A field guide to the Glenelg-Attadale Inlier, NW Scotland, with emphasis on the Precambrian high-pressure metamorphic history and subsequent retrogression

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Synopsis

The Glenelg-Attadale Inlier contains Proterozoic eclogites and Late Archaean mafic high-pressure granulites. Eclogites were formed both in the Palaeoproterozoic (around 1.75 Ga) and the Mesoproterozoic (around 1.1 Ga). The inlier is the only place in the British Isles that contains significant and unequivocal crustal eclogites and furthermore is one of the few places that retains clear evidence of having been strongly affected by the *c*. 1.1–1.0 Ga Grenvillian orogeny. The excursions provide an opportunity to study these rare rocks and gain insight into how they formed and how they were exhumed back to the surface.

Introduction

The Glenelg-Attadale Inlier (GAI), in the Northwest Highlands of Scotland, occurs within Neoproterozoic Moine Supergroup metasediments. The GAI can be divided into a Western Unit (WU) and an Eastern Unit (EU), separated by a ductile shear zone, the Barnhill Shear Zone (BSZ) (Fig. 1). The WU contains solely Late Archaean orthogneisses of tonalite–trondhjemite–granodiorite (TTG) affinity along with minor mafic

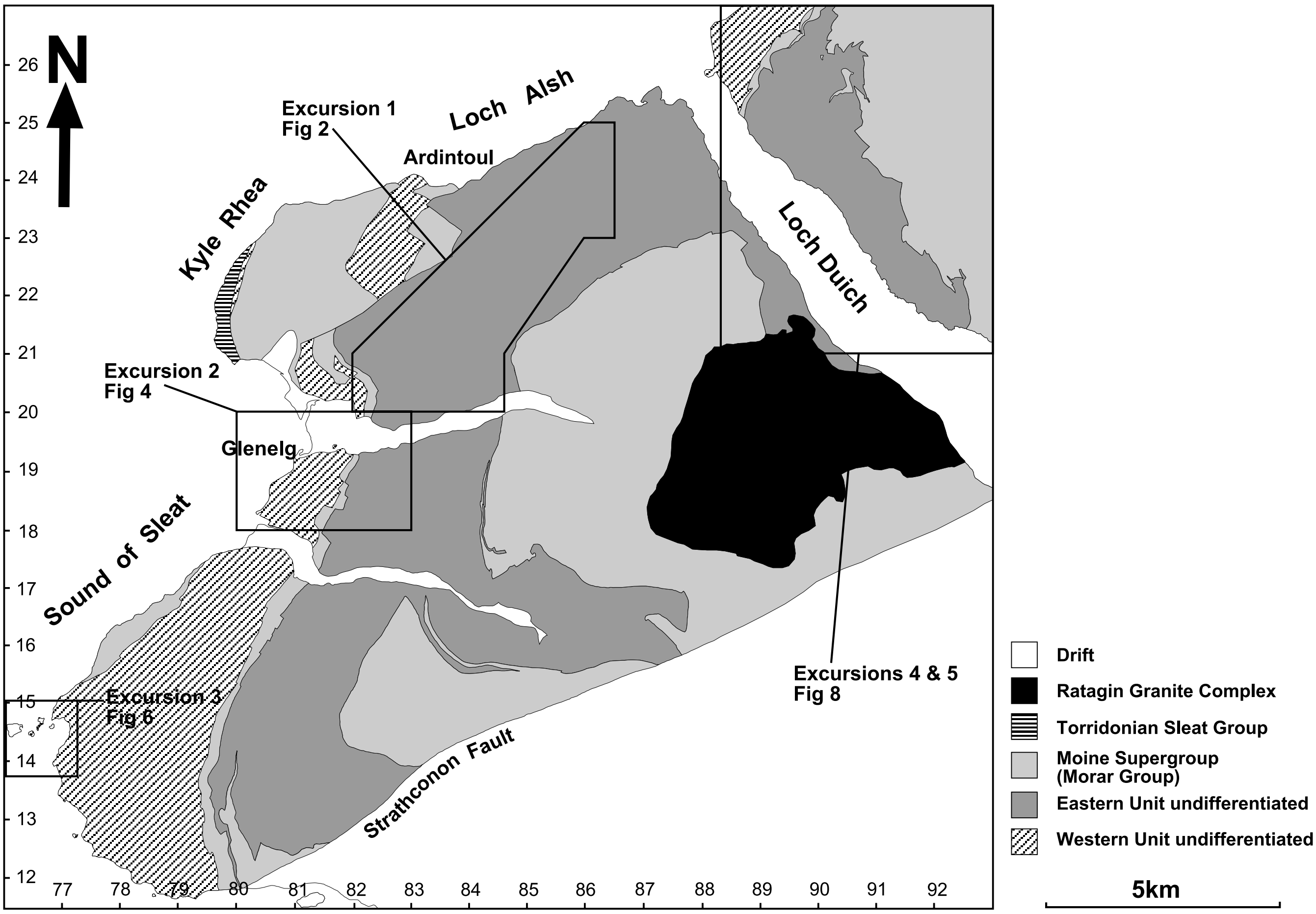


Fig. 1. Generalized geological map of the Glenelg-Attadale Inlier with locations of excursions 1 to 5 marked.

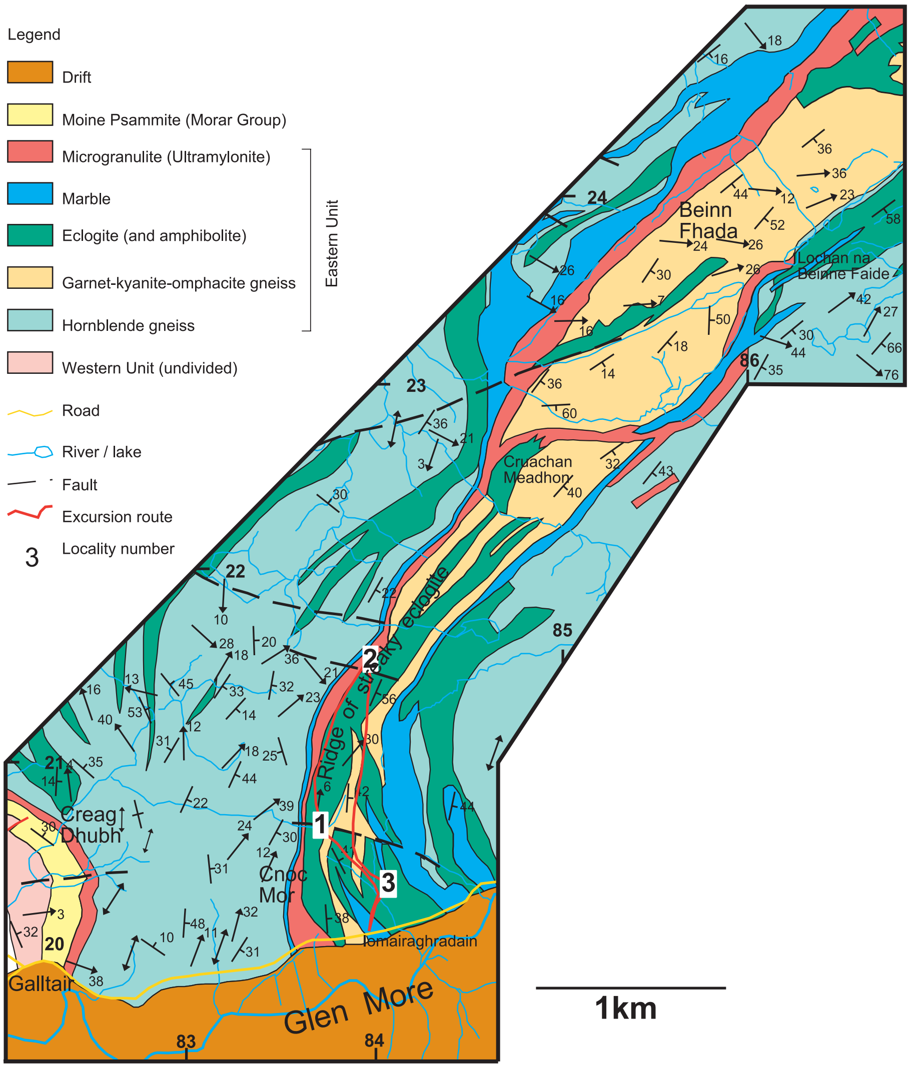


FIG. 2. Geological map north of Glenmore covering Excursion 1 (modified from Sutton & Watson 1959, plate 9).

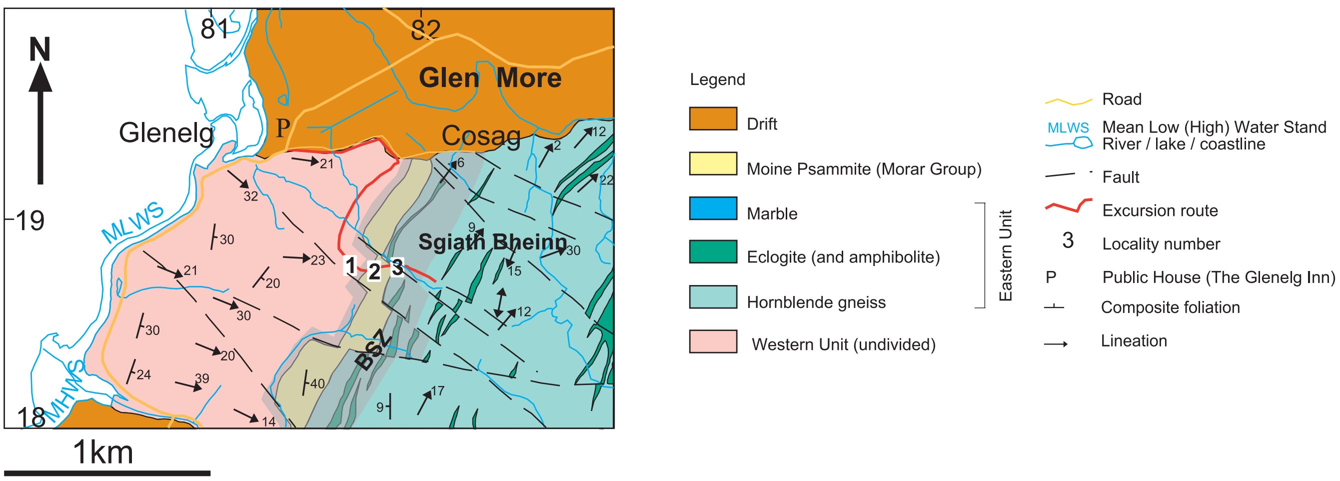
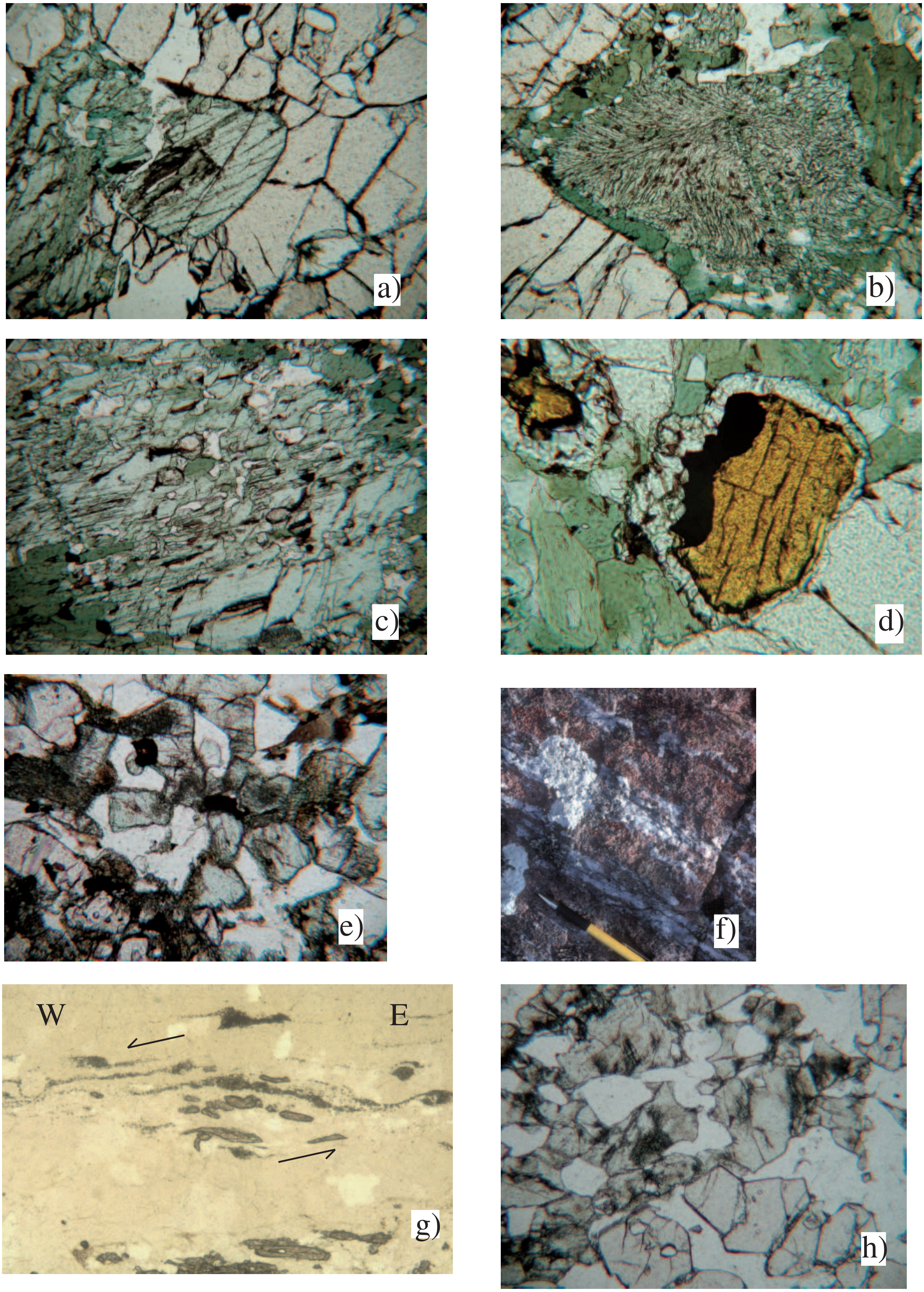


FIG. 3. Geological map south of Glenmore covering Excursion 2 (modified from Ramsay 1958, plates 37 and 38).

intrusions and subordinate ultramafic pods. In contrast, the EU contains Late Archaean TTG gneisses and a preponderance of eclogite (up to *c.* 25% of the outcrop) along with metasediments that include aluminous, calcareous and manganiferous metapelites, marbles and Mn-rich ironstones (eulysites). The WU contains Late Archaean mafic high-pressure granulite along with trondhjemitic leucosome and also, in one limited area, Palaeoproterozoic eclogite (*c.* 1.75 Ga). The EU, however, contains eclogite formed in the *c.* 1.1–1.0 Ga Grenvillian orogeny and other lithologies that display evidence of having undergone cofaciel metamorphism at that time, such as garnet websterite, omphacite–garnet–kyanite–oligoclase gneiss and phengite–garnet–kyanite–


a)
b)
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biotite gneiss. Hence, the GAI offers insight into high-pressure metamorphism within the Late Archaean, Palaeoproterozoic and Mesoproterozoic, and also within a range of lithologies, and is a useful natural laboratory.

This field guide includes localities that will give insight into a broad range of the issues concerning the development of the GAI. It is split into five excursions: Excursion 1 can be covered in one full day, whereas excursions 2 to 5 can be covered in half-day visits. The locations of the excursions are marked on Figure 1.

In Excursion 1, localities have been carefully selected that will afford the best coverage of the range of EU lithologies present and their metamorphic and structural evolution, with particular emphasis on the high-pressure (eclogite facies) metamorphism.

Excursion 2 will enable insight into the relationship between the WU and EU and the intervening strip of Neoproterozoic Moine rocks that is usually present.

Excursion 3 will enable insight into eclogite facies metamorphism in the WU, the nature of the contact between the WU and the Moine, and also D_2–D_4 shearing events.

Excursion 4 will enable insight into high-pressure granulite facies metamorphism in the WU and the nature of the contact between the WU and the EU along strike from Excursion 2.

Excursion 5 will enable insight into Neoproterozoic to Lower Palaeozoic deformation and their relation to the progressive decompression and retrogression of the EU eclogites. The nature of metasedimentary components within the EU that underwent eclogite facies metamorphism can also be studied.

Logistics

Local accommodation is available in Glenelg village, the Shiel Bridge Area and Dornie. Topographic maps of the area are available via the Ordnance Survey 1:25 000 sheet 413 Knoydart, Loch Hourn and Loch Duich. Geological maps of the area (1:50 000 sheets 71E Kyle of Lochalsh and 72W Kintail) are available from the British Geological Survey. The type of terrain to be covered includes roadside, rocky and potentially exposed coastline and moorland. The excursions described do not reach a greater altitude than *c*. 400 m above sea level, but a moderate level of fitness is required, especially for Excursion 1, and local weather conditions should be checked as the moorland is relatively exposed. Access and parking are described within each excursion.

Excursion 1

This transect through the eclogite facies EU of the GAI within the Northwest Highlands of Scotland demonstrates the range of lithologies that characterize the unit, and some spectacularly preserved eclogite facies assemblages, together with the dominant D_1 eclogite facies fabric. Figure 2 shows the location and path of the transect and localities along the route that serve to illustrate the petrology of these rocks.

Parking for localities 1 to 3 is available *c*. 3 km east of Glenelg village along the north side of Glen More, opposite a small farm (Iomairaghradain) that is on the south side of the road close to the Lamont Holiday Homes at Creag Mhor. Parking here is limited to two cars or one minibus, but passing places are closely spaced along the road so further vehicles could be parked close by. Access and parking for locality 4 are given below. Allow a whole day for this excursion.

Locality 1

A path leads up on the north side of the road through a gate and skirts the east side of Cnoc Mór. Follow the path up the hillside and pass through two gates to access the open hillside. Walk NNW uphill to locality 1 [grid reference NG 8371 2078].

A prominent ridge, elongated NNW–SSE for *c*. 2 km, forms a striking topographic feature north of Cnoc Mór [NG 836 210 to NG 849 226]. At the south end of the ridge [NG 8371 2078], eclogite and its retrogressed equivalent, amphibolite, are widely exposed. Eclogite occurs both as elongate pods from 1 m to tens of metres in diameter, wrapped by a dominant S_2 fabric, and as discrete layers a few millimetres to a few centimetres thick within surrounding felsic gneisses. The eclogite comprises coarse-grained dark green omphacite and dark red garnet, and is preserved in patches, commonly transected by veinlets (1–2 mm wide) where the eclogite has been retrogressed to amphibolite. The best preserved patches occur where the veining is least intense and require careful investigation. The eclogites are commonly tectonized with a dominant L_2–S_2 fabric and in these zones the rocks are thoroughly retrogressed. In the most retrogressed areas the only remaining evidence that

FIG. 4. (**a**) EU eclogite displaying equilibrium texture of garnet, omphacite and quartz. Omphacite partially replaced by amphibole. Field of view 1.5 mm. (**b**) EU eclogite. Omphacite replaced by symplectic intergrowth of diopside, plagioclase and quartz. Note replacement rim of amphibole, particularly between the symplectite and garnet. Field of view 1.5 mm. (**c**) EU eclogite. Amphibole replacing omphacite along rims, fractures and prismatic cleavage. Field of view 1.5 mm. (**d**) EU eclogite. Rutile/ilmenite intergrowth replaced by framboidal rim of titanite in retrograde matrix of amphibole and plagioclase. Field of view 0.75 mm. (**e**) EU felsic gneiss. Granoblastic polygonal texture of plagioclase, omphacite and garnet. Omphacite partially replaced by symplectites of diopside and plagioclase. Field of view 1.5 mm. (**f**) Field photo of EU streaky eclogite tectonite. L-S fabric defined by elongate feldspathic streaks and elongate omphacite and garnet. (**g**) EU streaky eclogite tectonite. Thin section cut parallel to the lineation. Streak comprises plagioclase and quartz and aligned kyanite needles. Note kyanite needles are asymmetric with tails implying a top-to-the-west sense of shear. Field of view 3 mm. (**h**) EU streaky eclogite. At margin of quartzo-feldspathic streak and basic domain, quartz and plagioclase form distinct embayments into matrix omphacite and garnet. Field of view 3 mm.

the amphibolite was once a high-pressure rock is the preservation of symplectitic amphibole and plagioclase rims partially replacing garnet.

The peak eclogite facies assemblage comprises omphacite (X_{Jd} 0.35–0.4) + garnet + rutile/ilmenite + quartz with a coarse granoblastic polygonal texture (Fig. 3a). The earliest stage of retrogression is marked by the formation of symplectites of diopside+plagioclase replacing omphacite (Fig. 3b), which are considered to have formed during an early, short-lived, decompression via the high-pressure granulite facies (cf. O'Brien & Vrána 1995). More pervasive retrogression within the amphibolite facies is marked by the progressive replacement of omphacite, along cleavage planes and around rims, by blue-green calcic amphibole of edenitic to pargasitic composition (Fig. 3c). Amphibole also partially to completely replaces the earlier symplectites and forms new straight contacts with the garnet (Fig. 3b). Dark green veins of millimetre to centimetre scale in which amphibolitization is strongest occur within pods and sheets of eclogite at high and low angles to the margins and record the ingress of fluids during retrogression. Zircon occurs both as small rounded inclusions within garnet and as larger ovoid growths within amphibolitized domains. Rutile/ilmenite is commonly preserved within unfractured garnet, but within fractured garnet and the amphibolitized matrix it is rimmed and partially replaced by framboidal titanite (Fig. 3d).

Sanders *et al.* (1984) measured Sm-Nd isotopes in garnet, omphacite and whole rock and calculated an age of 1082 ± 24 Ma, considered to represent a period close to the peak of eclogite facies metamorphism, and an age of 1010 ± 13 Ma, considered to represent the time of amphibolite facies retrogression. Brewer *et al.* (2003) dated ovoid zircon separated from amphibolitized domains within the eclogite by U–Pb methods and calculated an age of 995 ± 8 Ma. Together these data demonstrate that the eclogites were formed and retrogressed during the Grenvillian orogenic cycle. Geochemical evidence, from Hf isotopes in zircon from the eclogites, suggests that the protolith may have formed close to 2.0 Ga ago (Brewer *et al.* 2003).

The felsic gneisses that surround the eclogite pods and contain bands of eclogite locally show evidence of having undergone eclogite facies metamorphism. Where not retrogressed they contain garnet, omphacite, plagioclase, quartz, kyanite, rutile, biotite and scapolite (Sanders 1989; Storey *et al.* 2005) (Fig. 3e). From this assemblage Storey *et al.* (2005) calculated peak P-T conditions of *c.* 20 kbar and 750 °C. Typically the omphacite has been replaced by amphibole, and garnet is commonly partially replaced by biotite. The felsic gneisses are trondhjemitic in bulk composition and contain spherical and rounded zircons formed in the Late Archaean at *c.* 2.7 Ga (Storey 2002).

Locality 2

To the NNE [NG 8403 2141] the ridge contains a large proportion of a type of eclogite described by Sanders (1988) as 'streaky eclogite'. The rock is mafic and characteristically dominated by white quartzo-feldspathic streaks that vary from millimetre-scale isolated threads to interconnecting networks of veins of centimetre- to tens of centimetre scale, locally forming up to half of the rock mass. They are typically intensely rodded and the rocks are clearly strongly tectonized, with a dominant L>S (D_1) fabric. In addition to the streaks, the intervening eclogite patches also have a tectonic fabric defined by aligned omphacite grains and tabular garnet (Fig. 3f). Kyanite, which is sometimes preserved within the streaks at the microscopic scale, is also aligned and occasionally forms asymmetric fish, indicating non-coaxial shearing (Fig. 3g). Sanders (1988) demonstrated that the streaks formed during eclogite facies metamorphism and a recent P-T estimate places the peak conditions at around 20 kbar and 750 °C (Storey *et al.* 2005).

The streaks are considered to represent plagioclase that reacted with the surrounding eclogite during peak metamorphism to form kyanite (Sanders 1988). The initial mechanism of formation of the streaks is unknown, but one possibility is that they represent partial melt, an interpretation supported by field relationships, with the streaks forming interconnected networks of veinlets and veins. In thin section the streaks commonly embay matrix omphacite and garnet (Fig. 3h).

Along the length of the ridge the rodding lineation, which has been attributed to possible transcurrent shearing during eclogite facies metamorphism (Sanders 1988), plunges shallowly towards between 010 and 040°.

Locality 3

The eclogites, streaky eclogites and enclosing felsic gneisses are bounded at the base and top by layers of marble 50–100 m thick (Fig. 2). Along the path skirting the eastern side of Cnoc Mór down to the road at Iomairaghradain Farm [NG 8397 2039], exposures of marble are easily accessible. They have a distinctive black crust and contain abundant nodules that include silicate minerals that have not weathered as readily as the carbonaceous matrix. The marbles contain both calcite and dolomite as primary phases, together with silicates including forsterite, diopside, phlogopite, chlorite and clinohumite. The silicate phases occur as discrete mineral aggregates varying from a few millimetres up to nodules and bands tens of centimetres in diameter. Commonly, the nodules have a core of coarsely crystalline green-tinged diopside surrounded by a sheath of serpentinized forsterite. Flecks of mica and chlorite are common. Sanders (1989) performed calcite–dolomite solvus thermometry on rare calcite grains enclosed by silicate, in which evenly spaced exsolution lamellae of dolomite have formed, obtaining estimates of 740 ± 20 °C. This temperature is in agreement with the equilibration of eclogites, streaky eclogites and felsic gneisses, and suggests that all are cofaciel, although pressure cannot be determined. The presence of calcite rather than aragonite would be permissible at the P-T conditions of peak eclogite facies equilibration.

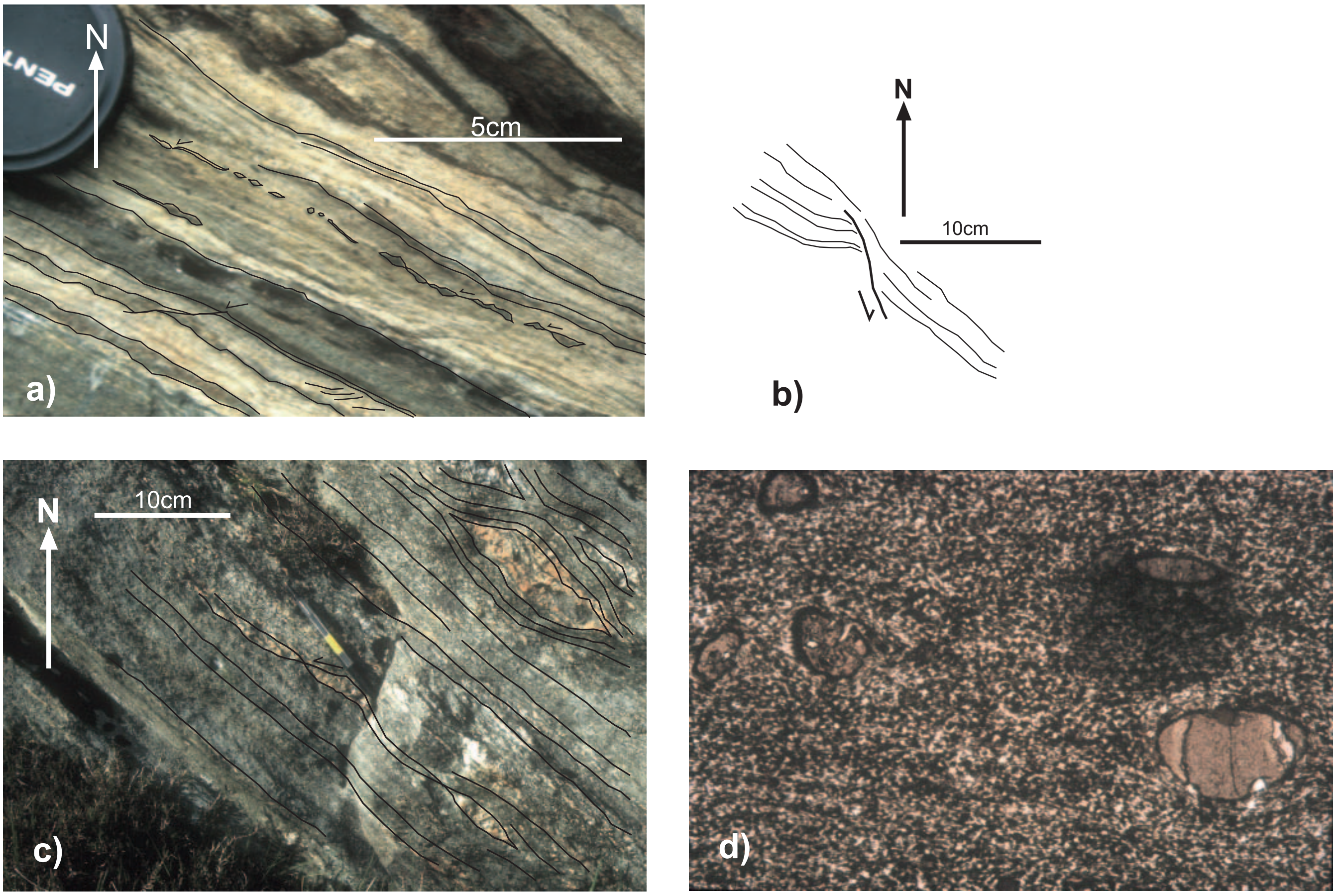


FIG. 5. (**a**) Banded, highly strained WU D2 L-S tectonites perpendicular to the transport direction. Trace of foliation and c' shear bands marked indicating top-to-the-west sense of shear. (**b**) Sketch of S_2 foliation in WU tectonized amphibolite disrupted by S_3 shear band with top-to-the-SE (extensional) sense of shear. (**c**) Highly strained Moine strip D_2 L-S tectonites perpendicular to the transport direction. Trace of foliation, pegmatite marker bands and c' shear band marked indicating top-to-the-west sense of shear. (**d**) Photomicrograph of EU ultramylonites. Thin section cut parallel to transport direction. Fine-grained matrix of amphibole and plagioclase with grain size of *c*. 5–10–μm diameter. Rounded porphyroclasts are garnet and titanite. Field of view 4 mm.

Locality 4

Drive eastwards over the Ratagain pass towards Shield Bridge and back down the other side. After approximately 8 km the first junction on the road is encountered – a left turn signposted towards Ratagan. This road is single track and follows the south side of Loch Duich. It is not suitable for vehicles larger than minibuses. After approximately 7 km, beyond the small hamlet of Letterfearn, is a large house called Druidaig Lodge [NG 8805 2460]. Parking is available about 200 m south of the house but is marked private and should only be used if prior permission is granted. Otherwise, a passing place opposite the house can be used. The land is private so permission should be sought where possible, but the lodge is currently used as a holiday home, so may not be occupied. Access is via the north side of the house alongside a brick wall, which is quite overgrown with vegetation. Follow the wall and cross a small wooden bridge to the left and then a fence immediately to the right. During the summer the hillside is covered with bracken, but walk uphill to the SW and after *c*. 50m you will encounter a semi-cleared path through the bracken up the hillside. Follow this path uphill to access the highest buff-coloured outcrops at the top of the hill [NG 8250 2443].

The EU contains an unusual rock type, eulysite, first described by Tilley (1936). Eulysite is rich in iron and manganese and typically contains the pyroxenes hedenbergite and Fe-hypersthene, and the olivine fayalite. West of Druidaig Lodge, hillside exposures contain eulysite and associated rocks. At the summit of the hill behind the lodge [NG 8250 2443] dark and dense rocks have a distinctive blue-black surface colour due to hydrated manganese oxide staining. These contain mainly pyroxene, garnet and magnetite ± fayalite. Typically, crystals of fayalite project from the weathered surface. On freshly exposed surfaces brown and translucent fayalite with a resinous lustre is associated with garnet. Both clinopyroxene (hedenbergite) and orthopyroxene (Fe-hypersthene) are present in varying proportions, with Fe-hypersthene minor in some examples and the main pyroxene in others. Magnetite is conspicuous in its abundance, but also hetereogeneously distributed. Sometimes it forms in narrow zones, giving the rock a banded appearance, enclosing fayalite and forming intergrowths

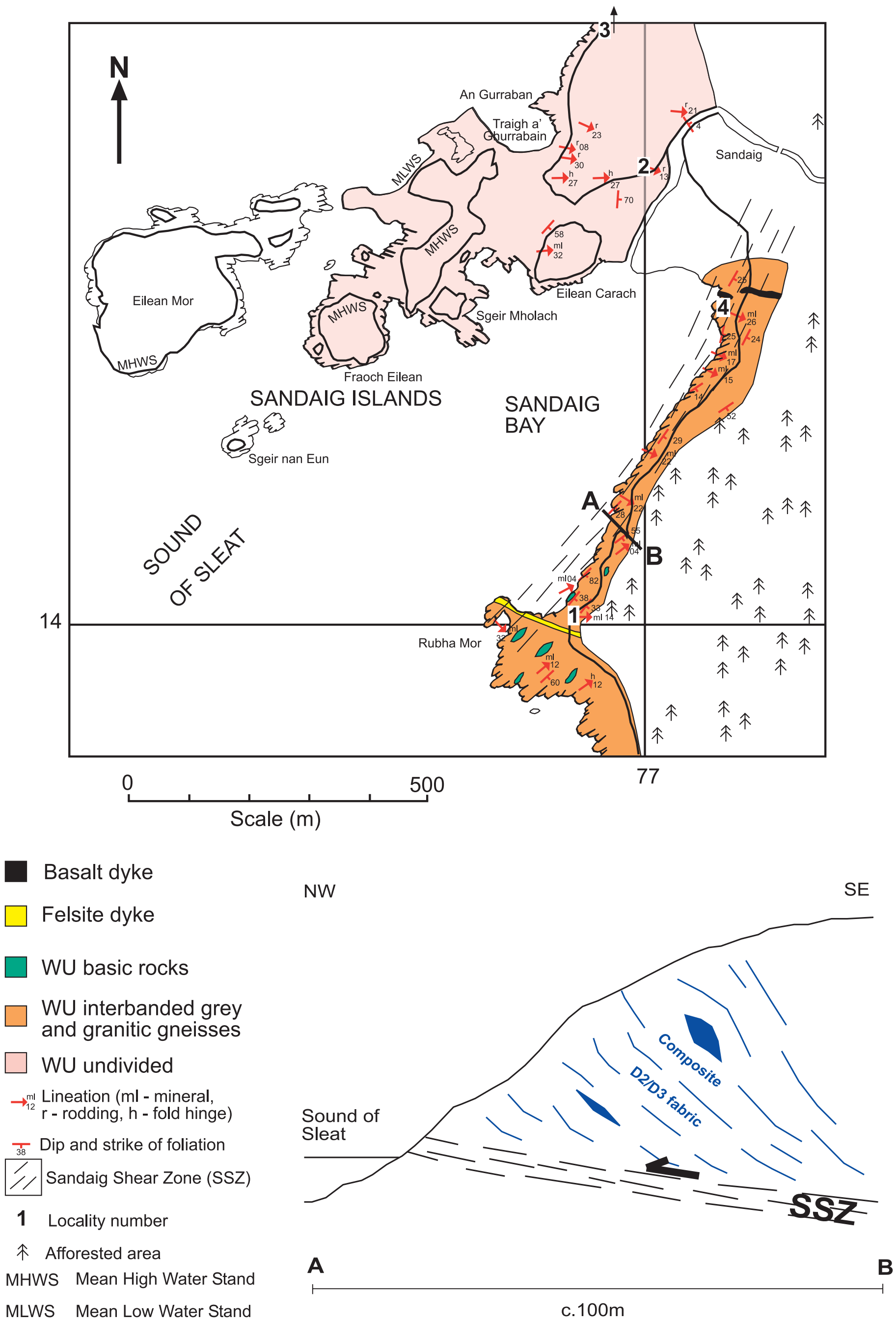


FIG. 6. Geological map of Sandaig Bay area covering Excursion 3.

with garnet. Taking magnetic compass measurements around these exposures is not recommended! Other phases sometimes present are grunerite, which is almost colourless with a fibrous habit and commonly grows in veins attesting to its secondary nature, apatite and pyroxmangite ($MnFeSiO_3$). The amphibole cummingtonite has also been reported as a replacement phase of pyroxene (Sanders 1972).

The bulk rock composition is unusually manganiferous with MnO 6–13%, FeO 20–30% and Fe_2O_3 10–20% (Tilley 1936). The intimate association of eulysite interlayered with pelite and marble within the EU argues for a sedimentary origin. The presence of calcium (3–10%) was interpreted by Tilley (1936) to imply original carbonate within the sediment, and one of the suggested protoliths was a cherty iron carbonate rock. Coats *et al.* (1996) went further and suggested that the eulysites represent metamorphosed exhalative sediments formed at a sea-floor vent.

Discussion and interpretation

The EU comprises chiefly felsic, intermediate to acid gneisses containing pods, lenses and layers of eclogite forming up to 25% of the outcrop. Metasedimentary rocks, pelite, marble and eulysite (more of these will be encountered in Excursion 5), are also common, the distinctive marble layers in particular locally forming continuous mappable units. Scattered small outcrops of ultrabasic rocks are also present within the gneisses and eclogites. It is likely that most of the basement gneisses formed from felsic igneous rocks in the Late Archaean and are thus analogous to the TTG gneisses of the Lewisian Gneiss Complex within the foreland of the Caledonian orogen and the gneisses of the WU of the GAI. The major distinction is the preponderance of eclogite and paragneisses that do not have a direct comparison, except perhaps within the Gairloch region of the Lewisian outcrop. It is possible that the metasediments and most of the eclogite protoliths formed as part of a volcanosedimentary sequence resting on the pre-existing trondhjemitic gneisses prior to the Grenvillian, possibly at around 2.0 Ga. The entire EU was subsequently buried to great depths, around 70 km, close to 1082 Ma ago during the Grenvillian, most likely by subduction.

Excursion 2

This excursion is a traverse from west to east across the contact between the WU and EU of the GAI (Fig. 4). The contact is a major kilometre-scale ductile shear zone with much of the strain partitioned into the EU in the hanging wall. The shear zone is termed the Barnhill Shear Zone (BSZ) (Storey *et al*. 2004, 2005). In most places, including this locality, the BSZ contains an intervening strip of Moine metasediments 200–300 m thick. Hence, this locality is critical in understanding the relationships between the EU and WU and between the GAI and Moine.

Either park in Glenelg village or drive up a small partially made-up road that turns sharply to the left off of the main road through the village as you head southwards; the junction is between the two entrances to the Glenelg Inn car park. The road follows the edge of the south side of Glen More towards a farm at Cósag [NG 823 193]. The farm is gated at the end of the road, but approximately 200 m before the gate there is a disused croft and it is possible to park here on the side of the track. Space is limited to two cars or one minibus. Allow 3–4 hours for this excursion.

Walk back towards Glenelg and, where the road turns a first right bend, cross the barbed wire fence and a small stream and walk uphill to the SW. After about 0.5 km [around NG 817 187] exposures of sheared orthogneisses occur.

Locality 1

At this locality [NG 8167 1871] there are low hummocky exposures of WU orthogneisses. The area is within a few hundred metres of a strip of Moine to the east and the rocks are highly strained. Speckled amphibolite (partially melted mafic rocks containing trondhjemitic leucosome) is quite common and the rocks are commonly characterized by a strong ductile D_2 L-S fabric, with a mineral stretching lineation plunging moderately steeply down dip to the east. In exposures where banded tectonized mafic and felsic layers occur, it is possible to derive kinematic information from the rocks perpendicular to the lineation, with σ-porphyroclasts and low-angle shear bands implying top-to-the-west sense of shear (Fig. 5a). However, it should also be noted that later upright D_3 extensional shear bands are common and disrupt the earlier fabric (Fig. 5b). In these zones, generally tens of centimetres in length, a new L-S fabric is developed with an L_3 mineral elongation plunging fairly steeply towards the SE.

Locality 2

To the east [NG 8172 1866], low angular outcrops stand slightly higher than the WU hummocks. These are composed of Moine rocks and are dominantly psammitic with variably deformed feldspathic sedimentary clasts and thin pegmatitic segregations. The rocks are penetratively tectonized and mylonitic; the fabric is generally tramline parallel and contains a strong mineral stretching lineation formed mainly by muscovite. There are two mineral stretching lineations within the Moine strip as a whole: the earliest plunges moderately towards the east (L_2) whereas a later lineation (L_3), commonly associated with upright extensional shear bands that rework the D_2 fabric, plunges steeply down to the SE and formed during D_3. Locally kinematic evidence can be found of D_2 fabrics, particularly where pegmatitic layers are disrupted, and these imply top-to-the-west sense of shear (Fig. 5c). The Moine strip here is approximately 200 m thick.

Locality 3

To the east further up the hillside [NG 8178 1868], strongly banded ultramylonites commonly have millimetre-scale mafic and felsic interlayers. The mafic layers contain highly rounded porphyroclasts of garnet and dark green-brown amphiboles. The ultramylonitic foliation is commonly disrupted by disharmonic folds with curvilinear hinges. A strong L_2 mineral stretching lineation is observed, plunging moderately towards the east, and the fold hinges are generally subparallel to this lineation. These are clearly sheath folds formed during shearing. The state of strain is so high that it is impossible to garner kinematic information from these rocks. In thin section the groundmass (chiefly pargasitic amphibole and plagioclase of the order 5–10 μm diameter) is intermixed (Fig. 5d), probably as a result of diffusion creep-assisted grain boundary sliding during deformation. The state of strain remains extremely high and towards the east the rocks are mylonitic for several hundred metres, forming part of the BSZ. At the summit of Sgiath Bheinn [around NG 8223 1873] and southwestwards along strike, the rocks are locally in a lower state of strain and it is possible to see disrupted migmatitic textures within the trondhjemitic gneisses. Where the strain is lower, the lineation plunges gently towards the north or south and is likely L_1, related to the lineation within the streaky eclogites to the north of Ben More described in locality 1.

Discussion and interpretation

Eclogites from the EU have been exhumed from *c.* 70 km to the surface and, at some point along the exhumation path, have been juxtaposed against both the WU and the Moine. Constraints on the timing of juxtaposition are the maximum age of deposition of the Moine (Morar Group) and the age of shearing along the BSZ. The youngest detrital zircon in the Morar Group is precisely dated at 980 ± 2 Ma (Peters 2001) whereas movement along the BSZ has a minimum age of 669 ± 31 Ma, based on synkinematic titanite in EU mylonites (Storey *et al.* 2004). Hence, the juxtaposition is Neoproterozoic in age and must be later than the initial uplift of the EU eclogites into the amphibolite facies mid-crust at 12–13 kbar and *c.* 650 °C at *c.* 995 Ma (Storey *et al.* 2005; Brewer *et al.* 2003).

The BSZ has a dominantly top-to-the-west sense of movement and is hence a contractional feature. Moreover, the slivers of Moine rocks within the BSZ must have been folded into this position during shearing. However, the contact between the structurally higher EU and overlying Moine is also a ductile amphibolite facies shear zone, the Inverinate Shear Zone (ISZ), but with a dominantly top-to-the-east sense of shear. This means that the EU is bounded on its lower side by a contractional shear zone and along its upper side by an extensional shear zone, describing an overall wedge geometry. This would have permitted the EU to travel from depth towards the surface to be emplaced and juxtaposed against the Moine during the (post-Grenvillian) Neoproterozoic, between *c.* 980 and 670 Ma.

Excursion 3

This excursion presents an opportunity to visit the only known occurrence of eclogite in the WU in the area of Sandaig on the shore of the Sound of Sleat (Fig. 6). Within this area, the contact between the WU and Moine can also be visited and assessed. The contact is affected by D_2 amphibolite facies shearing and a post-D_2 static amphibolite facies overprint. The S_2 fabric is overprinted by D_3, which largely manifests itself as steep SE-dipping lower amphibolite facies ductile extensional shears. These fabrics were reworked and cut by a greenschist facies brittle–ductile shear zone that is linked to the development of the Moine Thrust Zone.

Drive south through Glenelg Village towards Arnisdale. After *c.* 5 km, just before a bridged stream (Allt Mór Shantaig), there is a turning to a house (Upper Sandaig) on the right [NG 7835 1465]. There is ample parking space for several cars or minibuses if not occupied by other walkers. Follow the forest track down by the northern edge of the stream. After *c.* 300 m cross the stream using the large boulders that have been placed there, but take great care when they are wet as they can be treacherous. Keep following the forest track downhill and keep a note of any junctions that you cross for later reference. After *c.* 1.5 km (30–40 minutes) you will arrive in Sandaig Bay, a beautiful spot popularized by Gavin Maxwell in the book *Ring of Bright Water* and given the name Camusfearna. Allow 3–4 hours for this excursion.

Locality 1

Along the shoreline [NG 767 140] mafic boudins of the order of 1–3 m diameter occur within the dominant S_2 fabric. Relict eclogite is preserved within some of these boudins, although others are thoroughly retrogressed to amphibolite. In the best-preserved patches a granoblastic polygonal texture comprises omphacite, garnet, rutile/ilmenite and quartz (Fig. 7a). The mineral assemblage does not allow derivation of peak P conditions, but based on the X_{Jd} component in omphacite the minimum P is considered to be 13–14 kbar. Garnet coexisting with omphacite gives an Fe-Mg exchange T of *c.* 600–700 °C. The eclogite facies paragenesis is overprinted by an early short-lived high-pressure granulite facies event, which resulted in the formation of symplectites of diopside and plagioclase, partially replacing omphacite (Fig. 7a, b). P-T conditions based on symplectite-forming phases, together with adjacent rim compositions of garnet, provide estimates of 14–16 kbar at *c.* 650 °C (Storey 2002). This implies that the previous higher pressure eclogite facies event also has these minimum P conditions. Minor zircon occurs as rounded equant grains within garnet and in the groundmass. A zircon U–Pb ID-TIMS age of one multi-grain zircon fraction has been measured and returns a slightly discordant $^{207}Pb/^{206}Pb$ age of 1702 ± 7 Ma (Storey *et al.* unpubl. data). Garnet-omphacite Lu-Hf dating yields an age of 1658 ± 6 Ma (Storey *et al.* unpubl. data). These data indicate that the eclogite facies event is of Palaeoproterozoic age, in contrast with the late Mesoproterozoic (*c.* 1082 Ma) age of eclogite facies metamorphism in the EU. Amphibolite facies retrogression is ubiquitous and manifests itself, in the best-preserved eclogite patches, as rims of calcic amphibole surrounding omphacite (Fig. 7a, b) and sometimes growing along the cleavage. The symplectites are also partially to completely replaced by calcic amphibole (Fig. 7a, b). Rutile/ilmenite intergrowths are overgrown by framboidal titanite (Fig. 7b). At all scales the eclogite is cross-cut by veins in which the omphacite has been replaced by amphibole that is a much darker green. At the margins of the boudins, there is commonly a strong $S_{2/3}$ fabric and the basic rock has been entirely replaced by amphibole, biotite and epidote with a strong L-S fabric. The main S_2 fabric is locally disrupted by a new S_3/L_3 fabric associated with extensional SE-directed shearing.

Locality 2

Outcrops of felsic gneisses on the western side of a small stream in Sandaig Bay (Fig. 6) [NG 770 148] include minor deformed mafic sheets and lenses. The gneisses have a dominant L>S tectonic fabric with a rodding and mineral stretching lineation that plunges shallowly towards the east. This S_2 fabric was formed

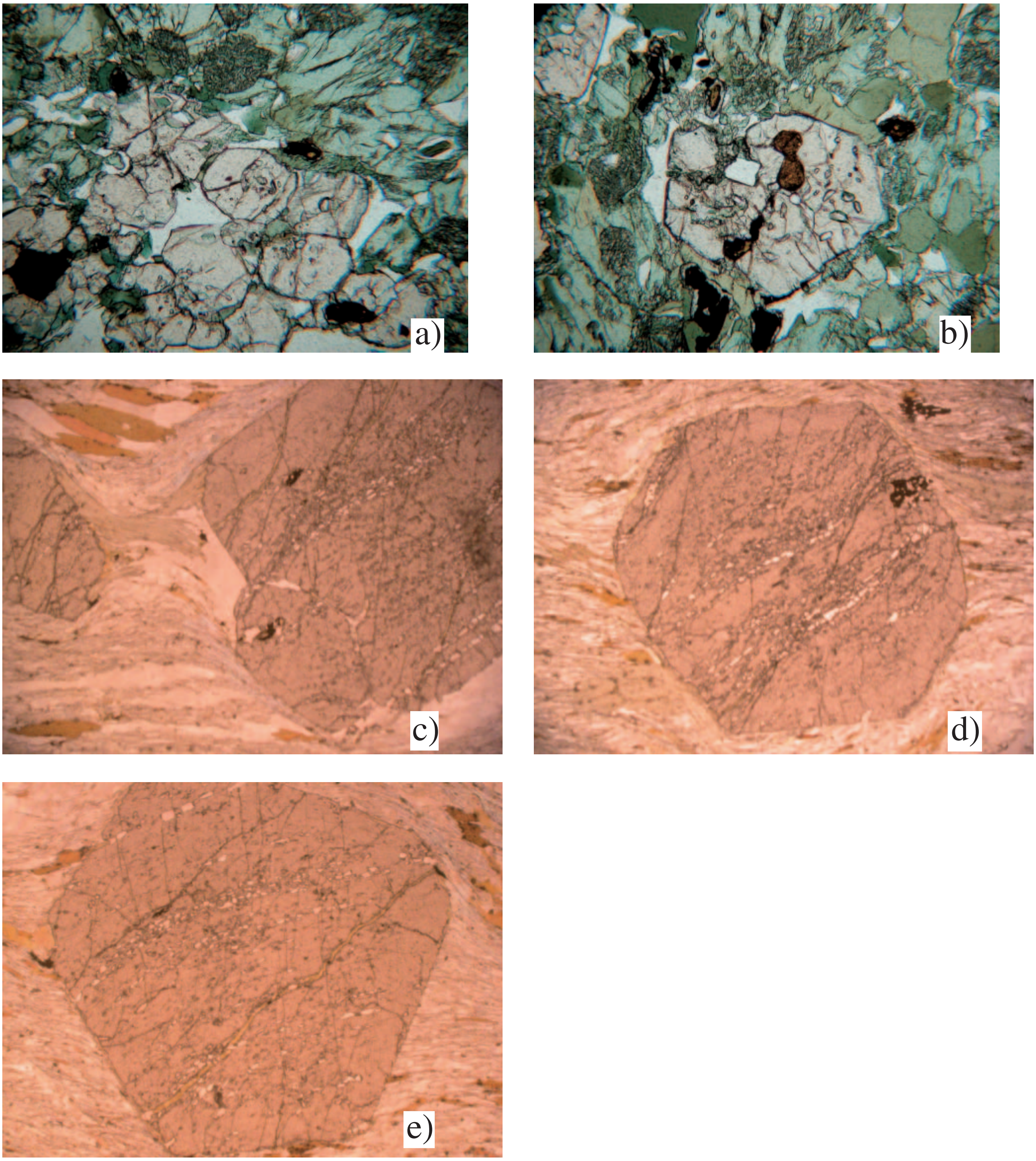


FIG. 7. (**a**) WU eclogite displaying a relict granoblastic polygonal texture of garnet, omphacite, quartz and rutile/ilmenite. Omphacite is partially replaced by symplectites of diopside and plagioclase. Omphacite also displays later partial replacement by calcic amphibole. Field of view 3 mm. (**b**) WU eclogite displaying relict texture of coarse granoblastic garnet, omphacite and quartz. Omphacite is partially replaced by symplectites of diopside and plagioclase and partially by calcic amphibole. Note rutile/ilmenite preserved as inclusions in garnet but rimmed by framboidal titanite in the retrogressed matrix. Field of view 1.5 mm. (**c**) Basal Moine garnet-mica schist. Note pressure shadows filled by white mica and chlorite. Inclusion trails in garnet are oblique to the foliation. Field of view 4 mm. (**d**) Basal Moine garnet-mica schist. Inclusion trails oblique to the foliation that wraps the garnet. Cores have higher density of inclusions than rims. Field of view 4 mm. (**e**) Basal Moine garnet-mica schist. Inclusion trails oblique to the foliation but note that trails in the clearer rim are in continuity with the external foliation. This indicates post-kinematic rim growth of the garnet. Field of view 4 mm.

under amphibolite facies conditions, coeval with shearing along the BSZ. The fabric is commonly overprinted by conspicuous randomly orientated needles of actinolite, which represent a post-D_2 static metamorphic overprint. The S_2 fabric is locally reworked by D_3 upright extensional shears (top-to-the-SE).

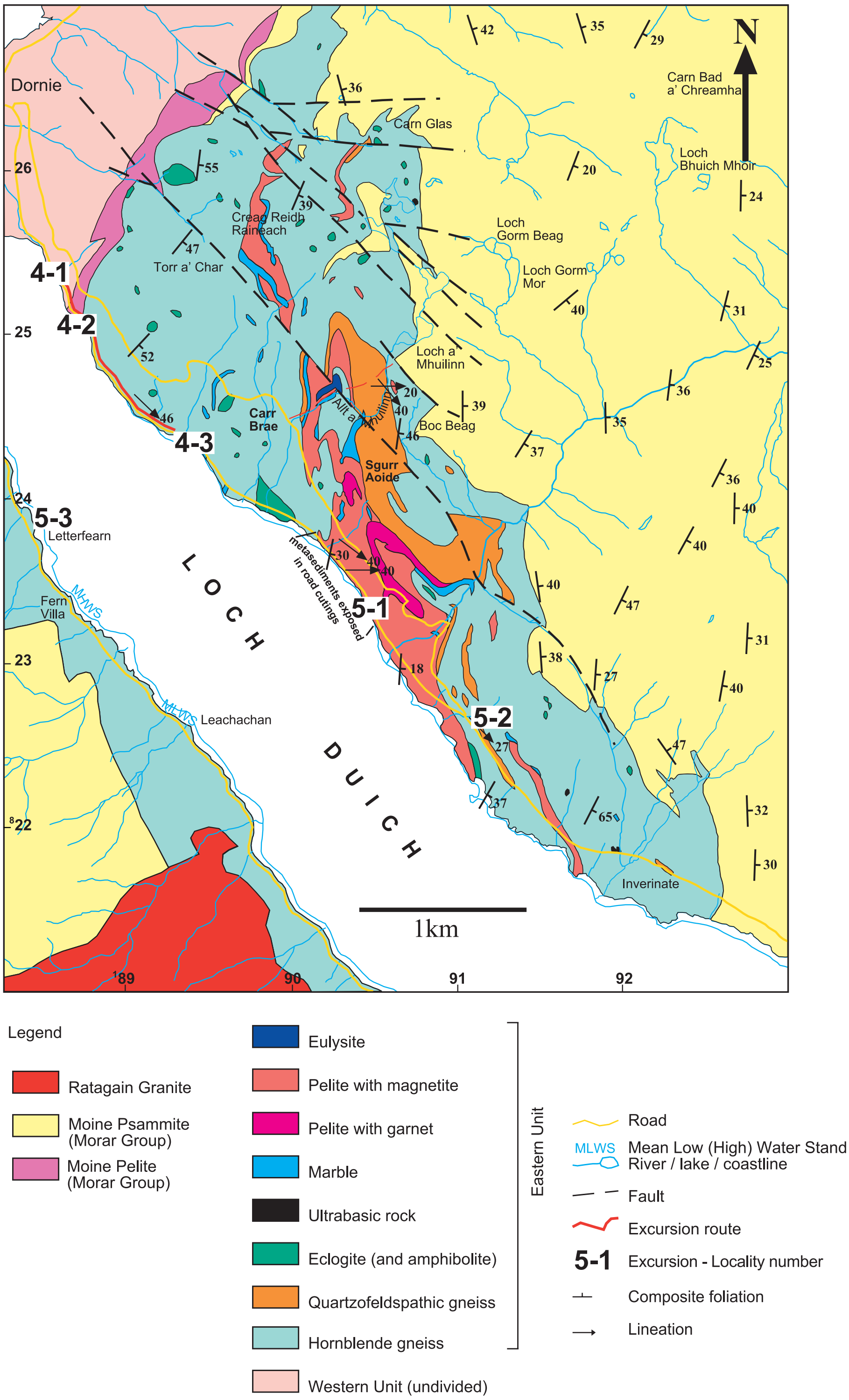


FIG. 8. Geological map north of Loch Duich covering excursions 4 and 5 (based on May *et al.* 1993, fig. 5).

Locality 3

To the NW, close to the shoreline [NG 770 151], the WU is in direct contact with the Moine, which in this locality is overturned and faces down to the west. A metapelite along the contact contains idioblastic garnet crystals up to 5 mm diameter. The pelite is dominated by biotite, quartz and feldspar with minor white mica that form a pervasive S_2 fabric. Generally the fabric wraps around the garnet porphyroblasts and pressure shadows filled with mica and retrograde chlorite are present locally (Fig. 7c). The garnets have cloudy cores and straight inclusion trails that are commonly oblique to the S_2 fabric (Fig. 7d). By contrast, the rims are generally clearer and with inclusion trails that are contiguous with the S_2 fabric (Fig. 7e). This suggests that rims are post-kinematic, with growth following foliation development. Randomly orientated actinolite needles are commonly present in the pelites overprinting the fabric. These most likely grew during the same static metamorphic event as those within the adjacent WU gneisses, coeval with growth of the garnet rims.

Further north and west, the pelites give way to psammite, a more typical lithology within the Morar Group. Ramsay (1958); Ramsay & Spring (1962) refer to the pelite unit as the basal pelite, present at all contacts with the GAI and Morar Group. The psammites are partly coarse-grained and Ramsay (1958) discovered occurrences of relict cross-bedding further north along this coastline, documented as further evidence for a modified unconformity.

Locality 4

On the eastern side of the small stream in Sandaig Bay (Fig. 6) [NG 7715 1455] the WU gneisses are flaggy and highly strained, with an S_4 fabric dipping shallowly towards the SE. The fabric is defined by chlorite and biotite and an associated L_4 mineral stretching lineation observable on foliation surfaces plunges down dip towards the SE (*c.* 140°). The most highly strained zone is mylonitic, with a brittle–ductile style of deformation. Microstructures, in the form of S-C fabrics and sigmoidal porphyroclasts, indicate a top-to-the-NW sense of displacement. The shear zone is of the order of 10 m wide across strike and can be traced southwards along the coastline (Fig. 6); here it is referred to as the Sandaig Shear Zone. The greenschist facies D_4 shearing is correlated with movement along the Moine Thrust Zone in the period 435–425 Ma, and documents the final major tectonometamorphic event to affect the GAI and Moine in this area.

Discussion and interpretation

This is the only area in the WU where eclogite occurs and is clearly distinct from the high-pressure granulites found further north. Prior to recent geochronology it has been assumed that the eclogite was coeval with that in the adjacent EU. However, this appears not to be so. The EU and WU are separated by a major shear zone, the Barnhill Shear Zone (BSZ), and it is likely that this represents a fundamental tectonic boundary separating crust that underwent high-pressure metamorphism during the Grenvillian orogeny from that which did not. As such, the BSZ represents, in some way, the Grenville Front as it passes through Scotland.

The modified unconformable relationship between the WU and the Morar Group indicates that the WU was exhumed and eroded by *c.* 980–870 Ma, at which time the EU may still have been buried within the mid-crust. The D_2 event that resulted in amphibolite facies shearing along the WU/Morar Group contact by inference has a minimum age of *c.* 670 Ma (Storey *et al.* 2004) and may reflect the time when the WU/Morar Group and EU were juxtaposed for the first time.

Extensional SE-directed shearing and major folding at higher structural levels during D_3 reworked earlier fabrics in the area at lower amphibolite facies conditions and occurred some time in the period *c.* 437–425 Ma (Storey *et al.* 2004), i.e. during Caledonian orogenesis. The extensional nature of much of the deformation implies that an earlier Caledonian crustal thickening event must have occurred.

Upper crustal deformation in the form of brittle–ductile D_4 shearing in the period *c.* 435–425 Ma, correlated with the Moine Thrust Zone, carried the GAI and Moine Supergroup westward over the Lewisian Foreland.

Excursion 4

This excursion presents an opportunity to visit the most accessible and best-preserved occurrence of mafic high-pressure granulite within the WU. A transect (Fig. 8) southeastward along the road allows study of the transition from relatively unstrained gneisses of the WU through to a major shear zone, the Barnhill Shear Zone (BSZ) that separates the WU from the EU. Away from the BSZ to the SE the strain gradient in the EU can be studied and contrasted with that in the WU.

The excursion is along the main A87 road on the north side of Loch Duich close to the village of Dornie and Eilean Donan Castle. Park either at the car park at Eilean Donan Castle or at a more convenient location *c.* 0.5 km south along the main A87 road where there is a conspicuous crag of green-black rock on the loch side of the road and an unofficial parking area for several vehicles [NG 885 254]. Leave the vehicle here and follow the transect by foot, taking care along this busy stretch of road. Allow 2–3 hours for this excursion.

Locality 1

A conspicuous outcrop of mafic high-pressure granulite occurs within a low-strain zone in the WU, close to Eilean Donan Castle [NG 885 254] on the lochward side of the road adjacent to the parking space (Fig. 8). The rock contains preserved patches of a high-pressure granulite facies assemblage with a granoblastic polygonal texture comprising garnet, diopside, plagioclase and quartz (Fig. 9a), with occasional brown hornblende (Fig. 9b) and orthopyroxene. Small patches of white trondhjemitic leucosome are present within the granulite (Fig. 9c) and locally these coalesce to form veins where melt has been able to migrate (Fig. 9d). The melting event occurred during high-pressure granulite facies metamorphism. Retrogression is evident even within the best-preserved patches, with thin symplectitic rims of amphibole and plagioclase along grain boundaries (Fig. 9e). In more extreme cases the diopside has been partially to completely replaced by calcic amphibole (Fig. 9f). The feldspar is commonly dusted with randomly orientated laths of zoisite that Rawson (2004) suggested may have resulted from later eclogite facies metamorphism under fluid- and deformation-limited conditions.

Dating of both the mafic high-pressure granulite and the trondhjemitic leucosome by the zircon U–Pb ID-TIMS method has been attempted and indicates a Late

Archaean (*c.* 2.7 Ga) age (Storey *et al.* unpubl. data), quite distinct from the Palaeoproterozoic eclogite facies metamorphism in the WU and late Mesoproterozoic eclogite facies metamorphism in the EU. However, the zircons have overgrowths and may have also lost radiogenic Pb, resulting in discordant analyses with a Palaeoproterozoic lower intercept around *c.* 1.7 Ga and possibly some later disturbance. Lu-Hf and Sm-Nd garnet-clinopyroxene dating from the mafic high-pressure granulite yields ages of 1718 ± 6 Ma and 1586 ± 5 Ma, respectively (Storey *et al.* unpubl. data). This indicates resetting of these systems during subsequent high-grade metamorphism in the Palaeoproterozoic and possibly later.

Locality 2

To the SE along the road the WU gneisses are dominantly felsic and dip towards the ESE. The gneisses become highly strained in the area [NG 887 252] where the roadside outcrop has been blasted creating a sub-vertical face that has been covered with wire netting for safety reasons. At the northern end of the netting the gneisses can be traced into the WU felsic gneisses, but at the southern end (*c.* 30 m away) they are ultramylonitic and have a distinctly different character. The gneisses commonly contain thin interbanded felsic and mafic gneisses, the latter commonly containing garnet. This lithological character can be traced south-eastwards to progressively lower strain where it is clear that these gneisses correlate with those of the EU. Thus, the contact between the WU and EU is exposed behind the netting. Interestingly, and in contrast with all other exposed localities of the BSZ throughout the GAI, no Moine metasediments are present within the BSZ here.

The EU ultramylonites have an extremely small grain size, of the order of 5 μm diameter, composed of amphibole, plagioclase and quartz, and the phases are thoroughly admixed, suggesting a diffusion creep deformation mechanism. Within the groundmass, porphyroclasts of garnet and dark green to brown amphibole have been rounded during deformation. A mineral stretching lineation is present on the ultramylonitic foliation surface that plunges steeply down dip towards the ESE. The strain has been sufficiently high that no kinematic indicators have formed and been preserved, but elsewhere along the BSZ there is evidence for a top-to-the-west (*sensu lato*) sense of shear. Synkinematic titanite within felsic mylonites from the BSZ south of Glen More have been dated to 669 ± 31 Ma (Storey *et al.* 2004), which is considered a minimum age for D_2 shearing.

Southwards along the road the D_2, steeply ESE-dipping high-strain fabric persists for up to 1 km. Along this section the S_2 mylonitic fabric commonly contains rootless isoclinal fold hinges within the foliation and a dominant ESE-plunging mineral stretching lineation. These folds and the high-strain S_2 fabric are commonly refolded and the axes of the new folds are subparallel to the transport direction, although they are locally curvilinear. It is likely that these folds are F_2 and formed during incremental shearing. The thickness of the zone of ultramylonites within the hanging wall of the BSZ (i.e. the EU) is in stark contrast to that within the footwall (the WU) and demonstrates that the majority of the strain was partitioned into the EU.

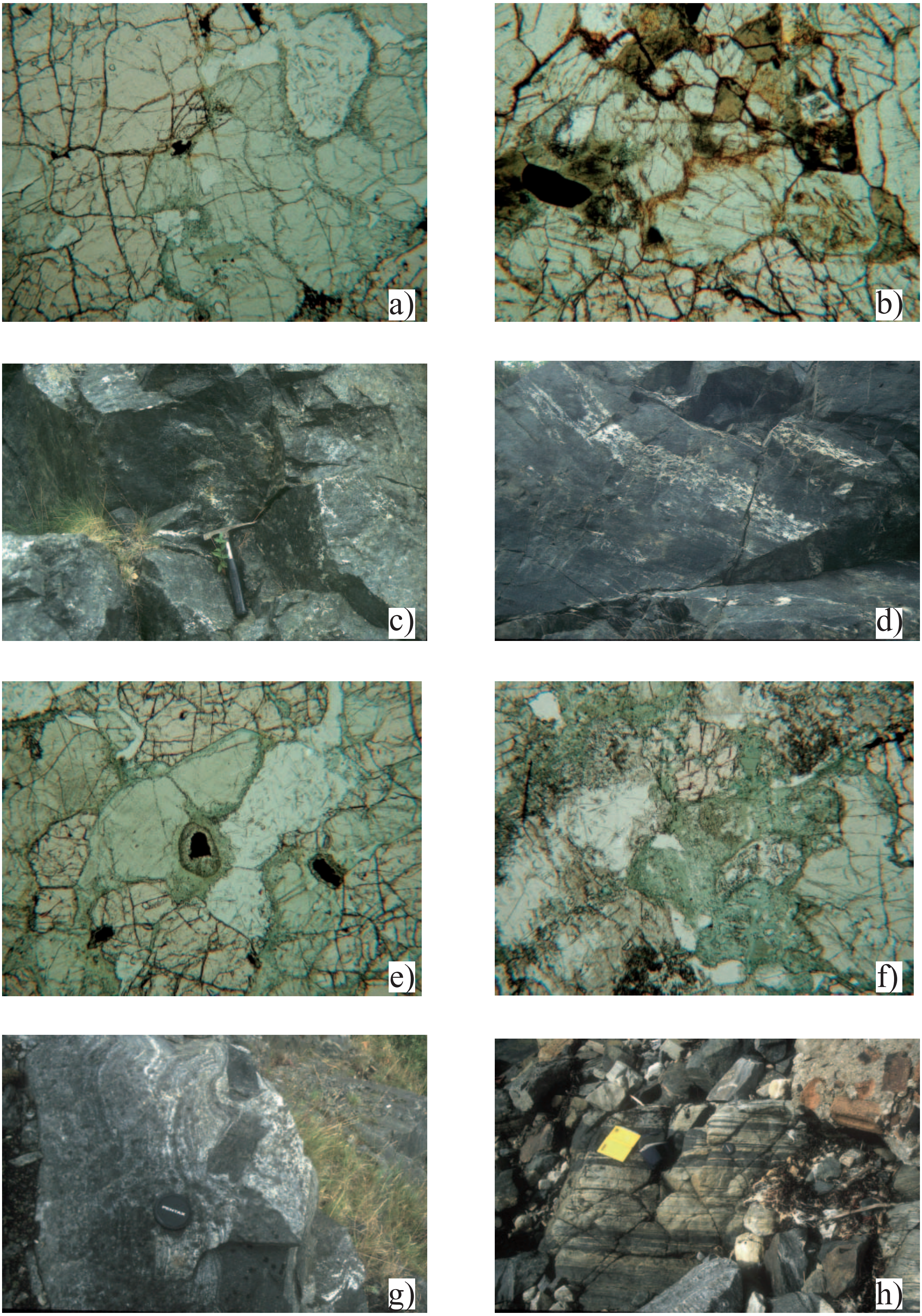
Locality 3

Further south, low outcrops on the landward side of the main A87 road [NG 8930 2445] are demonstrably lower strain as migmatitic textures are preserved within grey trondhjemitic gneisses and mafic gneiss inclusions retain sharp contacts with the surrounding gneiss (Fig. 9g) and locally partially melt at their contacts. The gneiss is typical of trondhjemitic gneisses elsewhere within the EU where the strain is sufficiently low and has a Late Archaean protolith age (Storey *et al.* unpubl. data). On the opposite side of the road, outcrops along the shore of Loch Duich illustrate how similar gneiss is transformed into the high-strain banded grey/mafic gneiss (Fig. 9h) typical of the dominant EU lithology.

Discussion and interpretation

Mafic sheets within the northern part of the WU locally contain relict high-pressure granulite facies assemblages associated with in-situ partial melt patches and veins producing trondhjemitic leucosome, reflecting a Late Archaean melting event. For the most part the granulite facies assemblage is retrogressed to amphibolite facies. In many mafic sheets within the WU the only evidence of a granulite facies event is the ubiquitous presence of trondhjemitic melt veins. The WU underwent eclogite facies metamorphism in the Palaeoproterozoic around 1.75–1.7 Ga that resulted in the partial resetting of U–Pb systematics in zircon and

FIG. 9. (**a**) WU mafic high-pressure granulite displaying coarse granoblastic polygonal texture of diopside, garnet and plagioclase. Note partial replacement along rim contacts of diopside by symplectites of amphibole and plagioclase. Randomly orientated laths within plagioclase are zoisite. Field of view 3 mm. (**b**) WU mafic high-pressure granulite displaying coarse granoblastic polygonal texture of diopside, garnet and brown hornblende. Field of view 3 mm. (**c**) WU mafic high-pressure granulite with trondhjemitic melt veins and patches. (**d**) WU mafic high-pressure granulite with trondhjemitic melt veins coalescing to form a mobilized sheet. (**e**) WU mafic high-pressure granulite displaying relict coarse granoblastic polygonal texture of diopside, garnet and plagioclase. Note symplectites of amphibole and plagioclase along diopside grain boundaries and ilmenite rimmed by framboidal titanite in these areas. Randomly orientated laths within the plagioclase are zoisite. Field of view 3 mm. (**f**) WU mafic high-pressure granulite displaying evidence of strong retroression with much of the diopside replaced by amphibole. Field of view 3 mm. (**g**) EU trondhjemitic gneiss with inclusions of partially melted mafic rock retaining mostly sharp contacts. Low strain zone within the EU at the margin of the BSZ high strain zone. (**h**) Typical aspect of EU banded trondhjemitic/mafic gneisses. Moderate strain area at the margin of the BSZ high strain zone.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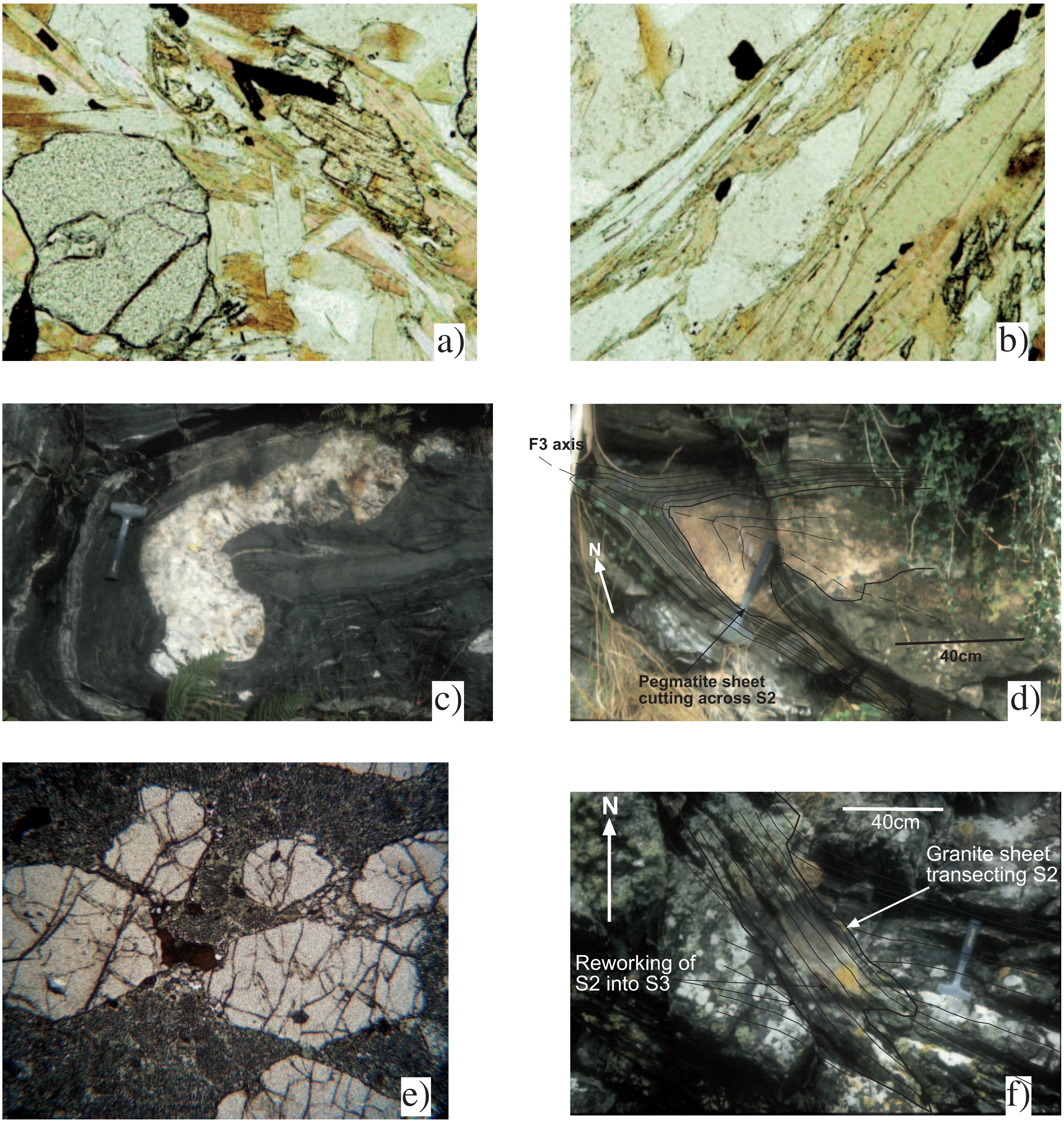

FIG. 10. (**a**) EU garnet, kyanite mica schist. Relict garnet in micaceous foliation. Field of view 4 mm. (**b**) EU garnet, kyanite mica schist. Biotite and phengitic mica intergrown in foliation. Field of view 4 mm. (**c**) EU calc-pelites containing leucosome vein that cuts across S_2 and note the F_2 rootless isoclinal fold within S_2. Vein and S_2 refolded around F_3 fold hinge. Note the boudinage of small leucosome veinlet on the left-hand side of the photo around the fold hinge. (**d**) Granitic pegmatite cutting high-strain S_2 fabric at low angle. Both pegmatite and S_2 are refolded around F_3 fold hinge. (**e**) EU streaky eclogite with relict garnet and omphacite aligned L-S shape fabric. Note elongate tabular nature of garnet. Relict omphacite grains are totally replaced by symplectites of amphibole and plagioclase. Field of view 2 mm. (**f**) EU amphibolites with strong S_2 fabric intruded by granite sheet. Granite sheet and S_2 fabric are reworked by later D_3 deformation, producing a new S_3 fabric.

complete resetting of Lu-Hf and Sm-Nd systematics in garnet and clinopyroxene. Apart from this, the presence of zoisite inclusions in granulite facies plagioclase may be the only petrologic manifestation of the later eclogite facies overprint. This is most likely due to the lack of fluid during the eclogite facies event resulting in metastability of the dry residual mafic granulites.

The protoliths to the EU grey trondhjemitic gneisses are of Late Archaean age but mafic xenoliths do not retain any evidence of having undergone a Late Archaean granulite facies event. Thus they may be broadly equivalent in terms of age and lithology to their counterparts in the WU but not necessarily part of the same tectonic unit.

The WU and EU are separated by a major, *c.* 1 km wide, D_2 shear zone with a dominant top-to-the-west (contractional) sense of displacement, with most of the strain focused into the EU in the hanging wall, implying that it travelled from greater depth. The shear zone was responsible for juxtaposition of the WU and EU and operated some time in the period *c.* 980–670 Ma.

Excursion 5

This excursion presents an opportunity to visit easily accessible roadside localities (Fig. 8) that have a strong bearing on the evidence for timing and the nature of Neoproterozoic to Lower Palaeozoic tectonic events responsible for decompression of the EU eclogites. The relationship between D_2 and D_3 fabrics is critical in terms of timing and their bearing on the retrograde exhumation path. An opportunity to visit EU metasediments that have undergone eclogite facies metamorphism is also presented.

The localities are based on roadside exposures on the northern (A87) and southern (Ratagan to Totaig road) side of Loch Duich (Fig. 8). Parking and access issues are described for each locality. Allow 3–4 hours for this excursion.

Locality 1

Along the main A87 road on the northern side of Loch Duich, road cuttings expose metasedimentary rocks belonging to the EU behind crash barriers [NG 905 233 to NG 900 239]. Park in a lay-by just to the south of the termination of the crash barriers where there is ample room for several cars or minibuses. Walk back along the road to the crash barriers and access the cliff exposures behind the barriers. The area can become overgrown but is usually cleared on an annual basis. Ticks are common at this locality so take care to minimize flesh exposure and check yourself afterwards.

At the southern end of the exposure metapelites show a strong S_2 schistosity. These contain biotite, plagioclase, garnet, kyanite, quartz, white mica and chlorite together with conspicuous mauve garnet porphyroblasts up to 10 mm diameter. Kyanite is less obvious in the field, but relicts are commonly present in thin section (Fig. 10a). Rawson (2004) identified phengitic white mica (>3.2-3.6 Si a.p.f.u.) intergrown with biotite in the matrix (Fig. 10b), also implying relicts of eclogite facies metamorphism.

Further northwards along the exposures the pelites become dominantly calcareous with increasing proportions of epidote. Marble used to be exposed at the northern end of the section but has since become overgrown. It is likely that this progression from aluminous to increasingly calcareous sediments is primary and formed part of an original subaqueous (sea floor?) succession subducted along with basalts and trondhjemitic gneisses to eclogite facies.

Within these exposures there is widespread evidence of partial melting of the metapelites, with leucosome development in veins (Fig. 10c). The leucosome development is also a time-marker as it demonstrably cuts across the dominant S_2 fabric but, along with S_2, is folded around F_3 fold hinges, resulting in boudinage of the leucosome around hinge zones (Fig. 10c). Unfortunately the leucosome does not contain U- or Th-bearing accessory minerals or other minerals that can be radiometrically dated. The area is dominated by M and W folds and occupies the hinge of a major F_3 fold that can be traced southwestwards throughout the GAI and the Moine.

Locality 2

Drive south along the A87 road for *c.* 800 m until you reach a left turn towards Carr Brae. Opposite this junction on the right-hand side of the road is off-road parking for several cars or minibuses. Walk south along the road and examine the low exposures on the landward side of the road, taking great care of traffic.

Approximately 50 m south of the Carr Brae junction [NG 9115 2260], low roadside exposures on the landward side of the road contain banded EU felsic gneisses with a strong S_2 fabric intruded by granitic pegmatite cutting S_2. Both the S_2 fabric and the pegmatite are locally folded around F_3 folds (Fig. 10d). The pegmatite contains euhedral igneous titanite that has been dated by U–Pb ID-TIMS methods to 437 ± 6 Ma (Storey *et al.* 2004). This date indicates that D_2 is older than this and D_3 younger.

Locality 3

Drive south along the A87 to Shiel Bridge and take the right turn towards Glenelg. After *c.* 1 km take the first right turn signposted to Ratagan and follow this single-track road (the same road as Excursion 1, locality 4) for *c.* 6 km until you reach the hamlet of Letterfearn. Park in the small bay at Letterfearn [NG 8845 2380]; there is space for only one vehicle so any more will have to use the nearest convenient passing place. Low outcrops occur on the north side of the bay on the beach, but take great care as the loch is tidal and the rocks can be treacherously slippery.

A cliff face *c.* 3 m high [NG 8845 2380] reveals mafic rocks with a dominant east-dipping amphibolite facies S_2 foliation and an east-plunging mineral stretching L_2 lineation. At the highest part of the face the amphibolite contains tabular garnet and elongate prisms of relict omphacite forming an L-S fabric coplanar and colinear with the D_2 fabric. The relict eclogite contains quartzofeldspathic streaks and is correlated with the streaky eclogites described by Sanders (1988) elsewhere in the EU (Excursion 1, locality 2), but no kyanite has survived here. Hence, this is a relict of the D_1 eclogite facies fabric that in this area evidently had a similar principal stretching axis to D_2. The D_1 fabric has been statically overprinted by amphibolite facies minerals, with omphacite replaced by symplectites of amphibole and plagioclase and neoblastic garnet (Fig. 10e).

A conspicuous steeply dipping granite sheet *c.* 20 cm wide cuts across the S_2 fabric (Fig. 10f). The granite sheet has also been deformed and contains a moderately strong foliation that can be traced into the contacts with the surrounding amphibolite. At the margins of the granite, the S_2 fabric is reworked and biotite has formed, marking retrogression to lower amphibolite facies. A new S_3 and L_3 fabric, defined by coexisting amphibole and biotite within mafic lithologies, is locally dominant and minor F_3 fold hinges occur within the amphibolite that disrupt the S_3 foliation. Adjacent to the face a small F_3 fold hinge is exposed on the beach, plunging towards the SE. Around the hinge of this fold the L_2 lineation is reorientated into a near-horizontal attitude with a north–south azimuth. Clearly, the granite sheet is a time-marker between D_2 and D_3. Dating of zircon fractions from the granite by U–Pb ID-TIMS methods gave a lower intercept age of 672 ± 75 Ma, whereas titanite gave an age of 520 ± 11 Ma (Storey *et al.* 2004). It is clear that D_2 must be Neoproterozoic in age and D_3 younger.

Discussion and interpretation

Relicts of D_1 eclogite facies fabrics are rare in the EU but where they occur the evidence suggests that they had a similar principal stretching axis to D_2. Similarly, rare D_1 kinematic indicators are consistent with a top-to-the-west sense of shear. This implies that the EU has travelled incrementally westwards from deep burial through decompression and final interbanding and juxtaposition against the WU and Morar Group. Thus, the EU originated from a position far eastwards from its present position in present-day coordinates.

A Neoproterozoic age for D_2 is confirmed by dating cross-cutting granite, with the zircon lower intercept age tantalisingly similar to the age of synkinematic titanite within the BSZ. Therefore, either the granite formed roughly synchronously with D_2 (but post-dated the main shearing, perhaps during thermal relaxation of the crust) or the tectonothermal event that resulted in granitic magmatism caused disturbance of the U–Pb system in titanite along the BSZ. An older age for D_2 would be more reasonable since at *c.* 670 Ma deposition and extension of the Dalradian Supergroup was proceeding further south in Scotland. However, based on current data this cannot be confirmed.

It is intriguing that D_3 is much younger (*c.* 437–430 Ma) since the deformation is dominantly extensional with a SE sense of shear. This implies that an earlier crustal thickening event occurred during Caledonian orogenesis, giving rise to a topographc high and gravitational instability. Grampian (*c.* 470–460 Ma) orogenesis is recorded further north in Scotland (Friend *et al.* 2000) and major crustal thickening within the Sgurr Beag Nappe occurred *c.* 455 Ma (see Storey *et al.* 2004). The data presented here imply that one of these events may have thickened the crust as far west as the GAI prior to final D_4 westward thrusting during the Moine Thrust Zone movements at 435–430 Ma.

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