A stratigraphic framework for the early Neoproterozoic successions of the Northern Highlands of Scotland.

UK Stratigraphic Framework Series

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Internal Report OR/21/072

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A stratigraphic framework for the early Neoproterozoic successions of the Northern Highlands of Scotland.

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Foreword

The purpose of a Stratigraphical Framework Reports is to establish a framework down to formation level that can be used as a central reference by geologists working with units in a particular time frame and region, in this case late-Mesoproterozoic to early Neoproterozoic rocks of the Northern Highlands of Scotland. The process of erecting a framework requires decisions to be taken about correlations and equivalences leading to a unified nomenclature. This nomenclature then supports the digital geological maps (GB-Geology, also known as DigMap) and the BGS Lexicon. The lithostratigraphical conventions applied are those of the North American Commission on Stratigraphic Nomenclature (1983) however, as many units are strongly metamorphosed and deformed, the conventions need to be applied with some flexibility.

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I'd like to thank all the people who have worked over the years on bedrock problems in the Northern Highlands, in particular: Helen Bonsor, Graham Leslie, Rob Strachan, Tony Prave, Kathryn Goodenough, and the late John Ramsay. Rob Strachan, Tony Prave and Helen Bonsor are thanked for providing thorough reviews.

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Summary

This report sets out a revised stratigraphic framework for the for the late Mesoproterozoic and early Neoproterozoic successions of the Northern Highlands of Scotland. The late Mesoproterozoic comprises the Stoer Group that, despite its small outcrop, is well exposed and studied. No major changes as to subdivision are proposed for this group.

The classic subdivision of Torridonian and Moine Supergroup for the early Neoproterozoic sedimentary rocks of the Northern Highlands of Scotland has become incompatible with new datasets (detrital zircon dates, radiometric dating of metamorphic and igneous events, sedimentological studies) and is now stratigraphically invalic. Supergroup status for the Moine is not warranted, since there is no stratigraphic continuity (as previously thought) between the Morar and Glenfinnan groups. Instead, the successions are grouped into two new Supergroups: an older *Wester Ross Supergroup* and a younger *Loch Ness Supergroup*. This subdivision is now compatible with the broad subdivisions in the wider North Atlantic region.

The Wester Ross Supergroup includes the Sleat, Torridon and Morar groups, and likely the Iona, Tarskavaig (Skye), and Sand Voe, Yell Sound and Westing (Shetland) groups. These units were deposited between c. 1000-950 Ma, sourced from the Grenville orogen and deposited in a broad foreland-basin setting. Some Wester Ross Supergroup units (and equivalents in Greenland and Svalbard) have been affected by c. 950-910 Ma Renlandian metamorphic and igneous events, and deposition must thus predate this orogeny.

The Loch Ness Supergroup includes the Glenfinnan and Loch Eil groups, as well as the Badenoch Group in the Grampian Highlands. Contacts between the Glenfinnan and Morar groups are sheared everywhere and there is no evidence for stratigraphic continuity. The Loch Ness Supergroup was deposited between c. 900 and 870 Ma and is at least partly associated with an extensional tectonic event.

The Wester Ross Supergroup and the Loch Ness Supergroup, together with the late (<720 Ma) Neoproterozoic Dalradian Supergroup, can be correlated with the three major Megasequences recognised in the wider Neoproterozoic Northern Atlantic setting, each recording major tectonic events in the Laurentian sector of Rodinia. The late Mesoproterozoic Stoer Group remains distinct.

All early Neoproterozoic Formation and Members across the Northern Highlands have been critically assessed and the terminology has been rationalised.

1 Introduction

The northern Highlands of Scotland are dominated by thick sequences of Early Neoproterozoic sedimentary rocks that form an important record of the early evolution of the Rodinia Supercontinent in Eastern Laurentia (e.g. Cawood *et al.* 2010; Krabbendam *et al.* 2017). Traditionally, these sequences were subdivided into unmetamorphosed ‘Torridonian’ rocks in the west and the metamorphosed Moine Supergroup in the east, separated by the Caledonian Moine thrust (Gibbons and Harris, 1994; Trewin 2002) (Figure 1).

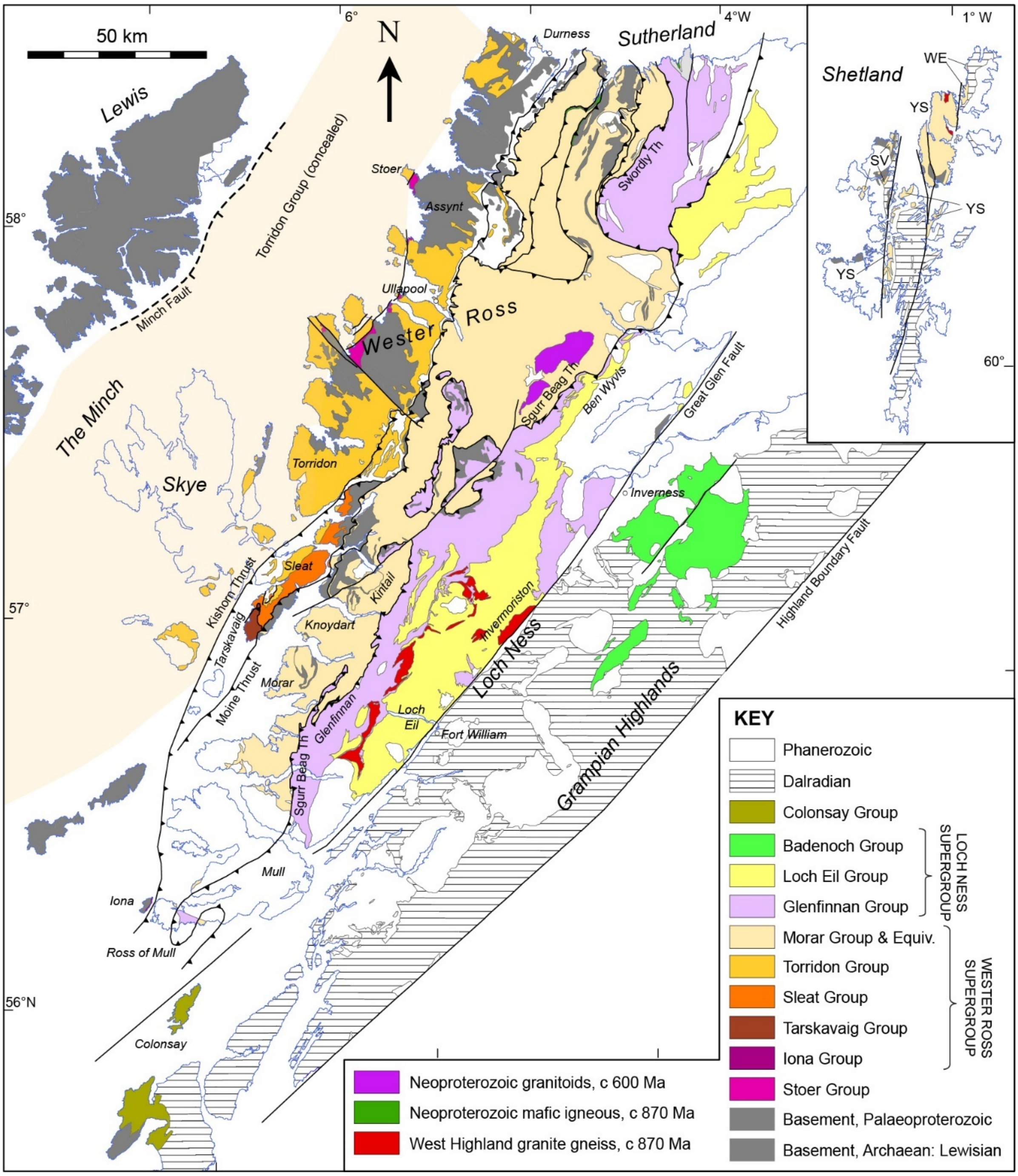

Figure 1 Geological map of Northern Highlands and Shetland (same scale) simplified after British Geological Survey (2007a). In Shetland: YS = Yell Sound; WE = Westing Group; SV = Sand Voe Group. Basement inliers: EG = Eastern Glenelg Inlier; SC = Scardroy Inlier; SW = Swordly Inlier

The 'Torridonian' rocks include the Stoer, Sleat and Torridon groups (e.g. Stewart 2002), whilst the Moine Supergroup was subdivided into the Morar, Glenfinnan and Loch Eil groups (e.g. Johnstone et al. 1969; Holdsworth et al. 1994).

Correlations between the Torridonian and the Moine successions have been tentatively suggested and discussed for over 90 years (e.g. Peach & Horne 1930; Kennedy 1951; Sutton & Watson 1964), but consensus throughout the 20th Century remained that such links were uncertain, and that sequences were deposited in different basins and possibly at different times (e.g. Soper et al. 1998; Stewart 2002; Strachan et al. 2002; Cawood et al. 2004). The Torridonian rocks were interpreted as continental rift sequences (Williams 1969a; Stewart 1982; 2002; but see Nicholson 1993), with a precursor of the Minch Fault as a basin-bounding fault to the west. The Moine rocks were generally seen as a shallow marine rift-fill (Soper et al. 1998), with a western basin-bounding fault approximately along the trace of the younger Moine Thrust.

However, in the last c. 20 years, sedimentological studies (Bonsor & Prave 2008; Krabbendam et al. 2008; Bonsor et al. 2010, 2011), the isotopic dating of detrital minerals such as zircon and rutile (Rainbird et al. 2001; Kinnaird et al. 2007; Cawood et al. 2004; 2015; Kirkland et al. 2008a; MacAteer et al. 2014; Krabbendam et al. 2017; Lebeau et al. 2020) and dating of metamorphic and igneous events (e.g. Cutts et al. 2009, 2010; Cawood et al. 2015; Bird et al. 2018) have added substantially to our understanding of the age and basin setting of these successions. Many observations are at odds with the with the traditional separation between 'Torridonian' and 'Moine'.

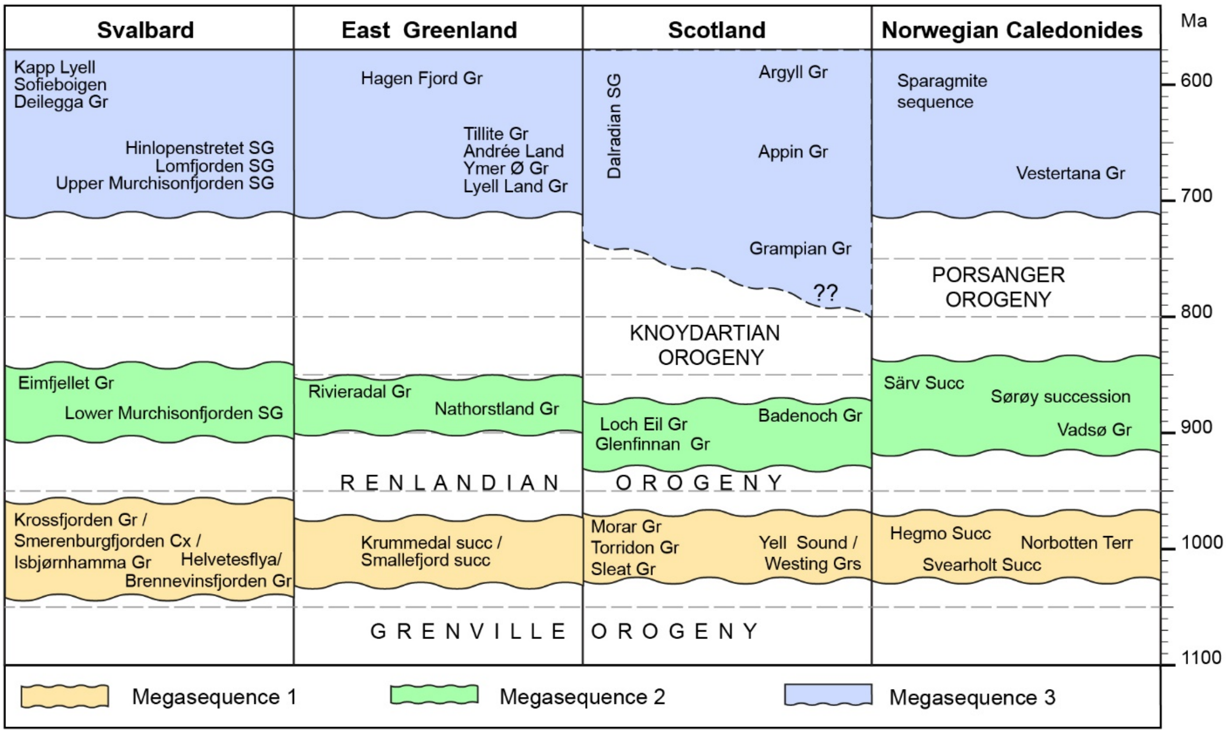

Figure 2 Summary diagram of Neoproterozoic Megasequences for the North Atlantic region (simplified after Olierook et al. 2020; see also Krabbendam et al. 2021).

Similar studies have been carried out on the broadly coeval Neoproterozoic sedimentary sequences in Greenland, Svalbard and Scandinavia and these suggest that they can be organised into three 'megasequences' (Kirkland *et al.* 2008a; Cawood *et al.* 2010; Agyei-Dwarko *et al.* 2012; Olierook *et al.* 2020)). Megasequence 1 (Figure 2) involved a period of deposition between c. 1000 – 950 Ma, following or overlapping with the Grenville Orogen. A number of Megasequence 1 units were deformed and metamorphosed during the c. 950-910 Ma Renlandian Orogeny (Cawood *et al.* 2010; Olierook *et al.* 2020). Megasequence 2 represents a period of sedimentation between c. 900 – 850 Ma, after the Renlandian orogeny. Megasequence 3 represent sedimentation after c. 725 Ma through to the Cambrian, and was associated with the final break-up of Rodinia and the development of the Iapetus ocean. The three-fold megasequences for the North Atlantic region, as proposed by Olierook *et al.* (2020), include the successions in Scotland (Figure 2): Megasequence 1 includes the Sleat, Torridon and Morar groups, Megasequence 2 the Glenfinnan, Loch Eil and Badenoch groups, and Megasequence 3 is represented by the Dalradian Supergroup. This division is clearly different from the traditional separation between 'Torridonian' and 'Moine'. As a consequence, a new stratigraphic framework (Krabbendam *et al.* 2021) proposes that the Scottish equivalents of Megasequence 1 are to be grouped as the *Wester Ross Supergroup*, and the equivalents of Megasequence 2 to be grouped as the *Loch Ness Supergroup* (Figure 2).

1.1 NOTE ON YOUNGEST DETRITAL MINERALS

In the absence of palaeontological evidence, maximum depositional ages of Precambrian sequences are commonly provided by the U-Pb dating of detrital accessory minerals such as zircon, titanite and rutile. It is now recognised that best practice is to use the youngest peak on a Kernel Density Estimation (KDE) plot and analyse a large number (n > 100-300) of detrital minerals (Vermeesch 2012; Pullen *et al.* 2014). It is possible that if a small number of zircons has been dated, the true youngest zircon is 'missed' in sampling (Pullen *et al.* 2014). As an example, Kinnaird *et al.* (1997) obtained a youngest zircon date of *c.* 1265 Ma from the upper Sleat Group (n = 30), whilst Krabbendam *et al.* (2017) obtained youngest zircons between 1060-1000 Ma for the same stratigraphic level (n = 150), thus lowering the maximum depositional age by c. 250 Myr. The data referred to in this report span 20 years and, though not necessarily of a quality or quantity that would now be regarded as best practice, nevertheless still provide useful constraints.

2 Setting and tectonic overview

Deposition of the late Mesoproterozoic and early Neoproterozoic successions of northern Scotland occurred broadly in the period 1200 – 870 Ma on the eastern portion of Laurentia (e.g. Cawood *et al.* 2004; 2015; Krabbendam *et al.* 2017). West of the Moine Thrust (Figure 1), the main depositional units are the Stoer, Torridon and Iona groups; these are only very weakly metamorphosed if at all, and show well preserved stratigraphical relations and sedimentary structures. Within the Moine thrust zone are the Sleat and Tarskavaig groups at low metamorphic grade (lowest greenschist facies). East of the Moine Thrust are the Morar, Glenfinnan and Loch Eil groups, within which there is evidence for amphibolite-facies metamorphism, partial melting and deformation at 950-940 Ma (***Renlandian***; Bird *et al.* 2018), 820-725 Ma (***Knoydartian***; Rogers et al. 1998; Vance et al. 1998; Tanner & Evans 2003; Cutts *et al.* 2010; Cawood *et al.* 2015) and 470-425 Ma (***Caledonian***; Bird *et al.* 2013; Mako *et al.* 2021; Strachan *et al.* 2020a).

The Moine Supergroup is cut by large-scale ductile thrusts, making it difficult to trace individual units. The relatively monotonous nature of the sedimentary protoliths, an absence of distinct marker lithologies, and the high degree of deformation and metamorphism has hampered sedimentological interpretation and correlation. Sedimentary structures are heavily modified or completely obliterated, with pelitic rocks (metamudstones) being particularly vulnerable to recrystallization and migmatisation. Nevertheless, some detailed sedimentological studies have been carried out in well-exposed low strain zones (Strachan 1986; Glendinning 1988; Strachan *et al.* 1988; Bonsor *et al.* 2010, 2012), but it should be appreciated that these studies represent a small sample of sections and are somewhat biased towards psammitic/sandy units. As a consequence, there is far less known about the sedimentology of the Moine rocks than of the Torridonian rocks.

In contrast, the abundant, excellent and abundant outcrops of the Torridonian rocks have made these a prime test-bed for sedimentological studies of pre-vegetation fluvial sedimentary systems and soft-sediment deformation features (e.g. Selley 1969; Stewart 1982; 1988; 2002; Nicholson 1993; Owen & Santos 2014; Ielpi & Ghinassi 2015; McMahon & Davies 2020). The overall stratigraphy is well understood (Stewart 1969; 2002; Park *et al.* 1994).

2.1 BASEMENT

The Neoproterozoic successions were deposited on crystalline basement of Archaean to Palaeoproterozoic age. Basal unconformities are locally well exposed, but strongly deformed east of the Moine Thrust. The nature of the basement is important to assess potential source areas, but also to interpret the disposition and stratigraphic bases of the different sequences. Most of the basement of the Caledonian foreland comprises the Lewisian Gneiss Complex, which is dominated by meta-igneous rocks with Archean protolith ages (e.g. Kinny and Friend 1997; Friend and Kinny 2001; Kinny *et al.* 2005; Fischer *et al.* 2021), but also contains some Paleoproterozoic igneous and sedimentary rocks, such as the Loch Maree Group, the South Harris Complex and various “Laxfordian” granitoids (e.g. Park *et al.* 2002; Mason *et al.* 2004; Kinny *et al.* 2005; Goodenough *et al.* 2013). In the far SW of Scotland and in west Ireland the c. 1750-1800 Ma Rhinns Complex is present (Marcantonio *et al.* 1988; Muir *et al.* 1992; Daly *et al.* 1991; Daly 1996). In an overall Atlantic setting, it thus appears there is a boundary that separates predominantly Archean basement to the north or NE and younger Paleoproterozoic basement to the south, which includes terranes such as the Makkovik, Ketilidian and Rhinnian. East of the Moine Thrust, basement occurs as tectonically emplaced inliers (‘Lewisianoid inliers’), either in the cores of major folds, or resting on ductile thrusts (Figure 1; Tanner 1970; Rathbone & Harris 1979; Strachan & Holdsworth 1988). Some of these inliers have been dated, and there appears to be a mix of Archean (c. 2900-2700 Ma) and Paleoproterozoic (1800-1710 Ma) protolith ages (Friend *et al.* 2008; Strachan *et al.* 2020b).

Some inliers record the effects of Grenvillian orogenesis. The Eastern Glenelg Inlier records high-pressure eclogite-facies metamorphism (1082 ± 22 Ma; 1010 ± 13 Ma; Sanders *et al.* 1984; Storey *et al.* 2005) and exhumation at 994 ± 8 Ma (Brewer *et al.* 2003). The Swordly Inlier also shows isotopic disturbance at c. 1008 Ma (Strachan *et al.* 2020b) and Archaean basement in NE Shetland was reworked at c. 1050 Ma (Walker *et al.* 2021).

2.2 RESTORATION OF LATER OROGENIC DEFORMATION

The Moine rocks are disposed in a series of broadly east-dipping ductile thrust sheets (Figure 1; Tanner 1970; Barr *et al.* 1986). The schematic restoration of the various thrust sheets (Figure 3) is an update of Winchester's (1988) diagram and conveys the relative disposition of units at the time of their deposition.

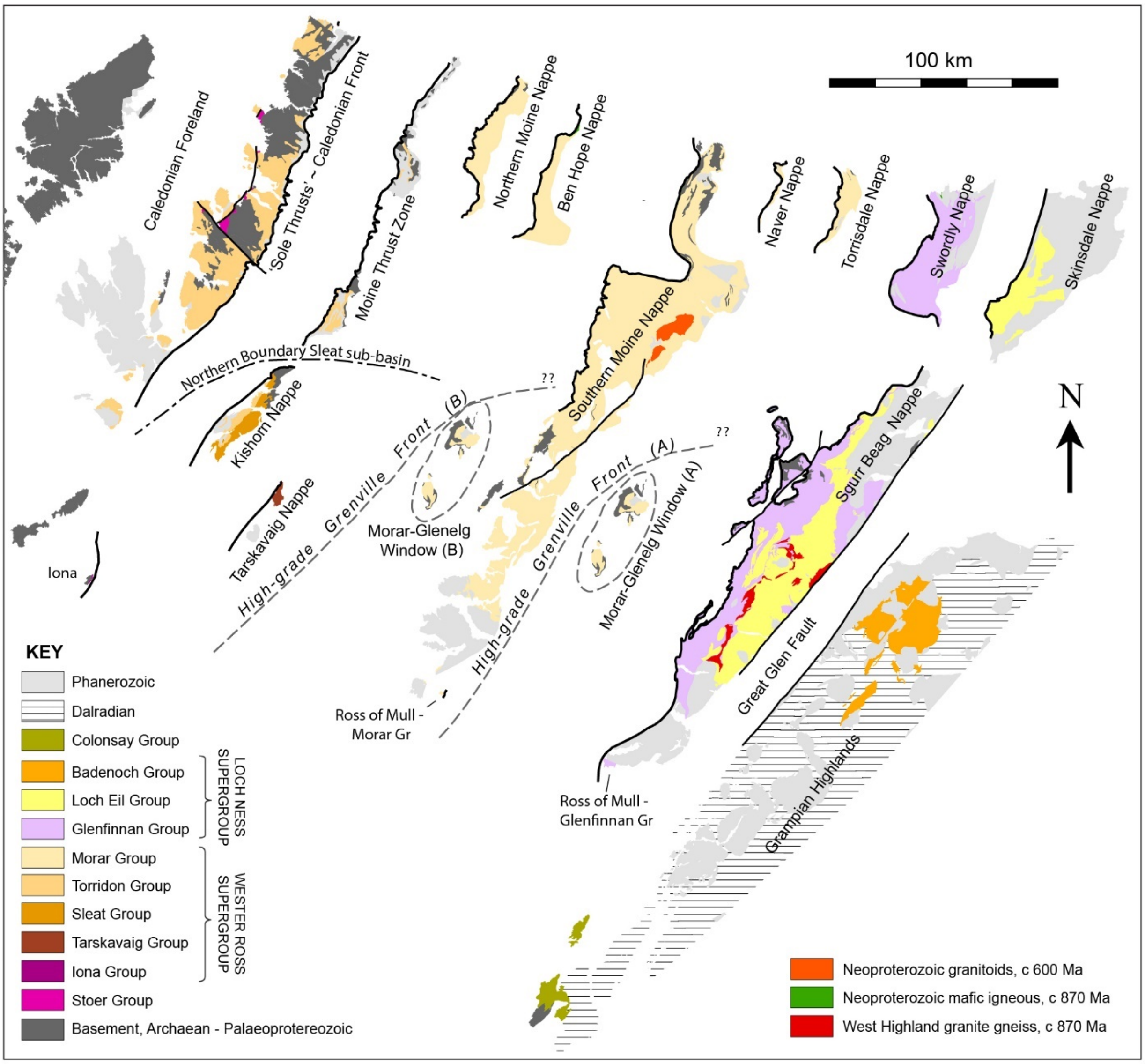

Figure 3 Schematic structural reconstruction of the Northern Highlands (modified after). Two possible positions of the Morar-Glenelg Window, and hence the Grenville front, are shown. No absolute displacement constraints are intended, scale is only applicable for the size of the nappes and does not depict absolute transport distance, nor the internal deformation of the nappes (after an idea from Winchester 1988).

For simplicity, all thrusts are assumed to have been transported to the WNW; in reality there was a more complicated interplay of NNW and WNW-directed movements (e.g. Kelley & Powell 1985; Krabbendam *et al.* 2011; Mazza *et al.* 2018). The restoration does not show the true displacement of the thrusts (the Moine Thrust alone likely had a displacement of > 100 km, Elliott & Johnson 1980; Strachan *et al.* 2002; Krabbendam *et al.* 2008), nor does it show the internal deformation, which was substantial (> 50% shortening) particularly in the ductile thrust sheets east of the Moine thrust (e.g. Roberts *et al.* 1987; Strachan & Holdsworth 1988; Holdsworth 1989; Krabbendam *et al.* 2011, Mazza *et al.* 2018). No Knoydart Thrust is shown: Krabbendam *et al.* (2014) showed it does not exist. The position of the Morar-Glenelg Window, the lower limb of the large poly-orogenic Southern Moine Nappe, remains uncertain given that the transport direction of an early (Knoydartian?) fold nappe is unknown and may have been towards the SE (Krabbendam *et al.* 2018). Nevertheless, the reconstruction provides relative disposition and possible original palaeogeographical extents of the different groups.

3 Reasons for high-level revision of the stratigraphic framework

The broad reasons for the revision into the Wester Ross and Loch Ness Supergroup are twofold (Krabbendam *et al. 2021*):

1) The Torridon and Morar groups can be correlated across the Moine thrust and should thus belong to the same Supergroup;
2) The Glenfinnan-Loch Eil groups are considerably younger than the Morar group and are separated by an orogenic unconformity, therefore should *not* belong to the same Supergroup (i.e. the Moine Supergroup).

3.1 TORRIDON - MORAR GROUP CORRELATION ACROSS THE MOINE THRUST

Evidence for correlation between the Torridon and Morar groups is as follows (Krabbendam *et al.* 2008; 2017):

i. The Morar and Torridon groups both unconformably overlie basement of comparable Archaean–Paleoproterozoic age (Holdsworth *et al.* 1994; Friend *et al.* 2008; Stewart 2002; Kinny *et al.* 2005; Strachan *et al.* 2020b). Both have locally developed basal conglomerate facies, together with (meta)siltstone and (meta)sandstone, above the unconformity. The Strathan Conglomerate (Mendum 1976) and the Meadie Schist Formation (Bird *et al.* 2018) of the basal Morar Group are the equivalent of the Diabaig Formation at the base of the Torridon Group;
ii. Youngest detrital zircons for all unite fall within the period 1070 – 1000 Ma; for units at comparable stratigraphic level they are within error; (Rainbird *et al.* 2001; Friend *et al.* 2003; Kirkland *et al.* 2008a; Cawood *et al.* 2015; Krabbendam *et al.* 2017**;** 2021);
iii. The detrital zircon spectra are similar, showing a dearth or sparsity of Archaean zircons, and sharp and well-defined dominant late Paleoproterozoic peaks either at c. 1650 or c. 1750 Ma, depending on the particular unit (Rainbird *et al.* 2001; Friend *et al.* 2003; Kirkland *et al.* 2008a; Cawood *et al.* 2015; Krabbendam *et al.* 2017). Peaks between 1500-1200 Ma also occur but are subsidiary to the main late Paleoproterozoic peaks;
iv. The Applecross–Aultbea formations (Torridon Group) and Altnaharra – Lower Morar formations (Morar Group) comprise 3-5 km thick sequences of monotonous, coarse to very coarse (meta)sandstone with local pebble lags and some finer-grained sandstone and minor muddy–pelitic layers that become more common at higher stratigraphical levels. The two sequences lack marker horizons of different lithologies. Sedimentary structures in the formations are the same in style, scale and frequency, and include metre-thick cross-stratified beds, unidirectional trough cross-bedding and 1–5 m deep nested channels. Soft-sediment deformation structures, such as contorted bedding and oversteepened to overturned cross-beds, are common (Selley 1969; Nicholson 1993; Stewart 2002; Owen and Santos 2014; Krabbendam *et al.* 2008; Bonsor *et al.* 2010);
v. Dominant paleocurrents in the Torridon Group range from SE to NE (Nicholson 1993; Williams 2001) and those in the lower Morar group are east to NNE, swinging to a more northerly direction (NNW-NNE) in the upper Morar group (Glendinning 1988; Bonsor & Prave 2008; Krabbendam *et al.* 2008; Bonsor *et al.* 2010; 2012);
vi. The Applecross–Aultbea and Altnaharra formations (basal Morar group) are interpreted as fluviatile, rapidly deposited in a high-energy, braid plain environment (Nicholson 1993; Stewart 2002; Krabbendam *et al.* 2008; Bonsor *et al.* 2010; 2012).

3.2 AGE GAP BETWEEN THE MORAR AND GLENFINNAN GROUPS

In the North Atlantic sequences, deposition of Megasequence 1 units (e.g. the Krummedal sequence in East Greenland, the Heggmovatn and Svearholt sequences in Norway and the Krossfjorden sequence in Svalbard) can be bracketed by youngest detrital zircons at c. 1070-1000 Ma and intrusions and/or metamorphism and migmatisation at c. 960-910 Ma (Strachan et al. 1995; Watt & Thrane 2001; Kirkland et al. 2007; Pettersson et al. 2009a, b; Agyei-Dwarko et al. 2012). The c. 960-910 Ma metamorphism is associated with the accretionary Renlandian Orogeny, an early phase of the Valhalla Orogen (Cawood et al. 2010). (Note: some older studies refer to this orogen as a 'northern branch of the Grenville Orogen'). The younger Nathorstland Group in east Greenland and the Sørøy sequence in north Norway are not affected by Renlandian magmatism or metamorphism, but contain youngest detrital zircons of Renlandian age and thus must post-date this orogeny (Watt & Thrane 2001; Dhuime et al. 2007; Kirkland et al. 2007): they are thus assigned to Megasequence 2 (Olierook et al. 2020).

In Scotland, evidence of Renlandian metamorphism or magmatism has been documented by Bird et al. (2018) as high-grade metamorphism at c. 950-940 Ma (Lu-Hf and Sm-Nd on garnet) in the Meadie Schist Formation (lower Morar Group in Sutherland), and with metamorphic ages in Shetland between 944 – 910 Ma (Cutts et al. 2009; Jahn et al. 2107; Walker et al. 2021). In Shetland, Yell Sound Group deposition is constrained between c. 1019 Ma (age of the youngest detrital zircon) and c. 944-931 Ma (age of high-grade metamorphism) (Jahn et al. 2017). Similarly, the depositional age of the Westing Group is constrained between 1031 ± 5 Ma (age of the youngest detrital zircon) and 925 ± 10 Ma (age of high-grade metamorphism) (Cutts et al. 2009). Overall, deposition of the Morar Group and its equivalents is therefore constrained between c. 1000 and c. 950 Ma (Figure 4).

In contrast, youngest detrital zircons from the Glenfinnan, Loch Eil and Badenoch Groups (Figure 4) are between c. 1000 – 900 Ma, typically some 100 Myr younger than the youngest zircons in the Morar and Torridon groups (Cawood et al. 2003; 2015; Friend et al. 2003; Kirkland et al. 2008a; Cutts et al. 2010; Spencer et al. 2015). Crucially, a number of the youngest detrital zircon ages in the Glenfinnan and Badenoch groups overlap or are younger than the 950-910 Ma dates for metamorphism of the Morar group and its equivalents. As a consequence, an orogenic, 'Renlandian' unconformity must separate the Morar and Glenfinnan groups, with an age gap of 50-100 Myr.

A sheared boundary between the Morar and Glenfinnan groups, mainly represented by the Sgurr Beag Thrust (Figure 1, 3), has been recognised since the 1970s throughout much of the Northern Highlands (Tanner 1970; Rathbone & Harris 1979; Kelley & Powell 1985; Barr et al. 1986; Roberts et al. 1987). Archaean-Paleoproterozoic basement inliers occur locally at the base of the Glenfinnan Group, (e.g. Scardroy Inlier) indicating that it was at least locally deposited unconformably upon basement. However, Holdsworth et al. (1987) argued for stratigraphic continuity between rocks correlated with the Morar and Glenfinnan groups on the Ross of Mull. They argued (i) that the boundary between the Shiaba (= Morar) Group and the Assapol (= Glenfinnan) Group was between the Upper Shiaba Psammite Formation and the Laggan Mor Formation, (ii) that this boundary showed stratigraphic continuity, and (iii) therefore there was a sedimentary transition between the Morar and the Glenfinnan groups. This interpretation formed a crucial part of the stratigraphic frameworks of the Moine Supergroup published in the late 1980s and 1990s (e.g. Roberts et al. 1987; Soper et al. 1998; Holdsworth et al. 1994).

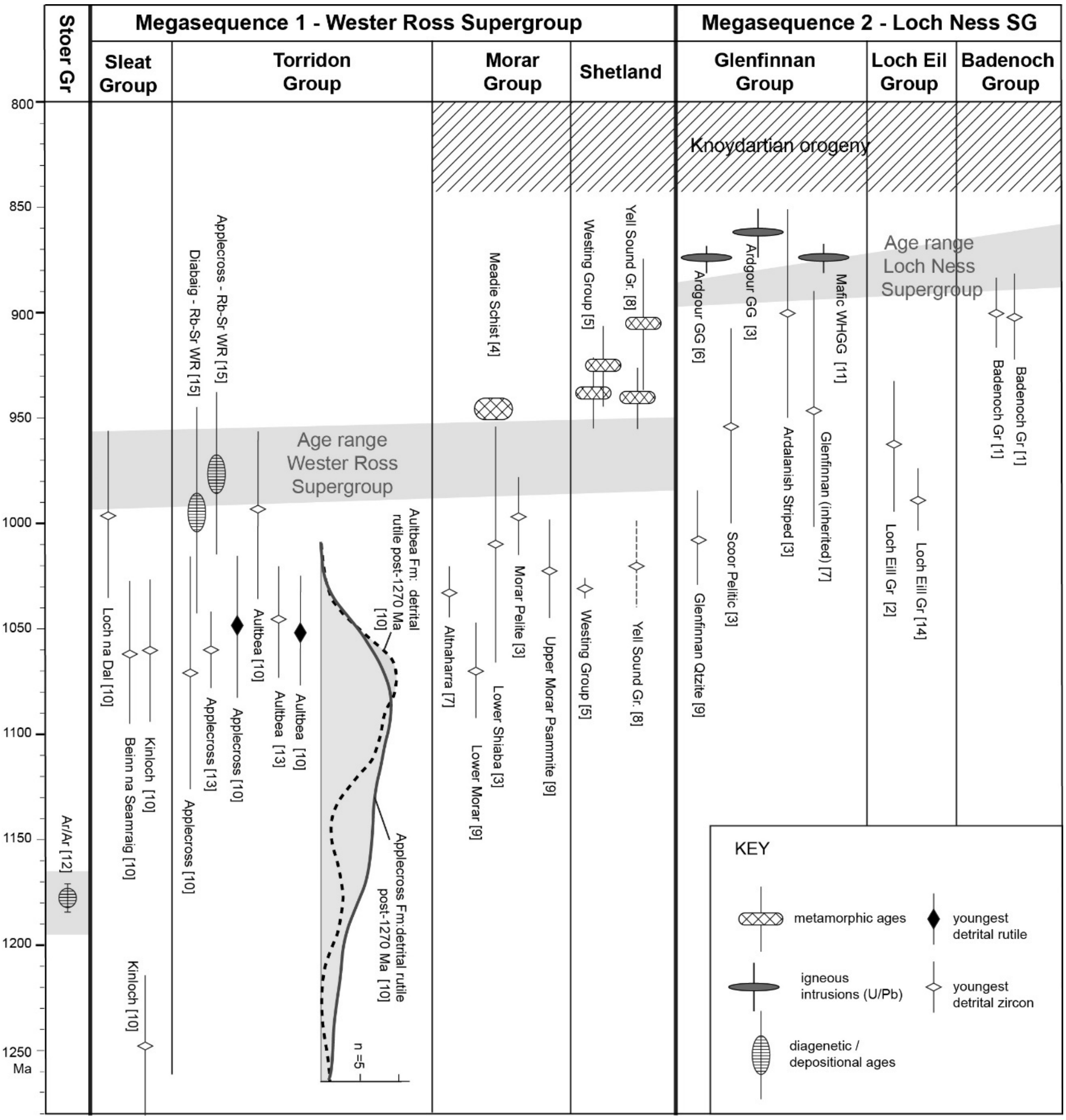

Figure 4 Overview of radiometric age constraints in Northern Scotland provided by youngest detrital zircons and rutile ages, metamorphic and intrusive ages and depositional/diagenetic ages. Data after: [1], [2], [3] Cawood et al. (2003; 2004; 2015); [4] Bird et al. (2018); [5] Cutts et al. (2009); [6], [7] Friend et al. (1997; 2003); [8] Jahn et al. (2017); [9] Kirkland et al. (2008a); [10] Krabbendam et al. (2017); [11] Millar (1999); [12] Parnell et al. (2011); [13] Rainbird et al. (2001); [14] Spencer et al. (2015); [15] Turnbull et al. (1996).

Re-evaluation of the section at Ross of Mull (Krabbendam *et al.* 2021) confirmed that the contact between the Upper Shiaba Psammite and the Laggan Mor formations is indeed transitional, marked by a gradual increase in pelitic beds and a concomitant decrease in psammite bed thickness (Krabbendam *et al.* 2021). However, the higher boundary between the non-migmatitic Laggan Mor Formation and the Scoor Pelitic Gneiss is marked by 100-200 thick high strain zone, culminating in a 10-20 m thick, extremely platy mylonitic zone below the contact with the migmatitic Scoor Pelitic Gneiss. Consequently, the field relationships on the Ross of Mull are reinterpreted (Krabbendam *et al.* 2021) as follows: (1) the Laggan Mor Formation is the local uppermost unit of the Morar Group; (2) a shear zone separates the Morar and Glenfinnan groups, the equivalent to (or possibly the same as) the Sgurr Beag Thrust elsewhere in mainland Scotland; and (3) there is no evidence for uninterrupted stratigraphic continuity between the two groups.

In summary: there is no evidence for stratigraphic continuity from the Morar Group to the Glenfinnan Group. Instead, detrital zircon dating and dating of metamorphism shows that the Morar Group and its equivalents in Shetland were deposited prior to the Renlandian orogeny, whilst the Glenfinnan-Loch Eil-Badenoch groups were deposited after this orogeny. It is thus untenable that these groups should belong to the same supergroup, and the concept of the Moine Supergroup is invalid.

4 Revised Neoproterozoic depositional evolution in northern Scotland

The broad framework of the Neoproterozoic depositional evolution in northern Scotland can be summarised as follows (Figure 5). Deposition onto Lewisian Basement commenced with the Stoer Group, at c. 1180 Ma, as a possible continental rift sequence prior to Grenville orogenic activity. Grenville orogenic activity between c. 1150-1000 Ma created an unconformity, with a c. 150 Myr gap. Deposition of the Wester Ross Supergroup, in a foreland basin setting to the Grenville Orogen, commenced at c. 1000 Ma. It comprised, firstly, deposition of the Sleat, Iona and Tarskavaig groups in a restricted basin followed by more extensive fluvial to shallow-marine deposition of the Torridon, Morar, Sand Voe, Yell Sound and Westing groups. Deposition ceased before 950 Ma, by which time Renlandian orogenic activity had deformed and metamorphosed parts of the sequence in Shetland and northern Sutherland.

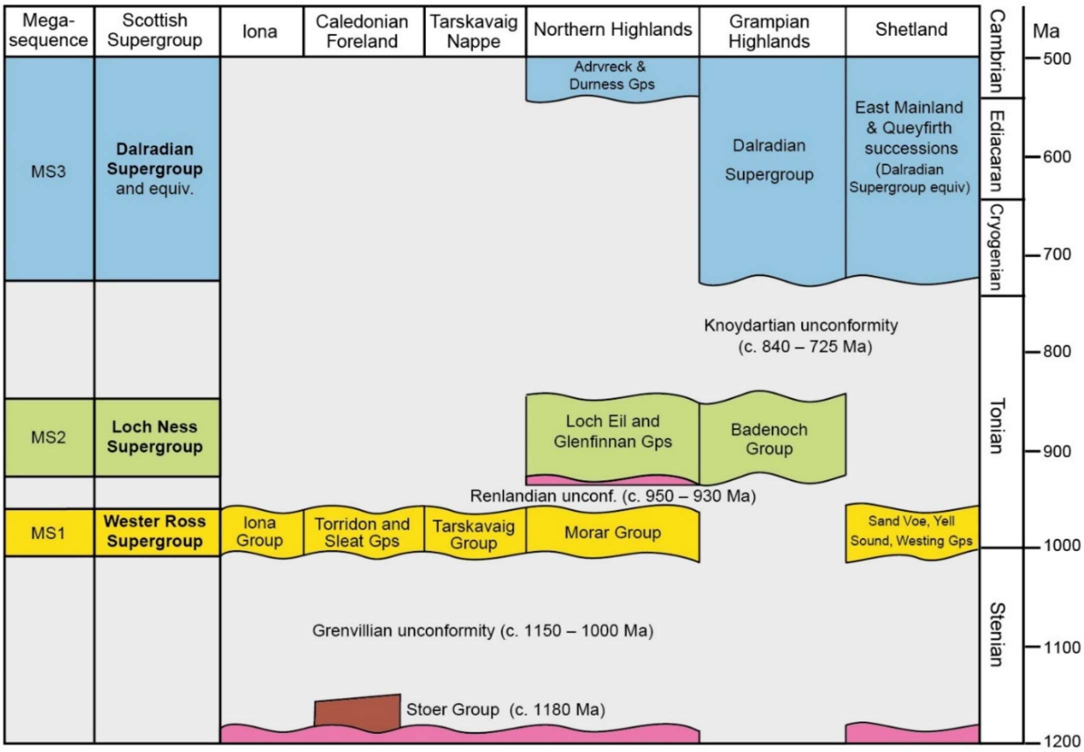

Figure 5 Revised stratigraphic framework for the Neoproterozoic successions of the Scottish Highlands (after Krabbendam et al. 2021).

After a break in deposition, represented by the Renlandian unconformity between c. 950-910 Ma, sedimentation commenced sometime after 910-900 Ma as the Loch Ness Supergroup. These rocks were deposited in a shallow-marine setting, possibly in a distal back-arc to the Renlandian orogen. Deposition ceased between 870-840 Ma, followed by a series of orogenic events and resulting in the Knoydartian Unconformity between c. 840-725 Ma. Rifting of the eastern margin of Laurentia likely commenced around 725 Ma, with the start of the deposition of the basal Dalradian Supergroup as preserved in the Grampian Highlands and Shetland. As rifting progressed into full ocean-opening and development of continental shelfs, deposition continued throughout the Ediacaran into the Cambrian. In the NW Highlands, global transgression led to deposition of the Cambro-Ordovician Ardvreck and Durness Groups.

5 Stoer Group

The Stoer Group was deposited in a small intracratonic basin during the Stenian Period (late Mesoproterozoic), well before deposition of the Torridon Group sandstones. Remnants of the Group are preserved in a number of small outliers in the Caledonian foreland of the NW Highlands, extending from the Stoer Peninsula to Poolewe (Figure 6, see also Stewart 2002). The importance of the Stoer Group belies the size of its extent: in Great Britain it is the oldest non-metamorphosed sedimentary sequence, preserves the oldest life forms, and comprises a meteorite impact ejecta deposit. It is well exposed on various headlands and shows a wide range of well-preserved sedimentary structures and facies. Rare but significant signs of early life occur in the Stoer Group (summarised in Section 5.10). The Group was deposited upon Lewisian Gneiss via a high-relief unconformity with palaeo-relief as much as 300 m. The Torridon Group overlies the Stoer Group via an angular unconformity (c. 15-30°).

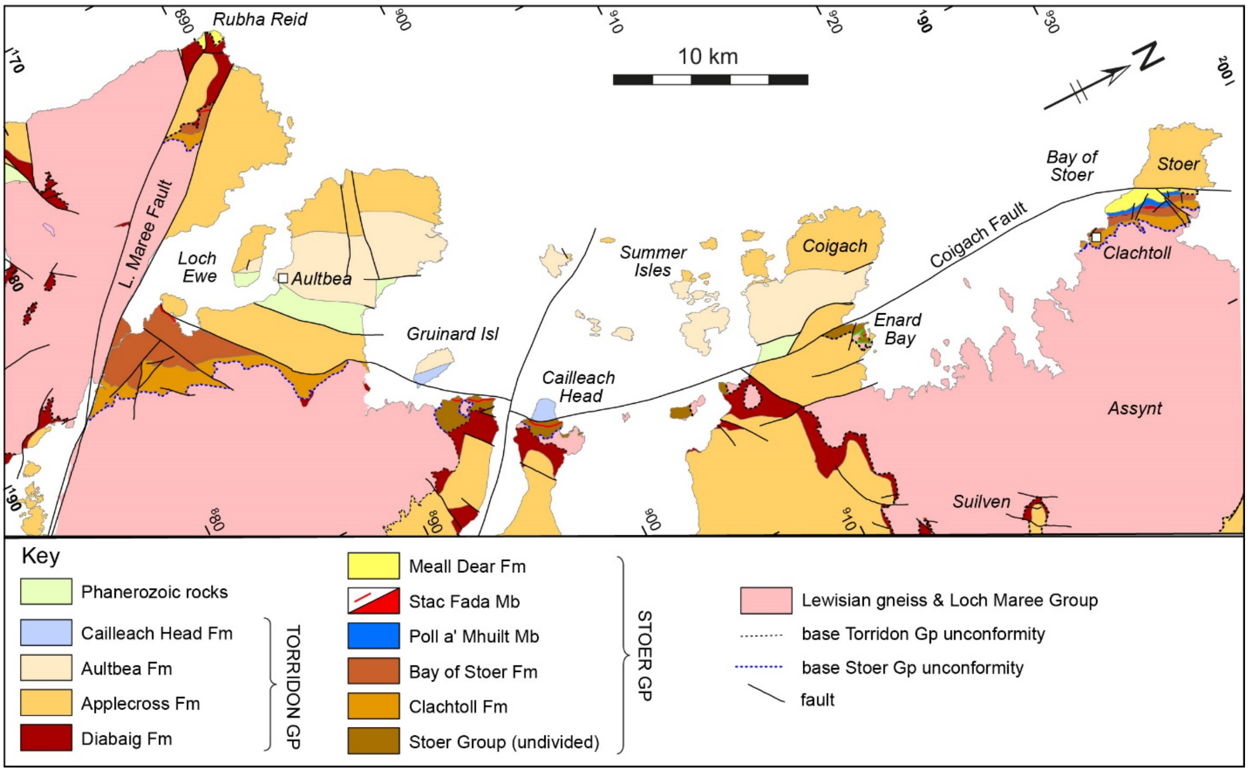

Figure 6 Simplified geological map: distribution of Stoer Group in the NW Highlands. (After 1;50 000 digital geological map, British Geological Survey).

5.1 SUMMARY OF STOER GROUP STRATIGRAPHY

The Stoer Group comprises three formations (Figure 7), from base to top: the Clachtoll, Bay of Stoer and Meall Dearg formations. The Group was deposited on significant relief of the underlying Lewisian basement: e.g. at Stoer and Poolewe the Clachtoll Formation occurs in deep palaeo-valleys whereas the Bay of Stoer Formation overlies a paleo-high of Lewisian Gneiss at Enard Bay. The Clachtoll Formation is marked by a variably developed basal breccia-conglomerate followed by sandstone with minor mudstone beds. The Bay of Stoer Formation comprises cross-bedded red sandstone with rare mudstone layers. Near the top of the formation, the Stac Fada Member is a green sandstone/mudstone with mafic fragments, accretionary lapilli and locally large gneiss clasts. This is followed by the Poll a'Mhuilt Member, comprising massive mudstone with thin stromatolitic limestone beds. The uppermost Meall Dearg Formation comprises thick-bedded, cross-bedded sandstone.

5.2 AGE CONSTRAINTS

Youngest detrital zircons are c. 1740-1730 Ma (Rainbird et al. 2001; Lebeau et al. 2020), although Kenny et al. (2019) reported yougne4st zircons of c. 1430, 1240 and 1230 Ma; deposition must postdate these dates. The unconformably overlying Torridon Group was deposited between 1000-950 Ma, and the two groups have different palaeomagnetic orientations suggesting a considerable time-gap between their deposition (Darabi & Piper 2004). $^{40}Ar/^{39}Ar$ dating of authigenic minerals of the Stoer Group (Stac Fada Member) has yielded an age of 1177 ± 5 Ma (Parnell *et al.* 2011), consistent with previous Pb/Pb dating of limestone (Turnbull *et al.* 1996). Deposition of the Stoer group thus occurred around c. 1180 Ma. No other sequences of this age occur in the British Isles and the Stoer Group thus remains its own independent group.

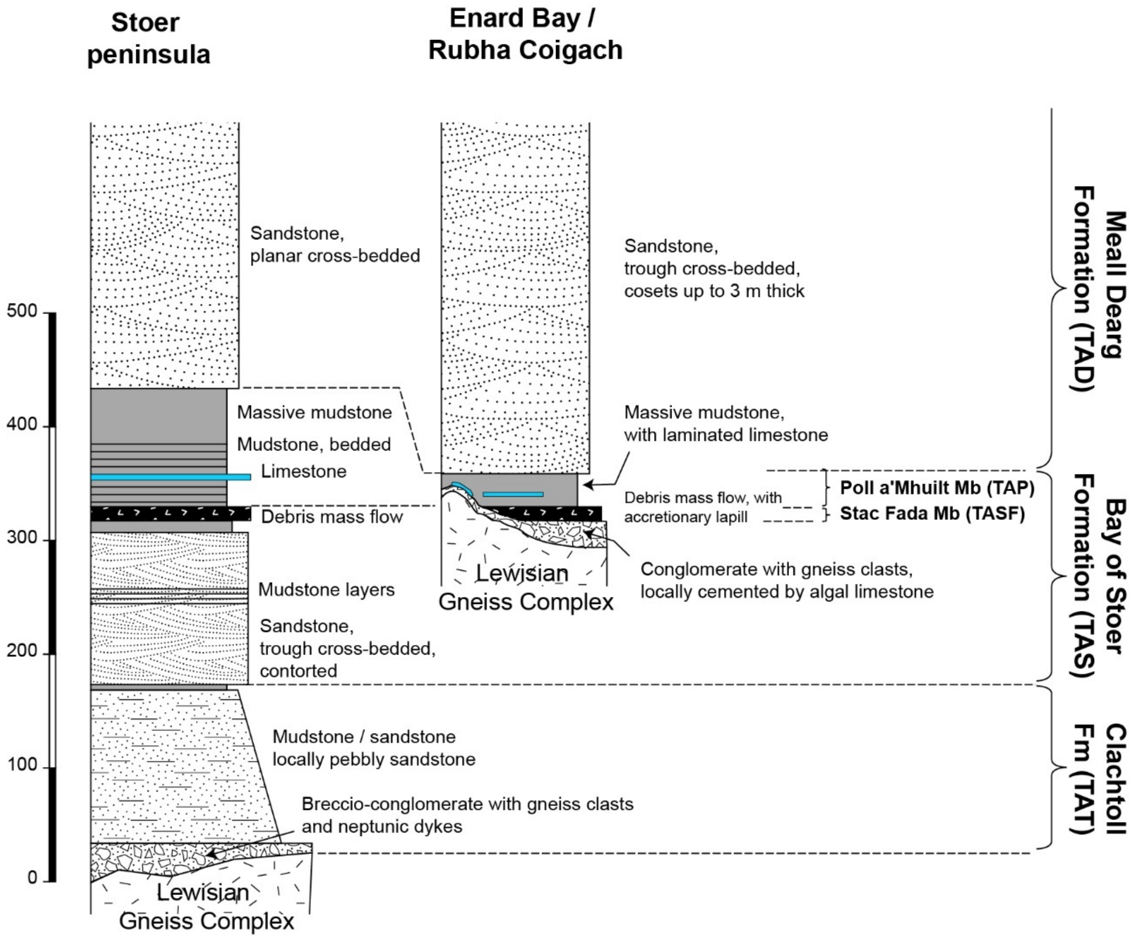

Figure 7 Stratigraphic columns of Stoer Group at Stoer peninsula and Enard Bay (mofiied after Stewart 1982; 2002).

5.3 DETRITAL MINERAL AGE DATA: INDICATIONS OF SOURCE AREA

Detrital zircon ages for the Stoer Group are mainly Neoarchaean (2900-2700 Ma), with a small number around 1850 Ma (Rainbird *et al.* 2001; Lebeau *et al.* 2020; Kenny *et al.* 2019), matching the protolith ages of the Lewisian Gneiss Complex. Detrital apatite ages are Palaeoproterozoic in age (1800-1600 Ma), which matches the youngest metamorphic events of the Lewisian Gneiss (Kenny *et al.* 2019). Together, the detrital data attest to local derivation of detritus.

5.4 INTERPRETATION: BASIN SETTING

The Stoer Group is characterised by pronounced vertical and lateral facies variations and records deposition in valley-confined rivers, braided rivers or alluvial fans, debris fans and lakes (Stewart 2002), as well as aeolian deposition (Lebeau & Ielpi 2017). Palaeocurrents are westward-directed in the Clachtoll Formation, flip 180° to the east at the base of the Bay of Stoer Formation, and flip again westward higher in that formation (Stewart 1982; 2002). This has been interpreted as being caused by different movement at different times of basin-bounding normal faults, compatible with a rift basin (Stewart, 1982). All Stoer Group outcrops occur east of the Coigach Fault, which may be syn-depositional but unlikely to have been a basin-bounding fault (Stewart, 1993). Thickening of the Bay of Stoer Formation south of the Little Loch Broom Fault suggests that this fault was also active during deposition. There is broad consensus that the above features point to an intra-continental rift basin setting of the Stoer Group (Stewart 1969; 1982; 2002; Lebeau *et al.* 2020), coeval with abundant rift-related magmatism elsewhere in Laurentia (Upton *et al.* 2003; Davidson 2008) and thus part of a widespread rifting event in Laurentia (see discussion in Lebeau *et al.* 2020); this activity is possibly linked to the post-1265 Ma rifting between Baltica and Laurentia that formed the Asgard sea (e.g. Cawood & Pisarevsky 2017). However, the re-interpretation of the Stac Fada Member as a meteorite impact ejecta blanket (Section 5.5) removes the volcanic element from the rift-related interpretation, and other basin settings may be more appropriate.

5.5 STAC FADA MEMBER: VOLCANICLASTIC VS METEORITE IMPACT INTERPETATION

Large rafts of sandstone derived from the underlying Stoer Group and large clasts of Lewisian Gneiss, combined with the occurrence of mafic, chloritic shards, accretionary lapilli and unusual geochemistry (elevated platinum-group elements compositions) suggest that the Stac Fada Member was created by an unusual geological event. Previous studies suggested a volcaniclastic origin, interpreting the geochemistry indicating mafic volcanism involving the interaction of hot or molten rock and wet, unlithified sediment and marked by ash or pyroclastic flows (Lawson 1972), volcanic mudflows (lahar) (Young 2002) or a pepperitic origin (Sanders & Johnston, 1989). Recently, the discovery shocked quartz, enrichment in platinum-group elements and shocked zircon (reidite) indicate an origin as a meteorite ejecta blanket (Amor *et al.* 2008; 2019; Branney & Brown, 2011; Reddy *et al.* 2015; Sims 2015).

6 Wester Ross Supergroup

In mainland Scotland, the bulk of the proposed Wester Ross Supergroup comprises the Sleat, Torridon and Morar Groups (Figure 8). Outlying groups that are included within the Supergroup – with varying degrees of certainty - include the Iona Group, the Tarskavaig Group within the Moine Thrust Zone, and the Sand Voe, Yell Sound and Westing groups of Shetland. Some parts of the stratigraphy are well established and summarised here. Other parts of the stratigraphy can be rationalised and are discussed in more detail.

6.1 AGE CONSTRAINTS

Detrital mineral age data are now available for most units of the Sleat, Torridon and Morar Groups, as well those in Shetland (Figure 4). Youngest zircons for the Sleat Group are between 1050 -1000 Ma (Krabbendam *et al.* 2017). Youngest zircons for the Torridon Group are between 1060-1000 Ma (Rainbird *et al.* 2001; Krabbendam *et al.* 2017) and youngest rutiles between 1150-1000 Ma (Krabbendam *et al.* 2017). Rb-Sr whole rock ages may date diagenesis around 1000–970 Ma (Turnbull *et al.* 1996). Youngest detrital zircons for various formations in the Morar Group, east of the Moine Thrust, range between 1070-1000 Ma (Friend *et al.* 2003; Kirkland *et al.* 2008a; Cawood *et al.* 2015), those for the Westing and Yell Sound groups on Shetland are around 1040-1030 Ma (Cutts *et al.* 2009; Jahn *et al.* 2017). The maximum depositional age is thus around 1000 Ma. Minimum depositional ages are constrained for the Morar Group by metamorphic ages (Lu-Hf and Sm-Nd on garnet) at c. 950 Ma (Bird *et al.* 2018). The Westing and Yell Sound groups on Shetland yield metamorphic ages (U-Pb zircon rims and monazite) in the range of 950-910 Ma (Cutts *et al.* 2009; Jahn *et al.* 2017). The age range of Wester Ross Supergroup units is thus constrained to be between c. 1000 and c. 950 Ma.

6.2 DETRITAL MINERAL AGE DATA: INDICATIONS OF SOURCE AREA

Detrital zircon ages for the different units in the Wester Ross Supergroup are remarkably similar to each other. They are characterised by a dominant Paleoproterozoic peak; for most units this occurs at c. 1650, other units show more c. 1740 Ma peaks or a mix between these two. Lower peaks occur between c. 1500 - 1200Ma, whilst pre-1900 Ma zircons are rare or absent. These zircon spectra do not match the Lewisian Gneiss, which cannot have been the main source: the main source of the Supergroup was thus more distal. The c. 1650 Ma zircons are regarded as being sourced from the trans-Labrador batholith, uplifted in the Canadian sector of the Grenville orogen (Rainbird et al. 2001). The c. 1740 Ma zircons are interpreted to be sourced from Makkovikian-Rhinnian rocks, uplifted in the Irish-Scottish sector of the Grenville orogen (Krabbendam et al. 2017). Altogether, the Grenville orogen is thought to be the main source of the detritus.

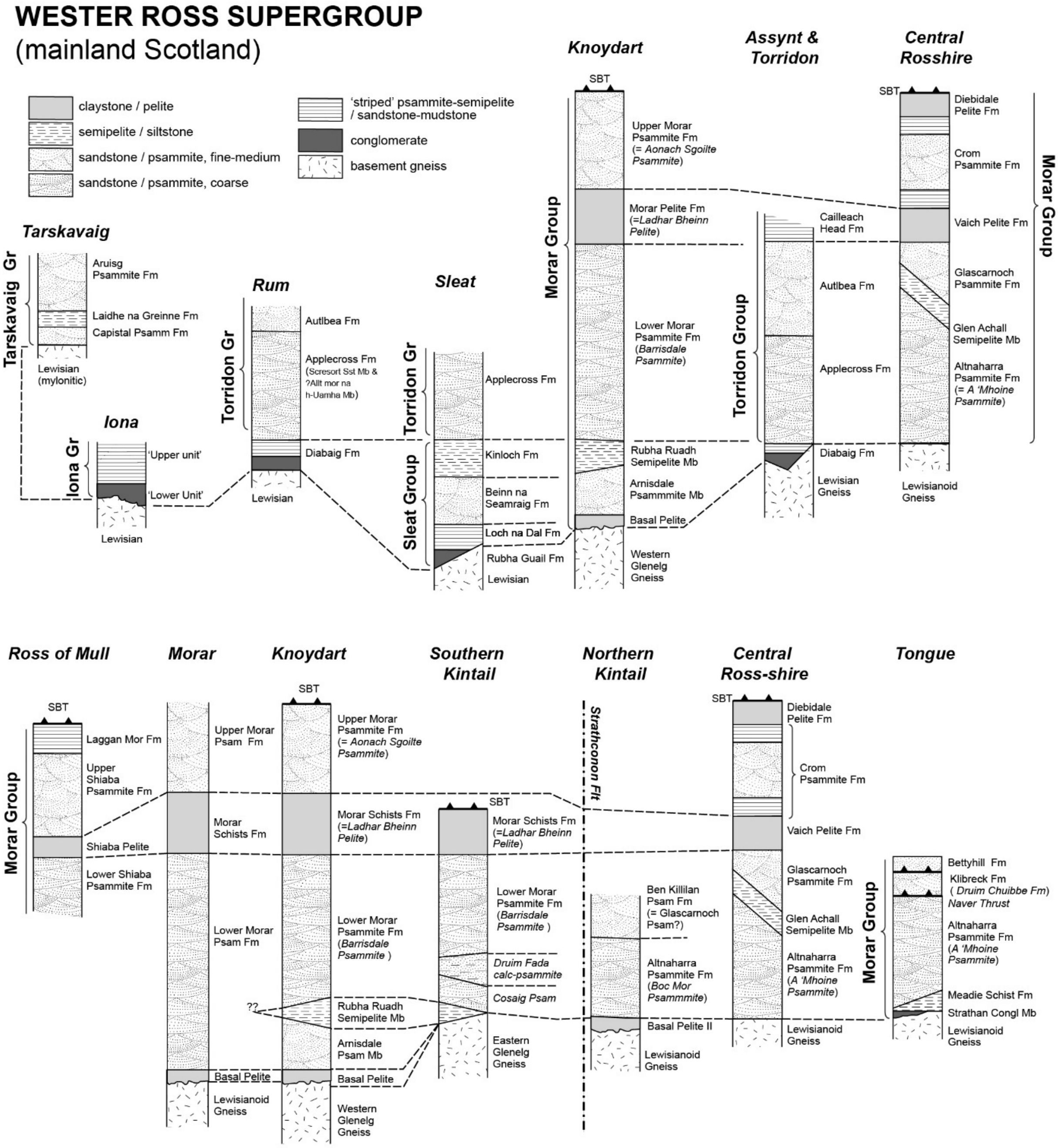

Figure 8 Stratigraphic correlation chart of the Torridon-Morar groups – Wester Ross Supergroup. References to columns: Iona: Stewart (2002); McAteer et al. (2014); Tarskavaig: Cheeney & Matthews (1965); Sleat: Stewart (1969, 2002). Assynt & Torridon: Stewart (1969, 2002); Ross of Mull: Holdsworth et al. (1987) and this paper. Morar: Johnstone et al. (1969); Powell (1974); Knoydart: Ramsay & Spring (1962); Krabbendam et al. (2014); Southern Kintail: Tanner (1965); Krabbendam et al. (2014, 2018); Northern Kintail: May et al. (1993). Central Ross-shire: Bonsor et al. (2010, 2012); Tongue: Strachan & Holdsworth (1988). Alternative or older names in italics.

6.3 SLEAT GROUP

The Sleat Group consists of c. 3.5 km of sandstone and mudstone separated into four formations (Figures 8, 9; Peach *et al.* 1910; Stewart 1988; 2002). The group occurs within the Kishorn Nappe, sandwiched between the Kishorn Thrust and Moine Thrust (Figure 1, 3). The strata are folded into the large-scale recumbent Lochalsh Syncline and beds are commonly steeply dipping or overturned. The Sleat Group was deposited unconformably on Lewisian Gneiss and is overlain sharply by Torridon Group sandstones via a very low-angle unconformity (Kinnaird, 2007), suggesting the Group is slightly older than the Torridon Group. The westward transport of the Caledonian Kishorn Thrust was considerable, so that the Sleat Group was originally deposited many tens of kilometres farther to the east than its present position. Importantly, the Sleat Group was not deposited north and west of the Kishorn Thrust since in Torridon and on Skye the stratigraphically higher Torridon Group lies unconformably over Lewisian Gneiss. Thus, the basin in which the Sleat Group was deposited was bounded to the north and west, broadly along the line of the Kishorn Thrust. There is no stratigraphic or faulted contact with the Stoer Group.

Group	Formation	Lithology
Torridon Group (TC)	Applecross Formation	Medium sandstone, cross-bedded, thick bedded/ contorted
	low-angle unconformity	
Sleat Group (TB)	Kinloch Formation (TBK)	Fine-grained grey sandstone and fissile mudstone (shale)
	Bean na Seamraig Formation (TBS)	Fine-grained, thick-bedded sandstone; minor mudstone
	Loch na Dal Formation (TDLN)	Interbedded grey sandstone and dark grey mudstone
	Rubha Guail Formation (TBE)	Conglomerate, epidote-rich sandstone
	major unconformity	
	Lewisian Gneiss (L)	

Figure 9 Stratigraphic overview of the Sleat Group (see also Peach et al. 1910; Stewart 1988; 2002).

The Sleat Group deposits represent fairly immature sediment in a basin smaller than the overlying Torridon-Morar groups (Krabbendam *et al.* 2017). Whilst Stewart (1988; 2002) interpreted much of the Group as terrestrial, e.g. lacustrine fan deltas; Bonsor (in Krabbendam *et al.* 2017) showed that numerous sedimentary features suggest tidally influenced deposition, and interpreted much of the group as shallow-marine shoreface deposits. Youngest detrital zircons are Grenvillian in age (1060 – 996 Ma; Krabbendam *et al.* 2017), so that the Group cannot be pre-Grenvillian in age, as previously suggested (cf. Kinnaird *et al.* 2007; Spencer *et al.* 2015). The overall detrital zircon spectra, with dominant Palaeoproterozoic peaks of 1750 or 1650 Ma, is very similar to that of the overlying Torridon Group (Krabbendam *et al.* 2017).

6.4 TORRIDON GROUP

The Torridon Group comprises four formations (Stewart 1988; 2002), from base to top: Diabaig, Applecross, Aultbea and Cailleach Head formations (Figure 8). In aerial extent and volume, the Applecross and Aultbea are by far the most dominant unit: exposed from Skye to Cape Wrath, as well as within the Moine Thrust Zone and some 4-5 km thick, this unit represents a staggering amount of sediment. Offshore, the Torridon Group occurs widely in the Minch basin (e.g. Stein 1992). The boundaries of the original basin are nowhere exposed or otherwise constrained, so the area and mass of deposition was much larger than the present exposure.

Deposition occurred unconformably on a landscape of Lewisian Gneiss with a relief of several hundred metres. In the Cape Wrath area in the north, the unconformity is rather flat, probably a high plateau, and Applecross Formation rests directly on Lewisian Gneiss (Williams 2001). It is here that remnants of palaeosols have been found, with 1-3 m thick Precambrian weathering profiles (Williams 1969b; Retallack & Mindszenty 1994; Young 1999).

The Diabaig Formation (TCD) is a varied sequence of breccias and conglomerates, locally interbedded with red sandstone. Laterally and upwards these facies pass into tabular-bedded red sandstone, with ripples and small scours and minor mass-flow deposits. These pass into generally thin-bedded grey shales and tabular sandstones. The Formation is interpreted as debris and alluvial fans deposited on the slopes of palaeo-valleys with valley fill marked by lacustrine and fluvial deposition (Stewart 1988; 2002). Figure 10 illustrates the stratigraphic members of the Diabaig Formation.

	Rum	Skye – Loch Scavaig	Raasay	Diabaig to Gairloch
Applecross Fm (TCA)	**Allt Mor Na H-Uamha Mb (TCAM)**		**Loch An Uach Mb (TCLU)** Fine-medium red sandstone, cross-bedded, locally contorted. (This unit was formerly part of the Diabaig Formation).	**Allt na Beiste Mb (NEW)** Fine -medium red sandstone, cross-bedded, rare pebbles, locally contorted, minor red shaley mudstone beds. (This member replaces the ***Dubh Loch Mb (TCD3)* –** formerly part of the Diabaig Formation).
Diabaig Fm (TCD)	**Laimhrig Shale Mb *(TCDL)*** Laminated dark-grey shaley mudstone, siltstone, and very fine- to fine-grained sandstone, with intercalated beds of pale grey fine-grained sandstone. Coarsening upwards.	(top not exposed) **Sgurr Na Stri Mb (TCDS)** Siltstone-mudstone, laminated, grey sandstone	**Brochel Mb (TCBL)** Grey mudstone, micaceous siltstone, coarse sandstone, thick-bedded 'greywacke' sandstone; medium-coarse, thick-bedded sandstone. (The **Brochel Mb (TCBL**) correlates with the ***Mullach Nan Carn Mb (TCDC)*** on Scalpay, which can be made redundant.)	**Horrisdale Waterfalls Mb (TCD2)** Siltstone-mudstone, finely interbedded, grey, shaley; grey sandstone with ripple laminations. Coarsening upwards.
	Fiachanis Gritty Sandstone Mb (TCDF) Coarse-grained sandstone, conglomerate and breccia, fining upwards to medium-grained sandstone.	**Bla-Bheinn Mb (TCDB)** Conglomerate, coarse, gritty sandstone (base not exposed)	**Torran Mb (TCTN)** Breccia-conglomerate, coarse sandstone	**Slattadale Mb (TCD1)** Breccia-conglomerate, coarse sandstone; tabular red sandstone.
Lewisian Gneiss (L)				

Figure 10 Stratigraphic overview of members of the Diabaig Formation and its members. Units that are redundant in italics.

The Applecross Formation (TCA) and Aultbea Formation (TCAU) comprise thick-bedded, trough cross-bedded red sandstone; the former is coarser-grained with thin pebble conglomerates whilst the latter is dominated by medium-grained sandstone. Soft-sediment deformation is common in the Applecross and ubiquitous in the Aultbea Formation. Figure 11 illustrates the stratigraphic members of the formations.

The Cailleach Head Formation (TCC) occurs only on Cailleach Head and Gruinard Island. It comprises thin-bedded siltstone and sandstone in c. 20 -50 m thick coarsening-upward cycles.

Each cycle has an erosional base overlain by laminated grey siltstone with desiccation cracks, followed by wave-rippled sandstone and then trough cross-bedded sandstone in upper parts. The Formation has been suggested to represent lacustrine deltas (Stewart 2002), although a shallow-marine environment cannot be ruled out (Bonsor pers. comm.). Either way, the base of the Cailleach Head Formation represents a major switch to a low energy environment that plausibly correlates with the flooding surface at the base of the Vaich Pelite and Morar Pelite formations (Morar Group).

6.4.1 Members of the Diabaig, Applecross & Aultbea formations

The Diabaig Formation is quite varied and local members have been defined (Figure 10). Two local members at the boundary of the Applecross and Diabaig Formation, the Dubh Loch Member (TCD3) in the Diabaig-Gairloch area and the Loch An Uach Member (TCLU) on Raasay, comprise fine-medium-grained, cross-bedded sandstone and were included in the Diabaig Formation on the basis of their pebble free nature (e.g. Selley 1965). Stewart (2002) argued that these members had more in common with the Applecross Formation: this placement is followed here, and these units locally form the basal member of the Applecross Formation. The Dubh Loch Member (TCD3) is renamed as the Allt na Beiste Member (Stewart 2002). The Mullach Nan Carn Member (TCDC) on Scalpay is correlated with the Brochel Member (TCBL) (Stewart 2002) and can be made redundant.

<table>
<tr><th></th><th>Rum</th><th>Soay - Skye</th><th>Scalpay - SE Raasay</th><th>North Raasay</th></tr>
<tr><td>Aultbea Fm (TCAU)</td><td>Sgorr Mhor Sandstone Mb (TCSM) Fine-grained sandstone, cross-bedded and contorted. No pebbles. Minor siltstone.</td><td></td><td></td><td>Aultbea Fm</td></tr>
<tr><td rowspan="4">Applecross Formation (TCA)</td><td rowspan="3">Scresort Sandstone Mb (TCAS)
Medium to coarse grained sandstone, cross-bedded, contortions common. Exotic pebbles.</td><td>Top not exposed</td><td rowspan="3">Top not exposed</td><td rowspan="4">Sithean Glac An Ime Mb (TCAI):
Feldspathic sandstone, fine to coarse grained; cross-bedded, some contortions. Thin beds of conglomerate.
Redundant: replaced by normal Applecross Formation (TCA)</td></tr>
<tr><td>Leac Nam Faoileann Mb (TCAF)
Fine-grained sandstone, cross-bedded and contorted. Heavy mineral bands common. Minor siltstone.</td></tr>
<tr><td>Bheinn Bhreac Mb (TCAB)
Medium to coarse to very coarse-grained sandstone, cross-bedded, contortions common. Exotic pebbles.
Redundant: equates with the Scresort Sandstone Mb (TCAS)</td></tr>
<tr><td>Allt Mor Na H-Uamha Mb (TCAM)
Feldspathic sandstone, fine to medium grained; cross-bedded, some contortions. Minor grey siltstone beds in fining upwards cycles.</td><td>Leac-Strearnan Member (TCAL)
Feldspathic sandstone, pale pink, fine to medium grained; cross-bedded, some contortions. Grey micaceous sandstone and minor grey siltstone beds.
Redundant: equates with the Allt Mor Na H-Uamha Mb (TCAM)</td><td>Leac-Strearnan Member (TCAL)
Feldspathic sandstone, fine to coarse grained; cross-bedded, some contortions. Minor siltstone beds.
Redundant: locally replaced by Applecross Formation (TCA)</td></tr>
<tr><td></td><td>Diabaig Fm (TCD)</td><td>Base not exposed</td><td>Diabaig Fm (TCD)</td><td>Diabaig Fm (TCD)</td></tr>
</table>

Figure 11 Stratigraphic overview of local members of the Applecross and Aultbea formations. Units that are redundant in italics.

On the Inner Hebrides, a number of local members have been described as part of the Applecross and Aultbea formations (Black & Welsh 1961; Nicholson in Emelues 1997; Stewart 2002). The stratigraphy and terminology can be rationalised, as it is not necessary or desirable that each individual island has its own stratigraphy (Figure 11). Some units can be discontinued, as they are in essence the same as the main Formations on the mainland: others can be correlated with each other between the islands.

The *Sithean Glac An Ime Member* (TCAI) that occurs only on Scalpay and SE Raasay, and the *Leac-Stearnan Member (TCAL)* as mapped on northern Raasay, simply represent the normal Applecross Formation, only 10 km to the NE on the mainland. These members are to be discontinued (Figure 11).

Stewart (2002) compared the stratigraphy of Rum and Soay – Skye and proposed a correlation between the two. The correlation is accepted here in part (Figure 11), so that Leac-Strearnan Member (TCAL) and the Bheinn Bhreac Member (TCAB) are made redundant as they equate with the Allt Mor Na H-Uamha Member (TCAM) and Scresort Sandstone Member (TCAS) respectively. However, the Leac Nam Faoileann Member (TCAF) and the Sgorr Mhor Sandstone Member (TCSM) are retained, since the arguments for correlation here are weak and inconsistent with the thickness difference of the Scresort Sandstone Member equivalents on Rum and Soay. The Sgorr Mhor Sandstone Member (TCSM) is retained within the Aultbea Formation, as proposed by Nicholson in Emeleus (1997).

6.5 SLEAT – TORRIDON GROUP RELATIONSHIP

The base of the Applecross Formation (which overlies both the Diabaig Formation and Sleat Group) is marked by a sharp contact marked by the incoming of cross-bedded, contorted sandstone, deposited in high-energy braided river. This represents a dramatic progradational change in deposition style over a very large area and hence is interpreted as defining a (near) chronostratigraphic surface. The contact is locally marked by a low-angle unconformity, both on Sleat (Kinnaird *et al.* 2007) and locally above the Diabaig Formation, where it is commonly described as sharp and erosive (Stewart 2002). It is thus plausible that the Diabaig Formation was deposited coevally with the Sleat Group. The lowest two formations of the Sleat Group (Rubha Guail and Loch na Dal formations) are similar to the Diabaig Formation, suggesting that the latter should be included in the Sleat Group. However, more detailed sedimentological comparisons need to be made before formalising this inclusion and herein the Diabaig Formation is retained within the Torridon Group.

6.6 MORAR GROUP

The Morar Group was previously defined as the lowest tectonostratigraphic unit of the Moine Supergroup (Johnstone *et al.* 1969; Holdsworth *et al.* 1994; Soper *et al.* 1998). It occupies a large swatch of the Northern Highlands, stretching from Mull to Sutherland. The dominant lithology is psammite, but substantial formations of semipelite and pelite also occur. Structurally the Morar Group is positioned (in broad terms) between the Moine thrust below and the Sgurr Beag thrust above.

In Morar, the Group comprises four formations (Figure 8); in ascending order the Basal Pelite, Lower Morar Psammite, Morar Schists and Upper Morar Psammite formations (Johnstone *et al.* 1969; Holdsworth *et al.* 1994). The base of the Basal Pelite Formation is locally marked by a thin, highly deformed basal meta-conglomerate. Although the contact is commonly highly sheared, it is generally accepted that the Morar Group was deposited unconformably upon

Lewisianoid basement (Peach *et al.* 1910; Ramsay 1957; Holdsworth *et al.* 1994, 2001). On Knoydart, a more involved stratigraphy was described by Ramsay & Spring (1962): of this stratigraphy, the lowest Arnisdale Psammite and the Rubha Ruadh semipelite are best regarded as members of the Lower Morar Psammite Formation. Noteworthy, the sandstone textures of the Arnisdale Psammite and Bean na Seamraig Formation (Sleat Group) are remarkably similar – massive, poorly bedded (meta)sandstones, hinting at a potential stratigraphic linkage.

The upper Barrisdale Psammite is likely contiguous with the remainder of the Lower Morar Psammite Formation and there is no point retaining this term. Tanner (1965) described two further units, the Cosaig Psammite and the Druim Fada Calc-psammite, in the basal part of the Lower Morar Psammite Formation. However, these are best interpreted as facies changes and should be viewed as informal names.

In Central Ross-shire, a thicker sequence is preserved. From base upwards: the Meadie Schist, Altnaharra Psammite, Glascarnoch, Vaich Pelite, Crom Psammite and Diebidale Pelite formations (Bonsor et al. 2010; 2012; Krabbendam et al. 2011). It is very likely that the broad tripartite Altnaharra Psammite - Vaich Pelite - Crom Psammite in the north can be correlated with the Lower Morar Psammite - Morar Schist - Upper Morar Psammite in the south, with the base of the Vaich Pelite and Morar Schists formations representing the same basin-wide flooding surface (Bonsor *et al.* 2010). Nevertheless, north-south correlations between the Morar Group sequence between Morar and Central Ross-shire are uncertain, mainly because of the complicated folding of units in the Kintail, Knoydart and Morar areas (Powell 1974; May *et al.* 1993; Krabbendam *et al.* 2014). As a result, different formation names are retained, with the Strathconan Fault as a convenient (if inelegant) boundary (**Figure 8**).

<u>In northern Sutherland,</u> two further units, the Klibreck Psammite Formation and the Bettyhill Formation, are likely part of the Morar Group. Both units are strongly deformed and show high-grade metamorphism. They may be correlated with the Altnaharra Psammite or the Glascarnoch Psammite Formation, respectively, but such correlations remain uncertain.

<u>On the Ross of Mull,</u> outcrops of Morar and Glenfinnan groups occur, isolated from the remainder of 'Moine' rocks on the mainland by Palaeogene volcanic and intrusive rocks. The sequence was thought to show continuous deposition (Holdsworth *et al.* 1987) but Krabbendam *et al.* (2021) showed that a mylonitic shear zone separates the two groups, similar to the Sgurr Beag Thrust on the mainland. The Laggan Mor Formation, previously assigned to the Glenfinnan Group ('Assapol Group'), is now assigned to the Morar Group ('Shiaba Group'). A shear zone marks the boundary with the overlying Glenfinnan Group (Krabbendam *et al.* 2021). The correlation in Figure 8 suggest that the transitional boundary between the Upper Shiaba Psammite and the Laggan Mor formations may represent a retrogradation trend (decreasing depositional rate) similar to the transition between the Crom Psammite and the Diebidale Pelite formations in central Ross-shire at the same interpreted stratigraphic level. Detrital zircon dating by Cawood *et al.* (2015) has shown that the age spectra of the Assapol and Shiaba groups is similar to that of the Glenfinnan and Morar groups, respectively, and the two local groups terms are now redundant.

6.7 TARSKAVAIG GROUP

The Tarskavaig Group is a poorly studied sequence of deformed, metamorphosed siliciclastic rocks restricted to the Tarskavaig Nappe, along the southeast Sleat Peninsula. The Tarskavaig Nappe occurs structurally above the Kishorn Nappe (which carries the Sleat Group) and below the Southern Moine Nappe, which carries the Morar Group (Figures 1, 3). The broad stratigraphy (Cheeney and Matthews 1965; Cheeney & Krabbendam 2009) is as follows (Figure 12). The base of the group comprises highly sheared psammite and pelite, the Capistal Psammite Formation, in contact with highly sheared, mylonitic Lewisian Gneiss; rare quartz pebble conglomerates near its base suggest a deformed unconformity. The overlying Laidhe na Greine Formation comprises interbedded psammite, semipelite and pelite, followed by the Aruisg Psammite Formation that is mainly composed of feldspathic psammite with minor pelitic beds. Cross-bedding occurs in the psammite, but is commonly obscured by deformation. Little is known about the detailed sedimentology and no detrital mineral age data are available so that correlation with other units remains uncertain.

Group	Formation	Lithology
Tarskavaig Group (TARS)	Aruisg Psammite Formation (ARU)	Feldspathic psammite with minor pelitic beds. Locally cross-bedding is preserved.
	Laidhe na Greine Formation (NEW)	interbedded psammite, semipelite and pelite, locally with graded bedding
	Capistal Psammite Formation (NEW)	sheared psammite and pelite, with rare quartz pebble conglomerate at or near base. Broadly coarsening upwards.
unconformity – strongly sheared (mylonitic)		
Lewisian Gneiss Complex (L)		

Figure 12 Overview of stratigraphy of the Tarskavaig Group (after Cheeney & Matthews 1965).

Restoration of westward Caledonian thrust movements would place the Tarskavaig Group originally farther east than the Sleat Group in the Kishorn Nappe, but west of the Morar Group, and broadly south of the northern limit of the Sleat basin (Figure 4). A correlation with the Sleat Group is thus more likely than with the Torridon Group; regardless the Tarskavaig Group is interpreted as part of the basal Wester Ross Supergroup (Figure 8).

The formations described by Cheeney & Matthews (1965) have not been incorporated into the BGS Lexicon, and the mapping presented by Cheeney & Krabbendam (2009) has not been incorporated into DigMap (as of 2021).

6.8 IONA GROUP

The Iona Group occurs as a small isolated outcrop on the island of Iona (Figure 1, 3). It comprises c. 700 m of siliciclastic sediments, deposited unconformably upon Lewisian Gneiss basement. The group is positioned just structurally below the Moine Thrust. However, it is unclear whether the Kishorn Thrust joins the Moine Thrust north of Iona (so that Iona would represent the Caledonian foreland) or if Iona occurs within the Kishorn Nappe (or an equivalent thrust sheet).

Two units occur: a lower unit, comprising conglomerate, pebbly sandstones with minor mudstone, and an upper unit of alternating sandstones and mudstone (Stewart 2002; McAteer *et al.* 2014); not dissimilar to the Rubha Guail and Loch na Dal formations of the Sleat Group. Detrital zircons from the upper unit show a unimodal peak between c. 1770-1800 Ma, a few Archaean grains and a youngest grain at 1490 ± 15 Ma (McAteer *et al.* 2014). The zircon age population is very different from the Neoarchean-dominated spectrum of the Stoer Group (cf. Rainbird *et al.* 2001; Kinnaird *et al.* 2007, Lebeau *et al.* 2020), arguing against correlation with the Stoer Group. However, the main 1770-1800 Ma peak is very similar to that from the Loch na Dal Formation (Krabbendam *et al.* 2017). The absence of Grenvillian zircons would at first sight argue against inclusion in the Wester Ross Supergroup. However, Kinnaird *et al.* (2007) also did not encounter Grenvillian detrital zircons in the lower units of the Sleat Group. The youngest *group* of zircons in the Loch na Dal Formation (Krabbendam *et al.* 2017) is also pre-Grenvillian in age (c. 1380 Ma). Thus, Grenvillian zircons in the lower Sleat Group are rare and only become more abundant higher in the sequence, presumably as higher-grade rocks in the Grenville orogen became progressively exhumed. Similarities in detrital zircon geochronology, lithology and structural and stratigraphic position, would suggest the Iona Group can be correlated with the lower units of the Sleat Group, together representing the lowest units of the Wester Ross Supergroup (Figure 8).

6.9 SHETLAND: SAND VOE, YELL SOUND AND WESTING GROUPS

Some 200 km NNE of mainland Scotland the Neoproterozoic rocks of Shetland includes three metasedimentary successions that are assigned to the Wester Ross Supergroup (Figure 1, 7). The three successions occur on different islands and are tectonically separated by Caledonian strike slip faults or shear zones (primarily the Walls Boundary Fault, and the Hascosay Shear Zone), hindering correlation between them (Figure 12).

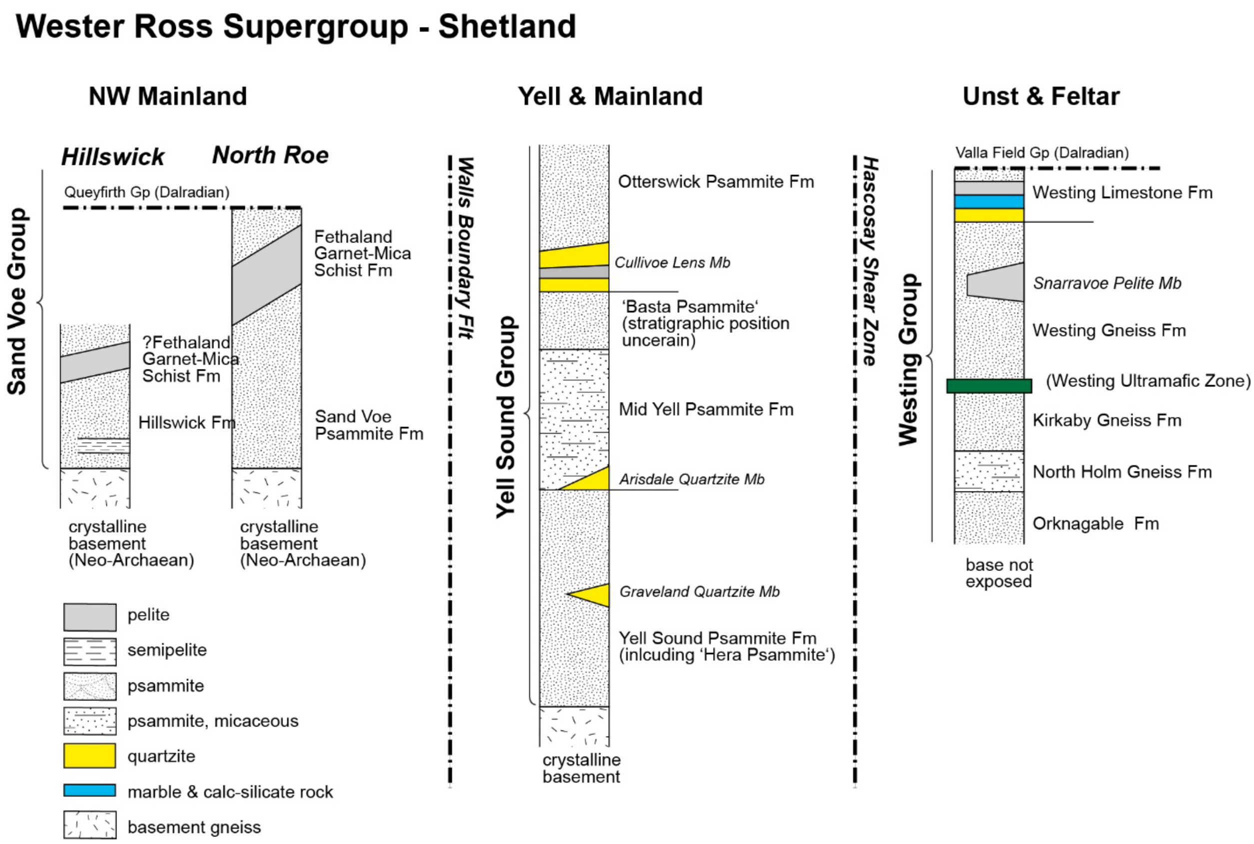

Figure 13 Proposed stratigraphy of Sand Voe, Yell Sound and Westing groups in Shetland. All groups are assigned to the Wester Ross Supergroup. See also Flinn (1994; 2014); Krabbendam et al. (2021).

6.9.1 Sand Voe Group

West of the Walls Boundary Fault in the NW Mainland, the Sand Voe Group (Figure 13) comprises a c. 800 m thick succession of mainly feldspathic psammite, locally containing sedimentary structures, overlain by a c. 300 m thick pelite (Flinn 1988). The Sand Voe Group overlies strongly reworked Neoarchaean basement and the relationship between the two units is thought to be a basement-cover unconformity (Pringle 1970; Kinny *et al.* 2019). However, no other constraints exist to refine its depositional age other than prior to the Caledonian orogeny. The Sand Voe Group resembles the Morar Group in north Sutherland with which it has been tentatively correlated (Flinn 1988). The 'Garnet-Mica Schist Unit' is not an appropriate name and is renamed the Fethaland Garnet-Mica Schist Formation, within the Sand Voe Group

The 'Hillswick Group' occurs near to the Sand Voe Group, and no separate group status is justified. It is proposed the 'Hillswick Group' is reclassified as the Hillswick Formation, within the Sand Voe Group.

6.9.2 Yell Sound Group

East of the Walls Boundary Fault, on the Mainland and on Yell, the Yell Sound Group (Figure 13; previously the Yell Sound Division) comprises psammitic gneisses with subordinate semi-pelitic and pelitic gneisses and quartzite (Flinn 1988). Metamorphic grade and tectonic strain are high and no sedimentary structures are preserved. The vertically banded Yell Sound Group has an outcrop width of c. 10 km but the original thickness is likely to have been considerably less. Its depositional age is constrained between c. 1019 Ma (age of the youngest detrital zircon) and c. 944-931 Ma (age of high-grade metamorphism) (Jahn *et al.* 2017). In NE Yell, the Yell Sound Group is bordered to its east by an inlier of Neoarchaean basement that may have been emplaced along a thrust (Jahn *et al.* 2017).

Subunits of Group were informally described in Flinn (1994). Some of these units are more conveniently classified as Formations and Members as per Figure 14:

Formation	Member	lithology
Otterswick Psammite Formation (OTPS)		psammite
	Cullivoe Lens Member (CULI)	massive quartzite interlayered with coarse pelitic schist with kyanite; occurs near the probable base of the Otterswick Psammite Formation
Mid Yell Psammite Formation (NEW) (formerly Mid Yell Lens)		micaceous, schistose psammite, to semipelitic schist, with minor calc-silicate rock. This is a new formation.
	Arisdale Quartzite Member (NEW)	massive, poorly-bedded quartzite occurs locally at the base of the formation
Yell Sound Psammite Formation (YSPS)		predominantly psammite with some quartzite layers
	Graveland Quartzite Member (NEW) (formerly Graveland Lens)	thin-bedded quartzite and interlayered quartzite and siliceous psammite; occurs within the Yell Sound Psammite Formation.
crystalline basement		

Figure 14 Overview of units in the Yell Group, Shetland (compiled after Flinn, 1994).

The 'Herra psammites' are probably best seen as part of the Yell Sound Psammite Formation, whilst the stratigraphic position and status of the 'Basta psammite' remains uncertain.

6.9.3 Westing Group

On the islands of Unst and Feltar and some smaller isles in NE Shetland, and tectonically separated from Yell Sound Group by the Hascosay Shear Zone, are outcrops of the Westing Group (Figure 13). This Group comprises a relatively thin succession of gneissose psammite and pelitic gneiss with subordinate marble (Flinn 2014), structurally overlying crystalline basement. Its depositional age is constrained between 1031 ± 5 Ma (age of the youngest detrital zircon) and 925 ± 10 Ma (age of high-grade metamorphism) (Cutts *et al.* 2009), supporting inclusion within the Wester Ross Group

The base of the Westing Group is not exposed so that its relation with its basement, and hence the position with respect to the Yell Sound Group, is uncertain. At its top, the Group is structurally overlain by the Valla Field Group seen as part of the Dalradian Supergroup, via a tectonic contact (Flinn 2014), possibly a sheared unconformity.

From (probable) top to base, the Westing Group includes the sequence, as per Figure 15 (Flinn 2014):

Formation	Member	lithology
Westing Limestone Formation (WELS)		thinly interbedded calc-silicate rock, marble, quartzite and variably gneissose psammite
Westing Gneiss Formation (WEGN)		dark biotite-rich and garnetiferous psammite with minor pelitic kyanite- or staurolite-bearing schist and subsidiary calcareous and calc-silicate rock layers
	Snarravoe Pelite Member (SNAP)	schistose pelite; occurs close to the top of the formation
the Westing Ultramafic Zone, a hornblende-rich high strain zone, occurs at this level, but should not be seen as part of the sequence)		
Kirkaby Gneiss Formation (KIGN)		psammite, locally gneissose, with muscovite, biotite and garnet, and locally micaceous psammite and pelite
North Holm Gneiss Formation (NHGN		strongly gneissose psammite, with muscovite, biotite and garnet; pegmatitic granite veins are common
Orknagable Formation (ORKG)		psammite, variably gneissose, with minor quartzite and pelite
base not exposed		

Figure 15 Overview of units in the Westing Group, Shetland, in probable stratigraphic order (compiled after Flinn, 2014).

Although the geochronological dating by Cutts *et al.* (2009) supports inclusion in the Wester Ross Supergroup, the Westing Group is unusual in two aspects compared to other units within the Supergroup. The first, is the occurrence of marble and calc-silicate rocks in the Westing Limestone Formation. Secondly, the detrital zircon population of the psammite sample analysed by Cutts *et al.* (2009) has a dominant peak of c. 1030 Ma (Grenvillian), with only minor Mesoproterozoic peaks; different from other Wester Ross rocks sampled thus far, which typically show dominant Mesoproterozoic peaks at 1650Ma or 1750 Ma and only a minor Grenvillian peak (e.g. Krabbendam *et al.* 2017) A possible explanation is that the Westing Group represents a stratigraphically higher unit than the Yell Sound Group, with a different source and sedimentological regime.

6.10 DEPOSITIONAL SETTING OF THE WESTER ROSS SUPERGROUP

There is now compelling evidence that the Wester Ross Supergroup accumulated in an orogen-parallel foreland basin to the Grenville Orogen (Rainbird *et al.* 2001; Bonsor and Prave 2008; Krabbendam *et al.* 2008; 2017).

Foreland deposition is interpreted to have commenced in the Sleat Group (and likely Iona and Tarskavaig groups) in a shallow marine basin. This basin was bound to the north, as the Lewisian Gneiss basement remained exposed in the north. Despite this, little Archaean-age detritus entered the basin. Instead, detritus dominated by ca. 1750 Ma zircon ages in the lower Sleat Group likely originated from the Scottish-Irish sector (likely dominated by Rhinnian-age rocks) of the Grenville Orogen; the change to c. 1650 Ma detritus in the upper Sleat Group suggests a switch to the Canadian sector of the Grenville Orogen (Krabbendam et al. 2017). With the start of Applecross Formation deposition, a major change in basin dynamics occurred. The Applecross–Aultbea and Altnaharra formations are interpreted as fluviatile and were deposited rapidly in high-energy braid plain settings (Nicholson 1993; Stewart 2002; Krabbendam *et al.* 2008; Bonsor *et al.* 2010; 2012). This represents large-scale progradation with deposition that spilled over onto previously exposed basement, indicating a major migration of the depocentre away from the orogen. Similarities in detrital zircon spectra suggest that in this phase, detritus was transported as far to the north as Greenland and Svalbard.

The fluvial deposits of the Applecross-Altnaharra Formation pass laterally eastwards and upwards into distal braidplain and shoreline deposits (Glascarnoch Formation) and into below-wave base shallow marine environments (Vaich Pelite Formation), the base of which represents a flooding surface (Bonsor *et al.* 2010, 2012). This interval likely correlates with the highest preserved Torridon Group unit, the Cailleach Head formation, which is interpreted as deltaic/lacustrine and represents a significant drop in sedimentation rate (Stewart 2002), consistent with a rise in base level.

A further progradation-retrogradation sequence is preserved in the upper Morar stratigraphy in the east, with a return to tidal shoreline and fluvial braidplain to shoreline deposition in the Crom Psammite Formation, with the highest preserved unit in the Morar group, the Diebidale Pelite Formation, recording shallow-marine conditions.

6.11 EARLY LIFE IN THE STOER, SLEAT AND TORRIDON GROUPS

The Stoer, Sleat and Torridon groups together form some of the few well-preserved non-marine sequences of Mesoproterozoic age worldwide. They are highly relevant to ongoing debates concerning when and how the first non-marine life evolved (Brasier *et al.* 2017). Putative microfossils were first described from phosphate bearing shales from the Cailleach Head Formation as "*minute spherical bodies, […] also brown fibres about 0.004 mm in breadth, […] either straight, curved or even looped*" (Teall, in Peach *et al.* 1907; p.287-288).

In the Stoer Group, stromatolitic limestone occur in the inferred lacustrine Poll a' Mhuilt Member (Upfold 1984), although a stromatolitic origin has been disputed (Stewart 2002). At the palaeo-hill at Enard Bay, microbial-appearing limestone encrusts Lewisian Gneiss boulders on the unconformity surface. Spheroidal nannofossils were recovered from the Pollt a' Mhuilt Member (Downie, 1962; Cloud & Germs, 1972). On surfaces with desiccation cracks, certain wrinkles have been interpreted as remnants of microbial mats (Prave, 2002).

In the Torridon Group, the Diabaig Formation preserves various structures interpreted as remnants of microbial matts (Callow *et al.* 2011). Strother *et al.* (2011) and Battison & Brasier (2012) identified a range of microfossils, interpreted as eukaryotes, in grey shales of the Diabaig and the Cailleach Head formations, but also in other formations. A major issue relevant to the early development of eukaryotes at present, is whether the host-strata are in fact marine or non-marine deposits (Stüeken *et al.* 2017)

7 Loch Ness Supergroup

The Loch Ness Supergroup comprises the Glenfinnan and Loch Eil groups, the upper part of the previous Moine Supergroup, as well as the Badenoch Group in the Grampian Highlands, south of the Great Glen (**Figure 16,17**). The Glenfinnan and Loch Eil groups are considered conformable across a possibly diachronous stratigraphic contact (Strachan *et al.* 1988). The Glenfinnan Group comprises predominantly pelitic, semipelite and 'striped' psammite/pelite units, whilst the Loch Eil Group is dominated by psammite with minor quartzite units. The Badenoch Group comprises semipelite and psammite, with minor quartzite (Leslie et al. 2013). The Glenfinnan and Badenoch groups are strongly deformed and metamorphosed, commonly migmatitic, hindering sedimentological interpretations, whereas the Loch Eil Group contains locally abundant sedimentary structures that suggest a shallow-marine origin (Strachan 1986; Strachan *et al.* 1988). The stratigraphy was established by Roberts *et al.* (1987), Strachan (1986) and Strachan *et al.* (1988), although some rationalisation in terms of formation names is proposed here. A schematic stratigraphic framework showing possible lateral facies variations, modified in part after Roberts *et al.* (1987) and Strachan (1986), is shown in Figure 17.

7.1 AGE CONSTRAINTS

The youngest detrital zircons from the Glenfinnan, Loch Eil and Badenoch groups (Figure 4) fall between c. 1000 – 900 Ma (Cawood *et al.* 2003; 2015; Friend *et al.* 2003; Kirkland *et al.* 2008a; Cutts *et al.* 2010; Spencer *et al.* 2015). Some youngest detrital zircon ages in the Glenfinnan and Badenoch groups are younger than the 950-910 Ma dates for the Renlandian metamorphism of the Morar Group and its equivalents. An orogenic, 'Renlandian' unconformity must therefore separate the Morar and Glenfinnan groups, with an age gap of 50-100 Myr. The West Highland Granite Gneiss Suite (WHGG), typified by bimodal igneous rocks, intruded broadly along the Glenfinnan – Loch Eil boundary at c.870 Ma (Friend *et al.* 1997; Millar 1999; Rogers *et al.* 2001; Cawood *et al.* 2015).

Deposition of the Loch Ness Supergroup is thus constrained between c. 900 – 870 Ma, although it is possible, if the intrusion of the West Highland Granite Gneiss Suite was syn-depositional, that deposition of the upper part of the Loch Eil Group continued sometime after that. The Loch Ness Supergroup rocks are also affected by Knoydartian tectono-metamorphism, with the earliest dates at c. 840 Ma (Rogers *et al.* 1998; Highton et al. 1999).

7.2 DETRITAL MINERAL AGE DATA

Detrital zircon ages for the different units in the Loch Ness Supergroup are quite similar to each other (Cawood et al. 2003; 2004; 2014; Kirkland et al. 2008; Spencer et al. 2015). Pre-2000 Ma zircons are absent, or very rare. Most units have broad Paleoproterozoic peaks, with some units the same c. 1650 Ma that is dominant in the Wester Ross Supergroup. Most units also have significant Mesoproterozoic peaks, including a major Grenvillian (c. 1100-1000 Ma) peak. The source area is discussed in Section 7.6.

7.3 GLENFINNAN GROUP

The Glenfinnan Group comprises pelitic and semipelitic schists and gneisses together with finely interbanded pelite-semipelite-psammite units, the so-called 'striped schists'. The Group is locally in basal contact with Archaean-Paleoproterozoic basement inliers (e.g. the 'Lewisianoid Scardroy & Monar Inliers) and the contact is considered to be a sheared basal unconformity of the Loch Ness Supergroup.

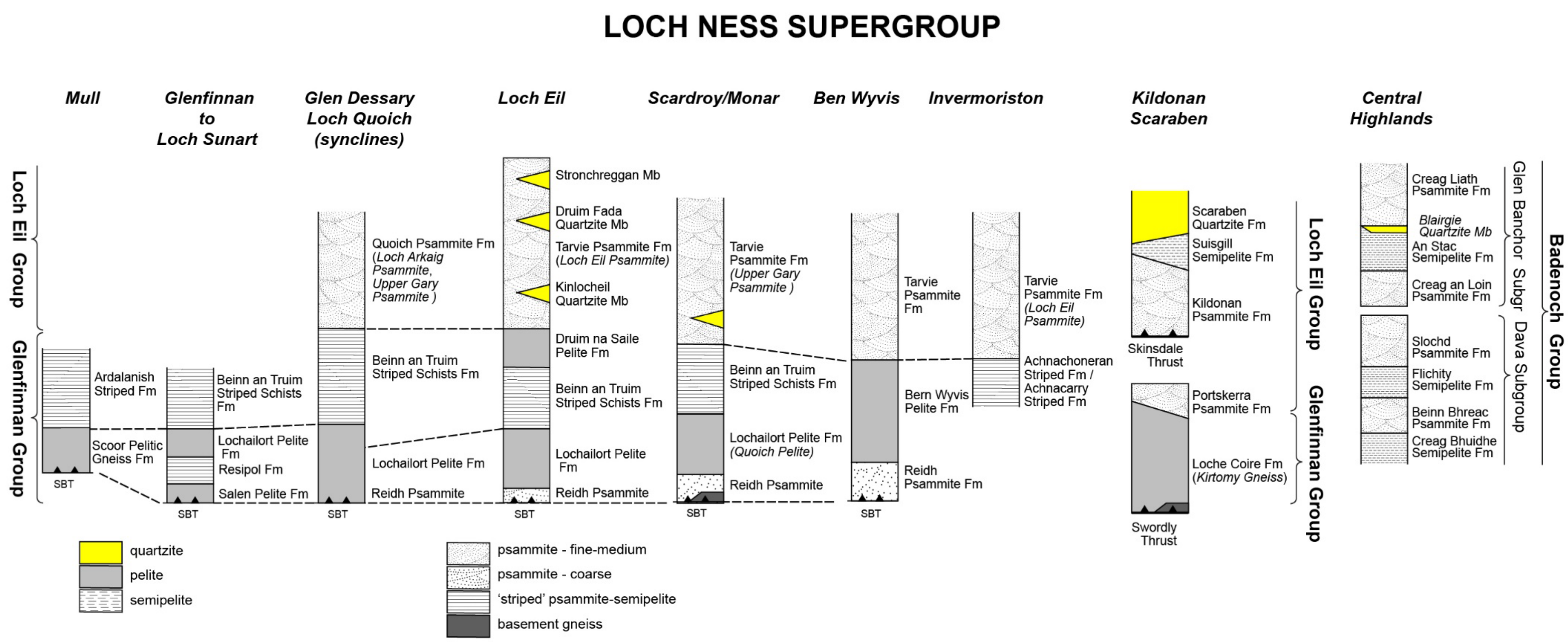

Figure 16 Stratigraphic correlation charts of the Glenfinnan-Loch Eil-Badenoch groups - Loch Ness Supergroup. References to columns: **Mull:** Holdsworth et al. (1987); **Glenfinnan**: Johnstone et al. (1969); Strachan (1985); **Glen Dessary / Loch Quoich:** Roberts et al. (1984, 1987); **Loch Eil:** Strachan (1985); **East Loch Quoich:** Roberts & Harris (1983); **Ben Wyvis:** Wilson (1975); BGS Sheet 93W (British Geological Survey 2004a); **Invermoriston**: Strachan et al. (1988); BGS Sheet 73W and 83W (British Geological Survey 1993, 2002a); **Kildonan – Scaraben:** Strachan (1988); **Central**

Across mainland Scotland the Glenfinnan Group - Morar Group contact is tectonic, defined by the Sgurr Beag Thrust or its lateral equivalents (Tanner, 1970; Rathbone & Harris 1979; Kelley & Powell 1985; Barr *et al.* 1986; Roberts *et al.* 1987). All units are strongly deformed and metamorphosed typically to amphibolite-facies, and partial melting and migmatisation are common, so that detailed sedimentological investigations are not possible. Nevertheless, the lithologies are compatible with a shallow- to nearshore marine setting. On many BGS maps, much of the Glenfinnan Group has not been subdivided into Formations. However, by extending from those sheets where Formations have been defined and mapped, it is possible to assign Formation status to much of the Glenfinnan outcrop (Figure 17). Nevertheless, the intense folding combined with lateral interfingering of units can result in non-unique solutions. A number of local terms can be made redundant.

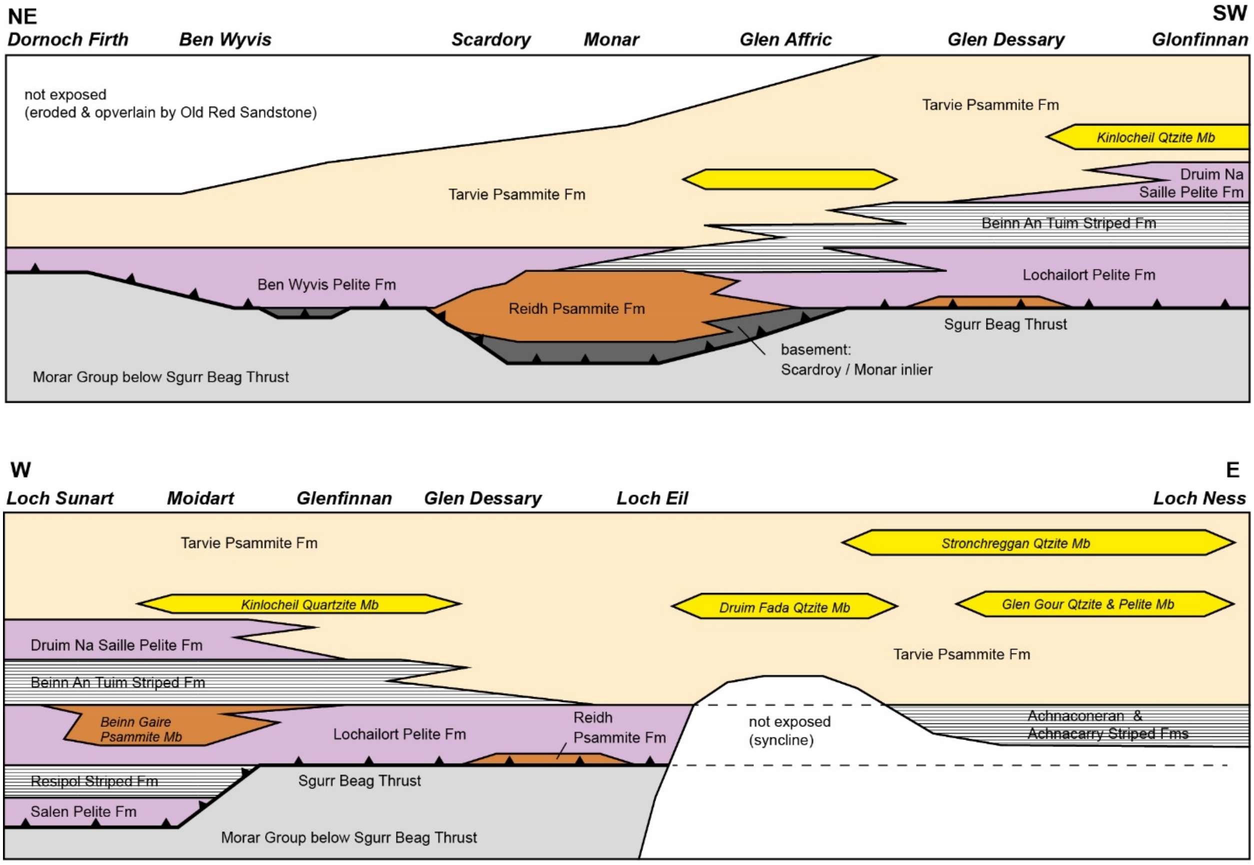

Figure 17 Stratigraphic diagram showing likely lateral relations of units in the Glenfinnan and Loch Eil groups. Bottom panel based on Roberts et al. (1987) and Strachan (1986).

Between the Sound of Mull and Loch Moidart, the lowest formation is the Salen Pelite Formation (SALP), comprising pelitic gneiss, followed by the Resipol Striped Schist Formation (RESI), a unit of interbanded gneissose psammite and pelite (Roberts et al. 1987). North of Glenfinnan, the lowest formation is the Reidh Psammite Formation (REP) (~ Quoich Banded Formation), which is thin and intermittent from Glenfinnan to Glen Shiel but thickens considerably in the Loch Monar area where it is in basal contact with the Lewisian Scardroy Inlier (here it includes the Garve Psammite / Ben Wyvis Psammite). Farther NE to the Dornoch Firth, it is thin or absent in the west but may thicken to the east).

Both the Resipol Striped Schist and the Reidh Psammite formation are overlain (overstepped) by the Lochailort Pelite Formation (MBLA), a pelitic to semipelitic gneissose unit susceptible to migmatisation, with minor psammite and quartzite units that increases in thickness and abundance towards the NE. Glenfinnan Group pelitic gneiss in the Fannich Inlier (previously informally termed the Meal an t-Sithe pelite; Kelly & Powell 1985) is now included in the Lochailort Pelite Formation. Other local terms include the Sgurr Beag Pelite, Quoich Pelite and the Fraoch Bheinn Pelite. Two outliers of the Sgurr Beag Nappe occur in the NW Highlands: the Fannich outlier and smaller Sguman Cointich outlier (Kelley & Powell 1985; May *et al.* 1993). Both contain lithologies similar to the Lochailort Pelite Formation, and have now been included in that formation, so that the local names Meal an t-Sithe pelite (in Fannich inlier) and Sguman Cointich Pelite become redundant.

The Ben Wyvis Pelite Formation (BWYP) may be a lateral equivalent of the Lochailort Pelite Formation, but this unit is retained as it occurs NE of the thick development of the Reidh Psammite Formation, and thus may be an independent Formation. It is possible that the Ben Wyvis Formation interfingers with the Beinn an Tuim Striped Schist Formation in Glen Affric and may be younger than the Lochailort Pelite Formation.

The Beinn an Tuim Striped Schist Formation (BTU), a unit of interbedded psammite, pelite and semipelite overlies the Lochailort Pelite Formation, followed by the Druim na Saille Pelite (DRSP), another unit of generally migmatitic pelitic gneiss (e.g. Roberts *et al.* 1987; Strachan *et al.* 1988). These units are not present NE of Scardroy where the Ben Wyvis Pelite Formation is directly overlain by Loch Eil Group psammite and suggesting that the boundary with the overlying Loch Eil units is diachronous (Strachan *et al.* 1988).

On the Ross of Mull, the Scoor Pelitic Formation (SCPE) and the overlying Ardalanish Striped Formation (ASTR) likely correlate with the Lochailort Pelite and Beinn an Truim Striped Schist, respectively (Holdsworth *et al.* 1987). As a consequence, the Assapol Group can be made redundant and the units can be assigned to the Glenfinnan Group (see also Cawood *et al.* 2015)

Adjacent to the Great Glen are two major outcrops of mixed, interbedded psammite-semipelite units that occur stratigraphically below the Loch Eil Group. The main outcrop of that Group forms a large syncline so that continuity with the Glenfinnan Group is likely, albeit not exposed. These units, the Achnacarry Formation (ACNS) near Loch Lochy and the lithologically similar Achnaconeran Striped Formation (ACHN) between Invermoriston and Muir of Ord, have been assigned to the Glenfinnan Group (Strachan 1985; Strachan *et al.* 1988; May *et al.* 1997) but cannot be reliably correlated with individual formations within that Group.

7.4 LOCH EIL GROUP

The Loch Eil Group is dominated by psammite of the Tarvie Psammite Formation, a fine-medium grained psammite with locally well preserved sedimentary structures that suggest shallow-marine (above wave-base) deposition and overall northward paleocurrent directions (Strachan 1986, Strachan *et al.* 1988). Previously defined psammite units, e.g. Loch Eil Psammite; Upper Garry Psammite; Loch Arkaig Psammite; Eastern Loch Quoich Psammite, all equate with the Tarvie Psammite Formation, and these terms become redundant.

A number of quartzite units isolated within psammite occur in the Loch Eil area (Strachan 1986) and these are assigned member status: Kinlocheil Quartzite Member, Druim Fada Quartzite Member and Stronchreggan Member (Figure 17, 20). Further to the NE, more such quartzite units occur and these may also deserve member status.

The sequence in the Scaraben area of East Sutherland and Caithness, very likely also part of the Loch Eil Group, is described in Section 7.

7.5 BADENOCH GROUP

The Badenoch Group (Leslie *et al.* 2013) comprises a series of high-grade metasedimentary rocks that occur as inliers within the Grampian Highlands (Figure 18). Previous names include the Central Highland Division (Piasecki & Temperley 1988), Dava-Glen Banchor succession (Roberson & Smith 1999) or sub-Grampian Basement (Cawood *et al.* 2003). Some link with the Moine Supergroup and an unconformable relation with the overlying Grampian Group (Dalradian Supergroup) has been long considered (e.g. Piasecki 1980; Piasecki & Temperley 1988) and debated (Highton *et al.* 1999; Roberson & Smith 1999; Smith *et al.* 1999; Oliver 2002). Radiometric dating has shown that the sequence was affected by Knoydartian metamorphism at c. 840 Ma (Highton *et al.* 1999) and yields a detrital zircon age spectrum similar to that of the Glenfinnan and Loch Eil groups, with the youngest detrital zircon at c. 900 ± 17 Ma (Cawood *et al.* 2003). Combined, these data support the original interpretations of Piasecki (1980) and Piasecki & Temperley 1988. The youngest detrital zircon precludes correlation with the Morar Group and any other units assigned to the proposed Wester Ross Supergroup, thus the Badenoch Group is assigned to the Loch Ness Supergroup. Whether a direct correlation with the Glenfinnan or the Loch Eil Groups is valid is uncertain.

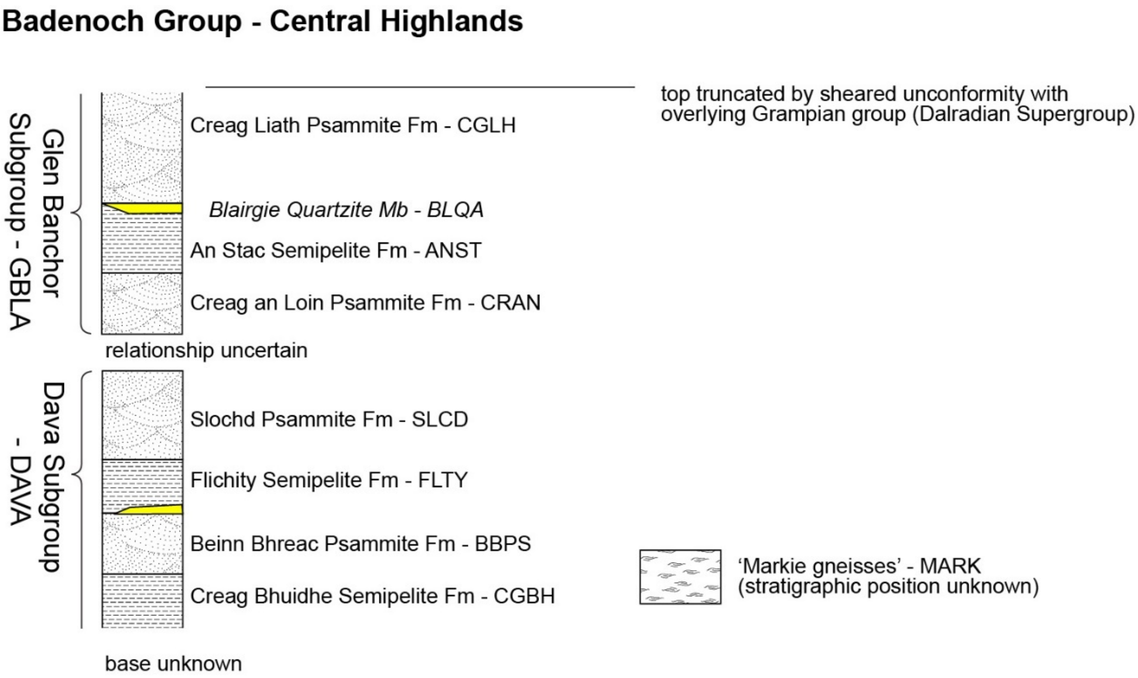

Figure 18 Stratigraphy of the Badenoch Group, Central Highlands (mainly after Leslie et al. 2013).

Rocks of the Badenoch Group are strongly deformed and recrystallised, commonly migmatitic, and do not preserve sedimentary structures. Two subgroups are recognised in different inliers (Leslie *et al.* 2013; British Geological Survey (2004b), the Dava Subgroup and the Glen Banchor Subgroup. Their relative stratigraphic position is uncertain, and although it is likely that the Glen Banchor Subgroup is younger than the Dava Subgroup, lateral equivalence is also plausible. Both subgroups comprise banded psammite at their bases followed by more semipelitic units and topped by psammite and quartzite. The lithologies are consistent with (but not necessarily uniquely so) shallow-marine deposition. The 'Markie gneisses,' as mapped on the Dalwhinnie sheet (British Geological Survey, 2002b), are poorly exposed and of uncertain status and stratigraphic formation. They are best seen as part of the Glen Banchor Subgroup, but without formal Formation status.

7.6 DEPOSITIONAL SETTING OF THE LOCH NESS SUPERGROUP

The depositional setting of the Loch Ness Supergroup needs to satisfy the following constraints:

I. The Glenfinnan Group occurs locally unconformable upon crystalline basement, with the coarse Reidh Psammite formation near the base of the succession. The remainder of the Group comprises predominantly low-energy deposits, likely shallow marine, but below wave base. The Loch Eil Group similarly records shallow marine deposition above wave base (Strachan 1988);

II. The Loch Ness Supergroup (and equivalent Megasequence 2 units father north) contain detrital zircons of Renlandian age, suggesting that the Renlandian orogen formed, at least partly, the source;

III. Archaean detrital zircons are rare/absent, suggesting that the Archaean cratonic areas of Laurentia were not major source areas and possibly largely covered by a blanket of Wester Ross Supergroup (and equivalent) sediments (Rainbird et al. 2012);

IV. The zircon age spectra are similar to the Wester Ross Supergroup implying that the Wester Ross and Loch Ness Supergroup had the same source, or that the Loch Ness Supergroup was sourced from reworked Wester Ross Supergroup rocks;

V. The Loch Ness Supergroup is intruded at c. 870 Ma by the bimodal West Highland Gneiss suite, with the mafic component showing MORB-like geochemistry (Millar 1999), suggestive of rifting activity.

Since Renlandian-age zircons (c. 950-910 Ma) would have been derived largely from the north, a purely Grenville orogen source from the south is unlikely. However, reworking of Wester Ross Supergroup, which would have represented the sedimentary cover over a very wide area (see also Rainbird *et al.* 1992; 2017) and which was deformed and presumably uplifted during the Renlandian orogeny, is a likely source. In part, the Loch Ness Supergroup could be a foreland basin or successor basin to the Renlandian orogeny, but this is at odds with 870 Ma rifting activity. A hybrid setting of a foreland basin, developing into a rift basin (possibly as a result of back-arc spreading?) would satisfy most of the above constraints.

8 Stratigraphic divisions in the 'Sutherland Moine'

In Sutherland, Moine units are particularly strongly deformed and metamorphosed, and dissected by a larger number of ductile thrust and thinner thrust nappes than elsewhere (e.g. Holdsworth 1989). The westernmost Moine rocks are unquestionably part of the Morar Group (Figure 8; Holdsworth *et al.* 1994) but the affinities of the sequences within the overlying Naver, Swordly and Skinsdale thrust nappes (Figure 3) are less certain. The metasedimentary rocks of the Naver and Swordly nappes are dominated by gneissic and migmatitic textures (Moorhouse & Moorhouse 1988; Strachan & Holdsworth 1988; Holdsworth 1989; Kocks *et al.* 2006; Strachan *et al.* 2020a) and correlations are further hampered by poor exposure. The units are commonly grouped as 'Sutherland Moine' or similar monikers (e.g. Moorhouse & Moorhouse 1988). Nevertheless, different units can be tentatively assigned to distinct groups (Holdsworth *et al.* 1994) based on lithological character and limited geochronological data. This designation is, with minor rationalisation, shown on Figure 19.

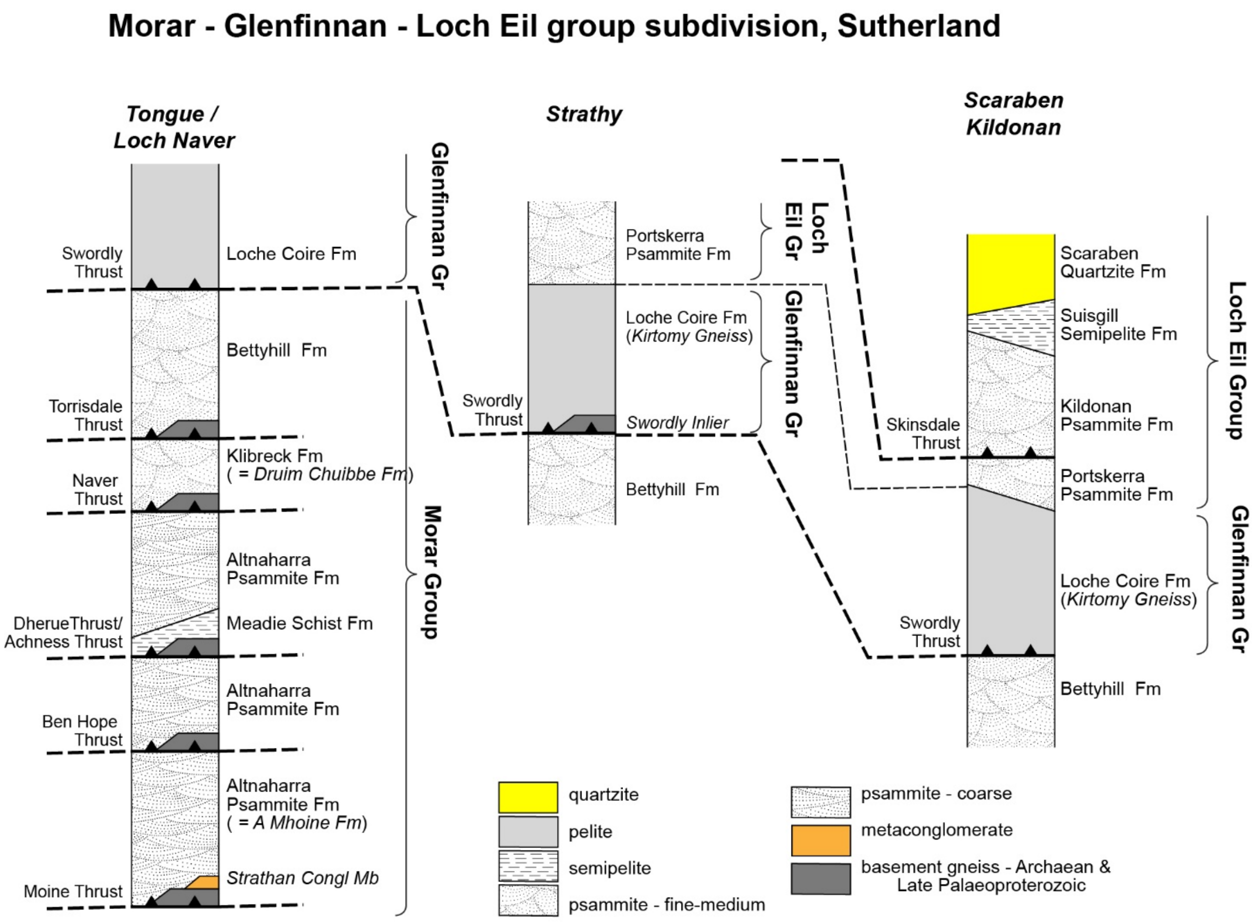

Figure 19 Tectonostratigraphic correlation of Morar, Glenfinnan and Loch Eil units in Sutherland (compiled after Strachan & Holdsworth 1988; Strachan 1988; Holdsworth et al. 1994).

Above the Naver Thrust, the Klibreck Formation (Druim Cuibhe Formation) and the Bettyhill Formation are dominated by psammite and assigned to the Morar Group, consistent with geochemical comparisons (Moorhouse & Moorhouse 1988). Correlation with, respectively, the Altnaharra Formation and the Glascarnoch Formation is likely (Strachan & Holdsworth 1988).

This is supported by U-Pb monazite ages of c. 950-900 Ma obtained from within garnet porphyroblasts (Mako *et al.* 2021), which imply that the rocks of the Naver Nappe were affected by Renlandian metamorphism.

Above the Swordly Thrust, the Loch Coire Formation (= Kirtomy Gneiss), a unit of pelitic to psammitic gneiss, is stratigraphically overlain by the Portskerra Psammite Formation, and each is assigned, respectively, to the Glenfinnan and Loch Eil groups (Holdsworth *et al.* 1994). Thin, highly sheared basement inliers occur at the structural base of the Loch Coire Formation analogous to the Lochailort Pelite Formation, which would support inclusion in the Glenfinnan Group, rather than correlation with pelitic formations high up in the Morar Group. However, maximum depositional ages for these two units are poorly constrained, and future dating may provide tighter constraints to guide correlations. The highest Skinsdale Nappe preserves a right-way-up succession of three units of likely Loch Eil Group affinity, the Kildonan Psammite, the Suisguill Semipelite and the Scaraben Quartzite formations (Strachan 1988). The metamorphic grade is lower than structurally deeper units, and sedimentary structures such as cross-bedding and graded bedding are locally preserved in the Kildonan Psammite Formation (Strachan 1988). Assignment to the Loch Ness Supergroup is supported by detrital zircon ages as young as c. 885 Ma in the Kildonan Psammite Formation (Kindgren *et al.* 2016).

9 Units of uncertain status

9.1 STRATHY COMPLEX

The Strathy Complex (MSC), on the north coast of Sutherland, is a fault-bounded assemblage of siliceous, grey trondhjemitic gneiss and ortho-amphibolite with minor calcsilicate, scapolite-diopside marble, quartz-garnet-magnetite rock, garnet-staurolite-sillimanite paragneiss, and rare ultramafic rocks (Moorhouse & Moorhouse 1983; Burns *et al.* 2004; British Geological Survey 1996). Lithologically and geochemically, the rocks are very different from the adjacent Loch Ness Supergroup rocks but also different from Lewisian gneisses and their related inliers in the Northern Highlands (Moorhouse & Moorhouse 1983; Burns *et al.* 2004). Geochemistry suggest an active, destructive plate margin origin, either in a juvenile intra-oceanic arc or an incipient back-arc, setting for the rocks (Burns *et al.* 2004).

Originally it was assumed the Strathy Complex represented 'sub-Moine' basement, of possible Grenvillian (Mesoproterozoic) age (Burns *et al.* 2004). However, U-Pb zircon dating of the grey gneiss has yielded a protolith age of 503 ± 3 Ma (Dunk *et al.* 2019), placing the origin in the late Cambrian. The Strathy Complex thus appears to have originated as an arc during subduction of a tract of the Iapetus Ocean, and is not part of the Neoproterozoic evolution of the Northern Highlands. Arguably, the Strathy Complex should be made part of an Iapetan Supersuite.

9.2 GLEN URQUHART COMPLEX

The Glen Urquhart Complex (GURQ), in Glen Urquhart close to the Great Glen, comprises an unusual assemblage of lithologies, including serpentinite, marble, calc-silicate rocks and kyanite-graphite pelite (e.g. Rock *et al.* 1986a, b), all enveloped and likely structurally underlain by Glenfinnan Group psammites and semipelites (Achnaconeran Striped Formation). Various origins have been proposed, including sub-Moine basement, part of the Moine succession, part of the Dalradian or an entirely separate lithotectonic unit (see overview in Cawood *et al.* 2004). Detrital mineral dating (Cawood *et al.* 2004) yielded a detrital zircon age spectrum similar to Loch Ness Supergroup units (but also comparable to Grampian Group units, compare Cawood *et al.* 2003), except for a youngest zircon at 880 ± 54 M, which is somewhat younger than those of the Loch Ness Supergroup. These ages exclude the possibility of a basement origin. Further, geochemically and mineralogically the Glen Urquhart Complex rocks are different to those of the Moine and Dalradian (Rock *et al.* 1986a). If the Complex is part of the Loch Ness Supergroup, it would most likely be stratigraphically higher and younger than the Loch Eil Group (Soper *et al.* 1998; Cawood *et al.* 2004), an inference difficult to reconcile with it being enveloped by Glenfinnan Group rocks. For the moment, there is no unequivocal evidence that links the Glen Urquhart Complex to any other litho-stratigraphical unit, so it remains an independent Complex.

10 Unit descriptions

10.1 STOER GROUP (TA)

Lithology: ***Sandstone, conglomerate near base;*** Conglomerate near base; red coarse, cross-bedded sandstone, locally with mudstone beds; green sandstone with mafic fragments and lapilli; thick bedded sandstone. massive mudstone with thin limestone beds;

Type section: Coastal section between Clachtoll and Rubh a' Mhill Dheirg, Stoer peninsula, northwest Highlands. *Reference Section*: South side of Enard Bay, between Achnahaird bay and Garvie Bay [NC 020 139 – NC 032 147]

Lower Boundary: Unconformable on Lewisian Gneiss Complex (L). The unconformity is sharp without weathering. The landscape on which the Stoer Group was deposited was hilly, with palaeo-valley several 100 m deep.

Upper Boundary: not exposed; the highest formation is eroded. Unconformably overlain by the Torridon Group via an angular unconformity

Thickness: 700 – 1500 m (minimum)

Geographical extent: Northwest Highlands: Stoer Peninsula; Rubha Coigach, Gruinard Bay-Loch Maree; east of the Coigach Fault, and west of the Moine Thrust

Age: Stenian Period. Direct Ar/Ar dating of the Stoer Group (Stac Fada Member) of authigenic minerals has yielded an age of 1177 ± 5 Ma (Parnell *et al.* 2011).

10.1.1 Clachtoll Formation (TAT)

Lithology: The base of the formation is a coarse cobble-breccia or breccio-conglomerate with clasts derived directly from adjacent hills of Lewisian Gneiss. The breccia is followed by red tabular pebbly, coarse sandstone, several 10m thick. This is followed by poorly bedded, dark-red muddy sandstone, locally with ripple laminations or desiccation cracks. Occasional very coarse sandstone with trough cross-bedding and rare thin (cm) calcareous beds occur within the muddy sandstone. Near the top a c. 5 m thick red fissile mudstone (shale) occurs. The lowest units show pronounced lateral facies variations, whereas more lateral continuity occurs in the top of the formation,

Interpretation: The breccia and conglomerate facies suggest deposition as rock falls and debris fans. Near Clachtoll these fan deposits are interpreted to pass laterally into lacustrine mudflats. The sandstones are interpreted to be deposit by a combination of aeolian and fluvial deposition (Stewart 2002). Fractures in the Lewisian Gneiss are filled with mudstone or fine sandstone, some of which show slickenlines, suggesting deposition of the Formation during active faulting (Beacom *et al.* 1999). These indicate depositional environments ranging from rivers confined to valleys; lakes and debris fans

Type section: Type Section - Coast section 500 m south and 300 m west of Clachtoll village. [NC 041 265 – NC 037 272].

Lower Boundary: Unconformable on Lewisian Gneiss Complex (L). The unconformity is sharp without weathering. The landscape on which the Clachtoll Formation was deposited was hilly, with palaeo-valley several 100 m deep.

Upper Boundary: Conformably overlain by Bay of Stoer Formation (TAS). The contact is defined as an erosion surface overlain by pebbly red sandstones of the Bay of Stoer Formation.

Thickness: 0-190 m (highly variable)

10.1.2 Bay of Stoer Formation (TAS)

Lithology: The Bay of Stoer Formation consists mainly of pebbly red sandstone, but in the top half of the formation are two very different members, the Stac Fada and Poll a'Mhuilt members (described in more detail below). The main red sandstone is thick-bedded with abundant trough cross-bedding in thick beds, commonly with erosional bases. Pebble beds with well-rounded clasts of gneiss and quartz occur. Soft-sediment contortions such as dewatering structures is common. Within the sandstone there are some five cycles of muddy sandstone followed by thin bedded red mudstone-sandstone alterations, showing planar and ripple laminations. These 5 – 20 m thick units have a large lateral extent and suggest lacustrine intervals within an overall fluvial sequence (Stewart, 2002).

Interpretation: Soft-sediment contortions and erosional bases of the beds suggest rapid fluvial deposition, likely in a braided river setting. The laterally persistent muddy sandstone – red mudstone cycles suggest lacustrine intervals within an overall fluvial sequence (Stewart, 2002).

Type section: Type Section - Coastal section along Bay of Stoer; [NC 037 272 – NC 030 285]

Lower Boundary: Conformably overlies the Clachtoll Formation (TAT). The contact is defined as an erosion surface where pebbly red sandstones of the Bay of Stoer Formation overlie muddy red sandstone of the Clachtoll Formation.

Upper Boundary: Conformably overlain by the Meall Dearg Formation (TAD), marked by the incoming of sandstone overlying the mudstones of the Pollt a Mhuilt Member.

Thickness: At Stoer: 240 m maximum; near Loch Maree, c. 1000 m.

10.1.2.1 STAC FADA MEMBER (TASF)

The Stac Fada Member is thin (10-30 m), but can be followed for over 50 km from Stoer to Poolewe and thus forms an important marker horizon.

Lithology: At Stoer, the unit comprises c.12 m of massive, poorly sorted greenish muddy sandstone. The sandstone contains abundant cm-sized angular fragments (‘shards’) of dark-green, devitrified mafic material and angular clasts of gneiss. There are also abundant vesicules, locally in vertical trails, that suggest degassing of hot material. These vesicles are now filled with clastic material as well as mineralised K-feldspar and calcite – it is these vesicle fills that were used for direct dating of the unit (Parnell *et al.* 2011). At Stoer, large folded and dismembered rafts of sandstone beds float in the matrix, suggesting mass movement. Accretionary lapilli occur at the top of the unit.

At Enard Bay, the Stac Fada member is a buff, massive sandstone rich in gneiss clasts, but with very well preserved and abundant accretionary lapilli. In other localities, different elements are present or absent, but the unit always contains green mafic fragments, normally in a massive sandstone; the top of the unit is locally reworked. At Gruinard Bay, gneiss fragments up to 40 cm across occur at the basal contact.

Interpretation: The rafts, large clasts, occurrence of mafic shards and unusual geochemistry suggests that the Stac Fada Member was created by an unusual and violent geological event. Previous studies suggest a volcaniclastic origin on the basis of the geochemistry of the mafic fragments and the occurrence of accretionary lapilli. Volcanic interpretations include an ash flow or pyroclastic flow (Lawson 1972), a volcanic mudflow (lahar) (Young 2002) or a pepperitic origin (Sanders & Johnston, 1989); all involving the interaction of hot or molten rock and wet, unlithified sediment. Recently, however, an origin as a meteorite ejecta blanket has been proposed on the basis of shocked quartz; enrichment in platinum-group elements, the occurrence of reidite (ZrSiO4) and shocked zircon (Amor *et al.* 2008; Parnell *et al.* 2011; Reddy *et al.* 2015; Sims 2015).

Type section: Small headland, locally known as Stac Fada, 800 m west of Stoer village, Stoer peninsula [NC 033 285]. *Reference Section*: Coast section at Camas a' Bhothain, Enard Bay [NC 031 146].

Lower Boundary: Conformably contact with remainder of the Bay of Stoer Formation (TAS). Locally (Enard Bay) directly overlying the Lewisian Gneiss (L) on palaeo-highs.

Upper Boundary: Conformably overlain by the Poll a’ Mhuilt Member (TASP)

Thickness: 10-30 m

10.1.2.2 Poll a' Mhuilt Member (TASP)

Lithology: The Poll a' Mhuilt Member is dominated by fissile, dark red to black mudstone (shale). In the lower half, the mudstone is interbedded with thin beds of siltstone, fine sandstone, with ripple laminations and desiccation cracks. A few thin limestone beds occur, with laminations suggesting a stromatolitic origin (Upfold 1984). At Enard Bay, such stromatolitic limestone was deposit directly onto boulders marking the unconformity. In the upper half of the Member, the mudstone is essentially massive, poorly bedded mudstone.

Interpretation: The unit is interpreted as a lake deposit (Stewart, 2002). At the palaeo-hill at Enard Bay, large boulders of Lewisian Gneiss have slipped from its ancient lake shore. These were previously interpreted as drop stones, suggesting a glacial origin (Davison & Hambrey 1996), but this interpretation is not generally accepted (Young 1999; Stewart 2002).

Type section: Coastal section (tidal!), c. 800 m west of Stoer Village, just west of 'Stac Fada' headland [NC 033 285 – NC 030 285]. *Reference Section*: Coast section at Camas a' Bhothain, Enard Bay [NC 029 146].

Lower Boundary: Conformably overlies the Stac Fada Member (TASF). Marked by incoming of first red mudstone. Locally directly overlying the Lewisian Gneiss (L) on palaeo-highs (e.g. Enard Bay).

Upper Boundary: Conformably overlain by the Meall Dearg Formation (TAD). Incoming of red sandstone, with erosive base.

Thickness: c. 100 m (maximum) - thins south of Stoer

Geographical extent: Northwest Highlands: Stoer Peninsula; Rubha Coigach, Gruinard Bay-Loch Maree

10.1.3 Meal Dearg Formation (TAD)

Lithology: The Meal Dearg Formation is dominated by pale-red fine-medium grained sandstone with bed 0.3 - 5 m thick. Planar cross-bedding is abundant; cosets up to 2m thick occur. Wave-rippled beds occur between cross-bedded strata. Pebble beds with orthoquartzite or vein quartz occur rarely.

Interpretation: At Stoer, the Meal Dearg Formation sandstones are interpreted as fluvial deposits in braided rivers (Stewart 2002), but at Enard Bay, the sandstones are interpreted to be largely aeolian in origin (Lebeau & Ielpi 2017)

Type section: Coastal section (tidal) between Rubh' a' Mhill Dheirg and Balchladich Bay, Stoer Peninsula [NC 030 285- NC 025 303]. *Reference Section*: east side of Achnahaird Bay, Enard Bay [NC 020 139 – NC 023 143].

Lower Boundary: Conformably overlies the Poll a ' Mhuilt Member (TASP). Marked by incoming of red sandstone, with erosive base.

Upper Boundary: not exposed – eroded. Unconformably overlain by Torridon Group (TC).

Thickness: 240 m (minimum)

10.2 SLEAT GROUP (TB)

Lithology: Slightly metamorphosed conglomerate at base, sandstone; interbedded sandstone and mudstone; mudstone commonly fissile (shale)

Geographical extent: Sleat, Skye; Kishorn

Age: Tonian. Youngest detrital zircons fall between 995-1060 Ma (Krabbendam *et al.* 2017). Assuming broad correlation with Morar Group: deposition between c. 1000 - 950 Ma.

Lower Boundary: Unconformable upon Lewisian Gneiss (sheared and overturned)

Upper Boundary: Overlain by Applecross Formation (trough cross-bedded sandstone), with low-angle unconformity (Kinnaird *et al.* 2007).

Thickness: c. 3500 m

10.2.1 Rubha Guail Formation (TBE)

Lithology: The lowest units comprise a basal conglomerate dominated by debris originating from the Lewisian Gneiss. The conglomerate is followed by a very coarse-grained grey-green sandstone, rich in epidote, with trough cross-bedding. Higher up sandstone beds are gradually replaced by laminated siltstone, locally with desiccation cracks.

Interpretation: Alluvial fans passing laterally and upwards into lacustrine or shallow-marine deposits (Stewart 2002)

Type section: Coastal section at Rubha Guail, Sleat, Skye. [NG 722 150 to NG 728 159]

Lower Boundary: Unconformable upon Lewisian Gneiss (sheared and overturned)

Upper Boundary: Conformable overlain by Loch na Dal Formation (TBLN). Incoming of interbedded sandstone-mudstone.

Thickness: c. 270 m (deformed)

Other names: 'Epidotic Grits'

10.2.2 Loch na Dal Formation (TBLN)

Lithology: Dominated by interbedded grey sandstone and dark grey mudstone (shale). The sandstone is coarse-grained and poorly sorted, akin to wackes. The sandstone beds show erosional bases, become finer towards their tops and are commonly ripple-laminated. The mudstone and associated siltstone are massive or laminated and commonly show graded bedding or lenticular flaser bedding.

Interpretation: Lacustrine or shallow marine fan deltas (Stewart 2002); shallow-marine tidally influenced shore face deposition (Krabbendam *et al.* 2017).

Type section: Coastal section at Loch na Dal, Sleat, Skye. [NG 720 150 to NG 706 155]

Lower Boundary: Conformable upon Rubha Guail Formation (TBE). Incoming of significant mudstone beds.

Upper Boundary: Conformable overlain by Bean na Seamraig Formation (TBS). Incoming of thick-bedded cross-bedded or contorted sandstone without mudstone.

Thickness: c. 800 m thick

10.2.3 Bean na Seamraig Formation (TBS)

Lithology: Dominated by fine-grained green-grey to buff-weathering sandstone, with minor mudstone. The sandstone is thick bedded (1-3 m) and over large parts appears massive with few well-preserved structures, hampering its interpretation. Soft-bedded contortions are common. Mudstone facies show pinstripe and lenticular ripple bedding. Locally, as in Kylerhea Glen, the sandstone is coarser grained, and shows trough-cross bedding, channels with erosive bases and contorted bedding, suggesting high-energy deposition.

Interpretation: The coarse trough cross-bedded facies is interpreted as a braided river deposit (Stewart 2002). The fine-grained massive sandstone together with the rippled mudstone facies suggest tidally influenced shallow channel / shoreface deposition (Krabbendam *et al.* 2017).

Type section: Beinn Bhreac to All a' Choin, Sleat, Skye [NG 721 162 to NG 708 189]. Reference section: Kylerhea Glen, [NG 762 206 to NG 742 213].

Lower Boundary: Conformable upon Loch na Dal Formation (TBLN). Incoming of cross-bedded sandstone without mudstone.

Upper Boundary: Conformable overlain by Kinloch Formation (TBK). Incoming of fining-upwards cycles of sandstone-siltstone.

Thickness: c. 1100 m

10.2.4 Kinloch Formation (TBK)

Lithology: Fine-grained grey sandstone and fissile mudstone (shale), in fining-upwards cycles (25-35 m) of fine-grained cross-bedded, contorted grey sandstone, passing upwards into interbedded sandstone and dark-grey fissile siltstone with wavy, lenticular and flaser ripple laminations.

Interpretation: Alluvial fan deposits interfingering with lacustrine or shallow-marine deposits (Stewart 2002). Tidally influenced shallow channel / shoreface deposition (Krabbendam *et al.* 2017).

Type section: Loch Eishort, Sleat, Skye [NG 668 169 – NG 677 161]

Lower Boundary: Conformable upon Bean na Seamraig Formation (TBS). Incoming of fining-upwards cycles of sandstone-siltstone.

Upper Boundary: Overlain by Applecross Formation (trough cross-bedded sandstone), with low-angle unconformity (Kinnaird *et al.* 2007).

Thickness: c. 1100 m

10.3 IONA GROUP (IONA)

Lithology: Lower Unit: is a very coarse cobble-boulder conglomerate, containing clasts derived from the underlying Lewisian gneiss. The conglomerate is interbedded with and graded upwards a pebble conglomerate. This is followed by a pink to grey coarse arkosic sandstone, interbedded rare mudstone beds. Upper Unit: comprises alternations of fine-grained grey sandstone and thin dark mudstone beds with ripple laminations. Various sedimentary structures (ripple laminations, parallel laminations, cross-bedding, scouring) occur in the upper unit. Paleocurrents are to the NE (Stewart 1962). The Iona Group is metamorphosed to lower greenschist facies, and is variably green in colour due to presence of chlorite and epidote. Part of the Group is hornfelsed by the nearby Ross of Mull granite. Deformation is highly variable: locally mylonitic zones occur.

Interpretation: Alluvial fan (locally debris fans) followed by lacustrine or shallow marine deposits (Stewart 2002)

Type section: not defined. Reference section: coastal section on NE coast [NM 292 262 – NM 295 260]

Lower Boundary: Unconformable upon Lewisian Gneiss inlier (L); unconformity is locally sheared

Upper Boundary: not exposed – eroded.

Thickness: c. 700 m. Lower unit: c. 0-165 m; Upper Unit c. 500 m (minimum).

Geographical extent: Iona

Key References: Bailey & Anderson (1925); Stewart (1962); McAteer *et al.* (2014).

10.4 TORRIDON GROUP (TC)

Lithology: Dominated by red sandstone: coarse in Applecross Formation; fine-medium in Aultbea Formation. Thick-bedded, cross-bedded and commonly contorted. Subordinate pebble conglomerate and thin grey siltstones. Planar and cross-bedding are common, with co-sets typically 0.5-1 m thick, locally up to 3-6 m. Soft-sediment deformation is common and ubiquitous in the Aultbea Formation. The higher Cailleach Head Formation comprises thinly bedded mudstones and siltstones in coarsening upwards cycles.

Interpretation: Fluvial deposition in east-flowing braided rivers on a wide braid plain, with channels 1-3 m (rarely 9m) deep (Nicholson 1993). Near ubiquitous soft-sediment deformation likely caused by high-water table, combined with rapid deposition (Owen 1995) in sheet floods. Lowest Diabaig Formation includes debris fans, alluvial fans and lacustrine deposits. The higher Cailleach Head Formation is interpreted as lacustrine / deltaic deposits.

Lower Boundary: Upon Kinloch Formation (TBK) (Sleat Group - TB) via minor unconformity: elsewhere with angular unconformity upon Stoer Group (TA) or Lewisian Gneiss (L).

Upper Boundary: not exposed, eroded. Unconformably overlain by Cambrian Ardvreck Group quartz arenite (ARDV)

Thickness: c. 4000-6000 m

Geographical extent: Northwest Highlands, from Cape Wrath to Rhum. Locally within Moine Thrust Zone (Assynt culmination and Kishorn Nappe)

Age: Tonian Period. Deposition of the Torridon Group is constrained between c. 1000 and 950 Ma: youngest detrital zircons and rutile fall in the range 1060-1000 Ma (Rainbird *et al.* 2001; Krabbendam *et al.* 2017), whilst the corelative Morar Group (Meadie Schist Formation) shows metamorphism at c. 950-940 Ma (Bird *et al.* 2018).

10.4.1 Diabaig Formation (TCD)

Distribution: The Diabaig Formation occurs between the overlying Applecross Formation above and the Lewisian Gneiss below. Distribution is patchy and thickness is highly variable. The basal unconformity surface has a high relief, and Diabaig Formation deposits typically form the infill to palaeo valleys 100-250 m deep.

Lithology: Several facies occur within the Diabaig Formation. Adjacent to steep palaeo-slopes, breccias and conglomerates dominate, typically with pebble to cobble-sized clasts of Lewisian gneiss ('breccia facies'); locally interbedded with red sandstone. Laterally and upwards this facies passes into tabular-bedded red sandstone, with ripples and small scours. In places, mass-flow deposits of sandstone occur.

Interpretation: Debris fans, alluvial fans, lacustrine.

Type section: Diabaig, coastal section [NG 797 601 – NG 793 603]

Lower Boundary: Unconformable upon Lewisian Gneiss (L)

Upper Boundary: Overlain by Applecross Formation (trough cross-bedded sandstone), normally with sharp boundary, possibly with low-angle unconformity.

Thickness: highly variable, maximum c. 200 m.

Geographical extent: Northwest Highlands, from Assynt to Rum

10.4.1.1 Fiachanis Gritty Sandstone Member (TCDF) - Rum

The Fiachanis Gritty Sandstone Member (TCDF) is the lowest member of the Diabaig Formation on Rum.

Lithology: Predominantly coarse-grained sandstone, with subordinate granular sandstone and basal breccia; breccias and granular sandstones occur at the base of the member, on or near the underlying Lewisian Gneiss; the coarse sandstones gradually become medium-grained towards the top of the member.

Type section: Isle of Rum, Fiachanis, [NM 374 939 to NM 375 939]

Lower Boundary: Unconformable upon Lewisian Gneiss (L).

Upper Boundary: Highly variable gradational and/or interdigitating transition into overlying Laimhrig Shale Member (TCDL), which may occur over several tens of metres of stratigraphical thickness, e.g. [NM 3695 9905].

Thickness: 35m-70m in type locality (highly variable elsewhere).

Geographical extent: Isle of Rum

Key reference: Nicholson in Emeleus (1997) - Rum memoir; Stewart (2002)

10.4.1.2 Laimhrig Shale Member (TCDL) - Rum

The Laimhrig Shale Member is the highest member of the Diabaig Formation on Rum.

Lithology: Laminated dark-grey shaley mudstone, siltstone, and very fine- to fine-grained sandstone, with intercalated beds of pale grey fine-grained sandstone that increase in thickness and abundance towards the top of the member.

Type section: Isle of Rum, Laimhrig, [NM 420 970 to NM 418 960]

Lower Boundary: Highly variable gradational and/or interdigitating transition from the underlying Fiachanis Gritty Sandstone Member (TSDF). [NM 3730 9366 or NM 3695 9905].

Upper Boundary: Overlain by the Allt Mor Na H-Uamha Member (TCAM) / Applecross Formation (TCA). The first thickly-bedded (> 2m), cross-bedded and/or convoluted fine- to medium-grained sandstone bed. [NM 4186 9604].

Thickness: 275m minimum in type-locality (stratigraphical base not visible)

Geographical extent: Isle of Rum

Key reference: Nicholson in Emeleus (1997) - Rum memoir; Stewart (2002)

10.4.1.3 BLA-BHEINN MEMBER (TCDB) - SKYE

The Bla-Bheinn Member is the lowest member of the Diabaig Formation on Skye.

Lithology: Coarse

Type section: Coastal

Lower Boundary: Unconformable upon Lewisian Gneiss (L).

Upper Boundary: Conformably overlain by the Sgurr Na Stri Member (TCDS); poorly exposed. Elsewhere unconformably overlain by Jurassic strata

Thickness: 70 m (minimum)

Geographical extent: Skye – Loch Scavaig

Key reference: British Geological Survey (2002c) Sheet 71W - Broadford

10.4.1.4 SGURR NA STRI MEMBER (TCDS) - SKYE

The Sgurr Na Stri Member is the highest member of the Diabaig Formation on Rum.

Lithology: Siltstone-mudstone, laminated, grey, grey sandstone

Type section: Coastal

Lower Boundary: Not exposed.

Upper Boundary: Conformably overlain by the Bla-Bheinn Member (TCDB); poorly exposed. Elsewhere intruded by Skye Central Complex (SKYC)

Thickness: poorly constrained.

Geographical extent: Skye – Loch Scavaig

Key reference: British Geological Survey (2002c) Sheet 71W - Broadford

10.4.1.5 TORRAN MEMBER (TCTN) - RAASAY - SCALPAY

The Torran Member (TCTN) the lowest member of the Diabaig Formation on Raasay

Lithology: Breccio-conglomerate, coarse sandstone

Type section: Raasay; Loch Arnish [NG 592 490 to NG 592 482]

Lower Boundary: Unconformable upon Lewisian Gneiss (L).

Upper Boundary: Not exposed, but likely conformably overlain by Brochel Member (TCBL).

Thickness: c 60 m (minimum)

Geographical extent: Raasay, Scalpay

Key reference: Stewart (2002)

10.4.1.6 BROCHEL MEMBER (TCBL) - RAASAY - SCALPAY

The Brochel Member (TCBL) is the highest member of the Diabaig Formation on Raasay and Scalpay. The Mullach Nan Carn Member is made redundant and superceded by the Brochel Member

Lithology: Grey mudstone, micaceous siltstone, coarse sandstone, thick-bedded 'greywacke' sandstone; medium-coarse, thick-bedded sandstone.

Type section: Brochel, Raasay: [NG 585 463 to NG 584 459]

Lower Boundary: Conformably upon Torran Member (TCTN); also unconformable upon Lewisian Gneiss (L)

Upper Boundary: Conformably overlain by Loch An Uach Member (TCLU) / Applecross Formation (TCA)
Thickness: c. 130 m
Geographical extent: Raasay, Scalpay
Key reference: Stewart (2002)

10.4.1.7 Slattadale Member (TCD1) - Diabaig to Gairloch

The Slattadale Member (TCD1) is the lowest member of the Diabaig Formation in the Diabaig – Gairloch area.
Lithology: Breccio-conglomerate, coarse sandstone; tabular red sandstone. Equivalent to Facies 1 of Diabaig Formation as defined by Stewart (2002).
Type section: not defined.
Lower Boundary: Unconformable upon Lewisian Gneiss (L).
Upper Boundary: Conformably overlain by Horrisdale Waterfalls Member (TCD2)
Thickness: c. 0-100 m
Geographical extent: NW Highlands: Diabaig to Gairloch
Key reference: Stewart (2002)

10.4.1.8 Horrisdale Waterfalls Member (TCD2) - Diabaig to Gairloch

The Horrisdale Waterfalls Member (TCD2) is the highest member of the Diabaig Formation in the Diabaig – Gairloch area. The overlying Dubh Loch Member (TCD3), formerly the highest member of the Diabaig Formation, is now seen as part of the Applecross Formation, and renamed as the Allt na Beiste Member (Stewart 2002). Equivalent to Facies 2 (‘grey shale facies’) of Diabaig Formation as defined by Stewart (2002).
Lithology: Siltstone-mudstone, finely interbedded, grey, shaley; grey sandstone with ripple laminations. Coarsening upwards.
Type section: Coastal outcrops at Diabaig: [NG 797 601 to NG 793 603]
Lower Boundary: Conformably upon Slattadale Member (TCD1); also unconformable upon Lewisian Gneiss (L)
Upper Boundary: Sharp contact with overlying Allt na Beiste Member - the lower Member of the Applecross Formation (TCA). Marked by abrupt appearance of trough cross-bedded sandstone.
Thickness: 115 m in type section at Diabaig, possibly thicker to the north
Geographical extent: NW Highlands: Diabaig to Gairloch
Key reference: Stewart (2002)

10.4.2 Applecross Formation (TCA)

Lithology: Dominated by thick-bedded (0.5 – 5m) coarse to very-coarse, pebbly red sandstone, with thin pebble conglomerates. Subordinate thin grey siltstones. Planar and cross-bedding are common, with co-sets typically 0.5-1 m thick, locally up to 3-6 m. Soft-sediment deformation is common but not ubiquitous.
Interpretation: Fluvial deposition in east-flowing braided rivers on a wide braid plain, with channels 1-3 m (rarely 9m) deep (Nicholson 1993). Near ubiquitous soft-sediment deformation likely caused by high-water table, combined with rapid deposition (Owen 1995) in sheet floods. Lower units may be alluvial fan deposits (Williams 1969a).
Type section: No single type section has been defined.
Lower Boundary: Upon Diabaig Formation (TCD) or Kinloch Formation (Sleat Group - TB) via minor unconformity: elsewhere with angular unconformity upon Stoer Group (TA) or Lewisian Gneiss (L).

Upper Boundary: Conformably overlain by the Aultbea Formation (TCAU), with gradational boundary, with incoming of consistent fine-medium grained sandstone.

Thickness: c. 2500 m.

10.4.3 Applecross Formation (TCA): local Members

A number of Members have been defined within the Applecross Formation, normally at or close to the base. These members typically have rather local distribution and are described here from north to south. All have the same age as the Applecross Formation.

10.4.3.1 Cape Wrath Member (TCCW) - Cape Wrath to Assynt

The Cape Wrath Member has been defined in the Cape Wrath area and extends as far south as Assynt (Quinag).

Lithology: Pebble and cobble conglomerates and very coarse to coarse sandstone, in beds < 4m thick. The unit contains numerous 20-30 m thick coarsening-up cycles, but shows an overall fining-upward trend in terms of clast size and decreasing frequency of coarse units. The sandstones show channels, planar and trough-cross bedding, with co-sets several metres thick, and is locally contorted.

Interpretation: Alluvial fan or megafan deposits (Williams 2001). Palaeocurrents vary from SE to NE.

Type section: Coastal sections in Cape Wrath area, NW Of Oldshoremore [NC 1859 – NC 1964]

Lower Boundary: Unconformable upon Lewisian Gneiss (L). Precambrian weathering profile occurs locally just below the unconformity.

Upper Boundary: Conformably overlain by the remainder of the Applecross Formation

Thickness: c. 450 m; thinning to the south.

Geographical extent: NW Highlands: Cape Wrath to northern Assynt

Key reference: Williams (2001); Stewart (2002)

10.4.3.2 Rubha Dubh Ard Member (TCAR): Assynt – Rubha Coigach

The Rubha Dubh Ard Member is a local member in the Assynt-Rubha Coigach area at the base of the Applecross Formation. The overlying Achduart Member is included in the Applecross Formation.

Lithology: Coarse, red sandstone with trough crossbedding at base, followed by medium-fine grey, tabular sandstone with ripple cross-lamination, and very thin grey, shaley siltstone units.

Type section: Coastal section at Rubha Dubh Ard, east of Achiltibuie [NC 042036 – NC 045034]

Lower Boundary: Unconformable upon Lewisian Gneiss (L) or overlying the Diabaig Formation (TCD) with a sharp contact.

Upper Boundary: Conformably overlain by the remainder of the Applecross Formation

Thickness: c. 50-100 m.

Geographical extent: NW Highlands: southern Assynt and Rubha Coigach

Key reference: Stewart (2002); Nicholson (1993)

10.4.3.3 Allt na Beiste Member (NEW): Daibaig-gairloch

This member replaces the Dubh Loch Member (TCD3), formerly the upper member of the Diabaig Formation. The Applecross Formation now encompasses this unit of cross-bedded sandstones at its base.

Lithology: Fine -medium red sandstone, cross-bedded, rare pebbles, locally contorted, minor red shaley mudstone beds.

Type section: Diabaig: [NG 797 601]

Lower Boundary: Sharp contact with underlying Horrisdale Waterfalls Member (TCD2) - the upper Member of the Diabaig Formation (TCD). Marked by abrupt appearance of trough cross-bedded sandstone.

Upper Boundary: Conformably overlain by the remainder of the Applecross Formation (TCA); marked by highest red shaley mudstone.

Thickness: 20-100 m (estimate)

Geographical extent: NW Highlands Diabaig to Gairloch.

Key reference: Stewart (2002)

10.4.3.4 ALLT MOR NA H-UAMHA MEMBER (TCAM): RUM – SOAY – SCLAPAY

The Allt Mor Na H-Uamha Member is the basal member of the Applecross Formation on Rum. It equates with the *Leac-Strearnan Member (TCAL*) on Raasay, Soay and Skye Rum: this latter unit can be rendered obsolete.

Lithology: Cyclically interbedded siltstone; very fine- to fine-grained sandstone and mudstone and " and fine- to medium-grained cross-bedded sandstones. the fine- to medium-grained cross-bedded sandstone beds increase in abundance towards the top of the Member.

Type section: Isle of Rum, Allt Mor Na H-Uamha [NM 420 972 to NM 411 975]

Lower Boundary: Upon the Diabaig Formation (TCD). Base (NM 4205 9722): at the lowest thickly-bedded (>2 m), cross-bedded and/or convoluted fine- to medium-grained sandstone

Upper Boundary: Overlain by the Scresort Sandstone member (TCAS) at the incoming of thickly-bedded, cross-stratified and/or convoluted coarse-grained sandstone (arkose) bed containing 'exotic' pebbles characteristic of the Applecross Formation.

Thickness: 415m in type locality

Geographical extent: Rum, Soay

Key reference: Nicholson in Emeleus (1997) - Rum memoir; Stewart (2002)

10.4.3.5 SCRESORT SANDSTONE MEMBER (TCAS): RUM – SOAY

The Scresort Sandstone Member is the main constituent member of the Applecross Formation on Rum. It now also encompasses the *Bheinn Bhreac Member* (TCAB) on Soay: this unit is now redundant.

Lithology: Medium- to coarse-grained sandstones containing "exotic" pebbles; abundant cross-bedding and soft-sediment convolution structures. Minor fine-grained sandstones, siltstones and mudstones.

Interpretation: Fluvial braidplain deposits;

Type section: Here Isle of Rum, Loch Scresort; [NG 423 001 to NG 327 020]

Lower Boundary: Conformably overlying the Allt Mor Na H-Uamha Member (TCAM): incoming of first' thickly-bedded, cross stratified and/or convoluted coarse-grained sandstone bed with 'exotic' pebbles characteristic of the Applecross Formation.

Upper Boundary: Conformably overlain by the remainder of the Applecross Formation Overlain by the Leac Nam Faoileann Member (TCAF) (Applecross Formation) on Soay; overlain by the Sgorr Mhor Sandstone Member (TCSM) (Aultbea Formation) on Rum. Marked by the disappearance of 'exotic' pebbles.

Thickness: c.2000m +/- 500m (allowing for uncertainty in fault displacements).

Geographical extent: Rum, Soay

Key reference: Nicholson in Emeleus (1997) - Rum memoir; Stewart (2002)

10.4.3.6 LEAC NAM FAOILEANN MEMBER (TCAF): SOAY

The Leac Nam Faoileann Member the top member of the Applecross Formation on Soay. It is possibly part of the Aultbea Formation, but the restricted thickness of the underlaying Scresort Sandstone Member on Soay argues against this.

Lithology: Fine-grained sandstone, cross-bedded and contorted. Heavy mineral bands common. Minor siltstone.

Type section: not defined

Lower Boundary: Overlying the Scresort Sandstone Member (TCAS), defined by a siltstone bed.

Upper Boundary: Not exposed

Thickness: c. 200 m (minimum: top not exposed)

Geographical extent: Soay

Key reference: Nicholson in Emeleus (1997) - Rum memoir; Stewart (2002)

10.4.3.7 Loch An Uach Member (TCLU): Raasay

Lithology: Grey mudstone, micaceous siltstone, coarse sandstone, thick-bedded 'greywacke' sandstone; medium-coarse, thick-bedded sandstone.

Type section: Not defined

Lower Boundary: Sharp, erosive contact with the underlying Brochel Member (TCBL) - Diabaig Formation (TCD)

Upper Boundary: Conformably overlain by the remainder of the Applecross Formation (TCA)

Thickness: c. 130m

Geographical extent: Raasay

Key reference: Stewart (2002)

10.4.4 Aultbea Formation (TCAU)

Lithology: Virtually exclusively fine-medium grained, pale red sandstone, thick-bedded (2-5m); some coarser grained and rarely pebbly sandstone occur locally. Cross bedding in large (1-4 m) cosets, but virtually all beds are contorted. Paleocurrents to east or NE.

Interpretation: Fluvial deposition in east-flowing braided rivers on a wide braid plain, with channels 1-3 m (rarely 9m) deep (Nicholson 1993). Near ubiquitous soft-sediment deformation likely caused by high-water table, combined with rapid deposition (Owen 1995) in sheet floods.

Type section: Coastal section, SW side of Gruinard Bay, Aultbea peninsula [NG 880 976 – NG 900 955]

Lower Boundary: Conformable upon Applecross Formation (TCA), with gradational boundary, with incoming of consistent fine-medium grained sandstone.

Upper Boundary: Conformably overlain by Cailleach Head Formation (TCC). The lower contact is only exposed on Gruinard Island – not re-analysed since Second World War due to anthrax contamination.

Thickness: c.2000-3000m (Estimate: the unit is nowhere exposed in one single section)

10.4.4.1 Sgorr Mhor Sandstone Member: Rum

The Sgorr Mhor Sandstone Member is a Member of fine-medium grained sandstone on Rum. Nicholson (in: Emeleus 1997) included this unit in the Aultbea Formation, whilst Stewart (2002) argued for inclusion in the Applecross Formation. Given that the underlying Scresort Sandstone Member is similar in thickness (c. 2500 m) as Applecross Formation elsewhere, the inclusion in the Aultbea Formation is retained.

Lithology: Fine- to medium-grained sandstones without "exotic" pebbles, thick-bedded. Abundant cross-bedding and convolute, soft-sediment deformation structures. Detrital heavy minerals of silt to fine-grained sand grade common.

Type section: Isle of Rum, Sgor Mhor: Guirdial Bay to Camas na h-Atha [NG 315 011 to NM 301 996]

Lower Boundary: Conformably upon the Scresort Sandstone Member (TCAS) of the Applecross Formation (TCA), marked by disappearance of 'exotic' pebbles characteristic of the Applecross Formation.

Upper Boundary: not exposed

Thickness: 175 (minimum)

Geographical extent: Island of Rum

Key reference: Nicholson in Emeleus (1997) - Rum memoir; Stewart (2002)

10.4.5 Cailleach Head Formation (TCC)

Lithology: The formation is dominated by thin-bedded siltstone and sandstone in a series of c. 20 -50 m thick coarsening-up cycles. Each cycle has an erosional base covered with laminated grey siltstone with desiccation cracks, followed by wave-rippled sandstone, topped by trough cross-bedded sandstone to the top. Palaeo-currents are to the NE.

Interpretation: The Cailleach Head Formation clearly represents a much lower energy environment that the underlying fluvial sandstones, with the siltstone deposited in standing, below wave-base water, and the sands possibly deposited by advancing deltas. Lack of carbonate and evaporate suggest a lacustrine rather than marine environment (Stewart, 2002), although a shallow-marine environment cannot be ruled out (Bonsor perss comm). The base of the Cailleach Head Formation represents a major retrogradational surface that likely correlates with the flooding surface at the base of the Vaich Pelite and Morar Pelite Formations (Morar Group).

Type section: Cailleach Head, Scoraig [NC 986 986 to NC 986 979]

Lower Boundary: Conformable upon Aultbea Formation (TCAU). The contact only exposed on Gruinard Island – and has not been re-analysed since the early 20th century due to anthrax contamination in the Second World War.

Upper Boundary: Erosional – not exposed. Unconformably overlain by Cambrian Ardvreck Group (ARDV).

Thickness: c. 630 m (minimum at type section); total possibly 1000 m.

Key reference: Stewart (2002)

10.5 MORAR GROUP: NORTH (CENTRAL ROSS-SHIRE AND SUTHERLAND)

10.5.1 Meadie Schist Formation (MESC)

Lithology: Lower part dominated by schistose semipelite, biotite-muscovite bearing. Upper part comprises schistose pelite, garnet-biotite-muscovite bearing, with local kyanite and staurolite. Minor micaceous, flaggy psammite. Quartz segregations occur. Strongly deformed and metamorphosed lithology.

Interpretation: No sedimentary structures are preserved. Deposition in low-energy environment (lacustrine or shallow marine) is suggested by the lithology. Very limited extent. Possibly correlatable (in the broad sense) with the Diabaig Formation.

Type section: not defined

Lower Boundary: Unconformable upon Lewisian Gneiss inlier (L); unconformity highly sheared

Upper Boundary: Conformably overlain by the Altnaharra Formation (ALPS)

Thickness: apparent stratigraphic thickness is c. 400m; true stratigraphic thickness probably less (? c. 100-200m) due to later deformation.

Geographical extent: Sutherland: Ben Loyal to Mudale

Key Reference: Bird *et al.* (2018); Moorhouse & Moorhouse (1988).

10.5.2 Altnaharra Psammite Formation (ALPS)

Lithology: Siliceous to feldspathic psammite with micaceous psammite, grey to buff; locally with micaceous layers. Gritty psammites occur in the lower part; higher up in the unit, thin semipelitic beds become more common. Generally, strongly deformed and flaggy ('bed' thickness 5 -30 cm). In low strain zones, the psammite shows thick beds (0.5 – 5m): sedimentary structures include channels with pebble lags, planar and trough cross-bedding, slump-like folds, dewatering pipes and oversteepened cross-beds (Krabbendam *et al.* 2008). Palaeo-currents are to east or NE.

Interpretation: Interpreted as high-energy braided fluvial deposits (Krabbendam *et al.* 2008).

Type section: Glen Cassley: River Cassley to Carn nan Bo Maola NC 436 089 - NC 462 098]. Reference area: Beinn Direach to Ben Hee: [NC406 380 – NC 445 342].

Lower Boundary: Unconformable upon Lewisian Gneiss inlier (L); unconformity highly sheared; locally conformable (?) on Meadie Schist Formation. In many places, base is cut and deformed by the Moine Thrust.

Upper Boundary: Conformably overlain by the Glascarnoch Psammite Formation (GLPS).

Thickness: c. 2500-3000 m (estimate); thinning to the east.

Geographical extent: Northern Highlands: Central Ross-shire, Sutherland. Occurs in various thrust sheets.

Old name: A' Mhoine Psammite Formation (AMPS)

Key Reference: Krabbendam *et al.* (2008); Bonsor *et al.* (2010); Holdsworth *et al.* (2001)

10.5.2.1 Strathan Conglomerate Member (STRC)

This metaconglomerate occurs locally at or near the base of the Altnaharra Psammite Formation.

Lithology: Metaconglomerate with heterogeneous clasts (quartzite, gneiss, vein quartz, quartz-magnetite rock, granite/pegmatite) in a green-grey psammite matrix. Occurs in two units, separated by psammite. The metaconglomerate is strongly sheared.

Interpretation: Basal conglomerate above unconformity.

Type section: Type area at Traigh an t-Strathain [NC 57 64]

Lower Boundary: Unconformable upon Lewisian Gneiss inlier (L); unconformity highly sheared;

Upper Boundary: Conformably overlain by the remainder of the Altnaharra Psammite Formation (ALPS).

Thickness: c. 20 m (estimate of deformed rocks).

Geographical extent: Sutherland. Ben Hutig to East Strathan.

Key Reference: Mendum (1976); Holdsworth *et al.* (2001)

10.5.2.2 Glen Achall Psammite and Semipelite Member (GACH)

This member comprises the upper unit of the Altnaharra [psammite Formation.

Lithology: Locally a 10-20 m thick garnetiferous semipelite unit at the base, followed by tabular to trough cross-bedded psammite, interbedded with garnetiferous semipelite in fining -upwards sequences. At the top of the formation is another c. 10-20 m thick garnetiferous semipelite with locally thin quartzite. Palaeocurrents in psammite NE to NW.

Interpretation: Distal, medium-to-low energy fluvial braidplain deposition (Bonsor *et al.* 2010)

Type section: North of Glen Achall: Meall Liath Choire to Cnoc Damh [NH 227 961 – NH 271 963]

Lower Boundary: Conformably upon the remainder of the Altnaharra Psammite Formation (GLPS). Incoming of significant (>2m) garnet-bearing semipelite layers.

Upper Boundary: Conformably overlain by the Glascarnoch Psammite Formation (GLPS). Boundary set above uppermost limit of thick (>2m) garnet-bearing semipelite units.

Thickness: c. 500 (estimated maximum); thinner to SW and NE.

Geographical extent: Central Ross-shire.
Old name: Loch Droma Pelitic Group (Sutton & Watson 1955)
Key Reference: Krabbendam *et al.* (2011); Bonsor *et al.* (2010)

10.5.3 Glascarnoch Psammite Formation (GLPS)

Lithology: Dominated by siliceous to micaceous psammite with subsidiary pelite beds. In lower part: thick beds (0.3-2 m) with trough-and-planar cross bedding in coarsening upwards cycles with cm thick pelitic beds. The higher part of the unit shows coarsening upwards units of rhythmically interbedded psammitic and pelitic beds, commonly with water escape structures and slump folds. The psammite beds are more siliceous and locally quarzitic. Cross-bedded and ripple laminations occur. Palaeo-currents are to the NE to NW in the lower part and bimodal in the upper part.
Interpretation: Lower part: distal fluvial braidplain; upper part tidally-influenced shallow marine-depositional setting (Bonsor *et al.* 2010).
Type section: Northern shore section along Loch Glascarnoch [NH 286 748 – NH 321 724]. Reference sections: shore section along Loch Fannich [NH 264 657 – NH 253 648], southern slopes of Beinn Dearg [NH 26 80 – NH 28 81].
Lower Boundary: Conformably upon the Altnaharra Psammite Formation (ALPS).
Upper Boundary: Conformably overlain by the Vaich Pelite Formation (VAPE). A progressive reduction in bed thickness down to *c.* 10 cm in the uppermost part Glascarnoch Psammite Formation is typical. Boundary with Vaich Pelite Formation is normally sharp incoming of thick-bedded semipelite beds.
Thickness: c. 4000-5000 m (estimate); thinning to the west.
Geographical extent: NW Highlands: Central Ross-shire to Sutherland.
Old name: Inverbroom Semipelitic Group (Sutton & Watson 1955)
Key Reference: Bonsor *et al.* (2010); Krabbendam *et al.* (2011)

10.5.4 Vaich Pelite Formation (VAPE)

Lithology: Thick-bedded semipelite and pelite, commonly garnetiferous. Commonly 'striped' appearance due to mm-scale alternations of quartzo-feldspathic and micaceous material. Pale brown cm-thick layers of siliceous psammite are sporadically developed. The unit is generally strongly deformed. A well-developed schistose mica fabric is ubiquitous. Sedimentary structures have not been observed and have presumably been obliterated.
Interpretation: Fine grain size indicate deposition in very low-energy, likely shallow marine below-wave base. The base of the Vaich Pelite Formation would then represent a flooding surface.
Type section: Eastern slopes of Seana Bhraigh [NH 287 866 - NH 310 853]. Reference area: south of Braemore Junction: Creag Dubh to Meall a' Chrasgaidh [NH 215 763 – NH 186 737].
Lower Boundary: Conformably upon the Glascarnoch Psammite Formation (GLPS). Boundary usually sharp incoming of dark semipelite and pelite beds.
Upper Boundary: Conformably overlain by the Crom Psammite Formation (CMPS).
Thickness: c. 300 m (estimate; unit is strongly deformed) thinner to SW and NE.
Geographical extent: NW Highlands, Central Ross-shire to Sutherland.
Old name: Sgurr Mor Pelitic Group (Sutton & Watson 1955)
Key Reference: Bonsor *et al.* (2010; 2012); Krabbendam *et al.* (2011);

10.5.5 Crom Psammite Formation (CMPS)

Lithology: The basal part of the Crom Psammite Formation comprises interbedded micaceous psammite and semipelite-pelite beds, in 10-20 m scale coarsening-upwards cycles, with a progressive upwards increase in psammite component. The central part of the unit is dominated by gritty (locally pebbly) arkosic psammite, with beds 0.5 – 2 m thick, with only thin (cm-scale) semipelite beds. Trough cross-bedding and water escape structures are common. The upper Crom Psammite Formation is similar to the lower part.

Interpretation: The lower and upper Crom Psammite Formation have been interpreted as shallow-marine, tidal shoreline deposits, whilst the central part has been interpreted as fluvial deltaic to fluvial braidplain deposition (Bonsor *et al.* 2012).

Type section: Glen Calvie: Croick to Beinn Tharsuinn. [NC 45 89 – NC 29 83]. Reference section: Allt Crom Loch section [NH 372 830 – NH 390 - 830]

Lower Boundary: Conformably upon the Vaich Pelite Formation (VAPE). Gradational; marked by increase of psammite beds.

Upper Boundary: Conformably overlain by the Diebidale Pelite Formation (DIEP). Gradational; marked by decrease of psammite beds.

Thickness: c. 2500-3000 m (estimate); thinning to the east.

Geographical extent: NW Highlands, Central Ross-shire; southern Sutherland.

Key Reference: Bonsor *et al.* (2012); Krabbendam *et al.* (2011).

10.5.6 Diebidale Pelite Formation (DIEP)

Lithology: Schistose garnetiferous pelite, locally with calc-silicate and psammite layers, more semipelitic towards its base. The formation occurs partly in the thermal aureole of the Carn Chuinneag granite gneiss pluton: hornfelsed pelite locally preserves laminations, ripple marks, cross-bedding and possible mud cracks (Wilson & Shepherd 1979). Andalusite and cordierite assemblages occur in the aureole.

Interpretation: Likely shallow marine (at and below wave base) – no detailed analysis has been carried out.

Type section: Rocky spurs between Glencalvie Lodge and Carn na Speireig (south of Croick): [NH 460 887 – NH 435 880]

Lower Boundary: Conformably upon the Crom Psammite Formation (CMPS). Gradational; marked by decrease of psammite beds.

Upper Boundary: not present: eroded or intruded by Carn Chuinneag Pluton (CCIA)

Thickness: c. 200-400 m (minimum estimate)

Geographical extent: Central Ross-shire.

Key Reference: Bonsor *et al.* (2010); Wilson & Shepherd (1979)

10.6 MORAR GROUP UNITS IN THE NAVER AND TORRISDALE THRUST SHEETS (NORTH SUTHERLAND)

10.6.1 Klibreck Psammite Formation (KLPS)

This is the same unit as the Druim Chuibhe Psammite Formation, which is now declared obsolete. It occurs solely in the Naver thrust sheet, and is a likely – but not proven – lateral equivalent to the Altnaharra Psammite Formation.

Lithology: Pink-grey feldspathic and micaceous psammite, gneissose, locally migmatitic, with quartzo-feldspathic layers and K-feldspar augen. Medium-coarse grained. Layers of garnet-biotite-muscovite pelite, gneissose to migmatitic. No sedimentary structures preserved.

Type section: not defined

Lower Boundary: Unconformable upon Lewisian Gneiss inlier (L); unconformity highly sheared. In many places, base is cut and deformed by the Naver thrust.

Upper Boundary: unknown: cut by Torrisdale thrust

Thickness: post-deformational thickness c. 250 m.

Geographical extent: Northern Sutherland: Ben Klibreck to Torrisdale. In Naver thrust sheet only.

Old name: Druim Chuibhe Psammite Formation (DMCB)

Key Reference: Holdsworth *et al.* (2001)

10.6.2 Bettyhill Formation (BTYH)

The Bettyhill Formation occurs solely in the Torrisdale thrust sheet, and is a likely lateral equivalent to the Altnaharra Psammite Formation or the Glascarnoch Psammite Formation.

Lithology: Pink-grey psammite, gneissose, locally migmatitic, interlayered on cm-m scale with gneissose semipelite and pelite. Abundant quartzo-feldspathic segregations. At the structural base is locally a c. 300 m thick sillimanite-bearing gneissose pelite unit. No sedimentary structures preserved. Thin amphibolite lenses are abundant.

Type section: not defined

Lower Boundary: Unconformable upon Lewisian Gneiss inlier (L); unconformity highly sheared. In many places, base is cut and deformed by the Torrisdale thrust.

Upper Boundary: unknown: cut by Swordly thrust

Thickness: post-deformational thickness c. 1000-2000 m.

Geographical extent: Northern Sutherland: Ben Klibreck to Bettyhill. Occurs in Torrisdale thrust sheet only.

Key Reference: Holdsworth *et al.* (2001)

10.6.2.1 Invernaver Pelite Member (INAV)

The Invernaver Pelite Member is a c. 100 m thick gneissose pelite unit, within the outcrop of the Bettyhill Formation. It occurs along the River Naver.

10.7 MORAR GROUP SOUTH: MORAR AND KNOYDART

10.7.1 Basal Pelite Formation (MABP)

Lithology: Semipelite and pelite, alternated with psammite, very locally with metaconglomerate. Normally highly strained and commonly gneissose; abundant quartz veins.

Interpretation: basal conglomerate and other facies above unconformity.

Type section: not defined.

Lower Boundary: Unconformable upon Lewisian Gneiss inlier (L); unconformity normally highly sheared

Upper Boundary: Conformably overlain by the Lower Morar Psammite Formation (GLPS).

Thickness: c. 0-100 m (estimate; strongly deformed)

Geographical extent: NW Highlands: Ardnamurchan, Morar, Knoydart, Kintail.

Key Reference: Ramsay & Spring (1962)

10.7.2 Lower Morar Psammite Formation (MALP)

Lithology: Siliceous to micaceous psammite, with minor semipelite. Lower part typically buff to pink fine-grained but thick-bedded (>1 m). Sedimentary structures are rare and ill-defined and any intrabed laminations are typically wispy (see Arnisdale Psammite Member below).

The top unit of the Formation, comprises coarse to gritty, thick-bedded (0.5 – 4m), arkosic psammite. Sedimentary structures are obvious and abundant, including channels with stacked planar and trough cross-bedding with cosets (0.3 -1 m). Soft-sediment deformation structures are abundant, locally affecting up to 4 m thick. Towards the top more thinly bedded and finer grained, with an increase in semipelitic beds towards its upper contact with the Morar Schists Formation.

Interpretation: Upper part: high-energy fluvial braidplain (Krabbendam *et al.* 2014).

Type section: NW of Ladhar Bheinn: Meall Gruamach to Mullach Li [NG 806 079 – NG 819 063]

Lower Boundary: Conformably upon the Basal Pelite Formation (MABP) or unconformable upon Lewisian Gneiss inlier (L); unconformity normally highly sheared.

Upper Boundary: Conformably overlain by the Morar Schists Formation (MAMS). Relatively sharp boundary with incoming of pelitic beds.

Thickness: c. 2000-3000 m (estimate, strongly deformed in places)

Geographical extent: NW Highlands: Ardnamurchan, Morar, Knoydart, Kintail.

Previous name: Barrisdale Psammite (for upper part of the formation in Knoydart: Ramsay & Spring 1962);

Key Reference: Johnstone *et al.* (1969); Ramsay & Spring (1962); Krabbendam *et al.* (2014)

10.7.2.1 ARNISDALE PSAMMITE MEMBER (MAAP)

Lithology: Typically buff to pink fine-grained massive thick-bedded (>1 m) but fine grained. Typically brown to orange-brown. Commonly strongly recrystallised: sedimentary structures are rare and ill-defined and any intrabed laminations are typically wispy.

Interpretation: Possibly shallow marine

Type section: nor defined

Lower Boundary: Conformably upon the Basal Pelite Formation (MABP) or unconformable upon Lewisian Gneiss inlier (L); unconformity normally highly sheared

Upper Boundary: Conformably overlain by the Rubha Ruadh Semipelite Member (MARRS); transitional contact of interbedded psammite and semipelite, indicating a broad fining upwards trend.

Thickness: c. 1000 m (estimate, strongly deformed in places)

Geographical extent: NW Highlands: Morar, Knoydart, Kintail.

Key Reference: Ramsay & Spring (1962); Krabbendam *et al.* (2014)

10.7.2.2 RUBHA RUADH SEMIPELITE MEMBER (MARRS)

Lithology: Thinly interbedded psammite, semipelite and pelite, with a general upward increase in pelitic material. Garnets are rare to absent and calc-silicate rocks are absent. Locally, quartz pebble conglomerate with a semipelitic matrix.

Interpretation: Possibly shallow marine

Type section: not defined

Lower Boundary: Conformably upon the Arnisdale Psammite Member (MAAP). Gradational contact, marked by increasing semipelite beds.

Upper Boundary: Conformably overlain by the remainder of the Lower Morar Psammite Formation (MALP). Sharp incoming of psammite.

Thickness: c. 200-300 m (estimate, strongly deformed): thins to north and south

Geographical extent: NW Highlands: Knoydart, Kintail.

Key Reference: Ramsay & Spring (1962); Krabbendam *et al.* (2014)

10.7.3 Morar Schists Formation (MAMS)

Lithology: Dominant pelitic to semipelitic beds. In places massive, elsewhere clearly interbedded. Locally three different units can be recognised: (i) interbedded pelite, semipelite and psammite with calc-silicate; (ii) schistose pelite with subordinate semipelite layers; (iii) laminated semipelite and micaceous psammite, with thin siliceous psammite and calc-silicate layers.

Interpretation: Likely shallow marine, low energy, in part below wave base.
Type section: not defined. Reference section: Knoydart west coast: [NG 724 064 – NG 687 031]
Lower Boundary: Conformably upon the Lower Morar Psammite Formation (MALP). Relatively sharp boundary.
Upper Boundary: Conformably overlain by the Upper Morar Psammite Formation (MAUP).
Thickness: highly variable due to deformation: c. 100 – 1000m
Geographical extent: NW Highlands: Ardnamurchan, Morar, Knoydart, Kintail.
Previous names: Morar Striped and Pelitic Schists (Johnstone *et al.* 1969); Ladhar Bheinn Pelite (Ramsay & Spring, 1962); Morar Pelite Formation (Mendum *et al.* 2009).
Key Reference: Johnstone *et al.* (1969); Ramsay & Spring (1962); Krabbendam *et al.* (2014); Bonsor & Prave (2008); Glendinning (1988)

10.7.4 Upper Morar Psammite Formation (MAUP)

Lithology: Dominated by siliceous, feldspathic to micaceous psammite, from coarse to fine grained. Commonly pebbly and gritty bands; also semipelitic layers and calc-silicate bands. Abundant cross-bedding and soft-sediment deformation structures.
Interpretation: Fluvial braidplain deposits (Bonsor & Prave, 2008).
Type section: northern shore of Arnamurchan peninsula [NM 611 691 – NM 548 716]; Reference section: northern shore of Rhue peninsula: [NM 654 852 – NM 611 848].
Lower Boundary: Conformably upon the Morar Schists Formation (MAMS)
Upper Boundary: unknown: not exposed.
Thickness: c. 2500 m (minimum; estimate)
Geographical extent: NW Highlands: Ardnamurchan, Morar, Knoydart, Kintail.
Previous names: Aonoch Sgoilte Psammite (Ramsay & Spring 1962); Ardnish Psammite (Powell 1964)
Key Reference: Bonsor & Prave (2008); Glendinning (1988)

10.8 MORAR GROUP SOUTH: ROSS OF MULL

10.8.1 Lower Shiaba Psammite Formation (LSHP)

Lithology: Feldspathic psammite, with thin pelitic, both gneissose. Strongly deformed. Some remnants of cross-bedding.
Type section: Coastal section on Ross of Mull, NE of Rubha nam Braihrean [NM 444 187 – NM 441 183].
Lower Boundary: not exposed
Upper Boundary: Conformably overlain by the Shiaba Pelite Formation (SAPE).
Thickness: c. 250 m (minimum estimate: post-deformational thickness)
Geographical extent: Ross of Mull
Key Reference: Holdsworth *et al.* (1987)

10.8.2 Shiaba Pelite Formation (SAPE)

Lithology: Gneissose pelite, garnetiferous, minor semipelite layers. Locally contains staurolite and kyanite. Strongly deformed.
Type section: Coastal section on Ross of Mull, NE of Rubha nam Braihrean [NM 441 183 – NM 440 181].
Lower Boundary: Conformably upon the Lower Shiaba Psammite Formation (LSHP)
Upper Boundary: Conformably overlain by the Upper Shiaba Psammite Formation (USHP).
Thickness: c. 130 m (estimate – post-deformational thickness)
Geographical extent: Ross of Mull

Key Reference: Holdsworth *et al.* (1987)

10.8.3 Upper Shiaba Psammite Formation (USHP)

Lithology: Psammite, siliceous and feldspathic, numerous thin gritty to pebbly psammite layers, rare calc-silicate layers. Sparse, thin garnetiferous gneissose pelite layers. Beds 20-100 cm; cross-bedding common; possibly herring bone cross-beds. Near top, interbedded psammite and pelite – transitional into the Laggan Mor Formation.

Type section: Coastal section on Ross of Mull, Rubha nam Braihrean to Traigh Bhan na Sgurra [NM 440 181 – NM 424 183].

Lower Boundary: Conformably upon the Shiaba Pelite Formation (SAPE). Relatively sharp boundary.

Upper Boundary: Conformably overlain by Laggan Mor Formation (LAMO). Transitional boundary: increase in interbedded semipelite beds.

Thickness: c 1700 m (estimate – post-deformational thickness)

Geographical extent: Ross of Mull

Key Reference: Holdsworth *et al.* (1987); Krabbendam *et al.* (2021)

10.8.4 Laggan Mor Formation (LAMO)

The Laggan Mor Formation (LAMO), previously assigned to the Assapol Group (equivalent to Glenfinnan Group) is now incorporated into the Morar Group (Krabbendam *et al.* 2021).

Lithology: Near base: feldspathic psammite and pelite interbedded (5-20 cm scale); siliceous psammite to quartzite interbedded on dm scale with subordinate dark pelite layers; near top pelite with subordinate psammite or quartzite interbedded on cm scale, with increase of strain.

Type section: Coastal section on Ross of Mull, Traigh Bhan na Sgurra [NM 424 183 – NM 423 188].

Lower Boundary: Conformably upon the Upper Shiaba Psammite Formation (USHP). Gradational boundary.

Upper Boundary: unknown: cut by shear zone, marked by zone of intense mylonitisation. Glenfinnan Group gneissose rocks in hangingwall above shear zone, possibly marking a sheared unconformity.

Thickness: c 400 m (estimate – post-deformational thickness)

Geographical extent: Ross of Mull

Key Reference: Holdsworth *et al.* (1987); Krabbendam *et al.* (2021)

10.9 GLENFINNAN GROUP (GLEN)

Lithology: Pelitic gneiss, and intimately interbanded ('striped') psammite, pelite, semipelite and quartzite, variably gneissose.

Age: Deposition between c. 900 - 870 Ma. Youngest detrital zircons fall between c. 1000–900 Ma (Cawood *et al.* 2003; 2015; Friend *et al.* 2003; Kirkland *et al.* 2008a; Cutts *et al.* 2010; Spencer *et al.* 2015); whilst the upper part of the Glenfinnan Group is intruded by the c. 870 Ma West Highland Granite Gneiss Suite (WHGG); (Friend *et al.* 1997; Millar 1999; Rogers *et al.* 2001; Cawood *et al.* 2015).

Type section: not defined

Lower Boundary: Overlies the Sgurr Beag Thrust; with Morar Group beneath; locally unconformable upon Lewisianoid Gneiss

Upper Boundary: Overlain by the Loch Eil Group (LEIL) with a transitional, possibly interfingering boundary

Geographical extent: Northern Highlands. Restricted to the Sgurr Beag Nappe and structural equivalents.

Key Reference: Roberts *et al.* (1987); Strachan *et al.* (1988); Krabbendam *et al.* (2021)

10.9.1 Salen Pelite Formation (SALP)

Lithology: Pelitic gneiss, with minor psammite.
Type section: not defined
Lower Boundary: Overlies the Sgurr Beag Thrust; with Morar Group beneath.
Upper Boundary: Overlain by the Resipol Striped Formation (RESI), likely conformable.
Geographical extent: West Highlands: from Lochaline, via Loch Sunart to Kinlochmoidart. Restricted to the Sgurr Beag Nappe.
Key Reference: Roberts *et al.* (1987)

10.9.2 Resipol Striped Formation (RESI)

Lithology: Psammite, with interbanded pelitic gneiss
Type section: not defined
Lower Boundary: Upon the Salen Pelite Formation (SALP), likely conformable.
Upper Boundary: Overlain by the Lochailort Pelite Formation (MBLA), likely conformable
Geographical extent: West Highlands: from Sound of Mull, via Loch Sunart to Kinlochmoidart. Restricted to the Sgurr Beag Nappe.
Key Reference: Roberts *et al.* (1987)

10.9.3 Reidh Psammite Formation (REP)

The Reidh Psammite Formation is the lowest unit of the Glenfinnan Group north of Moidart. Locally unconformable upon Lewisianoid basement. Generally thin and intermittent, it reaches substantial thickness near the Scardroy Inlier.

Lithology: Coarse, locally gritty, gneissose, commonly migmatitic psammite, interbanded with gneissose pelite, semipelite and quartzite.
Type section: *not defined*
Lower Boundary: Commonly a tectonic boundary – formed by the Sgurr Beag Thrust. Locally with strongly deformed unconformity upon Lewisianoid Basement (e.g. Monar Inlier)
Upper Boundary: Likely conformable contact with the overlying Lochailort Pelite Formation (MBLA)
Geographical extent: Northern Highlands of Scotland, Morar to Dornoch Firth. Restricted to the Sgurr Beag Nappe.
Key Reference: Tanner (1971); Strachan *et al.* (1988)
Alternative and older names: Quoich Banded Formation; Garve Psammite; Ben Wyvis Psammite

10.9.4 Lochailort Pelite Formation (MBLA)

Lithology: Coarse pelitic gneiss, garnetiferous, locally migmatitic, with gneissose semipelite and psammite; the latter increasing northwards. Quartzite occurs locally. Calcsilicate bands are common within psammite.
Type section: *not defined*
Lower Boundary: Overlies the Resipol Striped Formation (RESI) south of Moidart. Further north: either the base is cut by the Sgurr Beag Thrust, or overlies conformably the Reidh Psammite (REP), or occurs directly unconformably (sheared) on Lewisianoid crystalline basement.
Upper Boundary: Likely conformable contact with the overlying Beinn an Tuim Striped Schist Formation (BTU) in the south; in the north and east directly overlain by the Loch Eil Group.

Geographical extent: Northern Highlands: Loch Sunart to Monar. Restricted to the Sgurr Beag Nappe.
Key Reference: Tanner (1971); Roberts *et al.* (1987); Strachan *et al.* (1988)
Alternative and older names: Sgurr Beag Pelite; Quoich pelite; Fraoch Bheinn Pelite; Meal an t-Sithe Pelite (in Fannich inlier: Kelley & Powell, 1985); Sguman Cointich Pelite

10.9.4.1 Beinn Gaire Psammite member (BNGS)

The Beinn Gaire psammite is a local, more psammitic development within, and likely intimately interfingered with, the Lochailort Pelite Formation (MBLA) in Moidart, of which it is herein regarded as a Member.

Lithology: Psammite, quartzose and feldspathic, schistose, with layers of garnetiferous pelite and semipelite.

Type section: *not defined*
Lower Boundary: Upon the, and partly interbedded with, Lochailort Pelite Formation (MBLA), partly interbedded,
Upper Boundary: Interbedded with Lochailort Pelite Formation (MBLA) or overlain by the Beinn an Tuim Striped Schist Formation (BTU)
Geographical extent: Northern Highlands, from Loch Sunart to Glenfinnan. Restricted to the Sgurr Beag Nappe.
Key Reference: Brown *et al.* (1970)

10.9.5 Ben Wyvis Pelite Formation (BWYP)

Lithology: Coarse pelitic gneiss, garnetiferous, locally migmatitic, with gneissose semipelite and psammite. Quartzite occurs locally. Calcsilicate bands are common within psammite.
Type section: *not defined*
Lower Boundary: Overlies conformably the Reidh Psammite (REP) where predominantly siliceous psammitic lithologies pass into predominantly pelitic lithologies, or occurs directly unconformably (sheared) on Lewisianoid crystalline basement.
Upper Boundary: Overlain by the Tarvie Psammite Formation (TAPS), where predominantly pelitic lithologies pass eastwards into predominantly psammitic lithologies.
Geographical extent: Northern Highlands: Glen Affric to Dornoch Firth. Restricted to the Sgurr Beag Nappe.
Key Reference: Roberts *et al.* (1987); Strachan *et al.* (1988)

10.9.6 Beinn an Tuim Striped Schist Formation (BTU)

Lithology: Heterogeneous package of variably gneissose psammite, pelite, semipelite and quartzite, interbanded on the metre scale.
Type section: *not defined*
Lower Boundary: Likely conformable upon the Lochailort Pelite Formation (MBLA)
Upper Boundary: Likely conformable contact with the overlying Druim na Saille Pelite Formation (DRSP) in the south; north and east of Loch Arkaig directly overlain by the Loch Eil Group.
Geographical extent: Northern Highlands of Scotland, from Loch Sunart to Loch Mullardoch. Restricted to the Sgurr Beag Nappe.
Key Reference: Roberts *et al.* (1987); Strachan *et al.* (1988)
Alternative and older names: Strathan Striped Schists and Quartzites; Garry Banded Unit

10.9.7 Druim na Saille Pelite Formation (DRSP)

Lithology: Pelitic gneiss, variably migmatitic, with minor gneissose semipelite and psammite. Calcsilicate bands occur within psammite.

Type section: *not defined*

Lower Boundary: Likely conformable upon the Beinn an Tuim Striped Schist Formation (BTU)

Upper Boundary: Likely conformable contact with the overlying Loch Eil Group (LEIL).

Geographical extent: Northern Highlands, from Ardgour to Loch Arkaig. Restricted to the Sgurr Beag Nappe.

Key Reference: Roberts *et al.* (1987); Strachan *et al.* (1988)

10.9.8 Scoor Pelitic Gneiss Formation (SCPE) - Ross of Mull

Lithology: Pelitic gneiss, garnetiferous, with abundant, deformed quartzo-feldspathic segregations. Thin layers of semipelitic gneiss and calc-silicate rock.

Type section: *not defined*

Lower Boundary: Structurally overlying by the Lagan Mor Formation (LAMO), but separated by a shearzone with intense mylonitisation.

Upper Boundary: Likely conformable contact with the overlying Ardalanish Banded Formation (ASTR)

Geographical extent: Northern Highlands, Ross of Mull

Key Reference: Holdsworth *et al.* (1987); Krabbendam *et al.* (2021)

10.9.9 Ardalanish Banded Formation (ASTR) - Ross of Mull

Lithology: Strongly layered, interbedded semipelite, garnetiferous pelite (locally with kyanite and/or staurolite), micaceous psammite. Locally cm-thin calc-silicate ribs.

Type section: *not defined*

Lower Boundary: Likely conformable upon the Scoor Pelitic Gneiss Formation (SCPE)

Upper Boundary: Not seen

Geographical extent: Northern Highlands, Ross of Mull

Key Reference: Holdsworth *et al.* (1987)

10.9.10 Achnacarry Formation (ACNS) – Loch Lochy

Isolated outcrop of likely Glenfinnan Group rocks between Loch Eil and Loch Lochy. Possibly equivalent to Beinn an Tuim Striped Schist Formation, but may also be lateral facies change into psammitic Loch Eil rocks.

Lithology: Gneissose psammite and semipelite, interbanded; calc-silicate layers common.

Type section: *not defined*

Lower Boundary: No known, not exposed.

Upper Boundary: Likely conformable contact with the overlying Tarve Psammite Formation (TAPS), with a broad transition over 150 m from gneissose interbanded rocks to psammite.

Geographical extent: Northern Highlands, along NW shore of Loch Lochy. Restricted to the Sgurr Beag Nappe.

Key Reference: Strachan *et al.* (1988)

10.9.11 Achnaconeran Striped Formation (ACHN) – Loch Ness

Lithology: Psammite and semipelite, interbanded. Semipelite is muscovite-rich and locally migmatitic.

Type section: *not defined*

Lower Boundary: Not exposed

Upper Boundary: Likely conformable contact with the overlying Tarve Psammite Formation (TAPS), via a transitional boundary.

Geographical extent: Northern Highlands, along NW shore of Loch Ness from Invermoriston to Muir of Ord. Restricted to the Sgurr Beag Nappe.

Key Reference: Strachan *et al.* (1988); May *et al.* (1997); British Geological Survey (1993) Invermoriston, Sheet73W.

10.9.12 Loch Coire Formation (LOCE) - Sutherland

The Loch Coire Formation is a series of high-grade, mainly migmatitic semipelitic and psammitic rocks in norther Sutherland, restricted to the Swordly Nappe. The unit now includes the previous Kirtomy Gneisses. Inclusion in the Glenfinnan Group is likely, but not certain.

Lithology: Psammite, semipelite and pelite, interbanded, gneissose and migmatitic. Quartzo-feldspathic segregations common. Commonly garnetiferous. Some subunits are more psammitic; others more pelitic.

Type section: *not defined*

Lower Boundary: Lower boundary is mainly a structural boundary with the underlying Swordly Thrust. However, thin slivers of strained Lewisianoid gneiss ("Swordly Inlier") suggest the Loch Coire Formation may be deposited unconformably upon Lewisianoid Gneiss.

Upper Boundary: Likely overlain by the Portskerra Formation, but any contact is highly sheared. In part cut by overlying Skinsdale Thrust.

Geographical extent: Northern Highlands, Sutherland. Restricted to the Swordly Nappe

Key Reference: Strachan & Holdsworth (1988); Strachan (1988); British Geological Survey (2004c): Badanloch, Sheet 109W

Alternative and older names: Kirtomy Gneiss; Kirtomy Formation; Badanloch Pelite

10.9.12.1 Swordly Pelite Member (SWOR)

The Swordly Pelite Member is a local, more pelitic development within Loch Coire Formation.

10.10 LOCH EIL GROUP (LEIL)

Lithology: Predominantly psammite, with quartzite units near its base. Thin and local semipelite. Sedimentary structures locally preserved.

Age: Deposition between c. 900 - 870 Ma. Youngest detrital zircons fall between c. 1000–900 Ma (Cawood *et al.* 2003; 2015; Friend *et al.* 2003; Kirkland *et al.* 2008a; Cutts *et al.* 2010; Spencer *et al.* 2015); whilst the Loch Eil Group is intruded near its base by the c. 870 Ma West Highland Granite Gneiss Suite (WHGG); (Friend *et al.* 1997; Millar 1999; Rogers *et al.* 2001; Cawood *et al.* 2015).

Interpretation: Locally abundant sedimentary structures suggest shallow marine deposition - see Strachan (1986)

Type section: not defined

Lower Boundary: Upon the Glenfinnan Group (GLEN) with a transitional, possibly interfingering boundary

Upper Boundary: Not known, not exposed.

Geographical extent: Northern Highlands. Restricted to the Sgurr Beag Nappe and structural equivalents.

Key Reference: Roberts *et al.* (1987); Strachan (1986); Strachan *et al.* (1988); Krabbendam *et al.* (2021)

10.10.1 Tarvie Psammite Formation (TAPS)

The Tarvie Psammite Formation forms the main component of the Loch Eil Group in the Northern Highlands. It contains a number of local Quartzite members. The formation is contiguous with other psammite ‘formations’, these have all been amalgamated into the Tarvie Psammite Formation – see Alternative names below.

Lithology: Predominantly psammite, thin-bedded, siliceous to micaceous; more so to the NE. Local, thin semipelite beds are is muscovite-rich and locally migmatitic. Thick, laterally extensive quartzite lenses occur, in particular near the base. Tends to become more micaceous to the NE. Psammite is generally fine-grained. Locally well-developed cross-bedding, in places showing herring-bone cross-bedding, and symmetric ripple marks.

Interpretation: Tidal, shallow-marine.

Type section: *not defined*

Lower Boundary: Likely conformable upon Glenfinnan Group (GLEN), via a transitional boundary

Upper Boundary: Not exposed

Thickness: At least 2.5 km thick, up to about 5 km.

Geographical extent: Northern Highlands, from Loch Linhe to the Dornoch Firth and in numerous outliers. Restricted to the Sgurr Beag Nappe.

Key Reference: Strachan (1986); Strachan *et al.* (1988)

Alternative and older names: Loch Eil Psammite; Upper Garry Psammite Formation; Eastern Glen Quoich Psammite; Loch Arkaig Psammite

10.10.1.1 Quartzite members within the Tarvie Psammite Formation

A number of units of quartzite occur within the Tarvie Psammite Formation. As these are typically lensoid, with Tarvie Psammite above and below, and of limited geographical extend these have been demoted to member status. They are listed in Figure 20.

	Member	Lithology	Stratigraphic position	Geographical extent	Reference
Tarvie Psammite Formation (TAPS)	***Stronchreggan Quartzite Mb (STRCH)***	Quartzite, white, interbedded with siliceous and micaceous psammite and semipelite; more abundant near the top.	Highest unit, close to exposed trop of Tarvie Psammite Fm	Loch Eil to Loch Ness	Strachan (1986); British Geological Survey (2007b) Ardgour Sheet
	Glen Gour Quartzite and Pelite Mb (GGQP)	Top unit: Pelite, garnetiferous, gneissose, locally migmatitic. Basal unit: Quartzite, white, coarse, massive	In centre of Tarvie Psammite Fm. Possibly lateral equivalent of Druim Fada Quartzite Mb (DRMF)	Ardgour	British Geological Survey (2007b) Ardgour Sheet
	Druim Fada Quartzite Mb (DRMF)		In centre of Tarvie Psammite Fm	North of Loch Eil	Strachan (1986)
	Kinlocheil Quartzite Mb (KINQU)	Quartzite, feldspathic; massive and cross-bedded, with minor psammite and semipelite. A unit of thin-bedded quartzite and semipelite at the top.	Close to base of Tarvie Psammite Fm	Loch Eil	Strachan (1986); British Geological Survey (2007b) Ardgour Sheet

Figure 20 Quartzite members within the Tarvie Psammite Formation – TAPS (Loch Eil Group).

10.10.2 Portskerra Psammite Formation (PORK) - Sutherland

The Portskerra Psammite Formation is a highly gneissose psammite unit, likely stratigraphically upon the Loch Coire Formation. Inclusion in the Loch Eil Group is likely but not certain.

Lithology: Psammite and minor semipelite, gneissose, migmatitic. Local calc-silicate bands and rare quartzite.

Type section: *not defined*

Lower Boundary: Upon the Loch Coire Formation (LOCE), but contact is strongly sheared

Upper Boundary: Not exposed; cut by the Strath Halladale Granite

Geographical extent: Northern Highlands: East Sutherland and Caithness. Restricted to the Swordly Nappe.

Key Reference: Holdsworth *et al.* (1994); British Geological Survey (2003) Reay Sheet 115E.

Alternative and older names: Portskerra Gneisses

10.10.3 Kildonan Psammite Formation (KILD) – Sutherland, Skinsdale Nappe

Lithology: Psammite, siliceous to micaceous, medium-grained. Psammite shows locally tabular and trough cross-bedding. Subordinate layers of quartz and schistose semipelite. Locally very thin (<5 cm) schistose para-amphibolite.

Type section: Reference sections at Suisgill Burn [NC 915 271]; Torrish Burn [NC 971 199]

Lower Boundary: Not exposed. Base is interpreted to be cut by the Skinsdale Thrust.

Upper Boundary: Conformable overlain by the Suisgill Semipelite Formation (SUIS), with a gradational (100 m) boundary marked by increasing semipelitic layers. Locally overlain by the Scaraben Quartzite Formation (SCAB), but not exposed.

Geographical extent: Northern Highlands: East Sutherland and Caithness. Restricted to the Skinsdale Nappe.

Key Reference: Strachan (1988);

10.10.4 Suisgill Semipelite Formation (SUIS) – Sutherland, Skinsdale Nappe

Lithology: Semipelite, either coarse and schistose, or gneissose and migmatitic. Locally thin layers of psammite.

Type section: *not defined*

Lower Boundary: Conformable upon the Kildonan Psammite Formation (KILD), with a gradational (100 m) boundary marked by increasing semipelitic layers.

Upper Boundary: Overlain by the Scaraben Quartzite Formation (SCAB), but not exposed.

Geographical extent: Northern Highlands: East Sutherland and Caithness. Restricted to the Skinsdale Nappe.

Key Reference: Strachan (1988);

10.10.5 Scaraben Quartzite Formation (SCAB) - Sutherland

Lithology: Quartzite, medium-grained, well-bedded. Locally feldspathic. Rare layers psammite and semipelite.

Type section: Type area: Scaraben mountain [ND 080 270]; Berriedale Water ND 107 277]

Lower Boundary: Not exposed, but assumed to be conformably overlying the Suisgill Semipelite Formation (SUIS).

Upper Boundary: Stratigraphic top exposed. Unconformably overlain by Old Red Sandstone (ORS)

Geographical extent: Northern Highlands: East Sutherland and Caithness. Restricted to the Skinsdale Nappe.

Key Reference: Strachan (1988)

10.11 BADENOCH GROUP (BADN) – CENTRAL HIGHLANDS

Lithology: Typically gneissose and migmatitic psammite (feldspathic, to siliceous to micaceous) interbanded with semipelite and subordinate quartzite.

Interpretation: No sedimentary structures are preserved. The lithologies are compatible – but not uniquely so - with a shallow marine in origin.

Type section: not defined

Lower Boundary: not exposed; unknown.

Upper Boundary: Unconformably overlain by Dalradian Supergroup rocks, unconformity commonly sheared, and partially coincident with the Grampian Shear Zone.

Thickness: 3000-4000 m (estimated; deformed)

Geographical extent: Central Highlands; occurs in several inliers (Glen Banchor; Laggan; Kincraig; Dava Dome), surrounded by Dalradian Supergroup rocks.

Age: Tonian Period. Youngest zircons are at c. 900±17 Ma (Cawood *et al.* 2003). The Badenoch Group has been affected by high-grade metamorphism and partial melting at 840 ± 11 Ma (Highton *et al.*, 1999).

Key Reference: Leslie *et al.* (2013); Smith *et al.* (1999).

10.11.1 Creag Buidhe Semipelite Formation (CGBH); Dava Subgroup (DAVA)

Lithology: Gneissose to migmatitic semipelite, with only minor and local quartzite lenses. The semipelite (quartz + plagioclase + biotite) is locally muscovitic and garnetiferous. Migmatisation locally forms a stromatic layering. Locally interlayered units of quartzite and micaceous psammite, generally < 0.4 m thick. Irregular areas of abundant pegmatite veins may be locally differentiated.

Type section: Type area: summit and NE ridge of Creag Bhuide [NH 664 314]. Reference section: Meall na Fuar-ghlaic [NH 698 325].

Lower Boundary: Not exposed - interbanded with psammites of the Dava Subgroup (undifferentiated).

Upper Boundary: Conformable contact with the structurally overlying Beinn Bhreac Psammite Formation (BBPS) - no way-up criteria.

Geographical extent: Central Highlands, SE of Loch Ness. Strathnairn to Slochd area.

Key Reference: Leslie *et al.* (2013); British Geological Survey (2004b) Tomatin Sheet.

10.11.2 Beinn Bhreac Psammite Formation (BBPS); Dava Subgroup (DAVA)

Lithology: Gneissose psammite with subordinate micaceous psammite and siliceous psammite to quartzite units. Locally, migmatised/gneissose semipelite and psammite occur towards the top of the formation.

Interpretation: No sedimentary structures are preserved.

Type section: Type area on the hill Beinn Bhreac, at [NH 757 276]. Reference sections on the crags north of Brin Rock [NH 662 300] and on the ridge east of Mains of Flichity [NH 686 290].

Lower Boundary: Conformable contact with Creag Bhuidhe Semipelite (CGBH); contact is poorly exposed

Upper Boundary: Overlain by Flichity Semipelite Formation (FLTY) with a transitional, locally sheared contact. No way-up criteria.

Geographical extent: Central Highlands, SE of Loch Ness. Strathnairn to Slochd area.

Key Reference: Leslie *et al.* (2013)

10.11.3 Flichity Semipelite Formation (FLTY); Dava Subgroup (DAVA)

Lithology: Gneissose to locally migmatitic garnet-bearing semipelite, with thin quartzite units. A more massive, persistent and finely laminated quartzite marks the contact with the structurally underlying Beinn Bhuidhe Psammite Formation.
Interpretation: No sedimentary structures are preserved.
Type section: Type area: rocky ridge of Creag Flichity [NH 685 286]
Lower Boundary: Transitional with the Beinn Bhreac Psammite Formation (BBPS); incoming of first persistent quartzite layer. No way-up criteria.
Upper Boundary: Sheared contact with the structurally overlying Slochd Psammite Formation (SLCD). No way-up criteria.
Thickness: c. 300 m (deformed thickness)
Geographical extent: Central Highlands. Strathnairn to Findhorn area, in the Tomatin, Aviemore and Nairn districts.
Key Reference: Leslie *et al.* (2013).

10.11.4 Slochd Psammite Formation (SLCD); Dava Subgroup (DAVA)

Lithology: Gneissose to migmatitic psammite and siliceous psammite with subordinate massive coarse-grained arkosic psammite units
Interpretation: No sedimentary structures are preserved.
Type section: Type Area - Rocky outcrops south of the A9 and the railway at Slochd summit [NH 838 252]
Lower Boundary: Sheared contact with the structurally underlying Flichity Semipelite Formation (FLTY). No way-up criteria.
Upper Boundary: Unit appears to be stratigraphically overlain by the Glen Banchor Subgroup (GBLA), taken at the base of thick quartzite units near Lochindorb [NH 968 320].
Thickness: c. 1000 m (minimum; estimate)
Geographical extent: Central Highlands. Slochd area extending east and north across Dava Moor.
Key Reference: Leslie *et al.* (2013).

10.11.5 Markie Gneisses (MARK); Glen Banchor Subgroup (GBLA

The Markie gneisses form a series of outcrops, likely inliers, to the NW of the Laggan Inlier in Glen Markie (NE of Loch Laggan), likely structurally below the Loch Laggan Psammite Formation (Grampian Group). The lithology suggest affinity with the Glen Banchor Subgroup (Badenoch Group), but due to limited and poor exposure the stratigraphic nature and position is uncertain.
Lithology: Gneissose micaceous psammite and semipelite with lenses and sheets of locally migmatitic psammite. Subsidiary psammite and schistose semipelite. ***Interpretation:*** No sedimentary structures are preserved.
Type section: none defined. Reference Section: Allt Coire nan Eumlainn Fiadhaich, east of Markie Burn [NH 589 798 – to NH 596 979]
Lower Boundary: unknown
Upper Boundary: Likely overlain by the Loch Laggan Psammite Formation (Grampian Group), but nature of contact is not known.
Thickness: unknown
Geographical extent: Central Highlands. Glen Markie, NE of Loch Laggan.
Key Reference: British Geological Survey (2002b) Dalwhinnie Sheet.

10.11.6 Creag An Loin Psammite Formation (CRAN); Glen Banchor Subgroup (GBLA

Lithology: Interbanded psammite and micaceous psammite, medium- to coarse-grained gneissose and migmatised. Locally thin layers of siliceous psammite, quartzite and semipelite. Rare pods of amphibolite.

Interpretation: No sedimentary structures are preserved.

Type section: The type area is Creag an Loin hill at [NH 696 014], north of Newtonmore. A reference section is exposed on the eastern flanks of Sron Beag na h-Uamhaidh [NN 6437 9755].

Lower Boundary: Not exposed

Upper Boundary: Conformably overlain by An Stac Semipelite and Psammite Formation (ANST), with transitional contact; defined by the incoming of a predominantly semipelite units.

Thickness: Up to 200 m exposed.

Geographical extent: Central Highlands. Glen Banchor and Kincraig inliers.

Key Reference: Leslie *et al.* (2013)

10.11.7 An Stac Semipelite and Psammite Formation (ANST); Glen Banchor Subgroup (GBLA

Lithology: Garnet-mica semipelite, psammite and siliceous psammite, finely interlayered, with subordinate quartzite and calc-silicate rock, variably gneissose. The distinctive Blargie Quartzite Member (BQLA) is at or near its top.

Interpretation: No sedimentary structures are preserved.

Type section: Type area: An Stac [NH 680 004], north of Glen Banchor. Reference section: immediately north of Creag an Loin [NH 6875 0164].

Lower Boundary: Conformably upon Creag an Loin Psammite Formation (CRAN); marked by incoming of distinctive garnetiferous quartzite and/or semipelite

Upper Boundary: Overlain by Creag Liath Psammite Formation (CGLH); typically marked by a narrow shear zone. Elsewhere overlain by Grampian Shear Zone.

Thickness: 600-700 m (estimate; deformed)

Geographical extent: Central Highlands. Newtonmore - Glen Banchor - Kincraig areas.

Key Reference: Leslie *et al.* (2013)

10.11.7.1 Blargie Quartzite Member (BLQA); An Stac Semipelite and Psammite Formation (ANST)

Parent: An Stac Semipelite and Psammite Formation (ANST)

Lithology: Cream to pinkish white quartzite and siliceous psammite with subordinate semipelite.

Interpretation: No sedimentary structures are preserved.

Type section: South-east flank of Mullach Sron na H'uamhaldh [NN 628 971]. Reference Section - Eastern end of Blargie Craig [NN 600 953].

Lower Boundary: Conformably upon remainder of An Stac Semipelite and Psammite Formation (ANST). Marked by 5m thick zone of interbanded quartzite and semipelite.

Upper Boundary: Conformably overlain by Creag Liath Psammite (CGLH); marked by incoming of K-feldspar-bearing psammites.

Thickness: 75 m (maximum; deformed)

Geographical extent: Central Highlands, Laggan, Glen Banchor and Kincraig areas.

Key Reference: Leslie *et al.* (2013)

10.11.8 Creag Liath Psammite Formation (CGLH); Glen Banchor Subgroup (GBLA)

Lithology: Gneissose psammite, siliceous psammite with subordinate micaceous psammite and semipelite; interbanded. Locally K-feldspar-bearing psammites with distinct.

Interpretation: No sedimentary structures are preserved.

Type section: Creag Liath, north of Glen Banchor [NH664 007].

Lower Boundary: Conformable if sheared upon An Stac Semipelite and Psammite Formation (ANST); marked by incoming of psammite.

Upper Boundary: Unconformably overlain by Grampian and Appin Group rocks (Dalradian Supergroup (DALN)).

Thickness: c. 400 m (maximum; estimated; deformed)

Geographical extent: Central Highlands. Glen Banchor - Kincraig area.

Key Reference: Leslie *et al.* (2013)

Appendix 1 New units; obsolete units; Previous names

SUPERGROUP	GROUP	FORMATION	MEMBER
Loch Ness Supergroup			
Wester Ross			
	Yell Sound Group	Mid Yell Lens Fm	**Arisdale Quartzite Mb**
	Yell Sound Group	Otterswick Psammite Fm	**Cullivoe Lens Mb**
	Yell Sound Group	Yell Sound Psammite Fm	**Graveland Lens Mb**
	Yell Sound Group	**Mid Yell Lens Fm**	
	Torridon Group	Applecross Fm	**Allt na Beiste Mb**
	Tarskavaig Group	**Laidhe na Greine Fm**	
	Tarskavaig Group	**Capistal Psammite Fm**	
	Sand Voe Group	**Sand Voe Psammite Fm**	
	Morar Group	Glascarnoch Psammite Fm	**Ben Killilan Psammite Mb**

Table 1 New Units and their parents. New units are in bold and underlined

GROUP	FORMATION	MEMBER	OLD NAME / RANK
Yell Sound Group			*Yell Sound 'Division'*
Loch Eil Group	Tarvie Psammite Fm	**Druim Fada Quartzite Mb**	*Druim Fada Quartzite Fm*
Loch Eil Group	Tarvie Psammite Fm	**Glen Gour Quartzite and Pelite Mb**	*Glen Gour Quartzite and Pelite Fm*
Loch Eil Group	Tarvie Psammite Fm	**Kinlocheil Quartzite Mb**	*Kinlocheil Quartzite Fm*
Loch Eil Group	Tarvie Psammite Fm	**Stronchreggan Quartzite Mb**	*Stronchreggan Quartzite Fm*
Yell Sound Group	Lochailort Pelite Fm	**Beinn Gaire Psammite Mb**	*Beinn Gaire Psammite Fm*
Sand Voe Group	**Fethaland Garnet Mica Schist Fm**		*Garnet Mica Schist Unit (no rank)*
Sand Voe Group	**Hillswick Fm**		*Hillswick Group*

Table 2 Units with changed status; updated unit name bold and underlined.

OBSOLETE UNIT	MEMBER	FORMATION	GROUP/SUPERGROUP
Moine Supergroup - M			**Loch Ness Supergroup / Wester Ross Supergroup**
Central Highland Migmatite Complex – CEHI			**Badenoch Group**
Assapol Group - APOL			**Glenfinnan Group**
Shiaba Group - SHBA			**Morar Group**
Glenfinnan Group and Loch Eil Group (Undifferentiated) - GLEIL			**Glenfinnan Group / Loch Eil Group** (separate)
Sgurr Marcasaidh Fm - SGMC		**Ben Wyvis Pelite Fm**	Glenfinnan Group
Badenloch Pelite Mb - BACH		**Loch Coire Fm**	Glenfinnan Group
Garve Psammite Fm - GAPS		**Reidh Psammite Fm**	Glenfinnan Group
Kirtomy Gneisses - KIRY		**Loch Coire Fm -**	Glenfinnan Group
Easter Glen Quioch Psammite - QUIO		**Tarvie Psammite Fm**	Loch Eil Group
Loch Eil Psammite Fm - LEIP		**Tarvie Psammite Fm**	Loch Eil Group
Upper Garry Psammite Fm - UGPS		**Tarvie Psammite Fm**	Loch Eil Group
A' Mhoine Psammite Fm - AMPS		**Altnaharra Psammite Fm**	Morar Group
Druim Chuibhe Psammite Fm - DMCB		**Klibreck Psammite Fm**	Morar Group
Bheinn Bhreac Mb - TCAB	**Scresort Sandstone Mb**	Applecross Fm	Torridon Group
Leac-Strearnan Mb - TCAL	**Allt Mor Na H-Uamha Mb** (on Soay)	**Applecross Fm** (on Raasay)	Torridon Group
Sithean Glac An Ime Mb - TCAI		Applecross Fm	Torridon Group
Dubh Loch Mb – TCD3	**Allt na Beiste Mb**	Diabaig Fm	Torridon Group
Mullach Nan Carn Mb - TCDC	**Brochel Mb**	Diabaig Fm	Torridon Group
Dibidil Grit Mb - TCDD	Not clear where this name originates from		
Beinn Leamhain Psammite Fm - BELE	Not clear where this name originates from		
Inverscaddle Fm - INVSC	Not clear where this name originates from		
An Torran Pelite - ANTOR	Not clear where this name originates from		
Coire An Iubhair Fm - CAIUB	Not clear where this name originates from		
Kilmalieu Psammite - KILPS	Not clear where this name originates from		
Torr An Fhuich Psammite - TAFH	Not clear where this name originates from		

Table 3 Obsolete Units terms (bold italic) and their replacement names (underlined) – where appropriate.

PARENT	REPLACEMENT NAME	OLDER NAME	REFERENCE
	Wester Ross Supergroup - WRES	Moine Supergroup (part)	Krabbendam *et al.* (2021)
	Loch Ness Supergroup - LNES	Moine Supergroup (part)	Krabbendam *et al.* (2021)
Badenoch Group	Badenoch Group - BADN	'Younger Moine'	Johnstone (1975)
		Central Highland Division	Piasecki & Temperley (1988)
		Central Highland Migmatite Complex	Highton *et al.* (1999)
		Dava and Glen Banchor Succession	(Robertson *et al.* 1999)
		Sub-Grampian basement	Cawood *et al.* (2003)
Loch Eil Group	Tarvie Psammite Fm - TAPS	Upper Garry Psammite Fm	Robers *et al.* (1983)
		Easter Glen Quioch Psammite	
		Loch Arkaig Psammite	Robers *et al.* (1984)
		Loch Eil Psammite Fm	Strachan *et al.* (1988)
	Portskerra Psammite Fm - PORK	Portskerra Gneisses	
Glenfinnan Group	Glenfinnan Group - GLEN	Assapol Group	Holdsworth *et al.* (1987)
	Loch Coire Fm - LOCE	Kirtomy Gneisses	
	Beinn An Tuim Striped Fm - BTU	Garry Banded Unit	Robers *et al.* (1983)
		Strathan Striped Schists and	Robers *et al.* (1984)
	Lochailort Pelite Fm - MBLA	Meal an t-Sithe pelite (Fannich Inlier)	Kelley & Powell (1985)
		Sgurr Beag pelite	Tanner (1970)
		Quoich pelite	Robers *et al.* (1983)
		Fraoch Bheinn Pelite	Robers *et al.* (1984)
		Sguman Cointich Pelite	May *et al.* (1993)
	Reidh Psammite Fm - REP	Garve Psammite Fm	
		Quoich Banded Fm	Robers *et al.* (1983)
		Ben Wyvis Psammite	
Morar Group	Morar Group - MORR	Shiaba Group	Holdsworth *et al.* (1987)
	Upper Morar Psammite Fm - MAUP	Aonoch Sgoilte Psammite	Ramsay & Spring (1962)
		Ardnish Psammite	Powell (1964)
	Morar Schists Fm - MAMS	Morar Striped and Pelitic Schists	Johnstone *et al.* (1969)
		Ladhar Bheinn Pelite	Ramsay & Spring (1962)
		Morar Pelite Fm	Mendum *et al.* (2009).
	Lower Morar Psammite Fm - MALP	Barrisdale Psammite (in Knoydart)	Ramsay & Spring (1962)
		Boc Mor Psammite (in Kintail)	May *et al.* (1993)
	Diebidale Pelite Fm - DIEP	Upper Pelite	Shepherd (1970); Wilson (1975)
	Crom Psammite Fm - CMPS	Upper Psammite	Shepherd (1970); Wilson (1975)
		Upper Quartzite	Wilson (1975)
	Vaich Pelite Fm - VAPE	Lower Pelite	Shepherd (1970); Wilson (1975)
		Sgurr Mor Pelitic Group	Sutton & Watson (1955)
	Glascarnoch Psammite Fm - GLPS	Lower Quartzite	Shepherd (1970); Wilson (1975)
		Lower Psammite	Shepherd (1970); Wilson (1975)
		Inverbroom Semipelitic Group	Sutton & Watson (1955)
	Glen Achall Psamm and Semipel Mb - GACH	Loch Droma Pelitic Group	Sutton & Watson (1955)
	Klibreck Psammite Fm - KLPS	Druim Chuibhe Psammite Fm (in part)	Holdsworth *et al.* (2001)
	Bettyhill Fm - BTYH	Bettyhill Banded Fm	Holdsworth *et al.* (2001)
	Altnaharra Psammite Fm	A'Mhoine Psammite Fm	Holdsworth *et al.* (2001)
Torridon Group	Sgor Mhor Sandstone Mb	Guirdil Arkose	Black and Welsh (1961)
	Scresort Sandstone Mb - TCAS	Rudha Na Roinne Grit	Black and Welsh (1961)
		Loch Nan Eala Arkose	Black and Welsh (1961)
		Guirdil Arkose	Black and Welsh (1961)
	Allt Mor Na H-Uamha Mb - TCAM	Bagh Na H-Uamha Shale	
	Loch An Uach Mb – TCLU	Loch An Uachdair Mb	
	Horrisdale Waterfalls Mb – TCD2	"Grey Shale Facies"	Stewart (2002)
	Fiachanis Gritty Sandstone Mb - TCDF	Basal Grit	Black and Welsh (1961)
	Laimhrig Shale Mb - TCDL	Bagh Na H-Uamha Shale	Black and Welsh (1961)
Sleat Gp	Rubha Guail Fm - TBE	Epidotic Grits	Peach *et al.* (1910)
Sand Voe Gp	Fethaland Garnet Mica Schist Fm - GTMS	Garnet Mica Schist "Unit"	
	Sand Voe Group - SDVO	Fethaland Series	Mykura (1976); Phemister (1978)

Table 4 Older names, including those not in the BGS Lexicon, and their new equivalents, selected references.

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British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: https://envirolib.apps.nerc.ac.uk/olibcgi.

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