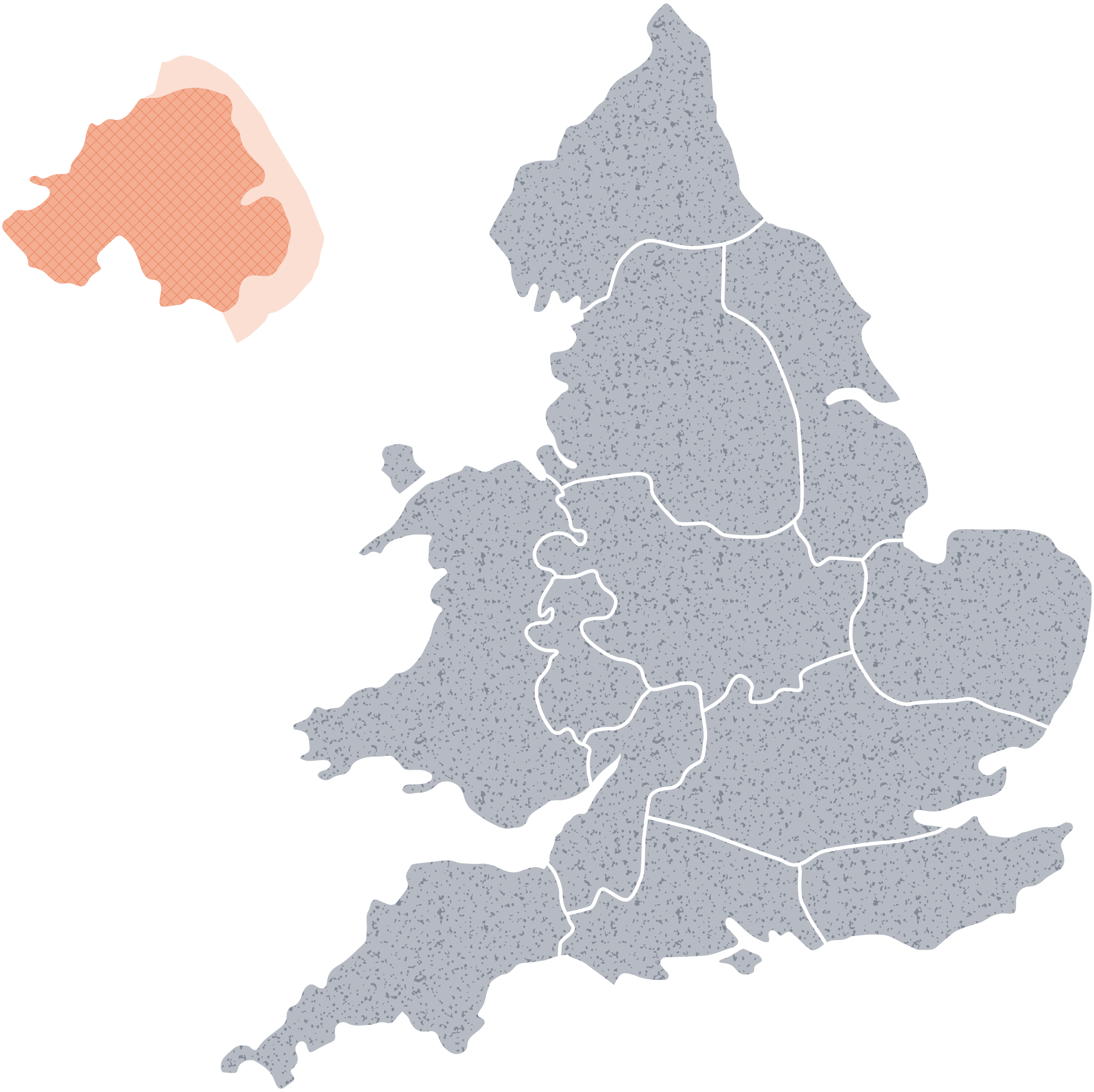
Radioactive Waste Management



Northern Ireland

REGIONAL GEOLOGY

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Clicking on words in green, such as sedimentary or lava will take the reader to a brief non-technical explanation of that word in the Glossary section. By clicking on the highlighted word in the Glossary, the reader will be taken back to the page they were on.

Clicking on words in blue, such as Higher Strength Rock or groundwater will take the reader to a brief talking head video or animation providing a non-technical explanation.

For the purposes of this work the BGS only used data which was publicly available at the end of February 2016. The one exception to this was the extent of Petroleum Licences which was updated to include data to the end of June 2018.

Introduction

This region comprises the country of Northern Ireland and includes the adjacent inshore area which extends to 20km from the coast.

Subregions

To present the conclusions of our work in a concise and accessible way, we have divided Northern Ireland into 4 subregions (see Figure 1 below). We have selected subregions with broadly similar geological attributes relevant to the safety of a GDF, although there is still considerable variability in each subregion. The boundaries between subregions may locally coincide with the extent of a particular Rock Type of Interest, or may correspond to discrete features such as faults. Although screening has focused on the 200 to 1,000m depth range, which is consistent with the Implementing Geological Disposal White Paper and National Geological Screening Guidance, we recognise that some rock types may be suitable as host rocks where they occur at depths greater than 1,000m.

Northern Ireland: summary of the regional geology

What follows is a summary of the geology of the region, emphasising the geological attributes that are relevant to meeting the safety requirements for a GDF. Information about the geology of the Northern Ireland has been summarised by the British Geological Survey (BGS) in a Technical Information Report (TIR) on which this summary is based. Information about the geology of the country comes from geological mapping, geophysical surveys and boreholes.

Available information for this region

Much of the surface geology of Northern Ireland has been surveyed in great detail and can be examined in numerous mountain, stream and coastal exposures of rock and man-made excavations such as quarries or road cuttings. There are about 45 boreholes extending below 200m, drilled during the search for hydrocarbons, minerals and geothermal resources across the country. A recent airborne geophysical survey, referred to as the Northern Ireland Tellus Project, has provided new, high resolution geophysical data that reveal patterns of the Earth's gravity and magnetic field. Understanding these patterns, when combined with geophysical seismic survey data obtained by sending sound waves through the ground, allows interpretation of the geological structure to a depth of several kilometres. There are a number of shallower boreholes that provide information on groundwater above 200m, but very little information within and deeper than the depth range of interest for a GDF, 200 to 1,000m below NGS datum.

Rock type

In order to describe the rocks present in Northern Ireland we have divided them into 4 groups: younger igneous rocks, younger sedimentary rocks, older sedimentary rocks and basement rocks. These are summarised in Figure 2, which is a simplified rock column showing the oldest and deepest rocks at the bottom, with progressively younger rock units towards the top. Figure 3 is a geological map of Northern Ireland showing where the major rock units occur at the surface. Figure 4 presents a schematic vertical cross-section through the country. Within the 4 groups, individual rock units have been identified as Rock Types of Interest for the development of a GDF; Higher Strength Rock (HSR), Lower Strength Sedimentary Rock (LSSR) and Evaporite. Figures 5a to 5d show where in the country there are likely to be Rock Types of Interest for the development of a GDF within the depth range of interest.

Younger igneous rocks

The youngest of the 4 main groups of rocks are the Antrim Plateau basalts that formed from molten lava originating from great depths during the Palaeogene period (approx. 25 to 65 million years ago), many millions of years after the other rocks had been formed. The granites and related rocks of the Mourne Mountains and Slieve Gullion Complex were formed as large masses, hundreds of metres thick, from the solidification of molten rock below ancient volcanoes. The dolerite and gabbro sills of the Antrim Plateau and its margins comprise less continuous masses of intrusive igneous rocks. The Antrim Lava Group rocks are basalts (extrusive igneous rocks), produced by the same volcanic activity as the sills about 60 million years ago. Recent interpretation of an airborne geophysical survey (Northern Ireland Tellus Project) has revealed large numbers of intrusive igneous dykes, most numerous in County Down, County Tyrone and County Fermanagh. They are typically less than 10m wide, although they can be as wide as 90m and are broadly aligned north-west to south-east. Where dykes are particularly abundant they are referred to as a dyke swarm. The granites and the thicker dolerite and gabbro sills are potential HSR host rocks.

Younger sedimentary rocks

The second group comprises a broadly horizontal sequence of younger sedimentary rocks, deposited between approximately 65 and 300 million years ago, including mudstones, limestones and sandstones. These rocks are found in the north-east, in the area of the Antrim Plateau and its margins, occurring underneath the basalts of the younger igneous rocks. They include 2 potential LSSR layers: the Jurassic Lias Group (about 200 million years old) and Triassic Mercia Mudstone Group (about 250 million years old). The Lias Group comprises up to 250m of mudstones and siltstones with thinner limestone and sandstone layers, and the Mercia Mudstone Group comprises up to 1,030m of mudstones with thinner siltstone and sandstone layers. Thick layers of rock salt (halite), potential Evaporite host rocks, are also present within the Mercia Mudstone Group under parts of south-east County Antrim between Larne and Belfast and may be present in some of the other sedimentary basins in County Antrim (Lough Neagh and Rathlin Basins).

Older sedimentary rocks

Rocks of Carboniferous to Devonian age (approx. 300 to 420 million years old) are present in the south-west, in the Lakelands of County Fermanagh and further east around Dungannon and Cookstown. These are referred to here as older sedimentary rocks and include limestones, sandstones, mudstones and some shallow coal seams. They have been buried sufficiently deeply such that they are now more compacted than the younger sedimentary rocks above; however, none of these rocks have been identified as potential host rocks by the BGS.

Basement rocks

The oldest group of rocks in Northern Ireland comprises rocks of Silurian age or older (more than about 420 million years old), together with Devonian granites which were intruded into them around 400 million years ago. They form the basement to the younger rocks and fall into 3 distinct terranes on the basis of their geological characteristics.

In the north-west, the basement comprises metamorphic rocks of the Dalradian Supergroup, sedimentary and volcanic rocks deposited approximately 570 to 650 million years ago, and referred to as the Grampian Terrane. The sedimentary layers originally comprised sandstone, mudstone and some limestone interleaved with basalt lavas and sills. When these rocks were buried and heated during a later period of tectonic movement they were metamorphosed to form schists, amphibolite and marble. These rocks are present at the surface in the Sperrin Mountains, and between Ballycastle and Cushendall (known as the North East Antrim Inlier).

In the central part of the country, the basement seen at the surface between Omagh and Cookstown comprises a complex mix of metamorphosed igneous and sedimentary rocks that originally formed an ocean floor and is referred to as the Midland Valley Terrane. Where these rocks do not reach the surface they are generally below the depth range of interest.

In the south-east the basement rocks, referred to as the Southern Uplands-Down-Longford Terrane, comprise sandstones and mudstones which have been pervasively folded and metamorphosed so that the finer grained rocks are now slaty. In the vicinity of Newry (from Slieve Gullion to Slieve Croob), a sequence of granite masses, several kilometres deep, were emplaced into these slaty rocks about 400 million years ago.

Rock Structure

As described under Rock Type above, the metamorphic basement rocks in Northern Ireland are divided into 3 broad 'terranes' based upon the type of folding and burial the rocks have experienced. The 3 terranes are divided by 2 major fault structures, which are considered to be continuations of similar structures in Scotland (see Figure 6). The Belhavel-Omagh Thrust-Highland Boundary Faults separate the Grampian Terrane from the Midland Valley Terrane (AA' on Figure 6), while the Southern Uplands Fault separates the Midland Valley Terrane from the Southern Uplands-Down-Longford Terrane (BB' on Figure 6).

As Figure 6 shows, most of the major faults are aligned broadly south-west to north-east. Although the basement rocks are extensively faulted, fewer faults affect the overlying older and younger sedimentary rocks in the south-west and north-east or the igneous rocks around Newry and the Mourne Mountains.

Faults occur on a diverse range of scales, from centimetres to kilometres, and the subsurface is criss-crossed by networks of numerous individual faults. However our work includes only those faults identified by the BGS with throws (vertical offset) of 200m or more. This is because the data available to the BGS are not able to resolve all faults consistently, across all thirteen regions, with throws less than 200m.

Folding is also predominantly confined to the basement rocks. Both the Dalradian metamorphic rocks of the Grampian Terrane and the weakly metamorphosed rocks of the Southern Upland-Down-Longford Terrane are tightly folded throughout. The older sedimentary rocks in the south-west were also gently folded by later tectonic movements about 290 million years ago, which has resulted in more intense deformation adjacent to some major structures such as the Omagh Thrust.

Groundwater

There is very little information on groundwater in the depth range of interest for a GDF, 200 to 1,000m below NGS datum, although there is information on groundwater in aquifers above 200m. Northern Ireland contains 4 major aquifers. Three of these are layers within the younger sedimentary rocks of the Antrim Plateau while the other is within the older sedimentary rocks in the south-west. There are no major aquifers in the north-west or the south-east.

The Cretaceous Ulster White Limestone Formation (equivalent to the Chalk Group in England) and Hibernian Greensand Formation act together as a single aquifer within 400m of the surface, which is used for public water supply across the north-west. Most exploitation and investigation of the older Sherwood Sandstone Group and Enler Group aquifers has been focused on the Lagan and Enler Valleys, west of Belfast. The low permeability Mercia Mudstone and Lias Groups provide hydraulic separation between the underlying Sherwood Sandstone Group aquifer and the overlying Cretaceous aquifer.

The Carboniferous Limestone aquifer is a major aquifer within the older sedimentary rocks in the south-west. In both the Carboniferous Limestone aquifer and the Ulster White Limestone Formation aquifers, karstic conditions have developed in some places, where concentration of groundwater flow has enlarged fractures by dissolution to form a network of major channels and caves, resulting in fast movement of groundwater near the surface.

The basement rocks do not normally provide a water source except where intensely fractured and weathered near the surface and there is little or no information about the hydrogeological properties of potential host rocks at depth. There are no thermal springs in Northern Ireland to suggest rapid flow of deep groundwater to the surface. Groundwater from depths greater than 400m is unlikely to be suitable as drinking water anywhere in the UK [1].

[1] Water Framework Directive UK TAG. Defining and reporting on groundwater bodies, 2012.

Resources

Lead was mined historically in the south-east to depths below 200m and the Conlig Mine was one of the major lead mines in the UK during the 19th Century (Figure 7a).

Two small shallow coalfield areas around Coalisland, just north of Dungannon, County Tyrone and Ballycastle, County Antrim were mined, initially at the surface and subsequently underground. Mining reached depths of around 270m below NGS datum at Coalisland (Figure 7b), but has now ceased in both areas.

There are no producing oil or gas fields in Northern Ireland, although recent exploration has indicated that there may be significant resources in the Rathlin, Larne and Lough Neagh sedimentary basins. A number of Petroleum Licences are currently held in this area to allow companies to explore for these resources (see Figure 7c).

Rock salt (halite) deposits occur in the younger sedimentary rocks around Larne. There is no borehole information from the deepest parts of the Lough Neagh and Rathlin basins to confirm if salt is also present there. Historically the rock salt in the Mercia Mudstone Group was mined in the south and east of County Antrim, using both conventional mining and solution mining. There is currently 1 active salt mine at Kilroot near Carrickfergus, which has a maximum depth of around 400m and around 2km2of workings (Figure 7d).

There are 2 projects to develop Compressed Air Energy Storage (CAES) and natural gas storage caverns in rock salt at depths of 1,400 to 1,800m below NGS datum on Islandmagee near Larne, County Antrim.

Iron ore in the Antrim Lava Group was worked extensively from the 18th century through to the 1920s (Figure 7d). The ore was accessed by horizontal tunnels (adits) driven into the valley sides and therefore was not worked deeper than 100m below NGS datum.

More recently drilling within the Sperrin Mountains has shown that copper, lead and zinc mineralisation occurs at depths greater than 100m below NGS datum in this area. Further lead-zinc deposits may also be associated with faults in Carboniferous rocks (approx. 300 to 360 million years old) in areas such as Navan and Meath. Two significant gold deposits occur at Cavanacaw and Curraghinalt near to Omagh in County Tyrone (Figure 7d), extending to depths of 300 to 400m respectively; recent exploration has identified further deposits near Clay Lake, County Armagh and to the south of Belfast.

There is some deep geothermal energy potential associated with the younger granite intrusions of the Mourne Mountains and the deep porous sedimentary basins of County Antrim.

Areas where concentrations of deep exploration boreholes would need to be considered in the siting of a GDF are shown on Figure 8.

Natural processes

The UK has low levels of earthquake activity and correspondingly low seismic hazard. Earthquakes are seldom large enough to be felt and the ground surface is not known to have been broken by active faults. There have been no recorded earthquakes of magnitude 3.0Mw or greater in Northern Ireland although earthquakes in western Scotland (e.g. 1880 4.9Mw Argyll earthquake) have been felt in Northern Ireland.

Whilst the design of a GDF will need to consider the potential impact of future earthquakes, there is no evidence that future seismicity anywhere in the UK would preclude its development.

Geological evidence suggests that Northern Ireland was extensively glaciated during the last continental-scale glaciation (the Midlandian Glaciation c.29,000 and 15,000 years ago, which is equivalent to the Late Devensian Glaciation of the rest of the UK). Geological evidence also demonstrates the presence of a small highland-scale glaciation in the Mourne Mountains (ending just over 11,000 years ago). Over the next million years, it is likely that Northern Ireland will experience further highland-scale glaciation and potentially lowland and continental-scale glaciations. The precise siting and design of a GDF would need to consider the potential impacts of glaciation and permafrost during future continental scale glaciations. These may include increased erosion and changes to groundwater movement.

The coastal parts of Northern Ireland are susceptible to future groundwater changes in response to sea level change. The precise siting and design of a GDF would therefore consider the potential impacts of future sea level change.

Further information

More information about the geology of Northern Ireland can be found in the BGS Regional Summary, with additional detail in the BGS Regional Guide. This also provides details about many of the sources of information underpinning the TIR.

Figure 1 Subregions of Northern Ireland as defined for the purpose of National Geological Screening.

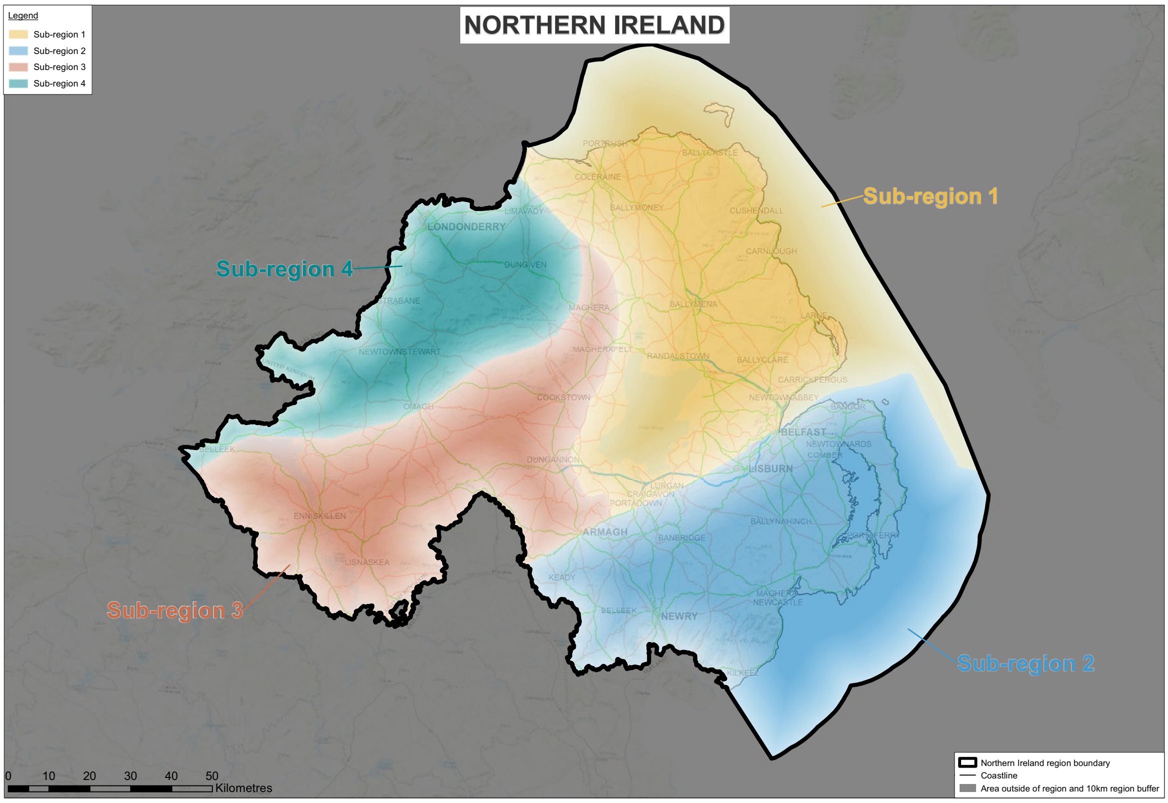

Figure 2 Table illustrating the sequence of the major rock units present in Northern Ireland and their possible significance for the siting of a GDF [2].

	Geological Period (age in millions of years)	Geological Unit	Dominant Lithology	Rock types of interest		
				LSSR	HSR	Evaporite
Younger Igneous Rocks	Palaeogene (23.0 – 66.0)	Mourne Mountains Complex	granite		✓	
		Palaeogene sills and sill complexes	dolerite and gabbro		✓	
		Antrim Lava Group	basalt			
Younger Sedimentary Rocks	Cretaceous (66.0 – 145.0)	Ulster White Limestone and Hibernian Greensand Formations	chalk and sandstone, siltstone and mudstone			
	Jurassic (145.0 – 201.3)	Lias and Penarth Groups	mudstone, siltstone, limestone and sandstone	✓		
	Triassic (201.3 – 251.9)	Mercia Mudstone Group (including Larne, Carnduff and Ballyboley halites)	mudstone, siltstone and sandstone with rock salt (halite)	✓		✓
		Sherwood Sandstone Group	sandstone, siltstone and mudstone			
	Permian (251.9 – 298.9)	Belfast Group	limestone, mudstone, sandstone and siltstone			
		Enler Group	sandstone, breccia, siltstone and mudstone			
Older Sedimentary Rocks	Carboniferous (298.9 – 358.9)	Coal Measures and Millstone Grit Groups	mudstone, siltstone, sandstone and coal			
		Tyrone Group ('Carbonifeous Limestone')	limestone and mudstone			
		Roe Valley Group	mudstone, limestone and siltstone			
	Devonian (358.9 – 419.2)	Fintona and Cross Slieve Groups ('Old Red Sandstone'	sandstone and conglomerates with mudstone			
Basement	Silurian to Devonian (358.9 – 443.8)	Newry Igneous Complex	granite and granodiorite		✓	
	Silurian (419.2 443.8)	Silurian sedimentary rocks (including Hawick and Gala Groups)	metamorphosed sandstone			
	Ordovician (443.8 – 485.4)	Ordovician sedimentary rocks (Leadhills Supergroup)	metamorphosed sandstone			
		Tyrone Igneous Complex	granite		✓	
	Neoproterozoic (Older than 541.0)	Dalradian Supergroup	Metasediments (psammite, quartzite, semipelite, pelite, limestone) and metamorphosed basic igneous rocks			
		Dalradian sills in Argyll Group	metabasites (metamorphosed dolerite and gabbro)		✓	
		Moine Supergroup (Tyrone Central Inlier and Lough Derg Group)	psammite and semipelite		✓	

[2] Gaps in time in this column with no rock types shown either represent periods when no rocks were being formed or indicate that the rocks formed during these periods have subsequently been removed by erosion.

Figure 3 Generalised geological map showing the distribution of rock units in Northern Ireland. The inset shows the location of Northern Ireland in the UK. The bold black lines give the locations of the cross-sections shown in Figure 4. See Figure 2 for the key to the rock types.

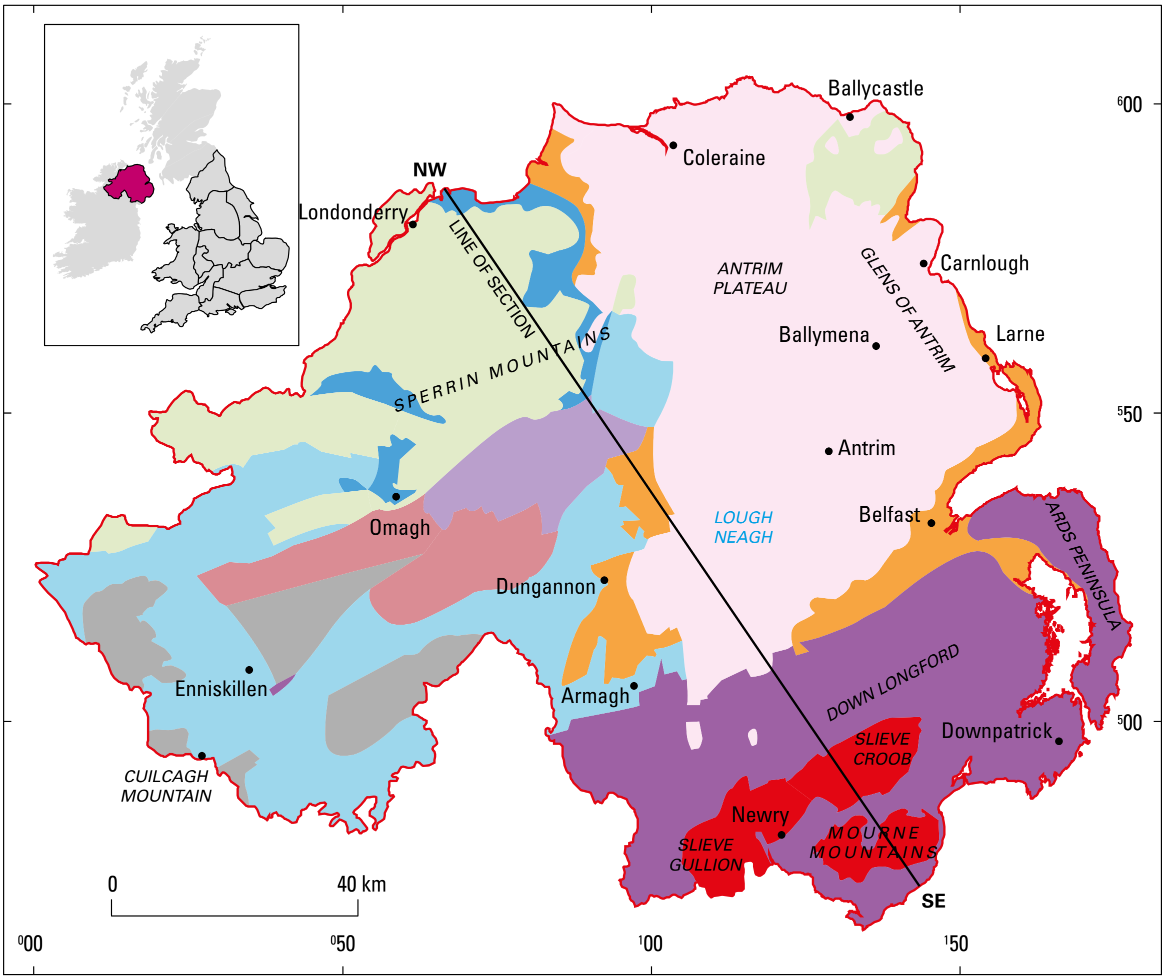

Figure 4 Schematic cross-section through Northern Ireland from north-west to south-east. The alignment of the section is shown in Figure 3. Note that the vertical scale is greatly exaggerated and actual dips of rock layers are much gentler than they appear here. Note also that the underground shape of the margins of the granite bodies (in red) are highly speculative and, as part of a site selection process, we would need to undertake detailed investigations to fully understand their detailed geometry. See Figure 2 for the key to the rock types.

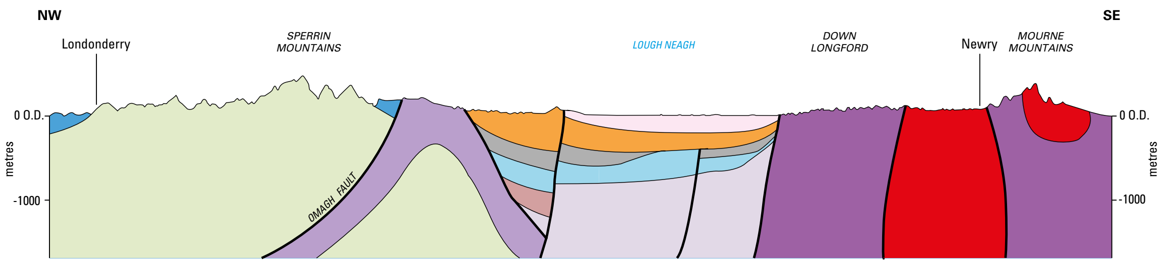

Figure 5a The areas of Northern Ireland where any of the 3 Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

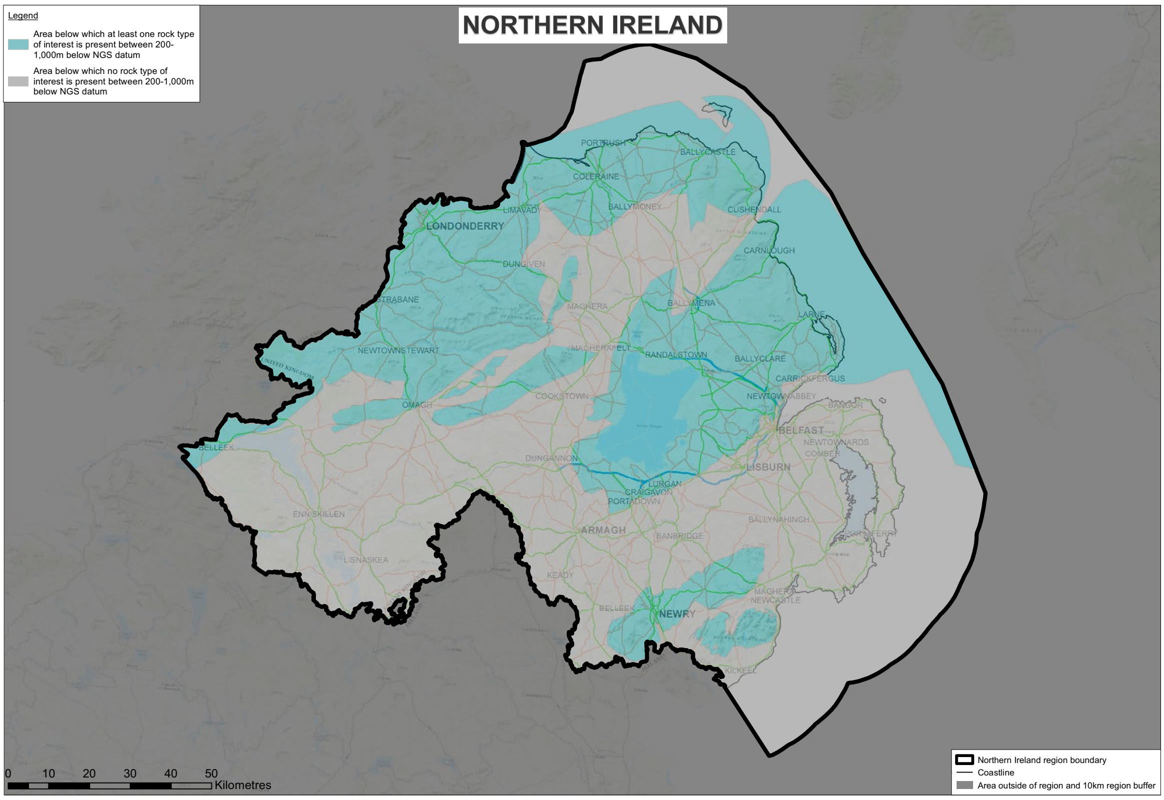

Figure 5b The areas of Northern Ireland where Lower Strength Sedimentary Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

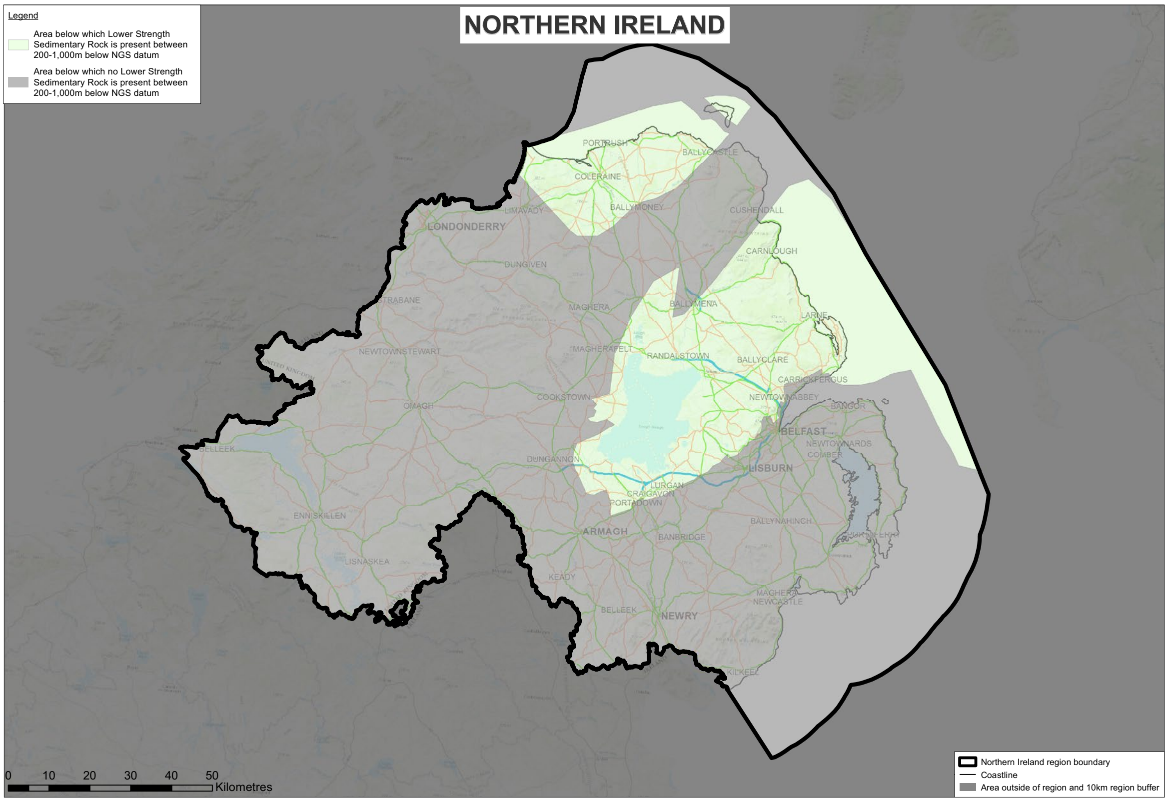

Figure 5c The areas of Northern Ireland where Higher Strength Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

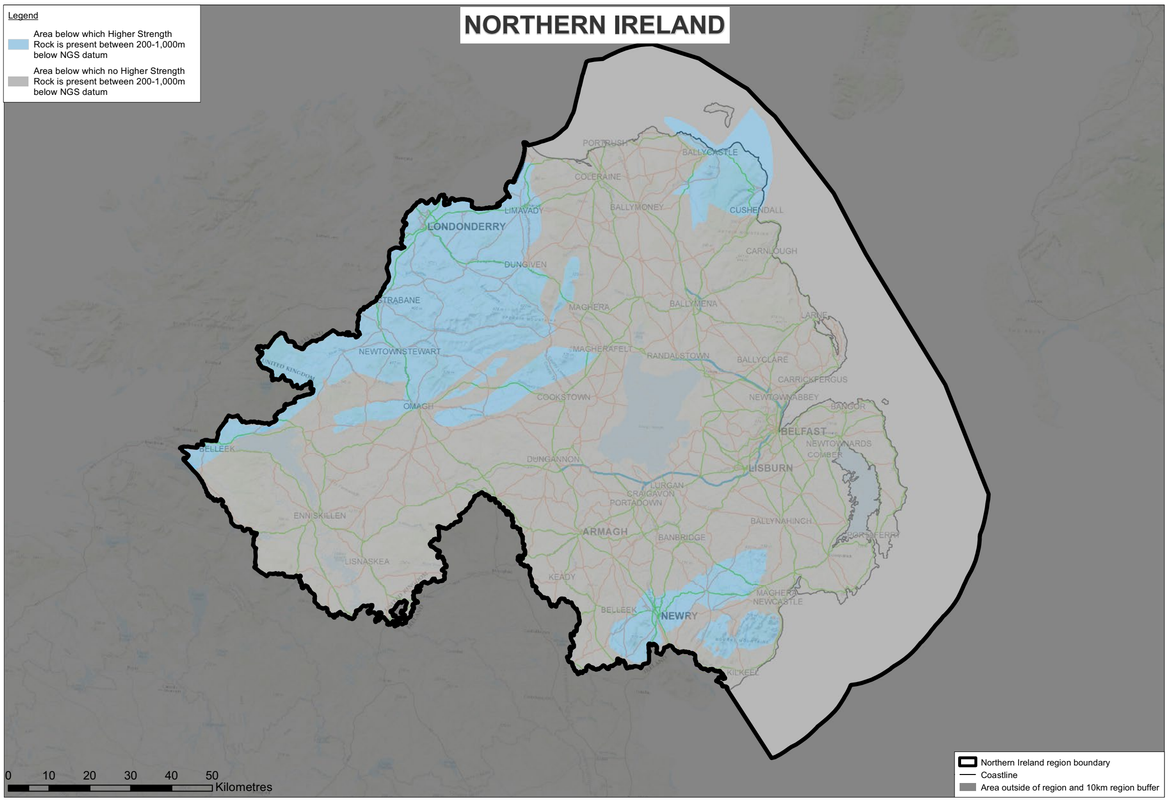

Figure 5d The areas of Northern Ireland where Evaporite Rock Types of Interest are present between 200 and 1,000 m below NGS datum.

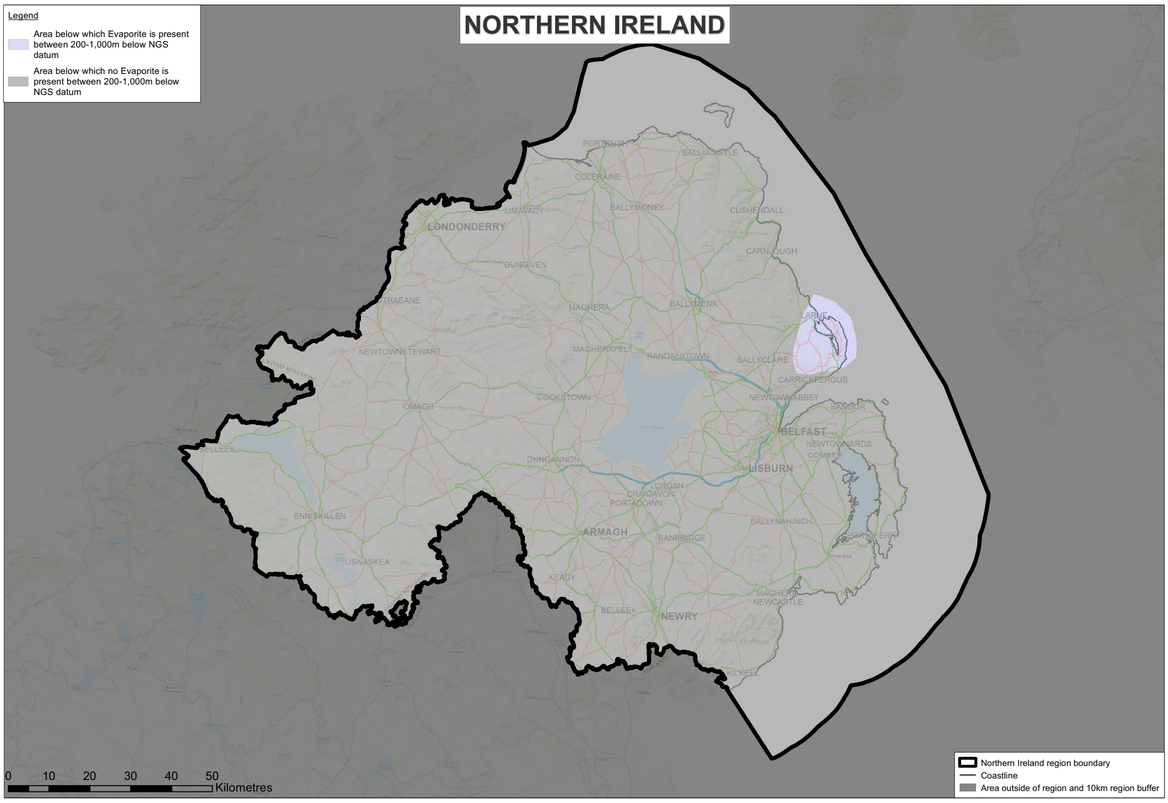

Figure 6 Location of major faults in Northern Ireland.

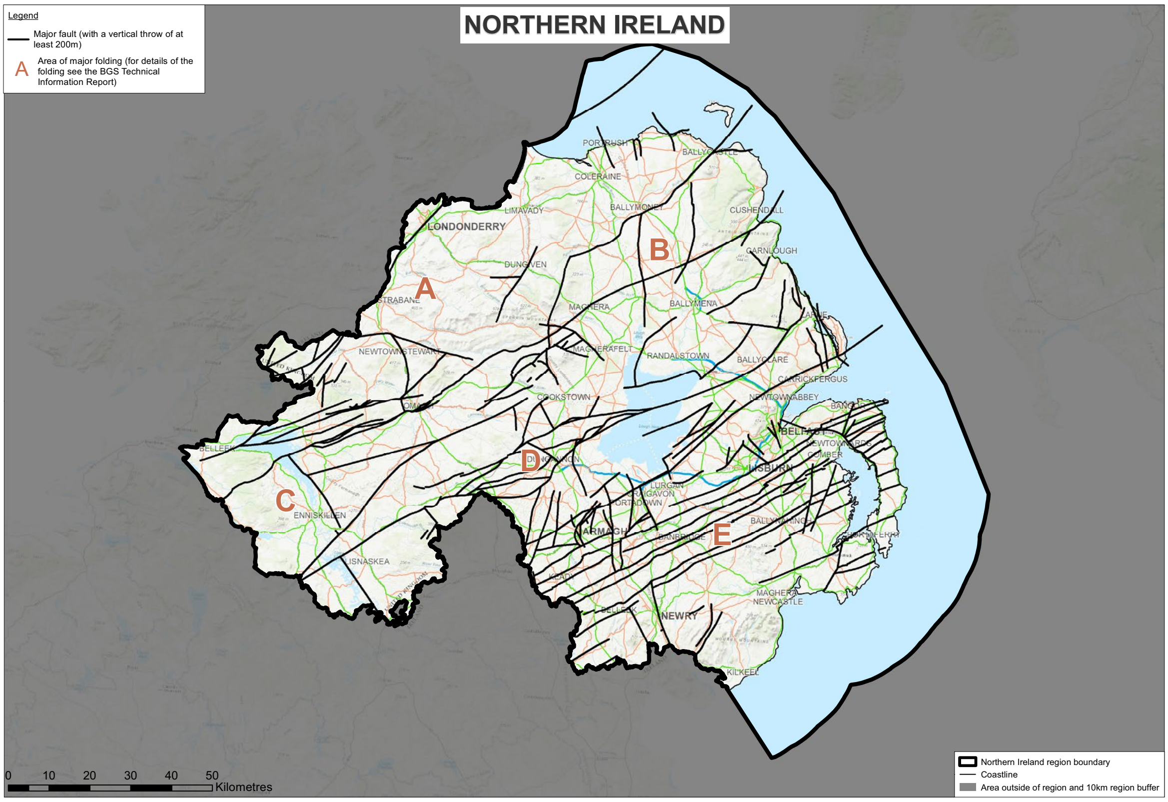

Figure 7a Areas of Northern Ireland with lead mines present below 100m.

Figure 7b Areas of Northern Ireland with coal mines more than 100m deep.

Figure 7c Areas of Northern Ireland with Petroleum Exploration and Development Licences.

Figure 7d Areas of Northern Ireland with historical iron ore mines less than 100m deep, known mineral prospects and evaporite mines below 100m.

Figure 8 Areas in Northern Ireland with concentrations of deep exploration boreholes.

Glossary

Active faults
A fault that has moved once or more in the last 10,000 years and is likely to become the source of an earthquake at some time in the future.

Adit
A horizontal entrance or passage into an underground mine.

Aquifers
Aquifers are rocks that contain freshwater in pores and/or fractures and whose porosity and permeability are sufficiently high to make the extraction of groundwater possible.

Basalt
Dense, dark-coloured lava rich in iron and magnesium. Forms during non-explosive eruptions of shield volcanoes, often in oceanic islands such as Hawaii.

Compacted
The action of squeezing as sediments become more deeply buried. Like wringing a sponge, compaction leads to loss of pore water and reduction of pore spaces between rock grains.

Compressed air energy storage
Compressed air energy storage (CAES) is a process whereby air is stored under high pressure which can then be released at times of high electricity demand. In large scale CAES facilities abandoned mine caverns are pumped with air when electricity demand is low. The air in these caverns is then depressurised later and the heat and depressurisation generates electricity through a conventional turbine.

Devensian
The most recent glacial period, popularly known as the last Ice Age, which occurred from c.110,000 to 12,000 years ago.

Dip
The angle, or slope of a plane, such as sedimentary layering, measured relative to the horizontal.

Dyke
Vertical or sub-vertical planar sheet of igneous rock intruded as hot magma along cracks and fractures in the earth's crust.

Dyke swarm
A large geological structure consisting of numerous vertical igneous intrusions (see 'dykes'), usually in a radial or linear pattern.

Erosion
The process by which the land surface is worn down, mainly by the action of rain, rivers, ice and wind leading to removal of huge volumes of soil and rock particles.

Extrusive igneous rock
Rock formed from ancient volcanic eruptions, either lava or pyroclastic material.

Fault
A fracture in the earth's crust across which the rock layers each side of it have been offset relative to one another.

Fracture
A crack in rock. Fractures can provide a pathway for fluids, such as groundwater or gas, to move in otherwise impermeable rock.

Gabbro
Dark-coloured, coarse crystalline igneous rock rich in iron and magnesium.

Granite
Pale-coloured, coarse crystalline igneous rock rich in silica, sodium, calcium and potassium.

Halite
A sodium chloride evaporite mineral that forms when salty water dissolves. Also known as rock salt, or just 'salt'.

Hydrocarbon
A compound of hydrogen and carbon. Hydrocarbons are the chief components of oil and natural gas.

Igneous
One of three main rock types (the others being sedimentary and metamorphic), consisting of hard, dense rocks made up of interlocking crystals. They form due to cooling of magma deep within the crust beneath volcanoes, or as lavas erupted at the surface.

Intrusive igneous rock
Rock formed when magma is forced along cracks and fissures in the earth's crust, subsequently cooling to form igneous dykes and batholiths before they reach the surface.

Lithology
The physical properties of rock types.

Marble
Hard, 'sugary'-textured rock type that forms due to metamorphism of limestone. Original structures found within the rocks (like fossils or sedimentary features) are usually destroyed or heavily modified. Marble is extensively used as a decorative building material or in sculpture.

Metamorphic/metamorphosed
A rock that has undergone change due to the action of temperature and pressure.

Schist
Recrystallized metamorphic rocks with a distinctive texture caused by the parallel alignment of tiny crystals of mica. As a result, schists are characteristically sheet-like, rather like the pages of a telephone directory.

Sedimentary
A type of rock resulting from the consolidation of material that has accumulated in layers to form gravel, sandstone, mudstone and limestone. The layers may be built up by movement from erosion (e.g. by rivers, the sea or wind) or by chemical precipitation. Generally, the material that accumulates has originated from the weathering of other rocks. Sedimentary rocks constitute one of the three main classes of rocks identified by geologists, the others being igneous and metamorphic.

Seismic survey
Geophysical method that produces an image of the subsurface by transmitting shock waves, or seismic energy, into the ground and measuring the pattern of energy that is reflected back to the surface. Widely used by the resource industries to provide information on the composition and structure of the underground geology.

Sill

Horizontal or sub-horizontal planar sheet of igneous rock intruded as hot magma along cracks and fractures in the earth's crust.

Slaty

Distinctive way in which slate rocks split into very fine sheets.

Solution mining

A technique to extract soluble minerals out of the ground by pumping liquids into a deposit, dissolving the target minerals, returning the water to surface and reprecipitating the mineral. Solution mining for rock salt is carried out in the UK and for other commercially valuable minerals around the world.

Radioactive Waste Management

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