9 Bridge of Avon

[NJ 1497 2032]–[NJ 1541 1915]

J.R. Mendum

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9.1 Introduction

The River Avon and adjacent areas around Bridge of Avon, 2 km north-west of Tomintoul, expose sections through the Ballachulish and Blair Atholl subgroup rocks that here are disposed in kilometre-scale fold patterns. The sequence includes several very distinctive units that can be recognized not only throughout the North-east Grampian Highlands but also along most of the Dalradian outcrop elsewhere and hence are valuable stratigraphical markers.

Here, the stratigraphy is condensed and probably represents deposition over an original basin high. The Ballachulish Subgroup sequence ranges from graphitic pelite of the Mortlach Graphitic Schist Formation up through the Corriehabbie Quartzite Formation to the mixed Ailnack Phyllite and Limestone Formation. The Inchrory Limestone Formation represents the overlying Blair Atholl Subgroup rocks. Although the lithologies are deformed and metamorphosed to kyanite grade (lower amphibolite facies), they clearly show internal bedding features in parts e.g. cross-bedding in the quartzite and grading in some of the semipelitic units.

The structure of the Dalradian rocks is complex and four deformation phases can be recognized. Bedding generally dips moderately to the south and south-east but dips vary from 25° to vertical locally. Cleavages are best seen in the more-pelitic units, notably in the graphitic pelite. Minor folding is well displayed in the thinner bedded units, notably in the calcareous semipelite and psammite. A set of faults that mainly trend north–south disrupt the structural pattern. These faults are of Devonian and later age, as several of them affect the conglomerates and sandstones of the late Silurian to Early Devonian Tomintoul Outlier, which overlie the Dalradian rocks about a kilometre south of the GCR site.

The Bridge of Avon area was mapped by L.W. Hinxman during the primary geological survey and brief descriptions were given in the Sheet 75 memoir (Hinxman, 1896). Hinxman mapped the area solely on the basis of lithology and in some areas his map linked together several stratigraphically disparate units. The area was remapped by the British Geological Survey between 1982 and 1988 (1:50 000 Sheet 75W, Glenlivet, 1996), and that work forms the basis for this account. A detailed geochemical study of Dalradian metacarbonate units by Thomas (1989, 1999) included several samples from the Bridge of Avon area.

9.2 Description

The Bridge of Avon GCR site encompasses some 1.4 km of the River Avon section, extending from downstream of the old General Wade bridge, up river almost to below the abandoned lime quarry at Creag Chalcaidh. It also includes the lowermost part of the Allt na Cluaine and some small crags marginal to alluvial terraces. Exposure is not continuous but amalgamation of all the information available gives a moderately comprehensive picture of the geology (Figure 6.18).

9.2.1 Stratigraphy

The Mortlach Graphitic Schist Formation forms the core of an F2 anticline that is mapped mainly from the float on Tom Beag, west-south-west of Bridge of Avon. Poor exposures are seen in the river section on its west bank. It consists mainly of dark-grey, to nearly black, schistose graphitic pelite and semipelite, with small garnets abundant in parts. Pyrite and quartz veins are also abundant locally and in thin section kyanite and staurolite porphyroblasts are common. The dominant parting is a millimetre-scale penetrative spaced cleavage (S2). The earlier fine-grained S1 fabric, which

generally lies near-parallel to bedding, is seen only in thin section. The formation shows a rapid transition upstream into the Corriehabbie Quartzite Formation, a white to fawn, blocky, commonly indurated, fine- to coarse-grained quartzite, with minor siliceous and feldspathic psammite. It is thin to medium bedded with some gritty feldspathic basal zones in individual sand units. Cross-bedding is present locally, defined by heavy-mineral streaks (magnetite/haematite). Around Bridge of Avon the quartzite formation is only about 55 m thick but it thickens to over 250 m a few kilometres to the north-east and farther south in the Water of Ailnack section. The outcrop pattern of the quartzite is convolute in the area north-west of Tomintoul as a result of both F2 and F3 kilometre-scale folding. These give rise to the interference structures seen in plan on (Figure 6.18), which together with the initial thickness variations and later faulting, result in a complex structural pattern. Some of the step-like offsets of the quartzite outcrop around Bridge of Avon are a product of local F4 folding.

The overlying Ailnack Phyllite and Limestone Formation consists of psammite, semipelite, metalimestone and minor pelite lithologies. Calcsilicate rocks are characteristic of parts of the formation and thin quartzite beds commonly occur near its base. An across-strike section occurs beneath the Bridge of Avon itself [NJ 1495 2015] but the unit forms a complex outcrop pattern in this area. It contains some prominent members that can be recognized widely on Sheet 75W (Glenlivet). At the base of the formation lies the Torulian Limestone Member, which here forms a prominent, almost pure white unit *c.* 5 m thick. Its outcrop can be traced from the bank into the rocky bed of the river, where it is cut out against a fault. The metalimestone consists dominantly of calcite with pyrite-rich laminae. It shows a poorly defined, thin banding that has been etched out by the river to show tight to isoclinal folds with amplitudes of up to 2 m. Their axial planes lie subparallel to the bedding, and the folds are confined to individual layers, in parts truncated by overlying thin beds. They are interpreted as slump folds but could be F1 structures.

The metalimestone member is succeeded by phyllitic semipelite and pelite, in parts graphitic, which is followed by thinly banded calcareous semipelite, calcsilicate rock and impure metalimestones that show good examples of F3 minor folding. These latter lithologies are exposed directly beneath the Wade bridge. They pass upwards into the more-semipelite-dominated upper part of the Ailnack Phyllite and Limestone Formation, which here is distinctive enough to be termed the Kylnadrochit Semipelite Member. This unit is about 65 m thick, and consists of purplish and greenish mid-grey, flaggy to blocky, calcareous, highly micaceous psammite and semipelite. The beds are laminated to thinly banded, commonly with retrogressed garnet porphyroblasts. They are folded by open to tight F3 folds that have attenuated limbs and a related penetrative S3 planar cleavage; they verge mainly to the south-west. In the lower part of the Allt na Cluaine section, between [NJ 1475 1932] and [NJ 1494 1937], more-pelitic and graphitic lithologies at the top of the member are exposed. These are charcoal grey to blue-grey, flaggy to fissile, calcareous semipelite and pelite with abundant small garnet porphyroblasts. Tight folding is present, but in the semipelitic units good fine-scale grading has been recorded. These uppermost lithologies are probably equivalent to parts of the Clashnoir Semipelite Formation, which is mapped as a separate unit in the Blair Atholl Subgroup to the north-east in the Braes of Glenlivet, where the sequence is considerably thicker.

In the Bridge of Avon area, the Kynadrochit Semipelite Member passes up by rapid transition into the Inchrory Limestone Formation, the main metalimestone unit of the Blair Atholl Subgroup. Transitional lithologies consisting of interbedded calcareous semipelite, graphitic pelite and grey crystalline metalimestone are seen below Urlamore at [NJ 1507 1998] and in crags east of the A 939 road at [NJ 1506 1967]. In the Campdalmore area, north-west of Tomintoul, the Inchrory Limestone Formation appears to be notably thick (*c.* 430 m), but where seen in the Creag Chalcaidh Lime Quarry [NJ 156 194], it contains numerous tight to isoclinal minor and medium-scale folds. The overall outcrop pattern also implies fold repetition and its true stratigraphical thickness is estimated to be closer to 150 m. The unit is composed of blue-grey, flaggy to massive, fine- to coarse-grained (typically 2 mm grain size), crystalline metalimestone, normally thinly to thickly bedded or banded. The finer grained variants are mid to dark grey, whereas the coarser grained metalimestones are pale bluish grey and commonly almost translucent. Laminae and thin interbeds of graphitic pelite are common and pyrite is also abundant. Minor thin siliceous, cherty bands are present locally in the metalimestone, and thicker calcareous semipelite interbeds are also seen. Calcite veining is common, and adjacent to faults the metalimestone is recrystallized. Good exposures are seen in the River Avon section at [NJ 1535 1917], where metalimestones with thin graphitic semipelite interbeds exhibit abundant tight F3 folding.

Dark-green amphibolite lenses and pods are seen in parts of the sequence, notably in the Inchrory Limestone Formation and the underlying Kylnadrochit Semipelite Member. They appear to cross-cut bedding locally but are strongly deformed and commonly boudinaged. They represent metadolerite or metabasalt intrusions and many show metamorphic reaction rims with the adjacent metalimestone. It is unclear as to whether they were intruded early in the geological history, possibly coeval with volcanic units in the Argyll Group, or whether they are linked to the Morven–Cabrach Pluton, which is mid Ordovician in age. A 0.5 to 1 metre-thick boudinaged sheet is seen in semipelites in the Allt na Cluaine at [NJ 1488 198] and amphibolite pods are abundant in the Inchrory Limestone Formation at [NJ 1529 1917] and at [NN 1506 1966]. Larger pods are seen on the north-west face of the Creag Chalcaidh Lime Quarry [NJ 1554 1944].

9.2.2 Structure

The distinctive lithologies in the Bridge of Avon area define a basic refolded F2–F3 fold pattern that is further complicated by the presence of late-stage steeply plunging open folds (F4) and the abundant faulting (Figure 6.17). The area lies close to the marked ‘knee-bend’ in the Dalradian succession, defined by the strike of bedding that swings from north-east around the Bridge of Avon and Bridge of Brown GCR sites to south-east farther south (see 1.2.2 in *Introduction*, (Figure 6.1) and Stephenson et al., 2013a, fig. 1). The vergence of the main folds changes from north-west to south-west respectively around this major structure.

The D1 structure is normally expressed as a bedding-parallel cleavage or schistosity, best seen in thin sections of the more-semipelitic or pelitic rocks. However, tight to isoclinal folds, invariably confined to individual beds or packages of beds, are seen locally, particularly in some of the metalimestone units. It is unclear whether they represent slump folding, convolute bedding or early tectonic deformation. Examples are seen in the Torulian Limestone Member and in the Inchrory Limestone Formation. Where differential weathering has occurred, such folds stand out in the metalimestones, but in quarries and in clean river sections the folds are more difficult to recognize, unless pelitic interbeds are present. In some clean-washed sections stylolites are preferentially seen, e.g. in the River Avon at [NJ 1573 1926] where they are folded. Early formed extensional slides are present in the sequence and a major south-easterly dipping slide does underlie the Bridge of Avon area at shallow depth. The metamorphic grade that accompanied D1 deformation is not known but was probably either greenschist or lower amphibolite facies.

The D2 deformation was penetrative and resulted in the generation of a widespread cleavage and tight folding on both small and medium scales. It was accompanied by middle amphibolite-facies metamorphism, and samples from pelites 1 to 2 km north-north-west of Bridge of Avon have yielded consistent pressure estimates of 8 to 8.5 kbar and temperature estimates of 620 to 650°C (Beddoe-Stephens, 1990). Minor folds are typically tight but vary from close to isoclinal. F2 fold axes plunge gently to moderately to the south-east and south-south-east, and their axial planes dip moderately to the south-east.

The D3 deformation has resulted in abundant medium- to small-scale folding and local generation of a penetrative or spaced S3 cleavage dependent on the intensity of deformation and lithology. F3 folds refold earlier D2 features but small-scale examples of fold interference structures are only rarely seen. Where the succession is thinly banded, F3 minor folds are abundant (Figure 6.19). F3 axes plunge gently to moderately to the south-east and south-west and fold axial planes mostly dip moderately to steeply to the south-east, although locally they do show considerable variation in orientation. The folds are typically asymmetrical and generally verge to the north-west and south-west. Accompanying metamorphism attained lower to middle amphibolite-facies conditions.

The D4 deformation was a relatively local event, manifested as steeply plunging medium-scale open folds that affect the outcrop pattern around Bridge of Avon and a late-stage steeply dipping crenulation cleavage in the Mortlach Graphitic Schist Formation. Such structures might reflect the unusual structural position of the area, which lies close to the northern termination of a fault system that extends southwards along the valley of the Avon to join the Loch Tay Fault. Alternatively they could reflect an earlier lineament, e.g. the NW-trending Lecht Lineament (Fettes *et al*., 1986) or the structural high that appears to have controlled sedimentation patterns in this area. The D4 structural event occurred under greenschist-facies conditions, possibly linked to retrogression of the earlier higher grade metamorphic assemblages.

Faulting is abundant in the Bridge of Avon area, which lies at the junction of the roughly N–S-trending fault system that tracks Glen Avon and the NW-trending Lecht Fault-system. The faults appear to be steeply dipping, commonly subvertical, and have associated localized brecciation and alteration. They are Early Devonian or later in age. There is no evidence that these late faults mimic or even reflect the earlier lineaments that controlled sedimentation.

9.3 Interpretation

The Dalradian rocks in the Bridge of Avon area show a condensed stratigraphical sequence. Most elements of the Ballachulish and Blair Atholl subgroup successions are represented but there seem to be gaps in the sequence. For example, it is clear that the Torulian Limestone Member overlies the Corriehabbie Quartzite Formation almost directly, whereas in adjacent areas some tens of metres of semipelite and micaceous psammite are present between the two units. As Appin Group units were deposited under shallow marine conditions and can be traced over much of the overall Dalradian outcrop, uniform conditions obviously prevailed over a wide area. Hence, in the Bridge of Avon area, deposition could be interpreted as having taken place over a basin high, albeit with some transitional lithologies being absent, and/or in part of the basin where sediment supply was deficient. The area lies close to the major strike swing of the Dalradian outcrop (the ‘knee bend’) that is now thought to reflect a lineament that stretched from Deeside to Dulnain Bridge and to have separated parts of the depositional basin. The localized occurrence of quartzites and metalimestones in the Lochaber Subgroup rocks some 5 km to the west and early-formed slides in the succession all suggest that structural activity occurred during and following deposition and that the basin geometry controlled the local patterns of sedimentation.

Deformation has been focussed on the Bridge of Avon area from early in the geological history. The presence of a slide, whose trace crops out just to the north-west, shows that early extensional movements occurred either during sedimentation of younger Dalradian rocks or early in the tectonic history of this area. The superimposition of F2 and F3 folds in this area has generated a kilometre-scale fold pattern that probably dates from the mid Ordovician and formed part of the Grampian Event of the Caledonian Orogeny. Minor fold orientations and vergence are variable, particularly for the F2 folds, but F2 and F3 vergence is mainly towards the north-west. The lower Ballachulish Subgroup units, the Mortlach Graphitic Schist and Corriehabbie Quartzite formations, form an anticlinal outcrop that closes both to the east and the west (a pericline). The major fold closures are defined by F2 anticlines and synclines with the F3 folds effectively corrugating the earlier pattern. The folding results from Grampian deformation of the thin, yet lithologically variable sequence, focussed on a pre-existing lineament. The major change in strike of the Dalradian succession that forms a ‘knee-bend’ just to the south of the Bridge of Avon area could also reflect the original basin geometry and presence of lineaments (Fettes *et al*., 1986).

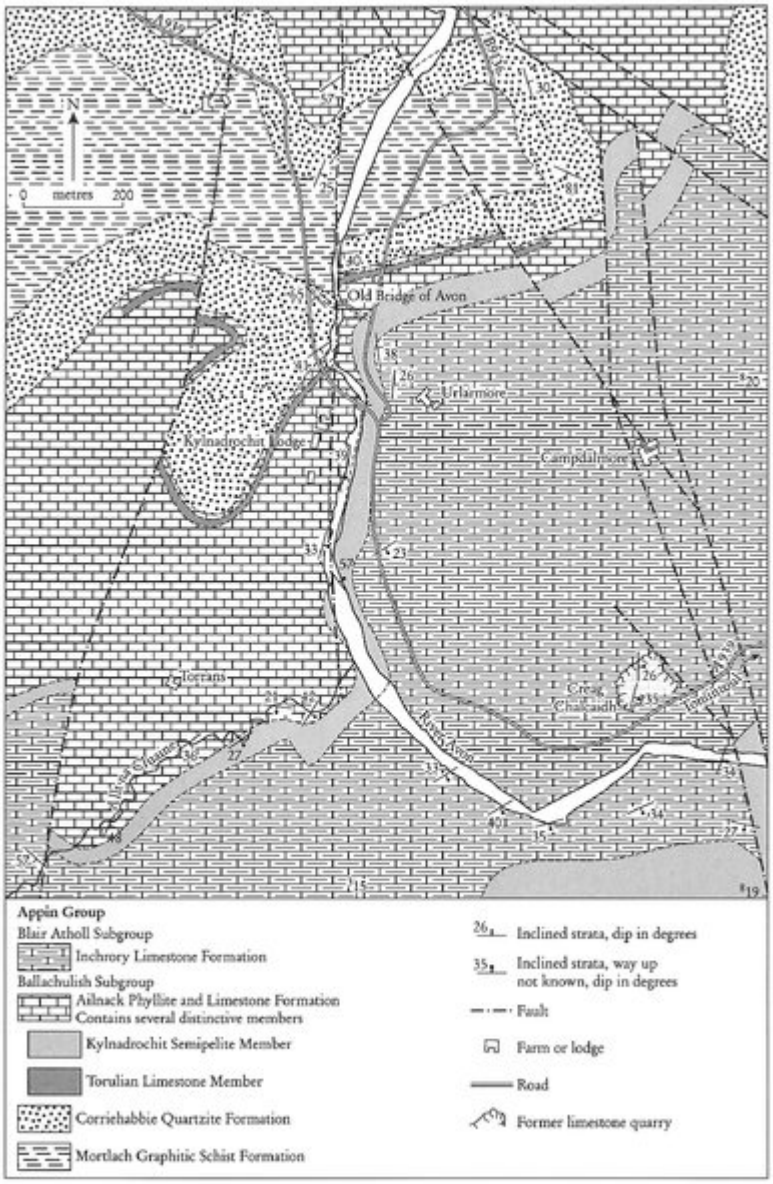
9.4 Conclusions

The Bridge of Avon GCR site provides an excellent stratigraphical cross-section through a condensed Appin Group succession that is interpreted as having formed on a high in the original offshore sedimentary basin. Although reduced in thickness, the characteristic lithologies of this Ballachulish and Blair Atholl subgroup sequence are still eminently recognizable and are representative of a large area of the North-east Grampian Highlands. The Ballachulish Subgroup comprises the Mortlach Graphitic Schist Formation, succeeded by the Corriehabbbie Quartzite Formation and the mixed Ailnack Phyllite and Limestone Formation. The overlying Blair Atholl Subgroup is represented in the site area only by the Inchrory Limestone Formation. These units represent alternating deeper and shallower water parts of the succession, providing a record of transgression and regression that is typical of many shallow marine sedimentary sequences.

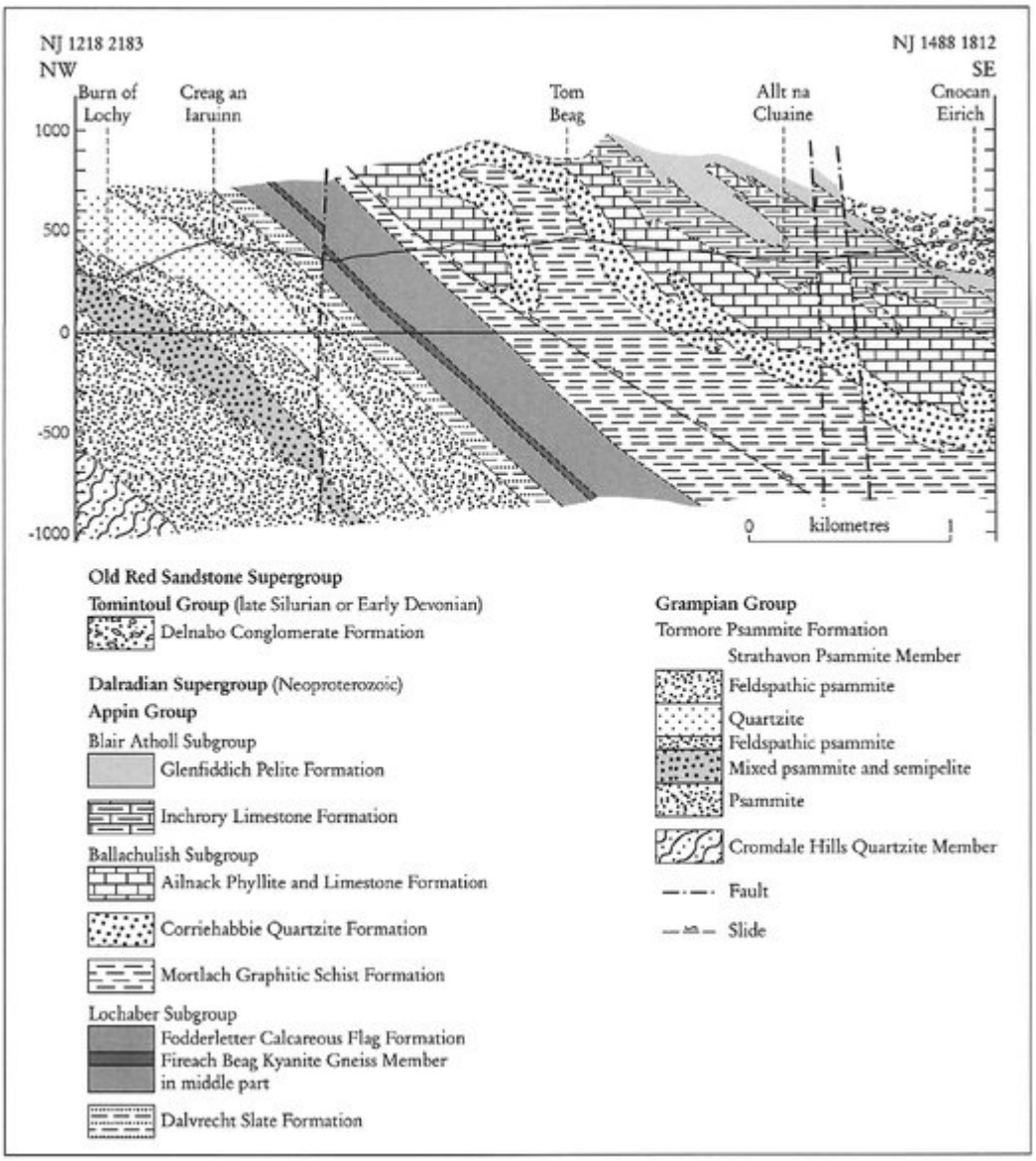
The sequence has undergone early tectonic sliding and subsequently has been deformed and metamorphosed under lower amphibolite-facies conditions during the Grampian orogenic event in the mid Ordovician. Although four phases of deformation can be recognized, only two main sets of folds and related cleavages are widely developed and they provide a good example of a kilometre-scale fold interference pattern. The overall geometry is of NW-verging folding and moderate to steep south-easterly dipping cleavages. However, the area lies close to a regional swing of strike (the so-called ‘knee-bend’) and change in fold vergence, with the fold structures in the rocks a few kilometres to the south generally verging to the south-west. The Bridge of Avon area forms a natural focal point in the Dalradian outcrop of the

North-east Grampian Highlands.

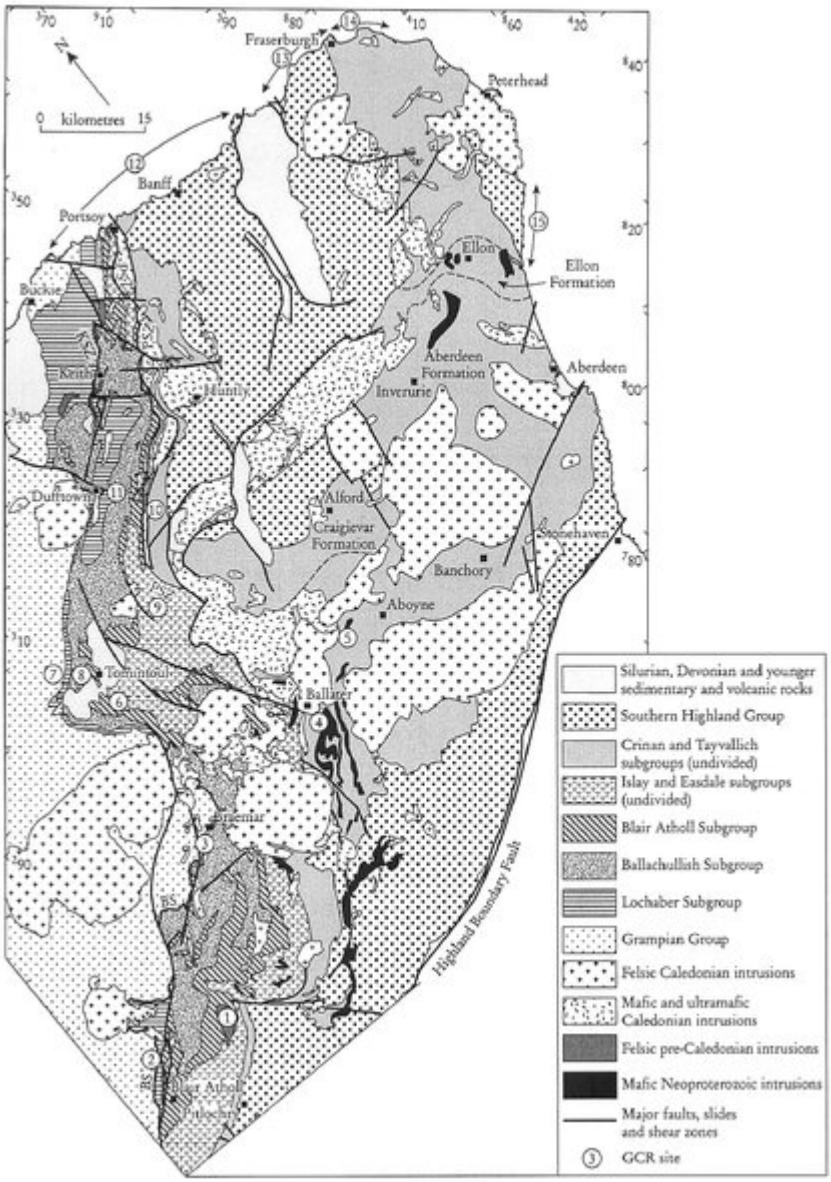
References



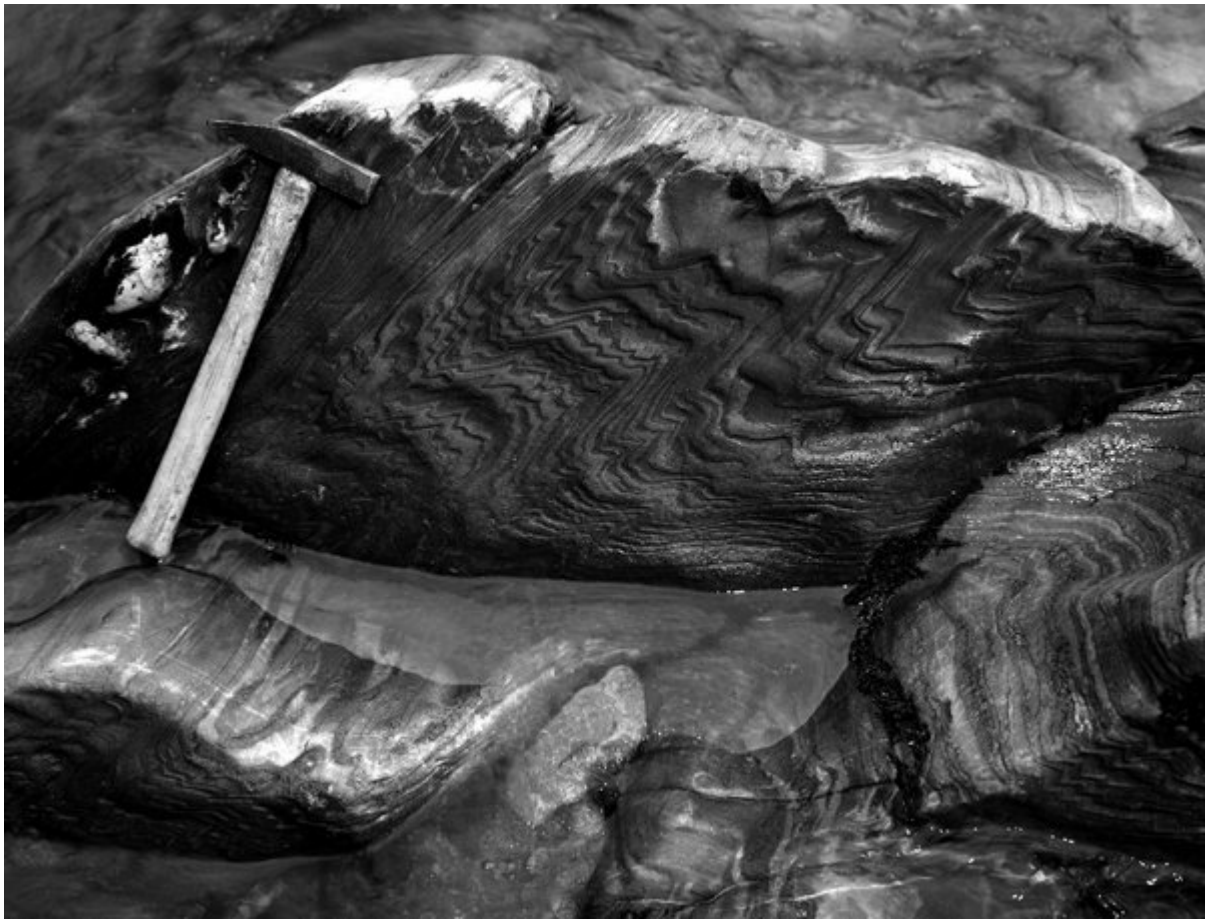
(Figure 6.18) Map of the area around the Bridge of Avon, based upon BGS 1:10 000 sheets NJ12SW (1991) and NJ12SE (1992) and on BGS 1:50 000 Sheet 75W (Glenlivet, 1996). The cross-section of (Figure 6.17) passes the south-west corner of this map.



(Figure 6.17) North-west–south-east cross-section across the area surrounding the Bridge of Brown and Bridge of Avon GCR sites. The line of section intersects (Figure 6.16) and passes to the south-west of (Figure 6.18).



(Figure 6.1) Map of the North-east Grampian Highlands based upon BGS 1:50 000-scale maps and showing the location of Dalradian GCR sites. GCR sites: 1 Ben Vuirich, 2 Gilbert's Bridge, Glen Tilt, 3 Glen Ey gorge, 4 Cairn Leuchan, 5 Balnacraig, Dinnet, 6 Muckle Fergie Burn, 7 Bridge of Brown, 8 Bridge of Avon, 9 Kymah Burn, 10 Black Water, 11 Auchindoun Castle, 12 Cullen to Troup Head, 13 Fraserburgh to Rosehearty, 14 Cairnbulg to St Combs, 15 Collieston to Whinnyfold. BS Boundary Slide, KSZ Keith Shear-zone, PSZ Portsoy Shear-zone.



(Figure 6.19) Asymmetrical minor F3 folds of thinly interbedded metalimestone, calcsilicate rock and calcareous semipelite of the Ailnack Phyllite and Limestone Formation at Bridge of Avon [NJ 150 201]. The folds show attenuated limbs and fold axes plunge at 25° to 152°. (Photo: BGS No. P 220186, reproduced with the permission of the Director, British Geological Survey, © NERC.)