23 Auchtertyre

[NN 354 291]–[NN 368 312]

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23.1 Introduction

The Auchtertyre GCR site, between Crianlarich and Tyndrum, contains the most extensive and most accessible exposures of stratabound sulphide mineralization in the Ben Challum Quartzite Formation, a unit of restricted distribution at the base of the Crinan Subgroup. Characteristic features of the quartzites are distinctive minor folds with strongly curving axes, which are restricted in this area to this particular formation.

The Tyndrum area occupies an important position for structural and stratigraphical correlations with adjacent regions. However, until the 1980s, the area had remained essentially unmapped since the original survey of Sheet 46 (Balquhidder, 1900) by B.N. Peach and others. It was the discovery of stratabound units of sulphide mineralization as part of the Mineral Reconnaissance Programme of the Geological Survey that provided the main incentive for renewed stratigraphical and structural study (Smith *et al*., 1984, 1988; Fortey and Smith, 1986; Hall, 1993).

The new mapping in the Auchtertyre area revealed a thick sequence dominated by feldspathic quartzites, between the Ben Lawers Schist Formation and the Ben Lui Schist Formation (Figure 3.54)a. This was named the Ben Challum Quartzite Formation and was considered to be equivalent to the Farragon Volcanic Formation at the top of the Easdale Subgroup, a unit of amphibolites and quartzites, which in upper Glen Lyon has a maximum thickness of 25 m. Subsequently it has been re-assigned to the Crinan Subgroup on sedimentological grounds, although it might merely reflect a diachronous facies variation and hence be broadly equivalent in time to the Farragon Formation. Scott (1987) showed that the Ben Challum Quartzite Formation forms a continuous mappable unit, which can be traced from the Tyndrum Fault to the Garabal Hill Fault, a total distance along strike of approximately 20 km. The formation is restricted to the area bounded by these faults. A maximum thickness of 500 m is likely but the formation thins towards the east and possibly also in the west, close to the Tyndrum Fault. With the exception of the Ben Challum Quartzite Formation, the Argyll Group stratigraphy of the Tyndrum area is identical to that in areas to the south-west and north-east (Roberts and Treagus, 1979; Nell, 1984).

The principal exposures of the formation occur at Auchtertyre, where river sections drain south-westward into Strath Fillan from the watershed with Glen Lyon and Glen Lochay to the north-east (Figure 3.54)a. Other than the river sections, most of the valley floors are filled with thick glacial till and moraine. Exposures also occur on the main peaks that form the watershed (e.g. Ben Challum, 1022 m, [NN 388 322]) but in general these are not as easily accessible or as informative as the river sections.

23.2 Description

The GCR site encompasses three main river sections through the Ben Challum Quartzite Formation (Figure 3.54)a: the Allt Gleann a' Chlachain, the Allt a' Chaol Ghlinne and, below the confluence of these two rivers, the Allt Auchtertyre. These rivers provide near continuous exposure through the entire formation at its thickest part.

The Ben Challum Quartzite Formation contains a variety of rock types but is dominated by well-bedded quartzites rich in plagioclase feldspar in the range albite-oligoclase. In some beds feldspar is more abundant than quartz (Scott *et al*., 1988). The rock is generally fine to medium grained, but locally contains coarser pebbly beds. Beds range in thickness up to 2 m but are usually less than 0.5 m; bedding is normally continuous with no internal cut-offs and lacks recognizable

way-up criteria. Individual beds are separated by micaeous layers (mainly muscovite) generally less than 10 mm thick. Rarely the rock as a whole becomes more pelitic and garnetiferous, and as such is then indistinguishable from the overlying Ben Lui Schist Formation. Conformable amphibolite units up to 2 m thick occur sporadically throughout the Ben Challum Quartzite Formation, and this contrasts with the Farragon Volcanic Formation, which is dominated by amphibolite. The fine-scale layering in some amphibolite units was clearly disrupted before the deformation described below. Several layers of calcareous semipelite up to 1 m thick form a minor component of the sequence (e.g. at [NN 3601 3057]), and minor occurrences of graphitic pelite occur in the lower part of the formation.

The Ben Challum Quartzite Formation contains two units of stratabound sulphide mineralization: the Auchtertyre Horizon and the overlying Ben Challum Horizon (Fortey and Smith, 1986; Smith *et al*., 1988; Scott *et al*., 1988, 1991). The weakly mineralized Auchtertyre Horizon is about 80 m thick in total; the best exposures are around the intersection of Allt Gleann a' Chlachain and the Allt a' Chaol Ghlinne [NN 3543 3023], and a further 100 m upstream in the Allt Gleann a' Chlachain (Figure 3.54)a. Mineralization occurs as bedding-parallel sulphide laminae, up to 10 mm thick, in which pyrite predominates over minor chalcopyrite and sphalerite, and leads to a characteristic rusty weathering of the host quartzites. There are substantial thicknesses of non-mineralized quartzite in the total thickness.

The Ben Challum Horizon is approximately 20–30 m thick at the type locality on Ben Challum [NN 387 322] to the north-east of the GCR site, and on Creag Bhocan [NN 315 280], to the west of Strath Fillan (Scott *et al*., 1988). It consists of layers of pyrite, chalcopyrite and sphalerite, up to 0.3 m thick, in chloritic schist and albitic quartzite. In the GCR site, the horizon is seen only as about 10 m of pyritized quartzite immediately below the top of the formation in the Allt Auchtertyre at [NN 3541 3013].

An enigmatic unit of ultramafic rock characterizes the boundary between the Ben Challum Quartzite Formation and the overlying Ben Lui Schist Formation. It can be traced intermittently across the Tyndrum area, but exposure of this part of the succession is poor in the Allt Auchtertyre; the unit is best exposed on the flanks of Ben Challum and on Creag Bhocan (Scott *et al*., 1988). The variable mineralogy of the unit is compatible with an igneous origin and a subsequent high degree of alteration. It generally contains a combination of chlorite, ankerite, talc, fuchsite (chromian muscovite), quartz and amphibole, with accessory chromium- and zinc-bearing spinel, thiospinel, pyrite, pyrrhotite, pentlandite and millerite (Scott, 1987). The exposures in the Allt Auchtertyre occur close to the railway bridge and include chloritic schist containing carbonate porphyroblasts over 50 mm in diameter.

Two principal phases of ductile deformation are recorded in the Ben Challum Quartzite Formation. The most striking feature of the quartzites is the presence of non-cylindrical minor folds with strongly curving axes, of which numerous examples can be observed at all stratigraphical levels (Scott, 1987). The best examples occur within well-bedded feldspathic quartzites in which individual beds have constant thickness and are separated by thin partings of mica schist (Figure 3.55). Non-cylindrical minor folds do not occur in any of the adjacent formations.

The non-cylindrical folds are generally tight and fold hinges become more curved with a decrease in interlimb angle; a number of morphological types are present (Scott, 1987). The overall range of orientation of the hinges approaches 180° (Figure 3.54)b and (Figure 3.55) so that many hinges pitch down the dip of the schistosity. The effect of this is that subparallel hinges within a few metres of each other face in opposite directions. Exposed folds range in amplitude from tens of centimetres to 3 metres, but reversals of vergence indicate that the largest fold amplitudes must be of the order of 10–20 m. The vergence of such reclined fold-pairs can be difficult to determine but, when 'restored' to a horizontal position, it can be ascertained that most fold-pairs, minor and major, verge to the south. Disharmonic folding affects sequences where there are marked differences in bed thickness and competence. In suitable pelitic lithologies a well-developed axial-planar crenulation schistosity is present. These folds affect the earlier bedding-parallel schistosity as well as, locally, a strong lineation of the quartz and feldspar fabric that is developed on that schistosity. Rarely, isoclinal folds of bedding are seen to pre-date the main fold set (Figure 3.56). No minor ductile structures post-dating the non-cylindrical folds were identified in the field, although several minor deformation phases have been identified elsewhere in the area (Scott, 1987).

A subvertical NNE-trending fault-system, named the Auchtertyre Fault, causes apparent sinistral displacement of the boundary between the Ben Challum Quartzite Formation and Ben Lui Schist Formation by as much as 800 m (Figure

3.54)a. The fault can be observed in the Allt Auchtertyre.

23.3 Interpretation

The presence of layers of stratabound sulphide has promoted investigation of the Ben Challum Quartzite, both for scientific reasons, and in terms of its resource potential (e.g. Smith *et al*., 1984, 1988; Fortey and Smith, 1986; Fisk, 1986; Scott, 1987; Scott *et al*., 1988, 1991). Although no economic mineral occurrences have been discovered, the presence of this mineralization is important scientifically for two main reasons: (1) the nature of the mineralization provides information on the tectonic setting of sediment deposition and the geometry of depocentres; (2) stratabound mineralization is formed by relatively short-lived hydrothermal exhalation events on the sea floor. Geographically widespread mineralized units of limited thickness can therefore be regarded as time-lines in a succession otherwise devoid of chronostratigraphical control. In the Tyndrum area, the mineralization indicates a broad consistency between chronostratigraphy and lithostratigraphy.

The sediments that formed the Argyll Group are generally considered to have been deposited in an actively extending basin (e.g. Anderton, 1982), and there are clear indications of synsedimentary faulting at a number of levels within the Argyll Group succession in the area surrounding Auchtertyre. The evidence comes from the nature and geometry of sediment packages, the distribution of stratabound mineralization, and the metal zonation within individual mineralized layers (Scott, 1987). The exact position and original orientation of the bounding faults is difficult to constrain because of the subsequent multiphase deformation history. However, all the evidence is consistent with a fault-bounded depression in the Tyndrum area that most probably had a half-graben geometry with the controlling fault on the north-west side. The presence of a fault-bounded basin is the principal reason why the Ben Challum Quartzite Formation accumulated only in this area, and why exhalative submarine brines were also ponded in the same depocentre.

Although the evidence for active extension during Argyll Group sedimentation is convincing, the tectonic setting in which it took place has been disputed, and has ranged from a marginal basin setting (e.g. Wright, 1976; Henderson and Robertson, 1982; Nell, 1984) to an intracontinental basin setting (e.g. Phillips *et al.* 1976; Harris *et al*., 1978). There are two principal strands of evidence from the Ben Challum Quartzite Formation that can be used to imply an arc-related marginal basin setting.

(1) A major change of sandstone provenance in the Dalradian succession appears to occur between the deposition of the Carn Mairg Quartzite and earlier formations, in which K-feldspar is the dominant feldspar, and the Ben Challum Quartzite and later formations, in which plagioclase is the dominant feldspar. It is no coincidence that this change occurs across an interval of the succession characterized by the onset of extension, stratabound mineralization and significant magmatism.

The albite-rich composition of the Ben Challum Quartzite Formation has led to speculation that the sequence may include keratophyre tuffs (Fortey and Smith, 1986; Fisk, 1986). No textural evidence now remains for a direct igneous origin but, considering the high plagioclase content, it does not seem unreasonable to conclude that the Ben Challum Quartzite Formation was derived by erosion of igneous rocks of silicic to intermediate composition, possibly with a direct volcanic input. A preliminary whole-rock geochemical study of psammites from the Ben Challum Quartzite Formation is consistent with a back-arc or continental margin arc setting (Scott, 1987).

The mineralogy of the apparently conformable ultramafic unit at the top of the Ben Challum Quartzite Formation is compatible with an igneous origin, and represents a more-intense state of alteration than serpentinization (Scott, 1987). The chemistry is also consistent with an origin as an igneous body, or as a sedimentary derivative, which was hydrothermally altered on, or close to, the seabed. More-definite conclusions about the unit’s origin are precluded by the degree of alteration, but the presence of ultramafic rocks is compatible with an extensional setting in a marginal, possibly back-arc basin.

(2) The base-metal content of the mineralized layers in the Ben Challum Quartzite Formation is indicative of volcanic-associated massive sulphide (VMS) deposits, an unsurprising interpretation considering the abundant evidence for magmatic activity in the host succession. The extreme length/thickness ratio of the mineralized units in the Ben Challum Quartzite Formation, and the absence of an Fe-Mn-oxide or baryte facies, suggests similarities with Besshi

deposits, a type of arc-related VMS deposit described from Japan (Scott *et al*., 1988, 1991).

The closely packed, non-cylindrical minor folds, with strongly curving hinges (Figure 3.55), occur in this area only in the Ben Challum Quartzite Formation. These folds refold an earlier set of fold hinges as well as the earliest (S1) schistosity and are associated with a tight crenulation cleavage and garnet growth. They can be clearly correlated with the main regional D2 deformation phase. The entire outcrop of the Ben Challum Quartzite Formation lies on the right-way-up limb shared by the F2 Dalmally Antiform to the south (Figure 3.54)a and the F2 Ra Creag Synform to the north (Roberts and Treagus, 1975). This is supported by the dominant southerly vergence sense of minor fold-pairs observable at the site. The axial-plane traces of the major folds trend ENE, and rocks on the shared limb generally dip at moderate angles to the south. The geometrical relationships between the isoclinal folds and mineral lineations that pre-date the dominant D2 set (Figure 3.56) are not clear, but both are interpreted to be of the regional D1 phase, and related to the regional major F1 fold, the Ardrishaig Anticline (Roberts and Treagus, 1975).

The origin of the non-cylindrical folds with curving axes is not entirely clear. Many other examples of such folds have been ascribed to their occurrence in zones of extreme strain; however, this does not appear to be the case at Auchtertyre. Here, two factors are considered to be important: (1) the mechanical properties of the quartzite; and (2) the position of the outcrop relative to major D2 structures (Scott, 1987).

The presence of competent quartzite beds separated by thin pelitic partings has led to pronounced strain partitioning as beds moved relative to each other during folding (Scott, 1987). Internally, the quartzite beds were not subjected to intense stretching; pebbly beds, for example, do not show any significant elongation of clasts, which commonly show only a weak flattening in the approximate plane of bedding. It is not uncommon to find S1 fabric elements preserved within quartzite beds. In contrast, pronounced mineral lineations formed by microboudinaged garnet crystals within the pelitic seams indicate high D2 strain. This interbed slip was promoted both by the continuous nature of the bedding and by the overall structural position on a major F2 fold limb. In this location, it can be assumed that the principal D2 elongation direction would lie close to the average plane of layering, thus enhancing the tendency for layer-parallel shear.

As folding progressed, the initiation of minor folds in individual quartzite beds was impeded by adjacent beds, from which they were separated by a minimal thickness of pelitic material. In a succession where interbed slip was likely, the presence of F2 buckles or existing F1 hinges would cause variations in cohesion and heterogeneous strain, thus providing a mechanism by which non-cylindrical hinges could develop. There is no evidence to suggest significant transection of axial planes by the schistosity associated with the folds, which elsewhere has been reported to be a feature of this style of folding (Treagus and Treagus, 1981).

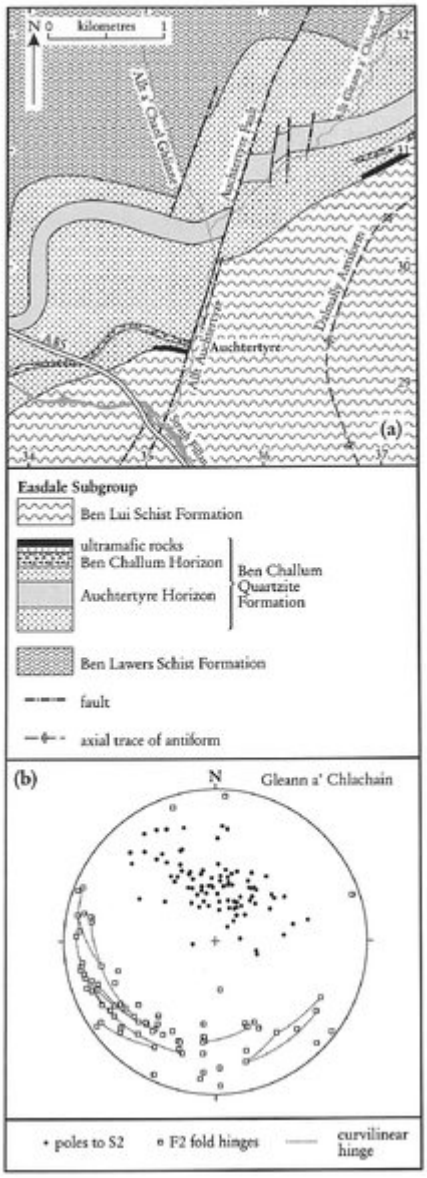
23.4 Conclusions

The Auchtertyre GCR site illustrates a style of stratabound sulphide mineralization that is unknown elsewhere in the Dalradian of Scotland. The mineralization occurs within the Ben Challum Quartzite Formation, a unit restricted to the Tyndrum area, which is important scientifically because of the insight it provides into the depositional settings of Argyll Group sediments. There is clear evidence that faults were active during deposition, that they acted as conduits for mineralizing fluids, and that they created the topography necessary to pond the fluids once they had been exhaled onto the sea bed. Contemporaneous magmatic activity provided the source of heat required to circulate the fluids through crustal rocks beneath the sea floor, where they were able to gather base metals such as copper and zinc. The chemistry and geometry of the mineralized units, combined with the mineralogy of their host sediments, suggest an island-arc-related tectonic setting.

An additional feature of the Ben Challum Quartzite Formation is the presence of well-exposed minor folds with exceptionally curved hinges, a feature found in this area only in this formation. The distinctive folds are thought to reflect the mechanical properties of the unusually well-bedded quartzites, which were able to slip relative to each other along intervening micaceous seams. The minor folds in the section also provide important information concerning the geometry of the major regional folds of the area.

This GCR site provides the only section through the entire Ben Challum Quartzite Formation and offers an excellent opportunity for further research into both stratabound mineralization and fold mechanisms.

References



(Figure 3.54) (a) Map of the Auchtertyre area. (b) Equal-area stereographic projection of poles to S2 planes and hinges of F2 folds (the range of plunge of folds with strongly curvilinear hinges is shown by the dashed lines). See text for explanation.

(Figure 3.55) Curvilinear F2 fold hinge in the Allt Gleann a' Chlachain, Auchtertyre GCR site. Hammer head is 15 cm long. (Photo: J.E. Treagus.)

(Figure 3.56) Refolded ?F1 folds in the Allt Gleann a' Chlachain, Auchtertyre GCR site. Pen is 13 cm long. (Photo: J.E. Treagus.)