Figures, photographs and tables

Figures

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

(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).

(Figure 3) Geological cross-sections through the igneous complex (see section lines on Coloured Map (Map 1) and (Figure 7)), from Weiss (1986) and Troll and Weiss (1991). 1 - metasediments. Lined patient indicates pelites and semipelites; lined pattern with dots represents quartzites. Squiggly lines indicate migmatitic rocks. The orientation of the lines gives the attitude of the bedding projected into the cross section. 2 - monzodiorites, showing flow- and deformation foliation. 3 - quartz diorites, showing alignment of metasedimentaty xenoliths. 4 - fine grained diorites with xenoliths. 5 - granites. The flue crossed ornament in the centre represents leucogranite, and the bounding stippled margin represents a gradational contact with the main granite. 6 - hybrid transition zones between granite and quartz diorite. The dotted line labelled '..Sgorr Dhearg' represents the projected topographic expression of this peak which occurs about 300 m N of the line of section.

(Figure 4) Pressure-temperature grid of reactions in the chemical system K_2O -FeO-MgO-Al₂O₃-SiO₂-H₂O for typical mineral compositions in quartz-bearing pelitic rocks from Ballachulish (Pattison Harte, 1997). Dehydration reactions below the initial melting reaction (PI+Kfs+Qtz+H₂O = L) are shown in solid lines. Higher grade reactions up-temperature of the initial melting reaction are shown in dashed lines. Als = andalusite or sillimanite. V = hydrous vapour, The short dashed line numbered 3 is the metastable extension of Ms+Qtz = Als+Kfs+V The dot-dashed reaction 5, Ms=Crn+Kfs+V, only occurs in quartz-absent rocks. The And=Sil curve is from Pattison (1992). H - And=Sil curve and triple point of Holdaway (1971); RGB - And=Sil curve and triple point of Richardson et al. (1969). Roman numerals - contact metamorphic zones referred to in the text. Zone IV comprises two different assemblages IVa and IVb that occur at the same grade in rocks of different composition. In quartz-absent rocks, Zone V can be divided into lower grade (Va) and higher grade (Vb) subzones based on the presence of muscovite (Va) and corundum (Vb), respectively. Reaction numbering in Arabic numerals follows the text except that the 'P' prefix is omitted. Isopleths are of (100x Mg/(Mg+Fe)) in cordierite.

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(Figure 6) Isobaric T-X_{CO2}, diagram (3 kbar) for selected equilibria in the chemical system

CaO-MgO-SiO₂-Al₂O₃-H₂O-CO₂, showing numbered reactions discussed in the text (Pattison & Harte, 1997: modified from Masch and Heuss-Aßbichler 1991). All reactions except C18 involve H₂O and/or CO₂. The unlabelled reactions are: Tlc + Cal + Qtz = Tr + CO_{2 +} H₂O. 18. Gros + Qtz = An + Wo (phases on the right hand side of the reaction are on the high-temperature side)

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Photographs

(Photo 1) (Frontispiece). Overview of the Ballachulish Igneous Complex and Aureole from Tom Meadhoin ridge, looking SW.

(Photo 2) View to SW from the summit of Sgorr Dhearg looking across Loch Linnhe

(Photo 3) View from Beinn Man looking NE to the town of Ballachulish and Loch Leven.

(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 guartz 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).

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(Photo 14) View of the contact between granite of the igneous complex (light coloured upper crags) and the Chaotic Zone pelitic migmatites (dark lower exposures).

(Photo 16) Stop 4-3. Crenelated graphitic phyllite of the Ballachulish Slate lithology with abundant cordierite porphyroblasts forming roughly ovoid 'blobs'. Characteristic of Zone III in this vicinity.

(Photo 17) Stop 1-5. A crenulated cleavage surface of the graphitic phyllite of the Ballachulish Slate lithology. The short elongate ribs, with widely varying orientation, mark the occurrence of abundant mm- to cm-long andalusite prisms. The full mineral assemblage in the rock is andalusite + cordierite + biotite + muscovite + quartz, characteristic of Zone IVa (see discussion under Stop -1-5). The andalusite in the rock shown is a little coarser grained than in most exposures in ZoneIVa.

(Photo 18) Stops 5-3 to 5-6. 1-8 and 3-5. Randomly orientated and alusite 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 and alusite crystals seen below the pencil

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(Photo 21) Stop 5-6. Detail of migmatitic rocks with boudin-type structures. The original lithology was of interlayered pelitic and semipelitic material and now shows rigid, pulled apart cordierite-rich hornfels (metapelite) layers (A), ductile semipelitic layers (B) and segregated Kfs+Qtz-rich leucosomes occupying the gaps between the pulled apart hornfels layers (C). Notice how the leucosome merges into the ductile semipelite, giving the impression of being extracted from it. Field of view is 5 cm across. See notes of Stop 1-9 for further explanation.

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(Photo 23) Stop 5-9. Calsilicate rock rich in grossular (equant crystals) and vesuvianite (indicated 'vesuv').

(Photo 24) Stop 5-10. 'Chocolate-tablet' migmatites. See the notes under Stop 5-10 far a description and explanation of the features visible in the top part of the photograph. Cutting across the bottom of the photograph is a lighter coloured dyke-like body of quartz-diorite, carrying many inclusions of pelitic hornfels; boundary picked out with white line.

(Photo 25) Stop 5-10. Detail of 'chocolate-tablet' migmatite. The rock consists of interlayered petite and semipelite. Cordierite-rich hornfels lavers and broken into angular fragments in a tablet structure, with mobile leucocratic material both cross-cutting and running parallel to the layering. The mobile leucocratic material separating the hornfels fragments merges into semi-pelitic layers and does not form extensively cross-cutting veins. Compare with (Photo 10) and (Photo 21).

Tables

(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.

(Table 2) Itinerary of stops for Day 2: Rock types and intrusive relationships of the igneous complex.

(Table 3) Itinerary of stops for Day 3: Part 1 Fraochaidh prograde sequence. b. Itinerary of stops for Day 3 Part 2 Chaotic Zone migmatites and nearby carbonates and calcsilicates.

(Table 4) Itinerary of stops for Day 4: Prograde metapelitic hornfels zones in the Ballachulish Slate along the Gleann a' Fhiodh–Coire Chaorann ridge: appinite and quartz diorite relations; migmatites and Crd+Grt+Opx hornfelses.

(Table 5) Itinerary of stops for Day 5: Medium- to high-grade interbedded pelitic and calcsilicate hornfelses and marbles; various migmatites, including 'chocolate-tablet' type; summit(s) of Beinn a' Bheithir.

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

(Front cover) Cover photograph. View looking east from the summit of Sgorr Dhonuill to Sgorr Dhearg. The ridge in the foreground is underlain by granite of the Ballachulish Igneous Complex. The summit of Sgorr Dhearg, is underlain by white Appin Quartzite or the host Dalradian metasediments. On the left skyline is Ben Nevis and the peaks the Mamore range.



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(Figure 3) Geological cross-sections through the igneous complex (see section lines on Coloured Map (Map 1) and (Figure 7)), from Weiss (1986) and Troll and Weiss (1991). 1 - metasediments. Lined patient indicates pelites and semipelites; lined pattern with dots represents quartzites. Squiggly lines indicate migmatitic rocks. The orientation of the lines gives the attitude of the bedding projected into the cross section. 2 - monzodiorites, showing flow- and deformation foliation. 3 - quartz diorites, showing alignment of metasedimentaty xenoliths. 4 - fine grained diorites with xenoliths. 5 - granites. The flue crossed ornament in the centre represents leucogranite, and the bounding stippled margin represents a gradational contact with the main granite. 6 - hybrid transition zones between granite and quartz diorite. The dotted line labelled '..Sgorr Dhearg' represents the projected topographic expression of this peak which occurs about 300 m N of the line of section.



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(Photo 22) (opposite, above). Stops-7. Calcite+spinel (Spl)+Forsterite-bearing dolomitic marble with folded veins of calcite and forsterite. The Forsterite is commonly, extensively altered to serpentine giving the veins a yellow-brown colour on the weathered exposure surface.



(Photo 23) Stop 5-9. Calsilicate rock rich in grossular (equant crystals) and vesuvianite (indicated 'vesuv').



(Photo 24) Stop 5-10. 'Chocolate-tablet' migmatites. See the notes under Stop 5-10 far a description and explanation of the features visible in the top part of the photograph. Cutting across the bottom of the photograph is a lighter coloured dyke-like body of quartz-diorite, carrying many inclusions of pelitic hornfels; boundary picked out with white line.



(Photo 25) Stop 5-10. Detail of 'chocolate-tablet' migmatite. The rock consists of interlayered petite and semipelite. Cordierite-rich hornfels lavers and broken into angular fragments in a tablet structure, with mobile leucocratic material both cross-cutting and running parallel to the layering. The mobile leucocratic material separating the hornfels fragments merges into semi-pelitic layers and does not form extensively cross-cutting veins. Compare with (Photo 10) and (Photo 21).

	Grid ref. (sheet NN)	Features		Grid ref. (sheet	Features
Stop 1-1 E. of Onich	0505/6105	Panoramic overview of the igneous complex and aureole from Onich	Stop 1-1A Onich shore	NN) 0320/6130	Petrology and structure of regional biotite- grade Appin metapelites and interbedded limestones
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 1-18 Onich shore	0430/6105	Quartzites and semi-pelites, with bedding and cleavage structures illustrating orientation and facing of major Appin Syncline structure
Stop 1-3 North shore of L. Leven	0575/5995	Incipient effects of contact metamorphism, shown by cordierite-spotted phyllites	Stop 1-1c Onich road	0235/6150	Complementary stop to Stop 1-1B (see text)
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 1-6A Gleann a' Chaolais	0310/5605	Late, fine grained microgranite
Stop 1-5 Gleann a'Chaolais	0425/5760	Monzodiorite with orthopyroxene- clinopyroxene, intruded early in the igneous complex	Stop 1-68 Gleann a' Chaolais	0345/5615	Cu-Mo mineralisation and sericitic alteration weakly developed in association with late microgranite
Stop 1-6 Gleann	0375/5675	Granite, typical of the inner part of complex, and intruded at later stage	Stop 1-7A Kentallen	0215/5895	Xenolith-bearing marginal quartz diorite
Stops 1-7,	0075/5705	High-grade calsilicate and pelitic hornfelses (with cordierite+K-feldspar ±andalusite	Stop 1-7a Kentallen	0135/5845	Lit-par-lit intrusion of high-grade hornfels
18	±corundum) and leucosome structures indicative of melting		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.

	Grid ref. (sheet NN)	Features
Stop 2-1 Glen Duror	0150/5430	Xenolith-rich quartz diorite
Stop 2-2 Parking place in Glen Duror	0425/5435	Biotite-poikilitic, two pyroxene monzodiorite, and start of the foot traverse
Stop 2-3	0410/5445	K-feldspar-porphyritic quartz monzodiorite of major apophysis of the the later 'granite'
Stop 2-4	0405/5455	Crushed and altered zone in two pyroxene monzodiorite
Stop 2-5	0395/5460 to 0390/5470	Varieties of two pyroxene monzodiorite Varieties of two pyroxene monzodiorite
Stop 2-6	0385/5485	Late stage rhyolite dyke
Stop 2-7 Edge of Sgorr Dhonuill plateau	0345/5515	Partially hydrated augite monzodiorite, showing the transition from two pyroxene monzodiorite into the hybrid transition zone
Stop 2-8	0350/5545	Pink biotite-hornblende quartz monzodiorite, representative of the hybrid transition zone
Stop 2-9	0370/5550	Pink biotite-hornblende granodiorite of the central 'granite'
Stop 2-10	0405/5555	Summit of Sgorr Dhonuill

(Table 2) Itinerary of stops for Day 2: Rock types and intrusive relationships of the igneous complex.

	Grid ref. (sheet NN)	Features		Grid ref. (sheet NN)	Features
Stop 3-1 Below (S of)	0140/5340	Fissile cordierite-spotted phyllites of Zone II	Stop 3-10 Above Auchindarroch	0165/5525	Hybrid granite of the igneous complex
A'Chruach			Stop 3-11	0160/5530	Disrupted pelitic and semipelitic rocks of the 'Chaotic Zona'
Stop 3-2	0170/5290	Hardened cordierite-spotted phyllites of Zone III	Stop 3-12	0160/5535	Intrusive veins and dyke cross-cutting disrupted migmatites
Coire na Capuill	0195/5275	Massive cordierite-rich homfelses of Zone III	Stop 3-13	0160/5565 to 0160/5575	Many good exposures of 'Chaotic Zone' migmatites
Stop 3-4	0210/5280	Cordierite+K-feldspar hornfelses of Zone IVb with honeycomb structure	Stop 3-14 Above	0145/5590	Striped calsilicates of the Ballachulish Limestone lithology
Stop 3-5	0215/5275	Andalusite+K-feldspar hornfelses of Zone	Lagnaha		
Stop 3-6	0225/5280	Va Corundum-bearing hornfelses of Zone Vb	Stop 3-15	0135/5580 to 0125/5560	Marbles, calsilicates and semipelites of the Appin Limestone/Appin Phyllite lithology
Stop 3-7	0235/5270	Different types of veins in homfelses: onset of partial melting			
Stop 3-8 Coire Dubh	0245/5265	Garnet+cordierite-bearing and spinel- bearing hornfelses			
Stop 3-9 Coire Dubh	0250/5265	Biotite+hornblende quartz monzodiorite of the igneous complex			

(Table 3) Itinerary of stops for Day 3: Part 1 Fraochaidh prograde sequence. b. Itinerary of stops for Day 3 Part 2 Chaotic Zone migmatites and nearby carbonates and calcsilicates.

	Grid ref. (sheet NN)	Features		
Stop 4-1 Low point of ridge	0690/5425	Quartzite and regional grade crenulated graphitic slate, Zone I		
Stop 4-2	0670/5415	Incipient cordierite spotting in grey phyllites, Zone II		
Stop 4-3	0655/5410	Widespread cordierite spotting in grey phyllites, Zone III		
Stop 4-4	0620/5380	Cordierite-rich hornfelses, Zone III		
Stop 4-5	0585/5380	Massive and alusite+cordierite hornfelses, Zone IVa		
Stop 4-6 0560/5340 Massive brown-weathering hornfelses and incipient m phenomena, probable Zone		Massive brown-weathering andalusite-rich hornfelses and incipient melting phenomena, probable Zone V		
Stop 4-7 0545/5345 Hill top		Migmatized cordierite+ K-feldspar+ andalusite+sillimanite hornfelses, Zone V,subzone of partial melting		
Stop 4-8	0535/5340	Appinite and quartz diorite relations		
Stop 4-9	0510/5305	Well exposed migmatites		
Optional Stop 4-9A	0475/5280	Coarse and alusite and corundum		
Optional Stop 4-9B	0385/5330	Orthopyroxene-garnet hornfelses		

(Table 4) Itinerary of stops for Day 4: Prograde metapelitic hornfels zones in the Ballachulish Slate along the Gleann a' Fhiodh–Coire Chaorann ridge: appinite and quartz diorite relations; migmatites and Crd+Grt+Opx hornfelses.

	Grid ref. (sheet NN)	Features
Stop 5-1 Allt Giubhsachain	0625/5740	Interbedded dolostone, limestone and quartzite
Optional Stop 5-1A	0615/5745	Siliceous carbonate exposures containing isobaric invariant assemblage cal+dol+tr+di+fo
Stop 5-2	0615/5730	Interbedded pelitic and semipelitic hornfels, Zone IVb
Stop 5-3	0605/5730	Muscovite + Qtz = Andalusite + K- feldspar (Zone IV/V) isograd
Stop 5-4	0605/5720	Spectacular massive cordierite + K- feldspar ± andalusite hornfelses, Zone V
Stop 5-5	0590/5750	Corundum-bearing hornfelses, Zone Vb
Stop 5-6 Ridge top	0590/5750 to 0575/5755	Increasing range and intensity of migmatitic features going upgrade
Stop 5-7	0570/5745	Veined calcite+dolomite+spinel+ forsterite(serpentine) marbles
Stop 5-8	0555/5730	Periclase-bearing marble outcrops surrounded by leucogranite
Stop 5-9	0555/5690	Layered grossular+vesuvianite-rich calc- silicates
Stop 5-10	0495/5575 to 0485/5545	Spectacular 'chocolate tablet' migmatites and xenolith-rich quartz diorite

(Table 5) Itinerary of stops for Day 5: Medium- to high-grade interbedded pelitic and calcsilicate hornfelses and marbles; various migmatites, including 'chocolate-tablet' type; summit(s) of Beinn a' Bheithir.