Forest Lodge

[NN 933 741]

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Introduction

In the second half of the eighteenth century the controversy regarding the origin of rocks which we now regard as 'igneous' was at its height. On the one side were the Neptunists, inspired by the teaching of Abraham Werner in Saxony, who believed that rocks such as basalt and granite were 'sedimentary', having crystallized from a supposed primeval ocean, as rock-salt does from today's oceanic water. Granites were considered to have crystallized first, to form a thick layer around the Earth's 'nucleus'. The granites were overlain by other layers of crystalline rock, those that we now know as 'metamorphic', followed by layers of sedimentary rock formed as a result of erosion of the 'Primitive' crystalline rocks and subsequent deposition. Rocks resulting from observed volcanic eruptions were attributed to the local action of 'subterraneous fires' (generally thought to be due to the burning of coal seams), but these, it was believed, could only consolidate as a glass.

By the 1760s prehistoric volcanic features had been recognized, in particular in the Auvergne region of France, where flows of crystalline basalt had been traced back into undisputed volcanic craters. The Vulcanists had made their point and gradually, over the next fifty years, most Neptunists came to accept the magmatic origin of basalt. The origin of granite was more difficult to prove since, by its very nature according to any of the theories of the day, it could not be observed forming *in situ.* It was James Hutton (1726–1797), a prominent member of the Edinburgh scientific community, who was to lead the Plutonists in establishing that granite crystallized from a molten fluid and not from an aqueous solution.

In his 'Theory of the Earth', delivered in two lectures to the Royal Society of Edinburgh in the Spring of 1785 (Hutton, 1788), he argued that the relative insolubility in water of quartz and other component minerals of granite, precluded the Neptunist theory. He recognized the significance of the intergrowth texture between quartz and feldspar in a sample of coarse-grained graphic granite (Hutton, 1788, plate II) and concluded that granite might have 'risen in a fused condition from subterranean regions' and that the country rock should therefore be broken, distorted and veined.

In the late summer of 1785, Hutton embarked upon the first of several excursions to find field evidence in support of his philosophical theories; these must have been among the first ever geological field trips. From the examination of debris washed down by rivers in the Highlands, he had already concluded that a major junction existed somewhere in the region of Glen Tilt, between a largely granitic terrain to the north and *'alpine schistus'* to the south. He stayed at Forest Lodge, where he soon found the evidence that he was seeking, particularly in those exposures in the bed of the River Tilt, less than 1 km from the lodge, which now constitute the GCR site. In Hutton's words, 'the granite is here found breaking and displacing the strata in every conceivable manner, including the fragments of the broken strata, and interjected in every possible direction among the strata which appear'. He also inferred from the highly crystalline nature of the country rocks that they had been subjected to intense heat and that the granite was responsible; hence the granite must have been injected as a very hot liquid, i.e. a magma.

Over the next three years Hutton was to find and document further examples of granite veining, particularly in Galloway and on the Isle of Arran, and a brief account of the field evidence was included in a discussion of the origin of granite (Hutton, 1794). The Glen Tilt sites were revisited by several of Hutton's contemporaries (Playfair, 1802; Seymour, 1815; MacCulloch, 1816), but his own detailed descriptions were not published until 100 years after his death in volume 3 of 'Theory of the Earth', edited by Archibald Geikie (Hutton,. 1899). By this time the magmatic origin of granite had, for the time being at least, become universally accepted and the Neptunist theory had lapsed into historical significance. In 1968 a collection of drawings came to light, many of which were clearly intended to accompany volume 3 of 'Theory of the Earth', but were 'lost' prior to its publication (Craig *et al.,* 1978). Several depict the Glen Tilt exposures and one is reproduced here (Figure 8.24).

The exposures described by Hutton occur on the margins of the Glen Tilt igneous complex, which occupies most of the ground to the NW of Glen Tilt in the area around Forest Lodge. Here, complex and varied contact relationships between granite, diorite and the metasedimentary country rocks are well displayed. Since the visits of Hutton's followers in the early nineteenth century, the exposures have received surprisingly little attention. The area was mapped by the Geological Survey in the late nineteenth century, but the accompanying memoir makes little mention of the contacts (Barrow *et al.,* 1913). Studies of the Glen Tilt complex by Deer (1938a, b, 1950, 1953) and Mahmood (1986) concentrate almost entirely upon the mineralogy and petrology of the granites, diorites and a wide range of contaminated and hybrid rocks, but provide few details of the field relationships. The site also lies along the line of the Loch Tay Fault, and the fault plane, with associated breccias and zones of silicification, is well exposed. The present account is based upon remapping by the British Geological Survey (Figure 8.22).

Description

The straight line of Glen Tilt at Forest Lodge is controlled by the Loch Tay Fault, one of the most important NE–SW-trending late Caledonian faults in the Grampian Highlands. Farther to the SW around Loch Tay, the fault has a net sinistral strike-slip movement of 7 km and a downthrow of at least 0.5 km to the SE (Treagus, 1991). In Glen Tilt the fault juxtaposes Grampian Group (and possibly lowest Appin Group) strata, cut by rocks of the Glen Tilt igneous complex, to the NW against upper Appin Group strata to the SE. There are no major intrusions and no widespread contact metamorphism to the SE of the fault. This would appear to be consistent with a significant downthrow to the SE, although there are no indications of the extent of strike-slip displacement in this area.

Where seen, the fault plane is near vertical and sharply defined, as below the waterfall at [NN 935 743]. It is commonly marked by zones of brecciation and silicification, such as below the waterfall at [NN 938 746] and in the river due south of the lodge [NN 932 740]. The zone of brecciation is never very wide, considering the magnitude of the fault, and rarely extends for more than about 10 m on either side of the fault plane. Silicification can extend slightly farther and is particularly noticeable in limestone beds which take on a distinctive yellow-brown colour. In many places the fault plane is occupied by a dyke, no more than 1–2 m wide, of either micro-granite or microdiorite, which in this area is invariably highly brecciated and silicified. Within 20 m of the fault plane minor buckle folds plunging generally between E and SE (e.g. around [NN 937 745]) are probably related to the strike-slip movements on the fault.

On the SE side of the fault, rocks assigned to the Blair Atholl Subgroup dip generally to the SE at 25–45°. At river level, most exposures are of metalimestones, which occur within a sequence of schistose to flaggy semipelites and pelites, with flaggy banded psammites and some massive quartzites (Smith, 1980). On the NW side of the fault in general, the metasedimentary rocks are psammites and quartzites of the Grampian Group, but in the area around the Glen Tilt igneous complex, lithologies include calcareous schists, paraamphibolites and impure metalimestones. This distinctive assemblage has been termed the Glen Banvie 'series' by Smith (1980); its stratigraphical affinities are uncertain, but it may be equivalent to part of the Lochaber Subgroup at the base of the Appin Group. In the Forest Lodge area the Glen Banvie 'series' rocks are commonly steeply inclined with a general NW–SE strike and tight upright minor folds that plunge north at 10–20°. It may be that they occupy the core of a large-scale late N–S fold, similar to those which control the outcrop pattern in the Schiehallion area and elsewhere in the Southern Highlands (Treagus, 1991). The Glen Tilt igneous complex occupies and largely replaces this proposed fold core.

The Glen Tilt igneous complex, a member of the South of Scotland Suite, comprises diorite, granodiorite, granite and a suite of microdioritic minor intrusions that together occupy an area of 12 x 6 km, extending north-westwards from the Loch Tay Fault in Glen Tilt. The north-western part is entirely granitic- (the Beinn Dearg pluton), but the south-eastern part has a complex outcrop pattern of granite and diorite with large areas of metasedimentary rock. Exposures are discontinuous, especially on the lower valley sides around Forest Lodge, where scree and other superficial deposits cover much of the outcrop. Consequently, the form of the intrusions is difficult to determine; dioritic rocks form most of the area to the NE of the lodge, with many small outcrops of biotite granite around the lodge itself. Intrusive relationships, where seen, are equivocal. The granite is not chilled at any contacts, although locally it is slightly reduced in grain size against country rocks. The diorite generally has a finer-grained marginal facies. Most contacts between granite and diorite are sharp, but locally they are gradational with evidence of hybridization. The granite is cut by microdiorite dykes that seem to be related pet-rogenetically to the diorites (Beddoe-Stephens, 1999). However, marginal granite locally contains blocks of fine-grained basic rock in an intrusion breccia; marginal dioritic rocks are commonly veined by aplitic granite; and some marginal diorites develop small feldspar porphyroblasts. Critical evidence of the intrusive relationships between granitic and dioritic rocks and with the metasedimentary country rocks occurs in the River Tilt exposures, examined by Hutton and now part of the GCR site.

A sharp contact between diorite and granite is exposed at the top of a waterfall [NN 935 743]. The biotite granite, here mostly on the SE side of the river, is brick red and equigranular with conspicuous milky white quartz up to 5 mm in diameter that weathers proud to give a nodular appearance. Most of the outcrop close to the contact is an irregular mix of veins of granite, granodiorite, diorite and vein quartz with no consistent crosscutting relationships. The veining continues into psammites and quartzites above the waterfall where almost 50% of the exposure is vein material. The diorite on the NW side of the river is medium grained (2–3 mm), equigranular and is composed essentially of dark-green hornblende and dark-pink plagioclase. It is cut by thin, irregular quartzofeldspathic veins and contains small granitic pods. The diorite remains even textured right up to the contact, but the granite has a very irregular texture and is also very hard and splintery. Small inclusions of psammite, quartzite, calc-silicate rock and grey metalimestone occur in the granite close to the contact, but not in the diorite. An island within the waterfall is formed by a larger inclusion of banded quartzite or psammite cut by pods and thin veins of granite, and the NW edge of this inclusion is marked by an intrusion breccia of quartzite/psammite and some amphibolite in a dioritic matrix.

The waterfall beneath the ruined abutments of Dail-an-eas Bridge [NN 939 747] (Figure 8.23) was the main focus of Hutton's observations and figures in several of his drawings (Figure 8.24). The abutments rest upon a coarse-grained brick-red biotite granite, crowded with xenoliths (up to 2 m), of psammite, quartzite, metalimestone and pale- to dark-green, banded pars-amphibolite. The coarse-grained granite and the inclusions are cut by thin, irregular pink granite veins with sharp, angular contacts. Immediately upstream of the bridge, a sharp contact between granite and metasedimentary rocks is near vertical, planar, trends WNW–ESE and forms a galley on the NW bank; it has possibly been modified by later faulting. Within 2–3 m of the contact the granite is slightly finer grained, with an irregular texture, and it is crowded with angular xenoliths. A few veins of red granite penetrate into the adjoining metasedimentary rocks, which dip steeply southwards and strike slightly oblique to the contact. The metasedimentary rocks consists of psammites, quartzites, metalimestone (one bed is 2.5 m thick) and banded, ribbed siliceous calc-silicate rocks with paraamphibolites. In thin section they show evidence of recrystallization due to hornfelsing and in several places skarns, with large (1 cm) pale-brown garnets, are developed at the junction between carbonate and calc-silicate rock. The veins that so impressed Hutton are mostly of irregular coarse-grained white quartzofeldspathic pegmatite, with some more regular veins and concordant sheets of white to grey microgranite or microgranodiorite. There are a few irregular veins of pink granite but, except for those at the contact (see above), these do not resemble the main granite body.

Interpretation

Although Hutton had correctly deduced that a junction between granite and 'schistus' would be found in Glen Tilt, he was unaware of the presence and significance of the Loch Tay Fault. So it was fortuitous that he found his evidence so easily; he may well have diet with only a faulted contact with no veins, xenoliths or other evidence to indicate an intrusive relationship. The contacts of the intrusive complex with large masses of metasedimentary rock are well exposed only in the valley bottom, where the River Tilt departs from the line of the fault plane, albeit by less than 50 m, in places like Dail-an-eas. Fortunately, the zone of brecciation and alteration associated with the fault is too narrow to have affected these outcrops and obliterate the detail.

The presence of large outcrops of metasedimentary rock, within those of igneous rock, in the Forest Lodge area suggests that this is a marginal zone of the intrusive complex. Unfortunately the exposures are too discontinuous to identify this as either a roof zone with pendants, a lateral margin with screens, or an area of in-situ country rock heavily impregnated with veins and irregular apophyses from the main intrusions. The consistent NW–SE strike of the bedding and shallow northerly plunge of fold axes in most of the outcrops does however suggest that re-orientation as a result of the intrusions has been minimal. The form of the main intrusions is likewise impossible to determine. Many of the granite outcrops seem to be relatively small, isolated bodies, but they are all coarse grained and have petrographical similari ties to a larger intrusion centred upon the ridge of Sron a' Chro, some 3 km to the west. The diorite is more widespread and continuous, dominating the higher, craggy slopes of Glen Tilt to the NE; it could be a highly irregular, steep-sided intrusion, but the outcrop pattern could be interpreted as a thick low-angled sheet with the Forest Lodge outcrops close to the lower margin.

Intrusive relationships between the granite and diorite are ambiguous. Earlier workers (Deer, 1938b; Mahmood, 1986) regarded the diorites as earlier. This is supported by the presence of granitic veins and feldspar porphyroblasts in the diorite. However, recent field and petrological studies (Beddoe-Stephens., 1999) suggest that the Sron a' Chro and related granite bodies in the Forest Lodge area were the earliest phase of the complex and that, during subsequent intrusion of the diorite, melting, hybridization and remobilization occurred, with back-veining of aplitic and pegmatitic veins into the still hot diorite. During crystallization of the diorite, slightly fractionated melts were expelled to form the microdiorite dykes which cut the Sron a' Chro granites.

Within the GCR site, the overall impression is that the diorite cuts the granite. Whereas the granite is commonly crowded with metasedimentary xenoliths, none of diorite are recorded. The diorite has far fewer metasedimentary xenoliths, giving the impression of a later event and the rounded pods of granite that have been recorded could be partly digested xenoliths. The granite is slightly finer grained against the metasedimentary rocks, but not against the diorite. It develops a highly irregular texture against both, but is hard and splintery against the diorite suggesting secondary silicification during recrystallization. More importantly, whereas thin sections of the diorite show primary crystal lization textures, those of the granite show evidence of strain-related recrystallization, implying thermal and deformational events associated with the diorite emplacement.

Relationships of the Loch Tay Fault to the intrusions are interesting. Treagus (1991) considers that the major NE–SW faults of the Grampian Highlands were initiated as dextral shears during a late phase of N-S-trending folding, which pre-dated the major intrusions. The Glen Tilt complex does seem to be located in the core of a major N-S late fold and an early shear or fracture could possibly have controlled the location of the SE margin or even have acted as a magma conduit. Clearly the major movements on the fault post-date the main intrusions of the complex, which are truncated and which do not appear on the downthrown SE side. Neither is there any major aureole development on the SE side. However, throughout most of its length in upper Glen Tilt, the fault plane contains minor intrusions of microgranitic and microdioritic rocks; most are highly brecciated with much secondary silicification, but others have suffered little or no brecciation. Clearly the fault was in existence soon after the emplacement of the Glen Tilt Complex, to control the site of minor intrusions. Some of these were then affected by subsequent brittle movement, to complete a long and complex cycle of inter-related faulting and intrusion in late Caledonian time.

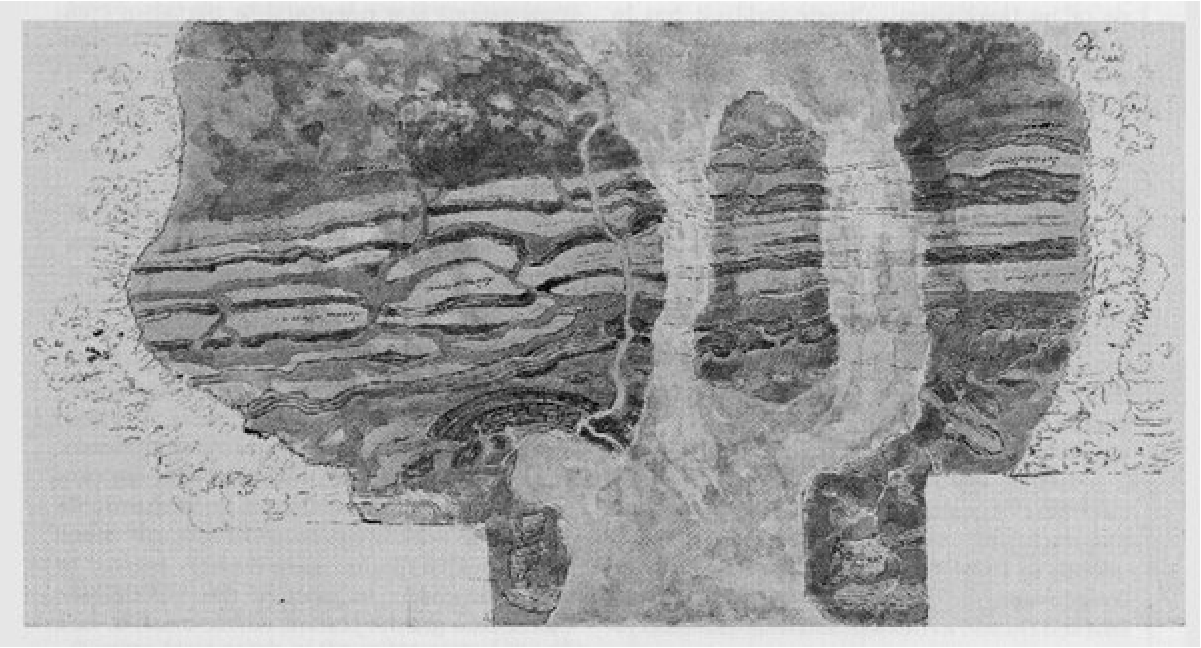
Conclusions

This site is of international importance on historical grounds. It was here in 1785 that James Hutton first found and documented field evidence to support his theory that granite was intruded into country rocks in a hot, fluid state.

Although there are much clearer examples elsewhere of granite veins emanating from a pluton, including some that were visited subsequently by Hutton, the exposures around Forest Lodge were the first to be evaluated. They enabled Hutton to demonstrate that granite crystallized from 'matter made fluid by heat', i.e. magma; that this matter was able to flow within the Earth's crust, veining, disrupting and recrystallizing pre-existing rocks; and that consequently granite is not universally the earliest formed rock. This effectively ended the Neptunist arguments of Werner and his disciples and for well over a hundred years was accepted as a satisfactory explanation for the origin of all granites.

It was not until the 20th century that people began to address the problem of where and how granitic magma might be generated. Once again this led to a division into two camps, with the essentially Huttonian 'magmatists' opposed by 'transformationists' who believed that granite was generated *in situ* from pre-existing rocks, by fluid or gaseous 'fronts' which modified the composition, mineralogy and texture of the rock without generating a melt; the process of 'grani-tization'. This time, however, it eventually became accepted that both arguments have their merits and that granites have formed in many different ways; in the words of H. H. Read (1957), 'there are granites and granites'. Mechanisms such as broad-scale, in-situ, solid state diffusion as a product of ultrametamorphism and the precipitation of granitic pegmatites from silicic, hydrous fluids are now well documented, and fractional crystallization of a more basic magma can result in a granitic residual melt. But by far the greatest volumes of granite are now considered to have crystallized from magma that originated by partial or complete melting of crustal material; a true vindication of the Huttonian theory.

References



(Figure 8.24) Plan of exposures in the River Tilt on the upstream side of Dail-an-eas Bridge, drawn by John Clerk of Eldin during Hutton's visit in 1785 and published as one of Hutton's 'lost drawings' by Craig et al. (1978). The outline is inaccurate and the detail is somewhat exaggerrated and stylized, but it illustrates well the features that Hutton observed; in particular the 'granite', 'limestone', 'schistus' and 'mixed rocks' are clearly labelled on the original. Note that the drawing is reproduced upside down to facilitate comparison with the photograph of Figure 8.23; the bridge abutments are indicated by the blank rectangles (bottom right and bottom left). Reproduced by permission of Sir John Clerk.

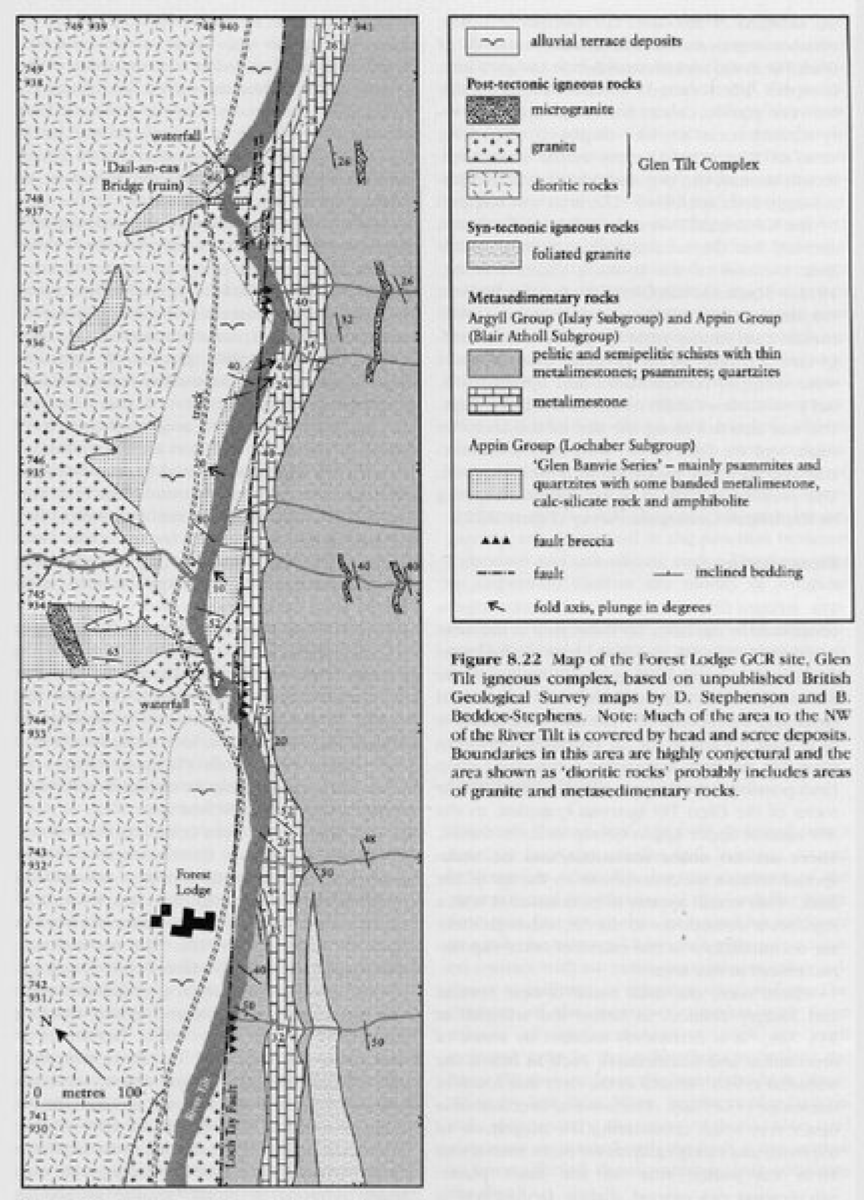


Figure 8.22 Map of the Forest Lodge GCR site, Glen Tilt igneous complex, based on unpublished British Geological Survey maps by D. Stephenson and B. Beddoe-Stephens. Note: Much of the area to the NW of the River Tilt is covered by head and scree deposits. Boundaries in this area are highly conjectural and the area shown as 'dioritic rocks' probably includes areas of granite and metasedimentary rocks.

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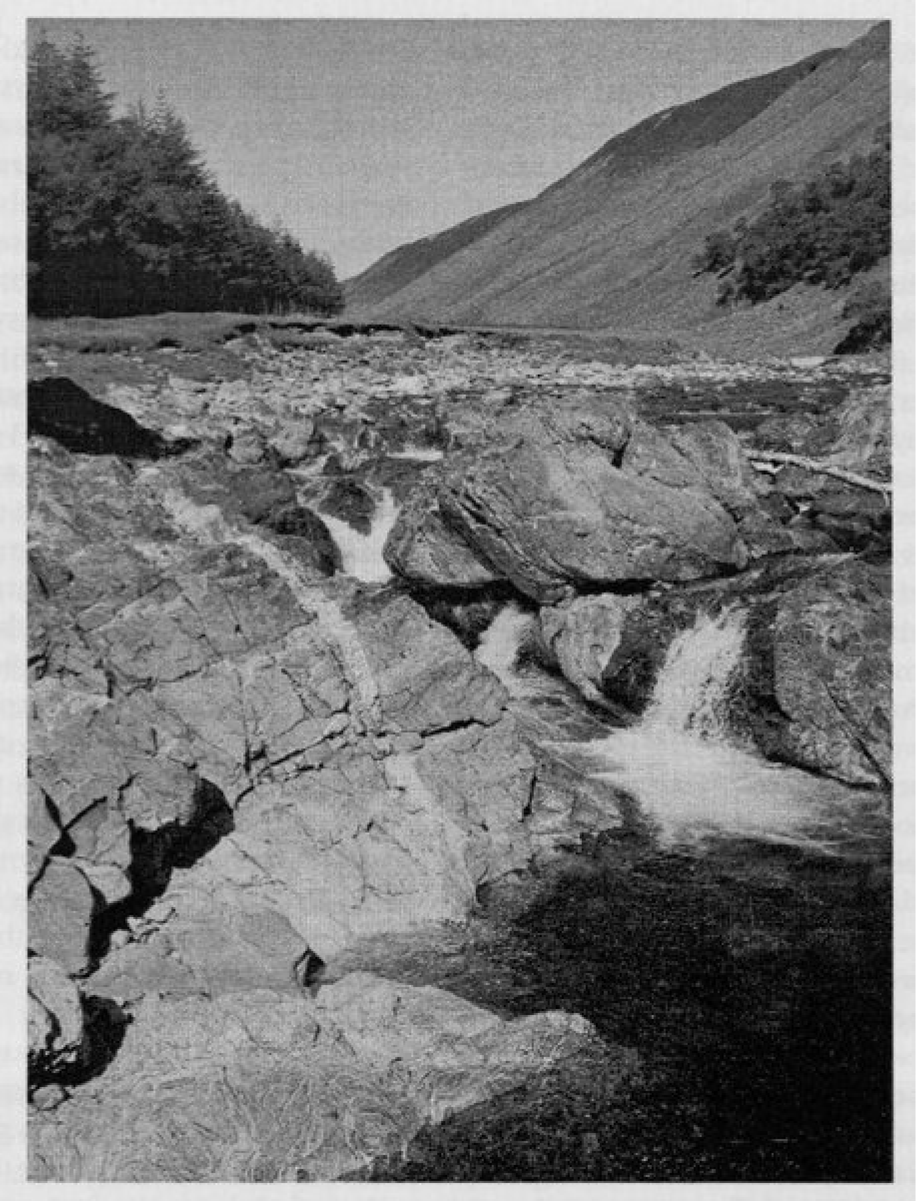

(Figure 8.23) The waterfall at Dail-an-eas Bridge above Forest Lodge: view from the ruined bridge abutment. Siliceous metasedimentary rocks and a 2.5 m-thick bed of metalimestone (the latter surrounded by and tunnelled through by the waterfall) are cut by granitic veins of various types. The most prominent vein is also clearly visible in Hutton's 'lost drawing', reproduced in Figure 8.24. (Photo: D. Stephenson.)