The Central Ox Mountains

Paul Ryan, Ken McCaffrey, David Chew, John Graham, Barry Long

Abstract The Central Ox Mountains is a southwest – northeast trending inlier of Dalradian rocks, mostly attributed to the Argyll Group, that lie along a major fault, the Fair Head – Clew Bay Line (FCL). Deposition was associated with rift related magmatism. These rocks were deformed, metamorphosed (up to kyanite zone) and subsequently exhumed during the mid-Ordovician Grampian Orogeny. Subsequent sinistral transpression along the FCL was associated with the emplacement of the granitoids of the Ox Mountains Igneous Complex and the development of major syn-metamorphic shear zones or 'slides' during the Early Devonian Acadian Orogeny. This chapter examines: evidence for early rifting along the FCL coeval with the opening of the Iapetus Ocean; Grampian deformation and metamorphism attributed to mid-Ordovician arc-continent collision; and the emplacement of the OMIC and the later development of the slides

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during early Devonian Acadian transpression attributed to the closure of the Iapetus Ocean.

4.1 Introduction

The Central Ox Mountains, County Mayo (Fig 4.1), is a low northeast-southwest trending topographic ridge which sits on the trace of a significant Caledonian deformation zone (the Fair Head – Clew Bay line) that defines the southern edge of the Laurentian continental margin in eastern Ireland (Soper & Hutton 1984; Hutton & Dewey 1986). The core of the ridge is an uplifted block (an inlier) of Precambrian to Palaeozoic metamorphic and igneous rocks (Fig. 4.1) unconformably overlain by Carboniferous and Devonian sedimentary rocks (Chapter 10). The north-eastern sector of the Ox Mountains in County Sligo contains granulite to eclogite facies Neoproterozoic rocks of the Slishwood Division which are

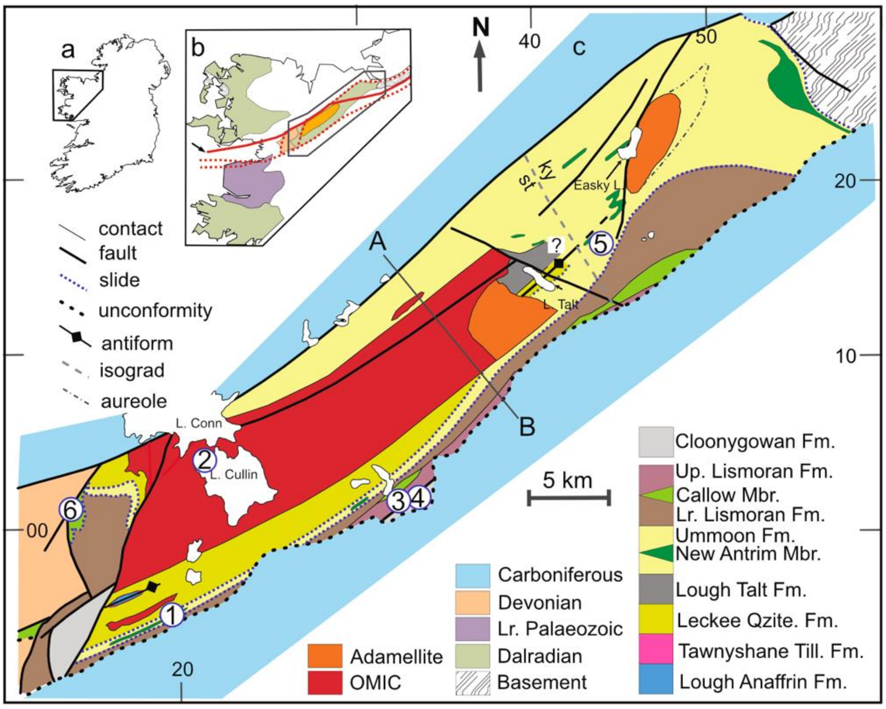
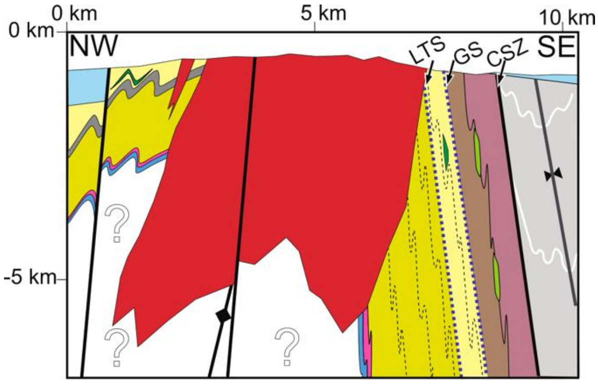


Fig. 4.1a Ireland with inset showing location of Fig 4.1b **b** summary geology of northwestern Ireland showing major faults in red. The Fair Head – Clew Bay Line is shown as a continuous red line (arrowed). Lr.Palaeozoic refers to the Cambrian to Silurian of South Mayo **c** Geological map of the Central Ox Mountains after Alsop and Jones (1991) and Daly (2009). Abbreviations: Fm. = Formation; Lr. = Lower; Mbr = Member; OMIC = Ox Mountains Igneous Complex; Qzite= Quartzite; Till. = Tillite; Up. = Upper. The position of the localities visited are shown.

Fig. 4.2 Speculative cross-section along line A-B of Fig. 4.1 after McDermott et al (1996), modified. Abbreviations: CSZ = Callow shear zone; GS = Glennawoo slide; LTS = Lough Talt slide. Colours as for Fig. 4.1c.



described in Chapter 3. The formation and preservation of the Inlier reflects uplift during late Caledonian strike-slip shear events that occurred along the Laurentian margin (Hutton & Dewey 1986). Within the central Ox Mountains inlier (Fig. 4.1) polyphase-deformed metasedimentary rocks of the Dalradian Supergroup (Alsop & Jones 1991) record two orogenic events. Firstly, early deformation fabrics (D1 and D2) and up to kyanite grade regional metamorphism developed during the Grampian Orogeny, associated with the onset of ocean closure. The later, early Devonian, Acadian orogeny marked final ocean closure,during which time the Ox Mountains Igneous Complex was emplaced (McCaffrey 1992) and the earlier Grampian fabrics were partially overprinted, reactivated and retrogressed (D3 and later). Deformation and intrusive structures preserved within these units enable the accretion events and, in particular, the strike-slip deformation to be examined and constrained.

4.2 The Dalradian

The metasediments of the Central Ox Mountains are assigned to the Dalradian Supergroup (Long and Max 1977). Alsop and Jones (1991) revised the stratigraphic scheme of Long and Max (1977) and established a correlation with the Dalradian succession in Donegal. Crucially, they identified a limestone/tillite/quartzite association at Lough Anaffrin (3 km northwest of Loc. 4.1, Fig 4.1c) where Appin Group limestones lie in the core of a D2 antiform (Long 1974). Alsop and Jones (1991) recognise the following formations - in ascending stratigraphic order: Lough Anaffrin; Tawnyshane Tillite; Leckee Quartzite; Lough Talt; Ummoon; Lower and Upper Lismoran; and the Cloonygowan (Table 4.1 and Figure 4.1). A further discussion of the Dalradian stratigraphy in Ireland is given in Chapter 2, Section 2.4.

Table 4.1 Stratigraphy of the Ox Mountains Dalradian Succession (Alsop and Jones 1991).

Group	Sub-Group	Formation	Lithology	Thickness
Southern Highland		Cloonygowan	Green/grey phyllites, psammites with quartz pebbles. Poorly sorted and beds up to 3 m in thickness	750 m
Argyll	Easdale	Upper Lismoran	Pale green semipelite interlayered with psammite	> 700 m
		Callow Member	Dark schistose amphibolite preserving some volcanic features	150 m
		Lower Lismoran	Grey-green semiplelite interlayered with psammite	400 m
		Ummoon including New Antrim Member (NAM)	Mainly semipelite with persistent schistose amphibolite of the NAM.	< 600 m NAM < 50 m.
		Lough Talt	Thin interbeds (< 1 m) of pelites, semipelites, calc-silicates, feldspathic psammite and quartzite	0 - 300 m
	Islay	Leckee Quartzite	Massively bedded, mostly impure quartzite	580 - 2300 m
		Tawnyshane Tillite	Pelites, semipelites and psammites with local coarse feldspathic detritus	45 m
Appin	Blair Atholl	Lough Anaffrin	Interbedded tremolite and serpentinite marbles and calc-silicates	> 80 m

The Lough Anaffrin Formation belongs to the Appin Group and all others to the Argyll Group with the exception of the Cloonygowan Formation which is attributed to either the Southern Highland Group (Alsop and Jones, 1991) or the Clew Bay Complex (Chew, 2001). The metavolcanic rocks of the New Antrim Member (Ummoon Formation, Locality 4.5) have continental tholeiite affinities and can be correlated with metavolcanic horizons in the Dalradian of North Mayo (Winchester et al 1987; Chapter 2). The lavas of the Callow Member (Lismoran Formations) were probably erupted in an oceanic (MORB) setting (Winchester et al 1987). The aim of this excursion is to investigate the complex tectonic evolution of this inlier rather than study Dalradian stratigraphy in detail. Only the Ummoon Formation (Locality 4.1 and 4.5), the Upper Lismoran Formation (Locality 4.3) and the Cloonygowan Formation (Locality 4.4) are visited.

4.3 The Ox Mountains Igneous Complex

The Ox Mountains Granodiorite is volumetrically the most important part of the Igneous Complex and was intruded as a composite tabular body c. 25 km long x 5 km wide, during regional transpressional deformation (McCaffrey 1992). Evidence for the timing of the intrusion events relative to the wall rock deformation history can be examined at Cloonkesh (Locality 4.1). The internal composite nature of the intrusion and a range of spectacular sinistral strike-slip shear zone related structures are displayed at Pontoon (Locality 4.2). The accurate U-Pb dating of the Ox Mountains Granodiorite at 412.3 ± 0.8 Ma by Chew and Schaltegger (2005) is important in constraining sinistral shear events along the Laurentian margin in early Devonian (Lockhovian) times (Becker et al. 2012).

4.4 Structure and metamorphism

The rocks of the Central Ox Mountains preserve a long history of metamorphism and deformation spanning the mid-Ordovician Grampian to late-Devonian Acadian Orogenies (Table 4.2). They sit astride a major fault zone, the Fair Head – Clew Bay Line (Fig 4.1b), that was active from the Neoproterozoic to the Carboniferous and marks the upper crustal boundary, in eastern Ireland, between the deformed Laurentian margin and outboard terranes (Chew and Van Staal 2014). There are currently no precise dates for the Grampian metamorphic peak outside of Connemara. However, studies (Flowerdew et al. 2000) in the Slishwood Division (see Chapter 3) suggest the main Grampian event took place between 470 Ma and 459 Ma after the juxtaposition of this division with the Dalradian of the Central Ox Mountains. Peak metamorphism at ~460 Ma (Locality 4.5) was followed by rapid uplift and cooling at 460 - 450 Ma. The later Acadian sinistrally transpressive event is dated by the syn-tectonic emplacement of the Ox Mountains Igneous Complex (OMIC) at 412.3 ± 0.8 Ma (Chew and Schaltegger 2005) which controlled the development of Devonian pull-apart basins (McCaffrey 1997; see Chapter 10).

4.4.1 Structure

The earliest Grampian deformation (D1) probably took place under low greenschist-facies conditions and is only evidenced as a fabric wrapped

Table 4.2 Deformation and metamorphic history of the Central Ox Mountains after Jones (1989), McCaffrey (1992; 1994; 1997), Flowerdew et al. (2000), Chew and Schaltegger (2005).

Time	Framework	Event	Kinematics	Nature of Deformation
Lower Carboniferous (Tournaisian) ~359-347 Ma	Basin margin normal faulting		Normal/dextral	Syn-sedimentary faulting on NW and SE flanks of inlier
Late Devonian ~383-359 Ma	Transcurrent faulting, basin inversion		Dextral	Brittle reactivation along the Knockaskibbole fault
Middle Devonian ~393-383 Ma	Pull-apart Devonian basin formation. Continued unroofing		Sinistral	Chevron folds and kink bands. Retrogression

Early Devonian ~407-393 Ma	Late- to post-Acadian pull-apart Devonian basin formation. Continued unroofing. Emplacement of late granites.	D4	Sinistral	Brittle reactivation of shear zones to form pull-apart basin
Early Devonian ~410 Ma	Acadian sinistral transpression		Sinistral	Final juxtaposition of greenschist-facies Southern Highlands Group against amphibolite-facies Argyll Group
Early Devonian (Lochkovian) 412.3 ± 0.8 Ma	Acadian Syntectonic granite emplacement and transcurrent shear, unroofing central Ox Mountains	D3 Post-peak metamorphic maximum conditions. Locally sillimanite in aureoles	Sinistral	Major F3 upright antiform. Ductile-brittle deformation progressively localized into shear zones within plutons and slides in wall rocks
Ordovician (Sandbian – Katian?) ~455-450 Ma	Late-Grampian orogenic collapse		Down-dip extension	
Ordovician (Darriwilian – Dapingian?) ~460 Ma	Grampian arc collision and obduction with ophiolites	D2 Penetrative fabric. Late MP2 regional metamorphic maximum (kyanite).	Dextral?	Major thrusting and pervasive fabric formation at mid-crustal levels. West directed overthrusting at upper-crustal levels.
Ordovician (Tremadoc – Floian?) ~470-460 Ma	Initiation of Grampian arc-continent collision	D1 (low greenschist?), not present in southwest.		
Ordovician (Tremadoc – Darriwilian) ~476-463 Ma				Juxtaposition of Central Ox Mountains with the Slishwood Division.

around by D2 fold closures (Jones 1989; McCaffrey 1992). A single large southwest-northeast trending D2 antiformal anticline preserves the only Appin Group sediments in its core (Fig. 4.3). Limited structural evidence suggests vergence towards the northeast and no major inversion of the stratigraphy. A penetrative fabric formed during D2 folding and the

Grampian metamorphic maximum was achieved late in this phase (MP2 of McCaffrey 1992, Locality 4.5). Structural correlations with the Clew Bay region (Chapters 3 and 6) suggest that this deformation had a dextral component until 448 Ma (Chew et al 2004). The Cloonygowan Formation (Southern Highlands Group) was thrust over the Upper Lismoran Formation (Argyll Group) during late D2 (McCaffrey 1992). However, the younger, lower metamorphic grade rocks still occupy the hanging wall suggesting that this thrusting did not fully reverse the original extensional geometry. Rapid uplift evidenced by common ~450 Ma cooling ages (Chew et al 2003; Flowerdew et al 2000) took place immediately after this event. A major southwest - northeast upright antiform formed during D3 with an axial planar crenulation cleavage (Figs 4.2, 4.3). This was associated with regional retrogression under greenschist facies conditions of the Grampian amphibolite facies assemblages (Fig 4.3). The OMIC was emplaced late during D3 sinistral transpression (see section 4.3 below) probably associated with the final closure of the Iapetus Ocean. High strain zones were developed within the OMIC and the country rock during this time. Those in the country rock likely reactivated earlier Grampian structures. These high strain zones or faults which formed during regional deformation and metamorphism are referred to as slides (Hutton 1981). In the Dalradian these zones form the Glennawoo, Lough Talt slides and the Callow shear zone which disrupt the stratigraphy but define formation boundaries (Fig 4.3). Later sinistral reactivation of these slides controlled the development of the Devonian pull-apart basins described in Chapter 10. These basins were inverted during latest Devonian, Acadian, reversal of slip sense along the Knockaskibbole Fault (Fig 4.3). Such reversal of shear sense is reported in multiply deformed terranes globally (Dutta and Mukherjee 2019).

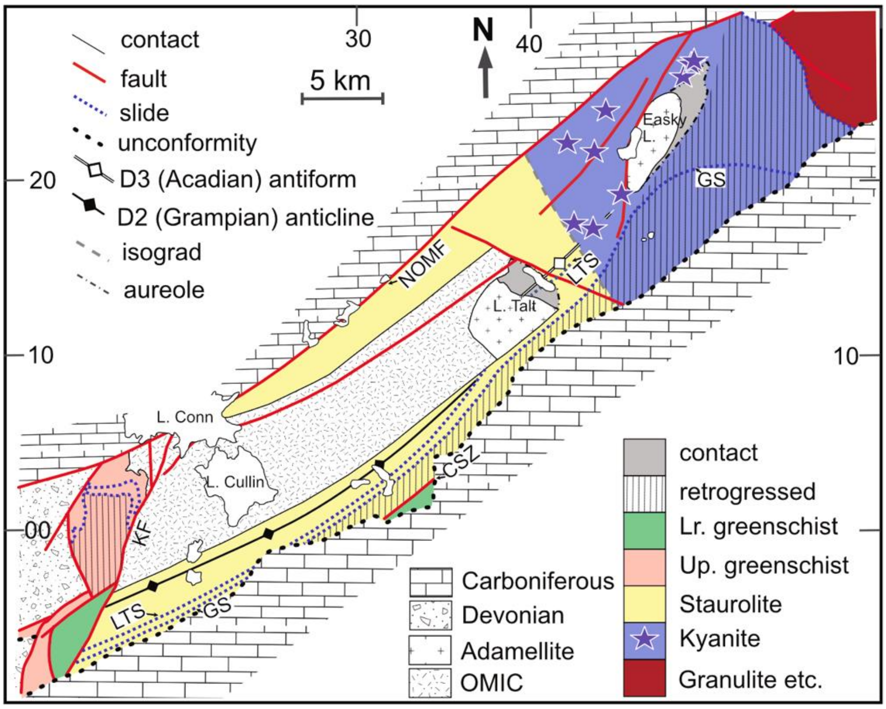


Fig. 4.3 Structural and metamorphic map of the Central Ox Mountains (after Yardley and Long 1981; McCaffrey 1992, 1997; Yardley et al 1979). Abbreviations: CSZ = Callow Shear Zone; GS = Glennawoo Slide; KF = Knockaskibbole Fault; Lr. = lower; LTS = Lough Talt Slide; NOMF = North Ox Mountains fault; OMIC = Ox Mountains Igneous Complex; Up. = upper.

4.4.2 Regional metamorphism

Yardley et al (1979) report progressive Barrovian style metamorphism ranging from the garnet zone to the kyanite zone in the Appin and Argyll Group rocks of the Central Ox Mountains Dalradian. The grade increases from southwest to northeast (Fig. 4.3) with staurolite occurring in all but the extreme southwest and kyanite in the northeast. Yardley et al (1979) suggest the peak of Grampian metamorphism occurred at 600°C - 620°C and at 0.6 – 0.7 GPa. Amphibolite assemblages were subsequently retrogressed to greenschist facies, especially in the Acadian D3 shear zones (Long and Max 1977; Yardley et al 1979; Fig 4.3). The Cloonygowan Formation, attributed to the Southern Highland Group, have sinistral shear fabrics and do not exceed low greenschist facies grade (Yardley et al 1979).

4.4.3 Contact metamorphism

The thermal aureole around the main granodiorite body of the OMIC is limited to the local development of fibrolite and sillimanite. This may reflect the gradual emplacement of the granodiorite as a series of sheets (McCaffrey 1992). In the Lough Talt area a late- to post-Acadian, poorly exposed, adamellite has a well developed aureole where sillimanite and andalusite overprint regional staurolite assemblages (Fig 4.3). Similar contact relationships are found in the aureole of the coeval Easky adamellite some 15 km northeast (Fig. 4.3) for which Yardley and Long (1981) report PT conditions of 595$\pm$30 ^{o}C and 0.25$\pm$ 0.05 GPa. This suggests ~13 - 17 km of exhumation during the Acadian and before the ~400 Ma (Long, Max and O'Connor, 1984) emplacement of the Easky adamellite.

4.5 The Excursion

4.5.1 Aim

This excursion has two aims. Firstly, to demonstrate the emplacement of a small Early Devonian granitic igneous complex, the Ox Mountains Igneous Complex, during sinistral transpression (Locs 4.1, 4.2). Secondly, to establish that this took place along a major long-lived structure, the Fair Head – Clew Bay Line, that was active from the Neoproterozoic to the Carboniferous (Locs 4.3, 4.4, 4.5 and 4.6).

4.5.2 Locality 4.1: Cloonkesh (53.893614°, -9.242484°)

Access and other information Limited parking is available on the roadside next to a series of low relief exposures on the northern side of the access road. The access road (53.893668°, -9.258042°) is a right turn onto the L5888, 150m north of the paired bridges over the Clydagh River on the R130 Castlebar to Pontoon road. Turn left after 350 m then continue a further 800m.

Evidence for the synkinematic contact relationships for the Ox Mountains Igneous Complex and the Dalradian country rocks can be examined just outside the main body of the intrusion at this locality (Fig 4.4a). Here, extensive exposures of psammitic to semi-pelitic lithologies of the Ummoon Formation (Table 4.1) contain metre to decametre-scale intrusive sheets of Ox Mountains granodiorite and pegmatites. They are part of the metasediments that have been correlated with the Argyll Group of the Dalradian Supergroup (Alsop & Jones 1991) and were deformed and metamorphosed to upper greenschist to lower amphibolite facies metasediments during the Grampian Orogeny.

At this locality, the main structures are tight to isoclinal upright folds with hinges parallel to the main gently NE- or SW-plunging stretching lineation (McCaffrey 1994). These folds formed during sinistral transpressional shearing that characterises the third phase (D3) structures in the Ox Mountains Inlier (Fig 4.4b, c). These folds, lineation and accompanying strong steeply dipping planar foliation deform a strong composite bedding, S1 and S2 fabric that formed during Grampian events along the Fair Head – Clew Bay line (Chew et al 2004).

In these exposures, in cross section view, the relationship between the upright F3 folds and folded sheet intrusions is well displayed (McCaffrey 1994) (Fig 4.4c, e). Minor intrusions clearly cross-cut the F3 folds but they themselves are folded with upright more open folds with the same geometry (Fig 4.4e) implying they were intruded during the D3 event. In plan view exposures, the intrusive rocks contain a pervasive foliation that is parallel to the fold axial planes. The sheet contacts that were intruded sub-parallel to the host rock fabrics show evidence for sinistral shearing on their margins (Fig 4.4d). Minor intrusions intruded at a high angle to the foliation shows evidence for anticlockwise rotation and shearing (Fig. 4.4e) . In summary these exposures show convincing evidence that the intrusion of the Ox Mountains granodiorite is synchronous with, and can be used to date, Late Caledonian sinistral shearing along the Highland Boundary (Fair Head Clew Bay line) on the Laurentian margin.

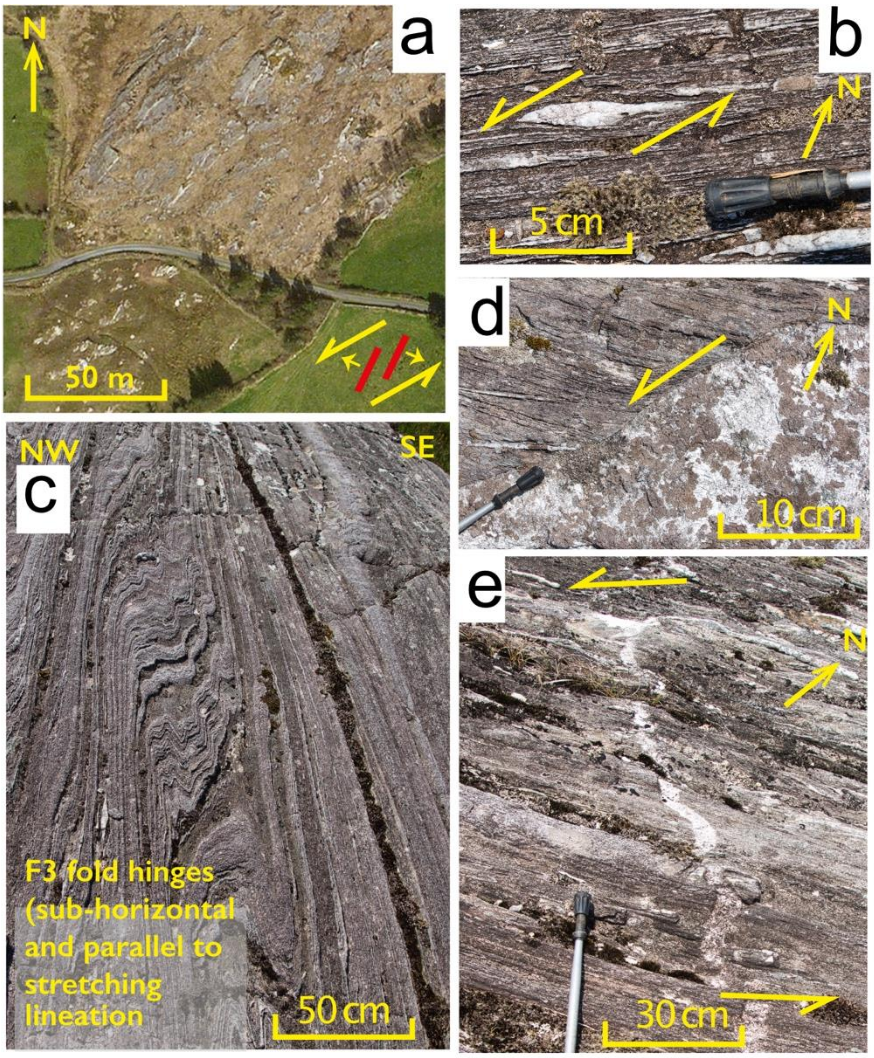
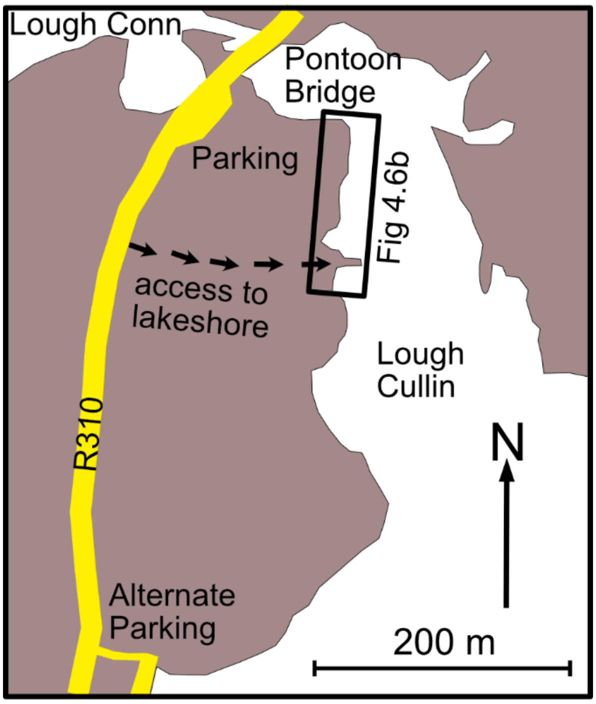


Fig. 4.4 a Digital Globe image of the Cloonkesh locality shows intrusive structures (light coloured veins). The inset at the bottom right shows the orientation of dilational structures under sinistral transpression **b** sinistral tails to asymmetric quartz boudin **c** subhorizontal F3 fold hinges in Ummoon Formation metasediments which are parallel to the stretching lineation. **d** granodiorite sheets emplaced along a left lateral shear zone **e** granitic vein that cuts across main D3 shear fabric but is itself buckled and sheared by anticlockwise rotation induced by sinistral shear. The photographs in Figs 4b to 4d are a guide the type of structures that cn be found at this locality.

4.5.3 Locality 4.2: Pontoon Bridge (53.986683° -9.198322°)

Access and other information Parking is available in a lay-by on the east side of the R310 just to the south-west of Pontoon bridge (53.987373°, -9.197352°). Immediately to the south, road cuts in the Ox Mountains igneous complex are now quite weathered and the internal details are much better seen on the lakeside exposures. Walk c. 100m south to the end of the road cuts and then access the lakeshore by walking east through a small stretch of forest for c.300m from 53.986683° -9.198322° (Fig. 4.5). In summer the undergrowth can be dense. If lake levels are low this locality can be accessed by parking at the small pier 400 m south (53.983692°, -9.198180°) and walking north along the lake shore.

Fig. 4.5 Location map for locality 4.2.



The excellent glaciated rock surfaces by the lakeshore have been described by McCaffrey (1992 fig.6; Fig. 4.6a). In this area the Ox Mountains igneous complex is characterised by tonalite intrusive sheets separated by granodiorite and granitic screens typically 10 - 15 m thick, although some zones within each sheet show a finer scale (c. 50 cm) sheeting (Fig. 4.6c, d). The sharp straight contacts indicate intrusion into a crystalline host and the absence of chilled contacts indicate no significant temperature difference between host granodiorite and tonalite intrusions.

The exposures to south of Pontoon bridge (Fig. 4.6) preserve excellent evidence of the types of structures that can form as a mid-crustal magmatic body cools whilst undergoing bulk transpressional deformation. These include : 1) Early discrete shears, possibly formed during crystallisation; 2) a penetrative solid state foliation with textbook quality shear band fabrics; and 3) late conjugate discrete shear zones that deform the foliation.

1) *Early discrete shears*. These structures described by McCaffrey (1994) are uncommon in plutonic rocks and their origin is difficult to determine because they are overprinted by the main foliation and in places by the late discrete structures. They are characterised by cm- to m-scale sinistral offsets of the granodiorite and tonalite contacts on thin (1 cm wide) slightly finer-grained bands that form generally clockwise to the main foliation. They are examples of single structures that deform several contacts (Fig. 4.6c, d) and examples of networks of connected shears that disrupt the multilayer of granodiorite and tonalite contacts (see Fig. 4.6d). The net effect of this shearing is to extend the contacts in a direction parallel to the intrusive contacts. These early structures possibly represent a form of 'melt enhanced embrittlement' (Davidson et al 1994). Their preferential preservation in the Ox Mountains Intrusive Complex may be a result of the dynamic tectonic environment in which they formed. They were uplifted and cooled before being completely overprinted by subsequent crystal plastic deformation during ongoing sinistral shearing.

2) *Main foliation*: The main penetrative foliation is not deflected by the early discrete sinistral shears and is a solid-state fabric , i.e. deformation occurred when all of the mineral phases had crystallised. It is a grain-shape alignment fabric defined by quartz, feldspar and mica which dips steeply to the NW (Fig 4.6e). On the foliation planes, a mineral lineation can be detected that gently

plunges NE or SW. A textbook sinistral shear band fabric (S-C fabric) is present in many parts of the intrusion and is especially well developed in the Pontoon exposures. The C planes and extensional shear planes (C') are penetratively developed anticlockwise of the main foliation and deflect the foliation and the 'tails' of feldspar grains in an asymmetrical sense that is consistent with sinistral shear (Fig 4.6e). Individual shear planes are defined by fine-grained quartz ribbons lined with mica grains. In thin section, McCaffrey (1994) showed that the shear planes were associated with the development of myrmekite. This is a feldspar and quartz intergrowth texture that forms by breakdown of K-feldspar as the plutonic phases cooled and in this case was likely induced by the deformation (cf Simpson & Wintsch 1989).

3) *Late shear zones*: The main foliation is locally intensified into a series of mylonitic shear zones, up to 50 cm across, that form on internal contacts. Some very good examples of strike-slip imbricates and duplexes (sensu Woodcock & Fischer 1986) are present at Pontoon. They are characterised by dark, fine-grained protomylonites. Also developed are a series of conjugate sinistral and dextral shear zones that modify the main foliation into broad fold structures by drag (McCaffrey 1992, 1994). Notable examples of the sinistral and dextral shears at Pontoon (53.986683° -9.198322) were illustrated in McCaffrey (1994, Figs 10 & 11) and shown in Fig 4.6f, g and h).

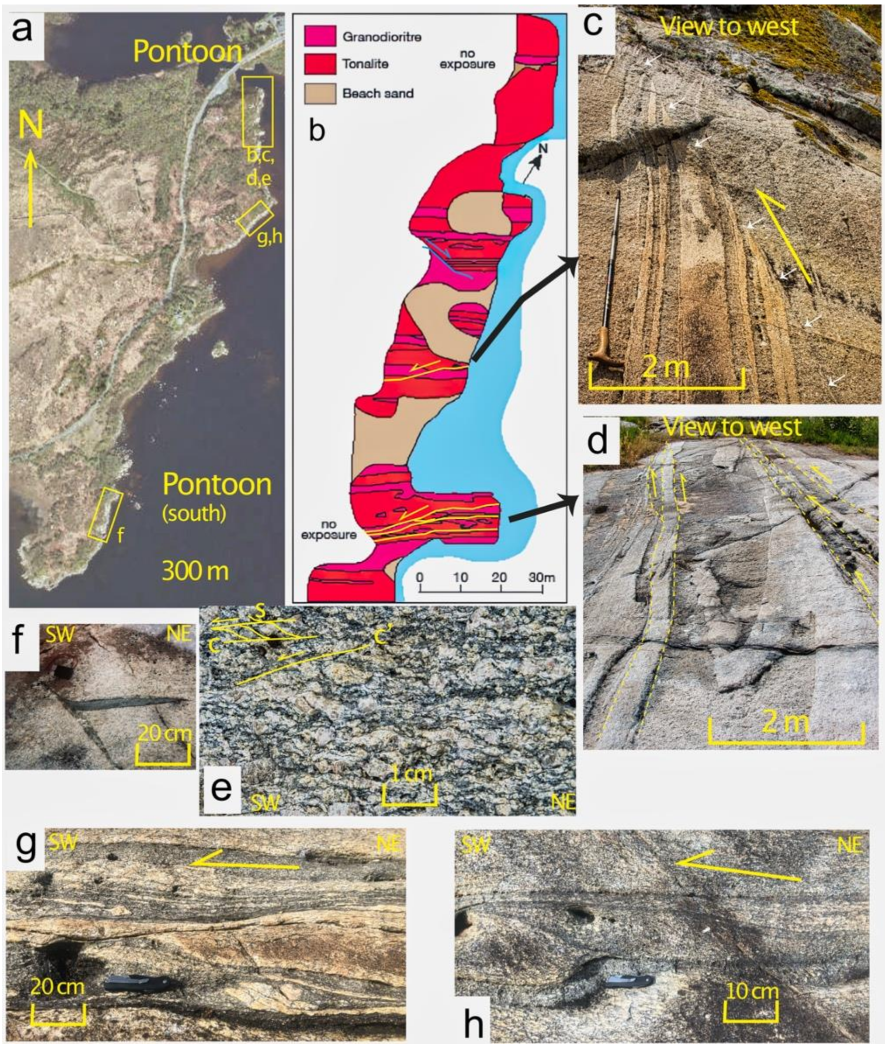


Fig. 4.6 a Digital globe image for the Pontoon locality. The position of the described features and a supplementary locality (Pontoon south) are shown **b** Sketch geological map showing details of the exposures on the lakeshore (after McCaffrey 1992) **c** Sheeted nature of the tonalite (darker) and the granodiorite (lighter) bodies **d** sharp contacts between the tonalite sheets and the granodiorite. The yellow dashed lines (solid on map) show the location of the early sinistral shears. These are (1cm wide) fine-grained relict high temperature faults along which the contacts are displace by sinistral shearing with displacements of the order of 1m or more **e S-C and** Extensional shear bands (C') deform main fabric **f** late dextral shear at Pontoon (on shoreline 500m west of Healy's Hotel) **g** late shear zone – a sinistral strike slip duplex **h** localisation of late sinistral shearing on internal contacts

4.5.4 Locality 4.3: Callow - Lismoran (53.968781°, -9.031283°)

Access and other information Proceed east to Foxford then take the N26 and drive 6.5 km to Callow. Park in the layby at 53.970434°, -9.031375°. Access requires walking, taking appropriate precautions, 190 m south on the N26 to the right hand fork for 'Lismorane'. Cross a small wall to visit the prominent frost shattered outcrops immediately northwest of this junction.

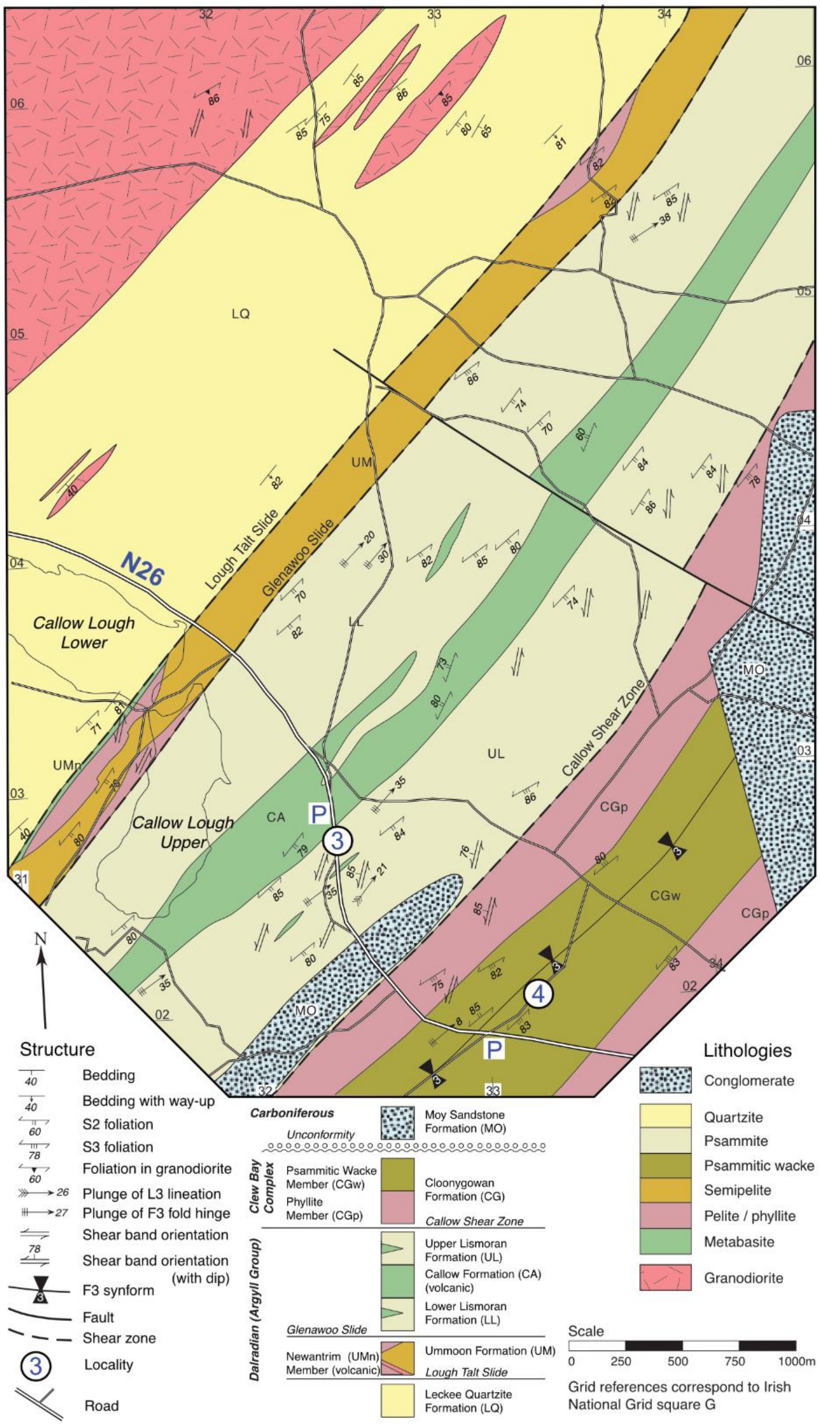

LQ
UM
LL
UL
CA
UMn
CGp
CGw
MO
N26
Lough Talt Slide
Glenawoo Slide
Callow Shear Zone
Callow Lough Lower
Callow Lough Upper
N
Structure
Bedding
Bedding with way-up
S2 foliation
S3 foliation
Foliation in granodiorite
Plunge of L3 lineation
Plunge of F3 fold hinge
Shear band orientation
Shear band orientation (with dip)
F3 synform
Fault
Shear zone
Locality
Road
Carboniferous
Moy Sandstone Formation (MO)
Unconformity
Clew Bay Complex
Psammitic Wacke Member (CGw)
Phyllite Member (CGp)
Cloonygowan Formation (CG)
Callow Shear Zone
Dalradian (Argyll Group)
Upper Lismoran Formation (UL)
Callow Formation (CA) (volcanic)
Lower Lismoran Formation (LL)
Glenawoo Slide
Newantrim (UMn) Member (volcanic)
Ummoon Formation (UM)
Lough Talt Slide
Leckee Quartzite Formation (LQ)
Lithologies
Conglomerate
Quartzite
Psammite
Psammitic wacke
Semipelite
Pelite / phyllite
Metabasite
Granodiorite
Scale
0 250 500 750 1000m
Grid references correspond to Irish National Grid square G

Fig.

4.7 Sketch geological map of the Callow area showing the locations of stops 4.3 and 4.4.

Localities 4.3 and 4.4 aim to show the stratigraphic and structural relationships across a D3 slide zone, the Callow shear zone. There are three such zones on the south limb of the major D3 antiform (Figure 4.2): the Lough Talt slide; the Glennawoo slide; and the Callow shear zone (Figures 4.2, 4.3). These were developed during D3 after the consolidation of the OMIC, which then became a buttress and deformation was concentrated in the country rocks (McCaffrey 1992; 1994). The geology of the Callow area has been described in detail by Jones (1989) and this account is based on this work.

The Lismoran Formation comprising pale green/grey psammites and semipelites is separated into Upper and Lower units separated by the amphibolites of the Callow Member. Locality 4.3 is in the highly sheared Upper Lismoran Formation (Fig 4.8a). The main S3 fabric is mylonitic, subvertical and strikes 060°. Quartz segregations are rodded and define a lineation that plunges 015° to the northeast. The F3 folds seen at Locality 4.1 are here transposed by the intensified S3 fabric. Shear band type asymmetric boudins within quartz veins (Fig 4.7b) and shear bands, on scales ranging from 1 - 50 cm, develop as the contact with the Cloonygowan Formation is approached (Fig 4.7). All indicators show a sinistral shear sense. Thin section analysis shows that S3 is defined by a strong crystallographic and dimensional orientation of quartz grains with large pressure-shadows filled by muscovite + chlorite + quartz + undeformed feldspar grains. This ductile fabric formed after, perhaps within 1 – 4 m.y., the crystallisation of the OMIC (McCaffrey 1992). However, sinistral motion on the faults bounding the block continued from the 412 Ma emplacement of the OMIC at least until the Middle Devonian (Table 4.3; Chapter 10).

Fig. 4.8 a General view of Locality 4.3 **b** Plan view of shear band type asymmetric boudinage of quartz veins. Sense of shear is indicated; however, this section is highly oblique to the local stretching lineation. Both photographs looking west from main N63 (53.968719°, -9.031394°).

4.5.5 Locality 4.4: Cloonygowan (53.961533°, -9.021189°)

Access and other information Drive a further 1.3 km south on the N26 and park at the oblique crossroads with the L5377 signposted for Cloonygowan (53.962342°, -9.019105°). Limited parking is available. Walk 150 m northeast on the L5377. The Cloonygowan Formation is exposed in roches moutonnées on either side of the road. The outcrops on the southeastern side are more accessible.

The rocks of the Cloonygowan Formation comprise interbedded green-weathering coarse greywackes with pebbles of plagioclase and opalescent quartz, greywackes with 5-10% pebbles and light greenish/grey phyllites. The matrix contains chlorite, quartz, plagioclase and pyrite. Sorting is poor and coarser beds exhibit normal grading. The Cloonygowan Formation displays two spaced cleavages probably produced by pressure solution where the rock has segregated into quartz and phyllosilicate layers. The early cleavage (S2) is close to bedding in most instances. It is cut and crenulated by a later upright S3 cleavage whose mean strike is 059°. In places, there is a well-developed sinistral S-C fabric. Minor F3 fold vergence gives a major synform running through the grit member (Fig. 4.7). An associated stretching lineation plunges at about 10° to the northeast. Way-up can be obtained in the grit member where graded bedding and sharp bases are visible. Based on this way-up evidence and employing facing directions on the cleavage, F2 fold closures can be inferred and have a much shorter wavelength than the major F3 synform. Jones (1989) reports sinistral shear bands within 50 m of the contact with the Upper Lismoran Formation.

The Upper Lismoran and the Cloonygowan Formations thus show a similar structural development but a disparity in maximum metamorphic grade during D2. The main Ox Mountains succession, east of the Knockaskibbole Fault, which includes the Upper Lismoran Formation attained amphibolite facies assemblages (Long and Max 1977, Yardley et al. 1979), whilst the Cloonygowan Formation did not exceed lower greenschist facies (Alsop and Jones 1991). The extent to which the relative uplift of the Ox Mountains Dalradian succession with respect to the Cloonygowan Formation was due to movement along the shear zone as a whole or displacement on the late Callow fault, which now separates these formations, is unresolved.

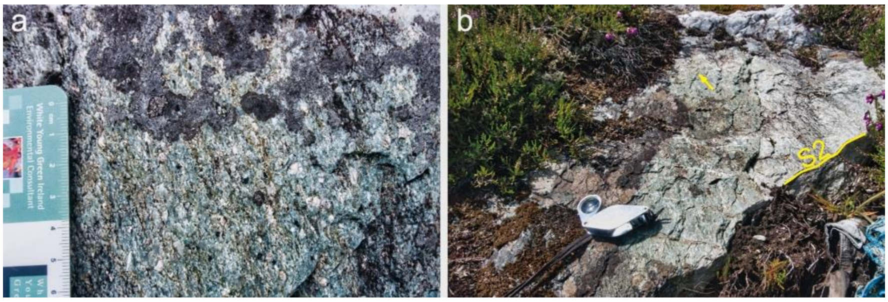


Fig. 4.9 a Greywackes of the Cloonygowan Formation with opalescent quartz and plagioclase granules **b** S2 (sub-horizontal and marked by a line) is folded by a minor F3 fold. The D3 stretching lineation, trending 060° is marked by an arrow. An extensional quartz vein at a high angle to this lineation and perpendicular to S2 is at the top of the view. Both photographs are from a locality at southeast side of road (53.962352°, -9.018910°).

4.5.6 Locality 4.5: Zion Hill (54.100308°, -8.877857°)

Access and other information Proceed to Swinford then take the N5 towards Dublin. Leave the N5 at the Charlestown junction and drive north on the N17 to Tobbercurry. Take the R294 to Annagh and drive 8.9 km to Mullany's Cross. Take the right fork and follow the signposts for 'Mass Rock'. Turn left after 1.7 km then left again after 3.8 km. Drive past the Mass Rock on your right, then turn right after 1.1 km at the 'T' junction with track. Zion Hill is 200 m north on the left. Parking (Fig. 4.10) is available at the small sandpit (54.102099°, -8.874272°). This locality is on private land and permission should be sought from the nearby farmhouse (54.102817°, -8.874216°). This locality is probably not suitable for large parties.

The aim is to demonstrate: the mafic vulcanism associated with Dalradian sedimentation; the Grampian D2 fabrics and the associated kyanite zone regional metamorphism (620±30°C and 8±2kbar); and the transposition of the Grampian fabrics (D2) during the formation of the D3 major antiform (Fig 4.3) synchronous with the emplacement of the OMIC in the southwest during the Acadian Orogeny.

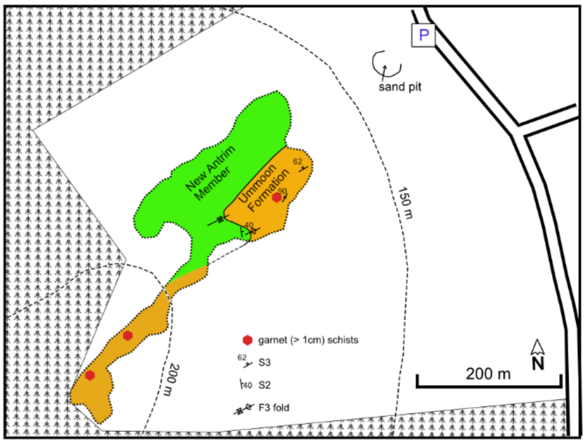


Fig. 4.10 Sketch geological map of Zion Hill.

Proceed southwest climbing the hill behind the small sandpit (Fig 4.10). There are low cliffs on the northwest face of the ridge. The main exposures are along the ridge, many of which are frost shattered but largely in place. Pelitic schists of the Ummoon Formation contain centimetric-scale porphyroblasts of garnet, kyanite and staurolite. Zion Hill is just east of the kyanite isograd (Yardley et al 1979). Almandine garnet can comprise up to 25% of the rock (Fig 4.11a). Garnet overgrows the S2 (Grampian) foliation, indicating that the Grampian metamorphic maximum postdated the major S2 fabric development event, but they are wrapped by the Acadian S3 fabric with the development of quartz-filled pressure shadows. The contact with the metadolerites of the New Antrim Member runs approximately along the ridge. The metadolerites are fine grained, sheared and locally have apparent relic ophitic texture. The contact with the pelites is sharp and highly sheared. However, the metadolerites share the same deformation history as the Ummoon Formation, which is consistent with them being erupted/intruded during sedimentation (Long and Max 1977). An earlier (S2) fabric within the metadolerites is preserved within the mesoscale F3 closures (Fig 4.10). This earlier fabric is at a high angle to and is folded by F3 (Fig 4.11b). The vergence of the asymmetric mesoscale F3 folds indicates that they lie on the southern limb of the main Ox Mountains antiform (Fig 4.1). Loose blocks of psammite within the Ummoon Formation, located within the fold closures, show that S3 is a spaced cleavage with pressure solution that crenulates S2 (Fig 4.11c).

The best examples of large (> 1 cm) kyanite (Fig 4.11d) and staurolite prophyroblasts occur on the ridge near to the summit.

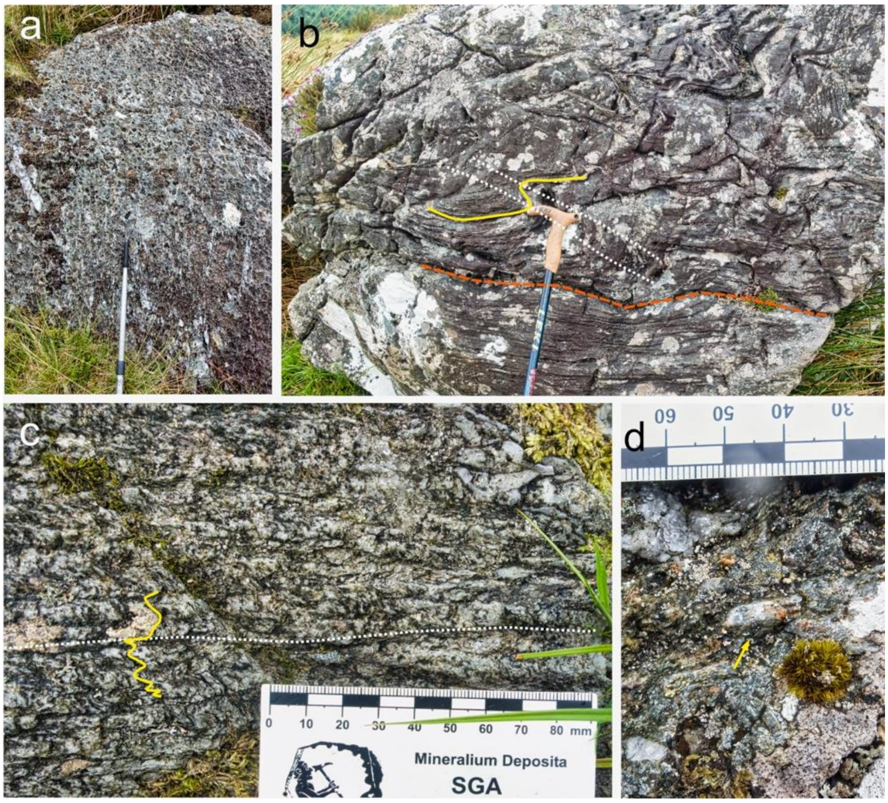


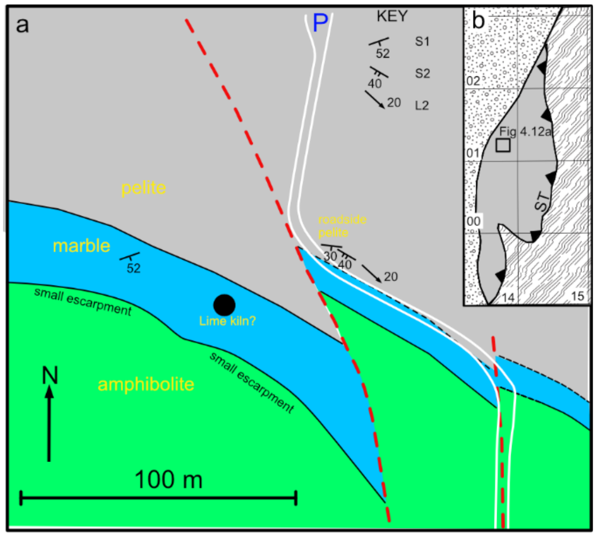
Fig. 4.11 **a** garnetiferous mica schist of the Ummoon Formation (54.099963°, -8.877060°) **b** F3 folds (dashed white lines mark F3 axial surfaces) developed in S2 in New Antrim Member (yellow line) above a small thrust (orange dashed line) (54.099724°, -8.878137°) **c** S2 (yellow line) crenulated by S3 (dotted white line) (54.100398°, -8.876661°) **d** Kyanite (arrowed) in Ummoon Formation 54.098614°, -8.879675°).

4.5.7 Locality 4.6: Windy Gap (53.954158°, -9.315519°)

Access and other information From Castlebar take the R310 for Pontoon; after c.1km take the left fork onto the L1721 towards Burren and proceed to the highest point of the road, called Windy Gap, and park in the large car park at 53.954232°, - 9.315546° with fine views over Glen Nephin to the north. This locality (Fig. 4.12) examines the Dalradian of the Raheen

Barr succession (Long and Max 1977) that underlies but is in faulted contact with the Devonian Kings Hill Formation (see Locality 10.5).

Fig. 4.12 **a** Sketch geological map of the Windy Gap region after Long and Max (1977). The 'P' in the north is located at the south end of the lay by **b** Outline map of the Sheeans region showing the Glenisland Formation (grey) in the hanging wall of the Sheeans Thrust (ST). Devonian sediments are shown with a dot - circle ornament and the main Ox Mountains Succession as wavy lines. Irish National Grid lines, Grid Square G, are shown.



The aim of this traverse is to demonstrate the association of mafic magmatism with Middle Dalradian sedimentation and to establish the lower maximum metamorphic grade typical of the southwestern region, west of the Knockaskibbole Fault (Figs 4.1, 4.3).

The car park lies on the Dalradian Glenisland Formation which contains pelites, white marbles, ortho-quartzites and massive amphibolites overlain by psammites (Long and Max 1977). The section examined occupies the lower part of this formation, and starts on pelites passing up section through marbles to the overlying amphibolites. The Glenisland formation is attributed to the Easdale Subgroup and correlated with the Nephin Succession of North Mayo (Winchester and Max 1996). The pelites are well exposed at a road cutting on the east side of the first bend south of the car park. Mica schists have a primary schistosity that is overgrown by idioblastic garnet. Currall (1963) reports a muscovite + chlorite + garnet + albite + quartz $\pm$ chloritoid (garnet zone) assemblage with no sign of biotite growth. Long and Max (1977) attribute this fabric, which is locally S1, to the Ordovician Grampian Orogeny and correlate it with S2 in the main Ox Mountains Succession. A retrograde crenulation cleavage, which is locally S2, (Fig 4.13b) is believed to be coeval with the Devonian emplacement of the OMIC and correlated with the regional S3 fabric (Long and Max 1977). The traverse then crosses a gully with limited exposures of white to grey marble (Fig. 4.13c), which have been exploited in the past for their lime content, and ortho-quartzite. This marble was used to make agricultural lime. A small circular depression probably represents the remains of an 'egg cup' lime kiln (Fig 4.12a). The ridge to the south marks the base of the meta-volcanic sequence. These are fine-grained poorly schistose rocks (Currall 1963) and in this region are mostly metadolerites which Winchester and Max (1987) characterise as continental tholeiites. The Glenisland Formation lies in the hanging wall of the Sheeans thrust (Fig 4.12b) which emplaces the Glenisland formation over the Ox Mountains Succession. The thrust dips to the northwest at between 5-15^{o} (Currall 1963) and is associated with cataclastic fault rocks suggesting post D3 emplacement (Jones 1989) which may have been associated with the inversion of the overlying Devonian basins (Chapter 10).

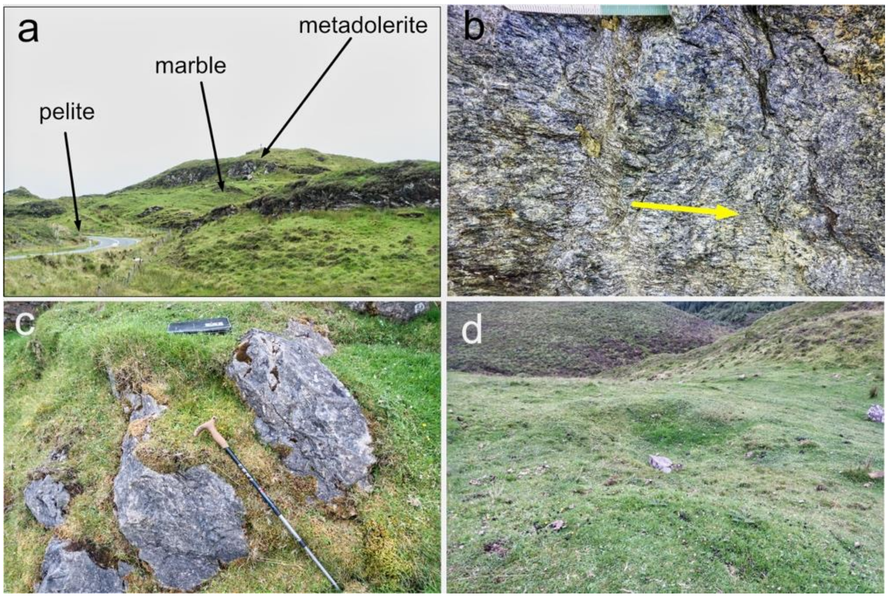


Fig. 4.13 **a** View of locality 4.6 looking south from the Windy Gap view car park **b** Garnet mica schists of the Glenisland Formation. The Grampian S1 fabric is in the plane of the photograph. The lineation associated with the Acadian S2 crenulation cleavage is marked by an arrow (53.953453°, -9.315410°) **c** clean, grey calcite marble of the Glenisland Formation (53.953095°, -9.316139°). The stick is 1 m. **d** Remains of 'egg cup' lime kiln where broken limestone was interlayered with fuel and burned to produce agricultural lime. 'Egg cup' kilns, named after their shape, had a ventillated grate at the base called the 'eye'and were used mainly during the 18th and 19th centuries. Field of view ~20 m, facing towards the west (53.953122°, -9.315725°).

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