Introduction

In this book we present the story of North Wales in early geological times. The field locations chosen have been regularly visited by our groups of students based in the town of Dolgellau in southern Snowdonia, and form a band of country extending roughly 30 miles inland from the coast of Cardigan Bay. Locations are described from the Lleyn peninsula in the north to Aberystwyth in the south. We exclude the geologically important island of Anglesey which is already well documented, for example: in the field guide by Treagus, Conway, Wood, & Loader (2008). We include only a small portion of the Snowdon mountain massif, and recommend the field guides by Roberts (1979) and Gannon (2008) for additional excursions in central Snowdonia.

This book is aimed at geology students or amateur geologists who have a good basic knowledge of geological terms and principles. Anyone not already possessing the requisite background knowledge may find that an introductory book such as *Understanding Geology* (Webster, 1987) is helpful. A glossary of geological terms is included at the end of the book. A term which is included in the glossary will be highlighted in **bold** on the first occasion that it is used in the text.

Particularly well exhibited in the region are: **turbidite** sediments, major and minor igneous **intrusions**, extrusive rocks including **pyroclastic** ashes and **pillow lavas**, **regional** and **contact metamorphic** rocks, fold and fault structures, **porphyry copper** and heavy metal **quartz vein** mineralisation.

Great advances in the understanding of geological processes on a global scale have occurred since the introduction of theories of plate tectonics. Igneous, sedimentary and metamorphic processes can all be related to the movement and interaction of crustal plates. Improved geophysical evidence from **palaeomagnetisim** studies, **radiometric dating** and evidence of sediment sources from **detrital zircon analysis** (Pothier et al., 2015) have helped to determine patterns of plate movement in the Welsh area since late Precambrian times. An objective of this book is to review theoretical plate tectonic models for the geological evolution of North and Mid-Wales, and to evaluate the field evidence for these models.

Visiting the field localities

We are sure that visitors will be aware of the care which should be taken to avoid accidents and environmental damage during geological fieldwork. However, there are some aspects particular to this field area which should be mentioned:

Much of the land is used for farming, forestry and water supply, and visitors are asked not to interfere in any way with these activities. Avoid disturbance to livestock, damage to walls and fences, or polluting any water courses. Please be considerate when parking on narrow lanes, to avoid obstructing access for farm vehicles.

There are undoubtedly some spectacular geological outcrops in the region, but many of the rocks can be difficult to identify. Weathered surfaces often show textural, depositional and structural evidence more clearly than freshly broken faces, so indiscriminate hammering of rock outcrops should be avoided.

Weather conditions on the mountains can change rapidly, and it is easy to become disoriented in low cloud and mist. It is safest to keep to lower ground during poor weather.

Special care should be taken when planning visits to coastal locations. Rising tides can close the exit routes from bays with high cliffs; always obtain information about local tide times. Cliff paths, especially in Lleyn, can be very narrow with a large drop to the sea so care is needed.

The many disused mines in the area are particularly hazardous, and should not be entered without an expert local guide. Timber may be rotten, making floors, shafts and tunnel roofs unsafe. Deep water may be present, and can contain toxic substances. In slate quarries, large slabs of slate can fall from the roofs of chambers without warning. For groups wishing to safely explore underground mines, we recommend the visitor attractions at: Sygun copper mine near Beddgelert, Llywernog silver-lead mine near Ponterwyd (advertised as the Silver Mountain Experience), and slate quarry tours in Blaenau Ffestiniog, Corris, and Llanfair near Harlech.

At the time of writing, access is generally available to the locations described in this book. However, this does not imply any public right of access. It is advisable to obtain permission from land owners, especially if visiting with a large group or intending to collect geological specimens.

Symbols are shown alongside field locations where particular care is necessary:

Dangerous drop, e.g. a cliff, quarry edge or mine shaft.

Hard hat recommended, e.g. below a quarry face of loose shale, or a sea cliff capped by glacial gravel.

Coastal location with a risk of being cut off by a rising tide.

Dense woodland where navigation is difficult.

Structure of the book

Central to our understanding of the geology of north- and mid-Wales is the concept of geological **terranes**. A terrane is a region of the Earth's surface where particular sets of geological processes have taken place to produce characteristic sequences of rocks. For example, various different geological terranes exist at the present day in the Pacific region: Indonesia and Japan are island arc terranes where lavas, ashes, and intrusive igneous rocks are forming; the South China Sea is a different terrane where layers of sand and mud are being laid down on the sea floor to create new sedimentary rocks. The mountains of China represent yet another older terrane where geological processes over millions of years have produced folded and metamorphosed rocks. Erosion in these mountains creates the sand and clay particles which are carried down rivers to the South China Sea to form new sedimentary deposits.

After formation, a terrane may be moved to another part of the Earth's surface by plate tectonic processes. Coastal mountain ranges of California originated as volcanic island arcs within the Pacific Ocean, and were then carried to the coast of the North American continent by **subduction** of the intervening **oceanic plate**. Movement of terranes may also occur along major **transverse** crustal fractures, as in the case of the San Andreas fault which is carrying a slice of coastal rocks southwards along the Californian coast.

Moving back in time to Wales during the Precambrian and Cambrian periods, we are able to use the terrane concept to interpret the stratigraphy of the region. Three contrasting terranes are present in North Wales. After forming in different locations, these were brought together by fault movements at the end of **Cambrian** times.

We will examine: the thick sequence of bedded sediments of the Harlech Dome; the sequence of volcanic ashes and slates of the Arfon region; and the highly deformed Monian rocks of the north of the Lleyn Peninsula including **mélange**, **schist** and **gneiss**.

Throughout the **Ordovician** and **Silurian** periods, North and Mid-Wales formed a single crustal block, with similar geological processes operating simultaneously across the whole of the region. The Ordovician was dominated by the eruption of volcanics, whilst the Silurian saw a return to the quiet deposition of great thicknesses of sediment.

A number of authors have produced plate tectonic models to explain the **Precambrian** (Kawai et al., 2007) and **Lower Palaeozoic** (Strachan, 2000) evolution of the Welsh region We trace the Precambrian origin of Wales within a microplate, **Avalonia**, at the edge of the great continent of **Gondwana**. We follow the movement of Avalonia across the **Iapetus Ocean** in Ordovician times, until its eventual collision and docking with the continents of **Laurentia** and **Baltica** in the Silurian period.

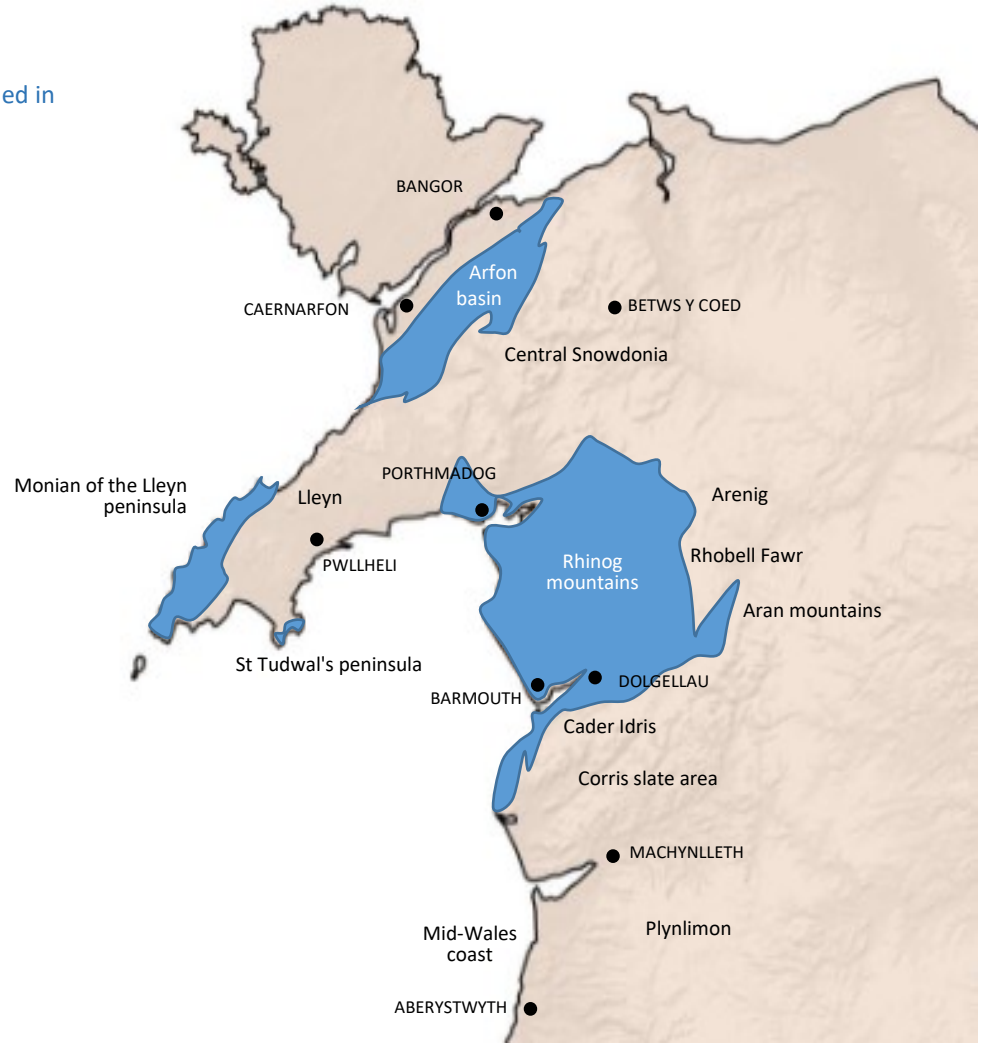
We move on to consider particular geological processes which are important in understanding the development of the North and Mid-Wales terranes. These processes include: the accretion of oceanic and continental sediments in a **trench** at a subducting plate margin; the intrusion of **magma** and eruption of volcanics above an active subduction zone (Kokelaar, 1988); and sedimentary deposition in subsiding marine basins along a continental margin.

The chapters which follow describe a variey of field locations to provide evidence for the geological history of the region (Fig.1).

We begin by considering the Monian of the Lleyn peninsula. Here we find a sequence of ocean floor basalts and sediments which accumulated during plate subduction as Avalonia converged with Gondwana in the late Precambrian, then broke away again during the Cambrian. We also find that sediments along the coastal margin of Avalonia slumped into the subduction trench to produce a highly contorted mélange. The sequence was further deformed to schist during lateral displacement along the Menai Straights Fault Zone which brought the Monian terrane to its present position alongside the sedimentary basins of North Wales.

Figure 1:

Field locations included in this guide



The Cambrian sedimentary successions of the Rhinog mountains, the Mawddach estuary and Ardudwy, Coed y Brenin and St Tudwal's peninsula form parts of a single terrane, **Megumia**, which originally extended into what is now Nova Scotia in Canada. In North Wales, thick sequences of grits, silts and muds accumulated in this marine basin under varying depths of water.

The third terrane we examine is the Arfon Basin. This geological succession formed in a separate marine basin some distance to the east, and has been carried to its present position by movement along the Menai Straights Fault Zone. The Arfon rocks consist of volcanic ashes, pebble conglomerates, and a thick sequence of muds which have been converted to slates in the historically important quarrying areas of Nantlle, Llanberis and Bethesda.

During the Ordovician period, the Avalonian microplate was carried across the Iapetus Ocean towards the continent of Laurentia.

Plate movement was related to the generation of new oceanic crust at a **mid-ocean spreading centre**, and subduction beneath Avalonia. Plate subduction led to volcanic activity in North Wales. The first volcano to develop was the Rhobell volcanic centre, active at the very start of the Ordovician period. This particularly well preserved volcanic sequence includes both lavas and sub-volcanic intrusions, along with a large copper ore body.

We then examine a series of volcanic centres at Cader Idris, the Aran mountains, and Arenig which skirt the southern and eastern margins of the Harlech Dome. These volcanic centres lie on two major crustal fracture zones which provided pathways for rising magma: the N-S oriented **Corris-Rhobell Fracture,** and the NE-SW oriented

Bala-Mawddach Fracture. These volcanic centres exhibit a clear division of volcanic rocks into contrasting low-silica **basalts** and high-silica **rhyolites**. This is characteristic of eruptions taking place in an **extensional basin** within continental crust during plate subduction along a continental margin.

We now turn our attention to the Ordovician of the Lleyn peninsula. In addition to marine sediments, we find a series of volcanic centres associated with the **Menai Straights Fault Zone**. Important **manganese ore** deposits occur in the region.

During the Upper Ordovician, volcanic activity reached its maximum intensity in North Wales. A major volcanic **caldera** developed in central Snowdonia, underlain by a huge magma chamber. We examine the rim of the caldera structure at Yr Arddu and Llyn Gwynant, and at Moel Hebog. In the Vale of Ffestiniog we identify evidence for another NE-SW crustal fracture zone which gave rise to volcanic centres from Penrhyndeudraeth to the Moelwyn mountains. We examine a magma chamber related to the Snowdonia caldera which is now exposed as the Tan y Grisiau **microgranite**.

At the end of the Ordovician period, volcanic activity ceased as Avalonia docked with the continents of Baltica and Laurentia. Great thicknesses of marine muds continued to be deposited across the margin of Avalonia, and were subsequently converted to **slate** by low grade metamorphism. We look at the slate deposits in Blaenau Ffestiniog, and discuss slate quarrying around Corris.

During latest Ordovician and throughout Silurian times, the Dovey valley, Plynlimon and the Mid Wales coast formed an area of extensive sedimentation in subsiding marine basins along the margin of Avalonia. Much of the sediment was deposited by turbidity currents. The area was subjected to extensive folding in **Acadian orogeny** during the **Devonian** period. Associated with the Acadian mountain building event was the emplacement of quartz **hydrothermal** vein deposits. Lead mining in Mid-Wales and the Dolgellau gold belt examine heavy metal deposits which have been economically important since Roman times, reaching a peak of production in the 19th century.

We conclude the book with a discussion and summary, in which we consider the extent to which field evidence supports the current plate tectonic models, and the questions which still remain to be addressed by geological research in North and Mid-Wales.

Field study locations

We describe field study locations which provide evidence for the early geological history of North and Mid-Wales, both in terms of large scale plate tectonic models, and in terms of the small scale geological processes producing particular rock formations.

The field locations are of three types, indicated by different symbols:

Individual outcrop: Individual locations are described which are of special geological importance, or illustrate geological features exceptionally well. These sites are accessible by road, with usually less than a mile to walk from the nearest parking place.

Walking route: We describe walking routes which visit a series of locations of geological importance, often returning to the starting point by a circular path. Car parking will normally be available at the start point. A distance and approximate time for the walk will be given.

Mapping area: We describe an area where no individual outcrop is of special significance, but where there is an important relationship between outcrops. This might, for example, be: the presence of a fold or fault structure, or the outline shape of a large igneous intrusion. In these cases, an excellent approach for students would be to record information from field observations on a detailed large scale base map. Apart from the rock types found, the dip directions and angles of beds might be shown, to help in determining the geological structure of the area.