Dalradian host rocks and contact hornfelses, Ballachulish Igneous Complex - an excursion

Excursion for day 1

Overview of the Ballachulish igneous complex, Dalradian host rocks and contact hornfelses

The aim of this excursion is to provide a series of road stops that give an overview of the regional host rocks, the main rock types of the igneous complex, and characteristic low grade and high grade metapelitic hornfelses in the aureole. The principal itinerary, summarised in (Table 1)a(below), provides about five hours of geology for a party moving at reasonable speed, and involves mainly short walks from the vehicle, with a moderate walk at the end of the excursion (Stops 1-7 to 1-9). Locations on geological and topographic maps are shown in (Figure 8), with better detail for Stops 1-7 to 1-9 in (Figure 11).

Note: to visit Stops 1-5 and 1-6 by vehicle involves driving on the forestry roads/tracks, for which a key is needed to open the Forestry gates (see section on Logistics for Field Excursions).

Possible additional locations for Day 1

Some additional stops, summarised in(Table 1) b (below), can readily be made with little increase in the distance travelled by vehicle. Another option for a party moving quickly and with good daylight until ca.7 p.m., is to add onto the Day 1 itinerary, a short visit to the spectacular anatectic migmatites of the 'Chaotic Zone'. To do the Chaotic Zone migmatites involves doing Stops 3-10 to 3-12 of Day 3, Part 2 (see (Figure 11)).

(Table 1)a Overview of the Ballachulish igneous complex, Dalradian host rocks and contact hornfelses

	Grid ref. (sheet NN)	Features
Stop 1-1 E.of Onich	[NN 0505 6105]	Panoramic overview of the igneous complex and aureole from Onich
Stop 1-2 North shore of Loch Leven	[NN 0730 5950] to [NN0745 5945]	Dalradian host rocks to the complex; the relations between metamorphic and structural development — debate between two famous geologists, Bailey and Tilley
Stop 1-3 North shore of Loch Leven	[NN 0575 5995]	Incipient effects of contact metamorphism shown by cordierite-spotted phyllites
Stop 1-4 Ballachulish Bridge	[NN 0520 5960]	Xenolith-bearing quartz diorite, typical of much of the outer part of the igneous Ballachulish complex in the north
Stop 1-5 Gleann a'Chaolais	[NN 0425 5760]	Monzodiorite with orthopyroxene, clinopyroxene, intruded early in the Gleann a'Chaolais igneous complex
Stop 1-6 Gleann a'Chaolais	[NN 0375 5675]	Granite, typical of the inner part of complex and intruded at later stage
Stops 1-7	[NN 0075 5705]	High-grade calsilicate and pelitic hornfelses (with cordierite+K-feldspar ±andalusite ±corundum) and leucosome structures indicative of melting

(Table 1)b Optional additional stops during Day 1 itinerary

	Grid ref. (sheet)	Features
Stop 1-1A Onich shore	[NN 0320 6130]	Petrology and structure of regional biotite-grade Appin metapelites and interbedded limestones
Stop 1-1B Onich shore	[NN 0430 6105]	Quartzites and semipelites, with bedding and cleavage structures illustrating orientation and facing of major Appin Syncline structure
Stop 1-1C Onich road	[NN 0235 6150]	Complementary stop to Stop 1-1B (see text)
Stop 1-6A Gleann a' Chaolais	[NN 0310 5605]	Late, fine-grained microgranite
Stop 1-6B Gleann a' Chaolais	[NN 0345 5615]	Cu-Mo mineralisation and sericitic alteration weakly developed in association with late microgranite
Stop 1-7A Kentallen	[NN 0215 5895]	Xenolith-bearing marginal quartz diorite
Stop 1-7B Kentallen	[NN 0135 5845]	Lit-par-lit intrusion of high-grade hornfels
Stop 1-7C Kentallen	[NN 0105 5790]	Kentallenite rock of Appinite suite

Stop 1-1. Overview of Ballachulish Igneous Complex and host rocks. [NN 0500 6105].

Directions: From the junction of the A82 and the A828 at a roundabout [NN 0570 5930] 0.5 km south-east of Ballachulish bridge, take the A82 road to Fort William and drive over the bridge. Proceed for 0.85 miles (1.4 km) from the north end of Ballachulish bridge to a petrol/gasoline filling station on the north shore of Loch Leven (left side of road). Park in the small parking area immediately past the filling station, beside a construction materials compound. Walk to the loch-side to look south across Loch Leven, for the excellent overview of the Ballachulish Igneous Complex and Aureole illustrated and described in (Photo 4) and its caption.

Turning away front Loch Leven and facing north across the road, a construction materials site occupies an abandoned quarry of the Ballachulish Slate. Former pyrite cubes have been pseudomorphed by pyrrhotite in these slates, and often weather out to leave rust coloured angular holes. These features may be seen by the roadside exposure without entering, the quarry. Note: the old quarry walls are very loose, you should not examine them without special precautions.

Optional Stop 1-1A: Regional biotite-grade Appin metapelites and interbedded Appin limestones [NN 0320 6130]

To the cast of the overview location of Stop 1-1 and through the village of Onich, there are numerous lochside and some roadside exposures of regionally metamorphosed Appin Quartzite, Appin Phyllite and Appin Limestone. These rocks are all in tile biotite zone of regional metamorphism, with the Appin Phyllite forming schists containing conspicuous porphyroblasts of biotite set in fine-grained matrix of muscovite, quartz, chlorite and sometimes dolomite. Good exposures of the Appin Phyllites and Limestones are found along the shore at [NN 0310 6130] to [NN 0330 6130], and are easily reached by parking at the Onich Hotel and walking down to the shore. Stop 1-1A corresponds to Stop 11/12 of Roberts & Treagus (1977).

Optional Stops 1-1B [NN 0430 6105] and 1-1C [NN 0235 6150] Structure of Appin Group rocks and the Appin Syncline.

These two stops are in the Appin Quartzite (with semipelitic interbeds) and show the differing orientation of cleavage and bedding on either side of a regional structure, the Appin Syncline (Figure 2). The Appin Syncline is slightly overturned towards the west and plunges south-east. Details of the structure and an extensive account of the field exposures may be found in the field guide of Roberts & Treagus (1977). Current bedding preserved in the quartzite at location 1-1B also shows the facing direction of the structure. Location 1-1B is by the shore and easily walked to from Stop 1-1. For Stop 1-1C, which is at a bend in the road on the west side of Onich, it is best to park near Onich Post Office and walk westwards along the road to the bend, but beware of the road traffic around the bend. Stops 1-1B and 1-1C correspond to Localities 15 and 9 of Roberts & Treagus (1977).

Stop 1-2. Regionally metamorphosed Leven Schist and Ballachulish Limestone/Slate separated by the Ballachulish Slide: the Bailey-Tilley controversy. [NN 0730 5950] – [NN 0745 5945]

Directions: From Stop 1-1, drive back towards Ballachulish bridge, but before reaching it turn left (east) on the B863 road heading towards Kinlochleven. Drive 1.4 miles (2.2 km) to a lay-by on the north side of the road [NN 0730 5980], about 50 m beyond a Forestry Commission road on the north side of the road. Cross the road and fence carefully and descend the slope on a bearing of 175° towards the obvious rocky promontory (Rubh' Aird Daraich) on the shore of Loch Leven [NN 0735 5945], on line with the abandoned Ballachulish slate quarries on the south side of Loch Leven.

Description: The rocky promontory consists of two small, low headlands separated by a small bay. Begin with the exposures leading to the westernmost headland. They consist of grey-green. finely striped phyllites or schists of the Leven Schist Formation, containing prominent porphyroblasts of garnet, now largely chloritised, and smaller porphyroblasts of biotite (both are easily seen on clean surfaces) - see (Photo 5). The dominant structural element in the rocks is a composite foliation of schistosity, fine striping and probably bedding, and this has been folded by cm-to m-scale tight folds with steeply dipping axial planes (trending NE–SW) and steeply plunging fold axes. An incipient axial planar cleavage is developed in the hinge zones of some of these folds. The folds are probably related to the nearby major Stob Ban synform, which on a major scale refolds the early nappe structures and their associated composite foliation (see Roberts & Treagus. 1977, and references therein).

From their most westerly appearance [NN 0730 5950], the exposures of the above garnetiferous phvIlites/schists, belonging to the Leven Schist stratigraphic unit, are exposed southwards and eastwards for about 100 m alone the shoreline, ending at a glacially smoothed whaleback (ruche moutonne) that forms a small promontory [NN 0735 5945]. The glacially smoothed rock exposures show grooves and striations trending 260°, consistent with ice movement westwards from the head of Loch Leven.

From the whaleback promontory go eastwards for about 40 in, across a sum!! bay with no outcrop exposure to a low-lying exposure of laminated grey marble interbedded with (lark-grey, graphitic phyllite (see (Photo 6)). About 20 m of this lithology is followed eastwards by a mixed series of strongly deformed graphitic phyllites, quartzose interbeds and rarer thin marble layers, which together form a small rock and grass promontory [NN 0745 5945]. These are in turn followed eastwards by a more homogeneous lithology of finely interlayered graphitic phyllite and metasiltstone showing numerous tight folds and other deformation features.

The marble layers are part of the Ballachulish Limestone formation, whereas the phyllite/siltstone lithology belongs to the Ballachulish Slate unit (Bailey & Maufe, 1960). In contrast to the garnetiferous Leven Schist phyllites, the Ballachulish Slate phyllites contain no garnet or biotite, and are generally very fine grained (compare (Photo 5) and (Photo 6)). Separating the Ballachulish graphitic phyllites from the garnetiferous phyllites of the Leven Schist is the Ballachulish Slide, across which a significant thickness of the Ballachulish stratigraphic succession is cut out. and which was originally interpreted as a ductile thrust fault formed earls in the regional deformation and metamorphism (Bailey & Maufe, 1960). The 'fault' or slide goes through the zone of no exposure in the small bay between the two rocky promontories. The Ballachulish Slide crosses Loch Leven to the lochside outcrops in front of St. John's Church, and then veers up the hill to the right (west), cutting across Meall a' Chaolais about half way up.

The Bailey-Tilley debate. The regional metamorphic grade in this region increases eastwards, so that at this locality one would expect the Ballachulish Slates to be slightly higher grade than the adjacent Leven Schists, whereas what one observes is an abrupt eastward transition from garnet- and biotite porphyroblastic Leven Schist to fine grained, garnet- and biotite-free Ballachulish Slate. This abrupt transition across the Ballachulish Slide from was the focus of a famous debate between E.B. Bailey (1916; 1923; 1960) and Elles &Tilley (1930). Bailey ascribed the abrupt mineralogical and textural transition across the slide/fault to the contrasting response of rocks of different chemical composition to similar metamorphic conditions. He laid special emphasis on 'delay of metamorphism' in the Ballachulish Slate, which he attributed to the abundance of graphite in these rocks. This explanation accorded with his view that movement on the Ballachulish Slide pre-dated metamorphism. Elles & Tilley, in contrast, contended that the garnetilerous Leven Schist rocks were of a higher metamorphic grade than those of the Ballachulish Slate graphitic phyllites, and the two had later been mechanically juxtaposed by the Ballachulish Slide, implying that the movement on the slide post-dated

metamorphism.

More recent evidence favours Bailey's position. Opinion on many of the 'slides' originally mapped by Bailey has strongly tended towards an early origin, with some workers laying emphasis on sedimentary facies variation or synsedimentary faults (Von, 1964: Litherland, 1980. 1982; Soper and Anderton, 1984: Anderton, 1985). The structural and metamorphic maps of Bailey (1923) and Elks and Tilley (1930) show that the garnet isograd cuts across the Ballachulish Slide to the north and east of this locality, implying that metamorphism post-dated 'sliding'. Other structural and regional metamorphic arguments in support of Bailey's position are made in Roberts (1976) and Atherton (1977).

From the mineralogical viewpoint, chemical analysis of rocks on either side of the Ballachulish Slide (Paulson & Vol 1. 1991) shows that the garnetiferous Leven Schist rocks have features favouring garnet and biotite development in place of chlorite. They are substantially richer in Fe than the Ballachulish Slate rocks (e.g., in garnet-bearing Leven Schist, Fe/(Mg+Fe) of garnet, biotite and chlorite are 0.95. 0.62, and 0.60, respectively, whereas Fe/(Mg+Fe) of chlorite in Ballachulish Slate is 0.39). The garnet also contains significant manganese (Mn/(Mn+Fe+Mg+Ca) = 0.15). Because the reaction accounting for the formation of garnet and biotite from chlorite, Ms+Chl+Qtz = Grt+Bt+H_2O (Atherton. 1977: Pattison, 1985) is favoured in Fe+Mn-richer rocks, it appears that at the grade of this locality, only the Leven Schists were sufficiently Fe-rich and Mn-rich for garnet and biotite to form. Further to the east along Loch Leven, in the direction of increasing grade, but west of where Leven Schist reappears across the folded continuation of the Ballachulish Slide, garnet also occurs in the Ballachulish Slate (Bailey, 1923; Elles & Tilley, 1930).

Thus the evidence strongly supports Bailey's general thesis that rock composition factors controlled the differences in metamorphic mineral assemblage between the rocks. Ironically, Bailey's (1916) specific suggestion that graphite was the reason for the 'delay of metamorphism' in the Ballachulish Slate, is probably misplaced. Other conditions being equal, graphite would tend to promote rather than delay the appearance of garnet and biotite, due to C-bearing volatiles such as CO, and CH causing reduced activity of water and thus promoting the reaction of formation from chlorite (Paulson and Voll, 1991). On the other hand, Bailey's observation that. graphitic metapelitic rocks tend to be finer-grained than non-graphitic metapelitic rocks at a similar grade has been verified in numerous other locations worldwide.

Regional P-T conditions for these rocks have been estimated (Pattison & Voll, 1991) to be about 450–500 °C and 5–7 kbar (ca. 17–23 km depth).

View from Stop 1-2 across Loch Leven to Coire Giubhsachain. Looking southwards across Loch Leven from Stop 1-2, one sees St. John's Church near the roadside and above this the steep hanging valley of Coire Giubhsachain (see also Coloured Map (Map 1)). This is bounded on the right (west) by a generally sharp northward-trending ridge running upwards from the rounded shoulder of Meall a' Chaolais to the more distant, prominent white, peak of Sgorr Dhearg. The ridge comprises interbedded metapelites, quartzites, marbles and calsilicates and, locally. apophyses of quartz diorite. Coire Giubhsachain is bounded on the left (east) by the quartzite ridge of Beinn Khan, rising upwards to the unnamed peak to the left (east) of Sgorr Dhearg. The axis of the Coire Giubsachain coincides roughly with the axis of a small, steeply SW-plunging syncline on the northeast flank of the igneous complex (2). The prominent white scar cutting steeply down Meall a' Chaolais (towards St John's Church) is the crush zone of the Ballachulish fault, a late-stage strike-slip fault with about 800 metres of post-intrusion sinistral displacement and a strike length of at least 80km (Paulson & Voll, 1991). The white outcrops to the left (east) of the fault are of Appin Quartzite. The Ballachulish Fault is probably related to the nearby Great Glen fault zone running along Loch Linnhe at the western end of Loch Leven (Figure 1), (Figure 2).

Stop 1-3. Incipiently cordierite-spotted Leven Schist phyllites. [NN 0575 5995].

Directions: From Stop 1-2, turn around and drive 1.1 miles (1.8 km) westwards back along the B863 road, turning in to the Allt Shellach (Holiday Fellowship) hotel. The hotel is 0.3 miles (0.5 km) east of the intersection of the B863 and A82. Park in the hotel parking lot and ask for permission to walk across the hotel grounds, to reach the field exposure you must walk through the garden on the west side of the hotel and descend the grassy lawn to the obvious rocky promontory on the shore (at low-normal tide: it is an island at high tide). Remember to keep gates shut as necessary.

Description: The rocks comprising the promontory are dark grey-green Leven Schist phyllites. In contrast to Leven Schist rocks at Stop 1-2, which belong to the regional garnet zone, the phyllites round here are everywhere without garnet and belong to the regional biotite zone. The phyllites contain 1-3 mm elliptical spots, hest seen as dark spots on freshly broken cleavage surfaces (see (Photo 7) for a phyllite showing similar features). The spots represent contact metamorphic cordierite, though detailed thin section examination shows that the cordierite has usually altered to give pseudomorphs of fine-grained intergrowths of muscovite+chlorite. Such incipiently spotted phyllites represent the outermost zone of demonstrable contact metamorphic recrystallisation in pelitic rocks caused by the Ballachulish Igneous Complex. The presence of stable chlorite in these rocks places them in Zone II of the aureole (ca. 560 °C). The pressure of formation of the cordierite in these contact metamorphic rocks is about 3 kbar (ca. 10 km depth), considerably less than the pressure of formation of the older regional metamorphic rocks exposed at Stop 1-2.

Stop 1-4. Marginal quartz diorite of the Ballachulish Igneous Complex. [NN 0520 5960].

Directions: From Stop 1-3, drive to the A82, and turn south, crossing the Ballachulish bridge and continuing on to the roundabout [NN 0570 5930]. Take the A828 road heading to Connel and Oban, and drive under the Ballachulish bridge to park near to the Ballachulish Hotel. Walk back to examine exposures under the bridge, or preferably up the set of steps to the monument to James of the Glen, observing the exposures beside the steps.

Description: The rocks belong to a relatively leucocratic phase of the outer quartz diorite shell of the igneous complex. Here, they are fine grained pink-grey hornblende- and biotite-bearing granodiorite and microgranodiorite. According to Weiss (1986) and Troll & Weiss (1991), these rocks represent a variably contaminated hybrid marginal phase of the outer quartz diorite of the igneous complex. Some mm-cm-scale metasedimentary xenoliths, some with angular margins, may be seen (see (Photo 8) for another exposure showing quartz diorite with abundant inclusions). The overall orientation of the xenoliths strikes about 140° (Weiss, 1986).

Local History: The monument at the top of the steps has considerable historical interest. It marks the spot where James of the Glen(s) was hung to death in 1752, following his execution for the murder of Colin Campbell of Glenure. By most accounts James of the Glen, or James Stewart of Appin, was an honourable man and a respected local leader of the Stewarts of Appin. Campbell of Glenure was a government dignatory, who had been appointed as Crown Factor for the forfeited estates of the local Jacobite, Stewart of Ardsheal. The time of the events was a very sensitive one, following the 'Forty-five' (1745) Jacobite rebellion. Control of the estates had been taken from Ardsheal and put under Crown jurisdiction because of the Stewarts' support for the 1745 rebellion. The estates factor, Campbell of Glenure, was murdered in 1752 by a shot in the back whilst travelling the 'old road', about two km to the west of Ballachulish. The government was determined that someone should pay for the crime and a lesson be taught to all local people: with the result that James of the Glen was seized and hung, without any substantial evidence of his guilt. Campbells and Stewarts generally had little love for one another. It has been suggested that the true assasin was James's ward, Alan Breck. But the true perpetrator(s) of Colin Campbell's murder were never identified, and James of the Glen's corpse was left hanging in gibbet chains at this spot until 1761, to serve as a warning. A Murder Cairn marks the spot of Campbell of Glenure's assassination, and can be visited by turning off the A828 at a marked road 1.35 miles (2.2 km) west of the Ballachulish Hotel [NN 0305 5955] and walking ca. 400 m along a footpath. Some of the historical events, and the tensions existing between different clans and the government at this time, are well protrayed in Robert L. Stevenson's (1886) adventure story 'Kidnapped'.

Stop 1-5. Orthopyroxene-clinopyroxene monzodiorite of the Ballachulish Igneous Complex. [NN 0425 570].

Note: Driving to Stops 1-5 and 1-6 from the Ballachulish bridge is highly recommended, but it entails traversing the roads/tracks of Forest Enterprise. These may be entered at [NN 0660 5865] (east of Ballachulish bridge, and near St John's church) or preferably (as described below) at [NN 0465 5890] just south of Glenachulish. The entrances at both of these locations are barred by gates, which are normally locked. To open the gates and gain access by vehicle to the forestry roads you must seek permission and obtain a key from the Forest Enterprise office in Oban (see section on Logistics for Field Excursions).

Directions: From Stop 1-4, drive westwards along the A828 road to [NN 0440 5945], where the small road leading to Glenachulish goes off on the left (south) side of the road: it is approximately 0.45 miles (0.75 km) past the Ballachulish Hotel.

At the start of the road to Glenachulish set your odometer. Drive along the twisty road/track with track through Glenachulish, keeping to the main route. At 0.45 miles (0.7 km) from the A828 there is a parking area, and just beyond this the main road/track makes a sharp swing to the right, whilst another track goes off on the left. Take this left turn, and you see a gate about 40 m along it (location [NN 0465 5890]). If you plan to drive to Stops 1-5 and 1-6, it is for this gate that you will need the key obtained from the Forestry Enterprise office in Oban. Alternatively, you can park the car in the nearby car park and continue on foot: it is a pleasant walk along forest tracks, but it is a distance of approximately 3.5 miles (5.6 km) there and back.

After going through the gate, at 0.85 miles (1.35 km) from the A828, the road/track divides, with one branch descending to the left and crossing a bridge over a stream: ignore this, keeping to the right branch. The road/track across the stream goes back to the forest entrance near St John's Church, and this is the way you would have come if you entered the forest by the St John's Church entranced At 1.05 miles (1.7 km). the road divides again (at [NN 0450 5800]), and you should follow the main road/track which bends very sharply right and proceeds steeply uphill for about 0.1 miles (0.15 km), where you then turn left (south) at the next junction onto a relatively level road. Stay on this road. At about 1.45 miles (2.3 km), there is a gate where a road comes down from the right. About 100 m further on, at about 1.5 miles (2.4 km), there is a rock cutting on the right and plenty of parking space on the left of the road/ track, just before the road curves right to go round a steep gully in which there is a stream with a waterfall. This is Stop 1-5. (The route followed to get here and to Stop 1-6 is one of the major forest roads and is marked as a track on the Coloured Map (Map 1).)

Description: The exposures of the rock cutting comprise grey (on fresh surfaces), medium grained orthopyroxene+clinopyroxene monzodiorite, sometimes with poikilitic biotite crystals and a few mm-cm mafic clots. Hornblende may partially rim some of the pyroxene crystals. A weakly defined flow foliation strikes about 120° (Weiss, 1986). This rock type is representative of the hot, relatively dry core of the early monzodiorite-quartz diorite envelope of the igneous complex. The emplacement temperature of the monzodiorite magma is estimated at about 1100 °C (Weiss & Troll. 1989).

Stop 1-6. Central 'granite' of the Ballachulish Igneous Complex. [NN 0375 5675].

Directions: From Stop 1-5, continue southwards along the same forestry road to a distance of 2.1 miles (3.4 km) front the A828. At this point the road swings round to the left (east) and crosses a bridge over a stream. This is Stop 1-6.

Description: Around the bridge are exposures of pink-grey hiotite granodiorite, weakly porphyritic in places. Hornblende, sometimes with relic cores of clinopyroxene, is also found in these rocks. This rock type is representative of the core of the central 'granite', emplaced into the earlier monzodiorite/ quartz diorite envelope. The emplacement temperature of the 'granite' was about 850 °C (Weiss & Troll, 1989).

Optional Stops 1-6A ([NN 0310 5605]; 580m) and 1-6B ([NN 0345 5615], 460m): Weak Cu-Mo mineralisation and sericitic alteration associated with late fractionated microgranite.

This optional addition to the itinerary is not recommended for those with limited time and whose main interest is to get an Overview of the Ballachulish Igneous Complex and Aureole. It involves a walk uphill of about 1 km and will take at least two hours.

Starting at Locality 1-6 wall: up the path starting on the west side of the bridge and proceed for about 800m to exposures of a late, fine-grained, leucocratic monzogranite. This is Stop 1-6A ([NN 0310 5605]; 580 m). The fine-grained monzogranite is interpreted as the final residual magma that evolved from fractional crystallisation of the main central 'granite', and it shows sharp to diffuse contacts with the host porphyritic granite.

Spatially associated with the fine-grained monzogranite is a zone of hydrothermal alteration (sericitisation) of variable intensity with which low grade Cu-Mo mineralisation is also associated. The altered and mineralised zone Occurs partly

in the fine-grained monzogranite and partly in the host porphyritic granite, and comprises a weakly developed stock work of sub-mm to rarely mm wide quartz veins containing variable proportions of pyrite, chalcopyrite and molybdenite. These features can be seen at Stop 1-6B ([NN 0345 5615], 460m). The mineralisation was found to be too weak to be of economic interest (Haslam & Kimbell, 1981). The style of the mineralization and alteration hears many similarities to economic Cu-Mo porphyry systems, only on a much smaller and weaker scale.

Haslam & Kimbell (1981) provide excellent detailed maps of the geology, alteration and mineralised zones.

Optional Stops 1-7A, 1-7B and 1-7C, en route to Stop 1-7.

Directions: From Stop 1-6, retrace your route to return to the A828 near Glenachulish. where you turn left (west) along the A828 towards Kentallen and Oban. From Glenachulish to Kentallen, the road follows the coastline and is simultaneously close to the contact zone of the Ballachulish Igneous Complex. Three optional stops may be made to examine exposures very close to the road.

Stop 1-7A: Xenolith-bearing marginal quartz diorite. [NN 0215 5895].

After having driven 1.5 miles (2.8km) southwest along the A828 from Glenachulish, on the southeast side of the road are several disused quarries, some converted to a facility for travelling workers and people. Drive ca. 150 m past the first, main quarry (with the buildings and caravans) and park on a small track on the left hand side, blocked a short distance up the track with large boulders. The track leads to some other quarries which comprise Stop 1-7A. The rock in the quarries is a hybrid marginal phase of the Ballachulish quartz, diorite containing numerous metasedimentary, especially metapelitic, xenoliths and mafic-intermediate igneous inclusions of sometimes similar mineralogy to the quartz diorite, but of different grain size (cognate inclusions?) (see (Photo 8)).

Stop 1-7B: 'Lit-par-lit' intrusion of high grade hornfels. [NN 0135 5845].

Continue SW along the A828 towards Kentallen for about 0.6 miles (1 km) past Stop 1-7A until the Holly Tree restaurant is reached, where you should seek parking.

Immediately adjacent to the pier by the Holly Tree restaurant are exposures of pitted high grade (Zone V) semipelitic hornfels (Appin 'Phyllite' unit) cut by dykes and veins of granite and granodiorite. This locality is about 100 m west of the contact with the marginal quartz diorite of the main igneous complex. The dyke and many of the thicker veins have intruded the metasediments parallel to relict bedding in a lit-par-lit fashion. Connecting with these are many straight-walled thinner veins which cut across layering at moderate angles. The hornfels is rich in cordierite and K-feldspar, with some layers containing andalusite and more rarely corundum. The hornfelses show the characteristic mesh or ribbed texture common throughout the high grade parts of the aureole (Zones IVb and higher), comprising ovoid pits (cordierite) surrounded by white ribs rich in K-feldspar (see (Photo 12)). Contact metamorphic temperatures were about 700 °C at this locality. Large loose blocks of kentallenite may also be seen by the pier (see next stop).

Stop 1-7C: Kentallenite. [NN 0105 5790].

Continue SW along the A828 to a lay-by on the SE (left) side of the road by a square stone building (the former Kentallen railway station), about 0.3 miles (0.5 km) south of the Holly Tree restaurant. The grid reference [NN 0105 5790] refers to in situ exposures of kentallenite, locally cut by veins of granite and lamprophyre, in the badly overgrown former railway cuttings immediately north of the stone building. Other in situ exposures of kentallenite may be seen along the A828 immediately to the south of the stone building, and up the hill slope. On the opposite side of the road to the lay-by, the steep embankment below the road provides many large clean blocks of kentallenite.

Kentallenite is an unusual, dark, coarse-grained, olivine + augite + hornblende + biotite + plagioclase + K-feldspar dioritic rock belonging to the Appinite suite, which was emplaced very shortly before the main Ballachulish Igneous Complex. It is a very attractive rock in hand specimen and thin section, with poikilitic crystals of biotite enclosing the other ferromagnesian minerals.

Stops 1-7, 1-8 and 1-9. High-grade calsilicate and pelitic hornfelses and evidence of partial melting. [NN 0075 5705] – [NN 0110 5740].

Visiting these stops involves a total round trip walk of about 1.5km, including ascending a grassy ridge (elevation gain about 120m). (Figure 11) shows more detailed geologic and topographic maps for this part of Day 1.

Directions: From Kentallen, continue to drive southwards on the A828, past the turn-off at the head of Kentallen bay to Ardsheal House, to Lagnaha farmhouse on the left (east) side of the road at [NN 0030 5635] (about 0.6 miles (1.0 km) past the Ardsheal turnoff). The objective is to visit exposures low down on the hillside between Lagnaha and Kentallen, about 1.0 km NNE of the farm buildings. The owner of the land (in 1999, Mr. Worthington) lives at Lagnaha farm and would appreciate being informed if these localities are to be visited.

About 150 m north of Lagnaha farm, there is a prominent parking area just off a small road on the cast side of the A828 [NN 0045 5650]. After parking you will proceed on foot NNE for about 0.6km along a track that follows the old railway line. Be sure to shut the gate half way along the track. Eventually an old railway bridge over a burn (stream) is encountered. Leave the track just before the bridge and climb over the fence to the east and descend to the burn.

Stop 1-7. Grossular-hearing calsilicate rocks. [NN 0075 5705], 65 m.

Directions: Your first objective is Stop 1-7, which is reached by walking about 200 m up the burn. It is located about 40m NE of where a fence crosses the burn, just SW of the confluence of two tributary burns. Along the way, exposures of Appin Quartzite can be seen in the burn and up the slope to the SE. Some exposures in the burn are of ribbed, rusty-weathering semipelites.

Description: NE-striking, steeply dipping exposures of high-grade contact metamorphosed Appin Limestones are seen by the burn. The rocks are dominantly green in colour and consist of calsilicates. Pale, brownish-purplish, grossular-rich garnets stand up on many relict bedding surfaces. Other minerals in the assemblage include diopside (green), plagioclase, calcite, and more rarely vesuvianite or idocrase (dark brown). Some layers contain abundant carbonate. The assemblages formed at 650–700 °C and indicate equilibration with water-rich metamorphic fluids (Pattison, I985).

The Appin Limestones here form thin horizons interlayered with pelitic and semipclitic rocks of the Appin Phyllite unit, which forms the extensive pelitic hornfelses of the next locality (Stop 1-8). Up the slope to the southeast are high standing outcrops of Appin Quartzite.

Stop 1-8: Massive cordierite+K-feldspar hornfelses locally containing andalusite±corundum, and with evidence of incipient partial melting. [NN 0080 5720]–[NN 0090 5730], 80–120m.

Directions: Walk a short distance northwards from Stop 1-7, leaving the streams on your right-hand side, and go gently uphill round the shoulder of the hillside to come on to the moderately steep, bracken-covered hill-slopes overlooking the old railway line and the Kentallen road. Extensive exposures around here and for about 150 m going up the gentle NE-trending ridge crest, or salient, form Stop 1-8. As one ascends the salient, bracken gives way to grass and there are increasingly steep crags overlooking the Kentallen road. Caution should be exercised when examining the rock exposures above and on the flanks of the crags.

Description: The exposures encountered here are dominantly of pelitic and semipelitic hornfelses, with some more psammitic and quartzite interbeds (see (Photo 9)). Sedimentary structures are preserved in some quartzite and semipelitic layers. Overall bedding orientation is 045°/70°SE, although there are abundant tight small scale folds. The semipelitic hornfelses are characterised by 1-5 mm ovoid pits and spots of cordierite, surrounded by lighter coloured rims rich in K-feldspar, giving a mesh-like or ribbed appearance; the full assemblage is Crd+Kfs+Bt+Qtz (see (Photo 12) for a good example of this texture). The pelitic hornfelses also contain andalusite and more rarely corundum, and are characterised by a more 'knobbly' weathered surface. This is because the andalusite occurs as upward-standing, 2-10 mm long. subhedral, prismatic crystals; whilst the rarer corundum occurs as tiny, <1 mm rounded 'pimples' (see (Photo 18) and (Photo 19)). The full assemblage in the corundum-bearing pelitic hornfels is And+Sil+Crn+Crd+Bt (no quartz — it all having been used up in prograde reactions consuming the chlorite and muscovite of the pre-existing phyllite

protoliths), indicating a metamorphic temperature of 670–700 °C. These rocks belong to Zone V in the aureole.

Note: Rarely around here and further up the hill, thin (ca. 0.5 cm) quartzo-feldspathic veins cut across pelitic hornfels layers. hut merge into the semipelitic layers. These features represent the beginning of field evidence of partial melting in the contact aureole. and are further described at Stop 1-9. More abundant corundum-bearing hornfelses are found in Coire Giublisachain, as described in the Day 5 excursion.

Stop 1-9: Partial melting in high-grade hornfelses – migmatitic features. [NN 0015 5740], 150 m.

Directions: Continue ascending the local ridge crest (salient) to the NE. The salient is bounded on the NW by the steep crags overlooking Kentallen and on the SE by a steep stream gully bounded by rock exposures. Follow this gentle salient for approximately 250 m to a patch of boggy ground, beyond which is a prominent S-SW facing craggy exposure. This is Stop 1-9.

Description (Stop 1-9): A variety of migmatitic features ascribed to small degrees of partial melting are well seen on the subvertical face (see (Photo 10)). Locally semipelitic layers vary in width and appear to have undergone internal (ductile) deformation, showing evidence for flowing into gaps between fractured cordierite-rich pelitic hornfels layers, the latter producing cm-scale rectilinear boudins. Micropegmatitic quartzofeldspathic material occupies the middles of the gaps between the hornfels boudins but does not cross-cut the semipelite. giving the appearance of having been extracted from the ductile semipelite. These features are interpreted as being due to localised partial melting of quartz and feldspar-rich semipelitic layers, causing them to become ductile and able to flow. The cordierite-rich pelitic hornfels layers responded to the stress in a brittle manner, leading to fracturing and partial disaggregation, thereby providing 'gaps towards which the ductile semipelite flowed and into which melt (now represented by quartzofeldspathic material) migrated. Although not by any means typical in migmatic gneisses, these rocks show an intimate mixture of metasedimentary and 'granitic' components, and are therefore described as migmatitic rocks. But note that are also sonic thin (cm-scale), fine-grained granite apophyses from the nearby Igneous Complex intruding the metasediments in a lit-par-lit fashion and these also contribute to the overall disruption of the primary layering.

Adjacent to the boggy ground immediately below (SW of) the outcrop face of Stop 1-9, and additionally about 50 m up-slope to the ESE of the outcrop face. are exposures of marginal quart/diorite of the igneous complex, some of which contain metapelitic xenoliths. The quartz diorite invades the metasediments in this vicinity in a series of broadly SW-trending apophyses (see Coloured Map (Map 1) (Map 1) and (Figure 11), although in the field the orientation of the contacts in individual outcrops nay vary. The overall NE trend of the apophyses is roughly parallel to the metasedimentary layering, perhaps representing on a larger scale the 'lit-par-lit' intrusive habit seen on the outcrop face of Stop 1-9 and at Stop 1-7B.

From Stop 1-9, return to the vehicles by descending the nearby SW-flowing burn to the railway track. A short distance down the burn, exposures on the NW side of the burn ([NN 0095 5725], ca. 120 m) show the three dimensional nature of the interbedded hornfelses seen earlier, including conspicuous white haloes of K-feldspar surrounding ovoid, weathered-out cordierite pits on weathered bedding surfaces.

Optional examination of Chaotic Zone migmatites

If you wish and if time allows. Day 1 may be extended to examine the severely disrupted migmatitic rocks of the 'Chaotic Zone', described in the first three stops (3-10 to 3-12) of part 2 of Day 3 (see (Figure 11)). From Stop 1-7, drive south along the A828 to the turn-off to Achindarroch. From the turnoff, follow the directions given for Day 3, part 2.

End of Day 1

	Grid ref. (sheet NN)	Features
Stop 1-1 E. of Onich	0505/6105	Panoramic overview of the igneous complex and aureole from Onich
Stop 1-2 North shore of L. Leven	0730/5950 to 0745/5945	Dalradian host rocks to the complex; the relations between metamorphic and structural development – debate between two famous geologists, Bailey and Tilley
Stop 1-3 North shore of L. Leven	0575/5995	Incipient effects of contact metamorphism, shown by cordierite-spotted phyllites
Stop 1-4 Ballachulish Bridge	0520/5960	Xenolith-bearing quartz diorite, typical of much of the outer part of the igneous complex in the north
Stop 1-5 Gleann a'Chaolais	0425/5760	Monzodiorite with orthopyroxene-clinopyroxene, intruded early in the igneous complex
Stop 1-6 Gleann a'Chaolais	0375/5675	Granite, typical of the inner part of complex, and intruded at later stage
Stops 1-7,	0075/5705	High-grade calsilicate and pelitic hornfelses (with cordierite+K-feldspar ±andalusite ±corundum) and leucosome structures indicative of melting

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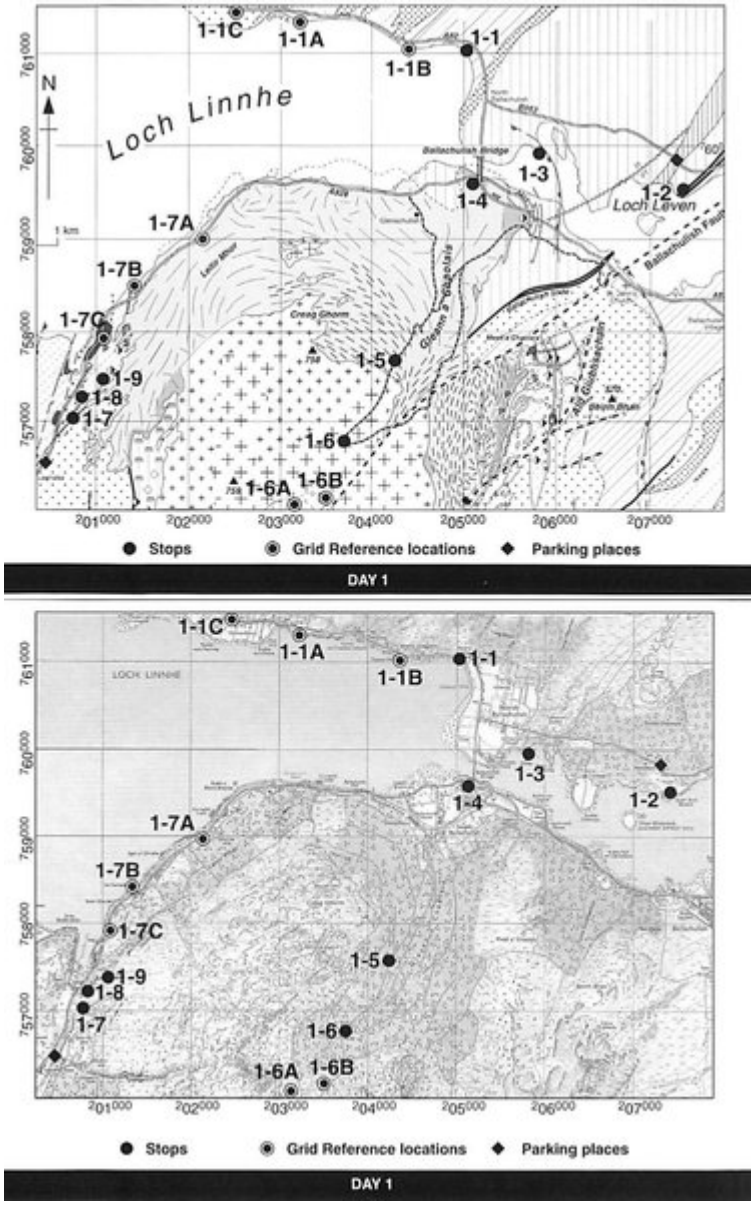
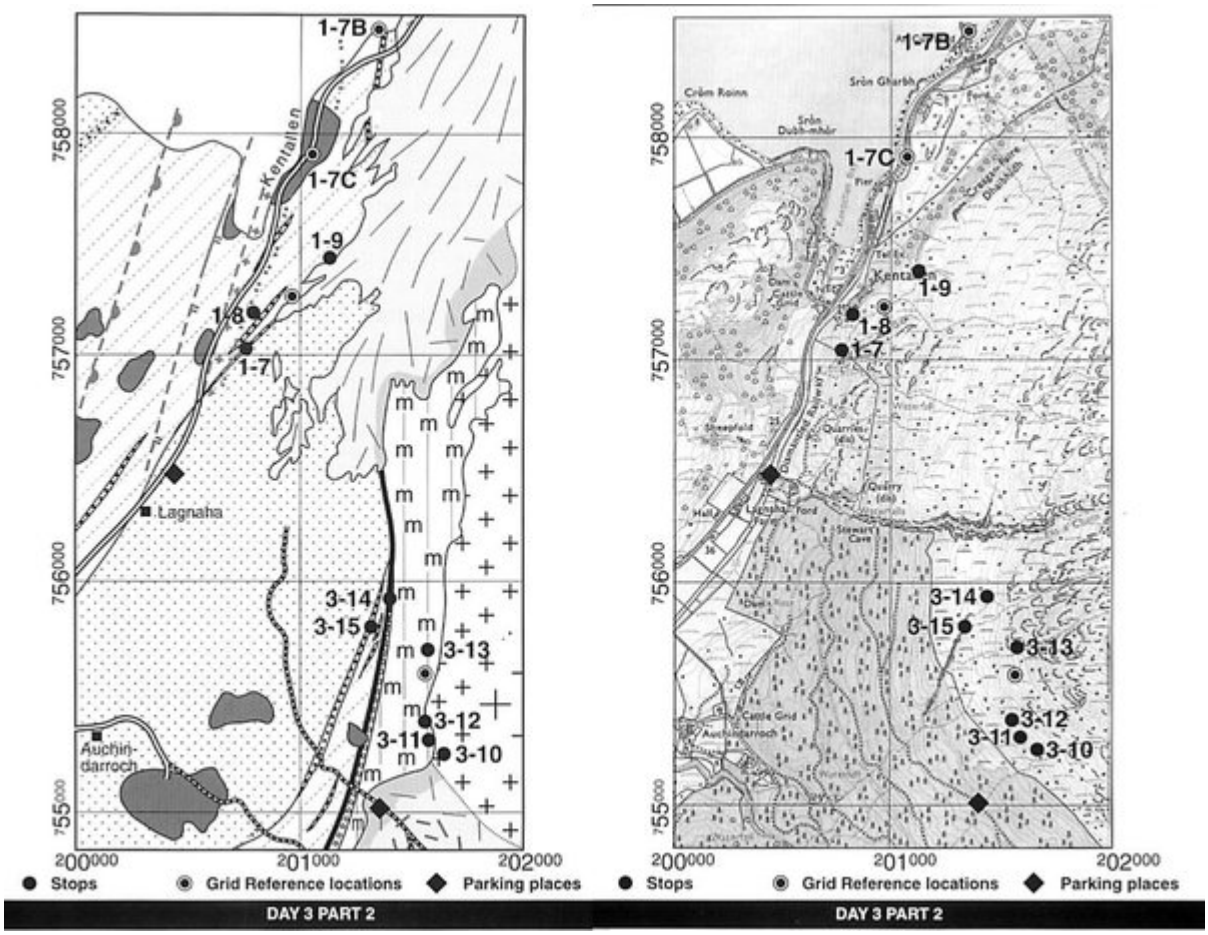
	Grid ref. (sheet NN)	Features
Stop 1-1A Onich shore	0320/6130	Petrology and structure of regional biotite-grade Appin metapelites and interbedded limestones
Stop 1-1B Onich shore	0430/6105	Quartzites and semi-pelites, with bedding and cleavage structures illustrating orientation and facing of major Appin Syncline structure
Stop 1-1C Onich road	0235/6150	Complementary stop to Stop 1-1B (see text)
Stop 1-6A Gleann a' Chaolais	0310/5605	Late, fine grained microgranite
Stop 1-6B Gleann a' Chaolais	0345/5615	Cu-Mo mineralisation and sericitic alteration weakly developed in association with late microgranite
Stop 1-7A Kentallen	0215/5895	Xenolith-bearing marginal quartz diorite
Stop 1-7B Kentallen	0135/5845	Lit-par-lit intrusion of high-grade hornfels
Stop 1-7C Kentallen	0105/5790	Kentallenite rock of Appinite suite

(Table 1) a. Principal itinerary of stops for Day 1: Overview of the Ballachulish Igneous Complex, Dalradian host rocks and contact hornfelses b. Optiollal additional stops during Day 1 itinerary.



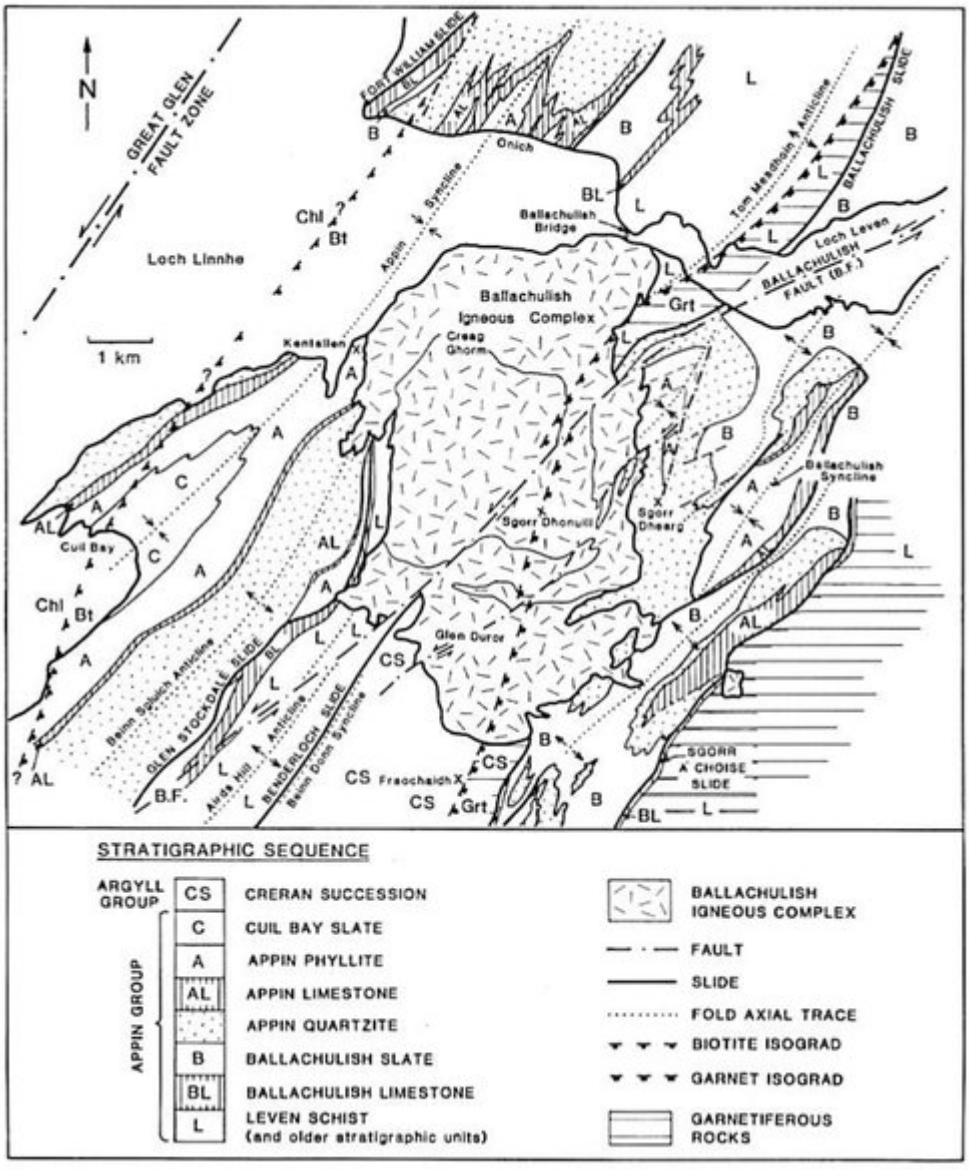
(Figure 8) (a) Geological map showing location of field stops for Day 2, see ((Figure 7) for key to geological map). Corresponding topographic map showing location of field stops for Day 1 (reproduced with permission by the Ordnance Survey).



(Figure 11) (a) Geological map showing location of field stops for Day 3 Part 2, (see (Figure 7) for key to geological map). Also shows Day 1, Stops 1-7 1-8 & 1-9. (b) Corresponding topographic map showing location of field stops for Day 3 Part 2: (reproduced with permission of the Ordnance Survey).

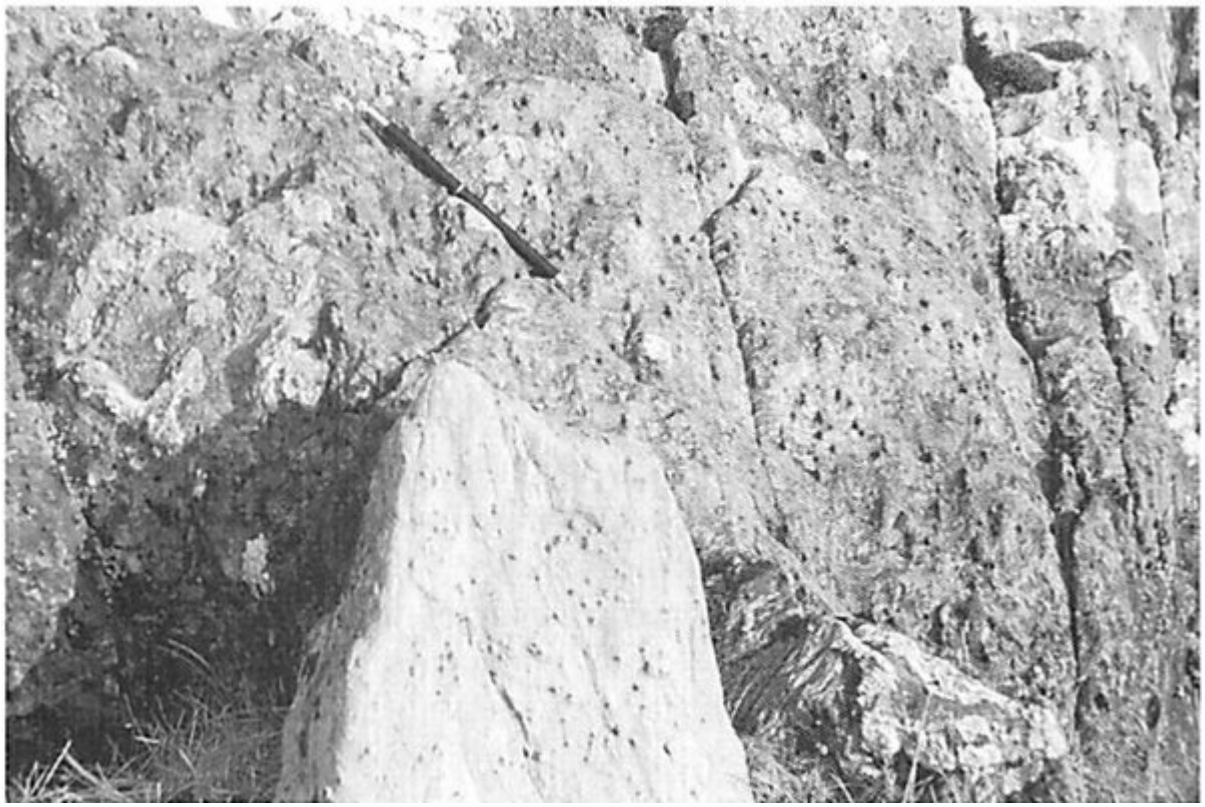
(Photo 4) View of the Beinn a' Bheithir massif underlain by the Ballachulish Igneous Complex and Aureole, taken looking south across Loch Leven from the Onich shore near Stop 1-1. The hill complex seen is referred to Collectively as Beinn Bheithir and the peaks of Sgorr Dhearg and Sgorr Dhonuill form the highest parts of this complex. To the right of the Ballachulish bridge one looks up into the valley of Gleann Chaolais. bounded on the right (west) by the rounded flank of

Creag Ghorm (758 m), and on the left (east) by a ridge leading from the rounded shoulder of Meall a' Chaolais up to the slimy) white peak of Sgorr Dhearg (1024 m). At the head of Gleann' a' Chaolais and to the right (west) of Sgorr Dhearg is Sgorr (1001 m) and its subsidiary peak in the foreground, the Devil's Tooth, which forms a prominent cliff-rimmed triangular peak overlooking the head of Gleann a' Chaolais. To the left (east) of Sgorr Dhearg is another more rounded, white peak (unnamed) with a ridge leading down to the rounded shoulder of Beinn Bhan the latter separated from the Sgorr Dhearg ridge by Coire Giubhsachain. The eastern contact of the Ballachulish igneous complex with the host Dalradian metasediments is subparallel with the lower part of the Meall Chaolais - Sgorr Dhearg ridge, but was obliquely across it in the grassy portion of the ridge just above Meall a' Chaolais, so that it lies on the nearside of the Sgorr Dhearg summit. Interbedded metapelitic, quartzitic and calcareous layers of the Appin Group give rise to the generally more angular exposures along the upper parts of the Meall a' Chaolais– Sgorr Dhearg ridge. The while peak of Sgorr Dhearg itself and the white outcrops along the Beinb Bhan ridge up to the unnamed top to the left (east) of Sgorr Dhearg are formed by Appin Quartzite. On the right-hand (west) side of the mountain panorama, the boundary of the igneous complex lies between Creag Ghorm (on the photo) and the next hill (off the photo to the west). Thus most of the ground across the loch is underlain by rocks of the Ballachulish Igneous Complex, which gives rise to generally rounded outcrops. Most of Creag Ghorm and Meall o'Choalais are occupied by various varieties of monzodiorite and quartz diorite (see Coloured Map (Map 1)), the earliest of two main phases of the igneous complex. The second phase of granitic rocks, which were emplaced into the diorites in the central parts of the complex, form Sgorr Dhonaill, the Devil's Tooth and the upper more southerly parts of Creag Ghorm (hugely out of sight).

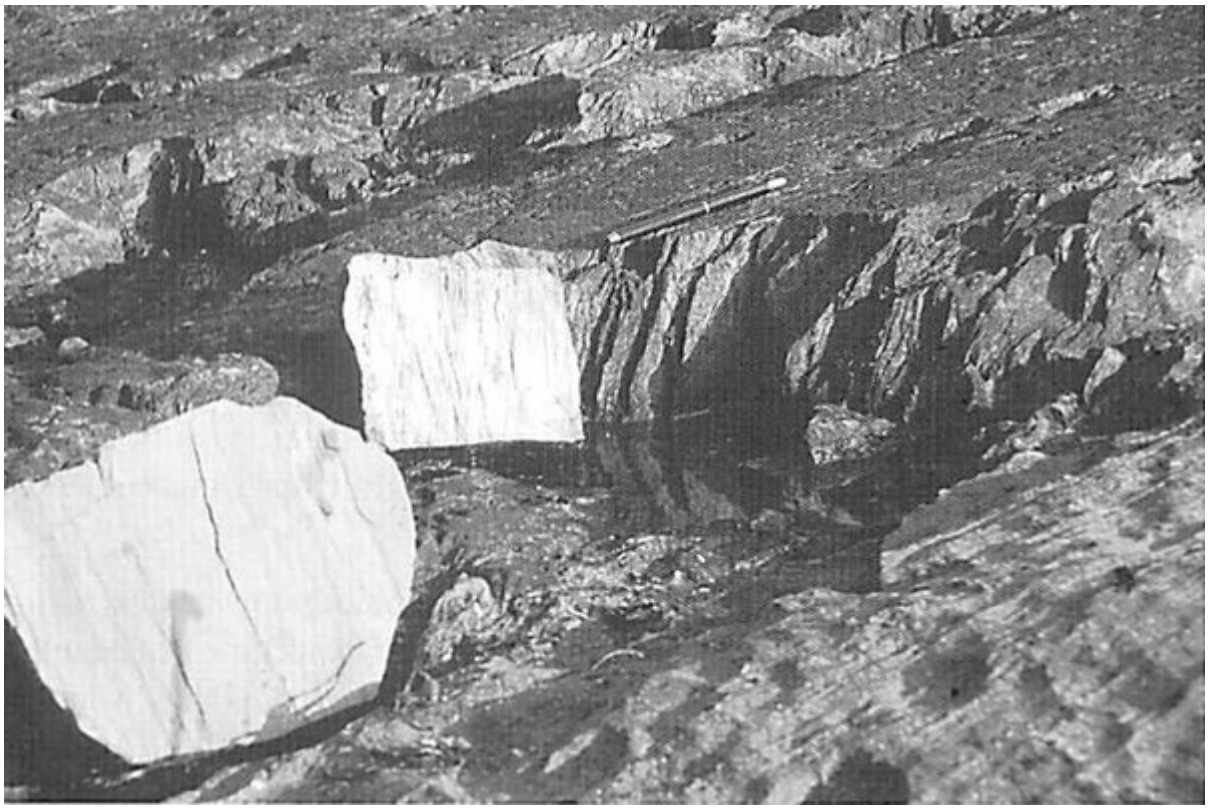


(Figure 2) Outline of lithostratigraphic units and major regional structures around the Ballachulish Igneous Complex. The position of the garnet isograd of regional metamorphism. Which formed prior to intrusion of the complex, is extrapolated

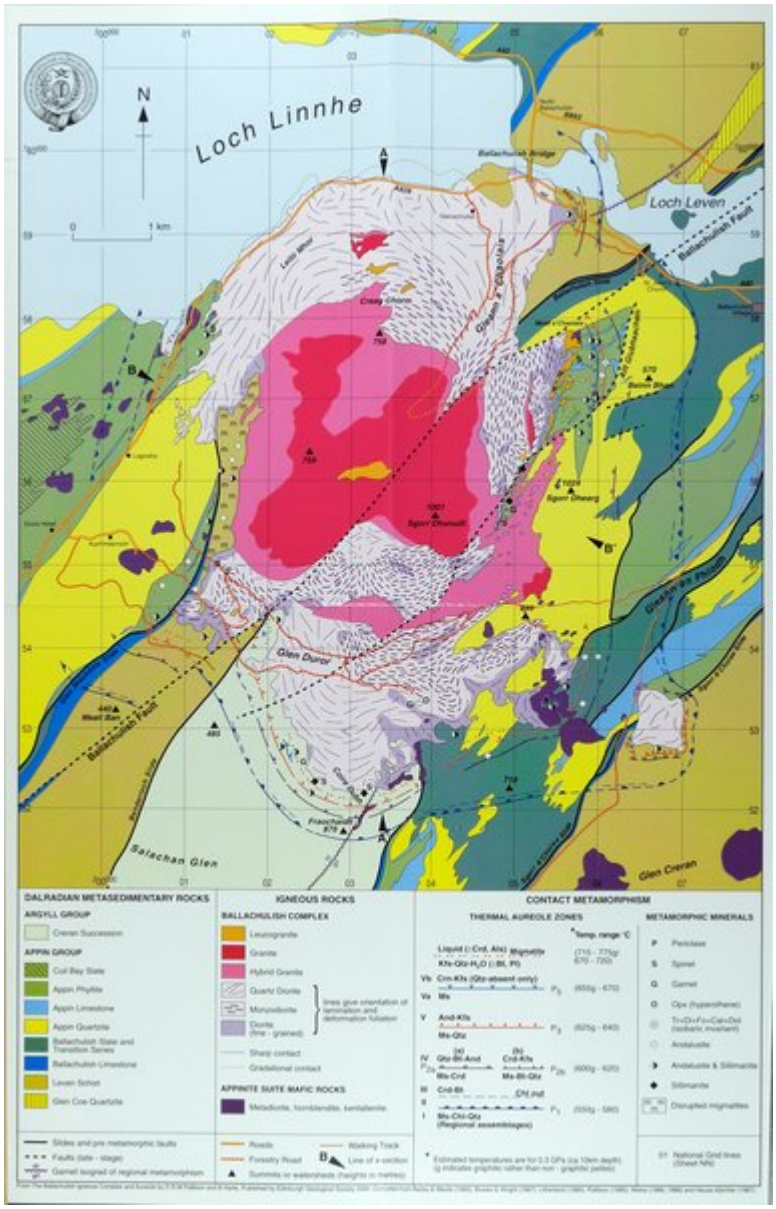
across the area of the complex. From Pattison & Harte (1997).



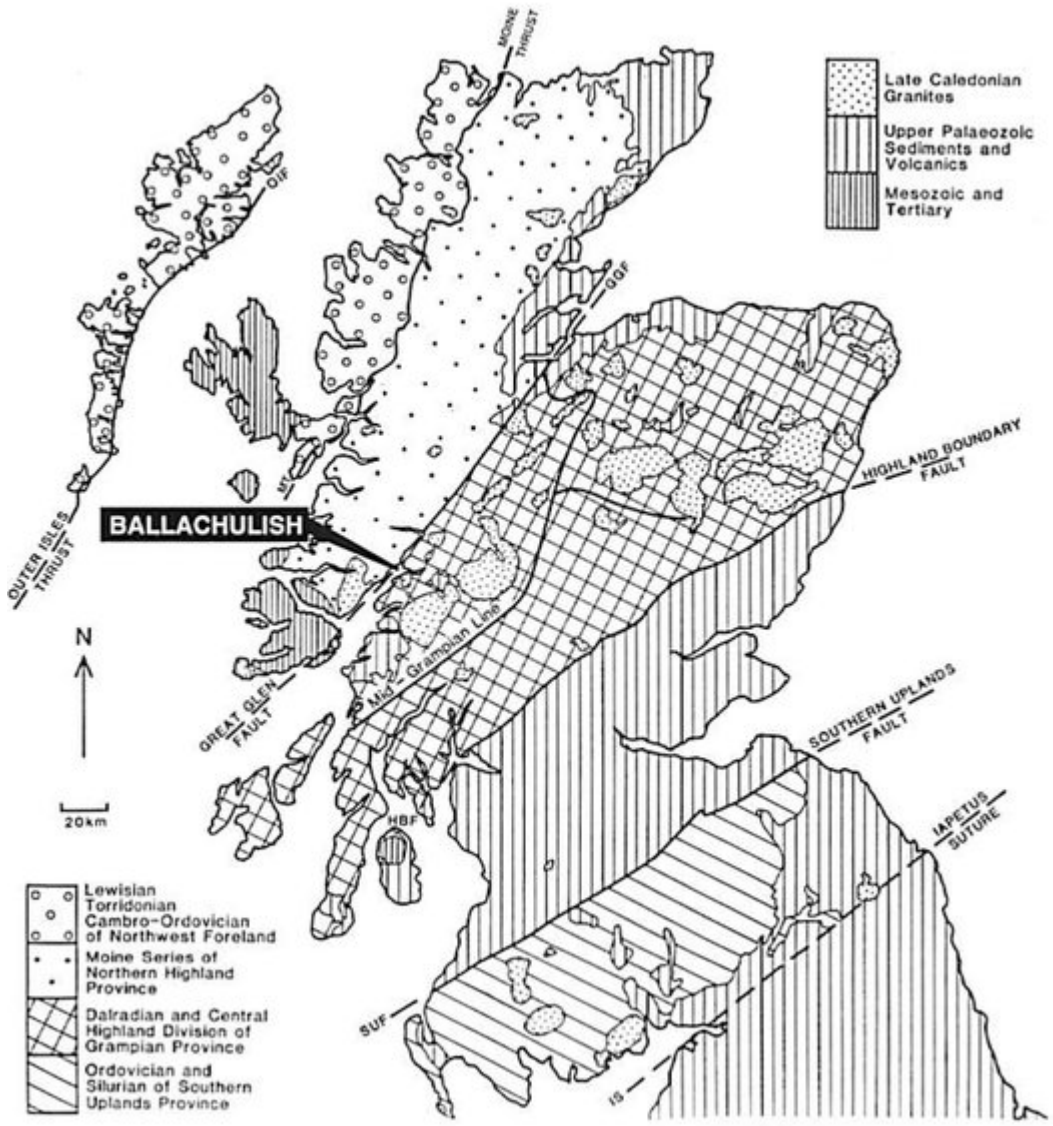
(Photo 5) Stop 1-2. Gametiferous phyllite/schist of the Leven Schist lithology, immediately west of the Ballachulish Slide.



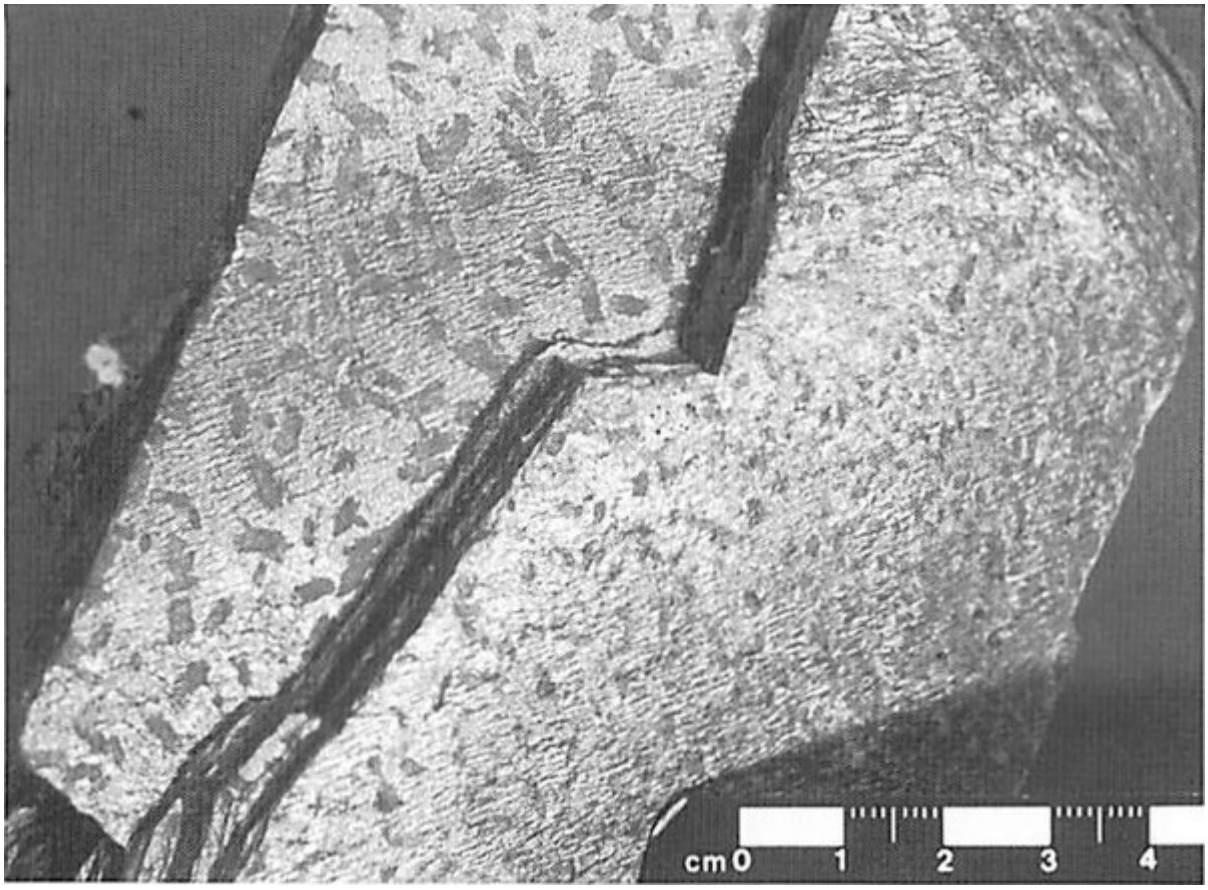
(Photo 6) Stop 1-2. Fine grained graphitic black slate/phyllite of the Ballachulish Slate lithology interbedded with dark grey marble of the Ballachulish Limestone lithology (foreground). These rocks lie immediately east of the Ballachulish Slide.



(Map 1) Geological map of the Ballachulish Igneous Complex and aureole. (map in endpocket).



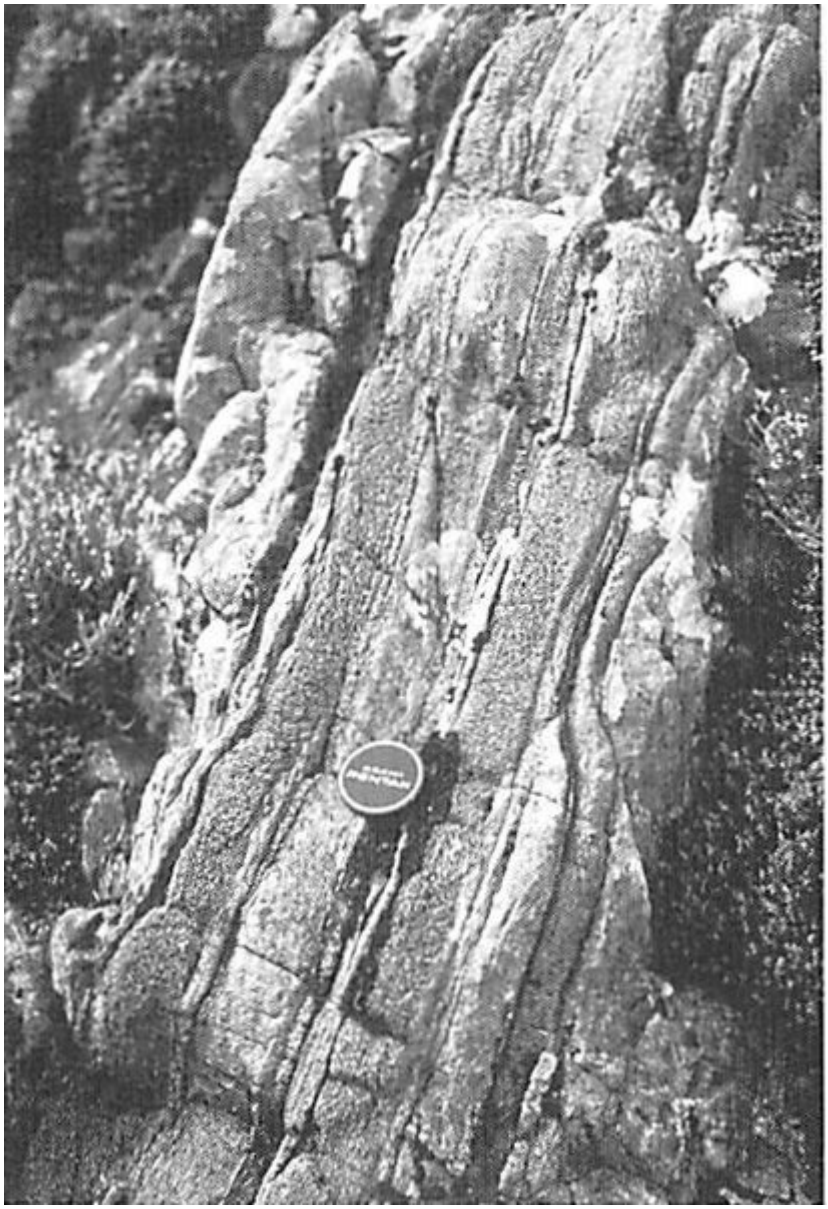
(Figure 1) Outline map of major geological provinces in Scotland, and the distribution of Caledonian igneous complexes ('granites'); with location of the Ballachulish area.



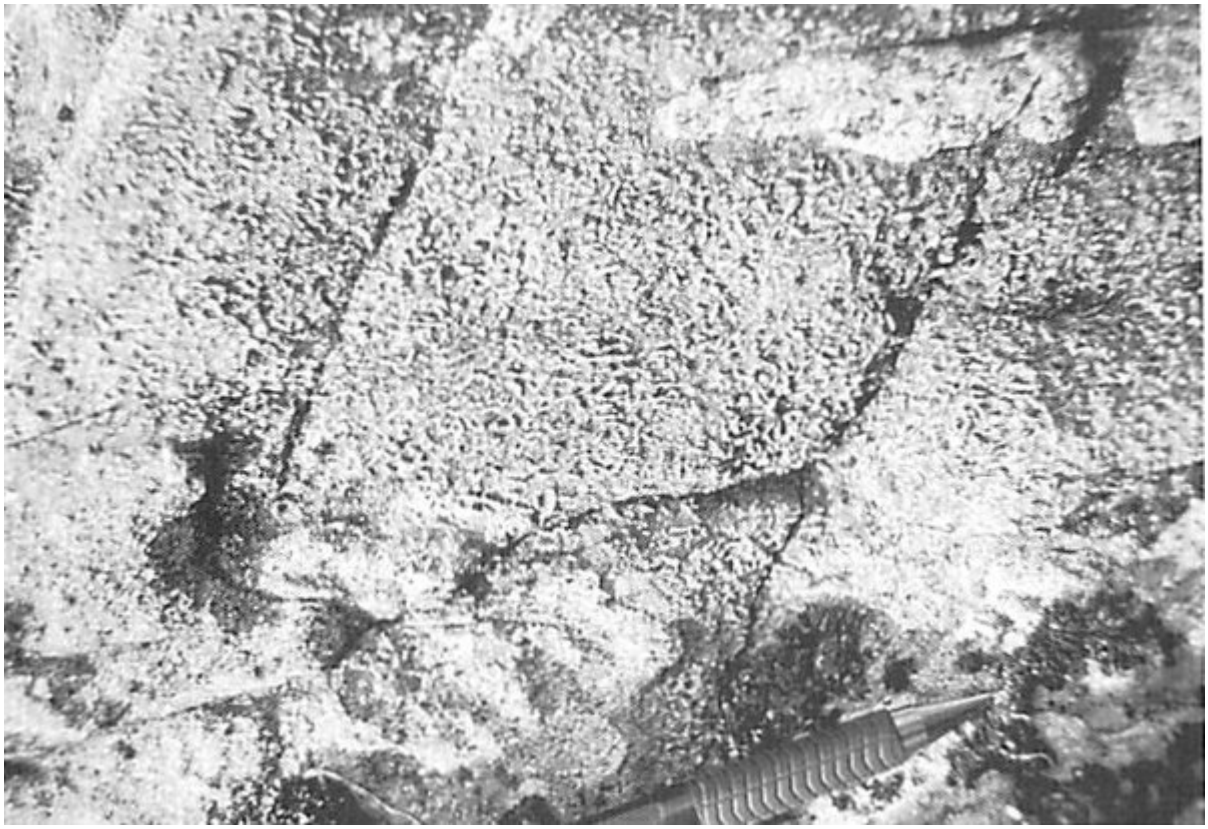
(Photo 7) Stops 1-3 and 3-1. Cordierite porphyroblasts visible as dark patches on cleavage planes of regional phyllites and schists. Note that the size of the patches varies in different parts of the rock. This sample comes from roadside exposures near the parking place for Day 3, Part 1, and shows a coarser development of cordierite patches than at Stop 1-3; but the style of development is similar at both these and other localities in the aureole.

(Photo 8) Stop 1-7/1. Inclusion-rich quartz diorite. The inclusions range from metasedimentary, especially metapelitic, xenoliths, to intermediate-mafic igneous inclusions of similar mineralogy to the host quartz diorite.

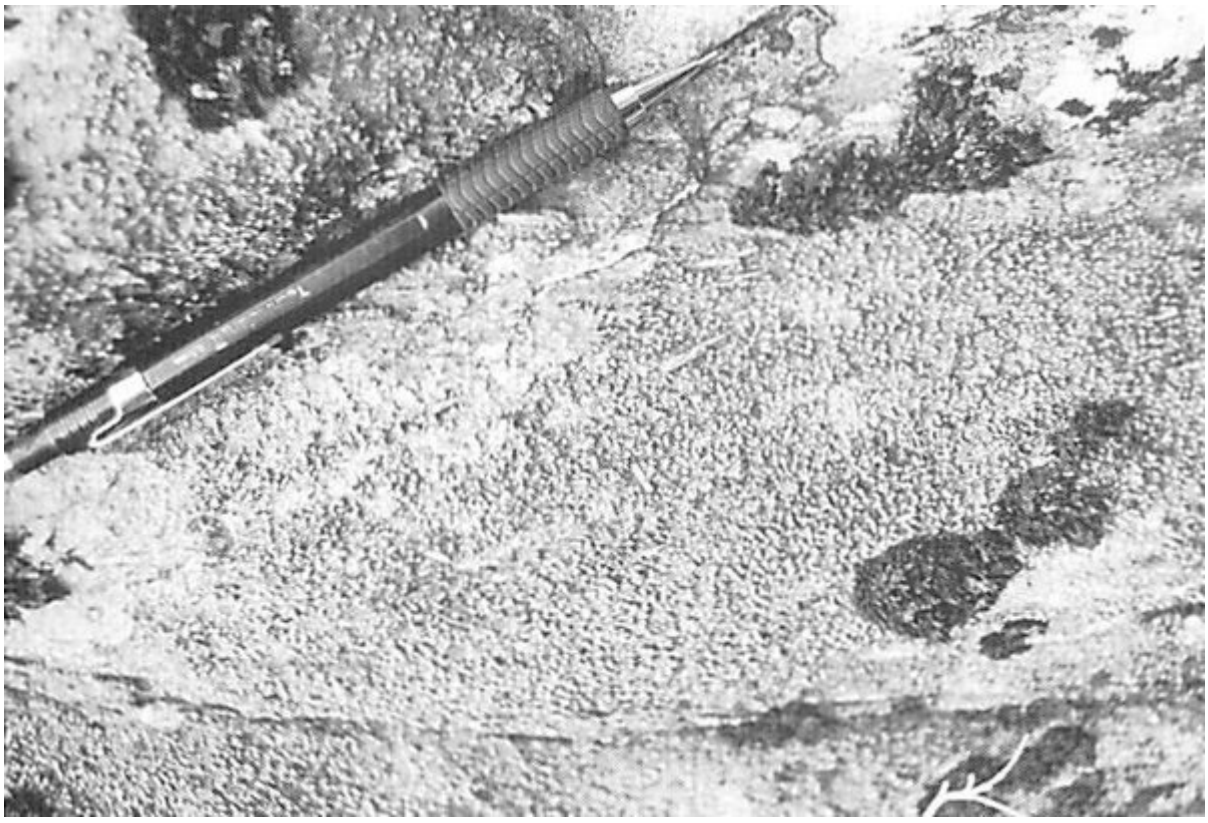
(Photo 12) Stops 3-4, 1-8, 5-2, 5-4 and 5-5. Massive Crd+Kfs-bearing pelitic hornfels characteristic of Zone IVb. The photograph was taken near Stop 5-5 in Coire Giubhsachain, but is representative of Zone IVb in many parts of the aureole. Note the mesh or honeycomb texture, defined by randomly orientated, weathered-out cordierite crystals (represented by pits) within a resistant, light coloured matrix rich in K-feldspar Note also that the matrix surrounding the pits is lighter colorant and more sharply defined than the matrix in hornfelses from Zone III (compare with (Photo 1)).



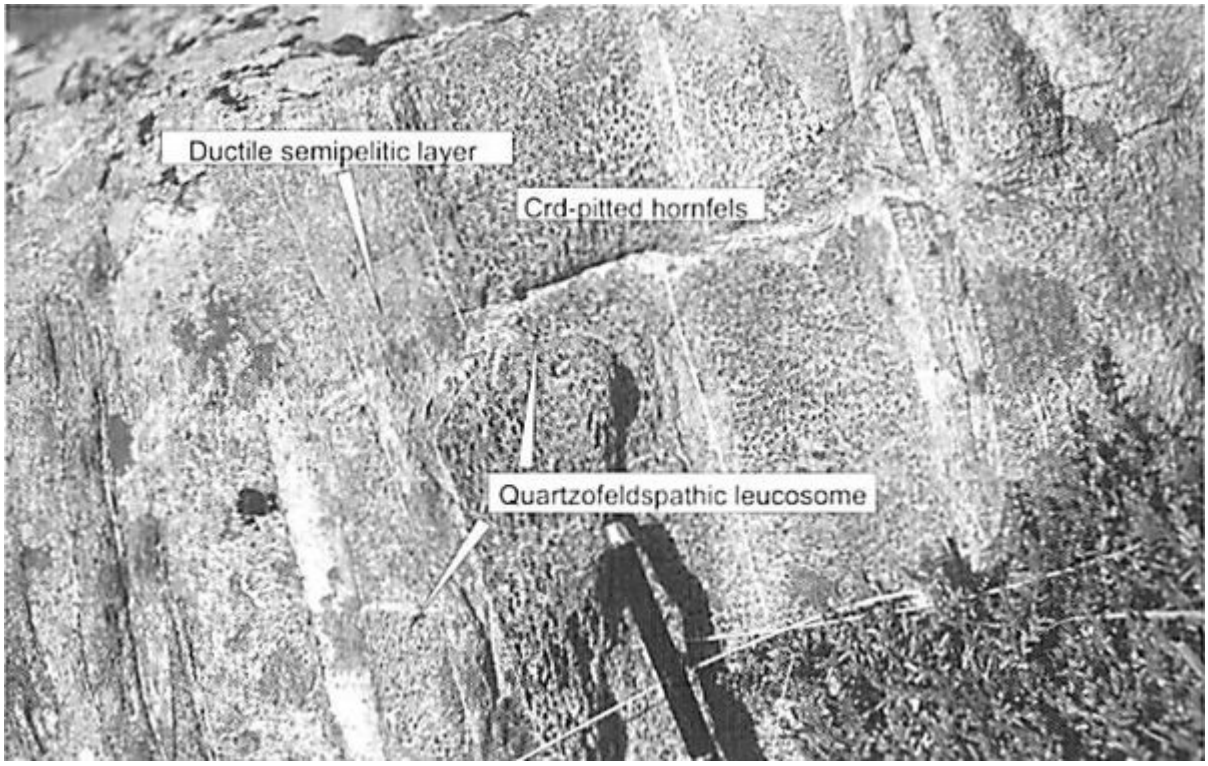
(Photo 9) Stops 1-8, 5-4 and 5-5. Interbedded psammite (light layers) and pelitic hornfels (dark, knobbly layers, rich in cordierite+K feldspar+andalusite), from Zone V. The actual exposure in the photograph is from near Stop 5-5, but is similar to exposures seen in the vicinity of Stop 1-8.



(Photo 18) Stops 5-3 to 5-6. 1-8 and 3-5. Randomly orientated andalusite prisms in a massive cordierite+K-feldspar-rich pelitic hornfels (Zone V). The photograph was taken at Stop 5-5.



(Photo 19) Stops 5-5, 1-8 and 3-5. Corundum-rich, quartz-absent pelitic hornfels of Zone Vb. The corundum is risible as abundant small, rounded 'pimples' that contrast with the more prismatic andalusite crystals seen below the pencil (compare with Photo IS).



(Photo 10) Stops 1-8 and 1-9. Incipient migmatitic features in interbedded pelitic and semipelitic hornfels, upper Zone V. See description of Stop 1-9 for an explanation of the features.