Argyll Group, Grampian Caledonides

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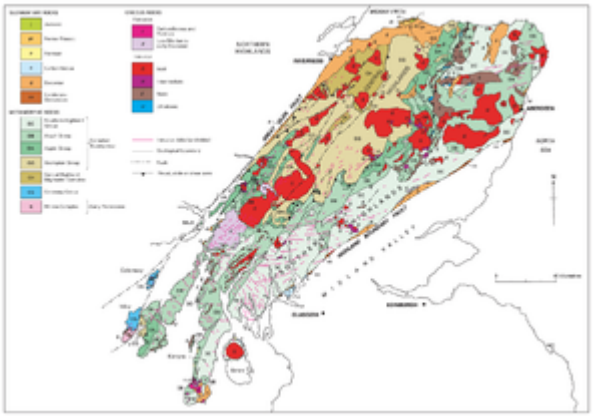
Argyll Group, introduction

Composite lithostratigraphical sections (not to scale) of the Appin, Argyll and Southern Highlands groups. P915418.

The Argyll Group has been divided into four subgroups (P915418). In the oldest, Islay Subgroup, conditions of deposition were similar to those of the preceding Appin Group. The deposits accumulated on or close to an extensive continental shelf and can be traced and correlated along the whole Dalradian outcrop. The base of the group as originally defined was marked by a tillite or a sequence of tillites, deposited from grounded ice sheets. This distinctive unit was, and continues to be, regarded as an important chronostratigraphical marker, not only in the British Isles but throughout the Caledonides. However, its use in defining a major *lithostratigraphical* boundary has led to problems where tillites occur in diachronous units (for example within the Ladder Hills Formation). The tillite-bearing sequence is followed by thick shallow-water shelf and deltaic quartzites which mark the end of stable conditions. The succeeding Easdale, Crinan and Tayvallich subgroups are generally characterised by basin deposits, turbidites and unstable basin margin slump deposits, with only one widespread major shallow-water interlude, in the upper Easdale Subgroup. It is rarely possible to trace individual beds in the Easdale and Crinan subgroups for any great distance and correlations are made on the grounds of general similarity of facies (P915418). In contrast, for most of its outcrop the Tayvallich Subgroup is dominated by a carbonate unit which forms one of the principal marker bands of the Dalradian succession. Further evidence for tectonic instability in the Argyll Group comes from the widespread syngenetic mineralisation in the Easdale Subgroup and from the penecontemporaneous igneous activity, evidence of which is found

throughout the group. The maximum development of volcanic rocks lies at the top of the Tayvallich Subgroup in the South-west Highlands.



Solid geology of the Grampian Highlands. P915411.

Rocks of the Argyll Group crop out over an area of some 5700 km^2 (P915411). Extensive outcrops occur on Islay and Jura, and Argyll Group rocks constitute almost the whole of the South-west Highlands to the north-west of Kintyre and Loch Fyne. The type successions for all four subgroups are found in this latter area where outcrops can be described in relation to three major structures, the Islay Anticline, the Loch Awe Syncline and the Ardrishaig Anticline (P915427). To the north-east of these structures, between the Etive Granite Complex and the Bridge of Balgie Fault, the Islay Subgroup, like much of the preceding Appin Group, is absent, although younger units are continuous. Farther to the north-east a full succession is present through the Tummel Steep Belt to the Glen Shee area, with the higher units continuing to middle Deeside. In the North-east Highlands, west of the Portsoy Lineament, the lowest units have been traced intermittently to the north coast. East of the Portsoy Lineament, the higher parts of the group are believed to be present in an undivided gneissose sequence forming a horseshoe outcrop pattern in the Turriff Syncline.

Block diagram of major structures in the Grampian Highlands. P915427.

Islay Subgroup

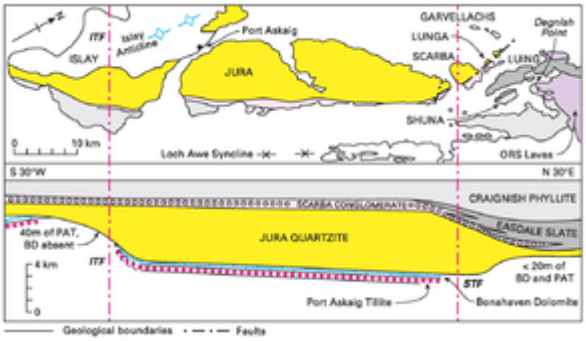
This largely psammitic subgroup is dominated in most areas by a thick quartzite formation. The quartzite and the underlying basal tillite-bearing formation are persistent and distinctive, enabling a good correlation of beds from Connemara to the Moray Firth.

Boulder bed in the Port Askaig Tillite Formation, Argyll Group, Islay; cleaved and containing large clasts mainly of granite. P215702.

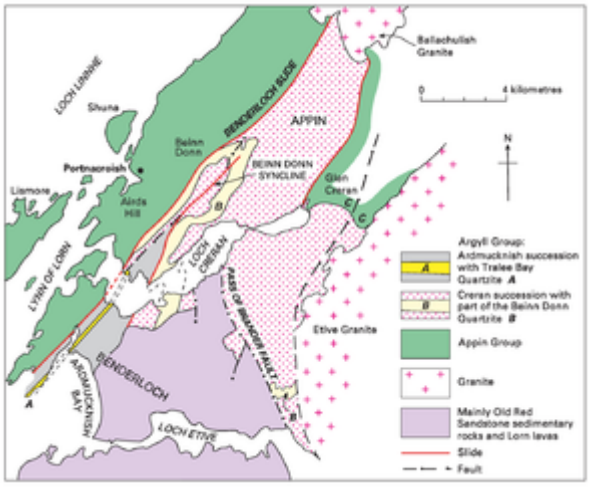
In the type area for the subgroup on Islay the basal *Port Askaig Tillite Formation* consists of a sequence of sandstones, siltstones, conglomerates and dolostones in which boulder beds have been recognised (Spencer, 1971; 1981; P215702). These beds range from 0.5 m to 65 m in thickness and contain boulders up to 2 m in diameter. One particular bed, the 'Great Breccia' contains large rafts of dolostone up to 320 m long. The lower beds contain clasts of dolostone, probably derived locally from within the formation or from the underlying Blair Atholl Subgroup. However, the higher boulder beds contain clasts of granite and granite-gneiss of extrabasinal origin. This division on the basis of clast content is also recognisable in boulder bed sequences outwith the type area. The boulder beds are generally regarded as tillites but isolated clasts in associated varved siltstones have been interpreted as dropstones from floating ice. Polygonal sandstone wedges have been interpreted as ice wedges formed during periods of emergence (Eyles and Clark, 1985).

Within the type area the formation varies considerably in thickness and in the number of tillites recognised. Around Port Askaig on Islay and on the Garvellach Islands, the formation is about 750 m thick and the combined sequence from the two areas may be up to 870 m, with up to 47 separate tillites recognised. However, to the south-west, on the Mull of Oa, the sequence is incomplete and less than 40 m thick. The presence of glacial deposits and their relationship to the adjacent dolomitic beds has considerable implications for the palaeogeography of Argyll Group time and for the age of the group, both of which are discussed in later sections.

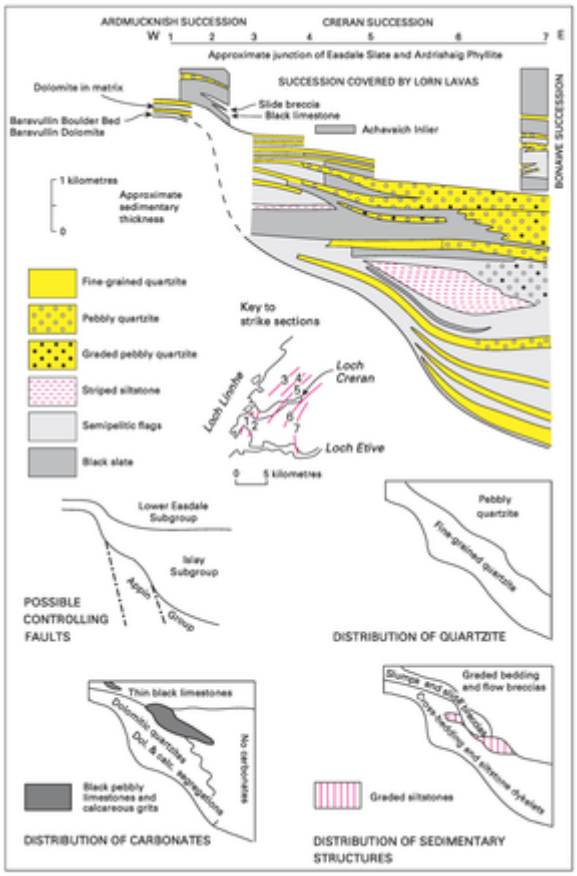
In the Port Askaig area of Islay tidal sandstones at the top of the tillite formation pass transitionally into the succeeding *Bonahaven Dolomite Formation* (Klein, 1970) which consists of up to 295 m of sandstones, pelites, dolostones and impure dolomitic rocks. It has been divided into four members by Spencer and Spencer (1972). Member 3 is the principal dolomitic unit, in which algal stromatolites occur at ten horizons in a total thickness of 150 m. The stromatolites have been described by Hackman and Knill (1962) and a sedimentological account of the whole member is given by Fairchild (1980a). More detailed studies of the diagenesis, petrography and geochemistry of the dolostones are described by Fairchild (1980b, 1985).



Geological sketch map and section of the Jura area—with along-strike stratigraphical section showing relationships at the end of Craignish Phyllite times. P915421.



Geological sketch map of Benderloch and south Appin to show the distribution of the equivalent Ardmucknish and Creran successions of the Argyll Group. P915422.



Variation in thickness and lithology over a possible fault-controlled basin margin, lower Argyll Group of Benderloch. P915423.

The succeeding *Islay (or Jura) Quartzite* marks an abrupt change to a thick succession of cross-bedded and pebbly quartzites characteristic of a tidal shelf environment (Anderton, 1976). The quartzites form almost all of the islands of Jura and Scarba (P915421) and crop out on both limbs of the Islay Anticline. Even in their thickest development of over 5000 m on Jura there are no marker bands by which they may be subdivided. However, in addition to the coarse sandstones and pebbly conglomerates, in parts there occur laminated or rippled fine sandstones and interbedded mudstones. Sedimentary structures imply dominant palaeocurrent flow directions towards the NNE throughout the formation, with a general change towards the finer-grained facies observed in the same direction. Within the type area the formation thins markedly along strike, to both the south-west and to the north-east (P915421; Knill, 1963).

Farther along strike to the north-east in the Benderloch area (P915422), the Islay Subgroup is reduced in thickness to between 300 m and 800 m in the Ardmucknish Succession (Litherland, 1980). However, the sequence here is similar to that of the type area in that it includes two dolomitic boulder beds at the base, followed by dolomitic flags and pebbly, cross-bedded quartzites. From Benderloch the subgroup increases in thickness across strike (P915423). Around Glen Creran, some 20 km to the east, the facies is markedly different to that of both the type area and Benderloch, the succession consisting predominantly of banded or flaggy quartzites and semipelites with no boulder beds (Litherland, 1980). Correlation is made mainly on the basis of stratigraphical continuity of distinctive formations both above and below. The exact limits of the subgroup are hence difficult to define here, but it is probable that between 2000 and 4500 m are present. Graded turbidites and ‘green beds’ of volcanic origin, which arerecognised in the lower part of the Creran succession, are features which become more common in the subgroup in the Southern and North-east Highlands.

Eastwards from the Etive Granite Complex to the Bridge of Balgie Fault in the Southern Highlands, the Islay Subgroup is not present. Rocks of the overlying Easdale Subgroup rest on a strongly deformed zone representing the Boundary Slide, beneath which are lower Appin Group rocks (Roberts and Treagus, 1979). It is impossible to determine if rocks of the Islay Subgroup were deposited in this area. If there was little or no deposition it is necessary to invoke a fault-bounded structural 'high', separating rapidly subsiding basins on either side, to account for the great thicknesses observed in the adjoining areas. Large parts of the succession have undoubtedly been excised tectonically, but it has also been suggested that contemporaneous erosion and resultant unconformities may account for many gaps in local Islay Subgroup successions (Pantin, 1961; Harris and Pitcher, 1975).

East of the Bridge of Balgie Fault, in the Schiehallion and Pitlochry areas, the Islay Subgroup is well developed, with a succession comparable with that of the type area (Bailey, 1925; Bailey and McCallien, 1937; Pantin, 1961; Harris, 1963; P915418). The *Schiehallion Boulder Bed* may be traced throughout most of the area, but is particularly well developed on the northern slopes of Schiehallion itself. The lower part has a matrix of calcareous mica-schists with only carbonate clasts, whereas the upper part is more siliceous with large clasts of granite, syenite and quartzite. The overlying *Schiehallion Quartzite* is typically massive, fine-grained and rarely cross-bedded. In the lower part, conglomeratic bands contain boulders of granite identical to those of the boulder bed; dolomitic beds, consisting of tremolitic limestone and calcareous pelites, are well developed locally.

Farther north-east, towards Braemar, thin developments of pebbly, granitic 'boulder bed' occur locally at the base of the massive *Creag Leacach Quartzite* (Upton, 1986). To the north of the Cairngorm and Glengairn granites the lower part of the Islay Subgroup consists of two interdigitating and diachronous formations. On Donside, semipelites and pelites with thin limestones and dolostones comprise the *Nochty Semipelite and Limestone Formation*. These lithologies pass laterally northwards into striped psammites with graded units, semipelites and minor pelites which together comprise the *Ladder Hills Formation*. This formation is several kilometres thick in its type area, but is absent or only thinly developed elsewhere. Boulder beds, typically underlain by a thin dolostone, occur locally towards the top of the Ladder Hills Formation. The best section of these boulder beds is found in the Muckle Fergie Burn, south of Tomintoul, where a limestone and a dolostone are succeeded by a 10 m-thick boulder bed containing clasts of dolostone in its lower, calcareous part and of granite and quartz-syenite above. Minor basic tuff bands also occur locally and in the Muckle Fergie Burn pillow lavas have been recognised just below the boulder beds. In some areas, for example in upper Donside near Corgarff, boulder beds occur within the lower units of the overlying *Kymah Quartzite* and in the Kymah Burn section thin basic lavas and tuff lenses are found near the base of the quartzite. The quartzite varies considerably in thickness, from only 10 m over fault-controlled structural 'highs' (e.g. Lecht–Cockbridge) to a more typical development of 300 to 500 m in adjacent basins.

The subgroup is probably cut out structurally to the west of Huntly, and to the east of Keith correlations are as yet uncertain. However, north of the River Isla the *Durn Hill Quartzite* is confidently assigned to this subgroup on account of loose blocks of tillite which have been found close to its base in several locations around Fordyce and Edingight (Spencer and Pitcher, 1968).

Easdale Subgroup

The base of the subgroup is marked in most places by rapid change to finer-grained rocks showing features typical of deep-water sedimentation and turbidity currents, with local incursions of coarse-grained mass-flow deposits. Higher parts of the subgroup are dominated by calcareous pelites and semipelites with local limestones, representing shallower-water sedimentation. These general

characteristics are preserved throughout the outcrop from Islay to the north coast and individual units can be traced for up to100 km, but the detailed stratigraphy is less continuous than in preceding subgroups.

In south-east Islay and south Jura the Islay and Jura quartzites are overlain by the *Jura Slate* which constitutes the basal part of the *Scarba Conglomerate Formation* (P915418 and P915421; Anderton, 1979). Here this formation is about 450 m thick consisting of grey and black slates with thick lenses of quartzite and conglomerate which pass upwards into persistent quartzite and conglomerate units. Sedimentary structures such as graded beds and erosional bases suggest deposition from turbidity currents on a subsiding offshore platform shelf. Farther north, on Scarba and adjoining islands, there is a pronounced increase in thickness and a change of facies. Proximal turbidites similar to those of the southern outcrops are interbedded with thick, coarse debris flows which are considered to have slumped downslope north-wards into a fault-bounded basin. The debris flows consist of locally derived blocks, up to 6 m in diameter, consisting of quartzite, limestone and phyllite, all in a gritty matrix. To the north of Scarba the debris flows and associated quartzites become finer grained and thinner as they become interbedded with and pass upwards into the deeper-water *Easdale Slate* (Anderton, 1979; P915421). The Easdale Slate consists predominantly of black, carbonaceous, pyritic slates, best developed on Seil and Luing where they have been quarried extensively (Baldwin and Johnson, 1977). Incursions of distal turbidites are seen as thin, poorly graded sandstones and occasional dolomitic carbonate beds (P219043).

Folded black slates and limestones of the Easdale Slate Formation, Argyll Group, Isle of Kerrera, Oban. P219043.

On the island of Shuna and on Degnish Point, the Easdale Slate passes upwards into the 20 m-thick *Degnish Limestone* (P915418), a complex unit composed of interbedded limestones, mudstones and calcareous sandstones which marks a passage into the shallow marine facies of the *Craignish Phyllite* (Knill, 1959; Roberts, 1966; Borradaile, 1973; Anderton, 1975). This phyllite unit, which is correlated with the *Port Ellen Phyllite* of Islay and Jura, consists of abundant alternations of laminated phyllites, quartzites, limestones and pebbly sandstones, with a total thickness of up to 4500 m. Many of the sediments were deposited on tidal flats and in subtidal environments with pseudomorphs after gypsum that indicate periodical emergence. Thick cross-bedded, dark grey limestones, intercalated with dark phyllites at the top of the formation comprise the *Shira Limestone and Slate*, which is a persistent marker unit, up to 300 m thick, in parts of the South-west Highlands.

In the Benderloch area (P915422; P915423), the top part of the Ardmucknish succession (600 to 1200 m thick) consists predominantly of black slates with a few thin black limestones and pebbly mudstones, the *Selma Slate Formation* (Litherland, 1980). The slates contain several beds of

calcareous grit and a sedimentary breccia with a variety of exotic clasts, the *Selma Breccia* (up to 100 m thick). The whole sequence is interpreted as equivalent to the Jura Slate and Scarba Conglomerate to the south-west. At the top of the Ardmucknish succession is a 200 m-thick, graded, pebbly quartzite, the *Culcharan Quartzite*. Correlation with the top part of the Creran succession to the east is difficult. Here black slates and striped siltstones of the *Salachan Formation* (1000 m thick) are overlain by the *Beinn Donn Quartzite Formation* (1500 m thick) (Litherland, 1980). South of Loch Creran the quartzites are pebbly and are intercalated with pelites, pebbly mudstones, calcareous grits and thin limestone breccias; Anderton (1985) regards the whole succession as typical of the Easdale Subgroup. A massive, pebbly quartzite with graded bedding and intraformational breccias, within the Beinn Donn Quartzite Formation, is correlated by Litherland (1980) with the Cairn Mairg Quartzite of the Southern Highlands However, the same quartzite can be traced around the Beinn Donn Syncline (P915422) where it changes in facies to cross-bedded quartzites and flags, regarded by Litherland (1980; 1987) as equivalent to the Islay and Jura quartzites. Regardless of whether this part of the succession is assigned to the Islay or the Easdale subgroup, it seems likely that the incoming of Easdale-type facies, marked by slide deposits, pebbly quartzites, pebbly limestones and pebbly mudstones, is diachronous, occurring earlier in the east than the west.

On the south-eastern side of the Loch Awe Syncline, only the top part of the South-west Highlands Easdale Subgroup succession is exposed in the core of the Ardrishaig Anticline. Here, the *Ardrishaig Phyllite* is lithologically similar to the Craignish Phyllite and is regarded as stratigraphically equivalent (Roberts, 1966; Borradaile, 1973). Sedimentary structures are not so well preserved as in the Craignish Phyllite owing to a higher metamorphic grade but pseudomorphs after gypsum have been recorded and sulphur isotopes are consistent with a shallow-water, mildly reducing marine environment (Hall et al., 1994). The amount of deformation makes estimates of thickness difficult but over 4000 m of succession are recorded in places. In Knapdale a diachronous, predominantly quartzitic unit, the *Erins Quartzite*, has an apparent thickness of up to 5000 m. The lower part is included in the Easdale

Subgroup, as are two more-pelitic lithologies, the *Stornoway Phyllite* and *Stronachullin Phyllite*, which locally separate the quartzites into lower and upper developments. The Shira Limestone is not present in Knapdale but farther to the north-east it appears on the north-western limb of the Ardrishaig Anticline as a gritty black limestone, more than 100 m thick. The whole subgroup becomes more pelitic towards the north-east around upper Loch Fyne, where the Ardrishaig Phyllite is overlain directly by the *St Catherine's Graphitic Schist* (apparent thickness 200 m), consisting of black, graphitic schists with thinly bedded limestones, and probably equivalent to the Shira Limestone (Roberts, 1966). Minor 'green beds' of tuffaceous or detrital volcanic material occur in the south-eastern parts of the Ardrishaig Phyllite and Erins Quartzite outcrop, and numerous metabasic sills may be near-contemporaneous with sedimentation (Chapter 8).

The Easdale is the earliest subgroup in the Dalradian which can be traced continuously from the South-west Highlands through the Southern Highlands to the Pitlochry area. In the area around Dalmally, Roberts and Treagus (1975) recognise a succession above the Boundary Slide Zone consisting of pebbly quartzites overlain by black slates and Ardrishaig Phyllite. The quartzites can be equated with the Carn Mairg Quartzite of the Southern Highlands and the black slates with both the Easdale Slate to the west and the Ben Eagach Schist to the east, hence providing a crucial link. East of the Tyndrum Fault, published information on the detailed stratigraphy is sparse. By contrast, the presence of extensive stratabound and vein mineralisation within the subgroup between here and Pitlochry has resulted in many publications which include brief descriptions and maps of the general geology (see Chapter 17). More detailed accounts of the stratigraphy have been provided by Nell (1984) and Scott (1987). Farther to the north-east, some stratigraphical details around Killin are

given by Johnstone and Smith (1965) and detailed accounts are available for Ben Lawers (Elles, 1926), Lower Glen Lyon/Schiehallion (Bailey and McCallien, 1937; Rast, 1958; Treagus, 1987), south of Loch Tummel (Sturt, 1961) and north of Loch Tummel/Pitlochry (Bailey, 1925; Harris, 1963).

Throughout the areas listed above a common succession may be recognised which, with only local absences, consists of Killiecrankie Schist–Carn Mairg Quartzite–Ben Eagach Schist–Ben Lawers Schist (P915418). Contrary to many previous accounts, the base of the subgroup is now drawn below the Killiecrankie Schist, which can be regarded as equivalent to the Easdale Slate and is a comparable deepwater facies. The *Killiecrankie Schist* is widely recognised east of the Loch Tay Fault but west of the fault it is found only in the Schiehallion area. It consists of semipelitic and pelitic garnetiferous mica-schists with abundant intercalated quartzose schists and pebbly quartzites. Minor amounts of graphitic schist are present locally and many concordant bands of amphibolitic metabasalt and thin beds of tuff occur towards the top of the formation. The *Carn Mairg Quartzite* crops out around Loch Lyon, in the Schiehallion area and can be traced eastwards to Ben Vrackie. It ranges from feldspathic, pebbly quartzite, to a psammitic greywacke and typically shows graded bedding. Locally it is absent and may, together with the quartzites in the underlying Killiecrankie Schist, represent sandy turbidites which periodically swept into the fine-grained basin sediments now represented by the Killiecrankie and Ben Eagach schists. The *Ben Eagach Schist* can be traced from north of Tyndrum eastwards to north of Loch Lyon and then continuously from north of Schiehallion and lower Glen Lyon to Ben Vrackie. It consists predominantly of distinctive dark grey to black graphitic schists, with impersistent thin limestones and amphibolites . Most of the stratabound mineralisation of the Argyll Group occurs in this formation, notably the bedded baryte and celsian with sulphides, up to 50 m thick, which extends intermittently for 7 km along strike around Ben Eagach and Farragon Hill, north of Aberfeldy (see Chapter 17). The *Ben Lawers Schist* forms a wide continuous outcrop extending from Tyndrum to Glen Lyon, Schiehallion and Pitlochry to the Glen Shee area. North of Loch Tay it occupies the core of the Ben Lawers Synform. The dominant lithology is a calcareous, pelitic mica-schist with some thin quartzite and limestone beds. Hornblende-schists of metasedimentary origin are common, but chloritic ‘green beds’ of volcanogenic origin and pods of basic and ultramafic igneous material are also recorded. A persistent zone of stratabound sulphide, mainly pyrite, occurs near the top of the formation. Above the Ben Lawers Schist, the top of the subgroup is marked by a variety of lithologies. Around Tyndrum, the *Ben Challum Quartzite Formation* consists of up to 500 m of quartzites and micaceous semipelites with minor amphibolites of possible volcanogenic origin and two bands of low-grade stratabound sulphide mineralisation (Fortey and Smith, 1986). This passes north-eastwards into the *Sron Bheag Schist* of the Ben Lawers area, consisting mainly of quartzose schists and hornblende-schists with various calcareous schists and limestones (Elles, 1926; Johnstone and Smith, 1965). East of the Loch Tay Fault the *Farragon Beds*, a complex series of quartzites, mica-schists, hornblende-schists and ‘green beds’ represent the earliest major volcanic episode in the Dalradian (Sturt, 1961; Harris, 1963).

The Killiecrankie Schist and Carn Mairg Quartzite cannot be traced with any confidence north-east of the Pitlochry area. In the Glen Shee–Braemar area, the Creag Leacach Quartzite of the Islay Subgroup passes up through a transition formation of interbedded quartzite and black schist into the graphitic *Glas Maol Schist* (Upton, 1986). The immediately overlying succession is dominated by metabasic intrusions with only small outcrops of limestone and calcareous schist.

North-east of the Lochnagar Granite in the Ballater area, the Easdale subgroup consists mainly of psammites and semipelites with calc-silicate lenses and thin impure limestones in the upper part. A sequence of banded amphibolites at the top of the subgroup represents basic lavas in an equivalent position to the Farragon Beds near Pitlochry. Farther north the more typical Easdale sequence is re-established in a belt extending from south of the River Don to north of Glenbuchat. Here, the Kymah

Quartzite is overlain by the *Culchavie Striped Formation*, a thick sequence of striped semipelites and psammites with a distinctive pebbly quartzite. These are succeeded in turn by the *Glenbuchat Graphitic Schist* and by calcareous semipelites and minor psammites with limestone and calc-silicate beds, termed the *Badenyon Calcareous Schist*. Graphitic schists are also present around the headwaters of the River Don, where they are overlain by a prominent metavolcanic unit consisting of amphibolites, vesicular basic pillow lavas and tuffaceous beds.

To the north of these outcrops, structural complexities, major dislocations and facies changes preclude any firm correlation with the established Easdale Subgroup successions. However, various local successions, mostly bound by faults and major shear-zones, occupy a similar stratigraphical position within the Argyll Group sequence. On the east side of the Portsoy Lineament, in the Cabrach area, a sequence of black pelites, semipelites, psammites, pebbly greywackes and metavolcanic rocks is termed the *Blackwater Formation* (Fettes et al., 1991). The metavolcanic rocks can be divided into three members which are composed of aphyric, pyroxene-phyric and pillowed metabasalts and both massive and autobrecciated ultramafic lavas (MacGregor and Roberts, 1963). The overall lithological assemblage of the Blackwater Formation is similar to that found elsewhere in the Easdale Subgroup but, since the formation appears to pass upwards into Southern Highland Group lithologies, it must be regarded as 'Argyll Group–undivided'. Semipelites and graphitic pelites with minor limestones occur above the Kymah Quartzite in the Drumdelgie area, west of Huntly. On the north coast, a thick sequence of semipelitic, pelitic and graphitic schists with limestone and quartzite in its upper part, termed the *Castle Point Pelite* and *Portsoy Limestone* formations (the 'Portsoy group' of Read, 1923), is widely sheared and attenuated within the Portsoy Lineament.

Crinan Subgroup

Throughout its outcrop, this subgroup exhibits a relatively simple stratigraphy in which local successions are dominated by single thick formations. Sedimentation was generally of deep-water, turbiditic type with marked variations in thickness and diachronous facies changes. The Crinan Grit of the South-west Highlands passes laterally into the generally thinner-bedded and finer-grained Ben Lui Schist of the Southern Highlands. In most areas of the North-east Highlands it has not so far been possible to differentiate the Crinan and Tayvallich subgroups; they crop out in a broad horseshoe of migmatitic and gneissose psammites and semipelites around the Turriff Syncline.

On the south-eastern limb of the Islay Anticline the *Laphroaig Quartz-schist* and *Ardmore Quartzite*, which crop out along the south-eastern coast of Islay, are correlated with the Crinan Grit (Borradaile, 1979). On both limbs of the Loch Awe Syncline, the subgroup is composed of the *Crinan Grit* (Knill, 1959; Roberts, 1966; Borradaile, 1973). The base is probably diachronous and the basal psammites and quartzites are locally interbedded with lithologies indistinguishable from the underlying Craignish Phyllite. Elsewhere an unconformity is implied by pebbly beds near the base of the Crinan Grit and by a basal conglomerate. Around the head of Loch Awe and on the north-western limb of the syncline the subgroup consists of 100 to 550 m of fine- and medium-grained, white quartzites with thin bands of quartzose gritty psammites and interbedded green or grey phyllites. Locally, thin limestones and black slate units are present. A lenticular zone of pale green tuffs occurs near Craignish, and the overlying psammites have a more chloritic matrix, reflecting a volcaniclastic component. On the south-eastern limb of the Loch Awe Syncline the thickness of the Crinan Grit increases to over 3000 m with the incoming of many thick-bedded coarse-grained psammites containing angular fragments of detrital feldspar, mica and carbonate. Pebbly and locally conglomeratic quartzites increase towards the top of the formation and in places become the dominant lithology. Well-developed grading, channelling and large-scale slump folding are common. The interbedded black limestones and slates are typically gritty and contain angular, slumped blocks of limestone. These features are indicative of proximal turbidite deposits which Anderton (1985)

considers were deposited in submarine fan channels flowing axially in a major NE–SW-trending basin along the line of what is now the Loch Awe Syncline.

Farther to the south-east, across the Ardrishaig Anticline, the subgroup crops out in a continuous strip along the west coast of Kintyre and through Loch Fyne to the Southern Highlands. In south Knapdale the subgroup is represented by the fine-grained upper part of the *Erins Quartzite* . Grey-green, phyllitic pelites and semipelites occur locally and pebbly quartzites, usually graded, become prevalent towards the top of the formation (Roberts, 1966). A zone of sparse, stratabound pyrite-chalcopyrite mineralisation in the Upper Erins Quartzite in the Meall Mor area suggests a possible correlation with the Ben Challum Quartzite at the top of the Easdale Subgroup in the Tyndrum area. In Kintyre, the Erins Quartzite crops out in a thin strip along the west coast where locally it contains several bands of limestone (McCallien, 1929). Above the Erins Quartzite, the *Stonefield Schist* consists of garnetiferous mica-schists and chlorite-albite-schists with beds of quartzose schist, schistose psammite and lenticular sandy limestones. When traced north-eastwards, across Loch Fyne, this formation has been termed the '*Garnetiferous Mica-Schist*'. North-east of Lochgair the Erins Quartzite lenses out and towards upper Loch Fyne, the Garnetiferous Mica-Schist becomes dominantly pelitic, before passing north-eastwards into the Ben Lui Schist of the Southern Highlands. The Erins Quartzite and the Stonefield Schist/Garnetiferous Mica-Schist/Ben Lui Schist are finer-grained than the Crinan Grit. Many authors have regarded these beds as more distal turbidites, deposited in the same basin as the Crinan Grit (e.g. Harris et al., 1978), but Anderton (1985) suggests that they were deposited in a separate parallel basin which exhibits a general fining from south-west to north-east.

The *Ben Lui Schist* crops out continuously in the Southern Highlands from Ben Lui to Ben Vuirich, notably over wide areas on both limbs of the Ben Lawers Synform and including structural outliers on the lower limb of the Tay Nappe around Lochearnhead. The formation consists mainly of garnetiferous mica-schists and turbiditic, graded schistose psammites, although sparse hornblende-schists and impersistent bands of limestone have been recorded in the Killin area (Johnstone and Smith, 1965) and near Pitlochry (Sturt, 1961). At the base of the formation, between Tyndrum and Glen Lyon, is a zone up to 50 m thick containing lenticular bands of talcose or chloritic soft green schists which are dolomitised locally. These schists contain lenses and pods of dolomite and magnesite with minor amounts of chromium, copper and nickel minerals. They probably represent sediments derived from the erosion of local ultramafic rocks (Fortey and Smith, 1986).

North-eastwards from Ben Vrackie, the metamorphic grade of the Ben Lui Schist increases. Abundant concordant quartzofeldspathic segregations occur together with many thick pegmatite veins, so that the rock takes on a migmatitic appearance. In the Glen Shee area and through to the headwaters of Glen Isla and Glen Clova, the pelitic and semipelitic *Caenlochan Schist* is considered to be equivalent to the Ben Lui Schist on account of the lack of calcareous lithologies. The schists grade into the lit-par-lit migmatites of the *Duchray Hill Gneiss* (Williamson, 1935) in which a variety of metasedimentary lithologies can be recognised, including distinctive bands of coarse-grained staurolite- and/or kyanite-bearing rock. The equivalent *Queen's Hill Gneiss* can be traced north-eastwards into Glen Muick and to Queen's Hill, near Aboyne (Read, 1927; 1928). Here the dominant migmatitic, semipelitic to pelitic gneisses are interbedded with psammites, rare quartzites and thin calc-silicate bands comprising the Queen's Hill Gneiss Formation. The formation also includes numerous bands of hornblende-gneiss, implying that it was a preferred horizon for the intrusion of basic sheets. Similar migmatitic and gneissose lithologies occur in lower Deeside in a belt between the Hill of Fare and Mount Battock granites.

To the north of Deeside, and to the east of the Portsoy Lineament, rocks which are generally ascribed to the upper part of the Argyll Group occur in a broad arc from middle Donside to Fraserburgh and in a narrower zone from Huntly to Portsoy. Within these poorly exposed areas

thick, mixed sequences of psammites, semipelites and pelites show little mappable variation and no consistent detailed stratigraphy has been established. The metamorphic grade is generally high and most of the rocks are migmatised, so that over considerable areas the rocks are predominantly gneissose. The migmatitic and gneissose textures clearly transgress primary lithological boundaries but, by analogy with the development of the Queen's Hill and Duchray Hill gneisses to the south, it has been traditional to assign all of the gneisses broadly to the Crinan Subgroup (Read, 1955; Harris and Pitcher, 1975). However, some probably belong to the Tayvallich Subgroup and it is possible that minor units of the Easdale Subgroup are included in some areas (e.g. near Portsoy).

In Middle Donside, from the eastern margin of the Movern–Cabrach basic mass to the Tillyfourie area, lithologies are comparable to those of the Queen's Hill Gneiss. These constitute the *Craigievar Formation (Donside Gneiss* of Read, 1955) which consists mainly of finely interlayered, schistose and gneissose psammites and pelites. Major developments of pelitic gneiss, concordant amphibolite and thin developments of limestone and calc-silicate-bearing rock occur locally. Relationships are further complicated by hornfelsing and partial melting close to the major basic intrusions. East and north-east of the Bennachie Granite, equivalent rocks are known as the *Aberdeen Formation* (Munro, 1986). The dominant lithologies are less pelitic than those to the west, consisting mainly of psammites and semipelites and characterised by conspicuous small-scale compositional banding. In the south, around Aberdeen and lower Deeside, the formation shows little variety, with lithological alternations rarely more than a few metres thick. To the north of Aberdeen, major sub-units of relatively more psammitic or pelitic rocks are up to 1 km thick and minor bands of calc-silicate rock and amphibolite are common.

The gneisses of the *Ellon Formation* crop out around the lower Ythan valley. (Read, 1952; Munro, 1986). They are derived mainly from semipelitic and psammitic metasedimentary rocks, although amphibolites are locally dominant. Calc-silicate rocks are rare. The gneisses are distinguished from those of the Aberdeen Formation by their lack of regular lithological banding, their poor fissility and a foliated, streaky appearance. Bodies of migmatitic 'granite' are widespread. The boundary with the Aberdeen Formation is transitional in places but elsewhere it is highly sheared. To the north and east of Ellon, the Ellon gneisses grade into the structurally overlying *Stuartfield 'division'* of semipelites, pelites, psammites and metagreywackes. The upper part of this division has a more coherent stratigraphy and is termed the *Strichen Formation*. To the north this may be further subdivided into a lower part containing massive channel quartzites up to 500 m thick (e.g. the *Mormond Hill Quartzite*) and an upper part containing calcareous beds; the latter have been taken to indicate that the Strichen Formation spans the boundary between the Crinan and Tayvallich subgroups (Kneller, 1988).

To the north of Peterhead is the *Inzie Head 'group'* (Read and Farquhar, 1956). This mixed assemblage of rocks has a general migmatitic appearance with more homogeneous quartzofeldspathic gneisses alternating with xenolithic gneisses. The xenoliths consist of a wide range of metasedimentary lithologies, including calcareous schists, and are locally arranged in trails resembling dismembered sedimentary units. More coherent bands of amphibolite, psammite and calcareous schist with impure marble have been mapped locally. The *Cowhythe Psammite Formation* (formerly the *Cowhythe Gneiss*) crops out in a north–south belt from the coast east of Portsoy to the north-east of Huntly (Read, 1923). It is essentially a psammitic to semipelitic schist with rare limestone and pelite bands. Streaky *lit-par-lit* migmatites and feldspathised rocks occur, particularly in the semipelitic units, but for the most part the original compositional banding can still be discerned.

Tayvallich Subgroup

This subgroup is characterised by carbonate sequences; the Tayvallich Limestone and its lateral equivalents, the Loch Tay Limestone and Deeside Limestone, together constitute one of the most persistent marker bands of the Dalradian Supergroup, stretching from Donegal to the Banchory area (Gower, 1973). In Scotland the limestones are mainly turbiditic and were probably deposited in pre-existing Crinan Subgroup basins following a reduction in the supply of clastic sediments to the fringing shelves (Anderton, 1985). In the South-west Highlands an episode of basic volcanicity, which commenced in early Tayvallich Subgroup times, resulted in the most extensive development of volcanic and subvolcanic rocks seen in the Dalradian succession (Chapter 8). Previous accounts have included the majority of these volcanic rocks in the overlying Southern Highland Group, following Harris and Pitcher (1975), who correlate them all with the Green Beds. However, since the eruptions started in the Tayvallich Subgroup and since volcanic events generally occupy a short time interval in relative stratigraphical terms it is appropriate to include the majority of the products in the Tayvallich Subgroup (Anderton, 1985).

In the Loch Awe Syncline and the subsidiary Tayvallich Syncline, the *Tayvallich Slate and Limestone Formation* exhibits marked facies changes from north-west to south-east comparable to those in the underlying Crinan Subgroup. The overall thickness varies considerably, mainly due to variations in the amounts of slate and volcanic material. The formation reaches a maximum of 1200 m, but the total thickness of limestones is relatively constant, at about 100 m. On the north-western limb of the Loch Awe Syncline fine-grained, dark, partly oolitic limestones and coarse-grained, graded, gritty limestones are interbedded with dark blue-grey phyllites or slates. These lithologies probably represent shelf sedimentation. Coarse, slumped limestone breccias, conglomerates and gritty psammites, all suggestive of an unstable shelf margin, attain maximum development along the axial zone of the syncline. On the south-eastern limb thinner lenses of limestone-breccias and conglomerates are interbedded with turbiditic psammites (Knill, 1963). Around the north-eastern closure of the Loch Awe Syncline, the Tayvallich Limestones are succeeded by the *Kilchrenan Grit* and the *Kilchrenan Conglomerate* (Borradaile, 1973). The former is a poorly graded, feldspathic psammite with mudstone flakes, whereas the latter is a matrix-supported ‘boulder bed’, up to 30 m thick, consisting of well-rounded quartzite boulders in a gritty black slate matrix. It has been interpreted as a slump conglomerate (Kilburn et al., 1965).

Basaltic pillow lavas, Tayvallich Volcanic Formation, Argyll Group, coast south-west of

Tayvallich, Argyll. P219459.

Volcanic rocks occupy much of the core of the Loch Awe syncline between the Pass of Brander in the north-east and Loch Crinan in the south-west. Smaller outcrops occur farther to the south-west, notably in the core of the Tayvallich Syncline. The *Tayvallich Volcanic Formation* has a very sharp base in its more northern outcrops, just above the Kilchrenan Conglomerate, but in the south the lower parts consist of a complex interdigitation of limestones, clastic sediments and volcanic rocks. The volcanic formation consists of up to 2000 m of commonly pillowed basic lavas (P219459), hyaloclastites and a variety of epiclastic volcanic rocks (Borradaile, 1973; Graham, 1976). The epiclastic rocks include breccias and waterlain pebbly deposits such as the *Loch na Cille 'Boulder Bed'* of the Tayvallich Peninsula (Gower, 1977). Extrusion of the main volcanic pile was clearly submarine but away from the main centre of volcanicity, which corresponds to the axis of the Loch Awe Syncline, air-fall tuffs have been recognised. A suite of metabasic sills with a similar geographical distribution to the volcanic rocks intrudes the whole succession from the Craignish and Ardrishaig phyllites upwards; their total thickness attains 3000 m in places. These were originally thought to be contemporaneous with the lavas (Borradaile, 1973; Graham, 1976), but they may well be near-contemporaneous with their host sediments, building upwards with time as shallow intrusions into soft sediments (Wilson and Leake, 1972; Graham and Borradaile, 1984; Graham, 1986). A suite of NW-trending metabasalt dykes on Jura may represent feeders for the lavas and sills (Graham and Borradaile, 1984).

To the south-east of the Ardrishaig Anticline the Tayvallich Subgroup is represented by the *Loch Tay Limestone* which maintains a thickness of around 100 m along strike from Campbeltown to Glen Shee (Bailey, 1925; Elles, 1926; Johnstone and Smith, 1965; McCallien, 1929; Roberts, 1966). Thinner developments are also present to the south-east of the main outcrop, at the base of structural outliers of Ben Lui Schist in the inverted limb of the Tay Nappe around Lochearnhead (Johnstone and Smith, 1965; Watkins, 1984; Mendum and Fettes, 1985). Throughout its strike length the formation consists of thick beds of crystalline limestone, locally with various calcareous schists and semipelitic mica-schists. Thin, black graphitic schists and metagreywackes are present locally and grading in all lithologies suggests a distal turbidite origin. Hornblende-schists and amphibolites, representing mainly intrusive basic igneous rocks, are present throughout the outcrop, although there is no continuous volcanic sequence comparable with the Tayvallich Volcanic Formation.

To the north-east of Glen Isla the limestone can be traced as a 10 m-thick unit in Glen Doll, but it is absent east of the Glen Doll Fault. Here, calcareous semipelites around the head of Glen Mark pass NNE into ribbed calc-silicate rocks and limestones of the *Water of Tanar Limestone*. In middle Deeside, this becomes the *Deeside Limestone* (Read 1927; 1928) which consists mainly of greenish calc-silicate rocks with calcareous psammite, hornblende-schist and thin layers of impure limestone. A discontinuous band of crystalline limestone, containing abundant pyrite and up to 15 m thick, has been quarried extensively. These calcareous rocks lie at the base of the Tarfside 'group' of Harte (1979), in which they are overlain by a diverse but dominantly psammitic unit, the *Tarfside Psammite Formation*, consisting of quartzites, psammites, semipelites and pelites with locally abundant calc-silicate and amphibolite bands. Parts of the unit are gneissose and between Glen Clova and Glen Lee pelitic and semipelitic gneisses predominate.

Minor folding in the metamorphosed Boyne Limestone Formation, Argyll Group, Boyne Bay, Banffshire. P219244.

To the north of Deeside most of the gneissose units already described probably include Tayvallich Subgroup rocks, particularly in those areas where calc-silicate and limestone bands are common. Notable examples are the calcareous part of the *Strichen Formation* at the top of the Stuartfield division and its lateral equivalent, the *Kinnairds Head 'group'* which is well exposed on the north coast at Fraserburgh (Read and Farquhar, 1956). In these units finely banded calc-silicate beds occur in a sequence of pelites, semipelites and psammites. The Strichen Formation also contains limestone bands up to 20 m thick. Grading in the coarser-grained lithologies, which include meta-greywacke, suggests a turbiditic origin and the units are transitional upwards into the more persistent turbidites of the Southern Highland Group.

On the Banffshire coast the Tayvallich Subgroup comprises a 1200 m-thick sequence, termed the *Boyne Limestone Formation*, which includes the *Boyne Castle Limestone*, a thickly bedded but finely banded limestone, some 200 m thick (P219244). Beneath the main limestone are subordinate purple phyllites, mica-schists and several thin bands of white limestone (Read, 1923; Sutton and Watson, 1955). Inland the limestone can be traced for only 2.5 km. The sequence above the Boyne Castle Limestone consists of semipelites, laminated and striped calc-silicate rocks, minor thin limestones and lenses of reworked carbonate material. These rocks were formerly described as the lower part of the Whitehills 'group' (Read, 1923; Harris and Pitcher, 1975). Concordant sheets and lenses of amphibolite probably represent metabasaltic sills.

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