8 The Rhobell volcanic centre

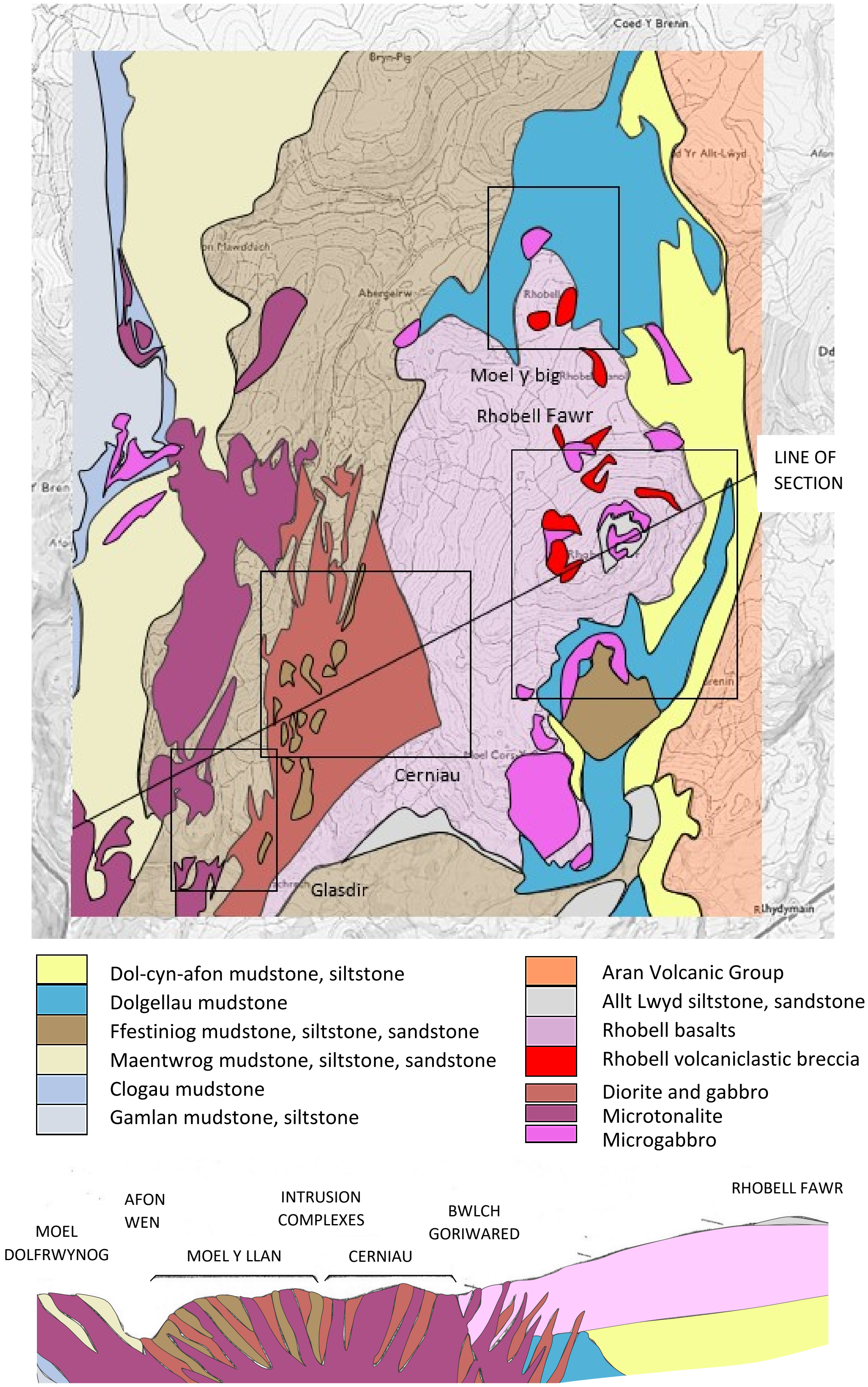


Figure 211: Field excursions.

During the Ordovician period, active subduction recommenced beneath the Welsh basin as the Avalonian microcontinent broke away from Gondwana and moved towards Laurentia. Subduction of Iapetus oceanic crust was accompanied by volcanic activity from sea floor vents. The first of the volcanic centres to be active at this time was at Rhobell Fawr, on the south-east edge of the Harlech Dome. The Rhobell volcano was built up from the sea floor to create an island, erupting mainly basaltic lavas and ashes.

Erosion has exposed a complex of igneous intrusions beneath the Rhobell volcano, which represents remnants of the conduit system which carried magma towards the surface from a magma chamber. Magma reached the volcanic vents along many north-south fractures, now infilled to form a swarm of dykes (fig.212). This zone corresponds with major deep crustal fractures on the eastern margin of the Harlech Dome. The Rhobell fracture zone had been active earlier during Cambrian times, allowing movement of crustal blocks and affecting water depth and sedimentation.

In the intrusion complex, early low-silica gabbroic sheets are cut by microdiorites and microtonalites with higher silica. This range in silica content has been explained by the crystallization processes which took place in the magma chamber at relatively shallow depth below the volcano (fig.213).

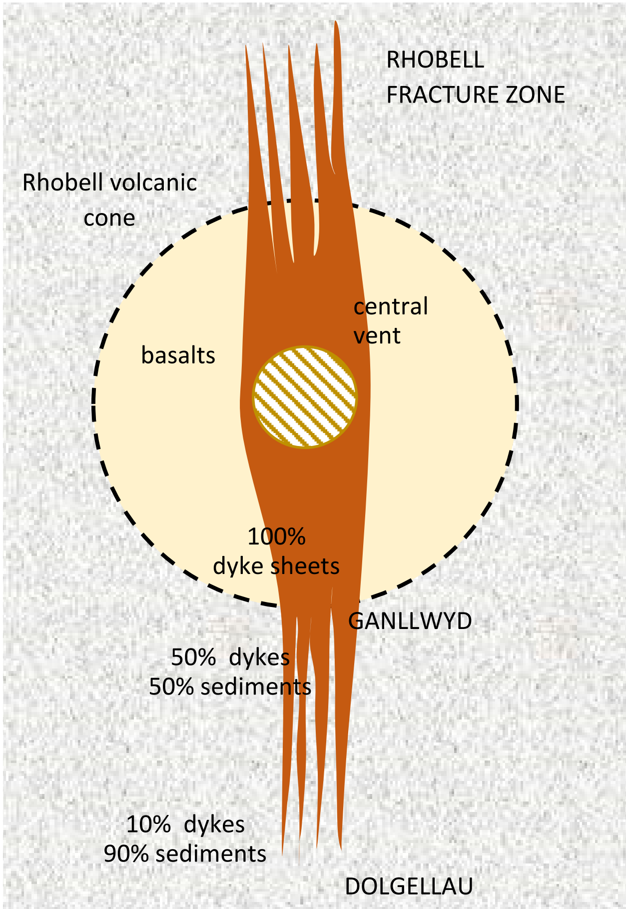


Figure 212: Diagrammatic plan view of the Rhobell volcanic centre.

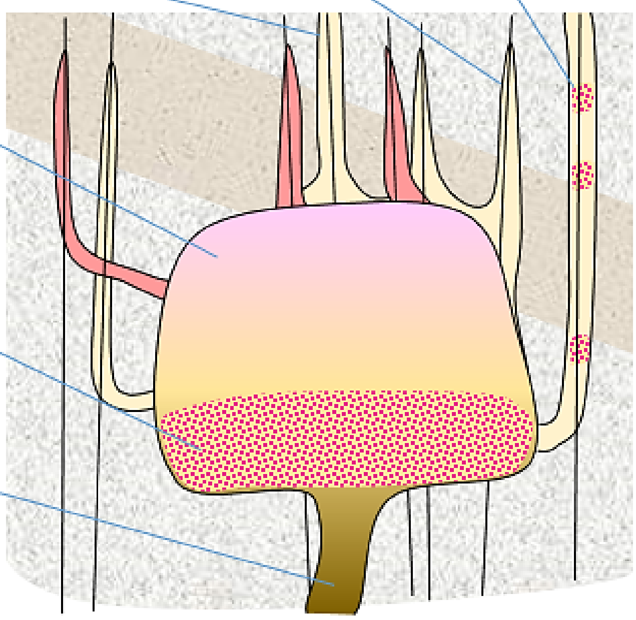


Figure 213: Processes in the Rhobell magma chamber.

Basaltic magma which had accumulated in the lower crust would be periodically released upwards through fissures to replenish the high level magma chamber. After entering the chamber, the magma temperature would fall as heat escaped to the surrounding country rocks. Crystallisation begins with minerals stable at higher temperatures, particularly the mafic minerals **olivine**, **pyroxene** and **amphibole**, along with the calcium and sodium feldspar mineral **plagioclase**. The melt may become gravity stratified, with the dense mafic crystals sinking towards the bottom of the chamber. A thick cumulate layer of early formed crystals, particularly amphibole, can develop at the base.

At various times during the cooling process, tension in the crust allowed fractures to open sufficiently for magma to escape upwards to form dyke intrusions. Some fractures reached all the way to the surface, with fluid magma erupting from volcanic vents.

Magmas which were released soon after the replenishment of the chamber would have a mafic composition, producing gabbro dykes and basalt lava flows. As the chamber became gravity stratified, fractures could tap the upper layers which had become more silica rich due to downwards settling of mafic crystals. This melt could escape upwards to produce **microtonalite** dykes. However, if fractures penetrated the lower layers of the stratified chamber, it was possible for a mafic melt to be released which contained blocks of the cumulate layer rich in large amphibole crystals. By a combination of these processes, an intrusion complex developed beneath the Rhobell volcanic centre containing the variety of igneous rock types which we see today.

In the later stages of the volcanic cycle at Rhobell, circulating hydrothermal fluids caused alteration of the sub-volcanic intrusions. Feldspars and mafic minerals were broken down to micas and clays, and a large copper ore body was emplaced. In recent years, consideration has been given to the opencast mining of this ore in the Coed y Brenin area, but development did not proceed for environmental reasons. These copper deposits around the village of Hermon will be examined in the following chapter 9: Coed y Brenin.

We can learn more about the volcanic processes operating in the Welsh Basin during Ordovician times by considering the origin of the magmas. It is clear that the volcanic activity was associated with subduction of an oceanic plate as the Avalonian microcontinent moved across the Iapetus Ocean. Magma was initially generated in the mantle wedge above the subduction zone, as a result of superheated steam being released from the descending plate and reducing the viscosity of the surrounding mantle **peridotite**. Diapirs of fluid material could rise to the base of the crust where deep magma reservoirs developed in **lithostatic equilibrium** with the surrounding rocks; the density of the magma was equal to the density of the surrounding crustal rocks and further upwards movement stopped. However, perhaps in response to crystallisation processes in the deep magma chamber, more fluid basaltic melts were intermittently released upwards to replenish the high level magma chambers.

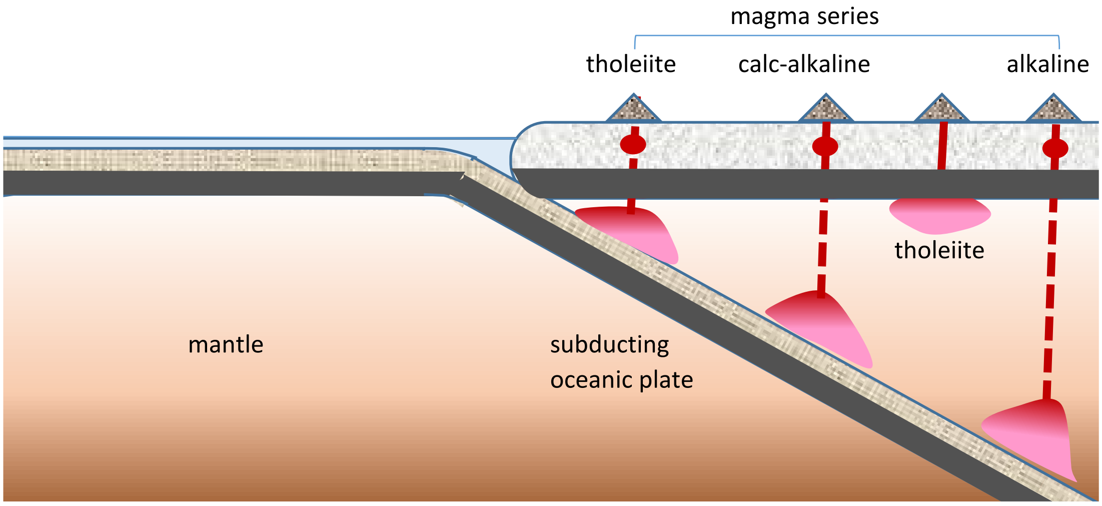


Figure 214: Generation of magmas at a subduction zone.

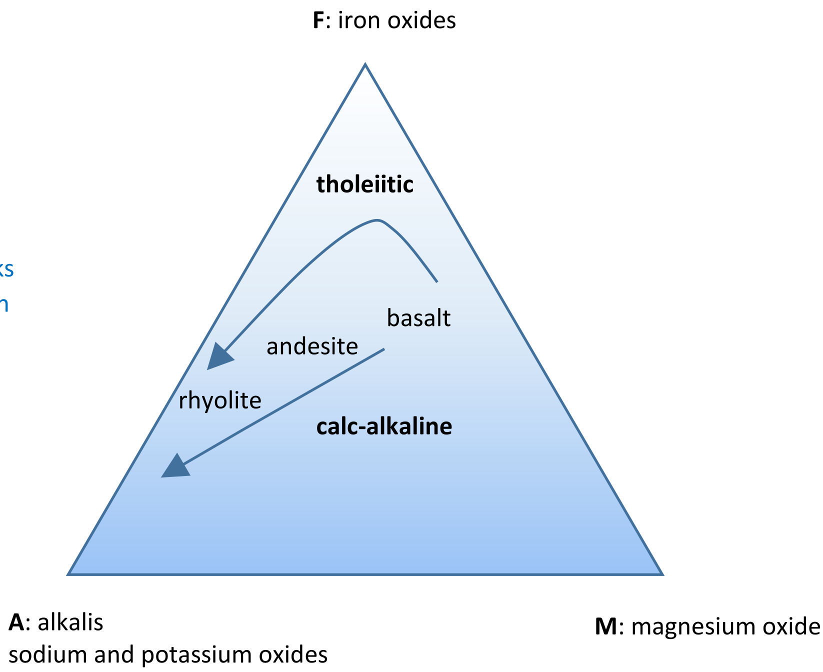


Figure 215: AMF diagram representing the chemical compositions of igneous rocks produced above a subduction zone.

A study of the chemical composition of basalts and other igneous rocks from present-day volcanoes at different distances from a subducting plate margin reveals interesting variations. Chemical composition of igneous rocks can be plotted on a triangular diagram using three components: percentage of iron oxides, percentage of manganese oxide, and percentage of the alkalis sodium and potassium (fig.215).

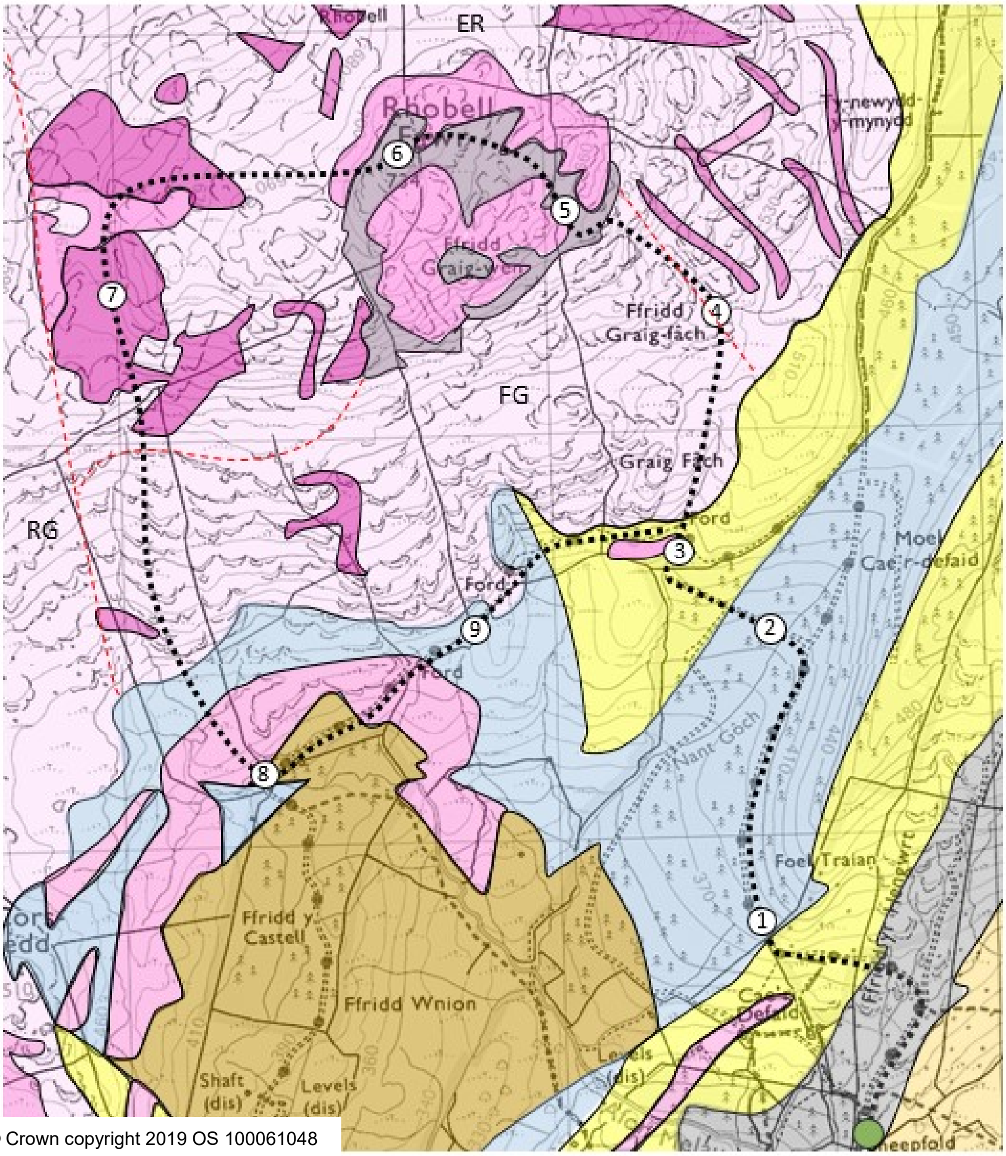
It is found that basalts erupted close to a subduction trench have a relatively high iron content, whilst the iron content falls and the alkali content increases for basalts erupted progressively further from the subducting margin. The high-iron basalts have been termed **tholeiites**, after the province of Thule in Greenland where similar rock types are found. The basalts found progressively further away from the margin are termed **calc-alkaline** and **alkaline**. All of the basalt types are able to evolve into higher silica andesites and rhyolites by removal of mafic minerals during fractional crystallization in a magma chamber, but the compositional paths will be different for tholeiites, calc-alkaline and alkaline parent magmas.

The chemistry of the parent magma is thought to be determined by the pressure and temperature conditions under which the melt was formed, which will differ with depth along the subducting plate. It is found that basalts of the Rhobell volcanic centre have a calc-alkaline character, which suggests that they were produced by melting some distance from the subducting plate margin. This is consistent with plate tectonic models which place the subduction zone in the area of the Isle of Man or northern Lake District during the early Ordovician period.

It is perhaps important to mention at this point that some anomalies are found in the rocks of the Welsh Basin. At Cader Idris, a major volcanic centre was active for much of the Ordovician period. Whilst many of the rocks have a calc-alkaline character similar to the Rhobell volcanic centre, some basalts have a tholeiite composition. We can explain this by identifying an alternative mechanism for the generation of magma. If pressure release occurs at the base of the crust due to deep faulting, a reduction in viscosity of the hot mantle peridotite can lead to partial melting and magma generation. The basalt melt produced may then quickly ascend along the crustal fracture and be erupted directly at the surface without the involvement of a high level magma chamber. The Cader Idris volcanic centre lies close to the deep crustal fractures of the Bala-Mawddach fault zone which was intermittently under tension during Ordovician times, allowing pressure release and magma generation at the base of the crust beneath the volcanic centre.

Rhobell Fawr

5 miles: approximately 3 hours



- Allt Lwyd siltstone, sandstone
- Rhobell Volcanic Group basalt
- Rhobell Volcanic Group volcaniclastic breccia
- Dol-cyn-afon mudstone, siltstone
- Dolgellau mudstone, siltstone
- Ffestiniog mudstone, siltstone, sandstone
- Microgabbro

FG Fridd Graig Wen
ER Eglwys Rhobell
RG Rhobell Ganol
BG Blaen y Glyn

Figure 216: Field excursion.

Start: We begin the excursion at Cae'r Defaid, which can be approached along minor roads from Llanfachreth village, or from the main Dolgellau-Bala road at Rhydymain. Park on the roadside at the end of the metalled road [SH797233].

1: Walk up the track into the forestry plantation, and continue through the forest.

2: After half a mile, turn left onto a forestry track to reach the base of Rhobell Fawr

From this vantage point, the geological structure of Rhobell Fawr can be appreciated. The succession of basalt lavas rest unconformably on folded, uplifted and eroded Upper Cambrian mudstones and siltstones of the Dolgellau and Dol-cyn-afon Formations. The summit of Rhobell Fawr

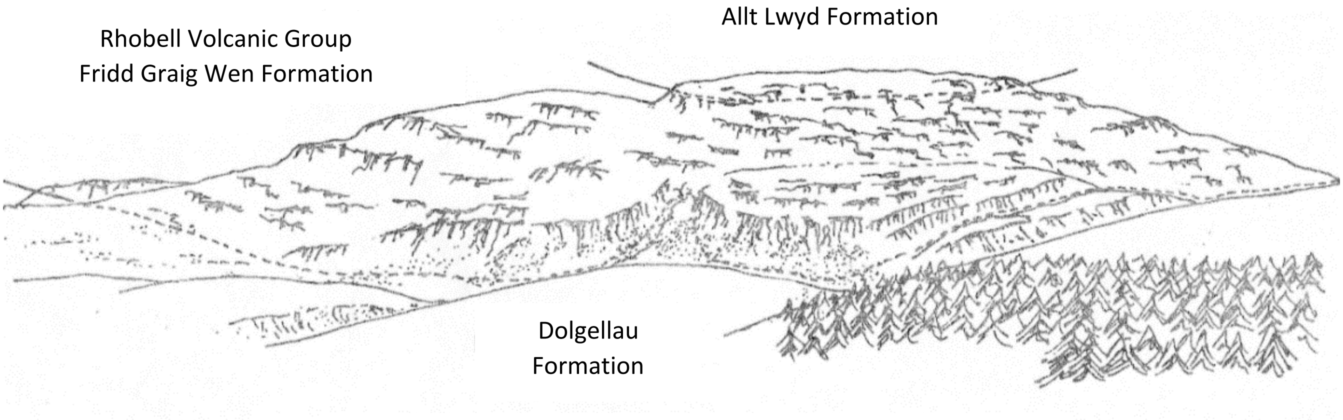


Figure 217: Rhobell Fawr viewed from the south east.

is composed of Lower Ordovician sandstones of the Allt Lwyd Formation, deposited following the subsidence and erosion of the Rhobell volcano after the eruptions ceased.

The lavas of Rhobell Fawr have been subdivided into four formations, which accumulated as the volcanic centre developed. The youngest of these, the Fridd Graig Wen Formation, outcrops on the eastern face of the mountain which we see from this point. Three earlier formations have been identified, outcropping progressively lower in the volcanic pile towards the west:

youngest	Graig Wen Formation
	Eglwys Rhobell
	Rhobell Ganol
oldest	Blaen-y-Glyn Formation

The four formations are almost entirely basalts with plagioclase and pyroxene as the main mineral constituents. The oldest Blaen-y-Glyn Formation, outcropping to the west of Rhobell Fawr, includes porphyritic basalts with large amphibole crystals (fig. 218).

Figure 218: Basalt with phenocrysts of amphibole, Blaen-y-Glyn formation.

3: Continue to the end of the forestry track, then cross grassland to reach low cliffs where the lower contact of the Rhobell volcanics is exposed.

The volcanic rocks overlie Dol-cyn-afon mudstone of the upper Cambrian. The mudstones have a strong cleavage, but the original bedding can be identified with a dip to the west of about 30^0 at this point. The mudstones are overlain unconformably by basalt flows, which have a steeper westwards dip of around 60^0. Uplift, erosion and folding of sediments occurred at the end of the Cambrian period, just before the first eruptions at the Rhobell centre. The extent of the unconformity varies around the base of the volcano, with lava flows intersecting the sediments almost at right angles in some locations. It is likely that the basalt eruptions took place onto a rough rocky surface, with lavas ponded-up behind ridges of rock in places.

The lava flows in the low cliffs of Graig Fach are solid and massive basalts, suggesting a rapid outpouring of a low viscosity lava. However, rubbly and brecciated basalts are common in the upper parts of the Rhobell succession as we shall see shortly. These represent slower moving, cooler or more viscous flows in which a solidifying crust was broken up and assimilated into the advancing lava mass.

4: Continue up the rocky slope of Ffridd Graig Fach, examining the outcrops of Rhobell lavas.

A variety of lava textures can be seen, including rubbly brecciated basalt (fig.220). The first eruptions of the Rhobell volcano may have been under water, or tectonic instability and uplift around the fracture zone may have produced islands onto which the basalts were erupted.

Figure 219: Unconformity at the base of the Rhobell Fawr volcanic succession, Graig Fach.

Orientations of the bases of lava flows, and bedding planes in the underlying mudstones, are shown.

Figure 220: (above) Basalt lava flows, Rhobell Fawr. (below) Detail of rubbly texture of a basalt flow.

In any case, it is likely that the Rhobell centre developed as a large, low sub-aerial volcano, with lava flows showing similar characteristics to the present day basalts of Hawaii and Iceland.

5: Continue around the promontory of Ffridd Graig Fach, then ascend alongside the prominent dry stone wall to the upper slopes of Rhobell Fawr.

Figure 221: Arenig basal sandstones near the summit of Rhobell Fawr.

As the summit is approached, the basalt lavas are seen to be overlain by bedded sandstones of the Allt Lwyd formation of Ordovician age (fig.221).

An angular unconformity can be identified below the sandstones, though not as pronounced as at the base of the Rhobell volcano. When eruptions ceased, the volcanic islands subsided and were subject to marine erosion. Subsidence may have been facilitated by the emptying of the high level magma chamber below the volcano. The sandstones around the summit of Rhobell Fawr illustrate characteristics of shallow water deposition below wave base. In other nearby areas, rocks of similar age include intertidal beach sands and pebble deposits indicating a nearby coastline.

6: Skirt around to the western edge of the summit plateau, past low cliffs formed by microgabbro sill intrusions. These thick sheet intrusions are typical of the Aran Volcanic Group, indicating renewed volcanicity around the Rhobell fracture zone in subsequent Ordovician times. We will see much evidence of the products of these later eruptions in the nearby mountains of Arenig and the Arans.

7: Continue downwards from the summit plateau to return to the Rhobell volcanic sequence. Descend past brecciated lava flows to the upper valley of the Afon Melau, then follow the stream downwards to reach a track around the base of the Rhobell mountain.

Prominent crags to the east of the stream are formed by a thick microgabbro intrusion. As around the summit of Rhobell Fawr, this intrusion is associated with the Aran volcanic group.

Figure 222: Columnar jointed microgabbro intrusion forming the crags above the Melau stream, Rhobell

8: At the track at the base of the hillside, we reach the Ffestiniog Flags Formation. These rocks are grey siltstones.

9: Cross the outcrop of the microgabbro sill intrusion to reach a small quarry cut in black Dolgellau mudstones.

Re-join the forestry track for the return to Cae'r Defaid.

Rhobell y Big

2 miles: approximately 2 hours

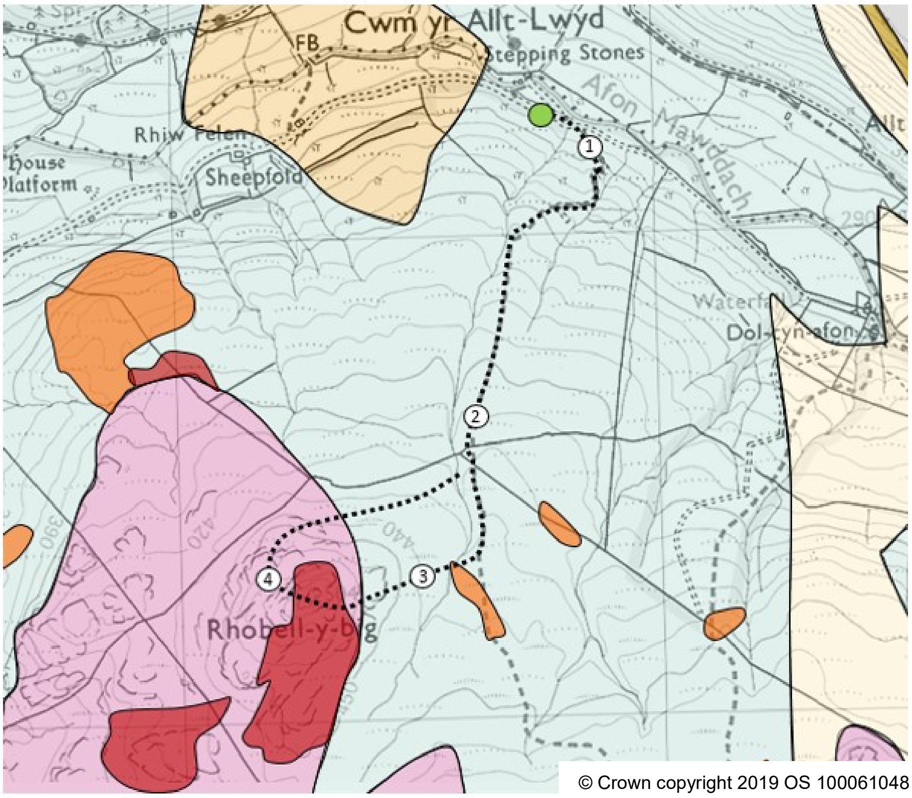


Figure 223: Field excursion.

The rocky peak of Rhobell-y-big is a clearly visible feature on the northern flank of Rhobell Fawr. The peak owes its prominence to particularly resistant beds of volcaniclastic breccia which are spectacularly exposed near its summit. The rocks occur stratigraphically within the Eglwys Rhobell formation of the Rhobell volcanic group. They are very poorly sorted deposits of rounded pebbles and larger blocks of basalt, with rarer fragments of Cambrian sedimentary rocks.

Figure 224: Conglomerate and breccia, Rhobell y Big.

The materials appear to have been deposited by sedimentary, rather than igneous, processes. They may represent sub-aerial water-transported debris flows caused by flash flooding, or unconsolidated volcanic debris which slumped into the shallow sea around the volcanic island. The pebble content was derived mainly from volcanic breccias outcropping on the slopes of the volcano.

In this excursion we climb from the Allt Lwyd valley, across moorland developed on Dolgellau mudstones, to reach the peak of Rhobell-y-big.

Start: Park alongside the minor road near the start of the track to Dol-cyn-afon [SH788292].

1: Take the path which winds uphill to the moorland above the Allt Lwyd valley.

On reaching the moorland, the peak of Rhobell-y-big comes into view.

2: Cross the moorland towards Rhobell-y-big, Leave the footpath as the peak is approached, cross a stream and ascend through the crags towards the summit.

Rough layering can be identified in the outcrops, indicating steep dips of more than 60^0 towards the east.

Figure 225: Summit platform of Rhobell y Big. The cliff face in the middle distance is a steeply dipping bedding surface.

3: Examine the outcrops of conglomerates and breccias. Many of the fragments are basalt lavas. Occasional blocks of crystal cumulate can be found, which were carried to the surface in a semi-solid state from the magma chamber beneath the volcanic centre.

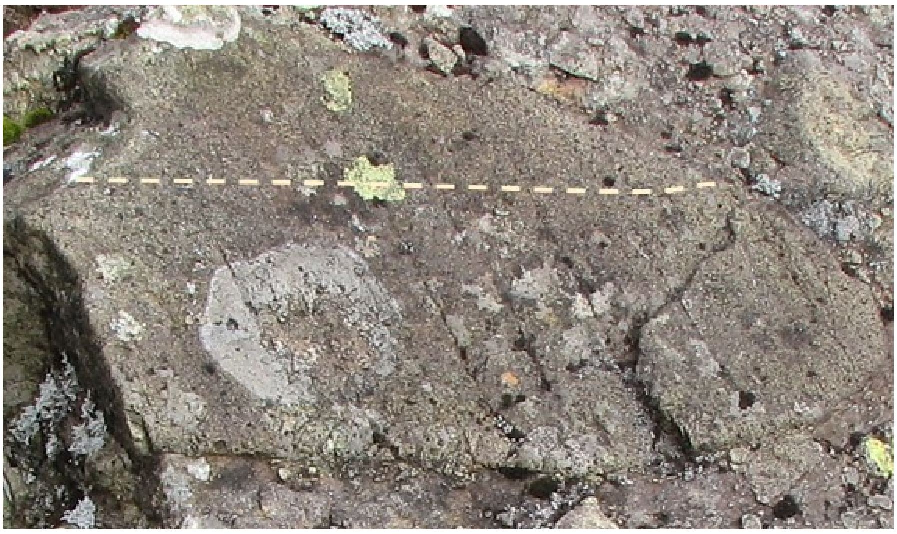


Figure 226: Block of crystal cumulate within the Rhobell-y-big breccia. The orientation of layering is indicated.

4: Descend around the western face of Rhobell-y-big, reaching massive basalt lava flows which lie stratigraphically below the breccias within the Eglwys Rhobell formation.

Cerniau

3 miles: approximately 2 hours

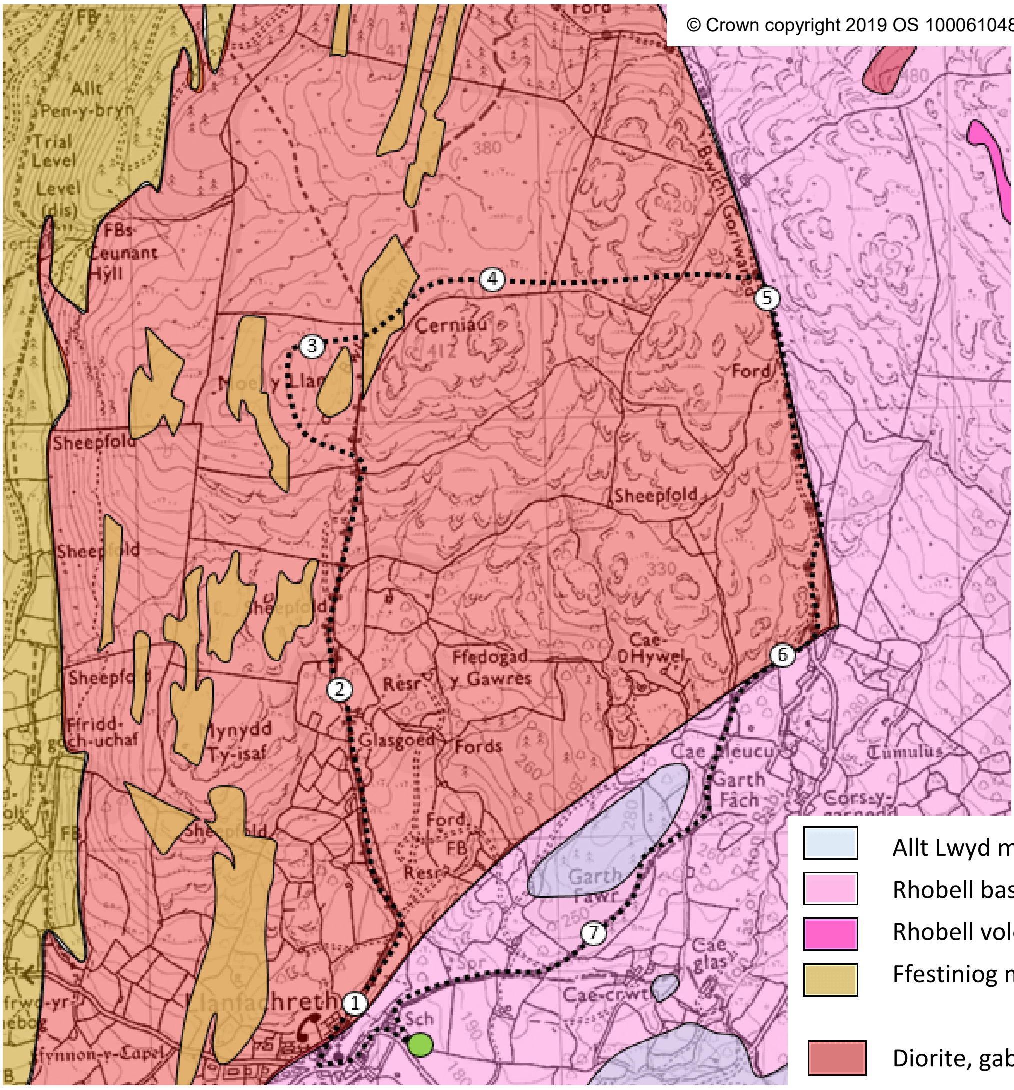


Figure 227: Field excursion.

In this excursion, we move to moorland east of Rhobell Fawr to investigate the sub-volcanic intrusion complexes which supplied magma to the volcano. We find many steeply dipping sheet intrusions oriented along the north-south crustal fractures of the Rhobell fault zone. The intrusions are separated from the basalt outcrop of Rhobell Fawr by a fault along the valley of Bwlch Goriwared.

The sub-volcanic intrusions have been divided into two outcrop areas: the Cerniau complex lying closest to Rhobell Fawr, and the Moel y Llan complex to the west. The rocks of Cerniau consist only of igneous intrusions whilst the Moel y Llan rocks include both intrusions and intervening slices of Cambrian sedimentary rock. In total, the emplacement of the numerous igneous sheets accounts for a crustal extension of about one kilometre across the Rhobell fracture zone. The intrusion complexes contain a variety of mafic microgabbros, intermediate microdiorites, and higher silica microtonalites. In general, the mafic rocks were intruded at an earlier stage, and were then cut by later sheets of the higher silica rock types. This may represent a greater amount of fractional crystallisation in the magma chamber over time, leading to the availability of higher silica melts. Few of these dioritic or tonalitic melts seem to have reached the surface to form eruptive rocks.

Start: A small car park is provided next to the school in Llanfachreth village [SH756225].

1: Walk back through the village past the church to the cross-road, then turn up the minor road to the north.

As you pass through woodland, intrusions of microdiorite in contact with Ffestiniog siltstones and mudstones can be examined in the roadside outcrops (fig.228).

Figure 228: Sill intrusion of microdiorite overlain by layered Ffestiniog siltstones and mudstones within the Moel y Llan intrusion complex, Llanfachreth.

2: Ascend past several houses until the road ends. Continue along a grassy track between dry stone walls to reach the moorland area of Moel y Llan.

Around the path, you will see a number of small outcrops of microgabbro and microdiorite in contact with Ffestiniog mudstones and siltstones (fig.233). The sheet intrusions dip at steep angles, and may show blocky or columnar jointing. The adjacent muddy sediments have become brittle and bleached due to the heat of the intrusions. The sedimentary strata have been disrupted by shear faulting, perhaps in association with the dyke emplacement. Beds of siltstone and thin sandstone have been broken into fragments, giving the rock the appearance of a breccia in some outcrops.

Figure 229: Outcrops of the Moel y Llan intrusion complex.
(above) steeply dipping Ffestiniog sediments overlain to the right by a microdiorite intrusion.
(right) Detail of the Ffestiniog sediments. A siltstone bed has been broken up by shearing, and the mudstone shows evidence of contact metamorphism.

3: Climb to the summit of Moel y Llan. From this point, descend across a broad, grassy upland valley, then continue along the line of a prominent dry stone wall towards the summit of Cerniau.

4: Sheet intrusions of microgabbro and microdiorite are exposed in the rocky terraces around the low summit of Cerniau.

Figure 230: (above) Mafic and intermediate dyke intrusions, Cerniau. (below) Autobrecciated dyke intrusion.

A variety of igneous textures can be found. Sheets vary in thickness from a few centimetres to several metres. Thicker intrusions are well jointed.

Some dykes of higher silica content exhibit autobrecciation. The high viscosity of the magma causes it to easily solidify along the intrusion margins. Early formed solid fragments can be incorporated into the remainder of the flowing magma.

5: Cross the summit of Cerniau and descend to the valley of Bwlch Goriwared. This long straight valley has been cut along the line of a major fault which separates the lavas of Rhobell Fawr from the Cerniau intrusion complex.

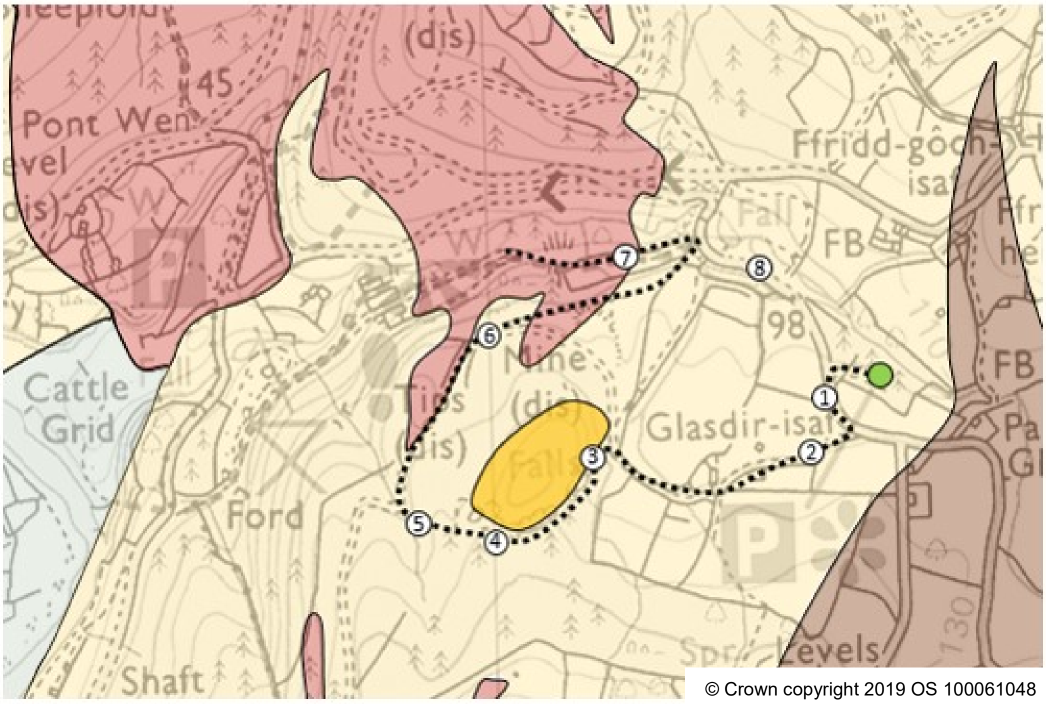
6: Descend southwards along Bwlch Goriwared until a gate is reached where a metalled road begins. At this point, take a footpath to the right to skirt around the crags of the Cerniau complex (fig.231).

Figure 231: Southern entrance to Bwlch Goriwared.

7: Return along footpaths and green lanes to Llanfachreth.

Glasdir

1 mile: approximately 1 hour



Rhobell volcaniclastic breccia
Ffestiniog mudstone, siltstone, sandstone
Maentwrog mudstone, siltstone, sandstone
Diorite, gabbro
Quartz-microdiorite

Figure 232: Field excursion.

A further interesting feature of the Rhobell volcanic centre is a series of vertical pipe-like bodies filled by breccia made up from fragments of the surrounding country rocks. These breccia pipes lie to the east of the volcanic centre, and cut through a mixture of Rhobell dyke and sill intrusions and sediments of the Maentwrog and Ffestiniog formations.

It is likely that the breccia pipes were produced by fumarole activity in late stages of the Rhobell volcano. As the magma chamber cooled beneath the volcanic centre, water dissolved under huge pressure became increasingly concentrated in the remaining melt. Eventually, a point was reached where this water could no longer remain in solution, and was released as superheated steam. Steam may also have been generated at the margins of the magma chamber as water circulated downwards from the surface and came into contact with hot rocks. Superheated steam moved explosively upwards, initially following crustal fractures. The surrounding rocks were broken up mechanically by the fluid stream, eventually creating pipes with an oval cross section.

The breccia pipe at Glasdir, which we examine in this excursion, is unusual in hosting a large low-grade copper ore body. Glasdir mine produced over a hundred thousand tons of ore, with around 1% copper content, between 1872 and closure in 1914. The mine also produced small but valuable quantities of silver and gold.

Start: From Ty'n y Groes, follow roads through Coed y Brenin forest in the direction of Llanfachreth. Park at the forest arboretum above Glasdir [SH745225].

1: From the parking area, walk up the road to the farm track which branches to the right.

2: Follow the track past the farm to the start of the forestry plantation.

3: A large open cast pit will be seen to the left of the track. Care should be taken when approaching the edges of any of the Glasdir workings, as deep drops occur.

The copper ore was worked in two opencast pits, and from a series of underground levels and shafts extending to about 200 metres below ground level. The underground workings of the mine are now flooded but the open pits remain dry.

Leave the track and walk up through the woodland, keeping the opencast pit on your right. A narrow bridge of rock will be seen, which separates the two open pits.

4: Skirt around to the head of the upper opencast pit and view the deep workings. A short tunnel in the hillside leads to a rock ledge above the pit.

The breccia pipe at Glasdir is oval in plan, measuring about 200 m by 100 m and elongated north-eastwards. It is infilled by small randomly oriented fragments of mudstone and siltstone from the adjacent Ffestiniog formation. The matrix of the breccia usually consists of quartz and chlorite, which may have been produced by hydrothermal alteration of clay minerals.

The workable copper ore was concentrated on one side of breccia pipe. Within the ore zone, the breccia contained a mixture of iron and copper sulphide minerals, along with calcite and some muscovite white mica.

Figure 233: The upper open pit, Glasdir.

5: From the head of the open pit, descend the hillside down a large waste tip, where samples of the ore may be found (fig. 234).

The most heavily mineralised rock fragments exhibit a rusty weathered surface. When broken open, a matrix of white chlorite is found which contains crystals of the iron sulphide minerals **marcasite** and **pyrite**. The copper sulphide **chalcopyrite** and the arenic sulphide **arsenopyrite** may be present, along with small amounts of the zinc sulphide **sphalerite**.

Figure 234: Glasdir ore. Breccia has been broken to show the matrix of chlorite, oxidised iron sulphides and rare crystals of chalcopyrite.

6: Descend over the waste tip to the forestry track, then follow the track to the right around the hillside.

7: Take the footpath down across the field to reach the minor road at the entrance to the Glasdir mill site. Continue along the track to the remains of the terraces on which the different levels of the processing plant stood. Concrete blocks mark the sites of machinery.

The mine was active from around 1850 to 1914. In the early years, the copper ore produced by the mine proved very difficult to treat. This was due to the very finely disseminated chalcopyrite. In addition, the very small crystals had a similar density to other minerals present, so separation by gravity methods was inefficient.

Several mine owners at Glasdir experimented with crushing the ore to a fine slurry, then using mineral oil to extract the sulphide phase. This process was eventually perfected by William Elmore, producing the froth flotation system which has become one of the most important mineral extraction methods in use throughout the world.

8: Return up the road to the car park.