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## Excursion 12 Braeleny, Keltie Water

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*Purpose:* To examine metamorphosed Dalradian sedimentary and volcanic rocks of the Southern Highland and Trossachs groups, and associated structural features, including folding and cleavage relationships; to view the Highland Boundary Fault and its relationship to the Dalradian and Lower Devonian lavas in the hanging wall.

*Logistics:* Access to Braeleny is by a narrow road leading north from the main A84 through Callander at [NN 6320 0770]. This gated road is not suitable for coaches, but can be negotiated by minibuses and cars, several of which can be parked at a small road junction [NN 6368 1074], 300 m south of Braeleny Farm [NN 6365 1106]. It is advisable to discuss access with the landowners at Braeleny Farm, especially during the lambing and stalking seasons. When the water is low the Keltie Water section may be followed with care, by crossing and recrossing the river which is feasible in several places. The traverse is thus described as if access to both banks and the bed of the river are available with only minor detours. When the water is moderate to high, it is advisable to visit localities in the west bank and then the east bank, crossing the river by a footbridge [NN 6420 1305] just below the point where the Allt Breac-nic and the Allt a' Chroin join to become the Keltie Water. **When the stream is in flood the available section is not worthwhile visiting.**

*Maps:* OS 1:50,000 Sheet 57 Stirling; OS 1:25,000 sheets 365 Trossachs and 368 Crieff; BGS 1:50,000 Sheet 39W Stirling; locality map (Figure 12.1).

This classic section in the Keltie Water and its headwater the Allt Breac-nic is one of the most important in Highland Border geology. It has been the subject of much work and debate, particularly on the age and nature of the Grampian Event of the Caledonian Orogeny.

The section begins in the Ben Ledi Grit Formation (Southern Highland Group) and traverses downstream into the Keltie Water Grit Formation (Trossachs Group, Tanner & Sutherland, 2007). The strata lie on the SE limb of a major downward-facing synform whose core is occupied by slaty metamudstones and metasiltstones belonging to the Ben Ledi Grit Formation, so the rocks young away from the synform in the direction of traverse. Bedding is subvertical in the Ben Ledi Grit Formation adjacent to the slates but the dip decreases progressively downstream, so that in the Keltie Water Grit Formation it dips gently to the NW, inverted. The traverse thus leads logically from older to younger rocks, but up-dip through an inverted succession.

The Keltie Water Grit Formation is a turbiditic metasandstone sequence that contains two metalimestone–black slate members. On petrographic grounds Tanner (1995) deduced that a stratigraphical transition exists between the pale Keltie Water Grit Formation metasandstones and the green Ben Ledi 'grits'. He recorded a single cleavage in the rocks, but Harris *et al.* (1998) re-affirmed that both units contain an early cleavage that faces up to the SE and strikes consistently clockwise to the inverted bedding, together with a later, downward-facing cleavage that in places crenulates the earlier fabric. A metalimestone bed within the Keltie Water Grit Formation correlates with the Leny Limestone as seen at the nearby Leny Quarry. Here early Cambrian trilobites have been obtained (Rushton *et al.*, 2011). Thus the section demonstrates a stratigraphical and structural conformity and dates the deformational structures as later than early Cambrian.

This section is therefore unique in linking undoubted Dalradian rocks with fossiliferous rocks of known biostratigraphical age, such that most geologists now conclude that the Grampian Event in this area commenced after the early Cambrian. This argues strongly for an entirely Palaeozoic Grampian orogenic event (Tanner & Sutherland, 2007; Tanner, 2011), while previously, structural and isotopic evidence from elsewhere in the Dalradian had tended to favour a Proterozoic age for the orogeny (e.g. Bluck, 2011). Readers interested in the history and details of this debate are referred to the Geological Conservation Review (GCR) of the Dalradian of Scotland (Stephenson *et al.*, 2013; Tanner *et al.*, 2013).

Walk from the parking area [NN 6368 1074] along the metalled road towards Braeleny Farm, where it becomes a rough track. Follow the track for c.2 km until it reaches a footbridge across the Keltie Water at the point where the Allt Breac-nic

and the Allt a' Chroin join to become the Keltie Water. Do not cross the footbridge but turn left (west) and continue up the Allt Breac-nic westwards along its south bank as far as Locality 12.1.

### **Locality 12.1 [NN 6320 1305] Ben Ledi Grit Formation**

From this point upstream, purple and grey slaty metamudstones and metasiltstones belonging to the Ben Ledi Grit Formation can be examined in the Allt Breac-nic. Downstream are green to grey-green gritty metasandstones, also assigned to the Ben Ledi Grit Formation. While the boundary between the two lithologies can be established with some confidence, the original stratigraphical boundary is not seen and extensive local brecciation suggests that the original relationships may have been modified by faulting. Beds of gritty metasandstone generally form the hills, while the slaty rocks occur in low ground and are poorly exposed.

### **Locality 12.2 [NN 6338 1310] Ben Ledi Grit Formation: bedding–cleavage relationship**

A ruined farmhouse can be seen on a glacial ridge above the stream. The start of the traverse stratigraphically upwards through the inverted Ben Ledi Grit Formation into the inverted Keltie Water Grit Formation begins at this locality. A marked volcanoclastic component in the Ben Ledi Grit Formation is seen at this locality, described by C. T. Clough on his original field map as 'capital green beds'. At a sharp 90° bend in the river, finely laminated green metasandstones can be shown to young downstream on the basis of well-preserved truncated laminations, which are transected by an upward-facing penetrative cleavage dipping upstream. The angular relationship between the upward-facing cleavage and bedding, both here and at Locality 12.3, are not consistent with the cleavage being related to the synform to the NW. Right-way-up bedding (seen from grading evidence) dips to the ESE at 80° and the cleavage dips NNW at between 60° and 80°.

### **Locality 12.3 [NN 6338 1309] Ben Ledi Grit Formation: younging evidence**

Several exposures in the stream indicate that the dip shallows rapidly downstream but that younging is consistently to the SE, based on graded bedding and loaded bases of green and grey metasandstone beds, together with ripple cross-lamination in the fine-grained tops of beds. The dominant cleavage in these rocks appears to be facing upwards to the SE or sideways and is inferred to be  $S_1$ , especially as there is a sporadic occurrence of a downward-facing spaced cleavage. Continue downstream along the south bank.

### **Locality 12.4 [NN 6412 1303] Ben Ledi Grit Formation: way-up evidence**

About 80 m upstream from the confluence of the two main streams and immediately to the SE of an island in the river, there are excellent exposures of metasandstones and fissile metamudstones dipping upstream. Load casts on all scales from 1cm to 20–30cm across are a feature of the original base of the metasandstone beds and unequivocally indicate inversion of the beds. Spaced cleavage dips upstream more steeply than bedding and thus is consistent with a synform occurring upstream. These beds are at or near the stratigraphical top of the Ben Ledi Grit Formation.

### **Locality 12.5 [NN 6428 1305] Keltie Water Grit Formation**

This locality comprises exposures of the oldest parts of the Keltie Water Grit Formation, extending from the footbridge across the river [NN 6425 1305] downstream to a right-angled bend [NN 6433 1272]. Downstream from the footbridge to the northern end of a 70–80 m-long break in exposure [NN 6430 1300], the rocks are in what was Tanner's (1995, fig. 3) Transitional Member of the formation, comprising green, brown, grey and white gritty metasandstones. Below the gap in exposure, the section lies in grey and white gritty metasandstones 'similar in field appearance and petrography to the Margie Grits in the North Esk section' (Tanner, 1995, p. 477). Locality 12.5 therefore offers an opportunity to study the nature of the transition from the older Ben Ledi Grit Formation to the younger Keltie Water Grit Formation. The section was crucial in deciding that a lithostratigraphical break does not exist between Southern Highland Group Dalradian and what is now assigned to the Trossachs Group (Tanner & Sutherland, 2007).

Some 50 m downstream from the footbridge and near the middle of the river, a metasandstone bed shows convoluted and discontinuous lamination, the result of soft-sediment deformation. Metasandstones containing abundant silty rip-up clasts are also seen near the west bank at this point. Below the major gap in the exposures, a series of rapids, some 150 m long, flow across granular metasandstones dipping at low to moderate angles upstream. Some beds are metasandstones with abundant silty rip-up clasts. Several beds are demonstrably upside down on the evidence of inverted load casts (Plate 12.1) and graded bedding. Spaced pressure-solution cleavage in metasandstones and apparently penetrative cleavage in metamudstones and metasilts face down across the inverted strata. Thin-section examination of the downward-facing cleavage in the finer grained beds reveals the cleavage to be non-penetrative and transecting an early fabric defined by mica alignment, suggesting that it is secondary.

### **Locality 12.6 [NN 6454 1261] Keltie Limestone and Slate Member**

A microgranitic body (Plate 12.2) marks the contact between the base of the Keltie Limestone and Slate Member with the overlying but stratigraphically older parts of the Keltie Water Grit Formation. Gritty metasandstone beds showing inverted grading (younging to the SE) occur upstream from the contact. This occurrence of metalimestone is petrographically and chemically indistinguishable from the limestone at Leny Quarry, the type locality that yielded the Cambrian fossils (Tanner, 1995, p. 476). It was shown by Tanner as an older precursor of the Leny Limestone. Here the metalimestone is associated with grey, blue, black and creamy phyllitic metamudstones, which show intense contortion, much of which appears rather brittle. The metamudstones are best examined in a low river cliff on the left bank, which extends upstream from the waterfall at the junction of the Allt na Mna Ruaidhe with the Keltie Water; **this exposure is accessible only at low water.**

Metalimestone, recorded by C. T. Clough, occurs in minor amounts in and near the east bank of the Keltie Water both below and above another microgranitic sheet, which forms the waterfall at the confluence; it was reported by Tanner (1995) as 4cm of dark calcite limestone bands in black slate below the waterfall, and also as a metre-sized lens in the old quarry about 100 m east of the confluence.

The stratigraphical contact, which appears conformable, of the Keltie Limestone and Slate Member with the overturned younger parts of the Keltie Water Grit Formation (formerly the Upper Leny Grits) occurs at [NN 6458 1245], 20–30 m downstream from the waterfall and confluence. It is best seen in the left (east) bank and below the water when the river is low and flowing clear. Lithologically the contact comprises a change from blue-grey phyllitic metamudstone to massive gritty metasandstone. From this contact towards Locality 12.7 there is a discontinuous c.100 m section through grey and white gritty metasandstones.

### **Locality 12.7 [NN 6450 1229] Keltie Water Grit Formation: cleavage evidence**

Just below a waterfall, rather broken exposures in the right (west) bank show an early cleavage in a thin slaty layer, which faces up to the south across shallow-dipping inverted gritty metasandstones. A steep spaced cleavage faces down across inverted bedding. The upward, southward-facing cleavage cannot relate to the major synform to the NW, whereas the downward-facing cleavage can. The presence of both cleavages in the Keltie Water Grit and Ben Ledi Grit formations (Localities 12.1–12.3) strongly supports the view of Tanner & Sutherland (2007) that all the rocks in the Allt a' Chroin and Keltie Water are unequivocally Dalradian and share a common structural history. By inference, this history must be younger than the fossiliferous early Cambrian Leny Limestone.

### **Locality 12.8 [NN 6452 1219] Leny Limestone and Slate Member and Highland Boundary Fault**

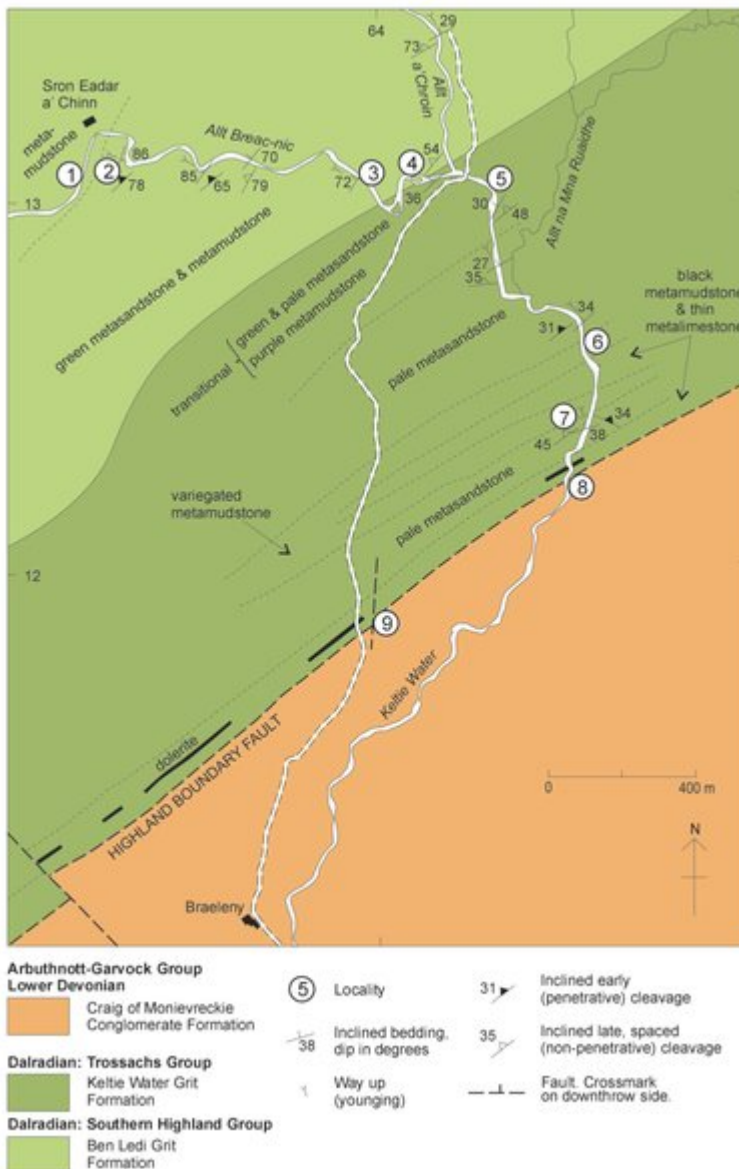
About 100 m downstream from the waterfall of Locality 12.7, to [NN 6452 1219], the traverse crosses the contact between gritty metasandstones and beds shown by Tanner (1995, fig. 3) as continuous with those in the Leny Limestone Quarry. The Leny Limestone and Slate Member here comprises only green and dense black phyllitic metamudstones, which are intensely contorted and are separated from brecciated Lower Devonian mafic lavas (Craig of Monievreckie

Volcanic Formation) by the Highland Boundary Fault, dipping at 54° towards N40°W. The fault (Plate 12.3), which is exposed in a low cliff forming the west bank of the stream, is marked by <1 m of crushed phyllite at [NN 6450 1220]. The green and black phyllites are cut by an unbroken <1 m basaltic dyke trending N30°E.

## Locality 12.9 [NN 6400 1187] Highland Border Complex: serpentinite

Return up the hill to the main track and walk back towards Braelery Farm. At [NN 6398 1178] follow a burn downhill for some 50 m to the point where an old wall is seen beside the stream. Brown-weathering carbonated serpentinite is exposed for 30 m, with black fissile mudstones striking downstream being seen near the middle of the exposure. This outcrop, interpreted on the BGS map to be fault bounded, is one of several outcrops of serpentinite that occur intermittently along the Highland Border. It is, however, rather less impressive than occurrences at Loch Lomond (Treagus, 2009).

### References



(Figure 12.1) Geological map of the Keltie Water section above Braelery Farm, showing localities for Excursion 12.



*(Plate 12.3) Locality 12.8. Highland Boundary Fault in west bank of Keltie Water. See text for detail.*



*(Plate 12.1) Locality 12.5. Load casts on inverted beds of Keltie Water Grit Formation, Keltie Water.*



*(Plate 12.2) Locality 12.6. Microgranite sill in Keltie Water, at inverted contact between the lower part of the Keltie Water Grit Formation (upstream, left) and the Keltie Limestone and Slate Member (downstream, right).*