by chert and basaltic lava of the Crawford Group (OS), and is overlain by a very much thicker accumulation of turbiditic sandstone (Plate P220190). The thrust sequence has been structurally steepened so that the original low-angle thrusts now appear as near-vertical, major strike faults running north-east to south-west and separating tracts of steeply inclined beds that strike north-east (Plate P220426).
Dob’s Linn, near Moffat. The burn has eroded a gorge through steeply inclined mudstone beds of the Moffat Shale Group, with the waterfall created by the base of the overlying (but now near-vertical) Gala Group sandstone. P220190.

Steeply inclined, early Silurian turbidite beds from the Hawick Group, cut by a strong slaty cleavage, exposed on the shoreline at Brighouse Bay, near Kirkcudbright. P220426.

Each tract has an internal sense of younging towards the north whereas the minimum age of each tract decreases southwards. Further, the time interval represented by the Moffat Shale Group increases southward through successive tracts showing that the onset of turbiditic sedimentation occurred progressively later southward. Although the sandstones comprise the vast majority of the succession, those in any one tract are either of the same biostratigraphical age, or only slightly younger, than the youngest part of the underlying Moffat Shale Group. Very close biostratigraphical control is provided by locally abundant graptolite faunas. The Crawford Group may range down to the Arenig whilst the overlying Moffat Shale Group is restricted to the Caradoc in the northern tracts but spans the Caradoc to Llandovery interval in the southern tracts. The age of the turbidite successions follows the top of the Moffat Shale Group in becoming younger southwards: Caradoc and Ashgill in the north of the terrane in the Tappins, Barrhill and Scaur groups (which jointly comprise the Leadhills Supergroup (O3-5)), Llandovery (and early Wenlock locally) in the Gala and Hawick groups (S1), and entirely Wenlock in the Riccarton Group (S2) that comprises the
southernmost tracts. Variations in age and composition of the sandstones allow division of the groups into formations. The maximum tract range is seen in southern Scotland; in Northern Ireland much of the Ordovician sector is obscured by post-Silurian strata.

**The Crawford Group represents vestiges of the uppermost oceanic crust**, and the Moffat Shale Group represents its pelagic sedimentary cover. This oceanic assemblage was carried by plate movement towards the Laurentian margin subduction zone (where volcanic activity was the likely source of the ash interbeds in the Moffat Shale), and on entering the trench was abruptly covered by a thick layer of clastic sediment carried out in and deposited from turbidity currents. The turbidite deposits dominate the succession, so that in any one tract thousands of metres of sandstone beds may overlie only a few metres of Moffat Shale Group mudstone. Deformation of each tract occurred largely as it was incorporated at the thrust front (Plate P000816 and P008464), and so was diachronous across the terrane. Occasionally, oceanic volcanoes were caught up in this process so that in a few places masses of mafic lava are interleaved with the turbidites.

Large-scale folding of early Silurian, Gala Group turbiditic sandstone beds at Pettico Wick, near St Abbs. P000816.

Complex, localised folding of turbiditic sandstone beds from the Ordovician, Barrhill Group at Portobello, Galloway. Field of view is about 10 m. P008464.

The two small Coldingham inliers of Silurian strata (S1–2), on the North Sea coast of the Southern Uplands, contain sandstone sequences that have been affected by variable degrees of ‘soft sediment’ deformation induced by submarine slumping, but show little sign of tectonic deformation. The sandstones probably accumulated in small basins perched atop the developing accretionary complex before being faulted down into its interior.

Subduction of Iapetus Ocean crust was largely orthogonal until the near-extinction of the ocean
late in the Llandovery. Then, relative movement between Laurentia and Avalonia became lateral and created zones of complex strike-slip deformation within the Southern Uplands. Eventually, in the mid Wenlock, the Southern Uplands accretionary complex (at the leading edge of Laurentia) over-rove the Avalonian margin, which accordingly was depressed by the accumulating load. This regional subsidence influenced sedimentation patterns farther south, in particular within the Windermere Supergroup.

**Lower Palaeozoic rocks of the Avalonian margin**

**On the south side of the Iapetus Suture**, rocks that originated on the southern, Avalonian continental margin of the Iapetus Ocean form the Lake District and several smaller inliers in northern England, and most of the Isle of Man. The Skiddaw (north-west England) and Manx (Isle of Man) groups consist largely of fine-grained, Tremadoc to Llanvirn, turbidite deposits (O1–3). The two groups were deposited in an extensional basin on the southern side of the Iapetus Ocean, as the Avalonian microcontinental block rifted from Gondwana. The Skiddaw Group is overlain by the largely subaerial volcanic rocks of the Caradoc, Borrowdale and Eycott Volcanic groups. These were erupted in response to subduction of oceanic crust and in turn are transgressed by another marine sedimentary sequence, the Caradoc to Pridoli Windermere Supergroup.

Slump folds affecting sandstone turbidites of the Skiddaw Group at Goat Crag, Buttermere, near Keswick. [P005042](#).

Thinly bedded, mudstone-rich turbidites from the Manx Group at Douglas Bay, Isle of Man. Similar rocks make up
much of the Manx and Skiddaw Groups. P018619.

The Skiddaw Group is made up of turbiditic sandstone and mudstone. It contains both a graptolite fauna and an acritarch flora that define a Tremadoc to Llanvirn biostratigraphy. The principal outcrop is in the northern Lake District with smaller inliers to the south and east. Two distinct stratigraphical belts are present, separated by a major wrench and thrust fault system, the Causey Pike Fault. To the north of the fault are preserved some 5000 m of mainly mudstone turbidites that were deposited between the Tremadoc and the early Llanvirn. Wacke-type sandstone beds occur sporadically throughout the succession and become dominant locally as the Loweswater and Watch Hill formations. South of the Causey Pike Fault is a major olistostrome (a huge and chaotic slumped deposit), emplaced from the south during the late Arenig and overlain by 1000 m or more of late Arenig to Llanvirn mudstone turbidites with sporadic interbedded volcanic ash layers. The Skiddaw Group is structurally complex, with a significant unconformity at the base of the overlying volcanic rocks. However, the pre-volcanic deformation was not orogenic. Much of the deformation was caused by synsedimentary slumping (Plate P005042), with more imposed during pre-volcanic uplift of the group from its deep marine depositional setting to the subaerial environment of the subsequent volcanism. Tectonic deformation and cleavage formation did not occur until much later, during the early Devonian, Acadian Orogeny. A similar but possibly older sequence, the Ingleton Group, forms part of the Craven inliers farther to the south.

The Manx Group is dominated by laminated mudstone and siltstone but in some parts of the sequence it is composed largely of thinly bedded, fine-grained sandstone; the depositional style is turbiditic (Plate P018619). Large-scale slumped deposits of pebbly mudstone occur in parts of the succession and rare volcanic rocks appear in one or two places. Acritarchs and rare graptolites prove a Tremadoc to Arenig age range. The succession is now steeply dipping and strikes approximately north-east, parallel to the long axis of the island. It crops out in a succession that becomes younger towards the north-west, although it is folded and disrupted by strike-parallel faults that locally repeat parts of the succession: the total thickness is likely to be in excess of 5000 m. There is a broad similarity with the northern succession seen in the Skiddaw Group of the Lake District inlier, although the structural style is different. The north-west part of the Manx Group outcrop consists of thrust slices emplaced south-eastward onto a folded foreland now represented by the south-east part of the outcrop.

The subduction of oceanic crust at the northern margin of Avalonia initiated uplift of the Skiddaw Group and later on caused the Caradoc episode of subaerial volcanism that was responsible for the Borrowdale Volcanic Group and the Eycott Volcanic Group. These groups now crop out, respectively, to the south and north of the Skiddaw Group, a disposition inherited from their having originally built up within opposing half-grabens, each originally 40 to 50 km wide. The Eycott Volcanic Group consists of more than 3200 m of basaltic, andesitic, and dacitic lavas and sills with subordinate pyroclastic rocks. The Borrowdale Volcanic Group forms the heart of the Lake District and produces England’s most spectacular mountain scenery (Plate P220598). It comprises at least 6000 m of strata: mostly andesitic lavas and sills in the lower part, and with voluminous silicic pyroclastic and volcaniclastic rocks forming the upper part (Plate P005147). The assemblage provides evidence for successive episodes of volcanic caldera collapse in an extensional tectonic setting. Radiometric ages from the lower part of the group suggest eruption at about 452 Ma. A large, compound subvolcanic batholith was intruded late in the volcanic episode at about 450 Ma.

The strata of the Windermere Supergroup (O5; S1–3; S3; S3–4), up to 8000 m thick, record the final stages of volcanism and the subsequent slow subsidence of the volcanic belt during the late Ordovician and early Silurian, followed by abruptly accelerating subsidence from the late Wenlock as the Iapetus Ocean closed and the Laurentian margin over-rode the Avalonian continent.
Convergence ceased by the late Ludlow and thereafter the rate of subsidence slowed, allowing sediment to fill the depositional basin. Uplift and deformation followed in the mid Devonian as an effect of the Acadian tectonic event. The main outcrop is in the southern Lake District, where the full succession is seen, with smaller isolated stratigraphical fragments preserved elsewhere in northern England and on the Isle of Man (Dalby Group).

Typical Borrowdale Volcanic Group scenery in Langdale, part of the Central Fells of the Lake District. P220598.

Pyroclastic beds in the Borrowdale Volcanic Group (Duddon Hall Formation) at Hollin House Tongue, Seathwaite, Lake District. P005147.
Tightly folded sandstone turbidite beds from the Austwick Formation of the Tranearth Group (Windermere Supergroup). P005543.

Post-volcanic subsidence allowed marine transgression across the eroded volcanoes. The lowermost part of the Windermere Supergroup, the Dent Group (O5), encompasses late Ordovician clastic and carbonate rocks that were deposited in near-shore and fluviatile environments; two volcanic intervals represent the final throes of eruption. Marine deposition continued from the Ordovician into the Silurian with a rise in global sea level producing a deepening depositional environment and allowing accumulation of mud and silt throughout the Llandovery — the Stockdale Group. The overlying Wenlock sequence, the Tranearth Group, is dominated by laminated hemipelagic mudstone but with the proportion of turbidite sandstone increasing upwards (Plate P005543). A calcareous siltstone unit spans the Wenlock–Ludlow boundary, marking a major marine regression, but the laminated hemipelagic mudstone reappears above it and continues upwards into the Ludlow. There, an abruptly increasing proportion of turbidite sandstone defines the Coniston Group (S3), deposited in response to the closure of the Iapetus Ocean when the loading of the Avalonian margin, over-ridden by Laurentia, produced a marked acceleration in subsidence and in the rate of deposition. As convergence between Laurentia and Avalonia ceased, isostatic adjustments reversed the earlier effects of loading so that the later Ludlow and Pridoli succession, the Kendal Group, reflects a slowing of the subsidence rate and a commensurate filling of the sedimentary basin. The strata are mainly silt- and mud-dominated turbidites, but the youngest beds (Kirkby Moor Formation; S3–4) are shallow-water sandstones and siltstones, some of which have been reddened.

Bedrock Geology UK North - contents

Introduction

Archaean and Palaeoproterozoic

Mesoproterozoic and Neoproterozoic

Lower Palaeozoic - Cambrian, Ordovician and Silurian

Caledonian Orogeny and associated magmatism

Mostly Devonian - the Old Red Sandstone Supergroup