Ben Hutig

[NC 540 652]

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Introduction

Ben Hutig (408 m) is the most north-westerly outpost of the Moine succession on the Scottish mainland, with the Moine Thrust Belt lying only about 1 km to the west. The basal units of the Moine succession form its western slopes, and the summit crags display excellent examples of highly flattened and elongated pebbles and of strongly rodded quartz veins. The bedrock consists of psammites, locally conglomeratic, and garnetiferous pelitic and semipelitic schists of the A' Mhoine Psammite Formation (Figure 6.5). All lithologies are cross-cut by prominent quartz veins. The lithologies form part of the Morar Group that to the west overlies Lewisianoid gneisses and mylonitic Moine and Lewisianoid rocks. The sequence is affected by two main phases of deformation and recumbent folding, termed 'D2' and 'D3'. The strongly elongate pebbles in the metaconglomerate units and the prominent quartz rodding developed in quartz veins both give rise to lineations that plunge east and relate to both the F2 and F3 folding. An earlier deformation phase, D1, produced a bedding-parallel fabric, but no large-scale D1 structures have been recognized. However, the upper greenschist-facies mineralogy which represents the peak metamorphic conditions attained in these rocks, is associated with D1. Recent Sm-Nd ages on garnets from the schistose pelite by Loch Vasgo (see Port Vasgo–Strathan Bay GCR site report, this chapter) and garnet and hornblende from the Ben Hope Sill amphibolites near Tongue, imply that this metamorphic event occurred between 830 Ma and 788 Ma (Strachan *et al.,* 2002b). Hence there is evidence for Neoproterozoic Knoydartian and later Ordovician and Silurian Caledonian tectonometamorphic events.

B.N. Peach and J. Horne first mapped the Ben Hutig area for the Geological Survey in 1884 and 1888. The rodded and folded quartz veins of Ben Hutig were first recognized by Peach and Horne (1907, p. 603), but subsequently were described and discussed in detail by Wilson (1953) in his paper on mullion and rodding structures in the Moine rocks of Sutherland. To explain the overall structural pattern, gentler eastern and southern slopes. They are underlain by dominantly feldspathic and siliceous psammites with interbedded meta-conglomerate and schistose, garnetiferous semipelite and pelite units of the A' Mhoine Psammite Formation (Figure 6.5). The psammites range from coarse-grained arkosic to fine- and medium-grained micaceous varieties. The metaconglomerates occur as individual beds and lenses that range from a few centimetres up to 2 m or even 3 m thick. They are poorly sorted beds with originally sub-rounded pebbles of quartz and, more rarely, quartz-feldspar in a feldspathic micaceous psammitic to quartzose matrix. The pebbles are now strongly deformed, ranging from highly prolate to oblate in shape. Good examples are seen in the area just southeast of the summit of Ben Hutig (Figure 6.6), and for some 700 m along the broad ridge north-west of the summit. Trough cross-bedding with prominent mud drapes is locally common in the psammites and bedding-foreset angles are exaggerated up to 90° in fold hinges. Locally, the psammites have a strong planar fabric and contain abundant phengitic muscovite.

Finely to coarsely striped, cream, dark-green and grey, felsic and mafic gneisses with ultramafic and amphibolitic mafic pods are exposed in a 150–300 m-wide zone below the western cliffs of Ben Hutig (Figure 6.5). These Lewisianoid gneisses are sheared in part, but only become locally mylonitic adjacent to their contacts with the overlying Moine sequence above and the mylonitic rocks below. These latter rocks form a thick unit of gently E-dipping 'Oystershell Rock' (Peach *et al.,* 1907). In their more-eastern outcrops their Moine heritage is locally seen, with garnetiferous semipelites and gritty psammites present, albeit strongly deformed.

The quartz veins in the Ben Hutig area occur predominantly in the pelitic units and the micaceous psammites of the Moine succession. They range from pods and lenticles up to some 60 cm thick, arranged parallel to bedding and the main S2 schistosity, to pervasive anastomosing veins, discordant to the bedding and S2. In the psammites, quartz veins are less abundant but are generally thicker, with veins up to 1.3 m thick (e.g. at [NC 5417 6541]). The veins are mostly of two distinct structural ages. The earlier veins either pre-date, or are synchronous with, the D2 deformation. They range from grey to white and show evidence of deformation during D2. The later prominent white veins are commonly discordant to the main S2 schistosity, but have been folded, lineated and recrystallized during the D3 deformation event. Hence they post-date D2 structures but pre-date the D3 event.

The rocks are affected by two main phases of deformation, D2 and D3. An earlier D1 event produced a bedding-parallel fabric and some quartz veining, probably coeval with the peak metamorphic conditions, which here attained upper-greenschist facies. D2 deformation produced both small- and large-scale, tight reclined folds with a gently E-plunging axial lineation and a pervasive, E-dipping, planar S2 fabric. D2 deformation was accompanied by greenschist-facies metamorphism. In the Ben Hutig area large-scale F2 folds, zones of platy psammite, and locally strong L2 lineations are all well seen. The lineations are coaxial with the fold axes and quartz rodding. In the crags 200–300 m east of the summit of Ben Hutig, a large-scale, upward-facing, tight F2 antiform is mapped. The structural pattern is dominated by a N-verging F2 fold pair, refolded by later F3 folding on the southern and eastern flanks of Ben Hutig. The deformed pebbles in the meta-conglomerate units are flattened in the S2 fabric and elongated along L2. In F2 fold hinge zones the pebbles are prolate but on the fold limbs they are generally oblate.

D3 produced open to tight asymmetrical folds that modified the pre-existing D1 + D2 structures. Immediately south and east of Ben Hutig summit, the S2 schistosity is folded and a penetrative S3 crenulation cleavage is locally developed. The F3 fold axes and related L3 lineations typically plunge gently to the north-east. The L2 lineation is commonly re-orientated into parallelism with L3. F3 folds vary in amplitude from a few centimetres to a few hundred metres.

The later, post-D2 quartz veins are prominently folded by F3 folds and exhibit a strong axial lineation (Figure 6.7). The quartz is strongly rodded but shows segregation within the fold profile into lenses and pods. All stages of this process, from minor necking of veins to complete segregation into pods, can be seen in the Ben Hutig area and for several kilometres to the east. They attest to the movement of quartz during D3 deformation from high-strain into low-strain areas. Care must be taken not to confuse the quartz vein structures with the deformed pebble beds that were deformed mainly during D2.

The mineral assemblages formed during the two greenschist-facies metamorphic events that accompanied the D1 and D2 deformations in the Ben Hutig area have been subjected to a pervasive late Caledonian retrogression at mid-to lower-greenschist facies (Read, 1931, 1934), probably related to the D3 event. Biotite and garnet have been altered extensively to chlorite, and new epidote, sericite and phengitic muscovite are widely developed.

Interpretation

The Moine psammites in the Ben Hutig area contain poorly sorted conglomeratic and gritty units, but cross-bedding is also locally well preserved. The psammites are interbedded with pelitic and semipelitic schists with few transitional lithologies. These metasedimentary rocks represent periods of rapid deposition of mature sands and pebble beds followed by periods of quieter mud and silt accumulation. They may have formed in a shallow-marine or possibly fluviatile environment. Holdsworth (1987, 1989a) suggested that the conglomerate units at Ben Hutig, in Strath Melness, and at Traigh an t-Srathain (Strathan Conglomerate see Port Vasgo-Strathan Bay GCR site report, this chapter) belong to the same basal Moine unit that has been repeated by folding and thrusting. However, lenticular conglomerate units apparently occur at several stratigraphical levels within the lower Morar Group succession in this area.

The key features of the Ben Hutig area are the excellent examples of conglomeratic beds, the quartz veins of two distinct ages, and the recognition of D2 and D3 deformation phases. In his detailed description and discussion, Wilson (1953) postulated that the rodding structures of Ben Hutig were related to SSW translation of the Moine rocks, unrelated to movements on the Moine Thrust. Wilson's interpretation of movement direction (tectonic transport) at right angles to the quartz rodding is no longer accepted. The historical interpretation of such structures and their kinematic significance are discussed in more detail in the Oykel Bridge GCR site report (this chapter). Wilson (1953) also failed to recognize the pebbly nature of the metaconglomerate on Ben Hutig, attributing all the quartz ellipsoids to segregation of quartz veins. Wood (1973) documented the conglomerate beds on Ben Hutig but implied that the structure and regional strain profile are simple. He recorded strongly prolate (constrictional) strain from measurements of the pebbles at seven localities, with a mean strain ellipsoid of X: Y: Z = 25: 1: 0.9. However, he failed to mention the quartz veining, and that the prolate strains occur generally in complex F2 hinge zones.

The finite strains obtained from the quartz pebble measurements result from the cumulative strain of three (D1 + D2 + D3) deformation events. D2 strain is dominant, but a number of unknown factors, such as the orientation of early strains, and the effects of refolding, make it very difficult to analyse the strain history. The overall shape of the finite strain ellipse changes from place to place within the area; moderately oblate (flattening) strains are recorded on F2 fold limbs, but elsewhere the finite strain is highly prolate. Note that finite strains are highly oblate in the deformed conglomerate at Strathan Bay, some 3.5 km to the east (Mendum, 1976; see Port Vasgo-Strathan Bay GCR site report, this chapter). The overall strain gradient increases downward towards the Moine Thrust in the west.

The quartz veining mainly occurred in two distinct phases; an early phase of segregation pods and veins synchronous with or perhaps post-dating D1; and a later more generally discordant phase that post-dates D2. Both types of vein are folded and lineated by the later D3 deformation. The lineation pattern in the psammites reflects both D2 and D3 phases of deformation, and the highly strained pebbles show clearly that this is the finite maximum extension direction. Segregation of the later quartz veins has occurred only during the D3 deformation. Hence, the prominent lineation developed in these later veins represents only the D3 deformation, but L3 generally lies sub-parallel to L2.

Holdsworth (1989a, 1990) proposed a model of overall W-directed, thrust-related, Caledonian deformation to explain the development of D2 and D3 structures in the Moine rocks of the Tongue-Ben Hutig area. He suggested that D1 was only manifest as a bedding-parallel fabric, but accompanied by upper-greenschist- to lower-amphibolite-facies metamorphism. Alsop and Holdsworth (1993) interpreted the later D3 folding as transient flow perturbations related to specific late-stage WNW-directed movements in the Moine Thrust Belt immediately to the west. Alsop and Holdsworth (2002) further refined this interpretation to suggest that the fold pattern represents a kilometre-scale F3 anti-formal culmination with variations in minor fold vergence, facing, axial-plane and fold-axis orientation, all compatible with a large sheath-fold structure.

Structures related to two distinct deformation events are readily recognized on Ben Hutig, and the accompanying metamorphic events differ in grade. Hence, it seems probable that the D2 and D3 events are discrete and may be separated by a considerable time-period. This would effectively preclude them being parts of a single period of westward translation. Correlation of deformation events along the orogen is problematic and the age of D2 in Sutherland is not fully known. Strachan *et al.* (2002b) have shown that the 51 fabric and related peak metamorphic minerals formed between 830 Ma and 788 Ma. However, the D2 event in the Ben Hutig area is likely to be of Caledonian age, but it is currently unclear as to whether it is a mainly Grampian Event, as reported from the migmatitic rocks of the Naver and Swordly nappes to the east (Kinny *et al.,* 1999), or whether it is a Scandian Event. Dallmeyer *et al.* (2001) obtained a range of ^{40}Ar-^{39}Ar muscovite and hornblende ages and Rb-Sr muscovite ages from across the Moine succession in Sutherland. The ages ranged from 440 Ma to 410 Ma and were interpreted to show that the dominant deformation event in the A' Mhoine Nappe was of Scandian age, linked to movements on the Moine Thrust Belt (see also Strachan *et* al., 2002a). Older ages of 450–490 Ma were obtained from muscovites in Moine rocks from the A' Mhoine peninsula, particularly from localities close to the Moine Thrust Belt. These muscovites are more phengitic (i.e. with higher Si and Mg content), and their corresponding Rb-Sr ages gave more-coherent values of around 420 Ma. The older ^{40}Ar-^{39}Ar ages were deemed anomalous due to excess radiogenic Ar.

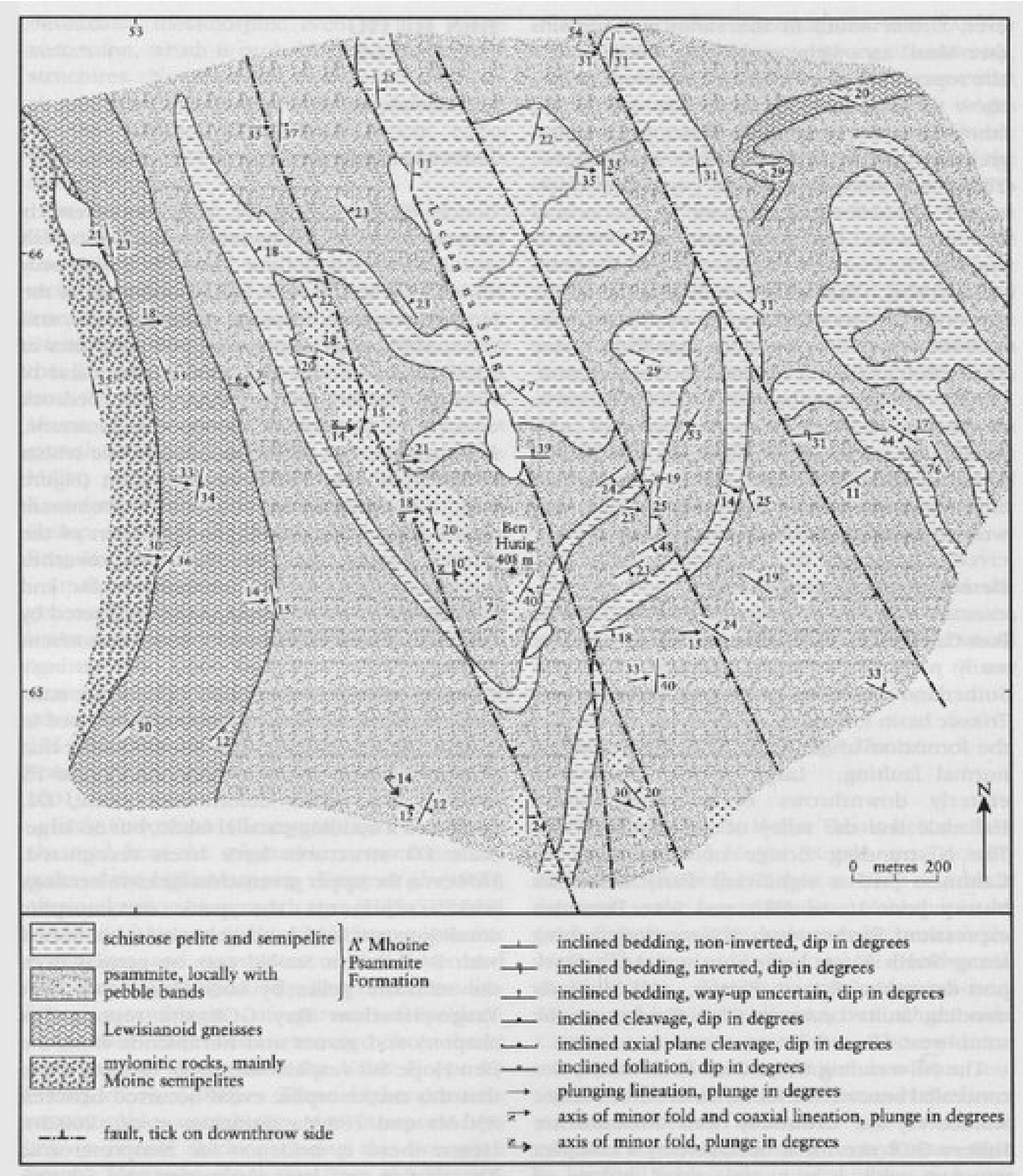
Conclusions

The Ben Hutig area is underlain mainly by Moine psammites, with some metaconglomerate lenses and pelitic and semipelitic schist units. The rocks lie in the lowermost part of the Moine Thrust Sheet in the A' Mhoine Nappe and form part of the basal unit of the Moine succession, the A' Mhoine Psammite Formation; inliers of the basement Lewisianoid gneiss occur nearby. Excellent examples of strongly elongated and highly strained quartz and quartzite pebbles are seen in metaconglomerate beds. Quartz veins, now tightly folded, stretched and locally even refolded, are common throughout the succession. The pebbles and the quartz veins serve as excellent strain markers. The overall strain, the majority of which relates to the D2 deformation, has resulted in prolate (cigar-shaped) and locally oblate (pancake-shaped) pebbles in the metaconglomerates, and strongly stretched, folded and lineated, quartz veins and pods. These veins and pebbly beds have been the subject of discussion regarding mechanisms of deformation and tectonic transport directions in the

Moine succession for many years.

The proximity to the Moine Thrust Belt allows us to compare deformation, folding and metamorphic patterns within the Moine Nappe and the nearby thrust belt. The deformed pebbles have been used to determine the overall strains in the basal Moine metasedimentary units, and the folded, lineated and segregated quartz veins have provided an insight into the metamorphic and segregation processes accompanying deformation. The Ben Hutig area is one of national importance, and is of considerable teaching value. It remains an area suitable for further research.

[References](#)



(Figure 6.5) Geological map of the Ben Hutig area.

(Figure 6.6) Rodded, flattened and locally folded pebbles in conglomeratic psammites of the R. Mhoine Psammite Formation, Ben Hutig, 40 m south-east of summit. The hammer is 37 cm long. (Photo: J.R. Mendum, BGS No. P552316, reproduced with the permission of the Director, British Geological Survey, © NERC.)

(Figure 6.7) Rodded, folded and segregated, originally discordant quartz veins in pebbly and gritty psammites of the A' Mhoine Psammite Formation. Ben Hutig, 100 m south-west of the summit. The hammer is 37 cm long. (Photo: J.R. Mendum, BGS No. P552315, reproduced with the permission of the Director, British Geological Survey, © NERC.)