Cnoc An Fhithich (Aird Grèin), Barra

[NF 658 045]

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Introduction

The Cnoc an Fhithich GCR site lies on the Aird Grèin peninsula in north-west Barra and is notable for its stunning examples of pseudotachylite veins and breccias. Although the rocks lie structurally below the Outer Hebrides Fault Zone (OHFZ) in Laxfordian felsic and mafic gneisses, they show features more typical of those found within the fault zone itself. The black to pale-grey, 'cherty' pseudotachylite veins and irregular pods represent the melt formed by frictional heating of the relatively dry gneisses during seismic movements. They appear to lie in a diffuse, moderately ENE-dipping zone discordant to the regional gneissose foliation and may be of Grenvillian (*c.* 1100–1000 Ma) or Caledonian (*c.* 470–425 Ma) age. These fault rocks and others within the OHFZ have provided a focus for studies of the mechanisms of earthquake generation and for models of the nature of faulting at different crustal levels (see 'Introduction', this chapter).

The host Lewisian gneisses on Aird Grèin are coarsely banded, partially migmatitic, felsic and subsidiary mafic gneisses that have been strongly reworked during the Laxfordian event. They contain irregular amphibolitic mafic pods and lenses that probably originated as members of the 'Older Basic' and 'Younger Basic' suites. The migmatitic aspect of the gneisses may relate partly to their earlier Scourian history, but undoubtedly has been enhanced by coarse recrystallization under amphibolite-facies conditions during the Laxfordian event. The gneissose banding has an overall moderate dip to the NNE.

Pseudotachylite breccia occurs widely along the trace of the Outer Hebrides Thrust, a marked feature that defines the base of the OHFZ in the Uists and Eriskay. In Barra pseudotachylite characterizes a major thrust zone that can be traced west from the islands of Fuiay and Flodday to Loch Ob and Beinn Bheireasaigh [NF 684 027]. From here it turns south down the central hilly spine of Barra to Sheabhal (Heaval) and Castlebay (see (Figure 2.28)). There is some doubt as to whether this thrust represents the OHFZ, or whether a more-significant part of the fault zone occurs offshore to the east in the Sea of the Hebrides, which seems more probable (Fettes *et al.,* 1992).

Throughout the Outer Hebrides pseudotachylite veins and breccias are commonly seen structurally below and to the west of the OHFZ (e.g. see Cnoca Breac GCR site report, this chapter). In most instances they have caused only minor disruption to the gneissose banding and represent small amounts of seismic fault movement. In Barra occurrences are found on Beinn Mhartainn [NF 664 021], in Bàga Thalaman (Halaman Bay), and on Ben Tangabhal in the south.

Although MacCulloch (1819) made the first mapped out the general distribution of fault reference to 'trap-shotten' gneiss in the Outer rocks on Barra and subsequently delineated the Hebrides, it was Jehu and Craig (1923) who OHFZ on the Uists and on Lewis and Harris (Jehu and Craig, 1925, 1926, 1927, 1934). In Barra, they recognized the presence of pseudotachylite, described its petrographical nature, and correctly ascribed its origin to melting of the country rock due to intense frictional heating caused by fault movement. Hopgood (1964) and Francis (1969) later carried out mapping as part of PhD studies on Barra, and defined most of the detailed occurrences of pseudotachylite. Bowes and Hopgood (1969) reported that pseudotachylite networks in Mingulay Bay are overprinted by the Laxfordian S3 foliation, but subsequent work by the Geological Survey showed that the fault rocks post-date all the Laxfordian deformation and granite intrusion (Fettes *et al.,* 1992).

Description

The hill of Cnoc an Fhithich forms the highest part of the broad rounded 'hogsback' of the Aird Grèin peninsula and rises to 96 m above OD. It is formed of glaciated, clean, periodically 'sandblasted' exposures, separated by grassy sandy depressions. Much of the site area is now a golf course belonging to the Barra Golf Club.

The Lewisian rocks are grey to buff and pink and white, banded, biotite- and hornblende-bearing felsic gneisses, with subsidiary dark green-black amphibolite bands and pods. Quartz-feldspar pegmatite patches up to a few metres across are moderately common. The rocks have a relatively crude banding and are coarsely recrystallized in parts. The banding and coincident foliation have a regionally consistent dip of *c.* 30° to the NNE. Several WNW- to NW-trending Palaeogene basalt and dolerite dykes, ranging from 1 m to 2.5 m thick, have been eroded into subvertical clefts on the coastal section, and are marked by grassy gullies inland.

The pseudotachylite is a black to charcoal grey, ultra-fine-grained rock that resembles its glassy basaltic namesake (tachylite). Jehu and Craig (1923) and Sibson (1975, 1977b) have reported relict glass from thin-section studies, but in almost all instances the glass is now devitrified (see Fettes *et al.,* 1992). It is commonly weathered or altered to a pale-grey colour. On Aird Grèin, pseudotachylite occurs in millimetre- to centimetre-thick veins and in irregular patches and masses that in places reach up to about 1 m thick. The veins range from planar to irregular, lensoid and bifurcate, and commonly have splays and offshoots. In parts they cross-cut one another and form intersecting networks. Pseudotachylite is commonly very closely jointed, and where planar vein surfaces are exposed, a fine tessellate jointing pattern is commonly seen. Pseudotachylite veins can be related to low- to moderate-angle dislocations and in many instances distinct offsets of the gneissose banding are visible. These dislocation surfaces range from low-angle thrusts to steeper reverse and normal faults.

A characteristic example of a pseudotachylite 'breccia' is seen at [NF 6596 0419], where a fault plane dipping moderately to the north-west bounds the main development of pseudotachylite, which is concentrated in the hanging-wall. The gneiss is broken and disorientated to varying degrees, with a more-competent quartz-feldspar pegmatite apparently focusing movement along its margins. The pseudotachylite vein network is probably the result of several small seismic events. Discontinuous planar pseudotachylite veins cut the complex in its upper part and also occur in the footwall gneisses. A smaller-scale example is illustrated in (Figure 2.29). Here the generation plane is near-horizontal, but melt has migrated into the foot-wall; net-veining and 'arrested' stages in the development of a 'breccia' or 'conglomerate' can be seen. Although pseudotachylite normally can be related to a specific surface, the main concentrations tend to occur in the adjacent gneisses, reflecting the near-instantaneous melt migration into adjacent fractures. This process can occur to the extent that the gneiss merely forms abundant inclusions in a pseudotachylite 'matrix'. The resultant rock-type, a pseudotachylite breccia or 'conglomerate', typically contains rounded gneiss fragments as well as pre-existing pseudotachylite (Figure 2.29)b.

In thin section pseudotachylite is a black or brown isotropic devitrified glass with the colour reflecting the included, very finely divided, opaque minerals. In some of the thicker veins radiating millimetre-size feldspar microlites are present. Quartz and feldspar porphyroclasts are very abundant where the pseudotachylite has formed from quartzofeldspathic gneiss. The quartz inclusions are typically angular with some showing corroded margins. Internally they have strain shadows and commonly show a network of fine cracks defined in part by opaque dust. In contrast, the feldspars are rounded to angular with diffuse margins, but irregular twinning, internal fracturing and strain shadows are common. Hornblende and biotite are normally consumed by the melting, with wall-rock crystals showing ragged edges. Jehu and Craig (1923) gave admirable descriptions of these phenomena. Some specimens show fine flow-banding textures in thin section and many show evidence of different generations of pseudotachylite. In addition, what appears to be wholly pseudotachylite is commonly an admixture of isotropic material and fine-grained cataclasite and ultracataclasite. Cataclasite is a cohesive, micro-crystalline, crush breccia with fragments mostly too small to be seen with the naked eye (< 0.2 mm across).

Interpretation

The Lewisian gneisses in the Cnoc an Fhithich GCR site area have been strongly recrystallized and have a pervasive Laxfordian planar fabric attributed to the combined $D2_L$ and $D3_L$ structural and related metamorphic events. The gneissose banding is somewhat diffuse, with few detailed Archaean features preserved. Zones of granitoid material and pegmatitic patches are common and the mafic bodies are all thoroughly amphibolitic and foliated.

The pseudotachylite occurs in a diffuse zone that represents multiple, small-scale seismic faulting in the Lewisian gneisses of north-west Barra. This zone can be linked to occurrences of pseudotachylite farther south in Baga Thàlaman (Halaman Bay) and on Ben Tangabhal where discrete thrusts have been mapped (see (Figure 2.28)). The occurrences together constitute an ESE-dipping zone that mimics the main thrust outcrop on Barra and may well represent a structurally lower part of the OHFZ. The age of faulting and pseudotachylite generation is not known, but is probably Grenvillian (*c.* 1100–1000 Ma) or Caledonian (*c.* 470–425 Ma) (see Fettes *et al.,* 1992; Imber *et al.,* 2001).

Jehu and Craig (1923) correctly interpreted pseudotachylite to be a product of frictional melting on fault planes during seismic movement, based on the features seen in the rocks on Barra. Later work by Sibson (1975, 1977b), mainly in the Uists and on Lewis, documented the nature of the pseudotachylite and its relationship to other fault rocks (see Fettes *et al.,* 1992; and 'Introduction', this chapter). It is clear from theoretical studies that the time frame for the generation of frictional melts during seismic movement and their cooling time are very small, normally only a few minutes in total (e.g. McKenzie and Brune, 1972; Sibson, 1977a). The fluid pressure of the melt, and brief but extreme temperature gradient, enable the melt to penetrate fractures or exploit inherent weaknesses in the rocks adjacent to the generation surface. Hence the melt may inject upwards, downwards, or sidewards, giving rise to lensoid and irregular masses of pseudotachylite. Blocks surrounded by the melt tend to be corroded and rotated, and Sibson (1975) documented examples from the Outer Hebrides. He suggested that with continued melt development the sudden heating would overpressure fluid inclusions in the gneiss blocks and consequently explosive decrepitation would occur in their marginal parts. Such effects would be maximized at their corners and hence the blocks or fragments would become rounded, resulting in a pseudotachylite 'conglomerate'. Sibson (1975) showed that such a process was geologically feasible and also documented relationships between amounts of fault movement and thicknesses of pseudotachylite generated. He noted that the zones of pseudotachylite, once formed, are stronger than the surrounding gneisses, and hence further fault movements occur adjacent to existing concentrations. The end results are wide zones of pseudotachylite net-vein and breccia development such as that seen at Cnoc an Fhithich (e.g. (Figure 2.29)b.

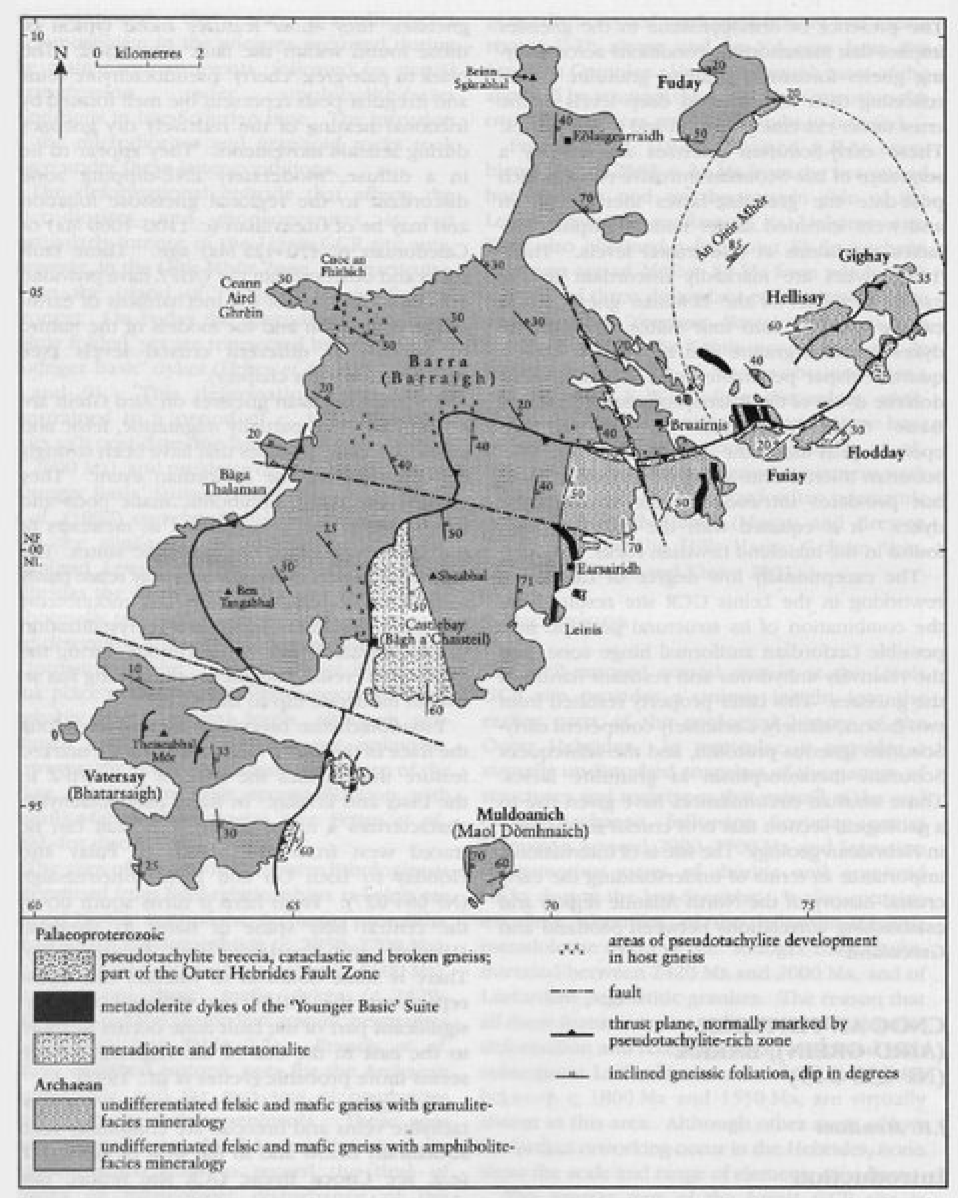
Sibson (1975) also postulated that the pressure (P) and temperature (T) conditions that prevailed at the time of seismic faulting were less than 3 kbar and 300° C respectively. Such values are typical of brittle fracture conditions above the frictional-viscous (brittle-ductile) transition that normally lies between 10 km and 15 km depth in the crust. He suggested that the P-T conditions at the time of pseudotachylite formation in the Outer Hebrides were compatible with crustal depths between 2 km and 10 km. Sibson (1977a) erected a fault-zone model based on his work in the OHFZ that envisaged frictional movement occurring at shallow crustal levels, coeval with ductile movement at mid- to lower crustal levels. However, Imber *et al.* (2001) have rejected the Sibson–Scholz model based on their more-recent work on the OHFZ (see 'Tectonic history of the Outer Hebrides Fault Zone' in the 'Introduction' to this chapter).

Conclusions

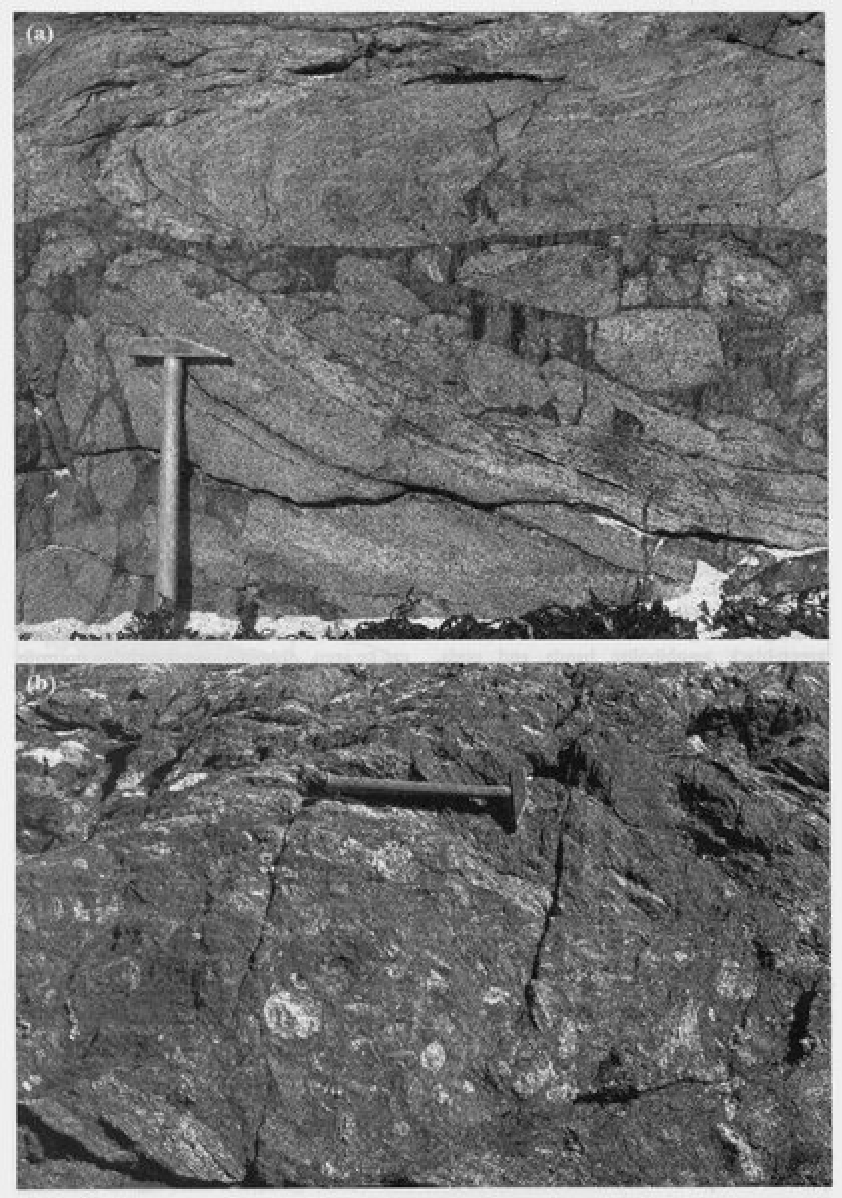
The Cnoc an Fhithich GCR site provides excellent examples of pseudotachylite vein and breccia development. Pseudotachylite represents frictional melts of the country rock formed by fault movements. The resultant melted rock solidifies very rapidly as a glass but devitrification normally occurs rapidly so that the rock is now a pale- to dark-grey and black, apparently cherty material. The complex geometry of these veins and lenses and their interaction with pre-existing features of the Laxfordian felsic and mafic gneisses are beautifully exposed on clean, etched crags and gently sloping surfaces within the site area. The pseudotachylite was generated on relatively planar fault surfaces but has migrated into the adjacent gneisses, so that offshoots, pods, lenses, breccias, and even pseudoconglomerates are common. Displacements across the fault surfaces range from a few centimetres to a few metres.

The zone of pseudotachylite development at Cnoc an Fhithich lies structurally below the Outer Hebrides Fault Zone (OHFZ) and forms part of an embryo thrust zone in western Barra. It represents one of the main types of fault rock seen in the OHFZ and may be of Grenvillian (1100–1000 Ma) or Caledonian (*c.* 470–425 Ma) age. These occurrences have been a prime area of study since Jehu and Craig (1923) first recognized the true frictional melt origin of the material. The site is very valuable for educational purposes and of national and even international importance.

References



(Figure 2.28) Simplified geological map of Barra showing Cnoc an Fhithich and other features related to the Outer Hebrides Fault Zone. Based on 1:100 000 geological map, Institute of Geological Sciences (1981).



(Figure 2.29) Cnoc an Fhithich. (a) Pseudotachylite veining in Lewisian gneisses on the south side of Aird Grein at [NF 6582 0402]. The hammer is 42 cm long. (Photo: British Geological Survey, No. P008346, reproduced with the permission of the Director, British Geological Survey, © NERC.). (b) Pseudotachylite breccia showing rounded and angular clasts and patchy development of pseudotachylite on Aird Grein. The hammer is 37 cm long. (Photo: J.R. Mendum.)