A Geological Field Guide to Cooley, Gullion, Mourne & Slieve Croob

Sadhbh Baxter

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Where it was deemed a useful aid to interpretation of either the outcrop or the field photograph, an annotated duplicate photograph has been included in some of the figures below. These paired photographs have not been captioned separately.

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Acknowledgements

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Using this guide

This guide has been written for use by teachers of geography and geology at Leaving Certificate, AS, and A-level. It should also be of use at tertiary level and for the interested amateur. It is intended as a geological field guide to be used in conjunction with course text books. Some background geological information is given, but more detailed information should be found elsewhere. Academic references are kept to a minimum in the text; in-depth descriptions of the geological history of the area may be found in a number of the publications listed in the Bibliography.

Appendix 1 outlines the subjects on the Leaving Certificate, AS-, and A-level syllabi that may be studied at sites described in the guide.

All of the sites, except for Localities 3 (Barnavave) and 26 (Ott Mountain) are within 20 minutes' walk of parking places, usually on relatively easy terrain. Barnavave is a follow-on site from Slate Rock (Locality 2), while Ott Mountain (Locality 26) is often also used to study the development of a river.

Maps

Ordnance Survey maps

Ordnance Survey of Ireland (OSI) Discovery Series Sheet 36 (1:50,000).
Ordnance Survey of Northern Ireland (OSNI) Discoverer Series Sheets 20, 28 & 29 (1:50,000).
OSNI outdoor pursuits maps ('Slieve Croob' and 'The Mournes') (1:25,000).

Geological maps

Geological Survey of Ireland: Geology of Monaghan-Carlingford, Sheet 8/9 (1:100,000).
Geological Survey of Northern Ireland: Geological map of Northern Ireland (1:250,000); Mourne Mountains Special Sheet (1:50,000)

Detailed maps and descriptions are also available in the GSNI's 'Geology of Northern Ireland, 2004 (W.I. Mitchell), and the geology of the Mournes is included on the back of the 1:25,000 OSNI outdoor pursuits map of the area.

Introduction

The Carlingford Lough & Slieve Croob region (Figure 1) is one rich in geology, archaeology and history. This guide aims to give an accessible description of the geology of the area, with detailed information on some of the key sites (Figure 2). Where appropriate, the links between the geology, landscape, biodiversity, legend and human settlement in the area over the past millennia are also explored.

The region in question comprises the Cooley Peninsula, Slieve Gullion and the Ring of Gullion, the Mourne Mountains and their low-lying coastal fringe, and Slieve Croob.

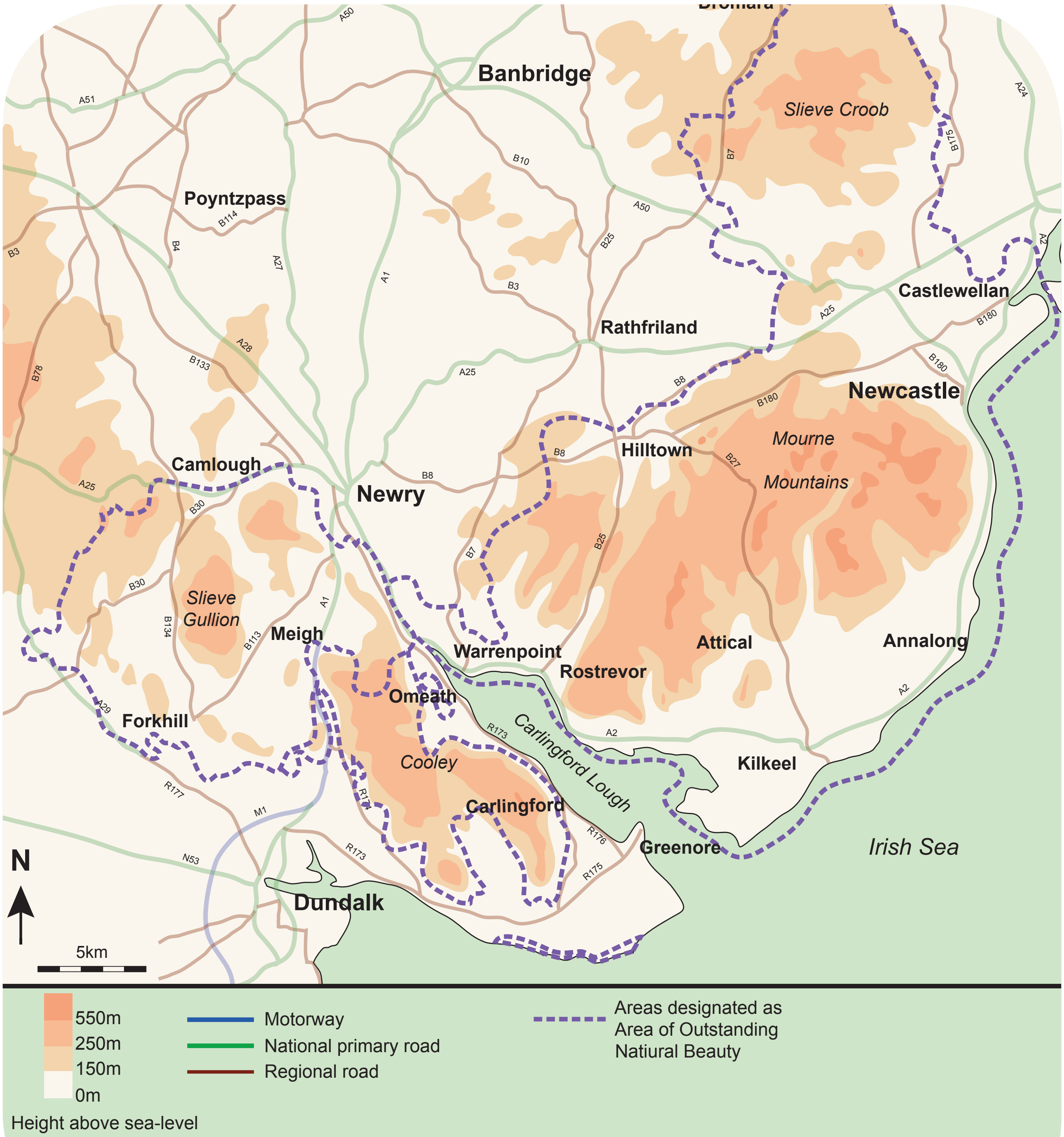

Figure 1 Geographical map of the Carlingford Lough region, showing upland areas, main settlements, roads, and areas designated as being of Outstanding Natural Beauty.

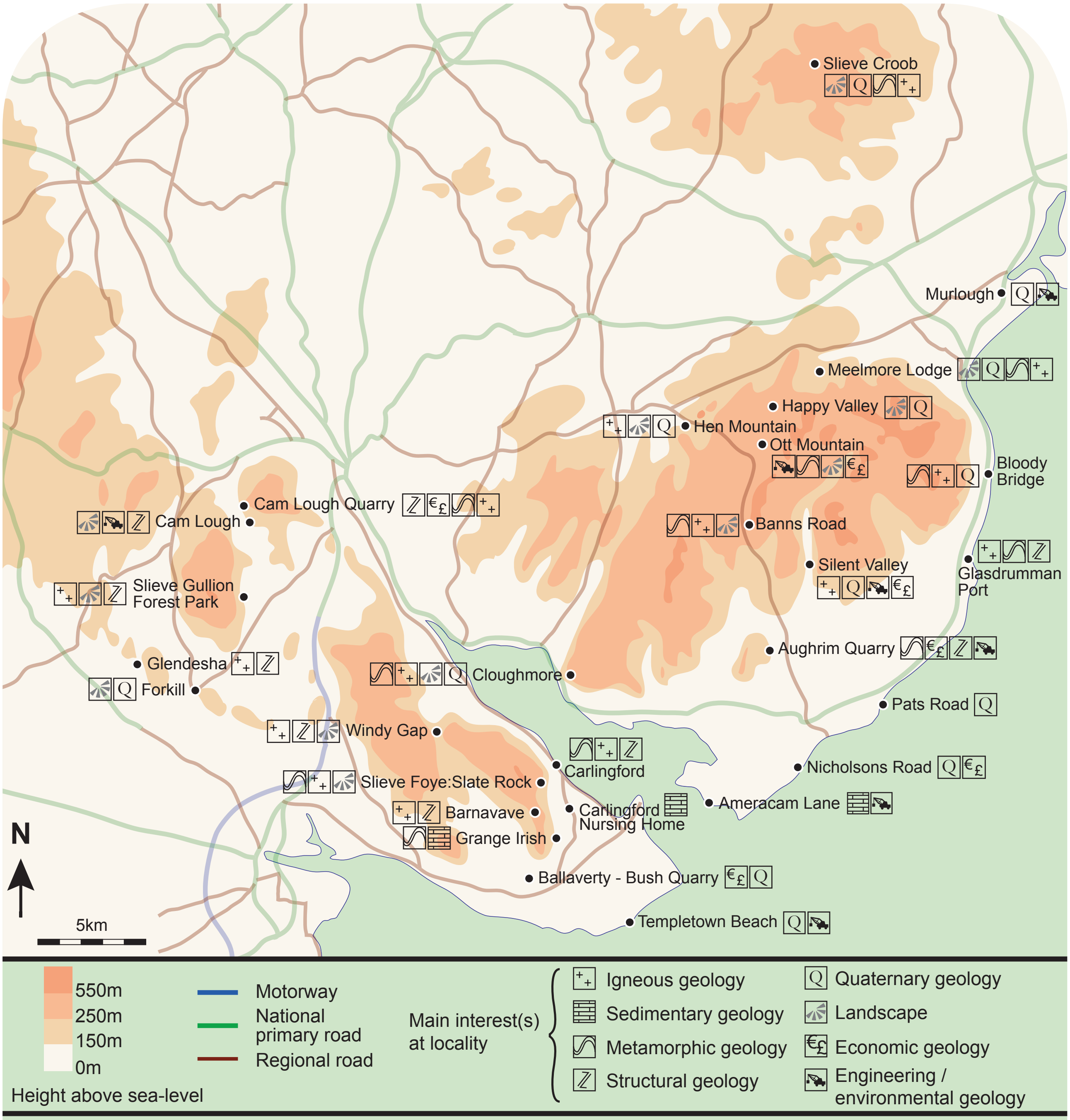

Figure 2 Geographical map of the Carlingford Lough region, showing the location of the sites described in this guide, and an indication of the main geological features seen at each.

The region owes its striking landscape to a combination of the underlying geology and the surface processes that have sculpted these rocks over the millions of years since their formation. The upland areas are all underlain by igneous rocks: Slieve Croob is formed of rocks belonging to the Newry Igneous Complex that was emplaced as the ancient Iapetus Ocean closed; the other areas in the Carlingford Lough region are underlain by granite and gabbro that date back to a period during the opening of the North Atlantic Ocean. The magmas intruded earlier rocks, including sandstone, shale, and limestone, which tell some of the geological history of the region back to 440Ma (million years), a period of time that represents around a tenth of the age of the Earth itself (Figure 3). These rocks have been baked and altered close to their contacts with the igneous intrusions. The ice that covered the region several times in the past 2Ma carved the rocks into corries and U-shaped valleys, and deposited glacial sediment in moraines and drumlins. The weight of the ice also pushed the Earth's crust downwards; the subsequent rebound of the crust after the melting of the ice led to the formation of raised beaches in this part of Ireland. All of the above are featured in sites described in this guide.

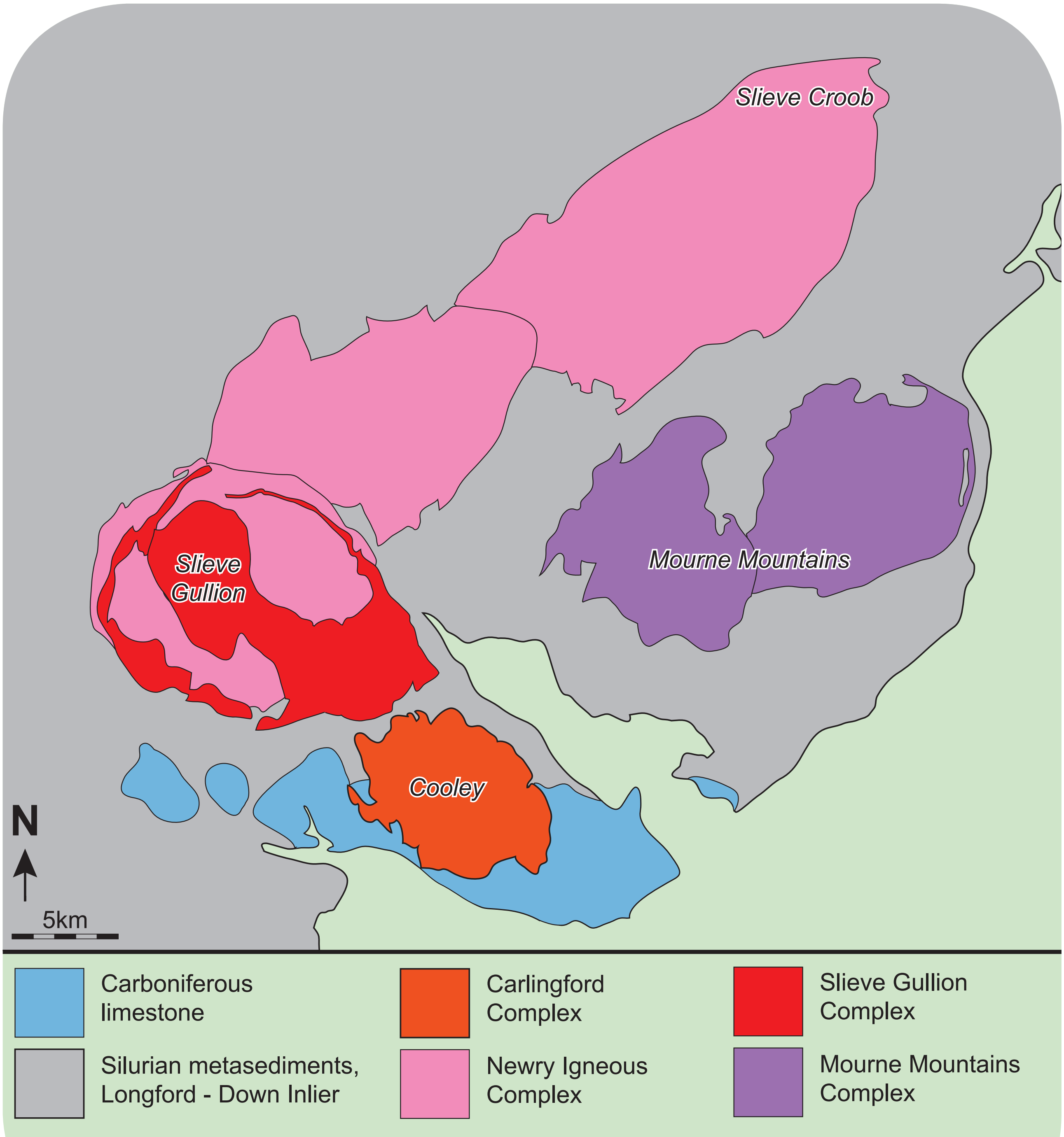

Figure 3 Simplified geological map of the Carlingford Lough region.

Clocks and rocks: geological time and the rock cycle

The geological time scale

Geological time can be considered in either a relative or absolute scale. The relative time scale uses the relationships between rock units to establish their relative age. This relies on principles such as superposition (younger rocks overlie older rocks), cross-cutting (the cross-cutting rock must be younger), and inclusions (bits of rock included in another must be older than their host).

Correlations across the world are made based on the presence of certain fossils in the rocks. This is how geologists subdivide the great extent of geological time into Eras – the Palaeozoic ('ancient life'), the Mesozoic ('middle life') and the Cenozoic ('recent life'). Further division of the eras gives us Periods, and these are subdivided into Epochs (Figure 4).

However, knowing the relative age of a rock has limited use. It does not allow, for example, calculation of rates of processes which have happened on Earth. The modern technique of radiometric dating allows geologists to get the exact age of many rocks using the proportions of radioactive parent and daughter isotopes in certain minerals in the rock (Figure 5). Particularly suited to these studies are volcanic rocks, which, when present in a sequence of fossiliferous sedimentary rocks, can be used to give an accurate age for certain points in the geological time scale.

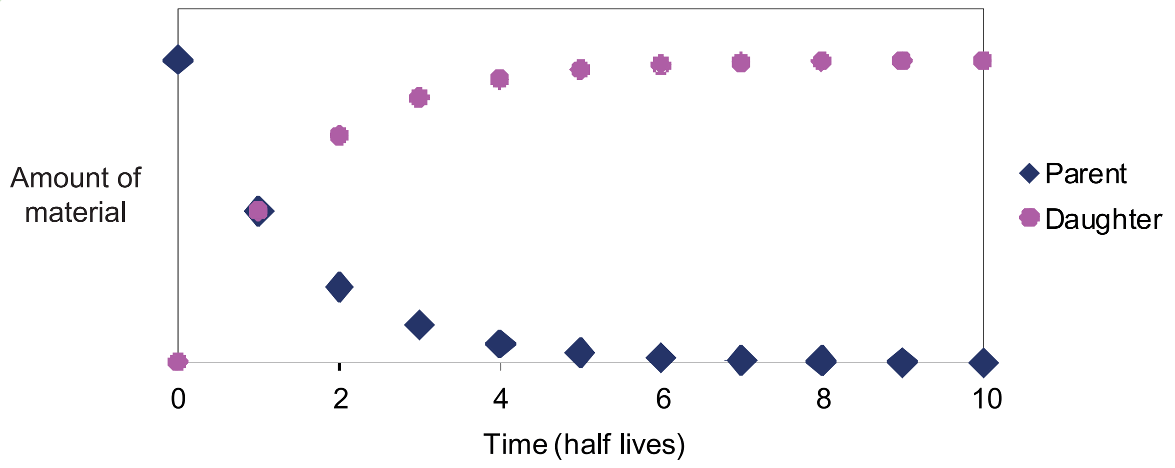

Figure 4 Schematic diagram illustrating the principle of radioactive decay: as the parent isotope (e.g. uranium) decays and becomes less abundant, the daughter isotope (e.g. lead) increases in abundance. Determining the proportions of parent and daughter isotopes in a mineral tells us for how long the decay process has been going on in the mineral. This means that for minerals extracted from an igneous rock, we also know when the rock crystallised from magma.

		Era	Period	Epoch	Ma	Local events	Irish events	World events
	Phanerozoic ('visible life')	Cenozoic	Neogene	Holocene	0.01	Isostatic adjustment - leads to raised beaches		
				Pleistocene	1.8		Glaciation - Ireland covered and sculpted by ice	
				Pliocene	5.3			
				Miocene	23			
			Palaeogene	Oligocene	34			Rifting of North Atlantic. Tropical climate. Diversification of mammals & plants
				Eocene	56			
				Palaeocene	65	Intrusion of igneous complexes	Volcanic activity especially in NE Ireland - Antrim Plateau Flood Basalts	
		Mesozoic	Cretaceous		144		Deposition of chalk	Mass extinction at end of Cretaceous
			Jurassic		203		Deposition of muds and limestone in NE - rest of island is land	Early Atlantic rifting
			Triassic		250		Desert conditions - evaporites (e.g. gypsum) deposited	Appearance of dinosaurs & early mammals
		Palaeozoic	Permian		298			Major mass extinction event; Variscan Orogeny in Central Europe
			Carboniferous		354	Deposition of limestone in shallow tropical seas	Ireland close to Equator, gradually flooded by sea	First land animals; winged insects
			Devonian		410	Intrusion of Newry Igneous complex	Semi-arid environment - deposition of 'Old Red Sandstone'. Intrusion of large granite batholiths.	First amphibious vertebrates; trees
			Silurian		440	Sediments which will form Longford - Down Inlier deposited	Orogeny as Iapetus closes	First land plants & arthropods; first fish
			Ordovician		495		Iapetus begins to close. Volcanic arcs.	Invertebrates diversify
			Cambrian		545		Iapetus Ocean opens	Modern animal phyla appear
Precambrian	Proterozoic ('first life')				2500		c. 1800 oldest rock in Ireland	c. 600 Good examples of multi-celled animals
	Archean				3800			c. 4000 Oldest known rocks on Earth
	Hadean				4500			c. 4600 Formation of Solar System

Figure 5 Simplified geological time scale with columns showing events represented by the geology of the Carlingford Lough region (coloured boxes), and some of those of interest nationally and globally.

The rock cycle

The Earth is an active planet, constantly in motion. Rocks, however permanent they seem, are also changing. This may be through surface processes such as weathering and erosion, or processes deep within the Earth that deform, heat, and even melt them. We use the concept of the 'Rock Cycle' to illustrate this (Figure 6).

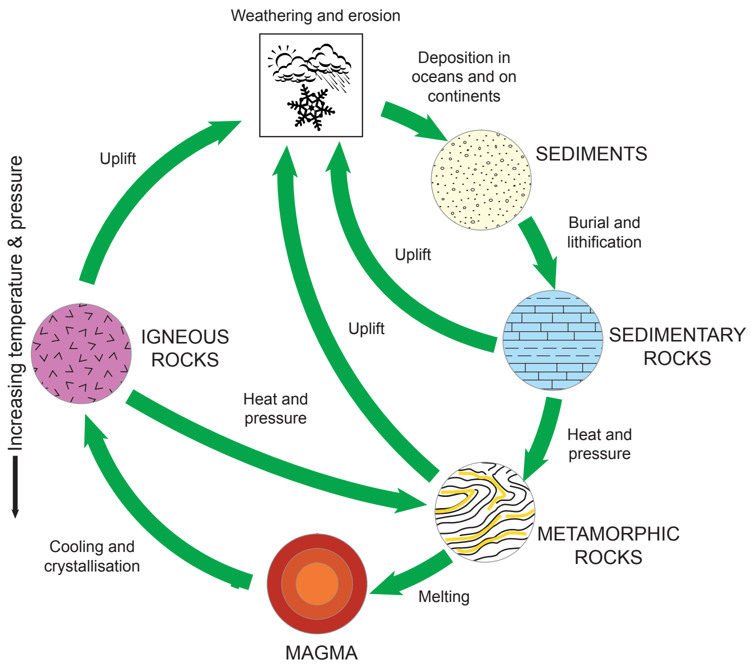

Figure 6 The Rock Cycle.

Classification of Rocks

Rocks are subdivided into three main groups: igneous, sedimentary, and metamorphic.

Igneous Rocks

Igneous rocks have crystallised from a magma, or melt, and are composed of interlocking crystals. Igneous rocks are classified based on (1) their grain size, and (2) their mineralogy (or chemistry).

The size of the crystals in igneous rocks gives an indication of the speed at which the magma cooled and crystallised. Large crystals imply that the magma cooled slowly (plenty of time for the crystals to grow). This will have been the case for an intrusive, or plutonic, rock, which crystallised beneath the surface. If, however, the magma is extrusive, or volcanic, the rapid rate of cooling will mean that only small crystals have time to grow.

The chemistry of the magma controls the mineralogy of the rock, which in turn helps to determine the name of the igneous rock. Magma with a high silica content will tend to form rocks containing quartz, alkali feldspar and mica; those with low silica content will tend to have little or no quartz, but will contain plagioclase feldspar, pyroxene and olivine.

The above criteria are summarised in Figure 7, which shows the general classification of igneous rocks described in this guide.

	Felsic (high silica)	Mafic (low silica)
minerals / grain-size	quartz, Na- & K-rich feldspars, micas	pyroxene, Ca-rich feldspar, olivine
fine-grained (volcanic)	rhyolite	basalt
medium-grained	microgranite	dolerite
coarse-grained (plutonic)	granite	gabbro

Figure 7 Simple classification of igneous rocks.

Sedimentary Rocks

Sedimentary rocks are divided into three main groups: clastic, organic, and chemical.

Clastic rocks are derived from fragments of other rocks. The grain size determines the classification of the rock – from fine-grained mudstone, through siltstone and sandstone, to coarse-grained conglomerate (rounded clasts) and breccia (angular clasts) (Figure 8).

Clast Size (mm)	Sediment Name	Rock Type
>256	boulder	conglomerate (rounded) / breccia (angular)
64-256	cobble	
2-64	pebble-granule	
0.625-2	sand	sandstone
0.005-0.625	silt	siltstone
<0.005	clay	shale/mudstone

Figure 8 Grain-size classification of clastic sedimentary rocks.

Organic rocks form through the accumulation of the remains of dead plants and animals. Such rocks include limestone (composed of the calcareous skeletal remains of sea creatures), and coal (formed from carbonaceous plant remains).

Chemical rocks form through the precipitation of minerals from water in arid climates. Examples include halite (rock salt), and gypsum (calcium sulphate).

Metamorphic Rocks

Metamorphic rocks result from the alteration of existing rocks through the agents of heat, pressure and circulating fluids, but without the occurrence of melting. They are divided into three groups: regional, contact, and dynamic (Figure 9).

Regional metamorphism results from the large-scale processes of plate tectonics. Rocks caught up in an orogeny (mountain building event) will be deformed and buried, leading to the growth of new minerals. The type of metamorphic rock formed will depend on the composition of the original rock (the protolith), and on the temperatures and pressures reached during metamorphism. For example, shale, with increasing metamorphism, will be changed into slate, phyllite, schist, and gneiss, while limestone will form marble, and sandstone will form quartzite.

Contact metamorphism occurs in rocks that have been intruded by magma. The increased temperature (frequently accompanied by circulating fluids) causes the growth of new minerals in the protolith. The zone of metamorphism is known as a metamorphic aureole (halo). Examples of contact metamorphic rocks include skarn (from limestone) and hornfels (from shale).

Dynamic metamorphism occurs in fault zones and is localised in the zone. The resulting rock depends on the depth at which movement has taken place – at shallow levels in the crust the rocks are brittle and will form a fault breccia, while deeper in the crust the deformation may be more ductile and result in a mylonite. In extreme circumstances the heat of friction may result in partial melting of the rock.

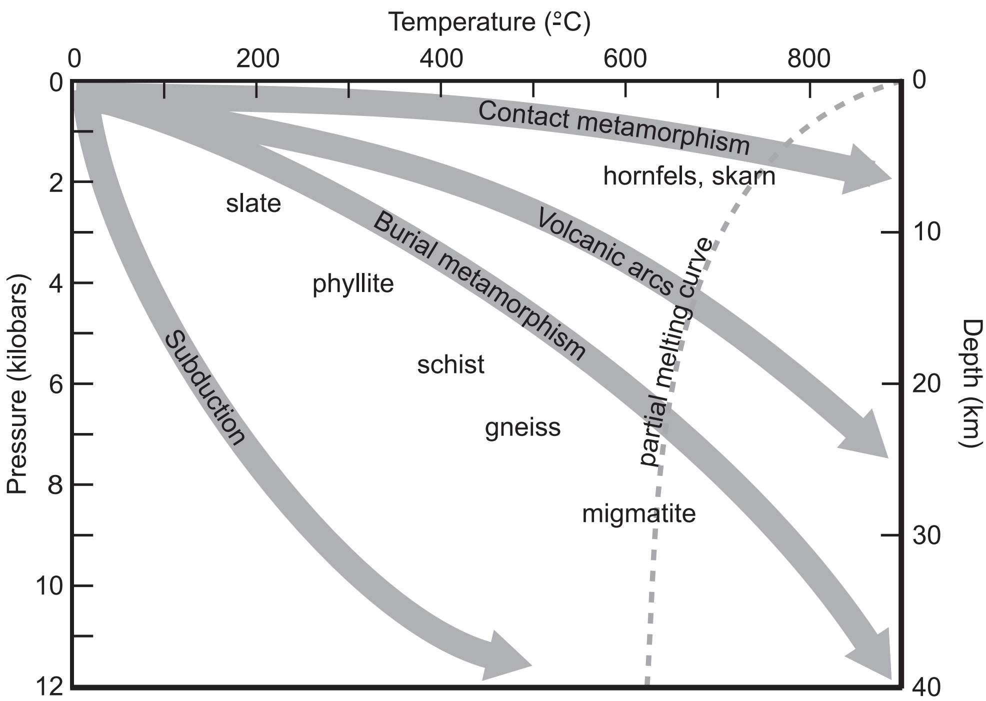

Figure 9 Simplified classification of metamorphic rocks based on the temperature and depth of metamorphism.

A well-travelled island: Ireland's journey across the globe

A Vanished Ocean

The earliest rocks in the region are Silurian sedimentary rocks (sandstones, siltstones and shales) of the Longford - Down Inlier. The original sediments from which these rocks are formed – sands, silts and muds – were deposited about 440Ma ago in the seas off a continent called Laurentia. This continent lay on the north-western margins of an ancient ocean, Iapetus, which divided the north-western and south-eastern parts of Ireland along a line that runs approximately from Clogher Head (north of Drogheda) to the Shannon Estuary (Figure 10).

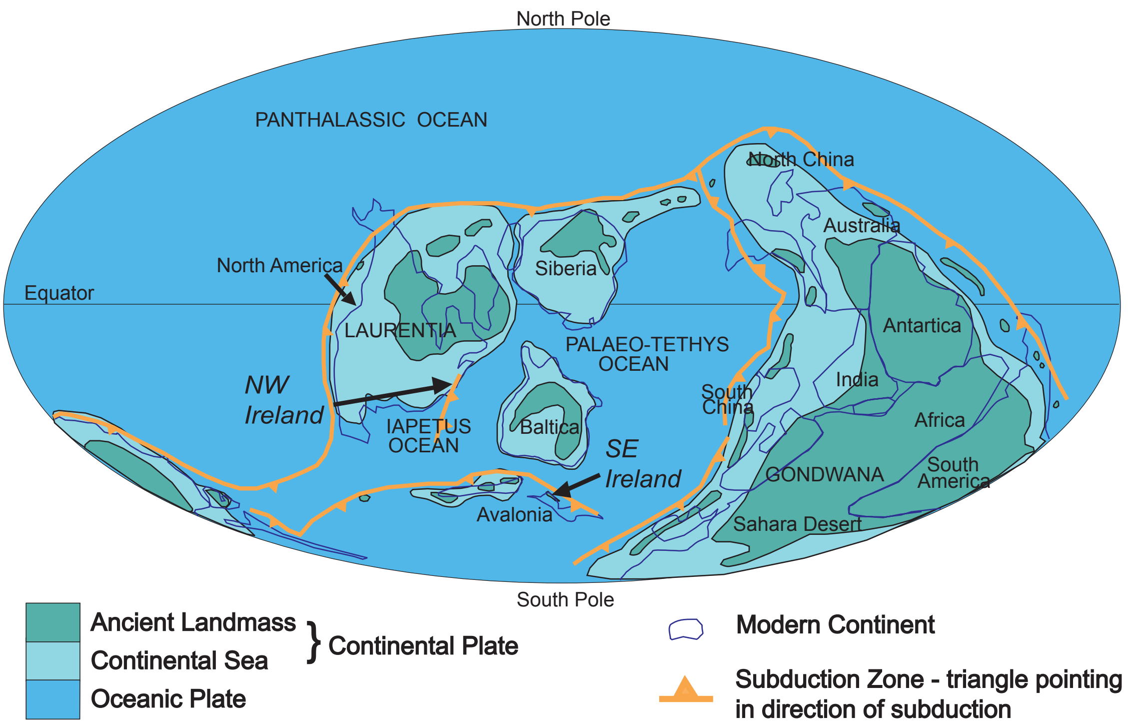

Figure 10 Plate reconstruction for the middle Ordovician.

In the earliest Ordovician, Iapetus began to close as the oceanic plate was subducted under the continental Laurentian plate. At the subducting margin, the sediments on the seafloor were scraped off the down-going oceanic plate and stacked against the continental margin, building a wedge of sedimentary rocks known as an accretionary prism (Figure 11).

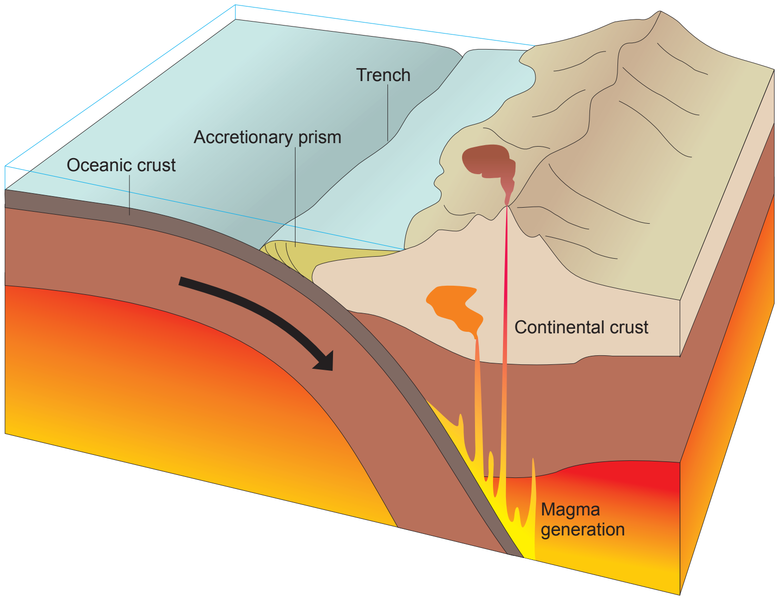

Figure 11 A subduction zone. In the Ordovician - Silurian Ireland was in such a plate tectonic setting. The rocks of the Longford – Down Inlier were part of an accretionary prism, while volcanic activity and mountain building are recorded in other parts of Ireland.

A similar process is happening today in the sea off Japan as the Pacific Plate is subducted there. The rocks of the Longford - Down Inlier today form steeply dipping, almost vertical, layers that trend or strike in a NNE-SSW direction, parallel to the Iapetus suture zone (Figure 12). Examples may be seen at Localities 1 (Carlingford), 17 (Aughrim Quarry), 21 (Glasdrumman Port), and 28 (Slieve Croob).

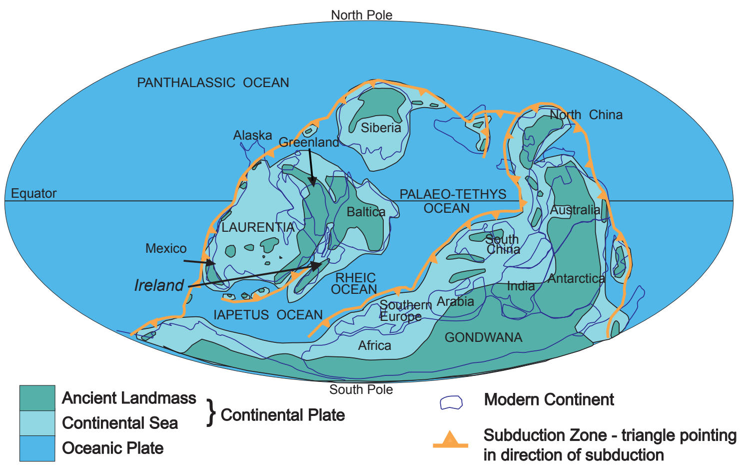

Figure 12 Plate reconstruction for Silurian times, as Iapetus closed.

Building Mountains

With the closure of Iapetus came continental collision and orogeny, or mountain building. This is occurring today in places such as the Himalaya, where India, drifting slowly northwards, is crashing into Asia. The closure of Iapetus brought the northern and southern halves of Ireland together, and the region lay along the line of the Caledonian-Appalachian mountain belt. Remnants of this mountain belt can be found today in

Arctic Norway, Scotland, Ireland, Newfoundland, and in the Appalachian Mountains of the USA (Figure 13). Movement of the colliding plates was not 'head-on' but oblique, and slivers of the plates slid past one another along strike-slip faults, similar to the movement of the plates along the San Andreas Fault in western North America.

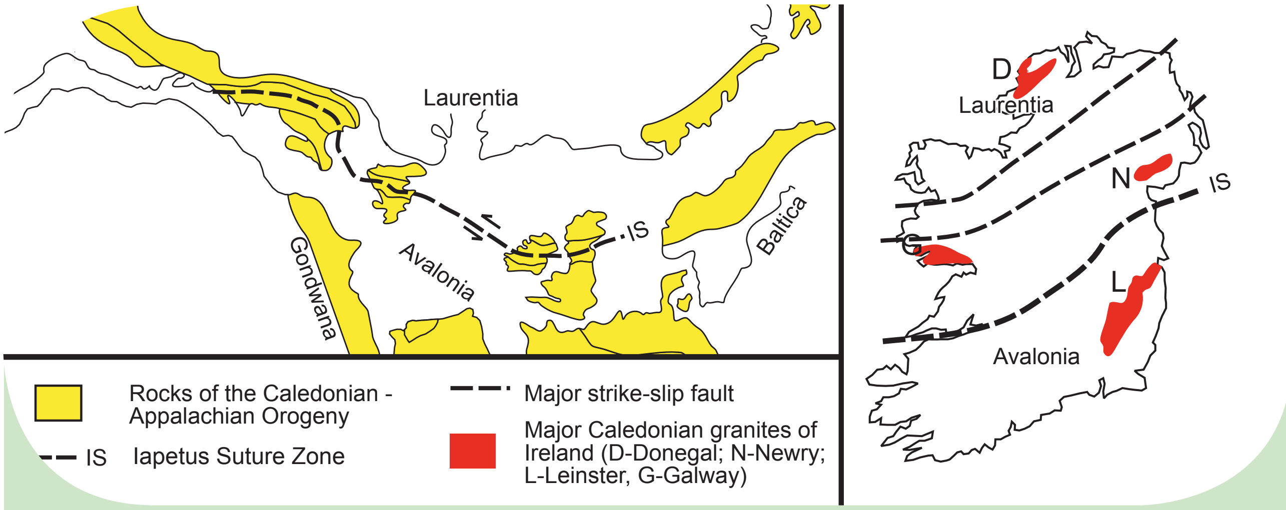

Figure 13 The Caledonian – Appalachian orogeny can be traced from Norway, through Scotland and Ireland, to Newfoundland and the east coast of North America. The trace of the Iapetus Suture crosses Ireland from just south of Dundalk to the Shannon Estuary. Orogeny and movement on the strike-slip faults associated with it led to the generation and emplacement of granite magma, now seen as the batholiths of Donegal, Newry, Leinster, and Galway.

Feeling the Heat

During and for a time after the orogeny, large volumes of magma were generated deep within the thickened crust. Some of this magma made its way up along the strike-slip fault zones to intrude the crust at a higher level, where it cooled and crystallised to form granite. There are several large granite intrusions in Ireland that date from this time – about 400Ma – including the Newry, Donegal, Leinster, and Galway Granites (Figure 13). The Newry Granite – or more properly, the Newry Igneous Complex – was intruded into the sedimentary rocks of the Longford - Down Inlier. It comprises a series of three overlapping granodiorite plutons that are elongate approximately parallel to the foliation of the sedimentary rocks into which they are intruded. The south-western-most pluton, which is approximately circular in outline, lies between Newry and Forkill. The great heat of the intrusion (800-1000°C) baked the sedimentary host or country rocks, and this can be seen at the margins of the pluton at Locality 9, Cam Lough Quarry, and, at the other end of the complex, in the north eastern pluton, at Locality 28, Slieve Croob. There is evidence at other sites of the forces acting at the margins of the granite as it was intruding into the sedimentary rocks: the granite has developed a foliation, or flattening fabric, evident as an alignment of crystals in the rock.

Tropical Ireland

At the time of the intrusion of the Newry Igneous Complex in the early Devonian, Ireland lay about 35° south of the equator at the south-eastern margin of the 'Old Red Sandstone' continent, formed by the closure of Iapetus. Rocks of Devonian age in Ireland are mainly terrestrial, formed from sands and gravels that were eroded from the Caledonian mountain ranges and deposited in huge alluvial fans. The desert environment and lack of vegetation (land plants were only beginning to get established) meant that there was little to protect the rocks from the agents of weathering and erosion. These sediments now form the sandstones of Cork and Kerry, and the boulder conglomerates of the Antrim coast. The south Down – Armagh – north Louth area was land at the time, and the lack of Devonian sedimentary rocks here is probably because none were deposited, rather than a lack of preservation. However, during this time, the continent of which Ireland was a part was gradually drifting northwards. By the early Carboniferous, 350Ma ago, Ireland was in equatorial latitudes, and the sea was advancing northwards over the land (Figure 14).

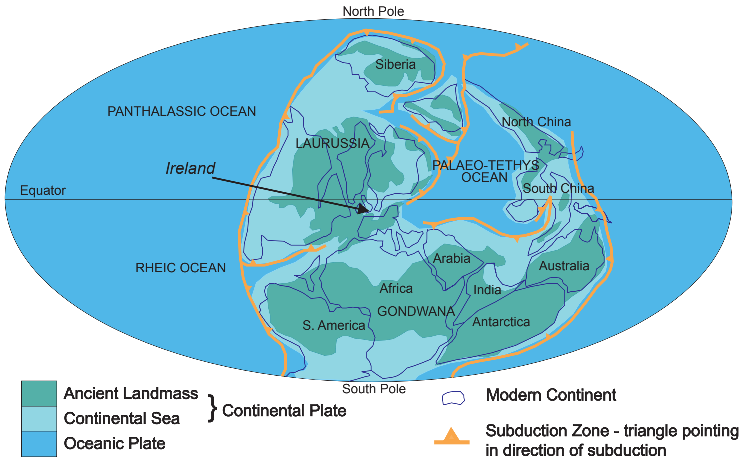

Figure 14 Plate reconstruction for Carboniferous times – Ireland lies close to the Equator.

Rocks from this time are preserved at a number of localities in the region. At Ameracam Lane (Locality 15) on the northern shore of Carlingford Lough, fossiliferous limestones, oolites, sandstones and pebble beds show that the sediments were deposited in shallow seas not far from the land. The low-lying, fertile farmland at the eastern and southern margins of the Cooley Peninsula are also underlain by limestone of the same age (about 320Ma) and can be examined at a number of sites – Localities 2 (Slieve Foye: Slate Rock), 4 (Grange Irish), and 5 (Carlingford Nursing Home).

A New Ocean Forms

None of Ireland's geological history for the following 260Ma is preserved in the rocks of the Carlingford Lough region, but the next major geological event to affect Ireland is well represented. This event was the opening of the North Atlantic Ocean which started about 65Ma ago at the beginning of the Palaeogene, when Ireland was at the latitude of present-day southern France. The stretching and subsequent rifting of the crust leading to the opening of the Atlantic caused large volumes of magma to be intruded and erupted, forming what is now known as the North Atlantic Igneous Province. Perhaps the most famous of the volcanic eruptions is now preserved in Antrim as the Giant's Causeway, but the volcanic plug of Slemish and the islands of western Scotland (e.g. Mull, Rum, Skye) are also parts of the Province. Iceland, of course, is part of the mid-ocean ridge that continues to create more Atlantic Ocean crust.

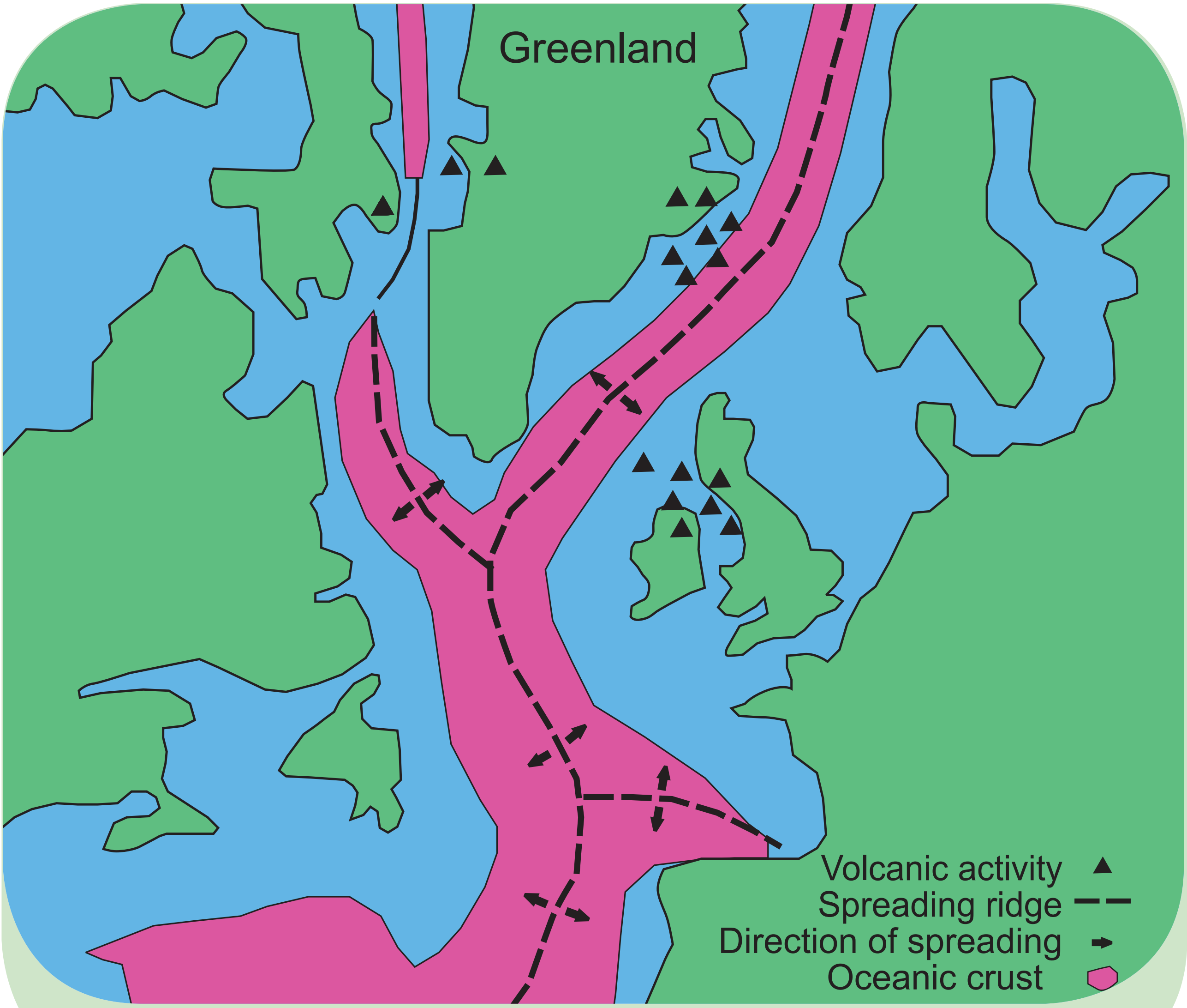

Figure 15 The opening of the North Atlantic and associated igneous activity.

In the region of Carlingford Lough, three centres of igneous activity were active from about 61-52Ma ago: Carlingford, Slieve Gullion, and Mourne. Carlingford and Slieve Gullion represent the eroded roots of volcanoes, but although the Mourne magma reached a high level in the crust, there was no volcanic activity associated with this intrusion. The three complexes intruded mainly into the sedimentary rocks of the Silurian Longford - Down Inlier (Localities 1 (Carlingford), 18 (Banns Road), 22 (Bloody Bridge River), 24 (Meelmore Lodge), 9 (Cam Lough Quarry)). However, the Slieve Gullion complex also intrudes the south-western pluton of the Caledonian Newry Igneous Complex, preserving evidence for explosive volcanic activity in the form of a volcanic agglomerate which contains fragments of the earlier rocks (Locality 11, Glendesha Forest). The Carlingford Complex intrudes Carboniferous limestone, and has uplifted it close to the margins of the intrusion (Localities 2 (Slieve Foye: Slate Rock) and 4 (Grange Irish)). All of the pre-existing rocks have been altered where they are in contact with the Palaeogene rocks.

The intrusions are dominated by granite[1], a silicic or felsic rock, but there are also significant volumes of mafic rocks such as gabbro, dolerite and basalt. Geophysical evidence suggests that there is also a large volume of mafic, high density rock beneath the granite of the Mourne Mountains. The presence of more than one magma – mafic and silicic – means that all three centres show evidence for interaction of contrasting magmas. This can be examined at Localities 3 (Barnavave), 12 (Slieve Gullion Forest Park), and 21 (Glasdrumman Port).
All centres also show evidence for widespread intrusion of minor bodies such as cone-sheets, dykes, and sills that injected into fractures in the crust around the central complexes – see Localities 1 (Carlingford), 4 (Grange Irish), 6 (Windy Gap (Long Woman's Grave)), 14 (Cloughmore), 15 (Ameracam Lane), 17 (Aughrim Quarry), and 21 (Glasdrumman Port)

[1] Much of the granite of Gullion and Cooley is a fine-grained variety often known as granophyre. This name is, however, not in the international standard nomenclature, and so, in this guide, the rocks are described as granite.

The Big Freeze

There is another gap in the geological record between the intrusion of the Palaeogene complexes and the onset of glaciation at the start of the Quaternary about 2Ma ago. There were perhaps as many as six periods of ice advance and retreat over the area until about 14,000 years ago. Only the last one is well recorded, as it obliterated much of the evidence of earlier activity.

The last advance and retreat of the ice is well represented in the surficial deposits that hide, over much of the area, the bedrock geology. This period of glaciation is known as the Midlandian in Ireland, and occurred between 19 & 13ka BP (thousand years before the present). The ice sheets flowed in a south-easterly direction from Lough Neagh, and in a southerly direction down the Irish Sea from Scotland (Figure 16). They eroded the bedrock over which they travelled, sculpting the landscape into often dramatic forms, such as corries, cols and U-shaped valleys (see Localities 19 (Silent Valley), 24 (Meelmore Lodge), 25 (Happy Valley), and 10 (Cam Lough)). They also picked up and transported a mixture sediment of all sizes, from boulders (Locality 14, Cloughmore) to fine clay, which it would later deposit as diamict in moraines and drumlins (e.g. Localities 7 (Templetown Beach), 16 (Nicholsons Road), 12 (Slieve Gullion Forest Park), 28 (Slieve Croob)). As the ice melted, water movement beneath and alongside the glaciers transported and sorted the sediments, leading to the deposition of sorted and stratified sands and gravels (e.g. Locality 8 (Ballaverty – Bush Quarry)).

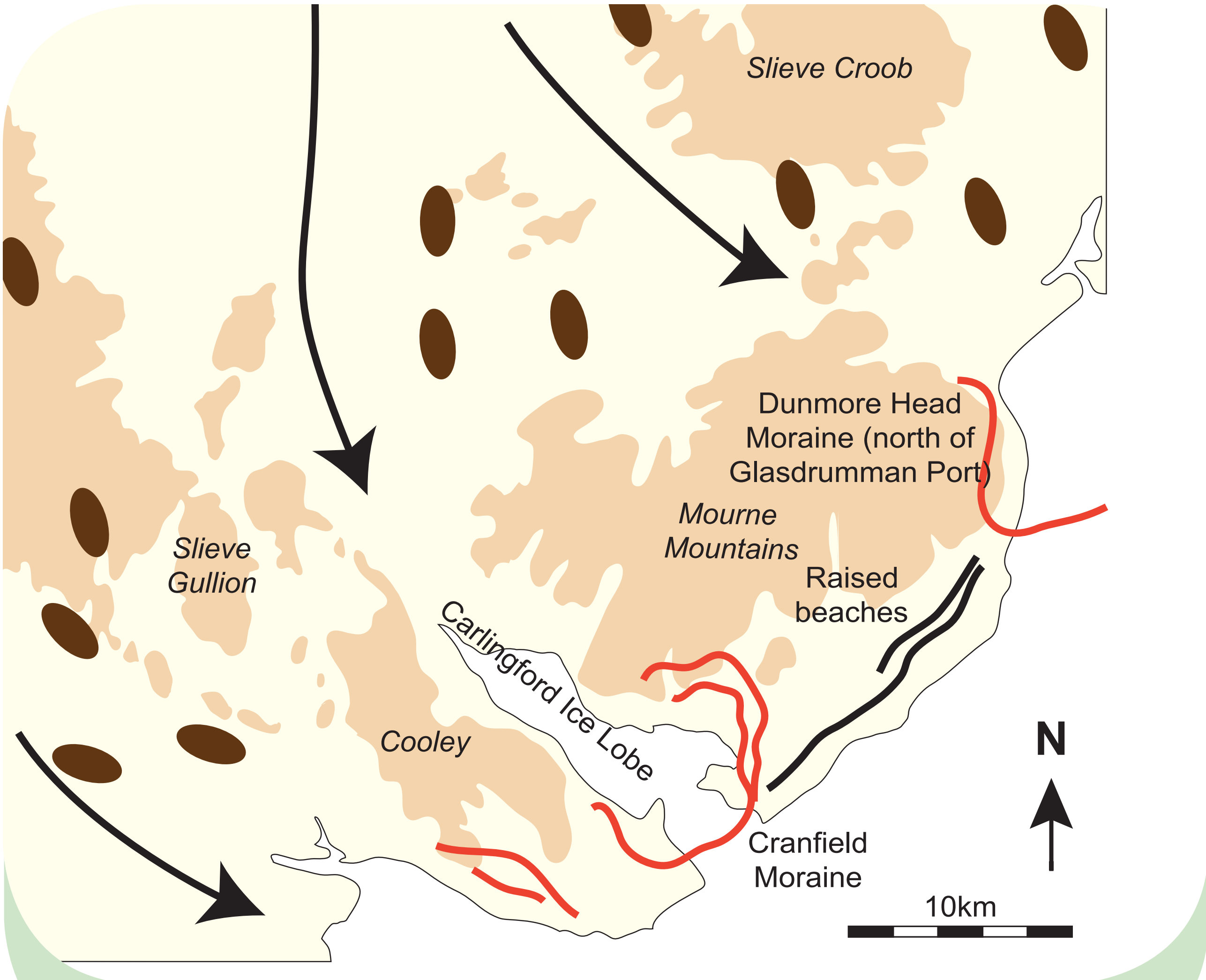

Figure 16 Generalised ice flows in the Cooley-Gullion-Mourne-Slieve Croob region during the last glacial maximum.

After the Ice

During glaciation, the great weight of ice on the crust caused it to be pushed downwards into the underlying mantle, and should have led to an (isostatic) rise in sea level. However, because water was being 'locked up' in the ice, there was actually a eustatic (global) fall in sea level. The net result was that Ireland experienced a fall in sea level during glaciation. As the ice melted, sea level rose quite rapidly, while the crust could only rebound slowly as the weight was removed. This meant that for some time, the sea level in the area was higher than it is now, relative to the crust. Evidence for the isostatic rebound of the crust can be seen today in the raised beaches that fringe the area (Figure 17), for example at Localities 7 (Templetown Beach), 16 (Nicholsons Road), and 20 (Pats Road, Kilkeel).

Figure 17 Oblique aerial view looking northward across the Mourne coastal plain to the Mourne Mountains. The village of Ballymartin is at the right centre; the highest peak is Slieve Binnian. (Photo: Mike Hartwell)

In the Mournes, the tors that form dramatic summits to many of the mountains (such as Slieve Binnian) were created when the granite was weathered along joints that developed as the crust rebounded after the melting of the ice (Locality 27, Hen Mountain). Further evidence of changing sea level since the end of glaciation (the ice had completely gone by 13ka BP) can be seen at Murlough (Locality 23), north of Newcastle. Here, sand dunes overlie a series of sub-parallel gravel ridges that record the gradual rise of the land from the sea. The dunes represent aeolian, or air-transported, sediment, sourced from local glacially-deposited material. Studies of dune soils clearly show increasing maturity of soils away from the sea, indicating that the dune system has been quite stable for several thousand years. The storm gravel beach at the top of the present-day sand beach is composed of clasts derived from a range of sources – most are locally-derived, but erratics from further afield – Scotland, Tyrone & Antrim – remind us of the ability of the great ice sheets to transport material for great distances.

Warming Up

The climate warmed significantly between the end of glaciation and 10,600 BP, a period of time in which the vegetation in Ireland would have consisted of grasses, willow, juniper, birch, and other such heath plants. This was also the time in which the famous Giant Irish Deer was present on the island, along with reindeer, red deer, wolves, and brown bear. There is no record of humans having made it to Ireland at this time.

[2]Recent research has suggested that parts of southern Greenland rose isostatically by 35mm from 2001-2006 due to the thinning of local ice sheets.

A Cold Snap

At about 10,600 BP the climate suddenly went into a cold snap that was to last about 500 years. The grasslands disappeared, to be replaced by tundra vegetation. This period saw the dying out of the Giant Irish Deer, and the probable disappearance of the reindeer and other large mammals. Remains of lemmings – the small Arctic mammals – have been found from this period. This time also saw the accumulation of snow and ice in upland areas, with local corrie glaciers developed in the Mournes.

The Beginning of the Holocene and Arrival of the First 'Irish'

The beginning of the Holocene c.10,000 BP was marked by a warming of the climate and the gradual development of vegetation from tundra to woodland consisting initially of birch and hazel, and, later on, of oak, elm and pine. This is the landscape that the earliest humans to reach Ireland about 9,000 BP would have encountered.

These people were Mesolithic (Middle Stone Age) hunter-gatherers, who would have used either flint (from the chalk of the north-east) or chert (from the Carboniferous limestone which covers much of Ireland) to make their arrows and axe heads. Flint nodules, transported by ice from Antrim, are not uncommon in the beach deposits in the Carlingford Lough region, and would have been a valuable resource for these early settlers. A site on the southern edge of the Cooley Peninsula provides the earliest direct evidence for human habitation in the area c.6,660 BP. Stone tools of a similar age have been recovered from the raised beach at Greenore.

The arrival of the first Neolithic (New Stone Age) people about 6,000 BP brought new tools, and a different way of life: they were farmers. Farming required cleared land, thereby bringing about the first human-wrought change of the Irish landscape as the forest was felled. These people also built large burial chambers, including the South Cairn on Slieve Gullion, the Ballykeel, Proleek, Legannany, and Kilfeaghan Dolmens, and the world-famous sites of Newgrange, Knowth and Dowth in the Boyne Valley.

This period also saw a deterioration in the climate, from warm, dry conditions – possibly one or two degrees warmer than today's – to the cooler, wetter one that we are familiar with. This change in climate led once more to a change in vegetation, as the pine forests declined and peat bogs developed.

About 4,000 BP, metal-working was introduced to Ireland – the Bronze Age had begun. One of the most notable features of this time was the manufacture of gold ornamentation such as crescent-shaped necklaces and brooches, many fine examples of which are to be seen in the National and Ulster Museums. It is still a mystery as to where the large quantities of gold needed to make these items were found, but recent research has suggested that there are sites in the Mournes that yield gold of a similar chemistry to the artefacts. Could there be undiscovered gold veins still in the mountains?

'Celtic' Ireland

The Iron Age (500BC – AD500) probably provides the background material which for many people would be the most notable tale in the area's history and legend: the Táin Bó Cuailgne, or the story of the Brown Bull of Cooley. This tale reflects the strategic importance of the area throughout history, given that it is both a major route for north-south travel along the eastern seaboard of Ireland, and a border region between the present-day provinces of Ulster and Leinster. The Dorsey in South Armagh is a linear earthwork that controlled travel in the area, presumably to and from the chief residence of the kings of Ulster at Eamhain Mhacha near Armagh.

Christianity

The region continued to be important during early Christian (from c.AD500) times, with some important ecclesiastical sites in Ireland (Armagh, Faughart, and Killevy) lying either within the area or close by. The older of the two churches in Killevy was founded towards the end of the 5th century, while near Rostrevor, the church of St Bronach (Kilbroney) dates from the 6th century. The Cistercians arrived to set up a monastery in Newry in 1153, following a request by Malachy of Armagh to their founder for monks to come to Ireland. Other notable sites in the area include the Dominican Abbey in Carlingford which dates from the 14th century, and the ruins of Kilwirra Church in Templetown, built in the 15th century and perhaps owned by the Knights Templar after whom the area is named.

From the Anglo-Normans to the Modern Age

The arrival of the Anglo-Normans (from about 1200) saw major defensive structures – King John's Castle in Carlingford and Greencastle (near Kilkeel) being built on rocky promontories on the shores of Carlingford Lough. The Anglo-Normans also founded the first proper towns in the area, including the walled town of Carlingford, which was an important venue for fairs and markets. The Tholsel and Mint in Carlingford date from the 15th century, as does Taaffe's Castle, the well-preserved large square keep in the centre of the town.

Bagenal's Castle in Newry is an example of a tower-house, built probably sometime in the 15th or 16th century, as is Narrow Water Tower-house (near Warrenpoint), built in a strategic location on a rocky outcrop to guard the head of the Lough. However, the Anglo-Normans did not control the whole area, with the Magennises dominant in Co Down. They built the 'New Castle' to guard a ford of the Shimna River, giving Newcastle its name, and held on to some of their property well into the 18th century.

The 16th and 17th centuries saw turmoil in the area, with many Irish lords losing their land to English and Scottish settlers. The landscape played a critical role in some of the events that took place during this time, with the Irish under Hugh O'Neill controlling the Gap of the North at Moyry until 1600. Bloody Bridge is named for a massacre of Protestant prisoners that took place there during the rebellion of 1641, while Newry was burned by the retreating forces of James II in 1689 on their way to the fatal Battle of the Boyne.

The 18th century saw the creation of some of the large estates in the area, such as Narrow Water Castle, Tollymore, Castlewellan, and Mourne Park in Co Down. The natural beauty of the area was beginning to be appreciated, with landscaped grounds and planting of trees intended to enhance the environment of the estates. Stone walls were built and hedges planted to divide the estates up for the tenant farmers who leased the land, substantially changing the landscape. However, the harsh living conditions for many of the tenants leading up to the Great Famine of 1845-49 saw almost half of the population around Slieve Croob either die or emigrate. Outside of the area, the discovery of coal in Coalisland, Co Tyrone led to the building of an inland waterway from Lough Neagh to Newry. Work started on the Newry Canal, the first summit level canal in either Ireland or Britain, in 1731.

The waterway was never used to transport coal from Tyrone to Dublin as intended, but it did lead to the development of Newry as the busiest port in the north of Ireland, and the creation of a wealthy merchant class in the area. The arrival of the railway in the mid 1800s ensured that the town continued to thrive despite the decline of the canal by that time. Two major building projects of the mid 19th century, the Cathedral of Saint Patrick and Saint Colman in Newry, and the Craigmore Viaduct (the '18 Arches') near Bessbrook, Co Armagh, were built of local granite.

The Quarry-Men

The commercial exploitation of the geological riches of the area intensified from the early 1800s. From this time, Mourne granite was valued as a building stone, and a large industry developed to supply the growing industrial cities such as Belfast and Liverpool with material: at one stage, five ships left Annalong Harbour every week bound for Liverpool with their cargo of 'setts' (paving stones). A small number of quarries are still active in the area, but most of the stone-masons working in the region today use imported stone. Other quarries, particularly those in the Silurian metasediments, are quarried for stone to be used as aggregate in the manufacture of concrete blocks and for road surfacing (e.g. Locality 17, Aughrim Quarry). Aggregate is also extracted from glacial moraines and outwash plains (e.g. at Localities 7 (Ballaverty – Bush Quarry), and 16 (Nicholsons Road)). Another economically important resource in the Mournes is water – the Silent Valley, Ben Crom and Spelga Dam reservoirs are major suppliers of water to the population of the Greater Belfast area.

A World-Renowned Centre for Geological Research

In the early 1930s, the area was a hot-bed of geological research. New models for the intrusion of igneous rocks, which would go on to influence geological research worldwide, were developed here. J.E. Richey, working in the Mournes in the 1920s, was the first to use a 'G' nomenclature to denote different granites in the same intrusive centre, a system that is now standard practice worldwide. He also developed the models for cauldron subsidence and ring-dyke emplacement, which envisaged the sinking of a large block of country rock along ring-shaped, outward dipping fractures. The resultant ascent of the magma up along the fracture formed a circular intrusion known as a ring-dyke (such as the Ring of Gullion), and intrusion along the top surface of the subsided block resulted in plutons such as the Mournes (Figure 18).

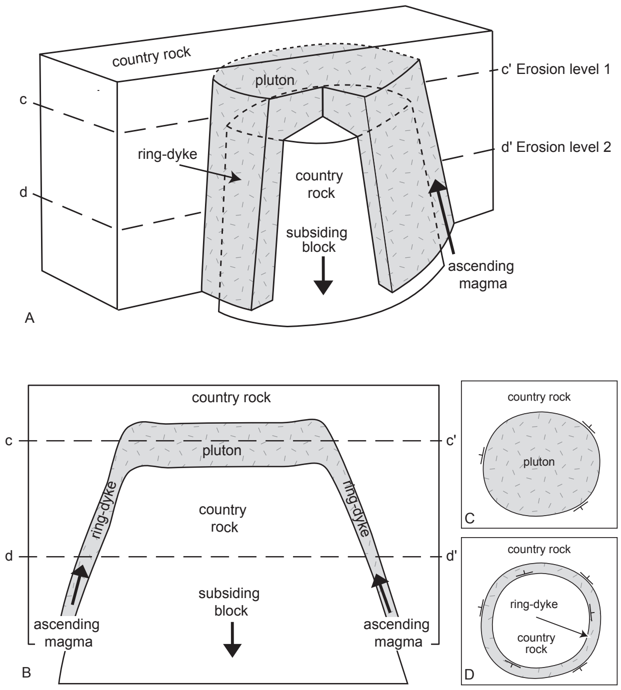

Figure 18 Schematic cross-section through upper crust illustrating cauldron subsidence model for ring-dyke and pluton emplacement. (A) 3D visualisation of cauldron subsidence model; (B) cross-section of pluton, ring-dyke and subsided block; (C) & (D) maps of the intrusion at different exposure levels—indicated in (A) & (B) by dashed lines—showing the different outcrop patterns that could result from such an intrusion. Note the outward-dipping contacts. (Drawing by Brian O'Donnell).

However, geological research is still very much alive in the region. More recent work has been using modern analytical techniques to analyse the rocks and has been questioning the old and accepted models of intrusion. Much has still to be learned from the rocks of the area!

A Landscape to be Treasured

Finally, the beautiful landscape and rich history of the region is a valuable resource for both residents and visitors. The creation and maintenance of the landscape as we now know it owes much to the people who make their living from it, such as the farmers and the quarry-men. Too often we lament or criticise the impact of man-made structures on our landscape, but it is important to note that some of the sites that feature in this guide would not be available to us without activities such as farming and quarrying – and we all like to have houses to live in and roads to travel on, and we admire the picturesque stone walls that enclose the fields.
It is hoped that this guide will help the reader to better appreciate the Cooley, Gullion, Mourne and Slieve Croob region, and recognise that the area is one linked by landscape, and a shared geological and cultural history rather than one divided by a border. Enjoy your field trips!

The Countryside Code

1. Access to the Countryside

Access to the countryside must be based on mutual respect and:

- Acceptance of the rights of farmers and landowners over access to their land.
- Acceptance of the need of recreational users to have reasonable access to the countryside and uplands.
- Acknowledgement of the concerns of farmers and landowners in relation to insurance and liability.
- Opposition to the use of any form of violent or threatening behaviour in relation to conflicts over access and where a conflict arises, rapid positive efforts should be made to resolve it by all parties involved.
- Recognition of the value that recreational activity brings the rural economy.
- Acceptance that recreational users in the countryside must be responsible for their own safety.

2. Plan Ahead and Prepare

- Before you go check, where possible, if access is allowed and your activity is permitted in the area you wish to visit e.g. is your dog welcome too? Is there parking available?
- When parking cars in unattended areas leave visible identification in your vehicle.
- Respect any signs, regulations, policies and special concerns for the area that you wish to visit. Permits may sometimes be needed for activities on public lands.
- Where possible travel by public transport and share cars.
- Ensure you have the skills and equipment needed for your activity.
- Check the weather forecast. Prepare for changeable weather and the possibility of something going wrong.
- For enviromental, safety and social reasons, keep group numbers small.

3. Be Respectful of Others

- Park Appropriately - avoid blocking gateways, forest entrances or narrow roads.
- Remember that farm machinery, local residents and the emergency services may need access at all times.
- Respect landowners, land managers and their property - avoid damaging walls and fences, do not disturb farm animals.
- Respect other visitors.
- Avoid making loud and excessive noise. Let nature's sounds prevail.
- Support local communities e.g. make a point of spending money in the areas you visit.

4. Respect Farm Animals and Wildlife

- Dogs should be kept under close control and should not be brought onto hills or farmland without the landowners permission.
- Observe wild animals and birds from a distance. Avoid disturbing them at sensitive times: mating, nesting, and raising young (mostly between spring and early summer).
- Never feed wildlife or farm animals. Feeding wildlife damages their health and alters natural behaviours.

5. Keep to Durable Ground

- Durable ground includes established tracks and campsites, rock, gravel, dry grasses. To avoid further erosion, keep to the centre of tracks at all times.

If Camping:

- Protect water quality by camping at least 30m from lakes and streams.
- Aim to leave your campsite as you found it, or better.

In Popular places:

- Concentrate use on existing tracks and campsites
- Walk single file in the middle of the track even when wet or muddy.
- Keep capsites small and discreet

In More Remote Areas:

- Disperse use to prevent creation of new tracks and campsites.
- Avoid places where impacts are just beginning to show.

6. Leave What You Find

- Repect property. For example, farming or forestry machinery, fences, stone walls, etc. Leave gates as you find them (open or closed).

- Preserve the past: examine but do not damage - archeological structures, old walls and heritage artefacts e.g. holy wells, mine workings, monuments.
- Conserve the present: leave rocks, flowers, plants, animals and other natural habitats as you find them. Fallen trees are a valuable wildlife habitat do not remove or use for firewood.
- Avoid introducing non-native plants and animals e.g. zebra mussels in rivers and lakes.
- Do not build rock cairns, structures or shelters.

7. Dispose of Waste Properly

- "If You Bring It In, Take it Out" - take home all litter and leftover food (including tea bags, fruit peels and other biodegradable foods).
- To dispose of solid human waste, dig a hole 10-12 cms deep and at least 30m away from water, campsites and tracks. Cover and disguise the hole when finished.
- Bring home toilet paper and hygiene products.
- To wash yourself or your dishes, carry water 30m away from small streams or lakes and if necessary use small amounts of biodegradable soap. Bring home any solids and scatter strained dishwater.
- For more information on sanitation in the outdoors read the "Where to go in the outdoors" leaflet (countrysiderecreation.com).

8. Minimise the Effects of Fire

- Where possible avoid open fires in the countryside.
  Fires can cause lasting impacts and can be devastating to forests, natural habitats and farmland.
- When camping use a lightweight stove for cooking.
- Take special care to ensure bottles and cigarettes are properly disposed of.

Where Fires are permitted:

- Use established fire rings, barbeques or create a mound fire.
- Keep fires small. Only use sticks from the ground that can be broken by hand. Do not cut growing vegetation for use as firewood.
- Avoid burning plastics or other substances, which emit toxic fumes.
- Burn all fires to ash, put out fires completely, and then scatter cool ashes.
- Dead and dry vegetation is highly flammable - do not light fires in these conditions. Winds can spreads fires - exercise extreme caution in such conditions.

9. Walk Safely

- Ask locally for advice on where to walk.
- Avoid steep ground, cliffs and unnecessary hazards such as crossing rivers.
- Remember, you are responsible for your own safety.
- If you need help in an emergency, phone 999 or 112.
- Have you left details of your walk with somebody and expected time of return?

10. Water Safety

- Reeds and grass can often obscure the edge of the pond.
- The banks of a pond may be weak and give way under your weight.
- Do not allow children to play near the edge of riverbanks - it can crumble away suddenly.
- Never walk on ice covered waterways.
- For seashore walks check the times of the tide to ensure that you won't be cut off by rising water.

Preserve the sites

Hammering of outcrops is generally unnecessary – sites have been selected that clearly illustrate the geology, and few of them need hammering for examination.

The Carlingford Complex

The Carlingford Igneous Complex is the oldest of the three Palaeogene intrusive complexes in the Carlingford Lough region, and is dated to 61.4±0.8Ma.

The complex makes up the central part of the Cooley Peninsula, forming the mountains of Slieve Foye, Barnavave, Slievenaglogh, and Slievestuckan. The southern half has intruded Carboniferous limestone, while the northern part intrudes Silurian metasediments of the Longford – Down Inlier (Figure 19)

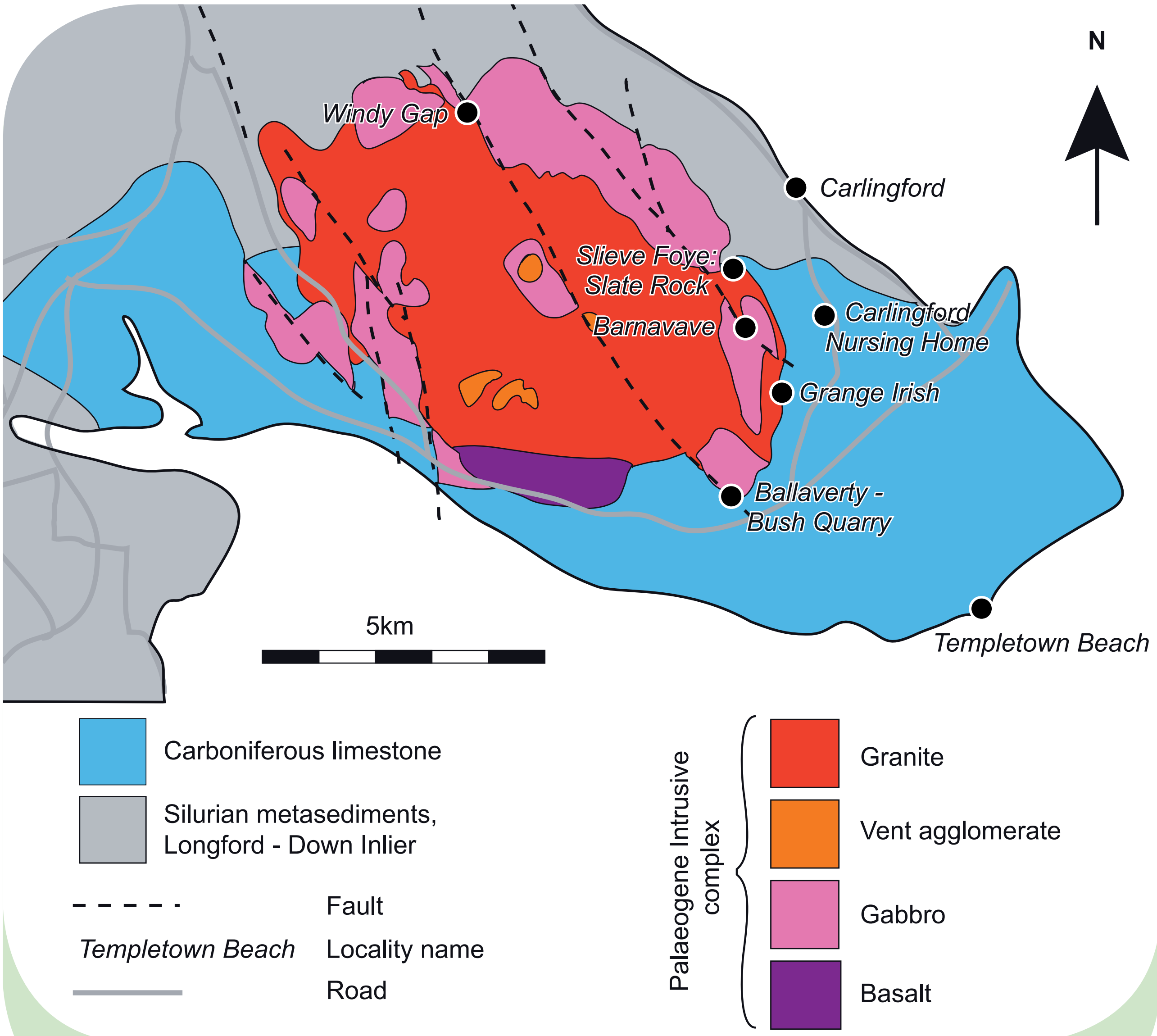

Figure 19 Simplified geological map of the Cooley Peninsula.

The earliest rocks of the complex are the basalts that are exposed on the southern edge of the complex on the slopes of Slievenaglogh. These eruptions were followed by intrusion of gabbro, which is now best exposed on Slieve Foye where four recognisable layers of gabbro form an intrusion over 365m thick. Gabbro magmatism was followed by at least two phases of granite magmatism – an early phase involving explosive activity now represented by vent agglomerates, and a later phase of granite emplacement forming a ring-dyke with a laccolithic top. This later phase of granite emplacement now forms the centre of the complex. The closing phases of magmatic activity in the Carlingford Complex saw the intrusion of cone-sheets as pressure from below uplifted the complex.

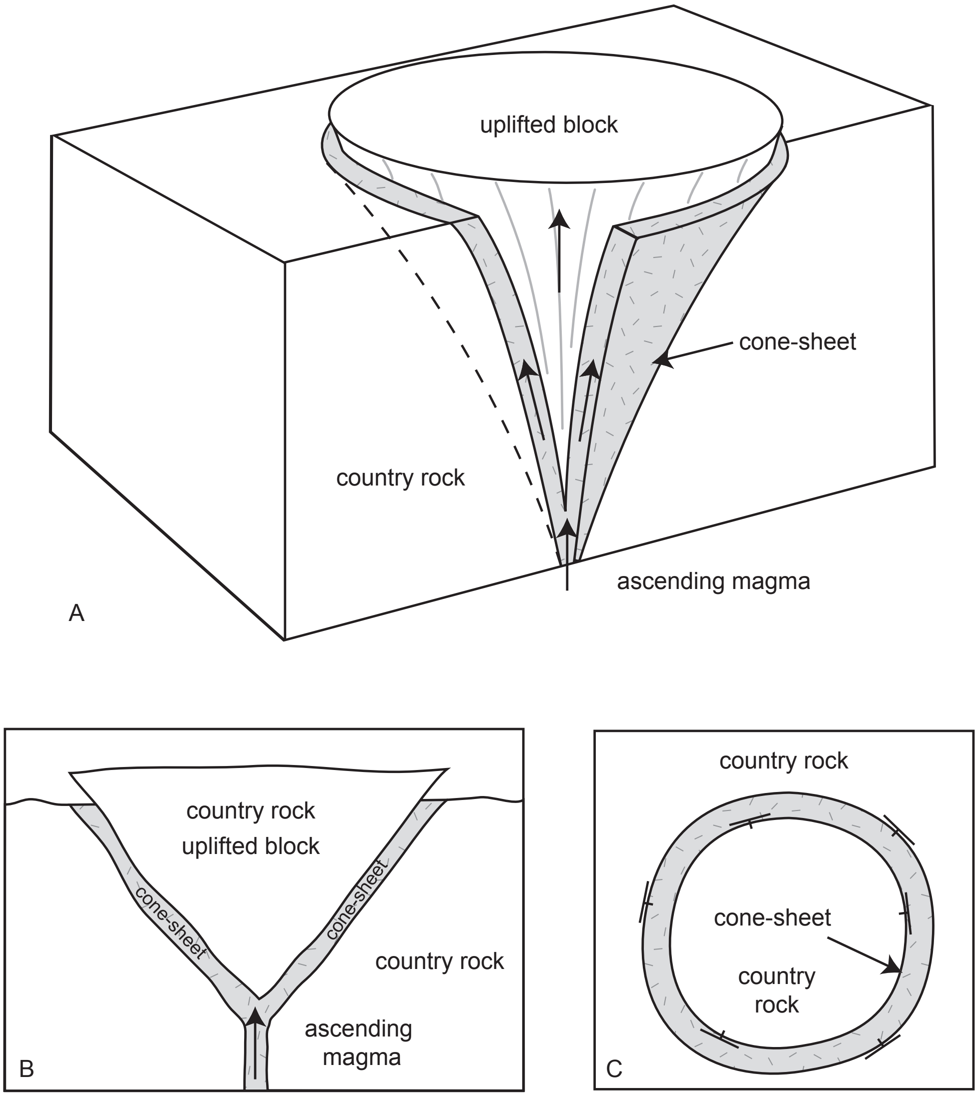

Figure 20 Schematic cross-section through upper crust illustrating cone-sheet intrusion. (A) 3D visualisation of cone-sheet intrusion; (B) cross-section of cone-sheet and uplifted block; (C) map of the intrusion showing the inward-dipping contacts of the ring-shaped intrusion. (Drawing by Brian O'Donnell).

Of particular interest in the Carlingford Complex is the way in which the intrusion has updomed and metamorphosed the Carboniferous limestone at its margins.

1 Carlingford

What can be seen	Metasediments; folding; sole marks; porphyry dykes; building stones
Grid reference of starting point	J 188 121
Distance/time (one way)	<200m/<10min
Terrain	Roadside, shore, some steps
Exercises that can be done	Measurement of bedding, examination of building stones, phenocryst population analysis
Other notes	Shore line section is only suitable at low tide and is likely to be slippery

Parking is readily available at the picnic area on the sea-side of the R173 to the north of Carlingford.

The outcrop at the southern-most picnic table is composed predominantly of steeply dipping Silurian metasedimentary rocks. These have an orientation of 050° 80°N, which is typical of the entire area, and, in the 'big picture' reflects the strike of the colliding margins of Iapetus when the rocks were deformed. Close examination of the outcrop will reveal small folds in the rock, showing that some of the beds have been tightly folded to be almost parallel to themselves (Figure 21). It might be useful to imagine folding a sheet of paper in a series of concertina folds – pushing the sides of the paper together will result in the limbs of the folds being parallel, or isoclinal, pulling the paper apart will make the folds more open.

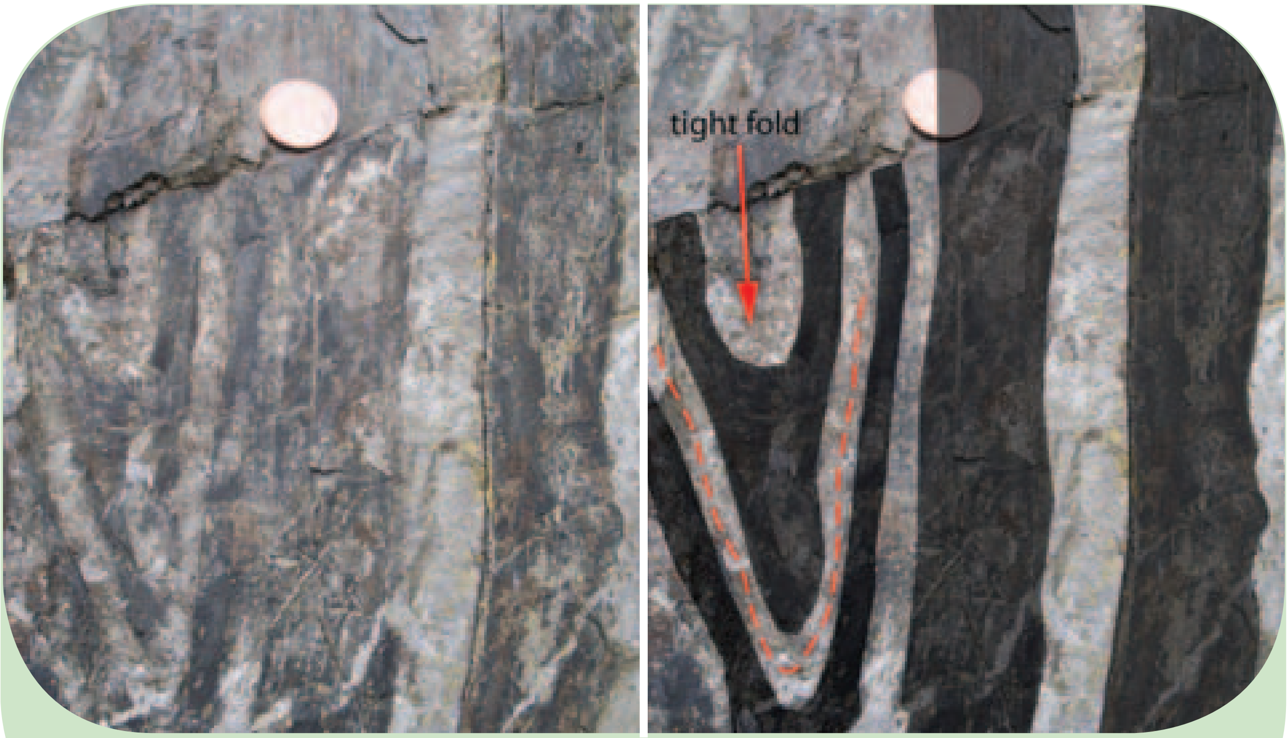

Figure 21 Tightly folded beds in metasediments, Carlingford. (1c coin, Ø=16mm)

[3] Note, however, that although the rocks here have been folded quite dramatically, the fold that is photographed is a sedimentary structure, formed when a soft sediment layer slumped and folded prior to lithification. It is, however, still an isoclinal fold.

Note also at this locality the occurrence of bioerosion – the roots of plants growing on the rock are breaking it apart. Seaweed on the shore will also be slowly eroding the rock. There are good examples of bioerosion caused by animals at Localities 8 (Templetown Beach) and 16 (Nicholsons Road).

Cutting across the metasediments is a porphyritic cone-sheet that is oriented at 160° 30°W – therefore striking almost parallel to the contact between the gabbro and the metasediments, and dipping towards the mountain (Figure 22). This is one of a series of cone-sheets intruded during the latter stages of intrusion of the Carlingford Intrusive Complex. The large white crystals in the cone-sheet are plagioclase feldspars.

Figure 22 Outcrop of metasedimentary rocks and cone-sheet at picnic area, north of Carlingford. Cone-sheet is under notebook, bedding in metasediments can be seen to be almost vertical. (Notebook is 21cm long)

Another cone-sheet can be seen down on the beach. A short series of steps to the north of the road-side outcrop leads down to the shore – turn right at the bottom of the steps and walk about 60m along the shore to a prominent 'jutting-out' exposure. The feldspar phenocrysts in this sheet can be seen to be crowded into the centre, leaving the margins devoid of larger crystals. This is an example of flow-sorting, where faster flow in the centre of the sheet has caused the concentration of crystals there. In the metasediments, the differing compositions of the beds is highlighted in this exposure by the degree to which a cleavage is developed – the finer-grained beds have a better developed cleavage than the coarser-grained ones (Figure 23).

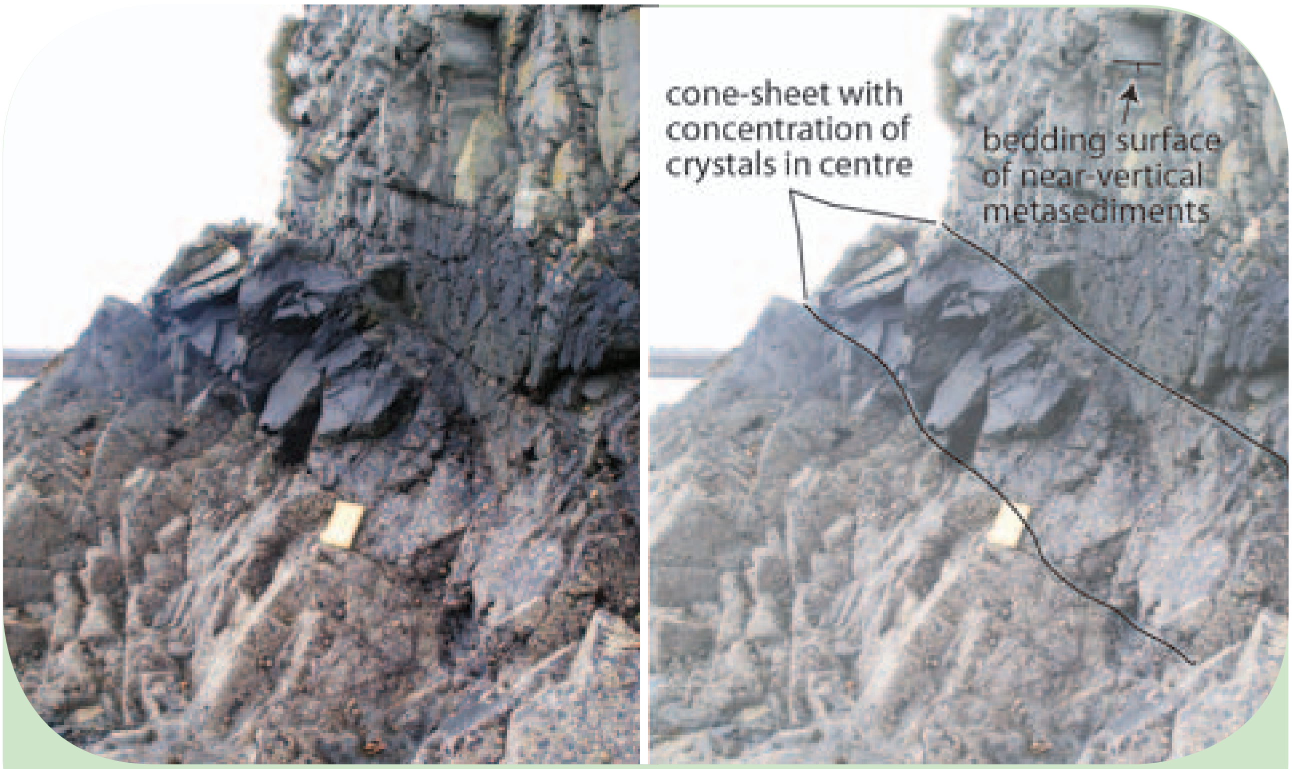

Figure 23 Cone-sheet with flow-graded phenocryst concentration in centre, intruding metasediments which show different degrees of cleavage development (dependent on grain size). Shoreline below picnic area, Carlingford. (Notebook is 21cm long)

If wished, some other features can be examined in the area by walking a few minutes towards the town and up to King John's Castle. At the top of the steps, at the base of the castle walls, an outcrop of the Silurian metasediments (with an orientation of 040° 80°W) is cut by a basaltic cone-sheet (005° 50°W). Examination of the surface of the metasediments shows that it has a slightly bumpy or ridged appearance. These bumps are "sole marks" – moulds of indentations that formed on the top surface of a layer of sediment due to the movement of pebbles or cobbles over it (Figure 24). These tell us that the surface that we are looking at is the base of the over-lying bed (they are the moulds, not the indentations), and therefore that the sediments in this outcrop are upside down, or overturned. We thus know that the beds in this outcrop get younger downwards.

Figure 24 Sole marks on bedding plane of metasediments, King John's Castle, Carlingford. These tell us that the beds in this outcrop are overturned. (1c coin, Ø=16mm)

The walls of the castle are also worth examining, as they display a wide range of rock types from the area (Figure 25). These include granite, dolerite, gabbro, metasediments, and limestone (including one that obviously came from the beach as it has been bored – see Locality 8, Templetown Beach).

Figure 25 Part of the wall of King John's Castle, showing the variety of rock types used in its construction.

2 Slieve Foye: Slate Rock

What can be seen	Metamorphosed limestone conglomerate; dolerite sheet; hornfels; gabbro
Grid reference of starting point	J 184 109
Distance/time (one way)	1.7km/20mins
Terrain	Hill walk, mostly on way-marked track, some off track
Exercises that can be done	Small mapping exercise; identification of different rock types
Other notes	The next site described, Barnavave, is a further 1.2km/25min walk from Slate Rock

Leaving Carlingford on the R173 going south towards Grange, follow the signs for the Táin Way (yellow 'walking man' sign). This turns right after the Church, and then right again a short distance later, up a narrow road that climbs the hill. This road is only suitable for smaller vehicles (not coaches). After almost 1km, at a left-hand corner, the Táin Way signs point up a track up the mountain. Parking is available in a small lay-by c.60m on from here at J 184 109.

Before going up to the outcrops on the mountain-side, it is worth spending a few minutes examining the rocks used in the dry stone wall in front of the house close to the parking space. The local lithologies are well represented in the wall, with some good examples of granite, dolerite (both porphyritic and equigranular), gabbro with net-veining, metasediments, and hornfels.

To get to Slate Rock, follow the Táin Way markers leading up the sides of Slieve Foye, passing through a gateway out onto the open mountain. After c.20mins walking (1.7km), the path turns left around a large outcrop with a south-westerly dipping planar surface. This is Slate Rock, and a number of features can be seen at this locality.

Figure 26 View looking to the north-west at Slieve Foye. The contact between the metasediments and the gabbro on the northern side of the mountain can be seen, as can a very clear fault. Slate Rock is labelled.

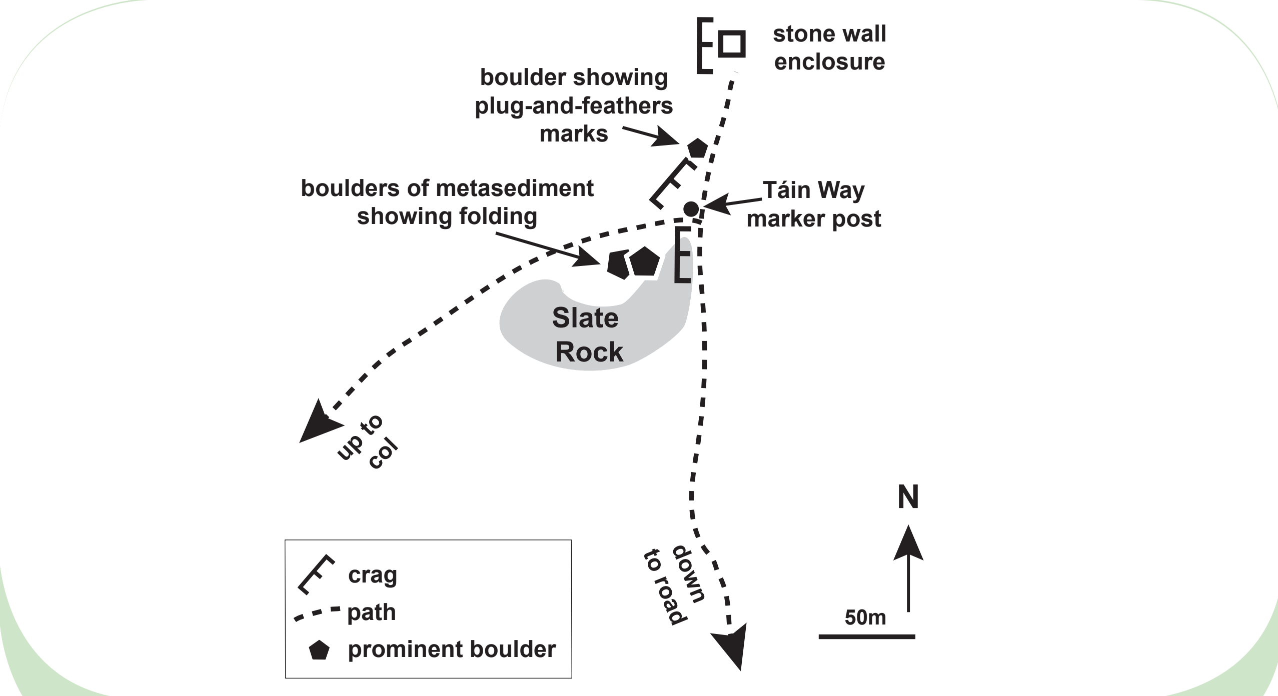

Figure 27 Sketch map of the area around Slate Rock.

Examination of Slate Rock shows that it is made up of clasts or fragments of other rocks in a finer-grained matrix or groundmass (Figure 28). Some of the clasts are up to 15cm in length. They vary in composition, with white quartz clasts probably the most readily identifiable. The original interpretation for this rock was that it was a volcanic agglomerate – the remains of an explosive eruption of a volcano which ripped up fragments of the older rocks through which the magma ascended (there is a good example of agglomerate at Locality 11, Glendesha Forest). However, a more recent study suggests that it is thermally metamorphosed conglomerate from the base of the Carboniferous limestone. The dipping surface of the outcrop is a bedding plane, and some internal structure, such as cross-bedding, can be seen in vertical faces through the beds. Away from the mountain, the Carboniferous limestone is almost horizontal – here, the beds are tilted due to updoming at the edge of the Palaeogene igneous intrusions that make up the mountains nearby. Other sites where the orientation of the Carboniferous limestone can be examined are at Grange Irish (Locality 4) and Carlingford Nursing Home (Locality 5).

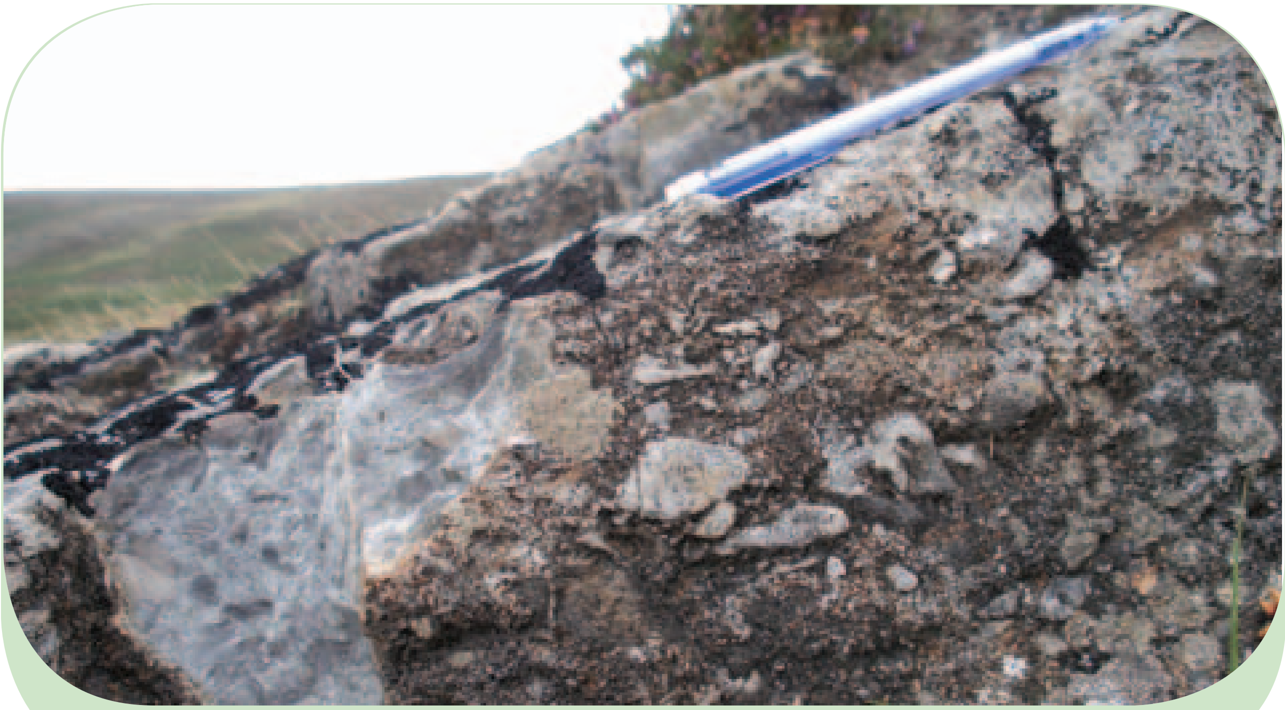

Figure 28 Fresh surface of conglomerate at Slate Rock. (Pencil is 15cm long)

At least one mafic dyke intrudes the conglomerate, trending NW-SE. Close examination of fresh surfaces of this intrusion shows that it is a fine-grained mafic rock, with some small (<2mm) plagioclase laths paralleling the margin of the dyke. This probably reflects the flow of the magma in the dyke as it was emplaced.
Two boulders at the top of the Slate Rock outcrop are examples of the metasedimentary rocks of the Longford - Down Inlier. The boulders show the intense deformation that the sedimentary rocks have undergone, both regionally during the Caledonian orogeny, and locally during the intrusion of the Palaeogene intrusive centre. They are useful to study because the folds can be examined in 3D – a situation not always possible with outcrops. Careful examination of the boulders will reveal tight folds in the beds, some of them almost isoclinal, where the limbs are parallel to each other. It might be useful to use chalk to pick out the patterns of folds on the boulders. In addition, the rocks can be seen to break in a very brittle or splintery fashion, typical of a hornfels, or thermally metamorphosed sedimentary rock.

At the corner of the Táin Way, at J 179 115, a small path leads northwards, initially climbing but then levelling out. A small quarried area at the corner exhibits examples of a porphyritic dolerite, with numerous feldspar phenocrysts up to 10mm in size. Approximately 100m northwards up the path (at J 179 115), another quarried area has a small dry stone wall enclosure at its base. Abundant, relatively fresh, loose fragments of the feldspar porphyry are available here. Note that on weathered surfaces the porphyry appears pitted due to the weathering-out of the feldspars. The porphyry here is part of a cone-sheet, one of the minor intrusions of the area (see Locality 1, Carlingford). Cone-sheets are essentially dykes that dip inwards towards a common point, like an ice-cream cone.

As you return to the main path, note the boulder on the right hand (upper) side of the track, about 40m before the corner. This boulder has 'plug-and-feathers' marks along one of its top edges, showing that it was split by human effort rather than naturally (see description for Locality 22, Bloody Bridge River). It also shows a good contrast between the weathered and the fresh appearance of the feldspar porphyry, but note that the green colour on the underside is nothing geological – it is marker dye coming off sheep's wool as they rub against the rock!

Slate Rock is also a good vantage point from which to examine the landscape and scenery of Carlingford Lough. To the north-east can be seen the Mourne Mountains, with, to the east, the flat-lying Mourne Plain. The lighthouse at the entrance to the lough is off Cranfield Point, and at low tide the wide expanse of sandy beach there may be visible, as may some of the low-lying islands at the mouth of the Lough which are of Carboniferous limestone (Locality 15, Ameracam Lane, is close to Cranfield). The southern shore of the lough has a similar flat-lying area stretching from Carlingford towards Greenore, with its commercial docks, and round to the tip of the peninsula. This flat-lying area is also underlain by Carboniferous limestone, and the farmland is noticeably better here than on the slopes of the mountains. The flat-lying areas on both sides of the lough are edged by good examples of raised beaches, described in more detail at Localities 8 (Templetown Beach) and 16 (Nicholsons Road).

3 Barnavave

What can be seen	Granite, gabbro
Grid reference of starting point	J 184 109
Distance/time (one way)	1.7km/20mins to Slate Rock, further 1.2km/25mins to Barnavave
Terrain	Hill walk, mostly on way-marked track, some off track
Exercises that can be done	Small mapping exercise; identification of different rock types
Other notes	This site is a follow-on from Locality 2, Slieve Foye: Slate Rock

To get to Barnavave (Bearna Mhedhbh – Maeve's Gap), continue up the Táin Way – a walk of 20mins (1.2km) will bring you to the col between Barnavave and Slieve Foye, at a height of 300m above sea level. On reaching the col, turn off the main track and make your way towards the south-east (left) along a small path which is upslope and parallel to a wire fence. A walk of c.500m will bring you into between the crags of Maeve's Gap. In legend this is where Queen Maeve of Connacht and her army camped while searching for the Brown Bull of Cooley, the tale recounted in the epic 'Táin Bó Cuailgne'.

On the way up to Barnavave, note the profile of Slieve Foye on the right – the gullies in the mountain mark the locations of faults within the gabbro. Faulted rocks tend to be more susceptible to weathering and erosion, and faults can often be identified in the landscape as linear features that are topographically lower than the surrounding land. Maeve's Gap at the summit of Barnavave is one such feature.

Figure 29 The view from Maeve's Gap looking south-south-west – crags on either side are of gabbro. In the background is the coastal plain underlain by Carboniferous limestone.

The rocks at Maeve's Gap are of dark, coarse-grained gabbro, but examination of the crags and the loose boulders at their base (e.g. at J 178 101) will reveal numerous veins of lighter coloured rock. This light-coloured rock is granite magma that was injected into the gabbro before it had crystallised completely. We can tell this because, in places, the veins have lobate (curved) contacts with the gabbro, indicating contact between two liquids. The veins are offshoots from the main intrusion of granite that underlies the lower ground to the south-west. There is a noticeable change in both the slope of the hillside and the scenery at the geological boundary, with the gabbro generally forming a much more rugged landscape than the granite.

Figure 30 Net-veins of granite in gabbro at the summit of Barnavave (highlighted in right-hand photograph). Note the lobate (curved) contact between the two rock types indicating that both were at least partially molten at the time of intrusion of the granitic magma.

Access to the top of the eastern hill J 178 102 (where there is a triangulation point) is easiest if you go back towards Slieve Foye. From the top, the north-north-east trending fault that runs through Maeve's Gap can be traced across the col and into the gabbro of Slieve Foye. The offset on the fault can be gauged by the contrast in geology across it at the northern end of the ridge.

NB: To return to the parking place, use the Táin Way again, as the 'direct' descent eastwards off Barnavave is a steep, hazardous one.

4 Grange Irish

What can be seen	Updomed limestone skarn; sill and dyke intrusion; view of Maeve's Gap (Barnavave – *Bearna Mhedhbh*)
Grid reference of starting point	J 188 095
Distance/time (one way)	<500m/<10mins
Terrain	Track & hillside
Exercises that can be done	Bedding measurements, acid test, identification of sill & dyke
Other notes	Caution must be exercised if tree-felling is taking place in the forest.

Access to this site is via a narrow, unmetalled track approximately 700m long that has a junction with the 'high road' between Carlingford and Grange at J 188 095. At the end of this track (J 184 092) is the entrance to Grange Irish Coillte forest. There is a limited amount of parking available here. A grassy lane (with a gate at the bottom) leads up the southern (left-hand) side of the forest – follow this for approximately 250m uphill, until you cross a gate onto the open mountainside. On reaching the open mountainside, turn right (west) – some small crags are less than 100m away (J 183 091).

Examination of the crags will show that they are of a grey-white rock with a sugary appearance that reacts with dilute hydrochloric acid. The rock is bedded, and the beds dip steeply to the east (it might be worth recording the orientation of these beds, as the dip of the limestone beds in the vicinity of the central intrusion varies). This rock is thermally metamorphosed limestone, or skarn, which has been tilted, deformed, and heated by the intrusion of the igneous rocks which make up the mountain. The reaction of the rocks with acid shows that the mineral calcite is present, but other, sometimes rare, minerals can also be found in skarn. These can include gemstones such as rubies and sapphires, but unfortunately none of these have been found in the skarn of Cooley!

Another feature to note in the area is in the field to the south-east, which can be examined across the boundary wall and fence (it is not advisable to try to cross these). Here, there is a very obvious overhanging ledge over a hollow. The ledge is a dolerite sill, intruded along the bedding planes of the limestone, while to the left (north) is a vertical dyke that strikes approximately NW-SE (Figure 31). This is an old quarry, probably worked to provide limestone for making lime fertiliser, with the useless (for this purpose) dolerite left behind. Looking north from near the wall, Maeve's Gap can be seen through the tree tops.

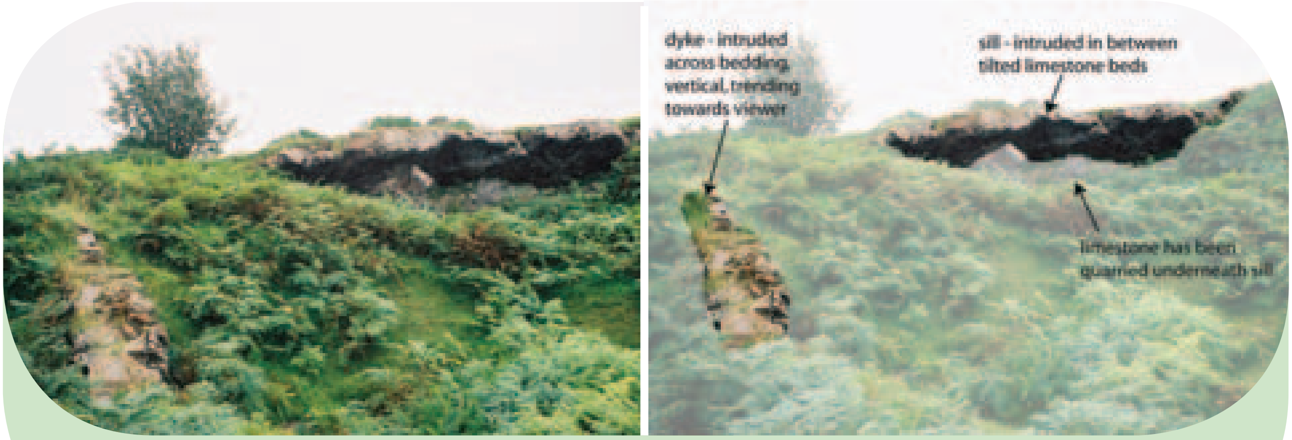

Figure 31 Sill (overhanging ledge at back) and dyke (left) exposed in old limestone quarry, south-east of skarn exposure at Grange Irish.

About 100m to the north of the junction of the track with the metalled road at J 188 095, there is a wide lay-by on the western side of the road. Less than 50m in from the road to the west is another small outcrop of dipping limestone beds, but these are less steeply dipping (170° 30°E) than the previous example, being further away from the intrusion and its updoming effect.

5 Carlingford Nursing Home

What can be seen	Horizontal beds of limestone
Grid reference of starting point	J 192 108
Distance/time (one way)	<100m/<10min
Terrain	Easy

Away from the intrusive complex, the Carboniferous limestone beds are essentially horizontal, but there are not many localities in the area where they can be examined. Often, old quarries have now been built in, and one such example is at the Carlingford Nursing Home, just south of the town on the R173.

Access through the nursing home to the limestone beds at the back can be arranged by calling the manager at 042-9383993, the only proviso being that the visiting group is able to show that it is covered by its own insurance.

The cliff at the back of the garden is of horizontally bedded limestone. The main purpose of stopping at this locality is to compare it to the dipping beds of limestone and skarn at Grange Irish, which have been updomed by the intrusion of the igneous rocks.

6 Windy Gap (Long Woman's Grave)

What can be seen	Granite; mafic dykes; gabbro; faulting; glacial moraines; U-shaped valley.
Grid reference of starting point	J 130 138
Distance/time (one way)	<200m/<10mins
Terrain	Roadside (for granite); hillside track (for gabbro)

Parking is available at the Long Woman's Grave court cairn (J 130 138). Legend has it that the site marks the grave of a Spanish noblewoman who dropped dead with shock when she was brought here to view the large estate of her new husband – she hadn't imagined that it would be mountain and bog. The site is also associated with the 'Táin Bó Cuailgne', which tells us that Maeve's army crossed the mountains here, tearing up the ground to insult the Ulster army.

This legendary explanation is not so far from the geological truth: the 'gap' at Windy Gap is due to a fault zone running approximately NW-SE (i.e. along the line of the road) through the intrusive complex here (Figure 32). As a result of faulting, the rocks are broken up and more susceptible to the processes of weathering and erosion. The fractured nature of the rock can be seen clearly on some of the outcrops, and there is extensive 'rusty' staining of the joint surfaces (Figure 33). The relative weakness of the rock has been exploited in particular by ice which moved across the area during the most recent glaciations, carving out the U-shaped valleys and leaving deposits of glacial diamict behind. Movement along the fault has juxtaposed different rock types against one another: to the west is granite, and to the east, gabbro. Further north along the road, the contact between the igneous rocks of the intrusive complex and the Silurian metasedimentary rocks is offset by almost 1km in a dextral, or right-handed, manner.

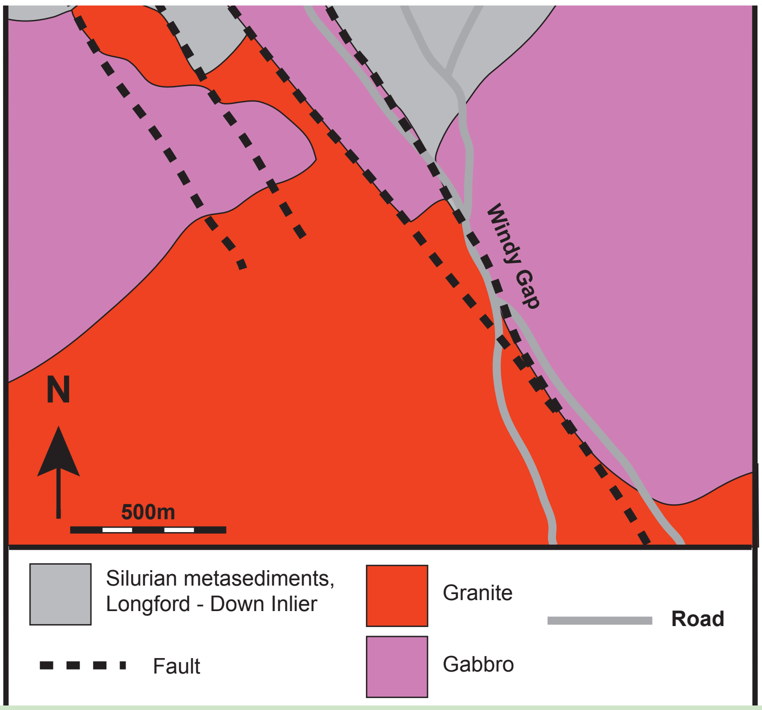

Figure 32 Geological sketch map of the Windy Gap area.

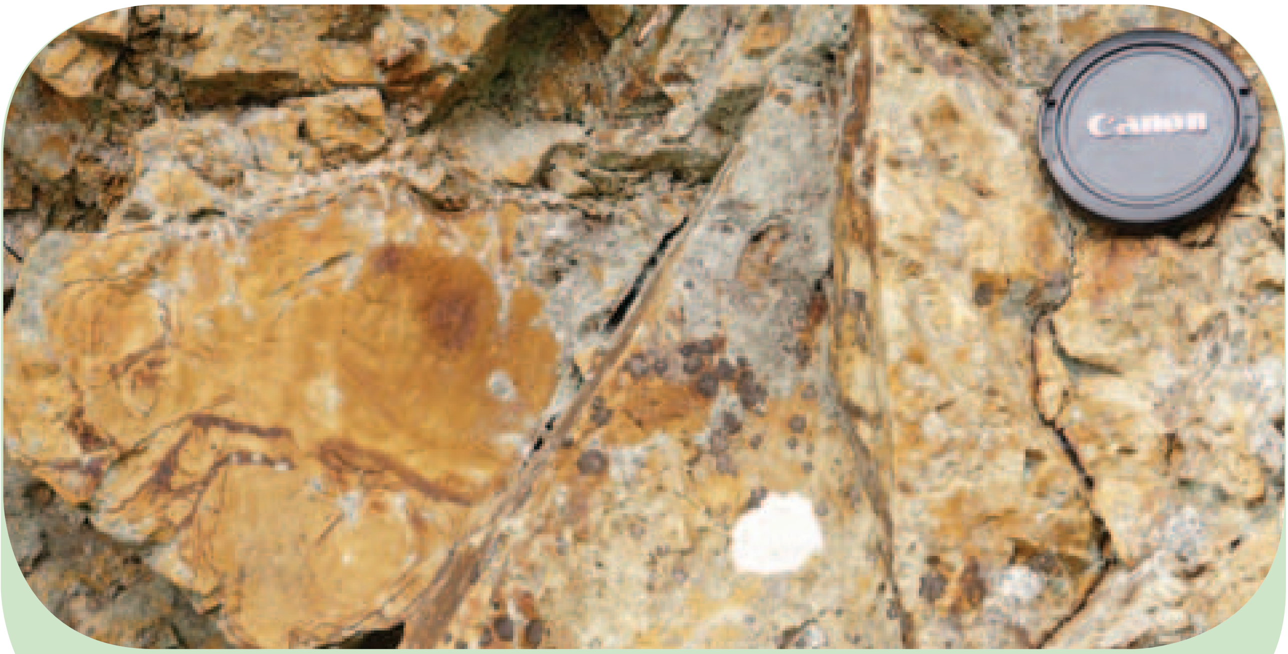

Figure 33 Faulted and altered granite, Windy Gap. (Lens cap Ø=6cm)

On the western side of the road, extending south for c.100m from the Long Woman's Grave, are good exposures (in road-side cuttings) of the granite that forms the central part of the Carlingford intrusive complex. Examination of the outcrops will also reveal that the granite is intruded by a number of dark, fine-grained sheets of basalt (Figure 34). These are cone-sheets, and dip in towards the centre of the intrusive complex, towards the south-west. The sheets are variable in width, and often show some offset due to faulting. Darker margins on some of the sheets indicate a finer grain size here than in the interior of the sheet, a consequence of chilling of the basaltic magma as it intruded the granite.

However, curvilinear contacts between the granite and basalt are a sign that the granite was not completely solid at the time of intrusion, even though the intrusion of the sheets requires that the granite was brittle enough to fracture. This tells us that magma (molten or partially molten rock) can behave in both a ductile and a brittle fashion. A useful analogy might be to compare how toffee deforms – deform it slowly and it will bend, or flow; deform it rapidly (e.g. hit against a hard surface) and it will fracture, or behave in a brittle manner.

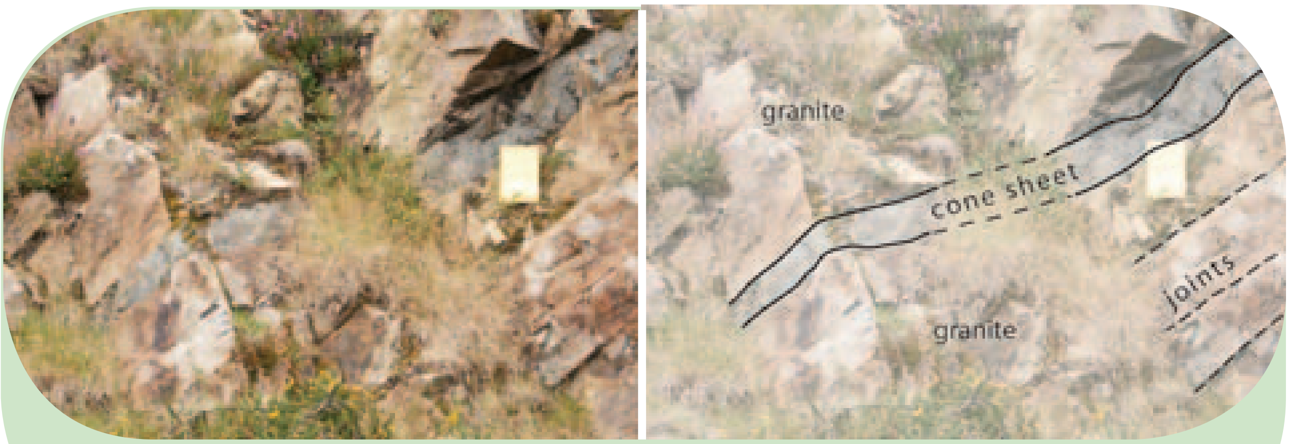

Figure 34 Granite at Windy Gap, notebook (21cm long) is at cone-sheet intrusion.

The scenery to the east of the road is dominated by the dark gabbro crags of Slieve Foye. A walk of less than 10mins ENE along the small path away from the parking area will get you to the base of the crags, but the gabbro can be examined in many of the boulders that have come off the mountainside. Note the large dark rectangular crystals of pyroxene, and the slightly rusty coloured spots that indicate weathered olivine. The contrast in colour between the granite and the gabbro reflects their different mineralogy, and therefore the chemistry of the magmas that crystallised to form them.

From the base of the crags, there is a good view of the contrasting landscape either side of the fault that runs through the Windy Gap. The western side of the valley is composed primarily of granite covered by glacial diamict – the terraces on the side of the mountain are glacial moraines that mark the edge of an ice sheet. To the north-west, some small crags mark the location of a small outcrop of gabbro. Down the valley to the NNW, the bedrock is of the country rock – the Silurian metasediments. These are best examined on the other side of the mountain at Locality 1, Carlingford .

7 Ballaverty – Bush Quarry

What can be seen	Economic geology - sand & gravel extraction
Grid reference of starting point	J 184 070
Distance/time (one way)	n/a
Terrain	n/a

Access to this site is not possible, but there are places to stop safely along the perimeter fencing to see the scale of extraction of sand and gravel from this quarry (Figure 35). The sand and gravel at this site were deposited by melt water from a glacier. Sand and gravel have importance as aggregate for building materials, and are used, for example, in the manufacture of cement and concrete.

Figure 35 Bush Quarry sand and gravel pit.

8 Templetown Beach

What can be seen	Raised beach, boulder pavement (Quaternary)
Grid reference of starting point	J 215 052
Distance/time (one way)	400m/<10min
Terrain	Beach
Exercises that can be done	Sedimentary logging; rock & sediment identification; coastal processes;

Park in the car park at Templetown Beach (J 215 052) – toilet facilities are available here.

A walk of c.400m eastwards along the beach is along the base of a 6m high cliff (J 219 052). The cliff is composed of a number of distinct layers. At the base is a massive (i.e. it has no major internal structures) mud that is about 1.5m thick. This mud contains the remains of small sea creatures, indicating that it was deposited in a marine environment. It has been dated (using 14C) to c.15,000 yrs ago, showing that at that time the area was deglaciated. The absence of large clasts in the mud also tells us that there were few ice rafts transporting material out into the bay; the mud was suspended in the water before being deposited.

Above the mud layer is a boulder pavement (Figure 36). This comprises a (generally) single layer of boulders, which are packed together tightly in places. The top of the boulder layer is almost level, and many of the boulders show a bevelled or polished surface. Striations can also be seen both on the top and bottom surfaces of the boulders, most of which are locally derived Carboniferous limestone. The gaps between the boulders are filled with the underlying mud, indicating that the boulders have been pushed down into the mud. Some of the mud 'pillars' preserve evidence of the deformation the mud underwent as it was squeezed upwards.

Figure 36 Section through cliff at Templetown Beach / Cooley Point. (Notebook is 21cm long)

The boulder pavement is interpreted as representing an intertidal area during a period of ice re-advance. Ice floes floating across the mud flats would have been able to transport boulders out over the mud, and drop them as the ice melted. The floes would also have exerted downward pressure on the deposited boulders, pressing them into the mud, abraded their top surfaces, and organised them into a pavement. Similar processes can be observed today in sub-polar regions.

Overlying the boulder pavement is a thin layer of finely laminated silty clay which passes upwards into sand and gravel beds, with a general coarsening upwards. These beds show structures such as cross-bedding, channels, and laminations. They are interpreted as subaqueous outwash deposits, the sediments derived from an ice sheet to the south in Dundalk Bay (the presence of Silurian sedimentary rocks rather than Carboniferous limestone suggests this). The subaqueous setting indicates that sea level had risen again at the time of deposition.

The section is exposed today because of isostatic rebound, the process by which the land has risen with respect to the sea. This occurred as the ice sheets melted at the end of glaciation, and the huge weight of ice that was pressing the crust down into the mantle was removed (much as a block of wood floating on water will pop back up if you press down on it and then remove your hand). In many places along the north-east coast of Ireland we see the evidence for isostatic uplift in the form of raised beaches, such as we can see here at Templetown. Note that the top of the cliff forms a horizontal line along this part of the coast, with the level land also extending inland for some distance. This flat area represents an ancient beach, now raised some 10m above the current sea level.

On returning towards the car park, it is worth examining the boulders that have been used as a coastal defence at the base of the small caravan park. The boulders are derived locally, and show the range of local rock types. The clean surfaces allow easy examination of the minerals and textures of the rocks.

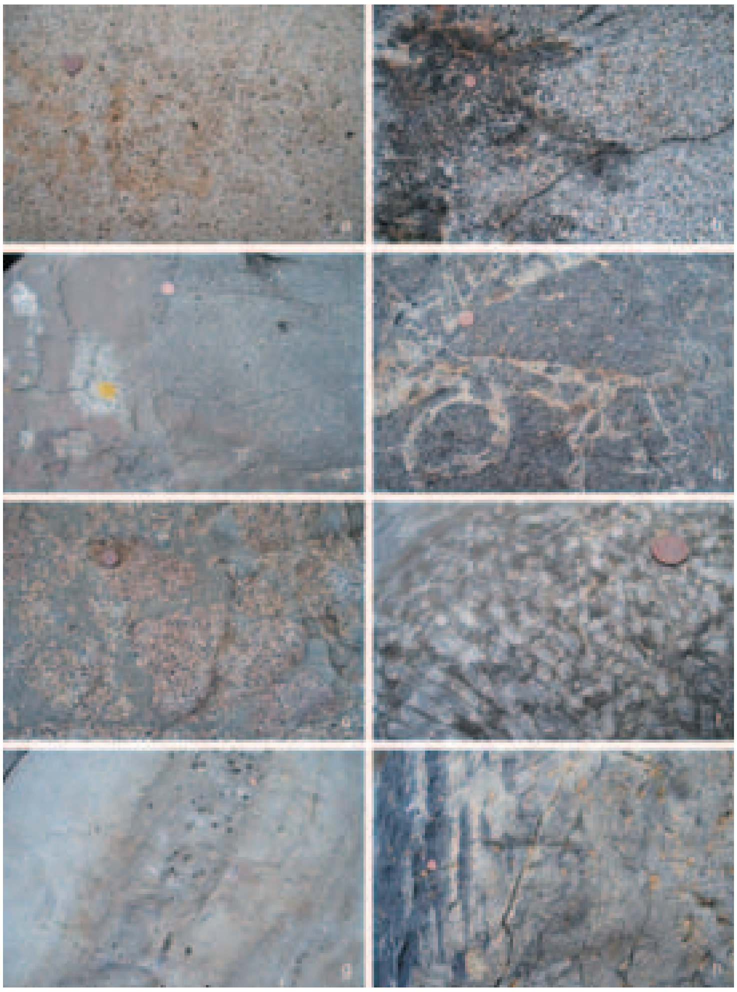

Figure 37 Photographs of the various local lithologies in the coastal defence boulders at Templetown Beach: (a) granite; (b) gabbro (with coarse gabbro pegmatite); (c) gabbro intruded by dolerite; (d) gabbro net-veined by granite; (e) mingled rock – granite enclaves in hybridised rock; (f) coral in limestone; (g) sandstone; (h) metasediments. (1c coin, Ø=16mm)

Two other interesting features of the area are:

1. Two good examples of bioerosion (erosion of rock by living organisms) can also be examined. In the cliff, material has been removed by sand martins excavating their nests – the holes in the sandy horizons in the cliff face. On the beach, many of the limestone boulders and cobbles have a honey-combed or spongy appearance (see Figure 38). These holes are bored by a bivalve – *Hiatella arctica* (its common name being 'piddock' or 'angel wings') – that also secretes acid which dissolves the limestone. The animal lives inside the safety of the hole for life, as it gets too big to get back out of the entrance. After the animal dies the shells sometimes remain inside the hole – shake the rock and a rattling sound might be heard.
2. The beach to the west of the car park may be suitable for a beach study – there is a notable difference in the gradient of the beach where it changes from sandy to gravel at the top of the beach.

Figure 38 Holes bored in limestone by bivalve *Hiatella arctica*. Remains of shell can be seen in the hole left of centre. (1c coin, Ø=16mm)

On the way back to the R175, there are good views of Maeve's Gap and Slieve Foye, with the line of sight almost directly along the fault zone through Maeve's Gap.

The Slieve Gullion Complex

The Slieve Gullion Complex was intruded about 58-56Ma ago into Silurian metasediments and the granodiorite of the Newry Igneous Complex (Figure 39). Three distinct units make up the complex. The earliest unit forms an almost complete ring 11km in diameter. The ring comprises high level intrusive rocks including a porphyritic felsite and fine-grained granite, as well as rocks formed during explosive volcanic activity such as vent agglomerate: these rocks now form the distinctive Ring of Gullion. The second phase of activity is represented by the 573m high Slieve Gullion, in the centre of the Ring of Gullion, a sheeted complex consisting of interbedded mafic and felsic rocks. The final phase of activity led to the emplacement of the granites of the south-eastern part of the complex.

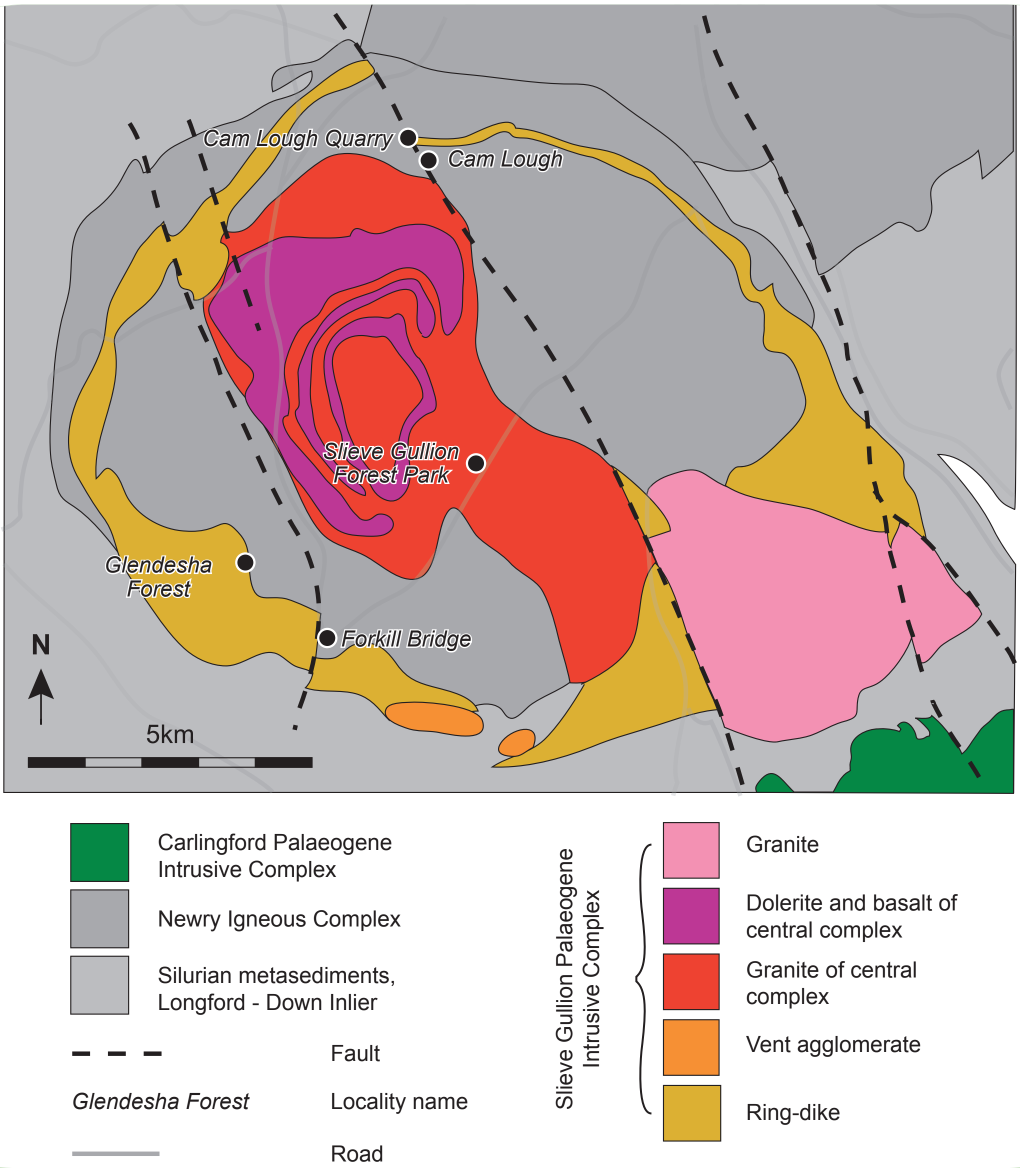

Figure 39 Geological map of the Slieve Gullion Complex.

The Slieve Gullion Complex has been the focus of geological research since the 1930s. It is a site where many new hypotheses were proposed to explain the rock relationships, hypotheses that went on to be applied worldwide.

However, good scientific research involves the proposal and testing of different ideas, and the complex has attracted its share of controversy and disagreement between geologists.

The structure of the ring-dyke was first mapped by Richey (1932), who applied the cauldron subsidence model first proposed by Clough *et al*. (1909) for intrusions around Glen Coe in Scotland. The model has been generally, but not universally, accepted since, both for the Ring of Gullion and for many intrusions in other parts of the world.

The first detailed map of the central complex was produced by Reynolds in the early 1950s. She considered the layered structure to represent interbedded volcanic rocks – rhyolites, lavas, tuffs, and agglomerates – that were 'transformed' into coarser-grained rocks through the action of hydrothermal fluids. 'Transformists' believed that granites were formed through the transformation of crustal rocks, in opposition to 'magmatists' who believed that granites resulted from the crystallisation of magma.

The Newry Igneous Complex was also believed by Reynolds to have formed through the alteration of the Silurian metasediments. Today, it is generally accepted that granites have a magmatic origin, but the subject did generate considerable debate.

In recent years the Slieve Gullion complex has attracted a new generation of researchers, and their ideas, based on analytical techniques that were not available to their predecessors, are challenging some of the long-held ideas about the formation of the ring-dyke.

However, despite these alternative ideas, the 'big picture' of the Slieve Gullion Complex being the remains of a large volcano still holds true. It is likely that periodic violent eruptions of ash led to pyroclastic flows, and that eruption and high level emplacement of magma (forming the centre of the complex) caused collapse and resurgence of a caldera whose margins are now preserved as the Ring of Gullion.

9 Cam Lough Quarry

What can be seen	Granite; metasediments; contact
Grid reference of starting point	J 037 246
Distance/time (one way)	<100m/5mins
Terrain	Flat
Exercises that can be done	Geological sketching; rock identification
Other notes	Stay away from quarry face, rocks may be unstable

Parking is available alongside the road at this now disused quarry near the base of Camlough Mountain. A clear contrast between dark grey rocks at the base and lighter coloured pinkish-brown rocks on top can be seen in the back wall of the quarry. The contact between the two rock types can be seen dipping away from the face northwards into the mountain (Figure 40). The paler rocks are part of the Slieve Gullion ring-dyke, intruded about 58Ma ago. The dark rock is a large xenolith (fragment, *lit*. 'foreign rock') of Silurian metasediments enclosed in granodiorite of the Newry Igneous Complex approximately 400Ma ago. This has hornfelsed or baked the metasediments, obscuring many of their original features. Those may be seen clearly elsewhere, such as in Carlingford (Locality 1). Close examination of the hornfels in the south-west corner of the quarry will show a strongly developed vertical foliation trending in an ENE direction. Also visible, with careful examination, are thin granitic bands: intrusions of the Newry Granodiorite (Figure 41).

Figure 40 Cam Lough Quarry: Contact between granite of the ring-dyke and hornfelsed Silurian metasediments of the Longford-Down Inlier.

Figure 41 Cam Lough Quarry: foliated Silurian metasediments of the Longford - Down Inlier intruded by small veins of Newry Granodiorite. Intrusion of the Newry Igneous Complex baked the deformed metasediments. (Pencil width =8mm)

Cam Lough

What can be seen	Glacial ribbon lake; ring-dyke; landscape; effect of geological faulting on landscape
Grid reference of starting point	J 037 241
Distance/time (one way)	<100m/5mins
Terrain	Flat
Exercises that can be done	Sketching; map interpretation

From this car park there are good views of Cam Lough itself – a narrow ribbon lake, occupying a valley carved out by ice moving southwards to Dundalk Bay. The gouging out of this valley was facilitated by the fact that a major fault zone cuts the rocks along this line, making them weaker and more susceptible to erosion. The effect of movement on this fault – of the order of 2km horizontally – on the landscape is clear from this view. To the east, at the quarry, the ring-dyke makes up the high ground (Camlough Mountain). On the far side of the lake, the ring-dyke makes up the small hills to the north-west (Sturgan Mountain) (Figure 42).

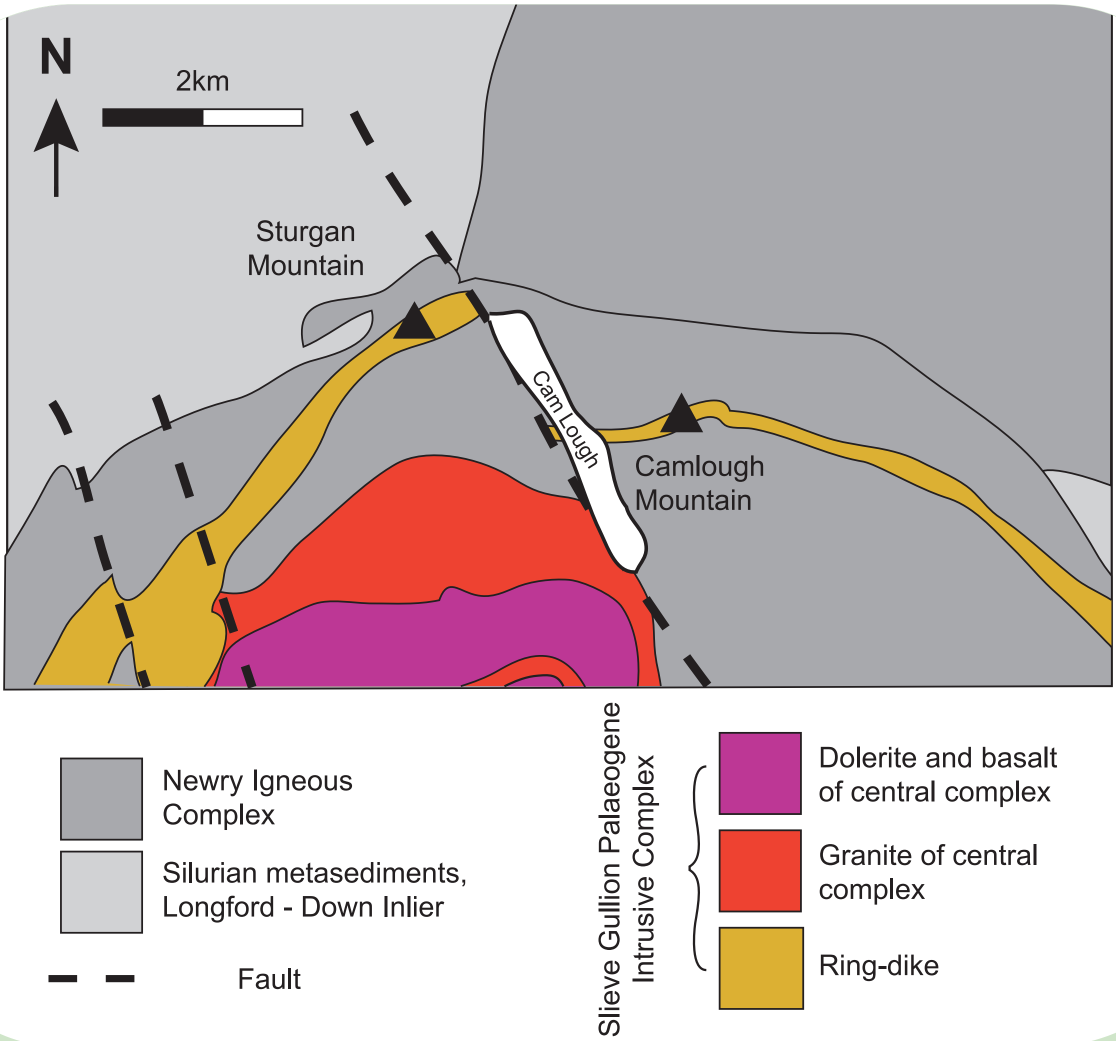

Figure 42 Geological sketch map of the area around Cam Lough, showing the offset of the ring-dyke along the Cam Lough Fault, the fault zone now occupied by a glacial ribbon lake.

A more elevated view of the area can be had from the Ballintemple Wood view point at J 032 232 (Figure 43). The road to this point is, however, twisty and narrow and is unsuitable for vehicles larger than a minibus.

Figure 43 View northwards of Cam Lough and the Ring of Gullion northwards from Ballintemple Wood. The dextral offset of the ring-dyke along the Cam Lough Fault is clear. Slieve Gullion itself is to the south.

11 Glendesha Forest

What can be seen	Vent agglomerate; porphyritic rhyolite
Grid reference of starting point	H 994 171
Distance/time (one way)	400m/10mins
Terrain	Forest track
Exercises that can be done	Identification and measurement of fragments

Take the track eastwards into the forest, following it round to the right (south-eastwards) after about 100m. Approximately 300m from the road (at H 996 169) along the forest track, there are some good exposures of volcanic agglomerate – rounded fragments of older rock types that have been caught up in a violent volcanic eruption. Here the fragments are mostly of Newry Granodiorite, some of them appearing quite red in colour due to alteration, but there are also fragments of fine-grained volcanic rock, and metasediments. However, there are no fragments of porphyritic rhyolite which outcrops nearby, meaning that the agglomerate predates the rhyolite.

Figure 44 Outcrop of the Forkill Breccias – thought to be a vent agglomerate – alongside the forest track in Glendesha. The rounded fragments are mostly altered pieces of Newry Granodiorite caught up in a volcanic eruption, but there are also fragments of Silurian metasediments and Palaeogene basalts, but none of the porphyritic rhyolite which outcrops nearby.

Another 100m along the track is Carrive Mass Rock, the site of Catholic worship during Penal times. The rock here is obviously different to the agglomerate – it is finer-grained, quite pale, and has a marked foliation or fabric to it (i.e. it appears lined or sheeted). This is part of the porphyritic rhyolite of the ring-dyke, and at this site, it has a strong sub-vertical fabric which strikes north-east. Across from the Mass rock, this rock continues as a small scarp up the hill.

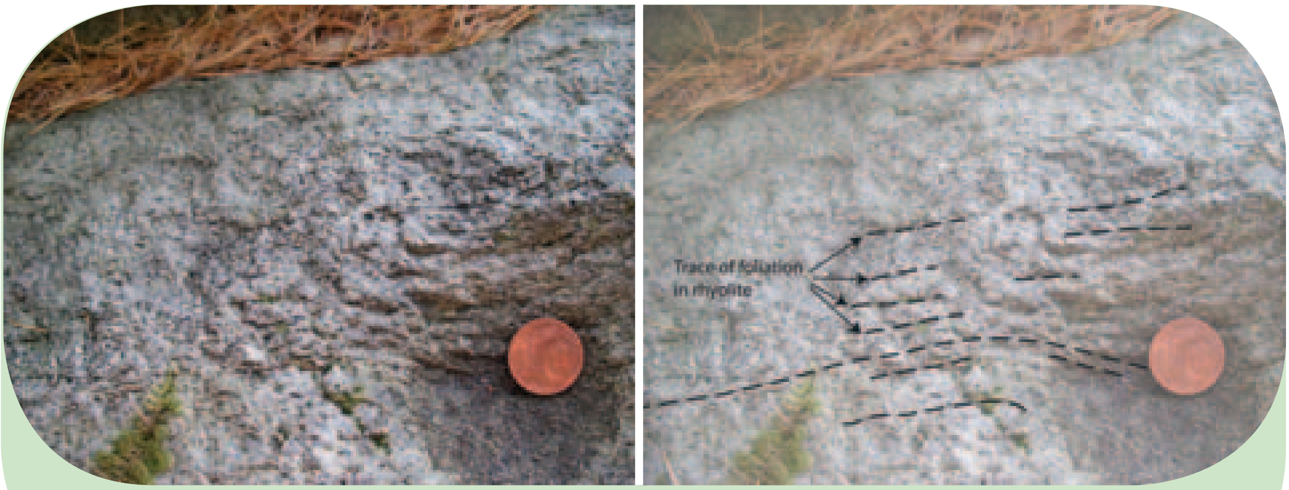

Figure 45 Porphyritic rhyolite exhibiting a strong foliation, Mass rock, Glendesha Forest. (1c coin, Ø=16mm)

12 Slieve Gullion Forest Park

What can be seen	Landscape views; interaction of basaltic and granitic magma; heath vegetation
Grid reference of starting point	J 043 191, signposted Slieve Gullion Courtyard
Distance/time (one way)	10km drive
Terrain	Forest drive
Exercises that can be done	Landscape study; study of magma interaction
Other notes	A one-way system operates in the Forest Park.

The Forest Drive on Slieve Gullion stays on the south western flanks of the mountain, and allows fine views from the Central Complex over the western parts of the ring-dyke that makes up the famed Ring of Gullion. Views of the northern portion of the ring-dyke are best from sites described under Locality 10, Cam Lough.

On the way along the Forest Drive, a number of stops may be made to view the surrounding landscape. (Good viewing points are at J 027 189 and J 018 205.) Slieve Gullion itself is part of the Central Complex, the interior of an extinct volcano, which is made up of layers of granite and basalt. The low land surrounding the mountain is underlain by much older Newry Granodiorite. Further off, the heather clad hills of the Ring of Gullion are made of rocks related to the volcano. To the south, the village of Forkill nestles between the hills of Carrickastickan and Croslieve. Looking further right, you can see the hills of Slievebrack, Mullaghbane Mountain, Cashel, and, to the north-west, Slievenacappel.

Figure 46 Oblique aerial view looking south-southwest from close to Sturgan Mountain (centre foreground) and Cam Lough (left foreground) to Slieve Gullion (left middle distance) and the hills making up the western part of the Ring of Gullion. (Photo: Mike Hartwell)

At J 033 191, the view includes not only a number of the hills of the Ring of Gullion, but also a view down the 'tail' of a glacial 'crag and tail' structure. Here the 'tail' has been forested – the 'v' of the forestry south from Slieve Gullion. The 'crag and tail' can best be viewed from a location such as Forkill Bridge (Locality 13).
At the top car park of the Forest Drive (J 019 198), crags to the east exhibit some mingling of granite and basalt. A boulder placed at the roadside here shows this interaction particularly well, as the two rock types have weathered quite differently. Note here also the scree developed on the mountainside, and example of the weathering power of ice even in Ireland's climate.

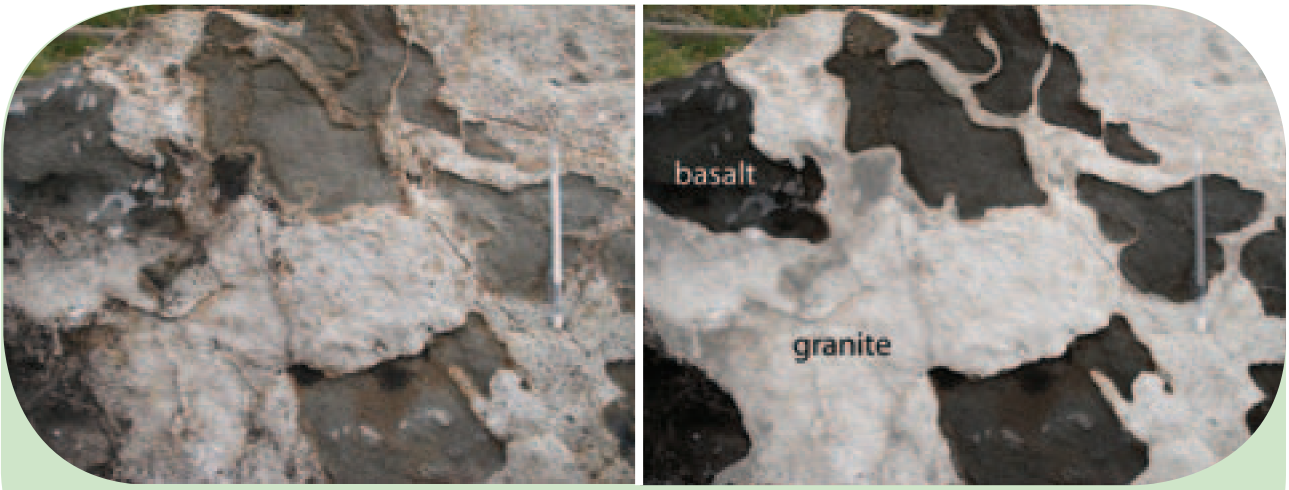

Figure 47 Boulder (locally derived), showing interaction between granite and basalt. Similar features (although not as clear) may be seen in the nearby crag to the east of the car park. (Pencil is 15cm long)

Slieve Gullion is also important for the vegetation that grows on its upper slopes, and as such is a Special Area of Conservation. The mountain preserves one of the most extensive areas of European Dry Heath in Ireland, characterised by ling heather, bell heather, dwarf gorse, and bilberry, with rarities such as cowberry.

13 Forkill Bridge

What can be seen	Landscape of Slieve Gullion, particularly 'crag and tail'
Grid reference of starting point	J 015 159
Distance/time (one way)	n/a
Terrain	n/a

From this point, which is sited at a low point on the Ring of Gullion, the view to the north-east is of Slieve Gullion. Of particular note is the 'crag and tail' structure – ice moving southwards across the high resistant rock of Slieve Gullion deposited material in the lee of the hill, resulting in a more gentle sloped tail on this side of the mountain. On Slieve Gullion, the tail has been forested. The 'bump' on the highest point of Slieve Gullion is the South Cairn, a large stone cairn, 30m in diameter and 4m high, which covers a Neolithic passage tomb that is similar in plan to Newgrange. Located at 573m, it is believed to be the highest surviving passage tomb in Ireland or Britain. This landscape was clearly significant to the earliest settlers in the area.

Forkill derives its name from *Foirceal*, meaning trough or hollow – the name refers to the glacial valley between the nearby hills of Carrickastickan ('pointed rock') and Tievecrom ('the sloping hillside').

Figure 48 View north-eastwards of Slieve Gullion from Forkill Bridge.

The Mourne Mountains Complex

The Mourne Mountains Complex consists of five principal intrusions that are divided into a Western and Eastern Centre, and minor dyke and cone-sheet intrusions. The divide between the two centres approximately follows the Kilkeel – Hilltown road. The granites were intruded into the Silurian Longford – Down Inlier about 56Ma, which have been altered to hornfels close to the complex. Although the granites intruded at a high level in the crust, there does not seem to have been any volcanic activity associated with the complex (unlike Carlingford and Slieve Gullion) (Figure 49).

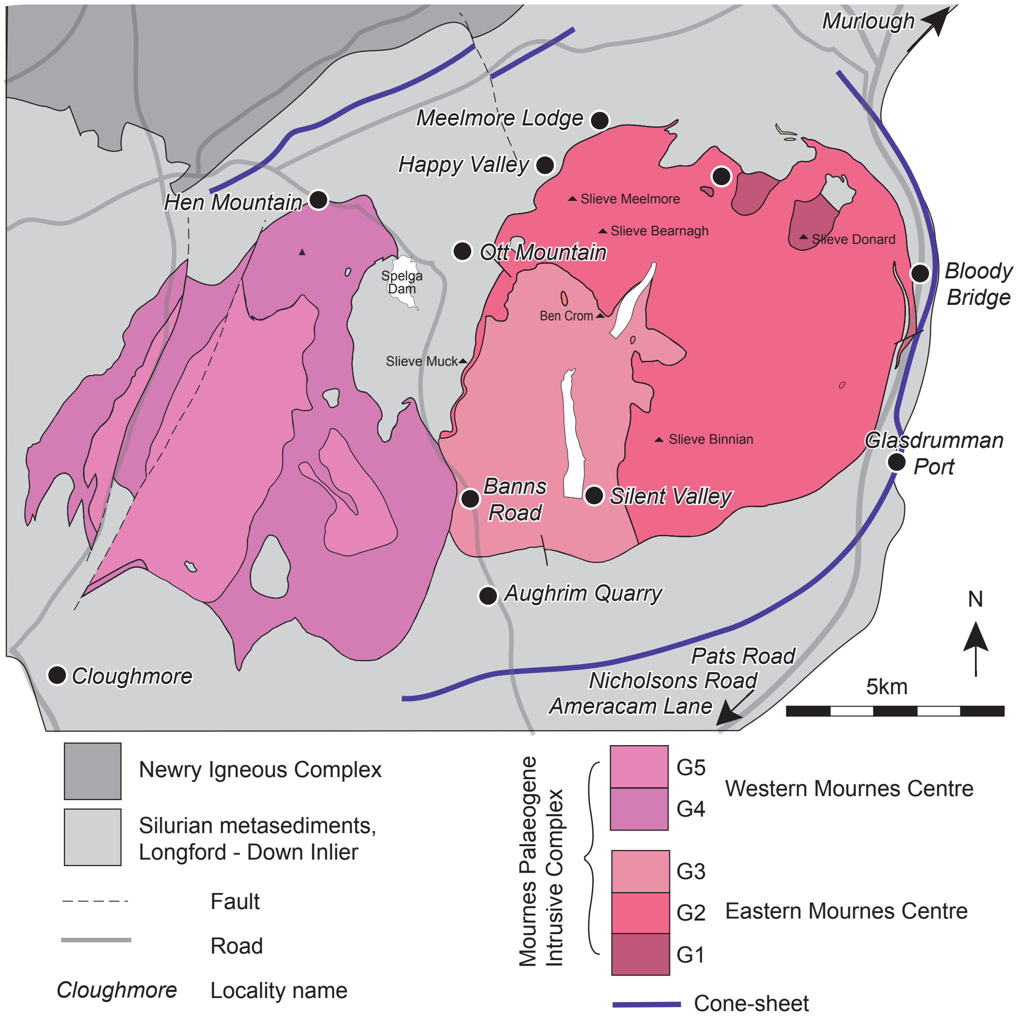

Figure 49 Geological map of the Mourne Mountains Complex.

The earliest phase of magmatism in the Mournes led to the emplacement of the extensive north-west trending dyke swarm now well exposed along the coast. This was followed by further fracturing of the crust and the emplacement of elliptical cone-sheets that now encircle the granites (see Figure 20). These cone-sheets dip at 35° towards the granite and indicate a focus some 3km deep.

The main phase of magmatism involved the emplacement of the granites. The granites all have gently dipping or flat-lying contacts, and, in places, steep contacts with the country rock. Richey (1928) interpreted this to mean that emplacement took place as a result of cauldron subsidence (Figure 50). However, a major problem with the cauldron subsidence model is the requirement of space for the subsiding block to sink into. The subsided block is also rarely identified in plutonic situations. Stevenson et al. (2007) reassessed the so-called 'space problem' posed by the emplacement of the Eastern Centre granites and suggested that the Eastern Centre was intruded as a relatively flat-lying sheet or laccolith. This involves the inflation of the intrusion with magma input from the south, and the resultant uplift of the overlying country rocks (Figure 51).

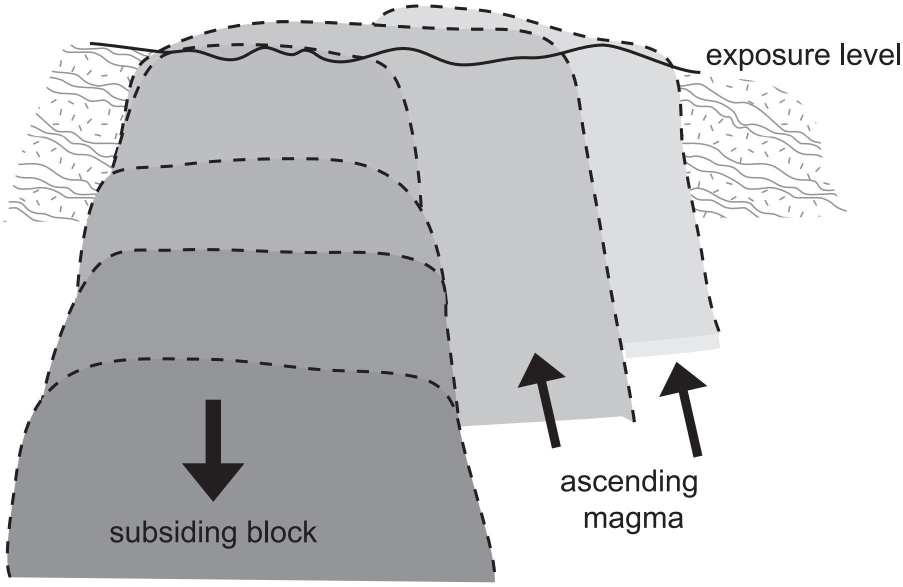

Figure 50 Richey's (1928) model of cauldron subsidence for the emplacement of the Mournes.

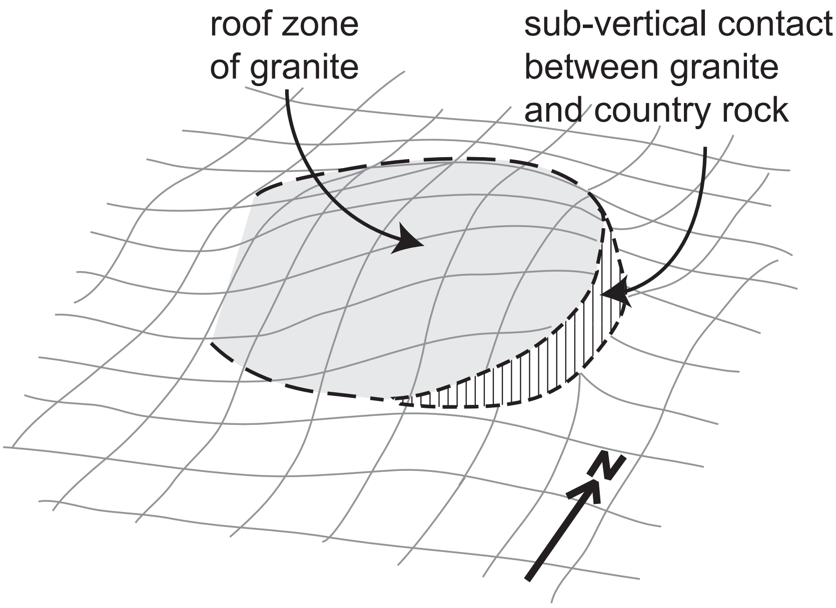

Figure 51 The laccolithic emplacement of the Mournes Eastern Complex as suggested by Stevenson et al. (2007). The gridded surface represents an arbitrary layer just above the initial emplacement level: the deformation of the grid schematically represents the uplift and deformation of the country rock as the laccolith inflates. The eastern end of the intrusion (vertical hatching) forms a steep sub-vertical faulted contact (now seen near Bloody Bridge).

The shallow level of emplacement of the granites means that most display some development of drusy cavities in their roof zones. These cavities formed as exsolved gases were trapped in the upper levels of the intrusion. They sometimes contain rare minerals such as topaz or beryl (aquamarine), or beautiful crystals of smoky quartz. The 'Diamond Rocks' locality near Hare's Gap (see Locality 24, Meelmore Lodge) is a famous site in the Mournes for drusy cavities, and, although not described in this guide due to the walk involved in getting to it, is well worth a visit if you are interested in mineral collecting.

14 Cloughmore

What can be seen	Glacial erratic; dyke; metasediments, good viewing point for landscape of lough
Grid reference of starting point	J 196 174
Distance/time (one way)	500m/10mins
Terrain	Path, steep in parts
Exercises that can be done	Bedding measurements

Park in the top car park, accessible from the Forest Drive 1.5km from Kilbroney Park on the A2 east of Rostrevor. The drive up to the car park is a narrow steep road not suitable for large coaches. It is possible to walk from the park, but it does involve a steep walk. From the car park, take the footpath westwards across the bridge and up to Cloughmore, keeping to the upper track. On the way up, there are some outcrops of grey-green striped metasediments, which fragment in angular blocks, and rounded granite boulders in the overlying material.

Cloughmore (J 192 173) is a large glacial erratic – it is a granite boulder that sits on an outcrop of metasedimentary rocks (Figure 52). The name itself comes from the Irish 'an Chloch Mhór' – 'the big stone'. Legend has it that Fionn MacCumhaill, the giant, threw the stone from Slieve Foye (across the lough) during a fight with a rival.

Figure 52 Cloughmore glacial erratic, a granite boulder resting on Silurian metasediments.

From the vantage point of Cloughmore, Carlingford Lough can be seen almost in its entirety, as can the rugged landscape of Slieve Foye across the Lough, and the flatter lands of the eastern Cooley Peninsula. To the west are the outer margins of the Slieve Gullion Complex: Anglesey Mountain and Clermont. The view to the north-west is across the hills and valleys of the Warrenpoint and Rostrevor area, sculpted by ice moving south and then south-east out of the Lough. The hills to the north mark the western edge of the Mourne Granite Complex.

Walk 200m south from Cloughmore along a grassy track to a rocky ridge (at J 192 171). This ridge is composed of a dyke intruding metasediments. The vertical dyke trends WSW-ENE, almost parallel to the strike of the metasediments, and its influence on the local topography is clear. The contact is not always easy to make out, but in places the sharp nature of the contact can be seen (Figure 53).

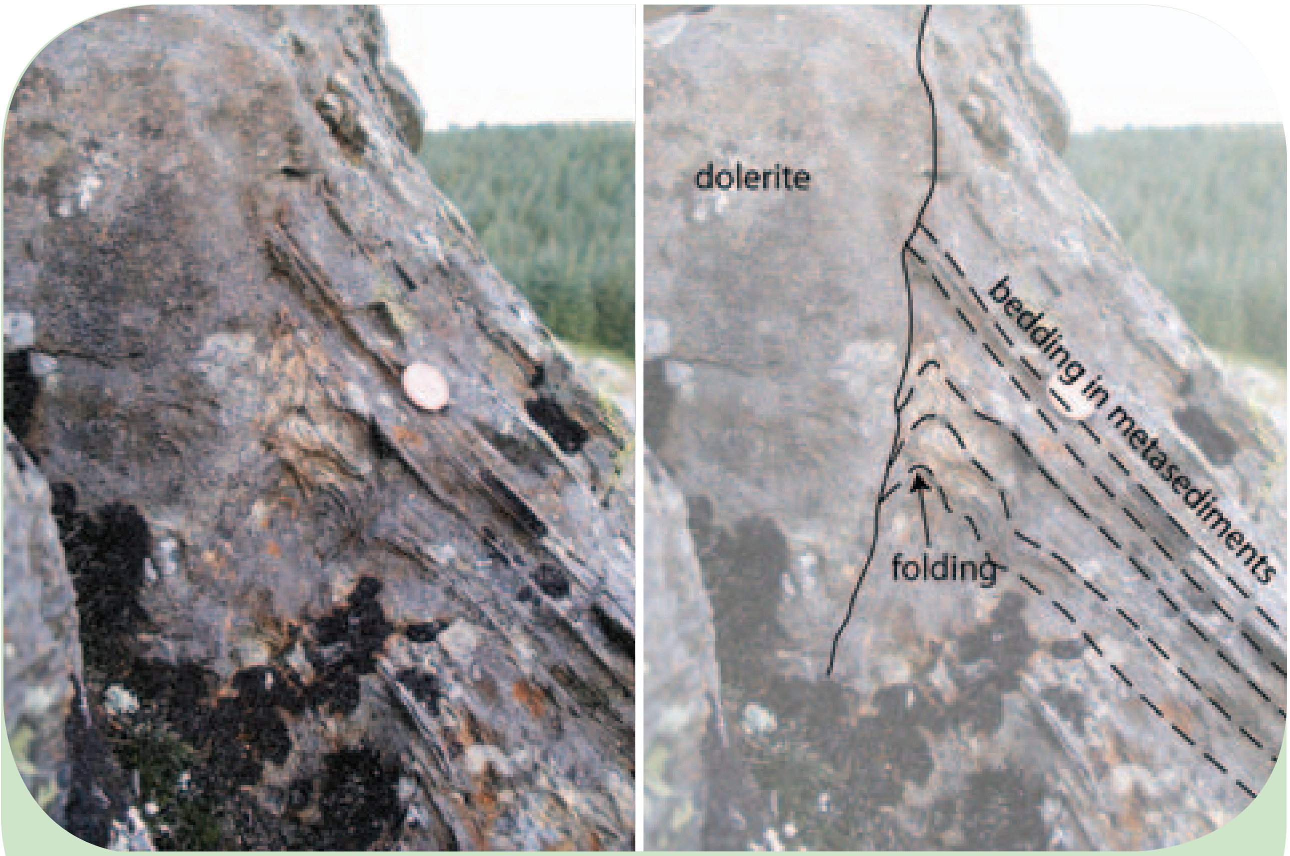

Figure 53 Contact between dolerite dyke and metasediments, near Cloughmore. Note small scale folding in metasediments. (1c coin, Ø=16mm)

Ameracam Lane

What can be seen	Dipping limestone beds; fossils (brachiopods, corals, crinoids, burrows); Palaeogene dyke intrusion; rock armour/coastal defence; beach environment
Grid reference of starting point	J 259 107
Distance/time (one way)	800m/10mins
Terrain	Beach
Exercises that can be done	Bedding measurements – dip, logging section, fossil identification, mineral identification (especially in boulders)
Other notes	Low tide needed for best access. Please do not hammer outcrops for fossil or mineral material – loose fossiliferous material is plentiful on the beach.

Park in car park at Cranfield West (J 259 107). Toilet facilities are available here. Walk c.700m westwards (right) along beach (less than 10min) towards Soldiers Point, where rock armour boulders are higher – this is approximately at the end of the tarred part of Ameracam Lane. (The name Ameracam derives from the Irish Iomaire Cam 'crooked ridge' – could this refer to the outcrop here?).

From here for about 100m westwards are clean outcrops of limestones, calcareous siltstones and shales which dip gently at about 15° to the west. Note that the beds are not uniformly thick or planar. Geologists often assume (to simplify mapping and interpretation) that sedimentary beds are of uniform thickness and planar, but this may not be true at the outcrop scale. The geological rule that 'the present is the key to the past' is useful here: observation of the present day beach shows similar undulations in the surface – a generally planar surface (the beach) can have small undulations on it, marked by patches of wet and dry sand. Therefore, although the limestone beds have been tilted, the undulations in the bedding surfaces may be an original feature rather than a sign of deformation.

The limestone contains corals, brachiopods and crinoid stem fragments, while the shale contains trace fossils in the form of burrows (Figure 55). Many good examples of these can be found in the loose material on the beach, and the loose limestone cobbles may also have been bored in more recent times by the bivalve *Hiatella arctica* – some of the holes still have shells in them (see Figure 38). Thin vertical veins of calcite cross-cut the limestone at 150°-170°.

Figure 54 Limestone and shale beds at Soldiers Point. View is approximately down dip. Note the undulations in the bedding planes. The mountains of the Cooley Peninsula are in the background. (Compass is 10cm long)

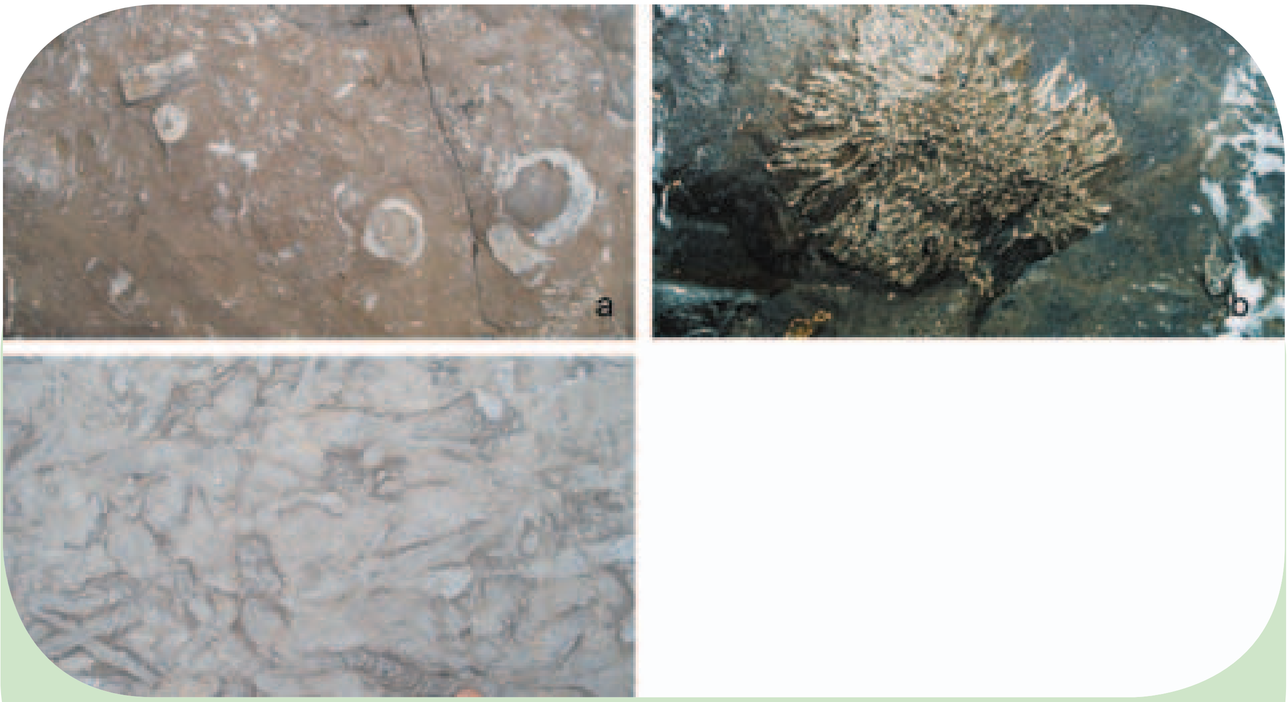

Figure 55 Fossils in limestone and shale, Soldiers Point: (a) brachiopods & crinoid stem fragments (1c coin, Ø=16mm); (b) coral (overturned *Siphonodendron martini* colonial coral, c. 25cm across); (c) burrows (note curved laminae in backfill). (1c coin, Ø=16mm)

Several sub-vertical, NW-striking mafic dykes intrude the limestone, ranging in width from 25cm to over 1.5m (Figure 56). Some of these show strong flow-banding at their margins, giving the rock a stripy appearance.

Figure 56 Vertical mafic Palaeogene dyke intruding Carboniferous limestones – view is south-east along dyke, limestone outcrops to either side. A good example of an overturned large colonial coral *Siphinodendron martini* Figure 55b) can be found on limestone outcrop on far left.

It is also worth examining the boulders that have been used as rock armour at the top of the beach. These are glacially rounded boulders of local granite, and some of them contain 'drusy cavities', hollows with a lining of well-developed crystals, usually of feldspar and quartz (which may be dark-grey, smoky quartz) (Figure 57).

Figure 57 Drusy cavity in granite boulder in rock armour at Soldiers Point. (1c coin, Ø=16mm)

The 'Diamond Rocks' is a site in the Mournes (J 325 290) famous for the quality of its drusy cavities, some of which contain semi-precious examples of beryl and topaz. The cavities form when gas exsolves from the magma (comes out of solution, as gas does from fizzy drinks when they are opened), but doesn't escape. Minerals can then grow unrestricted into the cavity, forming the good crystals that can be seen today.

If the tide is low, note that there are several outcrops of dipping limestone at low water mark. It may also be possible to see that from Cranfield across to Greenore, on the southern side of the lough, there are several areas of exposed rock. Carlingford Lough was originally very shallow (<3m at low tide) at its mouth, but a deeper channel was created to facilitate shipping to Greenore and Warrenpoint Docks. The shallowness at the mouth is a typical feature of a fjord – a drowned glacial valley –due to the reduced erosive power of the ice as it reached the coast.

16 Nicholsons Road

What can be seen	Section through glacial diamict, raised beach, coastal features – erosion and deposition
Grid reference of starting point	J 297 118
Distance/time (one way)	700m, <10mins
Terrain	Beach – sandy & rocky sections
Exercises that can be done	Sediment size distribution; identification of clasts in diamict & beach boulders
Other notes	Beach section – best at low tide

At the end of the level part of Nicholsons Road, some parking is available (with care) – it is not advisable to continue to drive down to the beach level. A walk of about 100m from the parking place drops down off the raised beach to the present day beach.

Turning north-east (left) at the beach, a walk of 600m brings you to Crawfords Point (J 301 121). The cliff section shows a sequence through glacial diamict at the base, to a sand and gravel section (an old beach) to the soil at the top (Figure 58). A drainage pipe protruding from the cliff at Crawfords Point has been laid down at the boundary between the sand/gravel layer and the diamict.

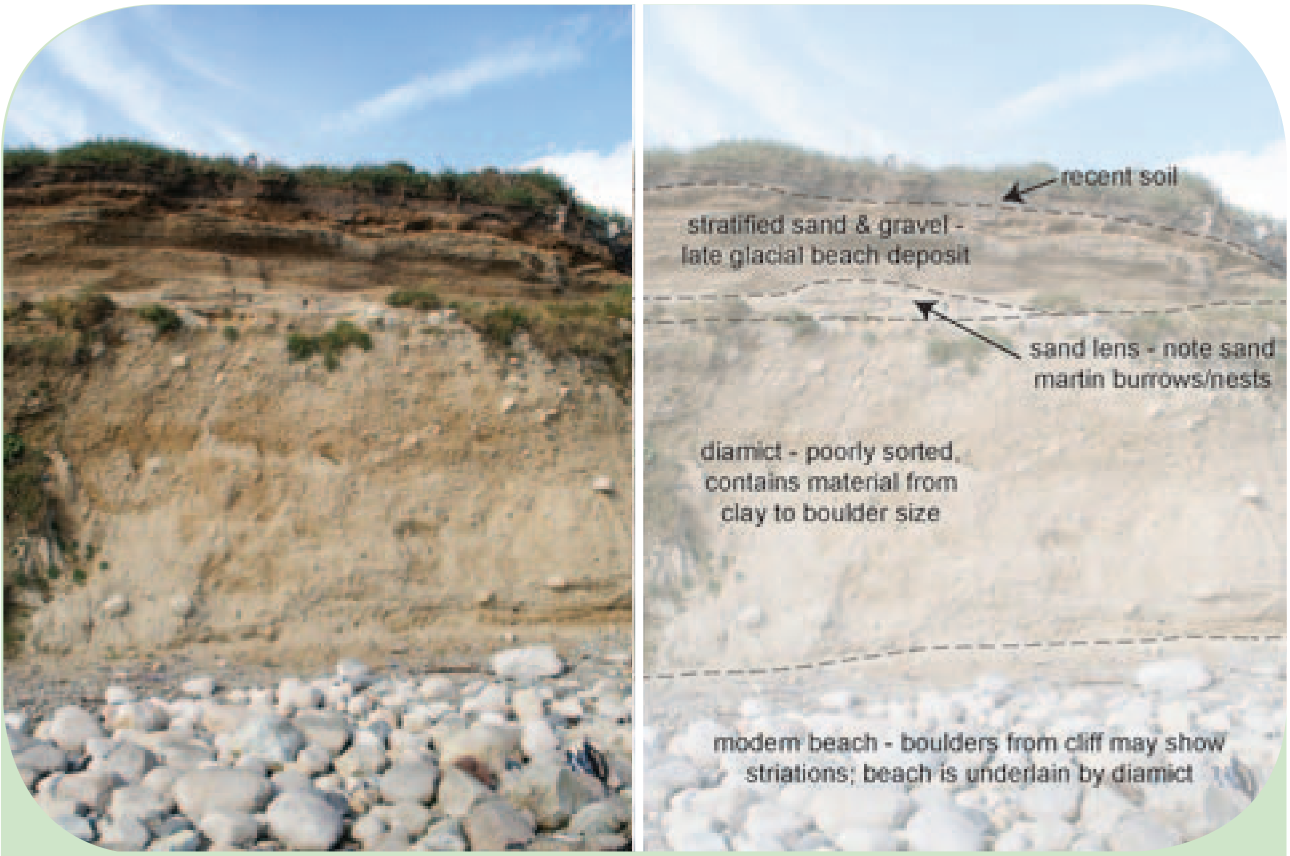

Figure 58 View of the cliff section between Nicholsons Road and Crawfords Point. Poorly sorted glacial diamict is topped by sand and gravel of an ancient beach, with a final topping of modern soil. Holes in the sandy layers are the nests of sand martins, and are an example of bioerosion (see Locality 8).

Note that the cliff is actively eroding here – there are fence posts and parts of fences hanging off the edge, and there are cracks and slumps in the cliff face itself. This is also a good locality to note different coastal processes – at Crawfords Point the beach is covered in large boulders, while towards Nicholsons Road the beach is sandy. The finer grained material is removed from the promontory and deposited in the bay.

Beneath the boulders at Crawfords Point there is diamict 'bedrock' – which looks like concrete. The boulders on the beach are mainly derived from the cliff, and can be examined for evidence of striations (scratches) that they incurred while being transported in the ice. The wide range of clast (fragment) sizes in the diamict is typical of a glacial deposit. Sediments transported by wind or water tend to be better sorted – this is obvious on the present day beach.

Back at the parking spot, you may notice that the wall has an unusual appearance, being made up of broken slabs of concrete (Figure 59). In 1942, an airfield was built locally for the US Air Force. Three runways were constructed in under six months by a workforce of 800: one approximately 1.8km long, and two shorter of 1.3km length. The end of one of the runways ended close to this point at Nicholsons Road. The total volume of concrete used in the site was over 30,000m^3. Aggregate was sourced from local sand and gravel pits, while cement was imported from Drogheda. A sand and gravel pit is sited along Nicholsons Road, and there are a number of others in the area. The pit here is owned by CES Quarry Products Ltd and may be open to school tours by arrangement – contact details as for Aughrim Quarry (Locality 17).

Figure 59 Dry 'stone' wall made of broken concrete slabs lifted from a local WW2 airfield.

Aughrim Quarry

What can be seen	Large-scale folds; dyke intrusions; economic geology
Grid reference of starting point	J 287 180
Distance/time (one way)	<100m/<5mins
Terrain	Track
Exercises that can be done	Rock relationships; sketching
Other notes	Access to the quarry needs to be arranged with the Health & Safety Officer for CES Quarry Products Ltd: Irwin Armstrong, email iarmstrong@cesquarryproducts.com, tel. 0784 110 2516.

Aughrim Quarry was opened in 1928 and over 0.5 million tonnes of material has been extracted from the quarry, mainly for use in the local building trade. The Polished Stone Value (PSV) of the rock from this quarry makes it unsuitable for use as aggregate for road surfacing.

The back face of the quarry was last blasted in the early 1980s, and weathering since then has enhanced the visual contrasts between different rock units in the quarry. Visible on the quarry walls are excellent sections through folds in the Silurian metasediments, and crosscutting dykes of both mafic and felsic composition (Figure 60). The view of the back wall is approximately along strike of the folds, and so is a reasonably accurate true cross section of the fold forms. The folding clearly shows the degree of deformation of the Silurian sediments.

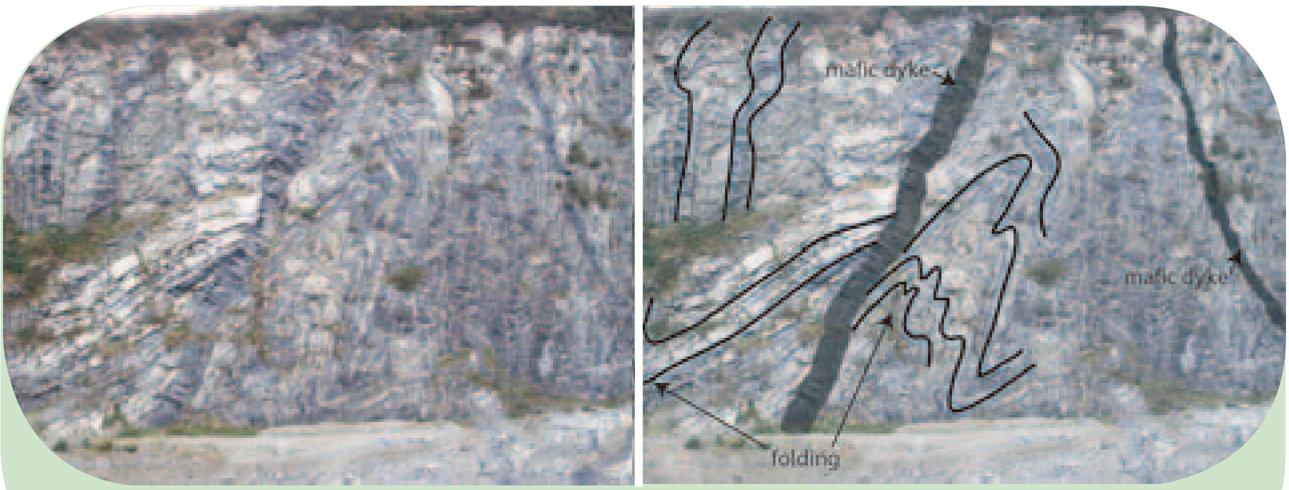

Figure 60 The back wall of Aughrim Quarry, showing large scale folds in the Silurian metasediments, and two sub-vertical mafic dykes. Wall is approximately 50m high.

18 Banns Road

What can be seen	Silurian metasediments cap on Slieve Muck
Grid reference of starting point	J 285 214
Distance/time (one way)	n/a
Terrain	n/a

From the car park at the entrance to Banns Road, north of Attical, the top of Slieve Muck can be seen to the north. The summit crags are of Silurian metasediments, and below them is the G3 granite of the Eastern Mournes Centre. This is also a good area to see the traditional stone walls of the Mournes, made predominantly of rounded boulders. The round boulders are 'core-stones'. Granite tends to be cross-cut by many joints formed during cooling and uplift: when weathering occurs along these joints, blocks of granite become loose. Continued erosion is concentrated at the corners, rounding off the boulders. In times past, these core-stones were worked by the 'stone men' into setts for paving, as they were the toughest part of the granite. Sett manufacturing was an important industry in the Mournes from the early 1800s.

Figure 61 View of Slieve Muck from Banns Road car park. The Silurian metasediments at the top of the mountain mark the western edge of the Eastern Mournes Centre. The northern margin may be seen on the slopes of Slieve Meelmore (Locality 24). The walls in the foreground are good examples of traditional dry stone walls, built with round granite core-stones. The lace-like walls resist wind better than solid block concrete walls, and provide good shelter to livestock.

19 Silent Valley

What can be seen	Glaciated landforms; economic, engineering, & environmental geology
Grid reference of starting point	J 306 210
Distance/time (one way)	n/a
Terrain	n/a
Other notes	Contact should be made with Northern Ireland Water (education@ niwater.com) to make arrangements for educational visits to the Silent Valley – a shuttle bus runs from the visitors' centre to Ben Crom dam during the summer season, but out of season it may be possible to make arrangements to take private transport to the dam.

Parking is available at the Silent Valley Mountain Park. There is an educational centre at the site, describing the building of the dams, along with information on water conservation and other such environmental issues. As early as 1891 the Mournes had been recognised as the best source for a plentiful supply of water for the industry and population of Belfast. By 1899 the Belfast City and District Water Commissioners had purchased the necessary 9,000 acres of the Mournes catchment area, and two years later water was being piped to Belfast. In 1904 construction of the now-famous Mourne Wall started along the boundary of the catchment area, taking 18 years to complete.

By 1910 the increasing demand for water led to the realisation that a dam and reservoir were needed, and design work commenced on the Silent Valley Dam. The outbreak of the First World War delayed the beginning of work on the dam until 1923. For the next ten years 2,000 men worked on the dam, some living in the specially constructed 'Watertown' on site.

Initial surveys for the building of the dam had indicated a depth to bedrock of less than 20m. However, when excavation started, it was found that the 'bedrock' that had been encountered was in fact a number of large glacial erratics, part of a glacial moraine in the valley. Bedrock was eventually met at over 50m depth, necessitating re-design of the dam and a huge increase in the costs of the build. An innovative but difficult and sometimes dangerous construction method was devised which involved men working in a pressurised trench. Eight men died during building of the dam, some from 'the bends' or decompression sickness, caused by working in the pressurised system.

The Silent Valley Reservoir was officially opened in 1933, and was augmented in 1957 by the building of the Ben Crom dam. Together, the two reservoirs can hold almost 21 billion litres of water.

The buildings and the surface dressing of the dam at the Silent Valley Reservoir are made of granite, and the project represents one of the last large projects created in Mourne granite.

If the trip to Ben Crom is made, climb the steps to the top of the dam wall. From here, the view is into the heart of the Mournes along the valley between Ben Crom to the west (left) and Slievelamagan to the east (right). At the top of the valley is Slievnaglogh. Note the steep crags and scree on the eastern sides of Ben Crom, in contrast to the smoother slopes of Slievelamagan. This is a relict of glaciation, when east- and north-facing slopes, sheltered from sun and wind, were much more affected by snow and ice than their south- and west-facing counterparts. The corrie at the top of Trassey (viewed from Locality 24, Meelmore Lodge) provides another good example.

Figure 62 Eastern slopes of Ben Crom from Ben Crom dam wall. Note the steep sides and scree. The base of the cliffs mark an internal boundary between two of the granites of the Eastern Mournes Centre.

Figure 63 Silent Valley (near) and Ben Crom (far) reservoirs looking northeast from the eastern slopes of Slievenaglogh. (Photo: Mike Hartwell)

20 Pats Road, Kilkeel

What can be seen	Section through diamict & raised beach
Grid reference of starting point	J 336 156
Distance/time (one way)	<100m/5mins
Terrain	Track
Exercises that can be done	Statistical exercises on diamict sediments

Ample parking is available at the entrance to the football grounds on Pats Road. From there, walk the short distance down the lane, turning right at the sea, to follow a low cliff section along the lane. This walk is off the raised beach down (almost) to the modern beach level.

The section shows contrasting layers within the diamict, and, at the top, an undulating contact between the diamict and the ancient beach deposits, with the modern soil horizon topping the section. The contact between the diamict and the beach deposits is an erosive one – again, the topography of the modern beach could be used to illustrate the local variations one can expect in an essentially horizontal surface.

At the southern (far) end of the section, there is a cross-section through a channel, infilled with cross-bedded gravel (Figure 64).

Figure 64 Cross-bedded gravels in channel through diamict, Pats Road.

Glasdrumman Port

What can be seen	Cone-sheet; metasediments; magma hybridisation; chilling; xenoliths; dyke; raised beaches
Grid reference of starting point	J 380 220
Distance/time (one way)	<200m/<5mins
Terrain	Lane & beach
Exercises that can be done	Mapping exercise (group – lots of places to measure bedding & contacts); rock identification;
Other notes	Coastal locality, low tide advisable

Access to this site is from the first farm track off the A2 south of the school in Glasdrumman (junction at J 375 218). A post-box is in the right-hand pillar at the top of the lane. Park at the end of the level part of the lane in front of a modern house – as with many of the sites on this coastline, the main road is on a raised beach and there is a drop to the modern shoreline.

Walk for a few minutes down to the shore, and turn north (left) along the coast. There are good exposures on the shore of steeply dipping metasediments. Near the top of the shore there are very distinctive rounded outcrops of pink granitic rock, which, on closer inspection, can be seen to be bounded at top and bottom by a darker rock. This is a 15m-wide cone-sheet that trends almost parallel to the coast at this point, and dips towards the mountains (Figure 65). The cone-sheet at Glasdrumman is part of a set of such intrusions that encircle the granites and pre-date them.

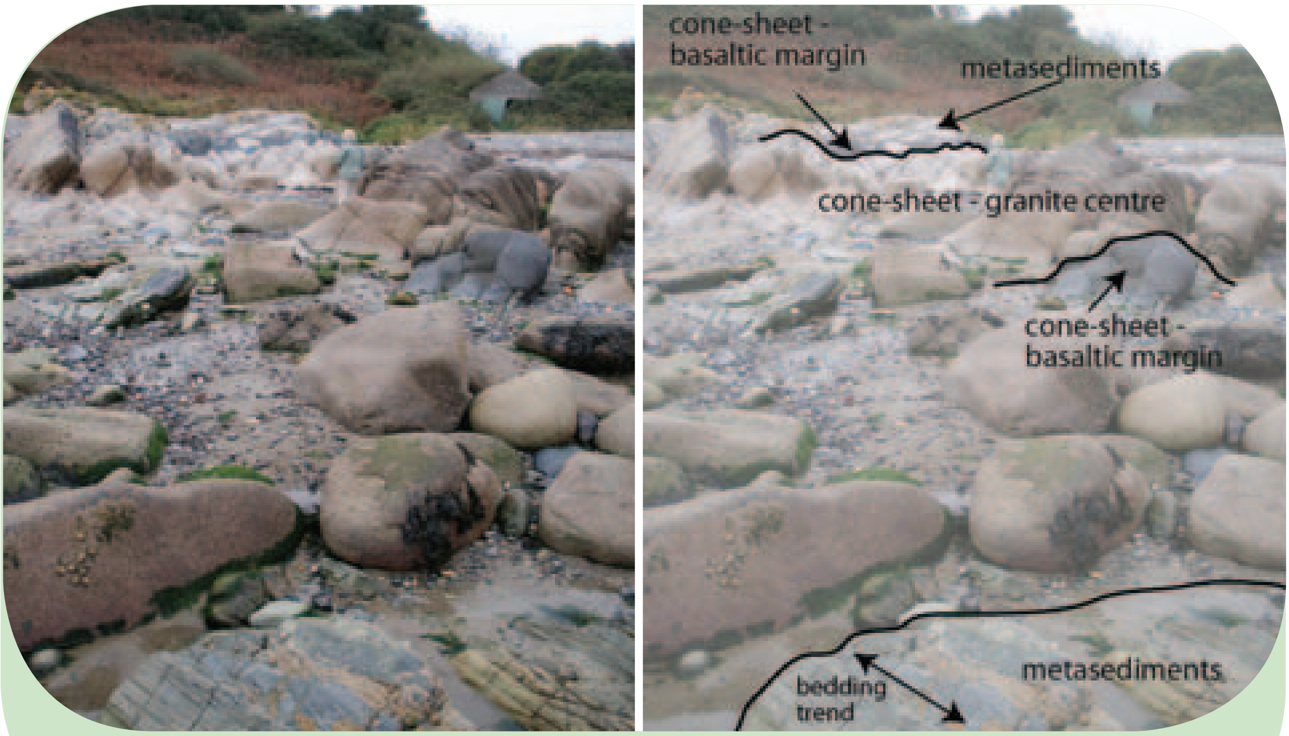

Figure 65 The cone-sheet at Glasdrumman Port, looking north. Both basalt margins are visible as dark layers at either side of the pink central granite porphyry.

Examination of the sheet along its exposure will show that the margins (Figure 66) are mafic and fine-grained (basalt), and the central area is of a porphyritic granite. Phenocrysts (large crystals) in the granite are of plagioclase and quartz. There is a hybridised zone between the basalt and the granite, indicating that their magmas mixed and mingled together. Variations within the granite and basalt (Figure 67) also suggest that more than one batch of each magma ascended through this conduit.

Figure 66 Detail of the eastern margin of the cone-sheet, showing the sharp contact between the metasediments (below) and the basalt (above). (20p coin, Ø=22mm)

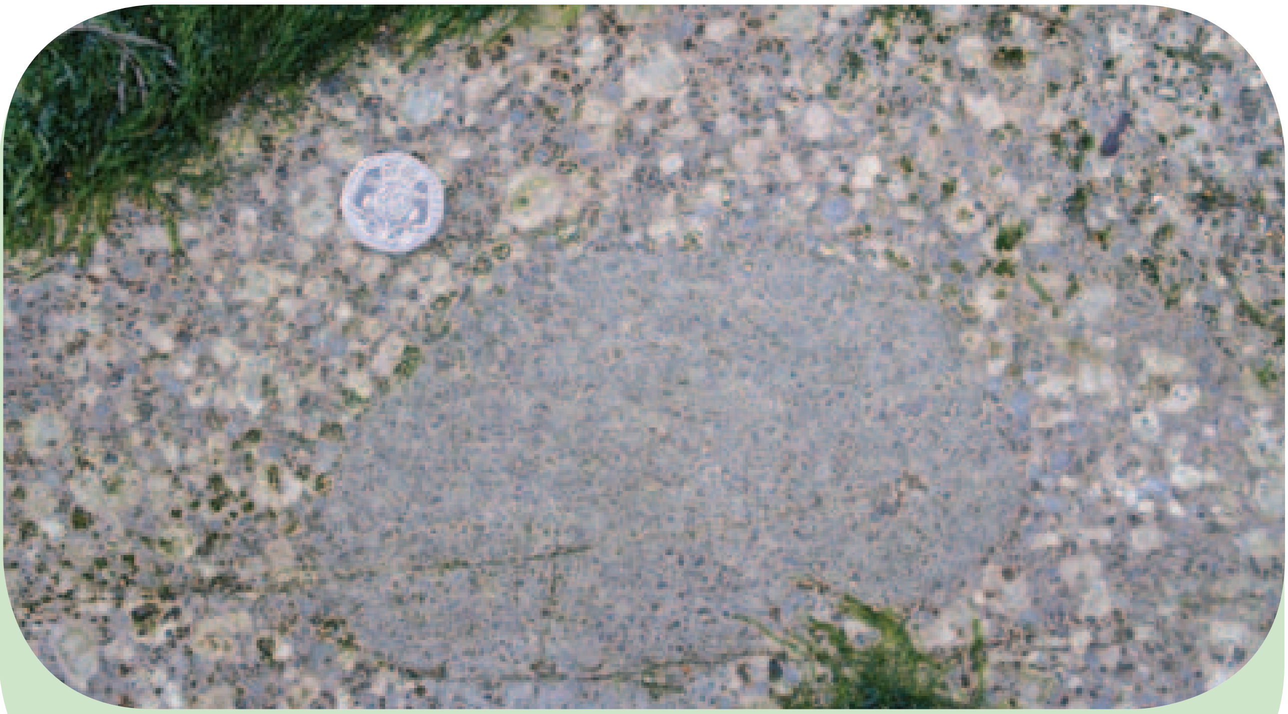

Figure 67 Varied composition within the granite porphyry, showing that more than one batch of magma was intruded. (20p coin, Ø=22mm)

Close to the margins, there are also xenoliths (fragments – lit. 'foreign rock') of the metasedimentary rocks that have been caught up in the intrusion, while the porphyry contains 'blobs' or enclaves of basalt. These blobs have lobate or crenulated (wavy) contacts with the granite, showing that they were included as magma rather than fragments of solid basalt (Figure 68). Similar features can be observed in the basalt-granite contacts in Carlingford (see Figure 37e&f) and Slieve Gullion (Locality 12).

Figure 68 Lobate inclusions of basalt in the granite porphyry indicate that the magmas were both liquid at the same time. (20p coin, Ø=22mm)

Further north along the beach, a vertical basaltic dyke about 3m wide trends approximately NW-SE. This is part of the extensive dyke swarm that represents the earliest phase of magmatic activity in the Mournes.

The headland to the north with the slightly conical appearance is Dunmore Head, the eroded remains of a lateral moraine of an ice sheet that was pushing southwards down the Irish Sea. Note also the two levels of raised beach at this locality - the lower one at the level of the base of the lane, while the higher one at the level of the parking area. The raised beaches result from the interaction of glacially-influenced isostatic and eustatic changes in sea-level as the last ice-sheet retreated along the coast. It is worth remembering that at that time the sea would have been eroding recently deposited moraine material, with little or no vegetation cover, which would have eroded relatively easily. Streams and rivers have also eroded the cliff between the two levels – note the deep gullies cut back into it at various places along this section. Good sections through glacial diamict and raised beaches can be studied at Localities 8 (Templetown Beach), 16 (Nicholsons Road), and 20 (Pats Road, Kilkeel).

Bloody Bridge River

What can be seen	Progressive hornfelsing of metasediments; intrusion of metasediments by granite; minor mafic dykes; glacial moraines; river processes
Grid reference of starting point	J 389 271
Distance/time (one way)	<1km/20mins walking
Terrain	Mountain track
Other notes	The sites may be not be easily or safely accessed at times of high water in the river.

Park at the Bloody Bridge car park, which is approximately 3km south of Newcastle on the A2. Toilet facilities are available here.

A good overview of the Bloody Bridge River section can be seen from the hill at the sea-ward side of the car park: a small path leads up steps and around this hill. Some of the blocks of granite in the wall here show 'plug-and-feathers' marks – a line of notches along their edges. This records the method used to split the granite for use: a line of small holes drilled in the piece of rock each had an iron wedge (the 'plug') inserted between two thin pieces of steel (the 'feathers'). Skilful hammer blows on the plugs (usually) resulted in the rock splitting cleanly along the desired line.

Looking south from this vantage point, the flat-lying raised beach at the top of the present-day coastal cliff is clear to see, as is the modern wave-cut platform in the Silurian metasediments exposed on the beach. Looking west, the view is up the valley of the Bloody Bridge River, where the deep incision (up to 20m deep and 100m wide) that the river has made into glacial deposits and bedrock in the valley is also clearly seen. If the weather is favourable, Slieve Donard, the highest mountain in Ulster at 853m, may also be visible to the west-north-west.

Crossing the road, take the National Trust path up along the course of the river, passing the original Bloody Bridge – scene of a massacre in 1641 – on the way. Good sections through the glacial sediments can be seen across the river.

Over the next 750m or so, the contact between Silurian metasediments and granite is crossed – to see this, leave the path at intervals to go down to the river to see the exposures. Care should be taken at the river bank. Approximately 500m up the path (J 384 270), there is a noticeable cut through glacial sediments on the southern (far) side of the river that also show strikingly different colours – orange on top and grey underneath. The boundary between the two is sharp, and is marked by a thin layer of iron mineralisation known as an iron pan (Figure 69).

Figure 69 Iron pan developed in glacial sediments along the Bloody Bridge River. The orange colouration indicates oxidation of iron ('rusting'), while the grey implies reduction of iron in water-logged sediment. (Lens cap Ø=6cm)

At this point (at the time of writing – this is a dynamic system!) the river has split in two – the southern course is the more dominant one, and the northern one may have very little water flowing in it. There is a high ridge of boulders between the two – this is a good reminder of how powerful flowing water is, as considerable energy would have been required to transport these boulders.

The bedrock here is of metasediments that have been baked by the intrusion of the granite to the west to form hornfels. The striped green and grey appearance is very clear, and the bedding can be seen to dip at c.30° east, or downstream.

A further 150m or so up from this (at J 383 270) a number of granite veins can be seen to intrude the metasediments. A little further uphill, the track crosses granite outcrop, formed of equigranular pinkish-coloured granite that has weathered in a rounded form. This is below the confluence of the Bloody Bridge and the Glen Fofanny Rivers, and marks the furthest point of this excursion. Note that the granite closest to the hornfels is finer grained than that away from the contact – it has been chilled against the older rock, and the crystals haven't had as much time to grow as they did in the hotter interior of the magma.

Figure 70 Granite veins injecting hornfelsed metasediments on the banks of the Bloody Bridge River. View is southwards across the river, metasediments can be seen to dip steeply eastwards (downriver).

23 Murlough

What can be seen	Sand dune system, multiple raised gravel ridges
Grid reference of starting point	J 394 338
Distance/time (one way)	<800m/<15mins
Terrain	Paths through sand dunes
Exercises that can be done	Identification of raised beaches; sediment analysis on beach and storm beach; vegetation and/or soil analysis of dune system; human interaction with the environment; coastal defence systems.
Other notes	This is National Trust property and contact must be made with the warden before visiting the site with a group: email murlough@nationaltrust.org.uk, tel. 028 4375 1467

The Murlough sand dune system lies to the north of Newcastle, between the Dundrum Inner and Outer Bays. It extends for approximately 5.5km in a south-west to north-east direction, and is up to 1.5km wide (Figure 71). The Royal County Down Golf Course occupies part of the south-western end of the system, while much of the north-eastern area is designated a National Nature Reserve (NNR) and is owned and managed by the National Trust.

Figure 71 Oblique aerial view of the coastline at Murlough, north of Newcastle. The beach, sand dune and estuary system are all clear in the photograph. (Photo: Mike Hartwell)

The main features of the area include:

A A low-angle, dissipative, wide sand beach, backed by a well-developed storm beach or gravel ridge. This beach is currently being monitored to assess the effect of various coastal protection structures erected along it, particularly at the Newcastle end. The storm beach is up to 4m high, and while it is dominated by locally-derived clasts of Silurian metasediment and Mourne granite (transported from the Dunmore Head moraine to the south by longshore drift), there are also numerous erratics including flint nodules from Antrim, and micro-granite from Ailsa Craig, a small island in the Firth of Clyde in Scotland. The clasts are size-sorted across the ridge-crest.

B A sand dune system underlain by a series of 12 sub-parallel gravel ridges. The dunes may be divided into three parts: landward, central and coastal.

The gravel ridges trend south-west to north-east. Where they are exposed in dune blowout floors, the western (landward) ridges are seen to lie at 9m OD while those closest to the sea reach a maximum height of 5m OD. As with the modern day storm beach, the ridges consist of a variety of clasts. The clasts are size- and shape-sorted across the ridge, and decrease in size north-eastwards, indicating longshore drift in their development. The ridges were formed from reworked glacial material around 10,000BP, and record a gradual drop in sea-level as the land rebounded after the end of glaciation.

The landward dunes are low relief, and have well-developed soils. 14C data on charcoal buried in these soils at archaeological sites has yielded dates of up to 5,000BP, but the dunes appear to date back to the early Holocene (perhaps to 7,000BP). Three separate palaeosol horizons can be identified, showing that the system experienced at least three periods of prolonged stability.

The central dunes are the highest (>30m OD). Their morphology indicates a main erosional force to be winds from the south – corresponding to the distance of greatest fetch. Buried palaeosols at the base of these dunes have been dated, using coins and pottery incorporated in the soils, to the early Mediaeval period (c. 650BP), showing that the formation of these dunes is more recent than this date.

The coastal dunes are modern dunes of low relief. They are not currently accreting sediment, but there was a period of dune formation 1969-79 following the inshore migration of a swash bar.

C A zoned ecology of the sand dunes, due predominantly to the maturity of the soil. Close to the sea, the ‘embryo dunes’ are dominated by salt-tolerant plants, such as marram grass. The growth of marram grass stabilises the sand, and further from the shore are the ‘yellow dunes’ with a well-established cover of marram. With increasing stability, moss and lichen become established, and the marram gives way to other plants. Shells gradually dissolve out of the soil, leaving it more acidic, until, in the most mature soils, heath vegetation develops (Figure 72).

Figure 72 Heath vegetation on the more mature dunes in Murlough; towards the sea the younger dunes are dominated by more salt-tolerant vegetation such as marram grass. Slieve Donard, the highest mountain in Ulster, is in the background. (Photo: Mike Hartwell)

D Dundrum Inner Bay, a typical estuary, linked to the Outer Bay by a tidal channel. It is covered only at high tides, so consists of mud and sand flats for much of the time, and is an important wildfowl and wader site. The Inner bay is possibly a remnant of a more extensive estuary or salt marsh that extended southwards as far as Newcastle. This now forms the flat-lying area between Newcastle and Dundrum, and is bordered on its northern and western margins by a raised beach, along which the Flush Road (from Maghera to Slidderyford Bridge) runs. The raised beach can also be seen from the main Newcastle-Dundrum road, and is crossed by the Newcastle-Castlewellan road at the Burrendale Hotel. A number of ancient monuments along this road suggest that the area was significant to the earliest human inhabitants of the region.

24 Meelmore Lodge

What can be seen	Col, corrie, contact
Grid reference of starting point	J 305 307
Distance/time (one way)	n/a
Terrain	n/a

A car park, café, and toilets are available at Meelmore Lodge. The view south from the campsite area is up the Trassey River valley, as far as Hare's Gap at the skyline. In the foreground, the fields are underlain by moraine material deposited from a glacier moving eastwards down the Shimna Valley (i.e. from right to left). In the middle distance, the broad U-shaped landform is a hanging valley, while in the distance is the col at Hare's Gap. The steep sides of the corrie at the northern side of this col are visible from this distance (Figure 73). These features are also easily identified on a map, and comparisons can be made with Locality 19, Silent Valley.

Figure 73 View south from Meelmore Lodge along the valley of the Trassey River.

The contact area between the metasedimentary rocks to the north (nearer) and the granites to the south (further away) is clearly visible on the slopes of Slieve Meelmore to the west (right) (Figure 74). This is the northern margin of the Eastern Mournes Complex – the western margin on Slieve Muck can be seen from Locality 18, Banns Road.

Figure 74 The slopes of Slieve Meelmore from Meelmore Lodge, with granite making up the far slope and metasediments making up the near one.

25 Happy Valley

What can be seen	View of U-shaped valley
Grid reference of starting point	J 290 300
Distance/time (one way)	n/a
Terrain	n/a

This is a good view up a U-shaped valley, carved out by glacial action (Figure 75). It is possible to pull in with care at the side of the Slievenaman Road to view the Happy Valley. To the east (left), note the crags on the northern slops of Slieve Meelmore – these are of Silurian metasedimentary rocks.

Figure 75 View south up along the Happy Valley, a good example of a U-shaped valley.

26 Ott Mountain

What can be seen	Landslip influenced by geology; juvenile river, interlocking spurs;
Grid reference of starting point	J 280 279
Distance/time (one way)	0.8km/20mins
Terrain	Mountain track, wet in places
Exercises that can be done	River study
Other notes	This site is included because it is often used as a site for river studies. The presence of a small landslip that is heavily influenced by the geological structure of the area is a good illustration of the need to consider geology in engineering schemes e.g. road cuts.

Park at the Ott/Blue Quarry car park. Cross the road and stile, and walk along the lower track for c.0.8km to the Shimna River. At J 286 274 there is a small (10 x 15m) landslip on the eastern (far) side of the river. The movement of the soil has been facilitated by the dip of the Silurian metasediments here – there is a small outcrop of bedrock at the bottom downstream corner of the slip. There is also a prominent fault or separation along the top edge of the slip.

Figure 76 Small landslip on the slope of the Shimna River, where mass movement has occurred on a dipping bedding surface of the Silurian metasediments.

This upper section of the Shimna River displays very good examples of interlocking spurs, typical of a juvenile river. The body of water below is the Fofanny Dam reservoir, and the recently built water treatment works can be seen to have been designed to minimise their visual impact on the landscape.

27 Hen Mountain

What can be seen	Granite tors, rounded mountains
Grid reference of starting point	J 24 28
Distance/time (one way)	n/a
Terrain	n/a

While a number of mountains in the Mournes display good examples of tors (e.g. Slieve Binnian, Slieve Bearnagh, the Castles of Commedagh), Hen Mountain provides a lower, and more easily viewed, example of this landform. The smooth contours of the Mournes which are also obvious in this area can be attributed to the mountains being shaped by an over-riding ice sheet that smoothed off the surface. It is believed that the tors represent post-glacial weathering of rock along rebound joints that developed after the unloading by ice and overlying rock.

Figure 77 Hen Mountain from the north, showing the smooth lower slopes, and the craggy summit tors.

The Newry Igneous Complex

The Newry Igneous Complex is one of several large granite batholiths intruded in Ireland during and after the Iapetus Ocean closed (Figure 13). It intruded the Silurian metasediments of the Longford – Down Inlier c.425Ma ago, and is elongate along the strike of these rocks in a north-east – south-west direction (Figure 78). The complex consists of three overlapping granodiorite plutons with a small area of ultramafic-intermediate composition rocks at the north-eastern end. The south-western pluton has itself been intruded by the Palaeogene rocks of the Slieve Gullion Complex.

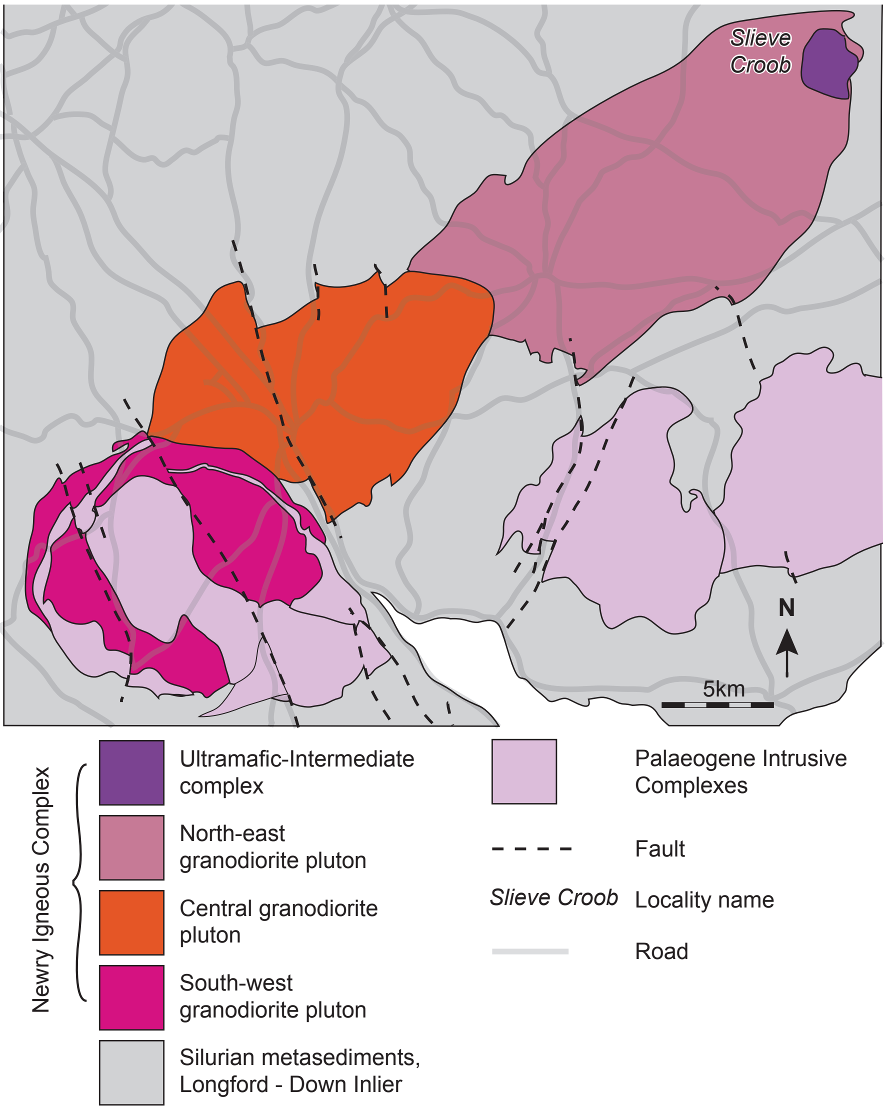

Figure 78 Geological map of the Newry Igneous Complex.

Like the rocks of Slieve Gullion, the Newry Igneous Complex has been the subject of debate between transformists, who held the view that the granodiorites were formed from the *in situ* transformation of the Silurian metasediments, and the magmatists, who believed that the complex formed through the emplacement and crystallisation of magma. The transformists interpreted hornfels formation and remobilisation of the metasediments close to the margins of the intrusion as support for their theory. However, despite this localised alteration of the metasediments, today it is generally accepted that the rocks are magmatic in origin.

The three granodiorite plutons are notable for their zoning: the north-east and south-west plutons are 'normally' zoned, with more mafic granodiorite at their margins grading to more quartz-rich granodiorite at the centre; the central pluton is reversely zoned. All three plutons show a strongly developed foliation at their margins that is sub-parallel to the foliation in the country rocks, but are unfoliated in their centres.

Slieve Croob

What can be seen	Excellent views of South Down landscape
Grid reference of starting point	J 300 452
Distance/time (one way)	2km/35mins
Terrain	Track, reasonably steep
Exercises that can be done	Landscape study; human settlement patterns
Other notes	Lower level views of the landscape may be had from Dree Road (J 300 452), Windy Gap (J 274 432), or Lighthouse Road (J 279 416)

Slieve Croob marks the most northerly extent of the Caledonian Newry Igneous Complex, and the contact between the Silurian country rocks and the granite is close to the summit of the mountain. On the walk up, the outcrops are of steeply-dipping metasediments, with their characteristic strike of NE-SW. Here, close to the igneous intrusion, the rocks have been baked and partially fused or mobilised, illustrating the great heat supplied by the intrusion of the Igneous Complex.

From the top of the mountain (at 534m), it can be seen that Slieve Croob is surrounded by low-lying rolling countryside. This is typical drumlin country, the rounded elongate hills formed under a moving ice sheet. The alignment of the long axes of the drumlins can be seen to change to flow around the high ground. To the south are the Mourne Mountains, with the conical profile of Slieve Donard distinctive at the eastern (left) end. The sand dunes and long sandy beach of Murlough and Newcastle can be seen to the north of the Mournes. To the north, Cave Hill and Belfast may be visible, while Lough Neagh lies to the north-west. On a very clear day the Sperrin Mountains may be visible beyond Lough Neagh, while the Isle of Man may be seen out in the Irish Sea. The River Lagan originates on the slopes of Slieve Croob. The river initially flows north-west to near Lurgan before changing direction to flow north-east through Belfast and into the sea at Belfast Lough.

Figure 79 View westwards from near the summit of Slieve Croob and the source of the River Lagan. (Photo: Mike Hartwell)

Figure 80 Slieve Croob from the Carnalroe Road. (Photo: Mourne Heritage Trust)

Appendix 1: Links with the syllabus

Leaving Certificate Geography

All **skills** can be taught and applied in the region: map interpretation, figure interpretation, photograph analysis, statistical analysis, figure drawing, information technology application.

1.1 The tectonic cycle: the area's geology reflects different plate tectonic settings – the closing of Iapetus and the opening of the Atlantic.
Geography of volcanoes and earthquakes: volcanic rocks associated with opening of Atlantic, fault zones are ancient earthquake zones.

1.2 The rock cycle: good examples of igneous, sedimentary and metamorphic rocks are available to study. Examples of physical and chemical weathering.
Mass wasting and erosion by rivers, sea, ice and wind: illustrated at a number of sites
Human interaction with rock cycle: extraction of building materials

1.3 Landform development (i): influence of geological structures on landform development. Faults, e.g. Cam Lough Fault, often form valleys. Good examples of folding, updoming, and faulting all to be seen in region. Influence of regional trend of folding in Silurian rocks on the general outline of the Newry Igneous Complex.

1.4 Landform development (ii): influence of rock characteristics on landform. Upland areas in region are underlain by relatively young igneous intrusions; low-lying plains are underlain by older rocks.

1.5 Landform development (iii): influence of surface processes. Coastal and glacial processes are well represented in the region.

1.6 Landform development (iv): the influence of isostasy on the development of landforms. Raised beaches, a result of isostatic adjustment, are well developed in the region.

1.7 Human interaction: vegetation development either side of the Mourne Wall illustrates the effect of overgrazing; some of the coastal sites have coastal defence structures; recreational pressures on coastal sites.

7.1 Geoecology (soil development): variations in parental rock type leads to variation in soil type; development of soils over time can be studied particularly well at Murlough.

7.2 Geoecology (soil characteristics)

GCE in Geography (CCEA)

4.4 Skills and techniques – data collection and data processing

3.3 Themes in physical geography

3.4 Themes in human geography – settlement patterns

3.6 Physical processes and human interactions – human use and interaction with fluvial and coastal environments, including sand dune ecosystem
Natural hazards and human activity – plate tectonics, distribution of volcanic and earthquake hazards

7.7 Processes and issues in human geography – agriculture, tourism

AS/A Level GCE Geology (WJEC)

GL1 Foundation geology – rocks and minerals
Rock cycle
Relationship of rock types to tectonic processes
Time and change
Uniformitarianism
Fossils
Relative dating of rocks (superposition of strata, 'way up', included fragments)
Geological maps – a record of geological change, faults, folds

GL3 Geology and the human environment
Volcanic hazards, earthquake hazards, mass movement hazards
Water supply
Mining

Civil engineering and geology (dams and reservoirs)

GL4 Granite composition related to tectonic setting
Xenoliths and enclaves
Sedimentary rocks – maturity
Metamorphic rocks – mineralogical changes, textures
Maps – structural features, outcrops and topography, faults, unconformities

GL5 Geological themes
Link between processes and product in modern settings
Climate change, isostatic response to ice loading and unloading
Quaternary deposits and landforms as a record of glaciation, influenced by geological structure and lithology
Geology of natural resources – industrial minerals (quarrying)
Geological evolution of Britain – distribution of rocks determined largely by tectonic activity and lithospheric plate movement
Former climates and latitudes interpreted through interpretation of sedimentary rocks and fossil assemblages
Geology of the lithosphere – the formation and deformation of continental crust

AS/A Level GCE Geology (OCR)

1.1 Global tectonics
Continental drift, sea floor spreading and plate tectonics
Geological structures – faults and folds, cross-cutting structures

1.2 Rocks – processes and products
The rock cycle
The geological column
Igneous processes and products – classification, grain size related to rate of cooling, concordant and discordant intrusions, intrusive and extrusive igneous rocks, caldera formation
Sedimentary processes and products – weathering and erosion, classification, sedimentary structures, sedimentary environments
Metamorphic processes and products – contact, regional and burial metamorphism

1.3 Practical skills in geology 1

1.4 Environmental geology
Water supply – especially reservoirs
Engineering geology – quarrying, dam construction, landslips, coastal defences,

1.5 Evolution of life, Earth and climate
Formation of fossils – body and trace
Dating methods, correlation methods and interpretation of geological maps
Changing climate

1.6 Practical skills in geology 2

Appendix 2: Bibliography and further reading

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Appendix 3: Some useful websites

Educational

www.habitas.org.uk/escr
geological sites in Northern Ireland included in Earth Science Conservation Review

www.mournelive.com/
website of the Mourne Heritage Trust

www.gsi.ie
Geological Survey of Ireland

www.geology.ie
website of the Irish Geological Association, details of field trips and lectures

www.bgs.ac.uk; www.bgs.ac.uk/gsni
British Geological Survey; Geological Survey of Northern Ireland

www.qpa.org.uk, www.virtualquarry.co.uk
UK Quarry Products Association sites

www.nienvironmentlink.org
environment information and links

www.gees.ac.uk
Geography, Earth and Environmental Sciences
esos.ukrigs.org.uk
a website for those interested in using field sites for educational purposes

www.geolsoc.org.uk
Geological Society of London's site

www.northstone-ni.com/about-us/education
Northstone basalt quarry – road aggregate

www.earthlearningidea.com
an idea each week for the International Year of Planet Earth, 2008

www.geopix.org
geological images and simple explanations

www.nrcan.gc.ca/mms/scho-ecol/toc_e.htm
Canadian site providing information about the uses of metals and minerals

www.usgs.gov
website of the US Geological Survey, extensive educational section

Visiting the Area

www.newryandmourne
www.carlingford.ie
www.louthcoco.ie
www.south-armagh.com
www.mournelive.com
www.kingdomsofdown.com
www.downdc.gov.uk
www.armagh.gov.uk
www.armaghanddown.com
www.visitnewryandmourne.com
www.banbridge.gov.uk
www.louthheritage.ie
www.louthholidays.com
www.discoverireland.ie

Appendix 4: Accommodation

The following list is not exhaustive, only including hostel-style accommodation. Self-catering cottages, B&Bs etc may be found through the local tourism offices (websites listed in Appendix 3).

Cooley	
The Foy Centre Dundalk Street Carlingford Co Louth	Tel: +353 (0)42 938 3624 Fax: +353 (0)42 938 3625 e-mail: info@carlingfordbeds.com www.carlingfordbeds.com
Carlingford Adventure Centre Tholsel Street Carlingford Co Louth	Tel: +353 (0)42 937 3100 Fax: +353 (0)42 937 3651 e-mail: info@carlingfordadventure.com www.carlingfordadventure.com
Gullion	
Tí Chulainn Mullaghbawn Newry BT35 9TT	Tel: +44 (0)28 3088 8828 e-mail: tichulainn@btconnect.com www.tichulainn.com
Mourne	
Meelmore Lodge 52 Trassey Road Bryansford Newcastle Co Down BT33 0QB	Tel: +44 (0)28 4372 6657 Fax: +44 (0)28 4372 3925 e-mail: info@meelmorelodge.com www.meelmorelodge.co.uk
Cnocnafeola Activity & Conference Centre Bog Road Attical Kilkeel Co Down BT34 4HT	Tel: +44 (0)28 4176 5859 / (0)28 4176 2952 Mob: +44 (0)7918 197 000 e-mail: info@mournehostel.com www.mournehostel.com
Cornmill Quay Hostel Marine Park Annalong Co Down BT34 4QJ	Tel: +44 (0)28 4376 8269 Mob: +44 (0)7729 808 206 e-mail: info@cornmillquay.com www.cornmillquay.com
Slieve Croob	
Slieve Croob Inn 119 Clanvaraghan Road Castlewellan Co Down BT31 9JG	Tel: +44 (0)28 4377 1412 Fax: +44 (0)28 4377 1162 e-mail: info@slievecroobinn.com www.slievecroobinn.com

Glossary

agglomerate	a rock composed of large fragments produced in a violent volcanic eruption
aggregate	pieces of (crushed) rock used in the manufacture of concrete or road surfaces
aeolian	to do with the wind
Avalonia	former continental mass that collided with Laurentia as Iapetus closed
basalt	a mafic fine-grained, volcanic rock, chemical equivalent of gabbro
batholith	igneous intrusion composed of a number of plutons
breccia	coarse-grained sedimentary rock with large (>2mm), angular clasts (cf. conglomerate)
calcite	mineral, calcium carbonate, $CaCO_3$, main constituent of limestone
Caledonian Orogeny	mountain-building event associated with closing of Iapetus
Carboniferous	period of geological time
cauldron subsidence	a proposed mechanism of granite emplacement, involves development of circular fracture (ring-dyke) along which country rock subsides, allowing ascent and emplacement of magma in shape similar to upside-down flower-pot
chilled margin	finer-grained margin of igneous rock where it has cooled rapidly due to coming into contact with cold country rock
clast	fragment of rock, usually refers to fragments making up sediments or sedimentary rocks
cleavage	tectonic cleavage is the splitting of rock into parallel plates when subjected to deformation; crystal cleavage is the tendency for some minerals to split along parallel planes, and is a diagnostic feature of minerals
cone-sheet	a planar, minor igneous intrusion, in the form of curved, inward dipping sheets (cf. ring-dyke)
conglomerate	coarse-grained sedimentary rock with large (>2mm), rounded clasts (cf. breccia)
corrie	a deep, semi-circular hollow formed at the head of a glacier, typified by steep back walls (from Irish coire 'cauldron'); also known as a cirque or cwm
country rock	the older rock into which magma may be intruded
cross-bedding	sedimentary structure in which laminations are at an angle to the bedding surface; results from ripple formation
Devonian	period of geological time
diamict	poorly-sorted sediment of glacial origin, ranging in size from clay to boulders; also known as boulder clay or till
dip	the angle of maximum slope of a planar surface (e.g. a contact or fault) measured in degrees from the horizontal; steeply dipping surfaces are close to vertical, gently dipping surfaces are close to horizontal; also the direction of dip; usually recorded in conjunction with strike
dolerite	medium-grained mafic rock, chemical equivalent of basalt and gabbro

drumlin	rounded, elongate hill formed under ice-sheet; elongation of hills parallel to ice-flow direction (from Irish droim 'ridge')
drusy cavity	cavity in igneous rock with well-developed crystals
dyke	minor igneous intrusion in which sheet of magma has intruded across structures in country rock (cf. sill)
enclave	inclusion of one igneous rock in another as a result of the mingling of two magmas
erosion	wearing away of the land surface by mechanical action of transported debris
erratic	distinctive clast transported from its place of origin by ice
eustatic	global change in sea-level (cf. isostasy)
fault	a break in the rock along which movement has happened
feldspar	most common mineral in Earth's crust, a complex aluminium silicate containing calcium ± sodium ± potassium
felsic	igneous rock containing high proportion of feldspar and quartz, and therefore high in silica, e.g. granite (cf. mafic); also used to refer to minerals high in silica such as quartz, feldspar
fjord	sea inlet that was once a glaciated valley, typically has a shallow mouth
foliation	a platy fabric in a rock usually due to the parallel alignment of flat platy minerals such as biotite
gabbro	coarse-grained plutonic mafic rock, chemical equivalent of basalt; typically consists of pyroxene, and calcium-rich feldspar
granite	coarse-grained plutonic felsic rock, chemical equivalent of rhyolite; consists of quartz, and Na- and K-rich feldspars
granodiorite	coarse-grained plutonic felsic rock, similar to granite but with greater proportion of Ca-rich feldspars and more mafic minerals
hornfels	metamorphic rock formed through contact metamorphism close to igneous intrusions; forms hard rocks that break in splintery fragments
hybridisation	process by which two or more magmas mix to form a rock type of intermediate composition; incomplete hybridisation produces a mingled rock with enclaves
Iapetus	ancient ocean that started to open c.800Ma and closed c.400Ma, approximately along the line of the present-day Atlantic; closing of Iapetus led to the joining of the SE and NW parts of Ireland in the Caledonian Orogeny; in mythology, Iapetus was the father of Atlantis
igneous	of magmatic origin (from ignis 'fire')
iron pan	thin layer of iron minerals deposited in soil below a leached horizon
isostasy	the process of equilibration of the Earth's crust relative to the mantle – analogous to a block of wood floating in water, which will rebound if depressed below its equilibrium level
laccolith	blister-like igneous intrusion with a domed top (cf. lopolith)

Laurentia	former continental mass that collided with Avalonia as Iapetus closed;
limestone	organic sedimentary rock formed from the accumulation of the remains of calcareous sea creatures
lobate	curved or lobed contact – in igneous rocks it implies that the contact was between two magmas rather than a rock and a magma
lopolith	saucer-shaped igneous intrusion (cf. laccolith)
mafic	igneous rock containing high proportion of minerals such as pyroxene, amphibole, and therefore low in silica (cf. felsic); also used to refer to minerals high in magnesium and iron such as pyroxene, amphibole, olivine
magma	molten rock
metamorphic	describing a rock which has been altered through the processes of heat and/or pressure
metasediments	umbrella term for metamorphosed sedimentary rock
Midlandian	youngest episode of glaciation in Ireland 35,000 -13,000 years BP
moraine	landform composed of diamict and/or sand & gravel formed at the margin of an ice sheet by a combination of depositional and tectonic processes
OD	ordnance datum i.e. mean sea level as defined for the Ordnance Survey
olivine	mafic silicate mineral rich in iron and magnesium
Ordovician	period of geological time
Palaeogene	period of geological time
palaeosol	ancient soil
phenocryst	larger crystal in porphyritic igneous rock
plagioclase	feldspar containing varying proportions of calcium and sodium
pluton	large igneous intrusion
plutonic	igneous rock formed below the surface; slow cooling allows larger crystals to form; relating to these rocks (cf. volcanic)
porphyritic	igneous rock composed of larger crystals (phenocrysts) in a finer-grained groundmass
protolith	the original rock from which a metamorphic rock has formed
PSV	Polished Stone Value – a measure of the resistance of rock types to polishing; higher values are required for aggregate to be used in road surfaces
pyroclastic	relating to material ejected into the atmosphere by explosive volcanic activity, such as ash or pumice; may form highly dangerous flows of hot ash and gas known as a nuée ardente; resultant rock types include tuffs
pyroxene	mafic silicate mineral rich in iron and magnesium
quartz	silicon dioxide, SiO_2

raised beach	ancient beach found above present-day sea level due to post-glacial isostatic adjustment
rhyolite	fine-grained volcanic felsic rock, chemical equivalent of granite; consists of quartz, and Na- and K-rich feldspars
ring-dyke	a planar, minor igneous intrusion, in the form of curved, outward dipping sheets (cf. cone-sheet)
sandstone	sedimentary rock, grain size = 2-0.625mm
scree	small loose stones, typically on a mountain side, formed through freeze-thaw action (comes from Old Norse word for landslip)
shale	sedimentary rock, grain size = <0.005mm
sill	minor igneous intrusion in which sheet of magma has intruded parallel to planar structure (e.g. bedding planes) in country rock (cf. dyke)
siltstone	sedimentary rock, grain size = 0.625-0.005mm
Silurian	period of geological time
skarn	metamorphic rock formed through contact metamorphism of limestone close to igneous intrusions
sole mark	sedimentary structure on base of bed consisting of cast of groove on top of underlying bed; useful indicator of 'way-up' of bedding
striation	scratch on rock surface caused during movement of ice; may occur on bedrock or on boulders transported in ice
strike	azimuthal direction of a horizontal line on a planar surface (e.g. contact or fault); usually recorded in conjunction with dip
tor	feature of granite uplands where uplift and weathering along joints has led to rocky outcrops with blocky appearance
tuff	rock formed from volcanic ash (a pyroclastic rock), usually formed from sand- to silt-sized particles
U-shaped valley	typical form of a glacial valley
volcanic	igneous rock formed above the surface; rapid cooling means only small crystals form; relating to these rocks (cf. plutonic)
weathering	chemical decay and physical fragmentation of minerals at the Earth's surface in situ (in place)
xenolith	inclusion of country rock in igneous intrusion ('foreign rock')

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