Moine geology of East Glenelg and Loch Duich, Loch Duich - an excursion

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By Craig Storey

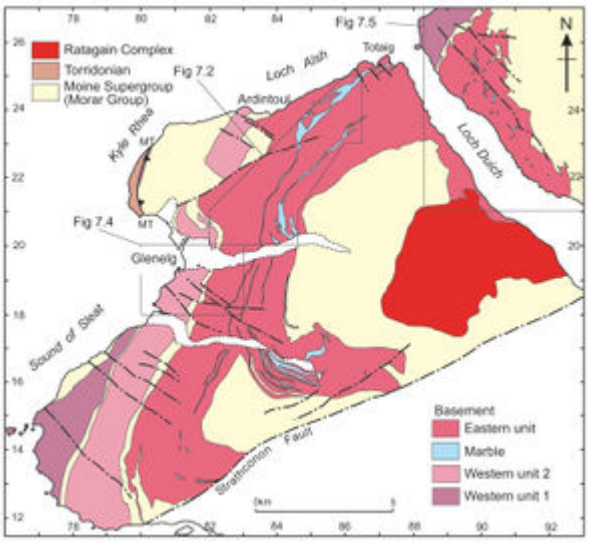

Fig. 7.1 Geological map of Glenelg and Loch Duich, showing the locations of (Fig. 7.2), (Fig. 7.4) and (Fig. 7.5).

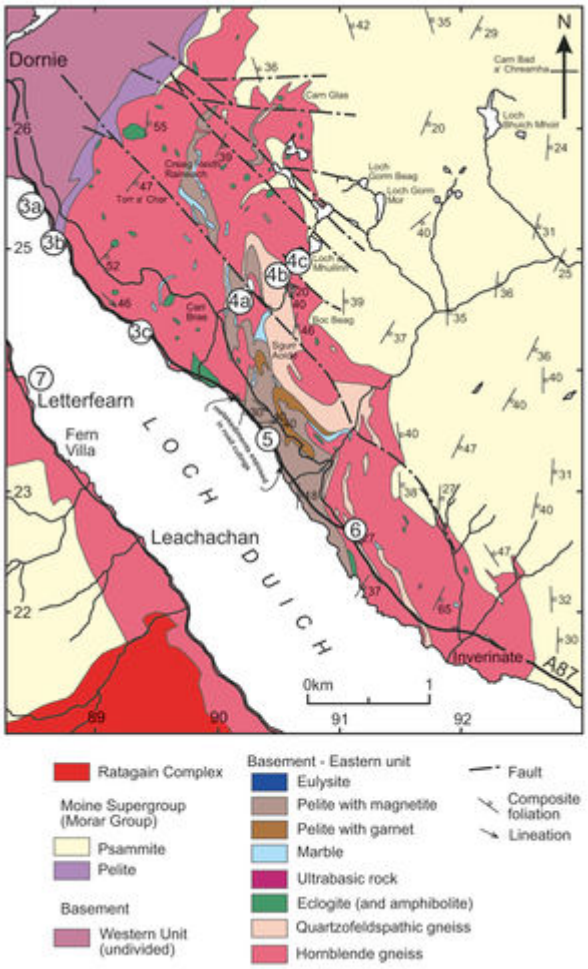

Fig. 7.5 Geological map north of Loch Duich covering Localities 7.3 to 7.7 (based on May et al., 1993, figure 5).

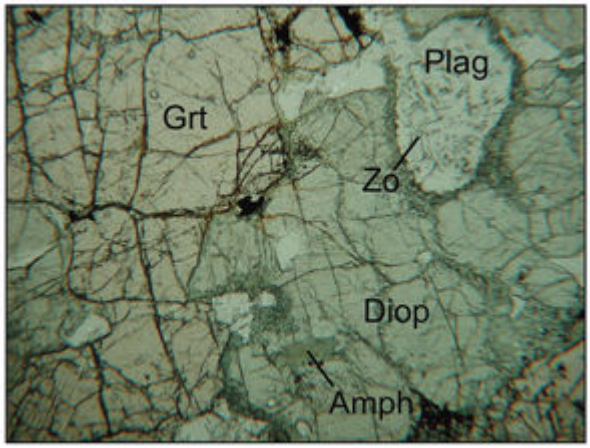

Fig. 7.6 Thin section of high-pressure mafic granulite from Locality 7.3A. Grt = garnet Plag = plagioclase Zo = zoisite Diop = diopside Amph = amphibole Field of view = 3 mm

□

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Excursion 7 East Glenelg and Loch Duich, Loch Duich - an excursion

Locality 7.3 Eilean Donan Castle [NG 885 254] to [NG 8430 2445]

Eilean Donan Castle (Fig. 7.5). A traverse across the boundary between the western and eastern Glenelg inliers; this is similar to Locality 7.2 (although no intervening Moine strip is present), but road cuttings offer more complete exposure.

Allow 2-3 hours for this locality. Park either at the car park at Eilean Donan Castle or at a more convenient location approximately 0.5km 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 (Locality 7.3A, [NG 885 254]). This is within the western Glenelg inlier. The outcrop is high-pressure mafic granulite of Late Archaean age (Storey, 2002; Friend *et al.*, 2008) and clinopyroxene, garnet, plagioclase, hornblende and minor quartz form a coarse granoblastic polygonal texture (Fig. 7.6). Patches and veinlets of trondhjemitic leucosome result from partial melting. On the opposite side of the road, melt veins are more widespread and have locally coalesced to form dcm-scale sheets. A serpentinite body is typical of the rare ultrabasic bodies that are ubiquitously altered to low-grade hydrous assemblages. Walk southwards along the road examining the roadside exposures; a strong, composite steep SE-dipping fabric characterizes the banded gneisses. After ~300m (Locality 7.3B, [NG 887 252]) there is a large sub-vertical road cutting on a shallow left hand bend covered by wire netting. Behind the netting is exposed the contact between the western and eastern Glenelg inliers. It is cryptic as there are no intervening Moine sedimentary rocks to guide. At the southern end of the netting, dark strongly banded ultramylonites contain rounded porphyroclasts of garnet and amphibole and are thought to have been derived by shearing of the eastern basement inlier.

The strong mylonitic fabric persists for up to 1km to the SE along the road. There are two dominant sets of fabrics. D_2 structures often comprise rootless isoclinal folds within the mylonitic foliation and have a strong associated mineral stretching lineation and axial planar mylonitic fabric. These are reworked by D_3 structures which comprise a strong L_3 mineral elongation steeply plunging towards the SE and F_3 curvilinear fold hinges generally close to parallel with the principal D_3 stretching orientation. F_2 isoclines and the mylonitic S_2 fabric are refolded around F_3 folds. Hence, D_2 was the main ductile shearing event, whilst D_3 involved both shearing and folding but, in this area at least, generally not a new penetrative axial planar foliation. Temperley & Windley (1997) describe the

same structures; although their interpretation that the D_2 fabric was extensional is questionable, their observations that the later D_3 deformation is accompanied by steep, extensional shear bands associated with the SE-plunging mineral stretching lineation appears sound. At Locality 7.3C [NG 8930 2445], low outcrops on the landward side of the road demonstrate that the strain here is lower because recognizable trondhjemitic rocks are exposed with migmatitic textures, enclosing partially melted xenoliths of basic rock. These xenoliths must presumably be older than the protoliths of the eclogites (see discussion at end of Locality 7.1 above). By the lochside here, banded trondhjemitic gneisses can be seen translated into high strain zones and, thus, afford an excellent glimpse into the protoliths at different states of strain.

Locality 7.4 Carr Brae to Loch a' Mhuilinn [NG 8995 2445] to [NG 9065 2480]

Carr Brae to Loch a' Mhuilinn (Fig. 7.5). A section across the highly tectonized contact between the upper boundary of the eastern Glenelg inlier and the overlying Moine rocks.

Allow 3-4 hours for this locality. Park at Carr Brae [NG 8995 2445] on the old road along the east side of Loch Duich where there is ample parking for a small coach/minibus and several cars. There is a small picnic area and a pleasant view, ideal for breaking up a day involving one of the other half-day excursions. Head directly uphill to the NE, following the Allt a' Mhuilinn stream, to outcrops on a steep section of the stream approximately 200m from Carr Brae at Locality 7.4A [NG 901 245]. Small layers of eulysite within marble and garnet-biotite gneisses outcrop on the immediate northern side of the stream. Eulysites are metamorphosed manganiferous rocks, characteristically containing fayalite, but hedenbergite, Fe-hypersthene, garnet, magnetite and grunerite are also common. They were first described from Glenelg by Tilley (1936). The eulysites typically have a bluish-black weathered surface (hydrated Mn-oxide) and are very hard; hammering is required to search out these layers for fresh samples. The intimate association of the eulysites with other metasediments can be demonstrated here and they are probably sedimentary (exhalative?) in origin.

Walk ~500m upstream to the NE to Locality 7.4B [NG 906 247] to lowlying outcrops of mylonitised felsic and mafic gneisses. The latter contain rounded porphyroclasts of garnet and amphibole, very similar to the highly deformed units at the base of the eastern inlier, suggesting a comparable state of strain and metamorphic evolution. Garnet-biotite gneisses (metapelites) occur sporadically and contain conspicuous leucosome, which has been remobilized during shearing. It is common to see two lineations on the foliation surfaces throughout this zone, with the earlier L_2 plunging gently towards the east, and a later, steeper L_3 (around 40°) plunging towards the SE (130-140°). The mylonitic S_2 fabric and L_2 are folded around curvilinear F_3 hinges. Locally, a new penetrative S_3 fabric develops axial planar to the F_3 folds and this is in the form of a platy biotite-dominated foliation, which also contains the L_3 mineral stretching lineation. In contrast, S_2 is defined by amphibole rather than biotite, and thus indicates higher grade conditions (i.e. D_3 is retrograde).

The boundary with the overlying Morar Group psammites is exposed at Locality 7.4C [NG 9065 2480]. The contact is intensely sheared and all rocks are ultramylonitic. The contact is marked by a ~5cm layer of ultraphyllonite, which would correlate with the 'basal pelite' of Ramsay & Spring (1962). If this is truly sedimentary in origin, rather than a tectonic phyllonite derived from breakdown of mafic basement rocks, then its preservation is truly remarkable. Although it has been proposed that this contact marks a modified unconformity between the Moines and underlying basement rocks (Ramsay, 1958; Ramsay & Spring, 1962), this view is difficult to sustain given the lack of anything resembling a basal conglomerate and the uniformly high tectonic strain. About 10m above the contact, the Moine psammites contain cm-dcm layers of intensely sheared and friable coarse grained pegmatite. The common presence of such pegmatites within the Moine in the vicinity of contacts with the basement suggests that they may be syn-kinematic, but fixing their precise

timing with respect to D_2 and D_3 remains elusive. The ultramylonitic contact can be followed to the SE around the southern side of Boc Beag, and the zone of highly sheared rocks (the Inverinate Shear Zone of Storey, 2002) is at least 300-400m thick within this part of the eastern Glenelg inlier.

Interpretation of the D_2 history of ductile shearing D_2 mylonitization of basement lithologies and Moine rocks occurred under upper amphibolite facies conditions (13 kbar and 650-700°C; Storey *et al*., 2005) and has been correlated with static replacement of the eclogite paragenesis within low strain eclogite boudins and layers. Brewer *et al*. (2003) dated this retrogression at ~995 Ma, by the U-Pb method on zircon. However, this is older than the youngest detrital zircon age obtained so far within the Moine rocks of the Morar Group (980 ± 2 Ma, Peters, *pers. comm*. in Cawood *et al*., 2007), and so it is likely that D_2 is composite, comprising an older phase associated with initial retrogression of the eclogites before the Moine rocks were deposited, and a younger phase common to both the basement and the Moines. Dating of syn-D_2 titanite within the shear zone at the base of the eastern Glenelg inlier yields an age of ~670 Ma (Storey *et al*., 2004) and thus the basement and the Moines may have been juxtaposed by shearing within the middle crust at some stage in the late Neoproterozoic.

Locality 7.5 Loch Duich roadside [NG 905 233] to [NG 900 239]

Loch Duich roadside (Fig. 7.5). Metasedimentary rocks within the eastern Glenelg inlier.

A superb road cutting that exposes metasediments of the eastern Glenelg inlier occurs behind double crash barriers beside the main A87 road on the east side of Loch Duich at [NG 905 233] northward to [NG 900 239]. This is Locality 7.5. There is a lay-by just to the south of the crash barriers in which to park and there is plenty of room for a coach/minibus and several cars. Beware of common sheep and deer ticks at this locality! At the south end of the cutting, pelitic schists contain biotite, plagioclase, garnet, kyanite, quartz, muscovite and chlorite. Leucosome is ubiquitous, demonstrating partial melting and, as much of the muscovite is retrograde, indicates that the muscovite-out melt reaction has been crossed. Rawson (2004) recorded phengitic (= high pressure) mica in preserved microlithons within these schists, which along with kyanite is probably the only remaining evidence of the earlier eclogite facies history. Further northwards, the rocks grade into calc-pelitic lithologies, with ubiquitous epidote imparting a greeny colouration. At the furthest north part of the outcrop the succession is capped by a marble horizon, although at the time of writing this has been largely overgrown. The rocks here display M and W folds as they are in the hinge zone of a major F3 fold. Rootless F_2 isoclines occur within the folded S_2 fabric and melt veins cut across S_2 but are folded around F3 hinges and have undergone boudinage. Hence, partial melting occurred between D_2 and D_3; an attempt was made to date these melts, but they did not yield uranium-bearing accessory minerals.

Locality 7.6 Loch Duich roadside [NG 9115 2260]

Loch Duich roadside (Fig. 7.5). Relationships between dated pegmatite and D_2 and D_3 structures.

Head south to the junction where the old road over to Dornie, via Carr Brae, meets the A87 at [NG 911 227]. It is possible to park in a lay-by on the A87 here and there is room for a coach/minibus and several cars. Walk approximately 100m south along the road and cross to low-lying outcrops on the landward side of the road [NG 9115 2260]. These expose typical banded mafic and felsic gneisses of the eastern Glenelg inlier with a dominant high-strain S_2 fabric. Conspicuous granitic pegmatites cut the dominant S_2 fabric in a number of places. F_3 folds, with curvilinear hinges, refold the S_2 fabric and a pegmatite. The pegmatite has yielded a U-Pb titanite age of 437 ± 6 Ma (Storey *et al*., 2004); D_3 must therefore be younger than this and D_2 older.

Locality 7.7 Loch Duich lochside [NG 8845 2380]

Loch Duich lochside (Fig. 7.5). Relationships between dated granite sheet and D_2 and D_3 structures.

Head southwards to Shiel Bridge on the A87 and take the turn towards Ratagan and Glenelg. After about 1 km take the sharp right turn downhill towards Ratagan on the small single lane lochside road that ends at Totaig. Continue past the Ratagan Youth Hostel to Letterfearn and use one of the passing places to park, leaving plenty of room for other cars to pass by. Space is restricted to a small minibus or two cars.

Exposures to be visited are on the loch shore at [NG 8845 2380] on the north side of a small bay at Letterfearn. Care is required as the tide imparts a treacherous slippery surface to the outcrops! A ~3m high south-facing exposure contains a granite sheet about 20cm wide coincident with a fracture in the rock. The margin of the granite cuts the dominant S_2 fabric. The S_2 fabric is within amphibolite and is defined chiefly by amphibole and plagioclase; on the east-dipping foliation surfaces a dip-slip L_2 mineral stretching lineation plunges moderately towards the east, but is variable as it is reworked by D_3 deformation. In the highest part of the outcrop, to the right (lochward) of the granite sheet, the amphibolite contains tabular garnet and elongated prisms of relict omphacite, replaced by symplectites of amphibole and plagioclase and neoblastic garnet. The retrogressed eclogite is of the streaky variety, containing quartzo-feldspathic threads, but no kyanite has survived. This is a relict of the D_1 eclogite fabric that has been statically overprinted during upper amphibolite facies retrogression. The fabric is coplanar and colinear with D_2 and implies that D_1 had a similar principal stretching axis to D_2. At the margins of the granite sheet the D_2 (and relict D_1) fabric is deflected into an upright attitude and a new S_3 foliation and L_3 lineation, defined by aligned amphibole and biotite, is developed that dips towards the SE with a dip-slip lineation. This D_3 fabric is also well developed within the granite sheet. Minor fold hinges throughout the host amphibolite are markedly curvilinear and vary in plunge by up to 80°. A metre behind this small exposure, on the beach, a prominent F_3 fold hinge plunges gently towards the SE. Note that the earlier L_2 lineation is folded around the hinge and reoriented into near horizontal with a N-S azimuth. The granite sheet was therefore intruded after D_2 and before D_3. Zircon fractions from the granite give a U-Pb discordia lower intercept age of 672 ± 75 Ma, whereas euhedral titanite gives a concordant age of 520 ± 11 Ma (Storey *et al*., 2004). D_2 is therefore at least late Neoproterozoic in age, and D_3 must be younger.

Interpretation of the D_3 history of folding and shearing

The evidence obtained from Locality 7.6 suggests that D_3 structures are younger than 437 ± 6 Ma and hence must have developed during the Lower Palaeozoic Caledonian orogeny. The D_3 fabric is reworked by brittle-ductile chlorite grade (greenschist facies) shear zones that can be confidently correlated with movements on the Moine Thrust Zone at 437-430 Ma (Freeman *et al*., 1998). Hence, it appears that D_3 is fairly tightly bracketed. Whilst it is clear that D_3 involved large-scale folding with axes trending NE-SW affecting the Glenelg inlier and surrounding Moine and giving rise to the spectacular fold interference patterns described by Ramsay (1958 and this volume), what has been understated is the amount of shearing associated with this deformation. Evidence of a locally penetrative lower amphibolite facies S_3 and associated L_3 mineral stretching lineation has been presented and is often associated with upright extensional top-to-the-SE shears. Temperley & Windley (1997) presented kinematic evidence for this episode of extensional shearing, but due to the lack of geochronology at the time interpreted this as being part of the extensional exhumation history of the eastern Glenelg inlier. However, since this is not the case, an explanation must be sought within the framework of the Caledonian orogeny. The Glenelg area is in the footwall of the Sgurr Beag Thrust, which has an earlier history than the Scandian (*c*.435-430 Ma) deformation that

typifies much of the NW Highlands (Kelley & Powell, 1985; Kinny *et al.*, 2003b). There is evidence of earlier Grampian (*c.*470-460 Ma) crustal thickening within the NW Highlands (Kinny *et al.*, 1999; Friend *et al.*, 2000) and one possible explanation is that the Morar Group and underlying basement underwent crustal thickening during the Grampian that was followed by extensional reworking prior to Moine Thrust (Scandian) times.

References

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