Chapter 14

Laurentian margin evolution and the Caledonian Orogeny – a template for Scotland and East Greenland.

A. G. Leslie, M. Smith

British Geological Survey, Murchison House, Edinburgh, EH9 3LA, UK.

E-mail: agle@bgs.ac.uk

N. J. Soper

Gams Bank, Threshfield, North Yorkshire, BD23 5NP, UK.

Abstract: *The orthotectonic Scottish Caledonides constitute only a small fragment of the Neoproterozoic to Paleozoic margin of Laurentia, albeit one which lies at a prominent bend in that margin. Sequences exposed in the Scottish outcrop include Mesoproterozoic, Neoproterozoic and Cambro-Ordovician strata which record sedimentation, volcanism and deformation related to the latter stages of the amalgamation of Rodinia, the subsequent breakout of Laurentia, and growth of the Iapetus Ocean. Metamorphic and tectonic overprints then record the destruction of that ocean through Ordovician arc accretion and mid-to-late Silurian collision of Laurentia, Baltica and Avalonia with the final closure of Iapetus by end-Silurian time. New isotopic data and recent advances in the understanding of the late Mesoproterozoic (Stenian) to Cambro-Ordovician stratigraphical framework now better constrain the sequence and timing of events across the 'Scottish Corner' and invite a dynamic comparison with the current research into the East Greenland Caledonides summarised in this volume. Although many broad similarities exist, the comparisons described here reveal for the first time a number of significant contrasts in the spatial arrangement of depocentres, location of rifting, patterns and timing of magmatism, metamorphism and contractional deformation. This expanded understanding of the late Neoproterozoic evolution of these adjacent sectors of Laurentia provides an important basis for reconstructions of the subsequent lower Paleozoic Caledonian orogenic evolution of the present North Atlantic region.*

INTRODUCTION AND REGIONAL COMPARISONS

The Caledonides of East Greenland disappear southwards beneath Paleogene flood basalts at Scoresby Sund (70°N). Thereafter, the most proximal sector of the preserved Laurentian margin at the onset of Silurian (Scandian) collision of East Greenland with Baltica is the Scottish Highlands and northern parts of Ireland. Palinspastic reconstructions (Dickin, 1992; Cambridge PalaeoMap, 1998) indicate that during lower Paleozoic time, Scotland may have lain as little as 500 km to the south of central East Greenland (Fig. 1).

With a present day along strike section of *c.* 600 km, and as one of the most intensively studied orogens in the world (Strachan et al., 2002), Scotland shares many aspects of Laurentian geology (Fig. 2**)** with the 1300 km long East Greenland Caledonides (see **Fig. X.x**, this volume). Nevertheless, several fundamental problems still lack a definitive interpretation despite thousands of publications detailing decades of field and laboratory investigations into the perplexing architecture and history of the Scottish Caledonides. The basin architecture accommodating each of the Stoer and Torridon groups (the 'Torridonian') and the Moine Supergroup is not resolved; whether or not parts of these sequences might be correlated within a single depositional system is still a matter of debate. The cause and spatial extent of the Knoydartian tectonothermal event (or events) is likewise unresolved and we cannot as yet define the age and nature of the base of the Dalradian Supergroup. The glacigenic deposits within the Dalradian Supergroup (tillites) are not yet age-constrained or definitively placed within a global sequence. These problems arise, at least in part, from the difficulty in dealing with the lack of critical exposure in an upland glaciated terrain where there is an extensive cover of superficial deposits.

Thus there is much to envy in the geological vistas of the fjords and mountains of East Greenland. With the completion of the 1:500k mapping and research programme by the Geological Survey of Denmark and Greenland (GEUS) it is therefore timely to explore the similarities and contrasts between these two sectors and their role in the Precambrian to lower Paleozoic evolution of the Laurentian margin. We note however, that while with our broadened perspective we may have moved on from the vestige of a beginning in our understanding of this part of the Laurentian margin, there seems to be no prospect of an end in view!

In this account we take the stance that the East Greenland and Scottish Caledonides record a shared Neoproterozoic to lower Paleozoic tectonostratigraphical and tectonometamorphic Laurentian geological history, albeit with a diachroneity and difference in detail that reflects their individual locations on the margin. An alternative ‘mobilistic’ model, not further discussed here but involving a protracted history of major lateral movements and the amalgamation of terranes of quite separate affinities, has been proposed for the Scottish Caledonides (Bluck et al., 1997).

During the late Neoproterozoic (ICS timescale, Gradstein et al., 2004), Scotland has been previously interpreted as occupying a stable promontory in the Archean to Paleoproterozoic Hebridean Shield (Dalziel and Soper, 2001) and ultimately close to an Ediacaran (Vendian) RRR junction (inset to Fig. 1, Soper, 1994a**).** The most recent analysis of the paleomagnetic and geological constraints argues that the western Scandinavian margin of Baltica faced the eastern Greenland margin of Laurentia in its right-way-up orientation (Cawood and Pisarevsky, 2006). The reconstruction of Figure 1 adopts this configuration and makes a schematic restoration on the numerous major thrusts identified in the Caledonides of East Greenland and the north of Scotland. On this basis, Scotland does lie on a corner in the Laurentian margin and potentially in the vicinity of a RRR junction but the concept of a ‘Scottish Promontory’ is not sustained.

In contrast, a general absence of volcanic activity or other evidence of extensive or rapid upper Neoproterozoic extension suggests that the East Greenland and Eastern Svalbard margin of Laurentia lay distant from such an Iapetan RRR locus. East Greenland was also apparently isolated from the active spreading junction which affected northern Greenland, western/central Svalbard, Scandanavia and Siberia as recorded by *c.* 650–600 Ma igneous mafic activity (Gromet and Gee, 1997; Bingen et al., 1998) (Fig. 1**)**. Earlier attempts at rifting, possibly signalling the initiation of continental breakup, are recorded in the *c.* 720 Ma Coronation mafic dike swarm of Baffin Island and West Greenland (Shellnut et al., 2004) and *c.* 700 Ma mafic sills in NE Svalbard (Johansson et al., 2004). Abundant mafic volcanics also mark extension and rifting on the Appalachian sector at this time (Bailey and Tollo, 1998; Tollo and Hutson, 1996; Tollo et al., 2004). Such activity is absent from Central East Greenland. Thus, over many millions of years the Neoproterozoic successions of Greenland perhaps record relatively quiescent deposition on a continental margin lying between migratory RRR junctions throughout the evolution of the Iapetus Ocean.

For reference we delineate in the inset to Figure 2, those fault-bounded crustal terranes identified in Scotland as having a distinctive geological history (*cf.* Strachan et al., 2002). Where practicable, we will however in this article refer to geographical regions (Fig. 1) rather than specific terranes; fault-bound terranes are not defined in the East Greenland Caledonides and the full status of some of the Scottish “terrane boundaries” outlined in the inset map (Fig. 2) is still a matter of debate. In general terms, the Neoproterozoic–Ordovician rocks of the Northwest Scottish Highlands preserve a record of the Laurentian autochthonous-parautochthonous foreland (Figs. 2 and 3A). These successions correspond stratigraphically and chronologically with rocks of the Laurentian foreland succession preserved in the nunatak region of central East Greenland, the parautochthonous belt of western Kronprins Christian Land in eastern North Greenland, and the parautochthonous successions exposed in tectonic windows along the length of the East Greenland Caledonides (Fig. 3B, C). Elements of the geology of the Northern and Grampian Highlands of Scotland may be compared with similar sequences in the Niggli Spids thrust sheet, Hagar Bjerg thrust sheet and Franz Joseph allochthon of central East Greenland, to the eastern hinterland of Dronning Louise Land, and to the Vandredalen Thrust Sheet of Kronprins Christian Land (Fig. 3A, B and C).

Bearing in mind the relative positions and regional structural trends (Fig. 1), it is then tempting to link the individual major fault structures in Scotland (e.g. Moine Thrust, Great Glen Fault, Highland Boundary Fault) with the major bounding structures of the East Greenland thrust sheets (e.g. Caledonian Sole thrust, Fjord Region fault, Western fault zone). That said, the differences in present knowledge and understanding of the history of these fault zones mean that such correlations remain speculative.

While such broad similarities invite comparison, intriguing contrasts also exist between Scotland and East Greenland. For example, the thick siliciclastic contemporaneous (early Neoproterozoic) sequences of the Krummedal succession of central East Greenland (Higgins, 1988) and the Moine Supergroup of the Northern Highlands in Scotland (Fig. 3A, B) share a similar provenance (Friend et al., 2003; Kalsbeek et al., 2000; Watt et al., 2000) and together, are remarkable for evidence of repeated HP-HT metamorphism. Whilst the metasedimentary rocks from the Northern and Grampian Highlands record evidence for a series of Neoproterozoic tectonothermal events between 820 Ma and 730 Ma (Fig. 4), these are unknown in

Greenland. Instead, the Krummedal succession was there affected by a single high grade metamorphic event which culminated in the generation of voluminous S-type augen granite, at *c*. 910 Ma (Leslie and Nutman, 2003).

The younger and well preserved mid- to late Neoproterozoic and early Cambrian sequences of the Grampian Highlands reveal a history of repeated uplift, rifting and complex internal basin architecture. Mafic volcanic rocks are developed at several levels in the evolving depositional pile with the transition from rift to drift in a developing Iapetus Ocean occurring at *c*. 610 – 600 Ma (Figs. 3A and 4). In contrast, the succession of mid- to late Neoproterozoic sediments in central East Greenland comprising the Franz Joseph allochthon, although extremely thick, records sustained subsidence but no active rifting. An apparent thickness of over 14 km of sediment is assigned to the Eleonore Bay Supergroup alone and a further 1 km to the Ediacaran Tillite Group (Smith and Sønderholm, this volume); mafic volcanic rocks are conspicuous by their absence (Fig. 3B). While there may be some limited evidence of stretching and rift shoulder uplift farther inboard on the restored margin (Leslie and Higgins, 1998, Leslie and Higgins, this volume), major extension and rifting is only clearly evident much farther north in eastern North Greenland where the late Neoproterozic Hekla Sund Basin rift-sag sequence dominates the geology (Fig. 3C; Higgins et al., 2001b). Neoproterozoic tillites if originally deposited, are now absent on the foreland in Scotland, whereas they are present in significant thicknesses, in both the parautochthonous foreland windows and the fjord region allochthon in East Greenland.

The ensuing Neoproterozoic and early Paleozoic deformation and metamorphism across Scotland and Greenland records the final amalgamation then breakup of the ancient supercontinent of Rodinia, followed by convergence, and eventual collision of Baltica with the East Greenland sector of the Laurentian margin in the Caledonian Orogeny (Fig. 4). Grampian (Ordovician) orogenesis and arc accretion dominates the structural framework of the Grampian, and parts of the Northern Highlands in Scotland, but is apparently only expressed in the southernmost extremity of the East Greenland Caledonides. Conversely, the subsequent Scandian (Silurian) orogenesis which documents the final collision and docking of Baltica with Laurentia dominates the structure in only the Northern Highlands in Scotland but is the pervasive control on Caledonian structural chronology and architecture throughout East Greenland.

In this chapter, we present a synopsis of the Archean to lower Paleozoic geology of the 'Scottish Corner' on Laurentia as a series of time slices summarised in the tectonostratigraphical template presented in Figures 3, 4 and 6. In this framework, we explore and test the key comparisons and contrasts between Scotland and East Greenland, drawing particular attention to the locations of rifting and spatial arrangements of depocentres, as well as to the key orogenic events. We conclude by presenting a dynamic synthesis of Iapetan rifting and Caledonian orogenesis in the Scottish Caledonides and, whilst recognising that no consensus can currently be reached, contend that taken together, the geology of Scotland and Greenland provide real constraint upon the Neoproterozoic to lower Paleozoic evolution of Laurentia.

ASSEMBLY OF A STABLE BASEMENT – PRE-STENIAN (1200 MA) HISTORY

The oldest rocks in Scotland comprise the crystalline basement rocks of the Lewisian Complex in the Hebrides and Northwest Highlands (Fig. 2; Plate 1A and B). This complex is exposed along the mainland coastal strip in the footwall of the Moine Thrust Zone (Fig. 2; Plate 1B) and extends westwards across the Outer Hebrides and to a broad region (Rockall) on the edge of the UK continental shelf (Dickin, 1992). East of the Moine Thrust Zone, geophysical data (Trewin and Rollin, 2002) imply that Lewisian, or similar, rocks underlie the Moine rocks in Scotland at least as far as the trace of the Great Glen Fault (Fig. 2). The Lewisian Complex is, and has been, the subject of intense scrutiny. Only a brief summary is provided below and the reader is referred to the comprehensive summary of Park et al. (2002) for further details and the recent review of Park (2005).

The oldest rocks comprise Archean age granulite facies orthogneiss (the Scourian) which had already been reworked by two tectonothermal events prior to the intrusion of the basic and ultrabasic magmas of the Scourie dike suite in mid-Paleoproterozoic time (Park et al., 2002; Park, 2005). The Scourian rocks are typically grey, banded trondhjemite-tonalite-granodiorite (TTG) orthogneisses with rare metasedimentary enclaves; basic enclaves may represent relict oceanic crust (Plate 1B). Studies of tectonothermal history in the Lewisian Complex have previously assumed that these rocks are broadly correlatable across the Hebrides and Northwest Highlands. Recent work by Friend and Kinny (2001), Kinny et al. (2005) and Park (2005) now proposes a series of discrete Archean blocks that amalgamated during the Paleoproterozoic, each with a more complicated, but as yet unresolved, early history.

Orthogneisses of the mainland central block yield 3.03-2.96 Ga protolith ages and record a granulite facies metamorphism (the Badcallian event) at *c.* 2.5 Ga (Whitehouse, 1989; Friend and Kinny, 1995; Corfu et al., 1998). Protolith ages in the northern block range from 2.84-2.68 Ga and in the southern block from 2.82-2.73 Ga (Kinny and Friend, 1997; Corfu et al., 1998).

The ensuing Inverian event post-dated a suite of pegmatites (2.49-2.48 Ga) and is marked by retrogression to amphibolite facies and the formation of shear zones that pre-date the earliest Scourian Dykes (Corfu et al., 1998). The Scourian Dykes were intruded, predominantly as quartz-dolerites, over a considerable period of time and with the main swarm emplaced at *c.* 2.42 Ga (Heaman and Tarney, 1989).

Younger supracrustal strata are represented in the Loch Maree Group which comprises two structural belts of metasedimentary and meta-igneous rocks (M on Fig. 2). The Loch Maree succession accumulated at *c.* 2.0 Ga and includes greywacke, quartzite, carbonate rock and banded iron formation, along with sheets of amphibolite. Park et al. (2001) interpreted these as greywackes that accumulated close to a continental source; the REE chemistry of the amphibolite, suggests an origin as oceanic plateau lava and subsidiary primitive island–arc basalt. The supracrustal rocks are cut by orthogneiss yielding U-Pb zircon ages of 1.9 Ga interpreted as the age of emplacement (Park et al., 2001). These cross-cutting gneisses have a primitive arc signature and thus provide further evidence of a Paleoproterozoic magmatic arc and subduction of oceanic material (Park et al., 2001).

The Laxfordian refers to tectonothermal events that modify the Scourie Dykes. An early phase, dated at 1.86-1.63 Ga, may be related to a network of low-angle transpressional shear zones (Coward and Park, 1987). Later-phase, steep shear zones and refolding in upright structures was accompanied by retrogression to greenschist facies.

The rocks of the Lewisian Complex exposed on the islands of the Outer Hebrides (Fig. 2) are broadly similar to the northern and southern mainland blocks but do show some significant differences. There are for example, far fewer Scourie Dykes and although the supracrustal rocks on South Harris have similar lithologies to the Loch Maree Group, they yield younger U-Pb ages <*c.* 1.9 Ga (Whitehouse and Bridgwater, 1999). Granulite facies metamorphism dated at 1.9–1.8 Ga is dominant. These differences led Friend and Kinny (2001) to argue that the Outer Isles basement has more affinity with East Greenland than with the adjacent Scottish mainland.

The pattern of protolith ages in the basement complexes in East Greenland also reflects this widespread Paleoproterozoic activity. Archean protolith (2.8–2.7 Ga) is also evident in the gneisses in Gletscherland and Nathorst Land which are broadly equivalent, therefore, to the Archean gneisses of the Ammassalik region (Rex and Gledhill, 1981; Thrane, 2002; F. Kalsbeek, unpublished data) (Fig. 1 in Chapter 2, this vol.). Paleoproterozoic (*c.* 1.9 Ga) gneissose and granitoid rocks that occur farther north in East Greenland (eastern Frænkel Land and Suess Land, Fig. 1 in Chapter 2, this vol.) were accreted around 2.0 Ga (Kalsbeek et al., 1993) and are in many respects similar to the somewhat younger (and better preserved) Ketilidian orogenic belt in South Greenland.

Reconstructions of the Paleoproterozoic belts and Archean cratons of the North Atlantic region (Buchan et al., 2000) show the Lewisian Complex as part of the Paleoproterozoic internal belt linking the eastern Churchill province of the Canadian shield, the Nagssugtoqidian of Greenland and the Lapland-Kola belt of Scandanavia (Fig. 5). Wright et al. (1973), Myers (1987), Kalsbeek et al. (1993) and Park (1994) highlight the many similarities of the Lewisian Complex to the Nagssugtoqidian, or Ammassalik Belt, of South-East Greenland. The latter comprises reworked Archean granitoid gneisses cut by mafic dikes and other intrusions (Kalsbeek, 1989). The central part of the Ammassalik Belt contains abundant metasediments with a depositional age of *c.* 2.0 – 1.9 Ga (Bridgewater et al., 1996) cut by subduction related 1.9 Ga old calc-alkaline granitoid intrusions (Kalsbeek et al., 1993) and by deformed and metamorphosed intrusions of the 1.89 Ga old Ammassalik Complex. The Charcot Land and Eleonore Sø supracrustal successions (Higgins et al., 2001a) of central East Greenland share many similarities with the Loch Maree Group rocks of Scotland and should be regarded as directly comparable.

By *c.* 1.9 Ga the ancient basement of Scotland (Lewisian Complex), Greenland (Nagssugtoqidian) and the coeval Lapland-Kola belt formed one continuous accretionary belt composed of various Archean cratonic components welded together during the assembly of Laurentia and Baltica (Fig. 5, Buchan et al., 2000; Dickin, 1992). By *c.* 1.84 Ga, calc-alkaline magmatism was concentrated along a new active margin represented by the *c.* 1.9 – 1.85 Ga Makkovik/Ketilidian belt of Labrador and South Greenland and the younger (1.85 – 1.50 Ga) Labradorian-Gothian belt of NE Canada and SW Scandanavia. In Scotland, the Labradorian-Gothian Belt is represented by the Rhinns Complex of Islay (Muir et al., 1994), part of a largely submerged area (the Malin Block) of juvenile Proterozoic crust forming at *c.* 1.78 Ga (Marcantonio et al., 1988).

MID-PROTEROZOIC BASIN EVOLUTION (*C.* 1200 – 900 MA)

There is a paucity of evidence to define the regional extent of the Mesoproterozoic to early Neoproterozoic Grenvillian global orogenic event (*c.* 1200 – 950 Ma) in Scotland and East Greenland. Evidence has yet to be determined in Greenland and, in the Western Highlands of Scotland, is only locally recorded in the Glenelg inlier where eclogite and amphibolite facies metamorphism is dated at *c.* 1000 Ma (Sanders et al., 1984; Storey et al., 2004). This time interval is marked in both East Greenland and Scotland by the accumulation of thick siliciclastic sedimentary successions, the degree to which syn-depositional crustal extension and active rifting was involved in these accumulations remains unclear.

The Stoer and Torridon groups (the 'Torridonian')

In Scotland the Lewisian Complex had, by late Proterozoic time, been deeply eroded and buried by an unconformable succession of red arkosic sandstones, informally referred to as the 'Torridonian' (Figs. 2 and 3; Plate 1C). These sediments are facies equivalents of similar red-bed successions in Labrador and the Great Lakes area, that are interpreted to have occupied rifts developed peripherally to the eroding and maturing Grenville orogenic belt that extended across Rodinia (Winchester, 1988, Turnbull et al., 1996; Gower, 1988). Whilst a number of lines of sedimentological evidence support a rift-dominated setting for these deposits in Scotland (Stewart, 2002), evidence of related volcanism is restricted to undersaturated mafic volcanoclastic detritus present in the Mesoproterozoic (*c.* 1200 Ma) Stoer Group (Stewart, 1991). The early Neoproterozoic (*c.* 1000–900 Ma) Torridon Group lacks any volcanic association, is unconformable on the Stoer Group, and the relative ages are in accord with paleomagnetic evidence that shows a 90° change in polarity across the unconformity (Smith et al., 1983). This unconformity broadly coincides with the climactic Grenvillian orogenic deformation in North America.

Active syn-depositional faulting cannot unequivocally be demonstrated in the Torridon Group as east-facing faults reactivated during Iapetan thrusting (Butler, 1997) may signify Iapetan rather than early Neoproterozoic extension. An alternative model is that the Torridon Group sediments were deposited in fluvial environments by major river systems draining the foreland to the Grenville orogen (Rainbird et al., 2001). Detrital zircons from the Torridon Group have yielded a minimum U-Pb age of 1060 ± 18 Ma (Rainbird et al., 2001), coeval with the later stages of Grenville orogenic activity. No comparable sediments are preserved in East Greenland.

The Moine Supergroup

In areal terms, the Moine Supergroup dominates the rocks of the Northern Highlands of Scotland (Figs. 2 and 3A). Inliers of similar strata occur southeast of the Great Glen Fault (the Dava and Glen Banchor successions), and form the basement to the younger Dalradian Supergroup in the Grampian Highlands (Smith et al., 1999).

The monotonous siliciclastic lithology of the Moine Supergroup provides few distinctive horizons that can be easily correlated over great distance. Three formal lithostratigraphical groups are recognised (Fig. 4); Morar (oldest), Glenfinnan and Loch Eil (youngest) (Holdsworth et al., 1994). The Morar Group comprises a 5 km thick tripartite psammite-pelite-psammite succession. The Glenfinnan Group is characterised by striped units of thinly interbanded psammites, semipelites, pelites and quartzites (Plate 1D) together with thick pelite formations; estimates of thickness vary from 1 – 4 km largely as a result of the high levels of ductile strain. The largely psammitic Loch Eil Group may be up to 5 km thick.

Detrital and inherited zircon grains constrain a source age for detritus of between *c.* 1.8 and 0.9 Ga; Archean sources (*c.* 2.9 Ga) are only prominent in basal units just above the inliers of Lewisian basement rocks (Friend et al., 2003; Cawood et al., 2004). The Moine rocks were thus probably derived from erosion of the assembled domains of the *c.* 1.1 – 1.0 Ga Grenville deformed basement and deposited in a distal foreland setting with respect to the relict mountainous hinterland in the core of the orogen. The youngest Moinian detrital zircons detected so far (*c*. 900 Ma) have been found in samples from the Loch Eil Group in the eastern part of the Northern Highlands whereas the minimum age detrital zircons from the western Morar Group rocks are more in accord with the minimum age samples from the Torridon Group at *c.* 1.06 – 1.00 Ga (Rainbird et al., 2001; Cawood et al., 2004).

Determination of the depositional environment of parts of the Morar (regressive tidal shelf) and Loch Eil (shallow marine) groups has been possible where low strain permits sedimentological study; paleocurrents in both areas indicate a general flow direction from south to north (Glendinning, 1988; Strachan, 1986). Soper et al. (1998) proposed deposition in two major half-graben basins that were bounded to the west by inferred east-dipping normal faults, schematically represented in Figure 3A. An initial phase of rifting is proposed to accommodate deposition of the Morar and Glenfinnan groups; the former displays marked westward thickening in its upper part consistent with deposition in a half-graben (Glendinning, 1988). The same formations appear to become progressively more distal eastwards and the striped and pelitic rocks of the Glenfinnan Group may represent a distal facies of the Morar Group (Soper et al., 1998). In this model, the Loch Eil Group marks the onset of renewed rifting; asymmetrical facies distribution and westward thickening is again consistent with deposition in a second half-graben bounded by an east-dipping normal fault (Strachan, 1986). Dalziel and Soper (2001) have suggested that the Moine rocks were deposited within an aborted rift zone formed during the early stages of Laurentian break-out from the supercontinent of Rodinia as East Gondwana separated from West Laurentia to form the Pacific Ocean.

Metasediments of the Glenfinnan and Loch Eil groups are cut by the West Highland Granite Gneiss and intruded by metabasic intrusions of tholeiitic affinities both dated at *c.* 870 Ma (Friend et al., 1997; Millar, 1999; Fig. 2; Plate 2A). The chemistry of the basic rocks is consistent with intrusion into thinned continental crust; Ryan and Soper (2001) have proposed emplacement of the basic intrusions at depth to provide the heat necessary to locally melt the underlying basement and Moine sediments. Granitic melts then migrated through the sedimentary pile to higher levels.

Geikie (1893) first proposed that the 'Torridonian' and Moine rocks could represent different elements of the same sedimentary succession foreshortened by Caledonian thrusting. The available isotopic constraints on the age of these deposits (Turnbull et al., 1996), and on the provenance of detritus, suggests that parts of these two extended sequences were broadly contemporaneous and presently, it remains a plausible hypothesis that the Torridon Group was deposited by a major fluvial system that flowed eastwards into a marine setting for the dispersal of the Morar Group sediments (M. Krabbendam, *pers.comm.*, 2006). This cycle of deposition probably spanned the period from *c.* 1000–900 Ma; accumulation of the youngest parts of the sedimentary pile (Loch Eil Group, Soper et al., 1998) was followed relatively soon after by *c.* 870 Ma intra-basinal acid and basic magmatism (Millar, 1999).

In East Greenland, comparable sequences of thick Mesoproterozoic metasedimentary rocks are represented by the Krummedal succession (Higgins, 1988, ***ref to Plate in earlier chapter?***), widely distributed in both the Niggli Spids and Hagar Bjerg thrust sheets. The Krummedal succession and equivalent successions are exposed over a N–S distance of at least 600 km in East Greenland; the reconstruction of Higgins et al. (2004) suggests that the original depositional basin was at least 300 km wide with the eastern limit undefined. Ion probe analyses of detrital zircon (Kalsbeek et al., 2000; Watt et al., 2000) and electron microprobe analyses of monazite (Gilotti and Elvevold, 2002) are available from Krummedal succession metasediments of both the Niggli Spids and Hagar Bjerg thrust sheets. Like the Moine Supergroup, deposition occurred after *c.* 1050 Ma while Archean and mid-Paleoproterozoic (1800–2000 Ma) detrital zircon grains are rare and indicate that the older rocks of western foreland region to the Grenville belt were not a significant source region; Watt et al. (2000) and Watt and Thrane (2001) advocated a distant source area.

The widespread occurrence of these marine siliciclastic successions in Greenland, NW Scotland and in the eastern province of Spitsbergen (Brennevinsfjorden Group, Helvetsflya Formation; Gee and Teben’kov, 1996; Gee et al., 1995) indicates that late Mesoproterozoic sedimentary basins extended over several thousand square kilometres, perhaps in a number of interconnected depocentres. The general lack of Archean detritus in the Moine and Krummedal sequences, implies that detritus was derived from more recently active interior areas of the Laurentian hinterland (e.g. the Grenville Belt) rather than more parochial Archean or Paleoproterozoic basement. Those sediments were then deposited in marginal settings floored by Archean to Paleoproterozoic continental crust. Since no equivalent of the early Neoproterozoic Torridon Group fluvial red-bed system seems to have been present at the paleolatitude represented by East Greenland, we conclude that it is possible that the Krummedal succession may represent a northward continuation of marine dispersal of parts of the Moine succession.

NEOPROTEROZOIC OROGENESIS (*C.* 900 – *C.* 730 MA)

In Scotland, the nature and timing of Neoproterozoic tectonothermal activity affecting the Moine Supergroup is problematical and highly contentious. Current debate is focussed on whether or not the Moine rocks were affected by one or more HP-HT granulite facies orogenic events between *c.* 820 and 730 Ma. These events both led to extensive migmatisation of the Moine metasediments but did not generate significant volumes of granitic melt in the form of discrete plutonic bodies. This contrasts markedly with central East Greenland where HP-HT granulite facies metamorphism culminated in generation of significant volumes of S-type granite at *c.* 910 – 930 Ma.

For Scotland, Ryan and Soper (2001) proposed that the protolith to the 870 Ma old West Highland Granite Gneiss (and the contemporaneous basic sheets) was generated in response to *crustal thinning and extension* affecting an undeformed sedimentary pile. The East Greenland granites are intruded by basic sheets and subsequently affected by sillimanite-grade ductile shear zones but no precise age constraints are available for these later events (Leslie and Nutman, 2003).

Evidence for a *c.* 820 Ma orogenic (Knoydartian) event exists in the Moine rocks of the Northern Highlands (Fig. 4). Bodies of pegmatite generated *in situ* in localised zones of high strain yield precise U-Pb zircon and monazite ages of 827 ± 2 Ma and Sm–Nd ages of *c.* 820 – 790 Ma obtained from post-D_1 Morar Group garnets apparently date the early metamorphism (Rogers et al., 1998; Vance et al., 1998). Peak pressures of 12.5-14.5 kb indicate *crustal thickening* at this time. A further episode of HP-HT metamorphism (*c.* 10 kb, 800°C) occured at 730 Ma (Fig. 4), seemingly restricted to the eastern part of the Moine outcrop (Tanner and Evans, 2003; Emery et al., in press).

Combined, these data from the Scottish and Greenland sectors apparently indicate three periods of orogenesis (*c.* 930 Ma, *c.* 820 Ma, *c.* 730 Ma) in this sector of Laurentia, each separated by *c.* 100 Ma. The wider significance of these orogenic events is unclear, not least because they occur at a time when the Rodinian supercontinent was undergoing late-stage amalgamation, even the initiation of fragmentation in some locations (Hoffman, 1991; Dalziel, 1992). It has been proposed that intracratonic movements accommodating extension and compressional deformation may account for these early to mid-Neoproterozoic orogenic events (e.g. Cawood et al., 2004; Emery et al., in press). Repeated HP-HT conditions are though largely inconsistent with models of intracratonic (LP, HT) orogenic belts (*cf.* Petermann and Alice Springs orogenies of Australia, Sandiford and Hand, 1998; Scrimgeour and Close, 1999; Shaw et al., 1992).

It is noted here that *c.* 950 Ma calc-alkaline volcanics have been recorded in the eastern Svalbard Nordaustlandet Terrane Kapp Hansteen Group along with 930 – 960

Ma augen granites emplaced synchronously with an episode of deformation and HP-HT crustal anatexis (Johansson et al., 2000). An alternative hypothesis which might be considered is that of a more marginal continental setting, in which a continental block is actively over-riding oceanic crust as a consequence of active spreading on an opposing plate margin. Thus, repeated Neoproterozoic tectonothermal events on the eastern Laurentian margin may have some analogy with the patterns of high heat flow and repeated deformation found in subduction zone continental backarcs (Hyndman et al., 2005).

MID-NEOPROTEROZOIC TO LOWER PALEOZOIC SEDIMENTATION

During the late Neoproterozoic, post-Pan-African rifting of eastern Rodinia culminated with the formation of the Iapetus Ocean as Baltica and Amazonia drifted away from Laurentia (inset to Fig. 1, Fig. 4; Soper, 1994b; Cawood et al., 2001, 2003, 2004). These rift and rift-drift events are recorded by the formation of widespread progradational passive margin sedimentary sequences, igneous activity and oceanic sedimentation along the eastern side of Laurentia that lasted from *c.* 700 Ma until the mid-Ordovician.

In Scotland, this geological evolution is recorded in two separate successions, the Cambrian to mid-Ordovician carbonate shelf succession of the Northwest Highlands and the Late Neoproterozoic to mid-Cambrian, shallow- and deep-water sediments and volcanic rocks of the Dalradian Supergroup in the Grampian Highlands. The former readily correlates with the foreland succession in East Greenland, the latter is comparable in age to the Eleonore Bay Supergroup in East Greenland (Soper, 1994b). Thus we can interpret the Hebridean Cambro-Ordovician and Grampian Dalradian rocks and their Laurentian correlatives as forming two sub-parallel sedimentary belts located along the eastern continental margin, with the shelf carbonate rocks lying on the landward side of the generally deeper water marine lithologies. Oceanic crust is presumed to have developed to the southeast of the present Dalradian outcrop Scotland with the youngest sediments ultimately prograding onto Iapetan oceanic crust.

The Pre-Dalradian Basement

In Scotland, south-east of the Great Glen Fault, the stratigraphically, and structurally, oldest known strata within the Grampian Highlands comprise the recrystallized and mainly gneissose to locally migmatitic psammite and semi-pelite of the Glen Banchor and Dava successions (Fig. 4, Piasecki, 1980; Smith et al., 1999; see also review by Strachan et al., 2002).

Rocks of the Glen Banchor and Dava successions are invariably intensely recrystallized, do not preserve sedimentary structures and commonly contain intrafolial isoclinal folds that deform the first foliation (usually a gneissosity) (Smith et al., 1999). In contrast, the overlying Grampian Group rocks are variably recrystallised, structurally less complex and commonly preserve sedimentary structures.

In the Dava and Glen Banchor succession, and locally close to the contact with younger rocks, late Neoproterozoic syn-tectonic blastesis and pegmatite segregation is present within ductile shear zones (Hyslop, 1992; Hyslop and Piasecki, 1999). U-Pb monazite analyses from such pegmatites have provided high-precision ages of 808 +11/-9 Ma and 806 ± 3 Ma, and a concordant age of 804 +13/-12 Ma from the host mylonite matrix (Noble et al., 1996). Recent U-Pb dating of single zircon grains within kyanite-bearing migmatites yielded an age of 840 ± 11 Ma (Highton et al., 1999). These data are interpreted as the effects, in the Dava/Glen Banchor succession rocks, of high-grade metamorphism and migmatization associated with Knoydartian orogenesis recognised farther west in the Moine Supergroup.

In contrast, isotopic evidence for Neoproterozoic tectonothermal events has yet to be recorded in the Dalradian rocks. There is evidence of progressive overstep of various lithologies onto the older strata (Smith et al., 1999; Robertson and Smith, 1999; British Geological Survey, 2002, 2004), and this, combined with $^{87}Sr/^{86}Sr$ isotopic signatures from the lowermost Dalradian strata (Thomas et al., 2004, see below), provides evidence for a significant stratigraphical and tectonothermal break at the base of the Grampian Group (Smith et al., 1999).

In Greenland, the very thick Neoproterozoic–Ordovician succession recognised within the Franz Joseph Allochthon is dominated by the Neoproterozoic Eleonore Bay Supergroup (Higgins et al., 2004). The lower contact of the Eleonore Bay Supergroup against the older gneissose metasedimentary rocks of the Krummedal succession in the Hagar Bjerg thrust sheet is likely to be a unconformity modified during westwards Caledonian transport (Leslie and Higgins, this volume).

The Dava and Glen Banchor succession rocks are interpreted to form a Moine-like metasedimentary basement that was affected by a Neoproterozoic Knoydartian tectonothermal event prior to deposition of the overlying Grampian Group. The relationship is thus analogous to that observed at the base of the Eleonore Bay Supergroup in Greenland.

Dalradian sedimentation (c. 730 – c. 470 Ma)

The Dalradian Supergroup comprises a relatively well-differentiated progradational passive margin sedimentary sequence dominated by marine meta-sandstones, siltstones, mudstones and carbonate rocks. They are subdivided into a Cryogenian (Grampian, Appin groups) and an overlying Ediacaran to mid-Cambrian (Argyll Group and Southern Highland Group) succession (Harris et al., 1978, 1994) (Figs. 4 and 6**).** The Dalradian Supergroup has an apparent total thickness of at least *c.* 25 km but this is unlikely to have been deposited in a single continuous succession. Significant volumes of the mid- to upper parts of the succession (e.g. in the southwest Scottish Highlands) are affected only by low-grade metamorphism and/or relatively weak deformation and here the sedimentological and basin evolution history can be interpreted with some confidence. When a restoration is made of the distribution of lithostratigraphy prior to the Ordovician (Grampian) folding, it seems reasonable to presume that deposition would have migrated broadly south-eastwards with time.

Key to unravelling the stratigraphy is a number of region-wide events that were probably broadly synchronous across Scotland and Ireland. These include, transgressive flooding surfaces (e.g. base of the Ballachulish and Easdale subgroups, Fig. 6), Neoproterozoic glaciation events (McCay et al., 2006) represented by such as the Port Askaig Tillite (base of the Argyll Group, Plate 2C), and rift-related magmatism (as represented by A_2-group granitoids and large volumes of basic volcanic rocks (e.g. Tayvallich Volcanics Formation, Plate 2D) in the Argyll Group (Tanner et al., 2006). These key horizons are used to help constrain the suggested correlation of Figure 6.

Modern sequence stratigraphical concepts have only been applied to the lowermost Grampian Group (Glover and McKie, 1996; Banks, 2005). The presence of previously undetected intra-basinal unconformities and periods of non-deposition are now recognised in the southern and central Scottish Highlands (BGS unpublished data). One such important unconformity which affects the Appin Group and Argyll Group succession is added to the detail on Figure 6. Alternative evidence for major stratigraphical and tectonic orogenic breaks (Prave, 1999; Alsop et al., 2000; Hutton and Alsop, 2004) has not been regionally validated and remains speculative.

Age constraints on the initiation of Dalradian sedimentation are poor. The Grampian Group must be younger (<800 Ma) than the pegmatites contained within the basement Dava and Glen Banchor successions and the youngest deformation event recorded within the equivalent Moine rocks to the NW of the Great Glen Fault is now *c.* 730 Ma (Tanner and Evans, 2003; Emery et al., in press). The youngest Dalradian detrital zircons yield ages of 900 Ma (Cawood et al., 2003) and $^{87}Sr/^{86}Sr$ whole rock isotope data from the lowermost metacarbonate rocks of the Grampian Group are consistent with a global late Neoproterozoic strontium sea-water signature younger than 800 Ma and possibly as young as *c.* 670 Ma (Thomas et al., 2004). Thus Grampian Group sedimentation is post-800 Ma, and could have initiated as late as *c.* 700–730 Ma.

Neoproterozoic augen granites such as the Ben Vuirich pluton (BV on Fig. 4) were intruded into Appin/Argyll Group Dalradian at 590 Ma (Rogers et al., 1989; Pidgeon and Compston, 1992). These rift-related intrusions have an A_2-group chemistry (Tanner et al., 2006) and are probably genetically linked with the Argyll Group mafic volcanism (Tayvallich Volcanics) dated at 595 Ma (Dempster et al., 2002). This magmatism is contemporaneous with a second pulse of bimodal magmatism throughout the Appalachians (e.g. Badger and Sinha, 1988; Rankin et al., 1989; Aleinikoff et al., 1995) and related to continental break-up in Laurentia (Cawood et al., 2001). Reliable information critical to the biostratigraphical age of the Dalradian Supergroup is only preserved in the uppermost parts of the Southern Highland Group where locally developed metacarbonate rocks (Leny Limestone) contain topmost Lower Cambrian *Pagetia* trilobites indicating an approximate age of *c.* 515 Ma the upper limits of deposition (Fig. 6; Pringle, 1940; Tanner, 1995).

Adopting an age of *c.* 730 Ma for the base of the Grampian Group has important implications for the ages of the tillite formations in the mid- to upper Dalradian (Port Askaig and Inishowen/Macduff). Brasier and Shields (2000), Condon and Prave (2000) and McCay et al. (2006) proposed that the Argyll Group tillites correlate with the Ghubrah (Sturtian) glacial dated at 723+16/-10 (Brasier et al., 2000) but deposits of this age would mean that accumulation of the Grampian and Appin groups would both overlap the HP-HT tectonothermal event recorded in the eastern parts of the Moine (Tanner and Evans, 2003; Emery et al., in press) and contradict the $^{87}Sr/^{86}Sr$

isotope data from the Grampian Group metacarbonate rocks (Thomas et al., 2004). Displacements on the Great Glen Fault would permit some room for manoeuvre here but even the larger estimates of displacement (e.g. Dewey and Strachan, 2003) seem unlikely to solve the space problems inferred in these overlapping ages. The scenario favored here (Fig. 6) envisages that two principal glacigenic intervals have been preserved in the Dalradian. We equate the younger Southern Highland Group glacigenic deposits in Inishowen (Donegal, Eire) and Macduff (NE Scotland) with the Gaskiers Formation (*c.* 580 Ma, Bowring et al., 2003) and the Varangerian tillites of Norway (620 – 590 Ma, Gorokhov et al., 2001; Bingen et al., 2005). The older Port Askaig Tillite Formation (Argyll Group) and the Storelv and Ulvesø Formations (Tillite Group) of East Greenland (Hambrey and Spencer, *19*87) are then equated with the Marinoan/Ghaub glacial (*c.* 635 Ma, Hoffmann et al., 2004). The Kinlochlaggan Boulder Bed is an isolated set of occurrences restricted to the central Scottish Highlands and assigned to the Lochaber Subgroup (British Geological Survey, 2002) (Fig. 6). It must, on that basis, presumably be significantly younger than 700 Ma and cannot correlate with the Ghubrah glaciation. The Kinlochlaggan Boulder Bed is interpreted as a mature sandy deposit containing glacially-rafted dropstones (BGS, unpublished data) rather than a sub-glacial till and may thus still mark the earliest record of glacial influence in the Dalradian.

Provenance studies summarised here (Fig. 7; Cawood et al., 2003, 2004) provide useful data that track the evolution and denudation history of the hinterland. Probability density distributions of concordant detrital zircon ages show that Grampian Group detrital zircons maintain the earliest Neoproterozoic to late Paleoproterozoic spectrum of the Torridon Group and Morar and Moine Supergroup (Cawood et al., 2003, 2004; Friend et al., 2003). However, quite different distributions are apparent in the data currently available for the remainder of the Dalradian Supergroup. After an early (Grampian Group) rifting episode in the Scottish sector of Laurentia, Appin Group shallow marine shelf sedimentary facies associations are developed during post-rift thermal subsidence (Stephenson and Gould, 1995). Flooding at the base of the Ballachulish Subgroup introduces, or just precedes, the arrival of Archean zircons in detritus and an apparent absence of Grenvillian ones. The onset of Argyll Group deposition coincides with supply of a broad spectrum of earliest Neoproterozoic to Archean detritus to an increasingly unstable and volcanically active margin (Stephenson and Gould, 1995). These successions are ultimately overstepped as the margin founders in response to Iapetan rifting and is inundated with immature siliciclastic detritus from Crinan Subgroup time onwards (upper Argyll Group). We apparently see less abundant Paleoproterozoic zircons in the sediment load upwards from the base of the Crinan Subgroup and these data might suggest that any *c.* 1800 Ma Rhinnian source became increasingly isolated from the Dalradian basins as Archean supply increased. Iapetan rifting may have removed, or more likely submerged, that sector of the Laurentian margin that had been supplying the Paleoproterozoic detritus, presumably as Amazonia and Baltica broke away.

Thus the picture emerges in Scotland of a Dalradian succession deposited in an evolving pericontinental environment over a period of *c.* 180–200 m.y. Fluctuations in water depth accompanied active rifting and the development of second and third order sub-basins on this sector of the continental margin.

In Greenland, the broadly time equivalent Eleonore Bay Supergroup (apparently 14.5 km thick), and overlying Tillite Group (0.8 km thick) and Kong Oscar Fjord Group (4.5 km thick) are, by comparison, more poorly constrained chronologically. Here, there is no evidence of contemporaneous volcanic activity and the available age data loosely bracket deposition in the period *c.* 940 to *c.* 460 Ma (Sønderholm and Tirsgaard, 1993; Smith et al., 2004). These East Greenland strata record shelf and ramp sedimentation which was probably punctuated by significant periods of non-deposition on a slowly subsiding passive margin, a setting in stark contrast to the linked Neoproterozoic rift basin architecture of Scotland. Farther north on the Laurentian margin, the Neoproterozoic Hekla Sund Basin (Higgins et al., 2001b) represents another locus of rifting activity in eastern North Greenland. In such a setting and based upon the data currently available, we propose a generalised correlation is possible between the Greenlandic and Scottish sectors in Laurentia (Figs. 3 and 6).

Cryogenian to early Ediacaran basin evolution (c. 730 – c. 610 Ma)

Grampian Group: The Grampian Group records the initiation of middle to late Neoproterozoic extension and basin development and comprises three main lithofacies associations (subgroups) interpreted as representing distinct phases of early and syn-rift extension followed by a protracted period of post-rift thermal subsidence (Fig. 6). Deposition occurred within a series of linked northeast-trending rift basins bounded by major crustal lineaments (Glover and Winchester, 1989; Smith et al., 1999; Banks, 2005). Despite regional deformation and metamorphism to amphibolite-facies conditions, the stratigraphical integrity and overall geometry of these basins has been preserved largely intact.

The actual base to the Grampian Group is unexposed, but the oldest unit is the spatially restricted and fault-bounded Glenshirra Subgroup that is nowhere observed in primary undisturbed contact with the underlying Glen Banchor or Dava succession rocks (Fig. 6). With a maximum exposed thickness of *c.* 2 km, the Glenshirra Subgroup comprises stacked shoaling sequences of geochemically distinct, immature arkosic psammite and beds of metaconglomerate (Banks and Winchester, 2004). Those authors interpret the sediments as alluvial fan and shallow water sediments deposited within a SE-thinning fan-delta clastic wedge. Progressive thickening and coarsening of the strata towards the west may imply the presence of a basin margin to the west or northwest (approximately coincident with the present trace of the Great Glen Fault). The clastic wedge was supplied from an exposed hinterland of mature crust beyond the basin margin (Banks and Winchester, 2004) which, based upon clast populations, was predominantly composed of quartzo-feldspathic gneiss and granitic rock. Detrital zircon populations are dominated by 1.8 Ga detritus with subsidiary 1.2 Ga detritus (Fig. 7), suggesting that 'Rhinnian-type' basement was an important source area (Cawood et al., 2003).

The Glenshirra Subgroup is abruptly but conformably overlain by a distinctive and regionally widespread succession of psammite and semipelite assigned to the Corrieyairack Subgroup (Fig. 6). This change records a basin-wide flooding event which heralded a period of subsidence and rift-related extension (Banks, 2005). A near complete sequence is preserved through the main rift cycle with 4–5 km of siliciclastic deposits deposited by prograding turbidite complexes (Banks, 2005). Variations in sediment supply and source area are indicated by changes in the proportions of plagioclase and K-feldspar, whereas variations in bed thickness and form reflect depositional processes. Bouma cycles are well represented but bottom structures are extremely rare (Banks, 2005). A reduction in sand grade sediment supply and development of shelf conditions along the tectonically active basin margins and intrabasinal highs is recorded by lateral thickness and facies changes to striped semipelite and psammite. This is followed by a renewed influx of sand-dominated turbidites (Plate 2B) deposited by fan-lobe systems derived from the northwest, passing south and eastwards into shelf environments (Glover et al., 1995; Robertson and Smith, 1999; Banks, 2005).

The turbidites of the upper Corrieyairack Subgroup are overlain by shallow marine sediments of the Glen Spean Subgroup that prograded into the basin from the northwest and southeast (Fig. 6) after a flooding event (Banks, 2005). Reduced subsidence and relative tectonic stability at this time is interpreted to represent a post-rift thermal subsidence phase (Glover et al., 1995). The lithological associations of the Glen Spean Subgroup, combined with well preserved sedimentary structures, indicate deposition in shallow (tidally influenced) marine shelf environments with intensive sediment recycling and winnowing of the underlying turbiditic rocks (Banks, 2005). Analysis of detrital zircon populations shows a marked absence of any Archean detritus with peaks at 2.0 Ga and 1.4 Ga in the Corrieyairack and progressive dilution by 1.1-0.9 Ga Grenvillian detritus in the Glen Spean Subgroup (Fig. 7; Cawood et al., 2003; Banks, 2005).

In Greenland, the Nathorst Land Group (Fig. 6; Sønderholm and Tirsgaard, 1993) comprises up to 9 km thickness of siliciclastic sediment that rests in sheared or unexposed contact with the Hagar Bjerg thrust sheet (Higgins et al., 2004). The Nathorst Land succession is informally subdivided into 7 formations (NLG1–7, Smith and Robertson, 1999), all of which record persistent fine-grained and shallow marine shelf sedimentation. Several lithofacies associations comprising sandstone-dolostone-quartz arenite alternating with heterolithic fine sandstones and siltstones and mudstone are identified. Carbonate deposits with parallel lamination of possible algal origin are present in the upper part of the group. Beautifully preserved delicate sedimentary structures including desiccation cracks, ripple-lamination, cross-lamination and heavy mineral bands are characteristic at several levels. Depositional environments include outer shelf storm influenced and inner shelf to tidally influenced shoreface. Two major flooding surfaces are identified at the junctions between the Nathorst Land Group formations 3 and 4 and between formation 6 and 7 (Smith and Robertson, 1999) and we tentatively match these with the flooding events that bracket the Corrieyairack Subgroup in the Scottish sector in order to help constrain the suggested correlation in Figure 6.

Appin Group: In Scotland, siliciclastic sedimentation continued up into the lowermost Appin Group (Lochaber Subgroup, see Fig. 6). Although locally conformable, the Lochaber Subgroup has a markedly diachronous base at the basin scale and, with an overall decrease in thickness of the subgroup to the southwest of its crop, is interpreted to have been deposited with considerable lateral facies variation during marine transgression (Key et al., 1997). Similarly, above the Nathorst Land Group in East Greenland, the base of the Lyell Land Group is marked by transgression, marked locally in places by an angular unconformity (Smith and Robertson, 1999). The Lyell Land Group comprises 3 km of siliciclastic shelf and coastal plain tidal sediments dominated by storm and wave events. Cyclical changes in sea level and shoreward reorganisation of facies are linked to large scale regressions that can be traced along 300 km of inferred paleocoastline (Tirsgaard and Sønderholm, 1997).

Across Scotland, we interpret the base of the succeeding Ballachulish Subgroup as transgressive with maximum flooding likely to have coincided with deposition of the Ballachulish Slate Formation in the locally anoxic environments which characterise the lower part of the subgroup (Fig. 6). Subsequent progradation is marked by progressive development of extensive shallow, tidally influenced, shelf sedimentation and a period of stability (Anderton, 1985). A four-fold subdivision at formation level can be traced with remarkable continuity for some 300 km across the Grampian Highlands in Scotland and northwest Ireland. Limestone-pelite-quartzite facies associations are characteristic and mark a significant break from the siliciclastic dominated record of the Grampian Group and Lochaber Subgroup as presently defined. Continuity at this regional scale, almost on a bed for bed basis, attests to the widespread stability and relatively uniform nature of the subsidence. Interestingly, available data indicates that Archean detrital zircon grains become evident in the sediment load at this juncture (Fig. 7; Cawood et al., 2003), further emphasizing the change which occurs at the base of the Ballachulish Subgroup.

In Greenland, the base of the Ymer Ø Group may record the same event recording a sharp break in sedimentary facies association from heterolithic sandstones in the Lyell Land Group below to fine grained mudstone above. A wide variation in lithology comparable to the Ballachulish Subgroup is also evident with siliciclastic mudstone and sandstone passing upwards into black limestone and dolomite with algal biostromes (Sønderholm and Tirsgaard, 1993). A wide range of environments are indicated at this time including, basinal and slope deposits, inner-shelf, and horizons of evaporitic sulphate deposition.

The Blair Atholl Subgroup marks the continued diversification of Dalradian lithologies in Scotland with renewed flooding and a change to deeper de-oxygenated marine conditions in the Scottish sector (Fig. 6; Stephenson and Gould, 1995). In the type area, the basal slates and phyllites are conformable with the underlying Ballachulish Subgroup but importantly, some hints of volcanoclastic detritus and minor tuff horizons are also recorded, pointing to the earliest signs of basin instability on this sector of the Laurentian margin.

In East Greenland the Ymer Ø Group is succeeded by the Andrée Land Group which should thus be broadly equivalent to the Blair Atholl Subgroup. The Andrée Land Group comprises 1275 m of algal limestone and dolomite deposited on a NE-facing storm influenced carbonate ramp (Frederiksen, 2001). Laterally extensive facies form cyclical stacking patterns in response to sea level fluctuations and are the basis for subdivision into seven formations. Changes in ramp geometry and transgression have been linked to an episode of extensional faulting that marked incipient stretching on this part of the margin (Frederiksen, 2001).

Lower Argyll Group: Argyll Group Dalradian sedimentation in Scotland as a whole records the rapid onset of instability in the mid- to late Neoproterozoic with the replacement of widespread shallow marine conditions of the Appin Group by cycles of rapid basin deepening. Initially, the distinctive successions of black graphitic pelite, metacarbonate rock and quartzite of the Appin Group are succeeded by an equally distinctive glacio-marine tillite (Plate 2C), the Port Askaig Tillite Formation and other correlatives. Above, deeper water psammites and quartzites comprise the remainder of the Islay Subgroup. The tillite formation comprises a prominent marker horizon across Scotland and Ireland and marks the onset of cold climate glacio-marine sedimentation equated here with the Marinoan glacial period at *c.* 635 Ma (Fig. 6). The top of the subgroup is located in Ireland by a cap carbonate (the Cranford Limestone Formation, McCay et al., 2006) after which cold climate conditions apparently ameliorated with no further sign of glacigenic deposits in the Argyll Group. Thereafter, variable lithofacies of psammite and quartzite and locally thick accumulations indicate that sediment input kept pace with extension in a series of north-east trending basins (Stephenson and Gould, 1995). Whilst detrital zircons from the tillite units are comparable to the enclosing Appin and Argyll group rocks (Cawood et al., 2003) this change in sedimentation is also marked by increasing volumes of Archean grains above the level of the tillite formations (Fig. 7; Cawood et al., 2003).

The Tillite Group in Greenland is likewise marked by units of diamictite sandstone, carbonate and shale (Fig. 6). Here, massive bedded diamictites and cross-bedded sandstones of an eolian origin mark the base and are overlain by shales and sandstones formed by debris flow and turbidite events. There is a second horizon of diamictite below tidally influenced dolomites and shales at the top of the group (Hambrey and Spencer, 1987; Moncrieff and Hambrey, 1988). We follow the assessment of Sønderholm and Smith (this volume) for a ‘Marinoan’ age for these deposits and thus make the *c.* 635 Ma chronostratigraphical correlation with the Dalradian Islay Subgroup used in the construction of Figure 6.

In Scotland and Ireland, the Easdale Subgroup sees a return to a wide range of finer grained lithologies including graphitic black pelite, calcareous semipelite and metacarbonate rock, commonly associated with pebbly quartzite and sheets of basic meta-igneous rock of varying abundance (Stephenson and Gould, 1995). Exhalative saline brines gave rise to a laterally persistent bed of stratabound sulphide, barite and vein mineralization (Hall et al., 1991). Taken together with the greater abundance of mafic meta-igneous rocks, these occurrences point to an increased extension in this sector of the Laurentian margin at the end of the Cryogenian.

In Greenland, an erosional break encompassing the later Ediacaran and earliest Cambrian separates the sediments of the Tillite Group from the Cambro-Ordovician succession of the Franz Joseph allochthon in the central fjord region of East Greenland (Fig. 6). Uplift and erosion in Greenland at this time coincides with the onset of enhanced rifting and mafic volcanism leading up to continental rupture in the Scottish sector.

Ediacaran basin evolution (c. 610–542 Ma)

Upper Argyll Group: In Scotland, individually thick formations of often immature sediment and deep water turbiditic facies characterize the succeeding Crinan Subgroup. This pronounced change in sedimentary facies association coincides with regional overstep in the southern and northeast Grampian Highlands and we suggest that it is this change that indicates the onset of rift-drift transition in the Scottish sector of Laurentia as Iapetan rupture expanded northwards. The overlying Tayvallich Subgroup is dominated by carbonates, locally accompanied by thick extrusive mafic volcanic rocks (including pillow lavas, Plate 2D), and sub-volcanic sills marking, perhaps for the first time, rupturing of the continental crust during rifting. Felsic tuffs within the Tayvallich Volcanic Formation have yielded U-Pb zircon ages of 601 ± 4 Ma (Dempster et al., 2002). Rapid lateral variations in facies and thickness associations with unconformities, overstep relations and pebbly beds typify this part of the succession.

Southern Highland Group: The uppermost unit of the Dalradian Supergroup is characterised by a *c.* 4 km thick pile of coarse-grained turbiditic siliciclastic and volcanoclastic strata lying immediately above the Tayvallich Subgroup (Fig. 6). These sediments mark rapid basin deepening that persistently stayed ahead of the sedimentary and volcanic fill. The coarse-grained sediments were probably laid down in slope apron or ramp settings with channels on the lower slopes and inner zones of deep water submarine fans with overbank deposits or as outer fan facies (Burt, 2003). No apparent match for these immature turbidite-dominated sedimentary facies associations occurs anywhere along the Greenland sector of Laurentia.

In Scotland, volcanoclastic units are a conspicuous component of the Southern Highland Group. They are most prevalent in the lowermost 1 km and are interpreted as recording, in part, the erosion of the underlying basic volcanics, but may also result from contemporaneous volcanism and ashfall on the hinterland (Pickett et al., 2006). This interpretation is not however strongly supported by the detrital zircon data, which are dominated by Archean detritus in both the volcanoclastic 'Green Beds' and their siliciclastic Southern Highland Group counterparts. Ages younger than 900 Ma are generally absent although one grain yielded an age of 553 ± 24 Ma (Cawood et al., 2003). An important glacigenic deposit is recognised in Inishowen in the north of Ireland (Condon and Prave, 2000). We follow those authors in correlating the Inishowen occurrences with others in the Southern Highland Group Dalradian at Loch na Cille and Macduff in Scotland and then on a global scale with the Gaskiers glacial at *c.* 580 Ma (Fig. 6).

Cambro-Ordovician sedimentation (c. 540 – c. 470 Ma)

No mid- to late Neoproterozoic tillite deposits are preserved on the foreland of the NW Highlands so that the early Neoproterozoic Torridon Group rocks are overlain unconformably by the Lower Cambrian Ardvreck Group (Eriboll and An t-Sron formations, Fig. 6). This siliciclastic succession is dominated by feldspathic to quartzitic sandstones with subsidiary siltstone and is interpreted as a transgressive sequence passing upwards into storm-dominated calcareous siltstones and regressive sands (McKie, 1990). The Ardvreck Group sediments are conformably but sharply overlain by 900 m thickness of Durness Group dolostone with limestone and minor chert (Ghrudaidh to Durine formations, Fig. 6) which accumulated on a low energy shelf (Park et al., 2002). From this change onwards, sedimentation in peri- and subtidal environments continued into the Middle Ordovician (Wright and Knight, 1995) and thus we see Greenland-style passive subsidence and a broad platformal shelf extending across inboard parts of the Scottish sector (*cf.* Higgins et al., 2001a). The lower siliciclastic formations contain distinctive *Skolithos* burrows (‘Piperock’) and pass up into dolomitic siltstone with minor limestone containing diverse macrofaunal assemblages and *Planolites* burrows (Park et al., 2002).

In the central fjord region of East Greenland (Fig. 6), the Cambro-Ordovician Kong Oscar Fjord Group is separated from the Tillite Group by a disconformity or erosional unconformity with cross-bedded quartz arenites with rippled bed tops passing upwards into shales, thin sandstones and limestones (Smith et al., 2004). Limestones and dolostones then increase upwards to become the dominant facies. The base of the Ordovician is marked by a transgression, above which subtidal carbonate environments dominate (Smith et al., 2004). The Cambro-Ordovician lithostratigraphy can be traced continuously over many hundreds of kilometres north-south along strike while demonstrating systematic thickening of the succession from inboard to outboard positions on the original depositional margin (Higgins et al., 2001a).

In summary, the NW Highlands Cambro-Ordovician succession of Scotland apparently represents an intermediate position on the slowly subsiding Laurentian carbonate platform which lay between more inboard and more outboard environments each of which are represented by Cambro-Ordovician sedimentary rocks in East Greenland (Smith et al., 2004).

The lower parts of the shallow-water carbonate shelf succession represented by the NW Highlands Durness Group and the Kong Oscar Fjord Group of East Greenland are thought to be contemporaneous with the younger elements of the deep marine turbidite basins of the southern Highlands of Scotland (Fig. 6; Wright and

Knight, 1995; Park et al., 2002). Tanner (1995) made it clear that the lower Paleozoic Leny Limestone Formation occurs in stratigraphical continuity with the uppermost parts of the Southern Highland Group and thus we have the only reliable biostratigraphical age for the Dalradian Supergroup. These metacarbonate rocks preserve *Pagetia* trilobites (Pringle, 1940) and constrain the uppermost Dalradian to be topmost Lower Cambrian in age, i.e. approximately 515 Ma. Acritarchs from the Leny Limestone Formation have been correlated with Greenland but are long-ranging (Downie, 1982).

Fault-bound slivers preserved locally along the Highland Boundary Fault and assigned to the Highland Border Complex preserve Arenig carbonate sediments and black shale and pillow lava of Arenig age along with remnants of a fragmented pre-Arenig ophiolite (Tanner and Sutherland, 2007; but see also review in Bluck, 2002). Whilst the provenance of these fault-bound slivers is undoubtedly Laurentian, and their stratigraphical ages overlap with part of the Ordovician Durness Group, their affinity with the Dalradian succession with which they are now juxtaposed has remained equivocal until now. Tanner and Sutherland (2007) have reappraised the paleontological and stratigraphical evidence and argue for a largely autochthonous Highland Border Complex in stratigraphical continuity with the Dalradian which was overridden by a Highland Border ophiolite early in the arc accretion process.

THE CALEDONIAN OROGENY

Ordovician arc accretion – Grampian orogenesis (470 – 460 Ma)

By mid-Ordovician time, the Grampian phase of orogenesis halted passive margin sedimentation (Fig. 6; Lambert and McKerrow, 1976; Soper et al., 1999; McKerrow et al., 2000). This phase records the convergence of the Laurentian continental margin with an intra-oceanic subduction zone and volcanic arc. The paleogeography of the margins of the Iapetus Ocean is likely to have been complex and the potential for preservation low; much of the evidence remaining is fragmentary. Parts of an Early Cambrian to Early Ordovician continent-facing mafic to silicic arc and supra-subduction ophiolites are exposed in western Ireland where it has proved possible to determine the sequence of events in a short-lived continent-arc collision orogeny (Dewey and Ryan, 1990; Dewey and Mange, 1999). There is indirect evidence that such an arc is buried beneath the Devono-Carboniferous sedimentary cover in the Midland Valley of Scotland (Bluck, 1983, 1984).

Accretion is thought to have resulted in an overthrust ophiolite nappe, perhaps analogous to the Shetland Ophiolite Complex which structurally overlies Dalradian rocks on Unst in NE Shetland. However, this particular fragment of Iapetan crust was apparently obducted at *c.* 490 Ma (Flinn et al., 1991), some 20 m.y. prior to the peak of Grampian regional deformation and Barrovian metamorphism in Dalradian and Moine sediments. It is this later stage (*c.* 470 Ma) that probably represents major collision and arc-accretion, albeit oblique convergence resulting in some diachroneity of development in the regional structural architecture. Geochronological constraints (Friedrich et al., 1999) for Grampian orogenesis indicate that deformation, magmatism and regional metamorphism and migmatisation occurred within an interval of *c.* 10 m.y. in the Middle Ordovician, between *c.* 471 Ma and 462 Ma. Switching subduction polarity at about this time initiated a south-facing arc and an Ordovician-Silurian subduction-accretion complex (Dewey and Ryan, 1990; Dewey and Mange, 1999). The Tyrone Ophiolite of Northern Ireland may represent an Arenig-Llanvirn back-arc basin overthrust by the Sperrins Nappe, part of the SE-facing and southerly directed nappe complex which includes the Tay Nappe in the southern part of the Grampian Highlands (Fig. 8; Krabbendam et al., 1997).

Grampian orogenesis affected all of the Dalradian and older rocks of the Grampian Highlands. Isotopic evidence proves that parts of the Northern Highlands were also affected by a *c.* 470 Ma tectonothermal event which has been correlated with Grampian orogenesis (Kinny et al., 1999; Rogers et al., 2001; Emery et al., in press). The effects of this event are most evident in east Sutherland and eastern Inverness-shire where the effects of the later (Silurian) Scandian reworking are weak. Peak Grampian deformation culminated in the formation of major fold stacks or nappe complexes and associated zones of structural attenuation. Although deformation was superimposed upon a complex stratigraphical template, the gross lateral continuity of the Dalradian lithostratigraphy precludes the existence of any large scale thrusting at the present exposure level in the Grampian Highlands (see the cross-section of Fig. 8). Illustration of the gross architecture of the deformation is best portrayed in the 3D-block diagram reproduced by Stephenson and Gould (1995, after Thomas, 1979).

Several suites of Ordovician plutonic rocks were intruded into the Dalradian rocks of the northeast Grampian Highlands during regional deformation and metamorphism at *c.* 470 Ma (Kneller and Aftalion, 1987; Dempster et al., 2002).

These include a syn- to late tectonic suite of basic and ultramafic plutons and two suites of syn- to late tectonic diorites and granites (Fig. 8).

There is scant evidence in the East Greenland Caledonides (or in Svalbard, Harland, 1997), of these short-lived lower Paleozoic marginal arcs and basins that must have accommodated subduction of Iapetan oceanic crust and convergence with Baltica. Rather, the evidence now available suggests that these distinctive orogenic elements were mainly incorporated as thrust sheets into the higher structural levels of the Scandinavian Caledonides (Roberts et al., 2001; Yoshinobu et al., 2002; Andréasson et al., 2003).

The earliest known (Ordovician and Silurian) granitoids in the East Greenland Caledonides are I-type calc-alkaline granodiorite and quartz-diorite intrusions in the Scoresby Sund region (70°–72°N), dated by SHRIMP U-Pb analyses of zircons to between 466 ± 9 Ma and 432 ± 10 Ma (A.P. Nutman and F. Kalsbeek, unpublished data). The older date is close to that of the youngest (Middle–Late Ordovician, *c.* 460 Ma) sediments preserved in the Franz Joseph allochthon suggesting that a tectonic control may have brought sediment accumulation to a close in this sector of the Laurentian margin. These I-type granitoids are only known in the south-eastern portions of the Hagar Bjerg thrust sheet perhaps indicating that that part of the Laurentian continental margin was closest to the site of collision during the Grampian phase of arc accretion on the Laurentian margin. No similar rocks are known in the whole of the East Greenland orogen farther north.

Laurentia/Baltica Scandian collision (c. 430 Ma)

Continued closure of the Iapetus Ocean in the Scottish sector after the Grampian orogenic event was achieved by reversal of the polarity of oceanic subduction (Dewey and Ryan, 1990). The paleogeographic details of these latter stages of convergence and collision are complex and result from the collision and interaction of three continental blocks, namely Laurentia, Baltica and Avalonia (Soper and Hutton, 1984; Soper et al., 1992; van Staal et al., 1998).

Baltica-Laurentia collision is expressed in Scotland as the Scandian orogeny in the Northern Highlands. Regionally significant ductile thrusting and folding of the Moine rocks and associated basement inliers culminated in the development of the Moine Thrust Zone at *c.* 430 Ma, marking the boundary with the autochthonous-parautochthonous foreland rocks of the Northwest Highlands. The Moine Thrust Zone is therefore a comparable structure to the Caledonian sole thrust of East Greenland (Higgins and Leslie, 2000).

Scandian ductile thrusting and folding of the Moine Supergroup: Scandian thrust-related folding and fabric development was pervasive within the Moine rocks of west Sutherland, but was restricted to localized reworking of migmatites and structures in the east above the Naver Thrust (Strachan et al., 2002) (NT on Fig. 8). By analogy, and in the absence of any reliable isotopic evidence to the contrary, a Scandian age may be inferred for some of the movement on similar structures farther south in Ross-shire and Inverness-shire, including the Sgurr Beag Thrust (SBT on Fig. 8). The total displacement along these thrusts is uncertain, but is likely to be at least tens of kilometres and conceivably >100 km in the case of the Sgurr Beag Thrust (Powell et al., 1981). This places this structure in the same order of magnitude as the Hagar Bjerg thrust in East Greenland, with which it shares a similar structural level in a foreland propagating system (*cf.* Higgins et al., 2004). In Scotland, intense upright folding followed internal ductile thrusting and resulted in the structure referred to as the Northern Highland Steep Belt (Fig. 9; Strachan et al., 2002). Regional deformation was accompanied by amphibolite-facies Barrovian metamorphism (Strachan et al., 2002).

This regional scale foreland-propagating thrust system was responsible for the major interleaving of Moine rocks with Lewisian-type basement in Sutherland (Strachan et al., 2002). Many basement inliers occupy the cores of sheath and isoclinal folds along the trace of many of the major thrusts (Fig. 8). The trace of the Sgurr Beag Thrust through Ross-shire and northern Inverness-shire to Loch Hourn is commonly marked by allochthonous slices of basement (Tanner et al., 1970); these may have been derived from a rift shoulder within the Moine sedimentary basin (Tanner et al., 1970; Soper et al., 1998) in the same style as the modified rift shoulder of the Hekla Sund Basin in eastern North Greenland (Higgins et al., 2001b).

Moine Thrust Zone: The Moine Thrust Zone is the westernmost and youngest of the system of Scandian thrusts on the Scottish mainland (Fig. 8). Although localized Caledonian displacements may also have occurred along the Outer Isles Fault Zone farther to the west, the Moine Thrust Zone is generally taken to define the northwest edge of the Caledonian orogenic belt (Strachan et al., 2002). In this regard it is most likely to correlate in style and structural level with the Caledonian Sole thrust in East Greenland (Higgins et al., 2004; Leslie and Higgins, this volume) providing a suitable analogue for the margin of the orogen in that region.

The Moine Thrust Zone varies from a relatively simple planar structure to a complex array of interconnected thrust sheets (Plate 1A; Krabbendam and Leslie, 2004). Detailed analysis has shown that the thrusts generally developed in a foreland-propagating sequence, with successively younger and lower thrusts transporting older and higher thrusts to the WNW in 'piggyback' fashion (Elliott and Johnson, 1980; McClay and Coward, 1981; Butler, 1982). Early-formed thrusts within the foreland-propagating sequence are commonly folded as a result of the accretion of underlying thrust sheets. The simple pattern outlined above is complicated in some areas by later, low-angle 'out-of-sequence' faults which cut through previously thrust and folded strata (Holdsworth et al., 2006).

Rb-Sr and K-Ar dating of recrystallized micas within Moine mylonites suggests that emplacement of the Moine rocks onto the foreland occurred at *c.* 435–430 Ma (Johnson et al., 1985; Kelley, 1988; Freeman et al., 1998). This is consistent with the U-Pb zircon age of 430 ± 4 Ma obtained from the syn-tectonic Loch Borralan Complex within the Moine Thrust Zone in the Assynt area (van Breemen et al., 1979). However, isotopic ages as young as *c*. 408 Ma have been obtained from mylonites in the Dundonell area, leading to the suggestion that, locally at least, thrusting may have continued into the Early Devonian after the main Scandian collision (Freeman et al., 1998).

The direction of regional thrusting was towards 290°N (McClay and Coward, 1981). It is difficult to estimate the displacement on the Moine Thrust itself, but its association with a very thick belt of mylonites (up to 100 m) suggests that it is a major displacement zone with a minimum offset of many tens of kilometres. The construction of balanced sections drawn parallel to the direction of thrusting demonstrates a minimum slip across the thrust zone of 77 km (Elliott and Johnson, 1980), and Butler and Coward (1984) showed that the Cambrian shelf sequence can be restored for *c.* 54 km to the ESE. A total minimum displacement for the Moine Thrust Zone of around 100 km is therefore commonly accepted.

The Caledonian orogeny in East Greenland was the result of Silurian collision of Baltica with the margin of Laurentia. The structural record and architecture of that part of the orogen preserved onshore records that collision in a system of foreland-propagating thrust sheets, that were derived from the Laurentian margin and translated westwards across the orogenic foreland (Higgins and Leslie, 2000; Higgins et al., 2004a; Higgins and Leslie, this volume; Leslie and Higgins this volume). Restoration of thrusting indicates that the site of collision was probably several hundred kilometres east of the present day onshore preserved part of the orogen. The thickened orogen was already recording the effects of east-directed thinning and collapse towards the core of the orogen, as latest Silurian, Early Devonian orogen-parallel strike-slip deformation began to dominate, dissecting the orogenic welt along its axis.

Siluro-Devonian Magmatism

Mid-Silurian to Early Devonian (*c.* 430–400 Ma) subduction-related magmatism is recognised throughout the Highlands of Scotland (Stephenson et al., 1999, and references therein). Recent geochronological research indicates that emplacement of the majority of these granites in the Northern and Grampian Highlands is focussed around 427-425 Ma (Rogers and Dunning, 1991; Oliver, 2001; Fraser et al., 2004), an interval more or less synchronous with the final closure of the Iapetus Ocean in the late Wenlock (e.g. Stone et al., 1987, 1993; Soper et al., 1992; Torsvik et al., 1992).

Magmatism overlapped Scandian age deformation and the emplacement mechanism of many intrusions was structurally controlled, either by ductile thrusts or by the later strike-slip brittle faulting. Two main groups are recognised (Stephenson et al., 1999) (Fig. 8), the first represented by a series of small alkaline intrusions that occur in the northwest of Scotland, mainly in the Assynt area. The second and volumetrically more important is commonly referred to as the ‘Newer Granites’ (Read, 1961) although it includes a range of related rock types, including diorite, tonalite and granodiorite. Members of this group are present on both sides of the Great Glen Fault but are particularly common in the Grampian Highlands. The magmatism is represented by mainly I-type, high-K calc-alkaline rocks, some of which are shoshonitic (high-K and high-Mg) in nature. Early Devonian intrusions may have acted as feeders to volcanic sequences (Stephenson et al., 1999).

A subduction zone setting with derivation of magmas from the melting of mantle and/or lower crustal sources has been considered appropriate for both the alkaline and Newer Granite suites (Stephenson et al., 1999; Strachan et al., 2002). This is reinforced by the calc-alkaline nature of the Newer Granite suite, in particular the Devonian volcanic rocks (Thirlwall, 1981, 1982). The isotope characteristics of the Newer Granite suite (Halliday, 1984; Stephens and Halliday, 1984; Thirlwall, 1988), as well as the presence of inherited zircons that can only have been derived from older continental basement, indicate some crustal recycling (O'Nions et al., 1983; Harmon, 1983). However, it is also clear that a proportion of magma was derived from the subcontinental lithospheric mantle (Stephens and Halliday, 1984; Tarney and Jones, 1994; Fowler et al., 2001). This mantle-derived magma is represented by the mafic enclaves and appinites associated with some plutons, and also by the calc-alkaline lamprophyre dike swarms. Thus we conclude that the Newer Granites were derived mainly from the melting of lithospheric mantle and lower crustal sources and that melting was probably initiated by the introduction of fluids derived from a northward subducting oceanic slab into an overlying mantle wedge.

It should be noted however that the emplacement of the Newer Granites lags some 30 m.y. after the commencement of NW-directed subduction in the Middle–Late Ordovician at *c.* 460 Ma (Oliver, 2001). Onset of plutonism in the late Llandovery at *c.* 430 Ma coincided with the time when tectonics in the Southern Uplands of Scotland changed from orthogonal underthrusting to sinistrally oblique underthrusting (Stone, 1995). This change in plate kinematics may ultimately have resulted in development of the crustal scale sinistral wrench faults which are believed to have acted as fundamental controls on the locus of magma emplacement (Hutton and Reavy, 1992; Jacques and Reavy, 1994).

Kalsbeek et al. (this volume) relate the voluminous Silurian S-type Caledonian granites of the Central Fjord Region of East Greenland to partial fusion of fertile lithologies within a thickening Krummedal supracrustal sequence, most obviously during foreland-directed translation of the Hagar Bjerg thrust sheet. Formation of this granite magma occurred prior to and during emplacement of the major thrust units and subsequent collapse of the thickened orogen between 435 and 425 Ma. Orogenic collapse followed rapidly on foreland propagating thrusting linked to Laurentia-Baltica collision (Gilotti, this volume; Leslie and Higgins, this volume) and may reflect the same change in plate kinematics which triggered emplacement of the Scottish Newer Granites at *c.* 425 Ma.

Sinistral trantensional faulting in the Northern and Grampian Highlands

The main phase of mid-Silurian Scandian ductile thrusting was followed by sinistral strike-slip displacements along an array of NE-trending structures that dissect the Northern and Grampian Highlands (Fig. 2). Strike-slip faulting and ductile shear zones developed prior to and during the oblique collision of Avalonia and Baltica with Laurentia throughout the late Silurian to Early Devonian (Soper et al., 1992). Most developed prior to the onset of post-Caledonian Old Red Sandstone (Devonian) deposition (Watson, 1984; Mykura, 1991). The most prominent are the Great Glen-Walls Boundary and Highland Boundary faults along which hundreds of kilometres of displacement may have occurred (Dewey and Strachan, 2003).

Seismic reflection studies show that the Great Glen Fault is coincident with a subvertical structure which extends to at least 40 km depth (Hall et al., 1984). Silurian mantle-derived lamprophyre dikes appear to have different isotopic signatures on either side of the fault, suggesting that this structure has some expression in the upper mantle (Canning et al., 1996, 1998). Stewart et al. (1999) argued that blastomylonitic rocks preserved in the core of the fault zone may reflect the presence of an exhumed positive flower structure formed during sinistral transpression along the same zone of weakness. Relationships between fault zone structures, dated igneous intrusions and post-orogenic sedimentary rocks constrain the main sinistral displacement along the Great Glen Fault to the period between *c.* 428 Ma and *c*. 400 Ma (Stewart et al., 1999). Newer Granite plutonism was thus initiated broadly concurrently with the onset of major sinistral transtensional displacement. A lower age limit of *c*. 400 Ma is indicated by the low strain nature of Old Red Sandstone (upper Emsian?) sedimentary rocks within the fault zone. Post-Old Red Sandstone structures along the fault zone are invariably brittle in style, and fault products are typically incohesive, comprising clay fault gouge and poorly consolidated fault breccia (May and Highton, 1997; Stewart et al., 1999).

Although the timing of late Caledonian sinistral transtension is relatively well constrained, the magnitude of early displacement along the Great Glen Fault is less certain because there is no unambiguous correlation of pre-Devonian features across the fault. The general consensus (Strachan et al., 2002) is that sinistral strike-slip displacements along the Great Glen Fault are unlikely to have exceeded 200 – 300 km, although Dewey and Strachan (2003) later argued that a bare minimum of 700 km displacement is required if no Scandian deformation should be identified in the Grampian Highlands. The lower value is however consistent with the most reliable paleomagnetic evidence (Briden et al., 1984), the inferred offset of reflectors within the mantle lithosphere (Snyder and Flack, 1990), correlation between the Moine Supergroup and the Dava/Glen Banchor successions, and similarities in the timing of Neoproterozoic and Ordovician tectonothermal events either side of the fault (Bluck, 1995; Stewart et al., 1999; Highton et al., 1999; Rogers et al., 2001). The possibility remains that the Great Glen fault does not after all represent a terrane boundary (*sensu stricto*), and that a greater apparent discontinuity (including a contrast in crystalline basement properties) exists between the Midland Valley and Southern Uplands of Scotland along the trace of the present Southern Uplands Fault.

The present Highland Boundary Fault is a high-angle reverse fault that emplaced Dalradian rocks onto the Highland Border Complex and Old Red Sandstone rocks of the Midland Valley (Anderson, 1946; Bluck, 1984). Geophysical studies have shown that the fault is broadly coincident with a change in lower crustal structure (Bamford et al., 1978; Barton, 1992; Rollin, 1994) and this implies that the present structure may have reactivated an older and more fundamental structure. Various workers have speculated that this may correspond to the edge of the Laurentian craton (e.g. Soper and Hutton, 1984). Although late Silurian to Early Devonian sinistral displacements comparable with the Great Glen Fault have been commonly assumed (e.g. Harte et al., 1984; Soper and Hutton, 1984; Hutton, 1987; Soper et al., 1992), other workers have argued against major displacements (e.g. Hutchison and Oliver, 1998) and thus the regional tectonic significance of this fault is uncertain.

In central East Greenland, mid-Devonian continental sediments were deposited on the eroded Caledonian orogen; sedimentation was controlled, in part, by sinistral displacements along the Western fault zone (Larsen and Bengaard, 1991; Olsen, 1993). Larsen and Bengaard (1991) tentatively linked the Western fault zone with the Storstrømmen Shear Zone to the north and with the Great Glen Fault to the south. Dewey and Strachan (2003) argued that relative motion between Laurentia and Avalonia/Baltica changed from sinistrally transpressive collision at about 425 Ma to more orogen parallel sinistrally transtensional movements which persisted until *c.* 400 Ma and were terminated, in Britain, by the brief Acadian Orogeny (Soper and Woodcock, 2003). Dewey and Strachan (2003) argue that the Great Glen Fault would have been the principal structure on which sinistral displacement was accommodated in the Scottish sector of the orogen, linked northward via the Walls Boundary Fault in Shetland into East Greenland as the Western fault zone.

Similar translations have been proposed to explain the juxtaposition of the separate terranes identified in Svalbard (e.g. Soper et al., 1992; Harland, 1997). Gee and Teben'kov (2004) proposed an alternative interpretation which minimises the scale of strike-slip displacement and, if proven, might argue that displacement on the major strike-slip fault systems transecting the Scottish Caledonides should be of a similar dimension, i.e. < 200 km.

A TEMPLATE FOR COMPARISON OF IAPETAN RIFTING AND CALEDONIAN OROGENESIS IN THE SCOTLAND – GREENLAND SECTOR OF LAURENTIA

The Iapetan geological record of Scotland constrains the establishment of the Laurentian passive margin and, culmination of the two-stage breakout of Laurentia from the supercontinent Rodinia. The uppermost Neoproterozoic to lower Paleozoic Scottish successions record proximity to a RRR junction (Soper, 1994a) and by late Neoproterozoic (Ediacaran) time, the 'Scottish Corner' may have resembled a patchwork of marginal plateaux or continental ribbons extending some 1000 km or more along the margin (Fig. 9), similar in style to the paleogeography proposed by Waldron and van Staal (2001) and Cawood et al. (2001) for the Newfoundland sector. The geological map of the UK-Faroes sector of the present day continental shelf comprises a framework of inter-locking depocentres (Hatton, Rockall and Porcupine basins) and structural basement highs (Rockall and Porcupine highs) and provides a good modern analogue for an late Neoproterozoic paleogeography of the 'Scottish Corner' of Laurentia.

In contrast, the lithostratigraphy of East Greenland can be traced continuously over considerable distances along strike along the original depositional margin. A general absence of volcanic activity suggests that the East Greenland sector may have lain (dependent upon stretching rates) at some distance from any focus of Iapetan volcanism (Fig. 1). There is systematic thickening of the successions from inboard to outboard positions in the sector and the pattern of N-S facies belts configures a slowly subsiding but relatively stable continental margin which must have extended beyond and included northeastern Svalbard at this time (Gee and Teben'kov, 2004).

In the following sections we provide a dynamic synthesis of the geological evolution of the Scottish sector of Laurentia (the 'Scottish Corner') through a complete Wilson Cycle encompassing the opening and closure of the Iapetus Ocean. The synthesis reflects the authors' stance in regard to the wealth of new and archive data available to geologists studying the evolution of the Scottish and East Greenland Caledonides.

Cycle I – Early (Failed) Cryogenian Rifting

Mid-Cryogenian rifting on the 'Scottish Corner' probably initiated post-730 Ma and then lasted for 60–70 m.y. with post-rift thermal subsidence extending for another *c.* 50 m.y. or so towards the end of the Cryogenian. Turbiditic sands and muds of the Grampian Group, derived from a hinterland to the west and northwest, infilled a series of basins (Banks, 2005) whose distribution and depositional geometry are constrained by the position, and uplift history, of discrete intrabasinal highs, e.g. Robertson and Smith (1999). These localised basins were infilled by the time progradational shelf sands extended from the south and east across these early (presumably failed) rifts and their margins in the upper Grampian Group. The continued sand and mud-dominated sedimentary facies associations of this first cycle culminated with diminished sediment input into marginal offshelf to lagoonal, locally emergent, even evaporitic environments as recorded in the lowermost Appin Group (Lochaber Subgroup) (Stephenson and Gould, 1995).

In Greenland, the contemporaneous Nathorst Land Group appears to reflect a more gradual and widely distributed subsidence with no sign of localised depocentres (Smith and Sønderholm, this volume). The correlation proposed here at significant flooding surfaces (Fig. 6) may signify short lived enhanced stretching which affected all of this part of Laurentia. Active stretching probably advanced northwards from the vicinity of the 'Scottish Corner' towards East Greenland, perhaps linking with an active rift system encroaching from the north.

Cycle I – Sag

A major margin-wide transgression across a flooding surface marks the base of the Ballachulish Subgroup in Scotland and the Ymer Ø Group in East Greenland (Fig. 6). Flooding saw the onset and development of wide-ranging and uniform sedimentary lithofacies. Typically, deposition of dark anoxic limestone and mud is followed by shallowing upwards cycles of progadational clean-washed sands and shallow water muds and limestones (Stephenson and Gould, 1995). Basins at this time were probably wide and shallow as evidenced by remarkably similar successions along strike extending across Ireland and Scotland and with tentative correlations possible at formation level across Greenland into the Hekla Sund basin of eastern North Greenland (Fig. 6). Renewed flooding (eustatic change?) heralds deposition of further muds and limestones (Blair Atholl Subgroup in Scotland and the Andreé Land Group in East Greenland) before 'Marinoan' diamictites are deposited during a major lowstand at *c.* 635 Ma. In the Southern Grampian Highlands, some parts of these basins were interspersed with sediment starved areas now expressed as major stratigraphical omission and subsequent overstep (BGS, unpublished data).

Cycle II – Renewed rifting to rift-drift transition in the Ediacaran

Renewed and vigorous extension is recorded by rifting in the Scottish Dalradian in early Ediacaran time. Contemporaneous mafic volcanism marks the transition to Iapetan rift-drift. Sharply-defined thickness changes become apparent in the Islay Subgroup depositional record and are most-likely fault controlled (Anderton, 1985). The upwards shallowing cyclical behavior recorded previously begins to repeat again in the Easdale Subgroup, albeit in an increasingly unstable, but still essentially shallow marine, on-shelf environment with deposition of quartzitic sands, limestones and muds. Instability is recorded in influxes of pebbly sands (Stephenson and Gould, 1995). Localised volcanigenic centres become a feature of this sector of the margin with punctuated episodes of mafic volcanism (Goodman and Winchester, 1993; Macdonald et al., 2005).

Sediment starved sectors in Scotland are only overstepped at this later stage (BGS, unpublished data) and a more rapidly foundering rift system (Crinan Subgroup) evolves, accumulating debris flows and slumps (Stephenson and Gould, 1995). Incipient volcanic spreading centres located mainly in the southwest (Tayvallich Subgroup, Fig. 6) give way to organised turbiditic submarine fans (Southern Highland Group) as final rupture occurs and this sector of Iapetus begins to widen. The major change to more immature sediment, increasingly dominated by Archean detritus, occurs at the base of the Crinan Subgroup and persists on through the Southern Highland Group as separation occurs (rift-drift transition) and the foundering margin evolves towards a stable passive margin by Cambro-Ordovician time. Laurentian fauna (*Pagetia*) contained within the uppermost, youngest Dalradian strata (Tanner, 1995) and conodont assemblages in the Durness Group (Wright and Knight, 1995) place the ‘Scottish Corner’ firmly on the Laurentian margin.

Erosion of the upper formations of the Eleonore Bay Supergroup to provide clasts in the latest Cryogenian to early Ediacaran (Marinoan) Tillite Group indicates pre-Tillite Group uplift but it is not clear whether the absence of any younger Ediacaran deposits merely records lack of supply and non-deposition or that extensional rifting and block tilting removed any sediment accumulation prior to deposition of the Cambrian succession (Smith et al., 2004; Smith and Sønderholm, this volume; Smith et al., this volume). Any accumulations may have been scavenged from this relatively stable, non-volcanic marginal platform into the active and volcanic rifts on the ‘Scottish Corner’.

Figure 9 presents a summary of how the Scottish sector may have looked at this time. Rifting leading to separation has just occurred at around 600 Ma; fragments of the continental margin have now broken away and Iapetan spreading ridges are active off to the lower right of the cartoon. Relative to the central parts of the Grampian and the southwest Scottish Highlands, we speculate that Connemara in western Ireland may have constituted a marginal plateau or ribbon while the Moray-Buchan area of northeast Scotland may have constituted a subdued marginal platform. The newly established peri-Laurentian trough receives a deluge of submarine debris flows (Crinan Subgroup) with localised volcanic centres building out volcanoclastic deltas. Carbonate build-ups are reworked from the shelf into deeper water as redeposited metacarbonate rocks in the Tayvallich Subgroup (Thomas et al., 2004). Submarine fans prograde from the margin into the trough and may extend along the trough axis, spilling out onto adjacent marginal platforms. Deltaic volcanoclastic debris is reworked along the margin as ‘greenbeds’ in the Southern Highland Group (Pickett et al., 2006). The extensional geometry of the various components of this architecture must of necessity be speculative, possible cross-section configurations are incorporated in the model of Figure 9. We can suggest however that these geometries subsequently exerted control on the collisional geometry and acted as nuclei for deformation structures during arc accretion in the Grampian Orogeny.

The analogue model of Figure 9 can be extended to include the East Greenland sector of the Laurentian margin. Although late Neoproterozoic extension may locally have affected the inboard portion of North-East Greenland (e.g. in the Målebjerg region, Leslie and Higgins, 1998; Leslie and Higgins, this volume), the lack of volcanism and persistent shallow marine shelf depositional environments imply a broad, gradually subsiding continental platform where subsidence rate was broadly matched by sediment influx, at least until the late Cryogenian. The Hekla Sund basin of eastern North Greenland preserves evidence of the northward change into to a more active, but non-volcanic, extensional setting on Laurentia, in the Cryogenian at least.

Evolution to a Cambro-Ordovician passive margin

By Cambro-Ordovician time, a broad carbonate platform was established along the continental margin of Laurentia facing the Iapetus Ocean. Orthoquartzite/carbonate successions which accumulated in this period are recognised all along the length of the Caledonian fold belt in East Greenland (Higgins et al., 2001a), across the far northwest of Scotland, and through Newfoundland and the Appalachians (see compilation in Dewey and Mange, 1999). Whether or not Cambro-Ordovician shelf, shelf-slope and rise successions either did (Dewey, 1969) or did not (Bluck et al., 1997) continuously extend across Scotland from the Laurentian foreland into the deeper water environments of the Cambrian upper Dalradian of the Southern Grampian Highlands has been a matter of debate. Some support for the former position comes however from reconstructions of the Newfoundland margin (Waldron and van Staal, 2001) and from East Greenland (Leslie and Higgins, 1998, this volume) and the new work of Tanner and Sutherland (2007) now resolves the matter in the Scottish sector. Analogues for the Cambro-Ordovician successions of the Highland Border Series are perhaps to be found in later pelagic passive margin sedimentation on a fragmented continental margin (Stoker et al., 2001) and which would accumulate in the troughs featured in the model of Figure 9.

Grampian Arc Accretion

Figure 10a illustrates our Early Ordovician (Tremadoc–Arenig) reconstruction of the Scottish sector of Laurentia. Cryogenian siliciclastic detritus has built out a progradational sedimentary prism, drowning in the process such intra-basinal structural features as the Glen Banchor ‘basement high’ (Robertson and Smith, 1999, GB on Fig. 10a). Ediacaran (*c*. 600 Ma) intrusion of extension-related bimodal magmatism (Tanner et al., 2006) into the expanding sediment prism is represented by the Ben Vuirich Granite Pluton and the Tayvallich Volcanics Formation (BV and TV on Fig. 10a respectively). The Cambro-Ordovician Durness Group represents major marine transgression onto the subsiding continental margin while deeper water contemporaneous successions accumulated on the Laurentian continental slope and rise (upper Dalradian Leny Limestone). Intra-oceanic obduction and accretion is under way by this time (Bluck, 2001) with the Midland Valley Arc beginning to encroach upon the Laurentian continental margin.

By Arenig-Llanvirn time, the Midland Valley Arc (MVA on Fig. 10b) has been accreted onto the continental margin. The arc is partly underthrust on the margin such that a zone of top-to-the-south or south-east non-coaxial simple shear formed in the lower structural levels of the Tay Nappe as recorded in the southern Scottish Highlands (Krabbendam et al., 1997). SE-facing extensional fault blocks on the ruptured continental margin (Fig. 9) would have rotated and steepened toward the interior of the orogenic wedge underneath the developing nappe (HB on Figure 10a). Syn-tectonic mafic and calc-alkaline felsic magmas emplaced into the thickening orogenic pile at *c.* 470 Ma (Friedrich et al., 1999) probably formed as a consequence of the suborogenic heating as the subducting oceanic crust detached southeastwards beneath the accreting magmatic arc (Dewey and Mange, 1999). The Grampian front clearly extended into the Moinian rocks of the Northern Highlands of Scotland (Dallmeyer et al., 2001) and crustal flexure at this time (*c.* 460 Ma) would have ended shallow water carbonate deposition on the continental platform.

No widespread evidence of Ordovician arc accretion survives in East Greenland, the terranes involved in collision being transported eastwards and incorporated into the higher structural levels of the Scandinavian Caledonides (Yoshinobu et al., 2002).

With rapid uplift and erosion of the thickened orogenic wedge post-dating the Grampian metamorphic peak (*c.* 465 Ma), Grampian age metamorphic detritus was dispersed across the accreted arc (or arcs) and supplied to an accretionary wedge facing the narrowing Iapetus Ocean. In Scotland, such detritus appears in the sedimentary record of the Southern Uplands accretionary prism in the Caradoc (Oliver, 2001). However, the system of large scale strike-slip displacements which affect this sector of the closing Iapetus in the Siluro-Devonian (*c.* 425-400 Ma) mean that the Late Ordovician/early Silurian sediment dispersal pathways cannot now be determined but are likely to have incorporated considerable distances along the orogenic belt.

Laurentia/Baltica Collision

Baltica collided with the East Greenland sector of Laurentia by late Llandovery/early Wenlock time. The reconstruction of Figure 10b and c speculates that the Scottish sector would also have experienced oblique collision with parts of Baltica. Post metamorphic peak exhumation of the Grampian orogenic wedge was largely complete and the lower inverted limb of the Tay Nappe had by now formed the flat belt identified in the cross-section in Figure 8. In contrast, Scandian nappe stacking dominated the structural architecture of the Northern Highlands of Scotland and the East Greenland Caledonides. One possible view is that the Grampian Highlands may thus have formed a relatively rigid block entrained between the contractional deformation zones at the leading edges of the colliding Laurentian and Baltican plates. At *c.* 425 Ma in the mid-to-late Silurian, large volumes of felsic magma were intruded into the Grampian and Northern Highlands and partitioned sinistral transtensional stresses began to replace early Silurian oblique convergence and transpression as evidenced by movements along the Great Glen (Stewart et al., 1999), Highland Boundary and Southern Upland faults. Juxtaposition of the present-day Southern Uplands region with the Midland Valley and Scottish Highlands was largely achieved at this time as “Scottish” Laurentia and Avalonia were now juxtaposed along WSW-ESE strike-slip systems, expressed today in the Southern Uplands Fault (see *c.* 410 Ma inset on Fig. 10c). Major pull-apart and extension in the more north-south trending tracts of the Caledonian suture between “East Greenlandic” Laurentia and western Baltica may have initiated the Early Devonian eclogite exhumation processes in the Western Gneiss Region of Norway and the eclogite-bearing terrain of East Greenland (Krabbendam and Dewey, 1998; *cf.* Gillotti et al., this volume). Evidence for orogenic collapse in the Scottish sector is possibly represented by the depositional architecture and deformation of the Old Red Sandstone (Middle Devonian) Orcadian basin in Orkney and Shetland (Seranne, 1992), and the top-to-the-NE-directed shear fabrics recorded in the Shetland Ophiolite Complex and the metasedimentary successions of Unst and Fetlar in NE Shetland (Cannat, 1989). NE-vergent extension in Shetland is opposite to the SW-vergent extension and exhumation of the Western Gneiss Region in Norway (Krabbendam and Dewey, 1998) and suggests perhaps an internal zone of collapse towards to the interior of the Caledonian orogen.

Conclusions and Future Research

A number of key observations and conclusions emerge.

1. By *c.* 1.9 Ga, the ancient basement of Scotland and Greenland lay within a continuous accretionary belt comprising various Archean cratonic components welded together during the assembly of Laurentia and Baltica. Calc-alkaline magmatism concentrated along a new active margin is represented by the *c.* 1.9–1.85 Ga Makkovik/Ketilidian belt of Labrador and South Greenland, juvenile Proterozoic crust forming at *c.* 1.78 Ga in the Rhinns Complex in Scotland, and the 1.85–1.50 Ga Labradorian-Gothian belt of NE Canada and SW Scandanavia.

2. Early Neoproterozoic fluvial red-bed successions (Torridon Group) buried deeply eroded Archean-Paleoproterozoic basement rocks in the foreland to the Caledonian orogen in Scotland; no comparable sediments are known in East Greenland.

3. Late Mesoproterozoic to early Neoproterozoic siliciclastic successions are widespread in Greenland (Krummedal supracrustal succession), NW Scotland (Moine Supergroup) and in the eastern province of Spitsbergen (Brennevinsfjorden Group). These successions are almost entirely marine deposits and indicate that a depocentre, or interconnected depocentres, may have extended over several thousand square kilometres along the Laurentian margin during this time. Since no equivalent of the early Neoproterozoic Torridon Group fluvial red-bed system seems to have been present at the paleolatitude represented by East Greenland, we conclude that it is possible that the Krummedal succession may represent a northward continuation of marine dispersal of parts of the Moine succession.

4. Three episodes of early to mid-Neoproterozoic orogenesis (*c.* 930 Ma, *c.* 820 Ma, *c.* 730 Ma) are recorded in the Scottish and Greenlandic sectors of Laurentia, each separated by *c.* 100 Ma. The Rodinian supercontinent was undergoing late-stage amalgamation during this time and so intracratonic movements accommodating extension and compressional deformation may be required to account for these orogenic events (e.g. Cawood et al., 2004; Emery et al., in press).

5. In Scotland, the mid-Neoproterozoic to mid-Cambrian Dalradian Supergroup was deposited in an evolving pericontinental environment over a period of *c.* 180 – 200 m.y. Fluctuations in water depth accompanied active rifting and the development of second and third order sub-basins on this sector of the Laurentian margin. In East Greenland, farther north on that same margin, the broadly time equivalent Eleonore Bay Supergroup, and overlying Tillite Group and Kong Oscar Fjord Group record no active rifting and contain no evidence of contemporaneous volcanic activity. East Greenland strata record shelf and ramp sedimentation which was probably punctuated by significant periods of non-deposition on a slowly subsiding passive margin. Farther north still, the Neoproterozoic Hekla Sund Basin represents another locus of rifting activity in eastern North Greenland. The youngest units of the Dalradian Supergroup in Scotland record rapid basin deepening that persistently stayed ahead of the sedimentary and volcanic basin fill. No apparent match for these immature turbidite-dominated sedimentary facies associations occurs anywhere along the Greenland sector of Laurentia.

6. The NW Highlands Cambro-Ordovician succession of Scotland apparently represents an intermediate position on the slowly subsiding Laurentian carbonate platform which lay between more inboard and more outboard environments each of which are represented by the Cambrian–Ordovician succession in East Greenland.

7. Mid-Ordovician Grampian orogenesis affected all of the Dalradian and older rocks of the Grampian Highlands as well as parts of the Moine Supergroup in the Northern Highlands. This phase records the convergence of the Laurentian continental margin with an intra-oceanic subduction zone and volcanic arc. There is, in contrast, scant evidence in the East Greenland Caledonides (or in Svalbard), of these short-lived lower Paleozoic marginal arcs and basins that must have accommodated subduction of Iapetan oceanic crust and convergence with Baltica.

8. Baltica-Laurentia collision is expressed in Scotland and East Greenland as the Scandian Orogeny. Regional-scale ductile thrusting and folding of the Moine rocks in the Northern Highlands of Scotland culminated in the development of the Moine Thrust Zone at *c.* 430 Ma, marking the boundary with the autochthonous-parautochthonous foreland rocks of the Northwest Highlands. The Moine Thrust Zone is therefore a comparable structure to the Caledonian sole thrust of East Greenland. Restoration of the system of foreland-propagating thrust sheets derived from the Laurentian margin and translated westwards across the orogenic foreland in East Greenland indicates that the site of collision was probably several hundred kilometres east of the present day onshore preserved part of the orogen.

9. Mid-Silurian to Early Devonian (*c*. 430 – 400 Ma) subduction-related magmatism is recognised throughout the Highlands of Scotland (Stephenson et al., 1999, and references therein). Kalsbeek et al. (this volume) relate the voluminous Silurian S-type Caledonian granites of this age in the central fjord region of East Greenland to partial fusion of fertile lithologies as a consequence of crustal thickening, most obviously during foreland-directed translation Hagar Bjerg thrust sheet.

10. The present distribution of Caledonian domains across the northern Atlantic region is in part a consequence of the transtensional shearing which resulted from relative lateral motion of the two large continental segments (Laurentia and Baltica) after their respective continental margins were in contact and subduction of oceanic crust had ceased. Sinistral wrench faults dissect the Caledonian orogen of both Scotland and East Greenland.

Together, East Greenland and Scotland preserve a partial 350 m.y. record of deposition and rifting leading towards opening and spreading of the Iapetus Ocean, and then of the arc accretion and continent-continent collision which consumed Iapetus. While the 'Scottish Corner' is undoubtedly geologically fascinating, and perplexing, these authors have found it hugely rewarding to work on the bigger scale. We present this overview as a comparative synopsis of our present understanding of the Scottish and East Greenlandic orthotectonic sectors of the Caledonian Orogen and as an encouragement to future researchers to address issues of diachroneity in otherwise similar events and strive for better understanding of the "big picture". The tentative (tectono)stratigraphical links correlations proposed here must be tested further. Many of those answers will lie in systematic analysis of Caledonian geology around the North Atlantic region, linking Scandanavia, Svalbard, Greenland, Scotland, Labrador and Norway.

Acknowledgements: MS and AGL publish with the permission of the Director of the British Geological Survey. Constructive comments and criticism was gratefully received from P. Cawood and from an anonymous referee.

REFERENCE LIST

Aleinikoff, J.N., Zartman, R.E., Walter, M., Rankin, D.W., Lyttle, P.T. and Burton, W.C., 1995, U-Pb ages of metarhyolites of the Catoctin and Mount Rogers formations, Central and Southern Appalachians: evidence for two pulses of Iapetan rifting: American Journal of Science, v. 295, p. 428-454.

Alsop, G.I., Prave, A.R., Condon, D.J. and Phillips, C.A., 2000, Cleaved clasts in Dalradian conglomerates: possible evidence for Neoproterozoic compressional tectonism in Scotland and Ireland?: Geological Journal, v. 35, p. 87-98.

Anderson, J.G.C., 1946, The geology of the Highland Border: Stonehaven to Arran: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 61,p. 479-515.

Anderton, R., 1985, Sedimentation and tectonics in the Scottish Dalradian: Scottish Journal of Geology, v. 21, p. 407-436.

Andréasson, P.G., Gee, D.G., Whitehouse, M.J. and Schoberg, H., 2003, Subduction-flip during Iapetus Ocean closure and Baltica-Laurentia collision, Scandinavian Caledonides: Terra Nova, v. 15, p. 362-369.

Badger, R.L. and Sinha, A.K., 1988, Age and Sr isotopic signature of the Catoctin volcanic province: implications for subcrustal mantle evolution: Geology, v. 16, p. 692-695.

Bailey, C.M. and Tollo, R.P., 1998, Late Neoproterozoic extension-related magma emplacement in the Central Appalachians: An example from the Polly Wright Cove pluton: Journal of Geology, v. 106, p. 347-359.

Bamford, D., Nunn, K., Proedehl, C. and Jacob, B., 1978, LISPB-IV. Crustal studies of northern Britain: Geophysical Journal of the Royal Astronomical Society, v. 54, p. 43-60.

Banks, C.J., 2005, Neoproterozoic basin analysis: a combined sedimentological and provenance study in the Grampian Group, Central Highlands, Scotland: PhD thesis, University of Keele, unpublished.

Banks, C.J. and Winchester, J.A., 2004, Sedimentology and stratigraphic affinities of Neoproterozoic coarse clastic successions, Glenshirra Group, Inverness-shire, Scotland: Scottish Journal of Geology, v. 40, p. 159-174.

Barton, P.J., 1992, LISPB revisited: a new look at the Caledonides of northern Britain: Geophysical Journal International, v. 110, p. 371-391.

Bingen, B., Demaiffe, D. and Van Breemen, O., 1998, The 616 Ma old Egersund basaltic dyke swarm, SW Norway, and late Neoproterozoic opening of the Iapetus Ocean: Journal of Geology, v. 106, p. 565-574.

Bingen, B., Griffin, W.L. Torsvik, T.H. and Saeed, A., 2005, Timing of late Neoproterozoic glaciation on Baltica constrained by detrital zircon geochronology in the Hedmark Group, south-east Norway: Terra Nova, v. 17, p. 250-258.

Bluck, B.J., 1983, Role of the Midland Valley of Scotland in the Caledonian Orogeny: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 74, p. 275-295.

Bluck, B.J., 1984, Pre-Carboniferous history of the Midland Valley of Scotland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 75, p. 275-295.

Bluck, B.J., 1995,. W.Q. Kennedy, the Great Glen Fault and strike-slip motion. In: Le Bas, M.J. (ed.) Milestones in geology: Geological Society, London, Memoir, v. 16, p. 57-65.

Bluck, B.J., 2001, Caledonian and related events in Scotland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 91, p. 375-404.

Bluck, B.J., 2002, The Midland Valley Terrane. In: Trewin, N.H. (ed.) The Geology of Scotland: The Geological Society, London, p. 149-166.

Bluck, B.J., Dempster, T.J. and Rogers, G., 1997, Allochthonous metamorphic blocks on the Hebridean passive margin, Scotland: Journal of the Geological Society, London, v. 154, p. 921-924.

Bowring, S., Myrow, P., Landing, E., Ramezani, J. and Grotzinger, J, 2003, Geochronological constraints on Terminal Neoproterozoic events and the rise of metazoans: Geophysical Research Abstracts v. 5, p. 13219.

Brasier, M.D. and Shields, G., 2000, Neoproterozoic chemostratigraphy and correlation of the Port Askaig glaciation, Dalradian Supergroup of Scotland: Journal of the Geological Society, London, v. 157, p. 909-914.

Brasier, M.D., McCarron, G., Tucker, R., Leather, J., Allen, P. and Shields, G, 2000, New U-Pb zircon dates for the Neoproterozoic Ghubrah glacaiation and for the top of the Huqf Supergroup, Oman: Geology, v. 28, p. 175-178.

Briden, J. C., Turnell, H. B. and Watts, D. R., 1984, British paleo-magnetism, Iapetus Ocean and the Great Glen Fault: Geology, v. 12, p. 136-139.

Bridgwater, D., Campbell, L., Mengel, F., Marker, M. and Scott, D., 1996, The Nagssugtoqidian of West Greenland in the light of comparative studies of juvenile components in the Palaeoproterozoic Torngat, SE Greenland Nagssugtoqidian, and Lapland-Kola 'collisonal' belt: Proceedings of the 2nd DLC Workshop on Nagssugtoquidian Geology, Danish Lithosphere Centre, Copenhagen, p. 8-19.

British Geological Survey, 2002, Solid Geological Map, Sheet 63E (Dalwhinnie). 1:50 000: (Keyworth, Nottingham: British Geological Survey.)

British Geological Survey, 2004, Solid Geological Map, Sheet 74W (Tomatin). 1:50 000: (Keyworth, Nottingham: British Geological Survey.)

Buchan, K. L., Mertanen, S., Park, R. G., Pesonen, L. J., Elming, S. A., Abrahamsen, N. and Bylund, G., 2000, Comparing the drift of Laurentia and Baltica in the Proterozoic: the importance of key palaeomagnetic poles: Tectonophysics, v. 319, p. 167-198.

Burt, E.C., 2003, Sedimentology, provenance and basin evolution of the upper Dalradian:Tayvallich Subgroup and the Southern Highland Group: PhD Thesis, Kingston University, unpublished.

Butler, R.W.H., 1982, The terminology of structures in thrust belts: Journal of Structural Geology, v. 4, p. 239-245.

Butler, R.W.H., 1997, Late Proterozoic rift faults and basement-cover relationships within the Ben More thrust sheet, NW Scotland: Journal of the Geological Society, London, v. 154, p. 761-764.

Butler, R.W.H. and Coward, M. P., 1984, Geological constraints, structural evolution and deep geology of the NW Scottish Caledonides: Tectonics, v. 3, p. 347-365.

Cambridge Paleomap Services, 1998, Timetrek v.3.11. Cambridge: Cambridge Paleomap Services.

Cannat, M., 1989, Late Caledonian northeastward ophiolite thrusting in the Shetland Islands, UK: Tectonophysics, v. 169, p. 257-270.

Canning, J.C., Henney, P.J., Morrison, M.A. and Gaskarth, J.W, 1996, Geochemistry of late Caledonian minettes from northern Britain: implications for the Caledonian sub-continental lithospheric mantle: Mineralogical Magazine, v. 60, p. 221-236.

Canning, J.C., Henney, P.J., Morrison, M.A., Van Calsteren, P.W.C., Gaskarth, J.W. and Swarbrick, A., 1998, The Great Glen Fault: a major vertical lithospheric boundary: Journal of the Geological Society, London, v. 155, p. 425-428.

Cawood, P.A. and Pisarevsky, S.A., 2006, Was Baltica right-way-up or upside-down in the Neoproterozoic?: Journal of the Geological Society, London. v. 163, p. 753-759.

Cawood, P.A., McCausland, P.J.A. and Dunning, G.R., 2001, Opening Iapetus: Constraints from the Laurentian margin in Newfoundland: Geological Society of America Bulletin, v. 113, p. 443-453.

Cawood, P.A., Nemchin, A.A., Smith, M. and Loewy, S., 2003, Source of the Dalradian Supergroup constrained by U-Pb dating of detrital zircon and implications for the East Laurentian margin: Journal of the Geological Society, London. v. 160, p. 231-246.

Cawood, P.A., Nemchin, A.A., Strachan, R.A., Kinny, P.D. and Loewy, S., 2004, Laurentian provenance and an intracratonic tectonic setting for the upper Moine Supergroup, Scotland, constrained by detrital zircons from the Loch Eil and Glen Urquhart successions: Journal of the Geological Society, London. v. 161, p.861-874.

Condon, D. J. and Prave, A.R., 2000, Two from Donegal: Neoproterozoic glacial episodes on the northeast margin of Laurentia: Geology, v. 28, p. 951-954.

Coward, M.P. and Park, R .G., 1987, The role of mid-crustal shear zones in the Early Proterozoic evolution of the Lewisian. In: Park, R.G. and Tarney, J. (eds.) Evolution of the Lewisian and Comparable Precambrian High Grade Terrains: Geological Society, London, Special Publications, No. 27, p. 127-138.

Corfu, F., Crane, A., Moser, D. and Rogers, G., 1998, U-Pb zircon systematics at Gruinard Bay, northwest Scotland: implications for the early orogenic evolution of the Lewisian Complex: Contributions to Mineralogy and Petrology, v. 133, p. 329-345.

Dalziel, I.W.D., 1992, On the organization of American plates in the Neoproterozoic and the breakout of Laurentia: GSA Today, v. 2, p. 237 and 240-241.

Dalziel, I.W.D. and Soper, N.J., 2001, Neoproterozoic extension on the Scottish promontory of Laurentia: Paleogeographic and tectonic implications: Journal of Geology, v. 109, p. 299-317.

Dallmeyer, R.D., Strachan, R.A., Rogers, G., Watt, G.R. and Friend, C.R.L., 2001, Dating deformation and cooling in the Caledonian thrust nappes of north Sutherland, Scotland: insights from ^{40}Ar/^{39}Ar and Rb-Sr chronology: Journal of the Geological Society, London, v. 158, p. 501-512.

Dempster, T.J., Rogers, G., Tanner, P.W.G., Bluck, B.J., Muir, R.J., Redwood, S.D., Ireland, T. R. and Paterson, B.A., 2002, Timing of deposition, orogenesis and glaciation within the Dalradian rocks of Scotland: constraints from U-Pb zircon ages: Journal of the Geological Society, London, v. 157, p. 909-914.

Dewey, J.F., 1969, Evolution of the Caledonian/Appalachian orogen: Nature, London, v. 222, p. 124-129.

Dewey, J.F. and Mange, M., 1999, Petrography of Ordovician and Silurian sediments in the western Irish Caledonides: tracers of a short-lived Ordovician continent-arc collision orogeny and the evolution of the Laurentian Appalachian - Caledonian margin. In: MacNiocaill, C. and Ryan, P. D. (eds.) Continental Tectonics: Geological Society, London, Special Publications, No. 164, p. 55-107.

Dewey, J.F. and Ryan, P.D., 1990, The Ordovician evolution of the South Mayo Trough, Western Ireland: Tectonics, v. 9, p. 887-903.

Dewey, J.F. and Strachan, R.A., 2003, Changing Silurian-Devonian relative plate motion in the Caledonides: sinistral transpression to sinistral transtension: Journal of the Geological Society, London, v. 160, p. 219-229.

Dickin, A.P., 1992, Evidence for an Early Proterozoic crustal province in the North Atlantic region: Journal of the Geological Society, London, v. 149, p. 483-486.

Downie, C., 1982, Lower Cambrian acritarchs from Scotland, Norway, Greenland and Canada: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 72, p.257-285.

Elliott, D. and Johnson, M.R.W., 1980, Structural evolution in the northern part of the Moine thrust belt, NW Scotland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 71, p. 69-96.

Emery, M., Friend, C.R.L., Kinny, P.D., Strachan, R.A. and Leslie, A.G. (in press), Metamorphic evolution and geochronology of Moine migmatites in Glen Urquhart, Inverness-shire: further evidence for Neoproterozoic (Knoydartian) orogenesis in the Scottish Highlands: Journal of the Geological Society, London.

Flinn, D., Miller, J.A. and Roddom, D., 1991, The age of the Norwick hornblende schists of Unst and Fetlar and the obduction of the Shetland ophiolite: Scottish Journal of Geology, v. 27, p. 11-19.

Fowler, M.B., Henney, P.J., Darbyshire, D.P.F. and Greenwood, P.B., 2001, Petrogenesis of high Ba-Sr granites: the Rogart Pluton, Sutherland: Journal of the Geological Society, London, v. 158, p. 521-534.

Fraser, G.L., Pattison, D.R.M. and Heaman, L.M., 2004, Age of the Ballachulish and Glencoe Igneous Complexes (Scottish Highlands), and paragenesis of zircon, monazite and baddeleyite in the Ballachulish Aureole: Journal of the Geological Society, London, v. 161, p. 447-462.

Frederiksen, K.S., 2001, A Neoproterozoic carbonate ramp and base-of-slope succession, the Andrée Land Group, Eleonore Bay Supergroup, North-east Greenland: sedimentary facies, stratigraphy and basin evolution: PhD thesis, University of Copenhagen.

Freeman, S.R., Butler, R.W.H., Cliff, R.A. and Rex, D.C., 1998, Direct dating of mylonite evolution: a multi-disciplinary geochronological study from the Moine thrust zone, NW Scotland: Journal of the Geological Society, London, v. 155, p. 745-758.

Friedrich, A.M, Hodges, K.V., Bowring, S.A. and Martin, M.W., 1999, Geochronological constraints on the magmatic, metamorphic and thermal evolution of the Connemara Caledonides, western Ireland: Journal of the Geological Society, London, v. 156, p. 1217-1230.

Friend, C.R.L. and Kinny, P.D., 1995, New evidence for protolith ages of Lewisian granulites, northwest Scotland: Geology, v. 23, p. 1027-1030.

Friend, C.R.L. and Kinny, P.D., 2001, A reappraisal of the Lewisian Gneiss Complex: geochronological evidence for its tectonic assembly from disparate terranes in the Proterozoic: Contributions to Mineralogy and Petrology, v. 142, p. 198-218.

Friend, C.R.L., Kinny, P.D., Rogers, G., Strachan, R.A. and Paterson, B.A., 1997, U-Pb zircon geochronological evidence for Neoproterozoic events in the Glenfinnan Group (Moine Supergroup): the formation of the Ardgour granite gneiss, north-west Scotland: Contributions to Mineralogy and Petrology, v. 128, p. 101-113.

Friend, C.R.L., Strachan, R.A., Kinny, P.D. and Watt, G.R., 2003, Provenance of the Moine Supergroup of NW Scotland: evidence from geochronology of detrital and inherited zircons from (meta)sedimentary rocks, granites and migmatites: Journal of the Geological Society, London. v. 160, p. 247-257.

Gee, D.G. and Teben'kov, A.M., 1996, Two major unconformities beneath the Neoproterozoic Murchisonfjorden Supergroup in the Caledonides of central Nordaustlandet, Svalbard: Polar Research, v. 15, p. 81-91.

Gee, D.G. and Teben'kov, A.M., 2004, Svalbard: a fragment of the Laurentian margin. In: Gee, D.G. and Pease, V. (eds.) The Neoproterozoic Timanide Orogen of Eastern Baltica: Geological Society, London, Memoirs, No. 30, p. 191-206.

Gee, D.G., Johansson, Å., Ohta, Y., Teben'kov, A.M., Krasil'schikov, A.A., Balashov, Yu. A., Larionov, A.N., Gannibal, L.A. and Ryungenen, G.I., 1995, Grenvillian basement and a major unconformity within the Caledonides of Nordaustlandet, Svalbard: Precambrian Research, v. 70, p. 215-234.

Geikie, A., 1893. On the pre-Cambrian rocks of the British Isles: Journal of Geology, v. 1, p. 1-14.

Gilotti, J.A. and Elvevold, S., 2002, Extensional exhumation of a high-pressure granulite terrane in Payer Land, Greenland Caledonides: structural, petrologic and geochronologic evidence from metapelites: Canadian Journal of Earth Science, v. 39, p. 1169-1187.

Glendinning, N.R.W., 1988, Sedimentary structures and sequences within a late Proterozoic tidal shelf deposit: the upper Morar Psammite Formation of northwestern Scotland. In: Winchester, J. A. (ed.) Later Proterozoic stratigraphy of the Northern Atlantic Regions: Blackie, Glasgow, p. 14-31.

Glover, B.W. and McKie, T.L., 1996, A sequence stratigraphic approach to the understanding of basin history in orogenic Neoproterozoic successions: an example from the central Highlands of Scotland. In: Hesselbo, S.P. and Parkinson, D.N. (eds.) Sequence Stratigraphy in British Geology: Geological Society, London, Special Publications, v. 103, p. 257-269.

Glover, B.W. and Winchester, J.A., 1989, The Grampian Group: a major Late Proterozoic clastic sequence in the Central Highlands of Scotland: Journal of the Geological Society, London, v. 146, p. 85-97.

Glover, B.W., Key, R.M., May, F., Clark, G.C., Phillips, E.R. and Chacksfield, B.C., 1995, A Neoproterozoic multi-phase rift sequence: the Grampian and Appin groups of the southwestern Monadhliath Mountains of Scotland: Journal of the Geological Society, London, v. 152, p. 391-406.

Goodman, S. and Winchester, J.A.W., 1993, Geochemical variations within metavolcanic rocks of the Dalradian Farragon beds and adjacent formations: Scottish Journal of Geology, v. 29, p. 131-141.

Gorokhov, I.M., Siedlecka, A., Roberts, D., Melnikov, N.N. and Turchenko, T.L., 2001, Rb-Sr dating of diagenetic illite in Neoproterozoic shales, Varanger Peninsula, northern Norway: Geological Magazine, v. 138, p. 541-562.

Gower, C.F., 1988, The Double-Mer Formation. In: Winchester, J.A. (ed.) Later Proterozoic stratigraphy of the northern Atlantic regions: Blackie, Glasgow, p. 113-118.

Gradstein, F.M., Ogg, J.G., Smith, A.G., Agterberg, F.P., Bleeker, W., Cooper, R.A., Davydov, V., Gibbard, P., Hinnov, L.A., House, M.R., Lourens, L., Luterbacher, H.P., McArthur, J., Melchin, M.J., Robb, L.J., Shergold, J., Villeneuve, M., Wardlaw, B.R., Ali, J., Brinkhuis, H., Hilgen, F.J., Hooker, J., Howarth, R.J., Knoll, A.H., Laskar, J., Monechi, S., Plumb, K.A., Powell, J., Raffi, I., Röhl, U., Sadler, P., Sanfilippo, A., Schmitz, B., Shackleton, N.J., Shields, G.A., Strauss, H., Van Dam, J., van Kolfschoten, T., Veizer, J., and Wilson, D., 2004, A Geologic Time Scale 2004: Cambridge University Press, 589 pages.

Gromet, L.P. and Gee, D.G., 1997, Age of high-pressure metamorphism in the high arctic Caledonides: U-Pb results from Biskayerhalvoya, MW Svalbard: Geological Society of America, Abstracts with Programs, v. 29(6), 49pp.

Hall, A.J., Boyce, A.J., Fallick A.E. and Hamilton P.J., 1991, Isotopic evidence of the despositional environment of Late Proterozoic stratiform barite mineralisation, Aberfeldy, Scotland: Chemical Geology, v. 87, p. 99-114.

Hall, J., Brewer, J.A., Matthews, D.H. and Warner, M.R., 1984, Crustal structure across the Caledonides from the WINCH seismic reflection profile: influences on the evolution of the Midland Valley of Scotland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 75, p. 97-109.

Halliday, A.N., 1984, Coupled Sm-Nd and U-Pb systematics in late Caledonian granites and basement under northern Britain: Nature, v. 307, p. 229-233.

Hambrey, M.J. and Spencer, A.M., 1987, Late Precambrian glaciation of central East Greenland: Meddelelser om Grønland. Geoscience, v. 19, p. 1-50.

Harland, W.B., 1997, The geology of Svalbard: Geological Society of London, Memoir, No. 17.

Harmon, R.S., 1983, Oxygen and Strontium isotope evidence regarding the role of continental crust in the origin and evolution of the British Caledonian granites In: Atherton, M.P. and Gribble, C.D. (eds.) Migmatites, Melting and Metamorphism: Shiva, Orpington, p. 62-79.

Harris, A.L., Baldwin, C.T., Bradbury, H.J., Johnson, H.D. and Smith, R.A., 1978, Ensialic basin sedimentation: the Dalradian Supergroup. In: Bowes, D. R. and Leake, B.E. (eds.) Crustal evolution in northwestern Britain: Geological Journal, Special Issue, No. 10, p. 115-138.

Harris, A.L., Haselock, P.J., Kennedy, M.J. and Mendum, J.R., 1994, The Dalradian Supergroup in Scotland, Shetland and Ireland. In: Gibbons, W. and Harris, A.L. (eds.) A revised correlation of Precambrian rocks in the British Isles: Geological Society, London, Special Reports, No. 22, p. 33-53.

Harte, B., Booth, J.E., Dempster, T.J., Fettes, D.J., Mendum, J.R. and Watts, D., 1984, Aspects of post-depositional evolution of Dalradian and Highland Border Complex rocks in the Southern Highlands of Scotland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 75, p. 151-163.

Heaman, L. and Tarney, J., 1989, U-Pb baddeleyite ages for the Scourie dyke swarm, Scotland: evidence for two distinct intrusion events: Nature, London, v. 340, p. 705-708.

Higgins, A.K., 1988, The Krummedal supracrustal sequence in East Greenland. In: Winchester, J.A. (ed.) Later Proterozoic stratigraphy of the northern Atlantic regions: Blackie, Glasgow, p. 86-96.

Higgins, A.K. and Leslie, A.G., 2000, Restoring thrusting in the East Greenland Caledonides: Geology, v. 28, p. 1019-1022.

Higgins, A.K., Leslie, A.G. and Smith, M.P., 2001a, Neoproterozoic – Lower Paleozoic stratigraphical relationships in the marginal thin-skinned thrust belt of the East Greenland Caledonides: comparisons with the foreland of Scotland: Geological Magazine, v. 138, p. 143–160.

Higgins, A.K., Smith, M.P., Soper, N.J., Leslie, A.G., Rasmussen, J.A. and Sønderholm, M., 2001b,. The Neoproterozoic Hekla Sund Basin, Eastern North Greenland: a pre-Iapetan extensional sequence thrust across its rift shoulders during the Caledonian orogeny: Journal of the Geological Society, London, v. 158, p. 487-499.

Higgins, A.K., Elvevold, S., Escher, J.C., Frederiksen, K.S., Gilotti, J.A., Henriksen, N., Jepsen, H.F., Jones, K. A., Kalsbeek, F., Kinny, P.D., Leslie, A.G., Smith, M.P., Thrane, K. and Watt, G.R., 2004, The foreland-propagating thrust architecture of the East Greenland Caledonides 72° - 75°N: Journal of the Geological Society, London, v. 161, p. 1009-1026.

Highton, A.J., Hyslop, E.K. and Noble, S.R., 1999, U-Pb zircon geochronology of migmatization in the northern Central Highlands: evidence for pre-Caledonian (Neoproterozoic) tectonometamorphism in the Grampian block, Scotland: Journal of the Geological Society, London, v. 156, p. 1195-1204.

Hoffman, P.F., 1991, Did the breakout of Laurentia turn Gondwanaland inside-out?: Science, v. 252, p. 1409-1412.

Hoffmann, P.F., Condon, D.J., Bowring, S.A. and Crowley, J.L., 2004, U-Pb zircon date from the Neoproterozoic Ghaub Formation, Namibia: Constraints on Marinoan glaciation: Geology, v. 32, p. 817-820.

Holdsworth, R.E., Strachan, R.A. and Harris, A.L., 1994, Pre-Cambrian rocks in northern Scotland east of the Moine Thrust: the Moine Supergroup. In: Gibbons, W. and Harris, A.L. (eds.). A Revised Correlation of Precambrian rocks in the British Isles: Geological Society, London, Special Reports, No. 22, p. 23- 32.

Holdsworth, R.E., Strachan, R.A., Alsop, G.I., Grant, C.J. and Wilson, R.W., 2006, Thrust sequences and the significance of low-angle, out-of-sequence faults in the northernmost Moine Nappe and Moine Thrust Zone, NW Scotland: Journal of the Geological Society, London, v. 163, p. 801-814.

Hutchison, A.R. and Oliver, G.J.H., 1998, Garnet provenance studies, juxtaposition of Laurentian marginal terranes and timing of the Grampian Orogeny in Scotland: Journal of the Geological Society, London, v. 155, p. 541-550.

Hutton, D.H.W., 1987, Strike-slip terranes and a model for the evolution of the British and Irish Caledonides: Geological Magazine, v. 124, p. 405-425.

Hutton, D.H.W. and Alsop, G.I., 2004, Evidence for a major Neoproterozoic orogenic unconformity within the Dalradian Supergroup of NW Ireland: Journal of the Geological Society, London, v. 161, p. 629-640.

Hutton, D.H.W. and Reavy, R.J., 1992, Strike-slip tectonics and granite petrogenesis: Tectonics, v. 11, p. 960-967.

Hyndman, R.D., Currie, C.A. and Mazotti, S.P., 2005, Subduction zone backarcs, mobile belts, and orogenic heat: GSA Today, v. 15, p. 4-10.

Hyslop, E.K., 1992, Strain-Induced Metamorphism and Pegmatite Development in the Moine Rocks of Scotland: PhD thesis, University of Hull.

Hyslop, E.K. and Piasecki, M.A.J., 1999, Mineralogy, geochemistry and the development of ductile shear zones in the Grampian Slide zone of the Scottish Central Highlands: Journal of the Geological Society, London, v. 156, p. 577-589.

Jacques, J.M. and and Reavy, R.J., 1994, Caledonian plutonism and major lineaments in the SW Scottish Highlands: Journal of the Geological Society, London, v. 151, p. 955-969.

Johansson, Å., Larionov, A.N., Tebenkov, A.M., Gee, D. G., Whitehouse, M.J. and Vestin, J., 2000, Grenvillian magmatism of western and central Nordaustlandet, northeastern Svalbard: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 90, p. 221-254.

Johansson, Å., Larionov, A.N., Gee, D.G., Ohta, Y., Tebenkov, A.M. and Sandelin, S., 2004, Grenvillian and Caledonian tectono-magmatic activity in northeasternmost Svalbard. In: Gee, D.G. and Pease, V. (eds.) The Neoproterozoic Timanide Orogen of Eastern Baltica: Geological Society, London, Memoirs, No. 30, p. 207-232.

Johnson, M.R.W., Kelley, S.P., Oliver, G.J.H. and Winter, D.A., 1985, Thermal effects and timing of thrusting in the Moine Thrust zone: Journal of the Geological Society, London, v. 142, p. 863-874.

Kalsbeek, F. (ed.), 1989, Geology of the Ammassalik Region, South-east Greenland: Rapport Grønlands Geologiske Undersgelse, No. 146.

Kalsbeek, F., Nutman, A.P. and Taylor, P.N., 1993, Palaeoproterozoic basement province in the Caledonian fold belt of North-East Greenland: Precambrian Research, v. 63, p. 163-178.

Kalsbeek, F., Thrane, K., Nutman, A.P. and Jepsen, H.F., 2000, Late Mesoproterozoic to early Neoproterozoic history of the East Greenland Caledonides: evidence for Grenvillian orogenesis?: Journal of the Geological Society, London, v. 57, p. 1215-1225.

Kelley, S.P., 1988, The relationship between K-Ar mineral ages, mica grain sizes and movement on the Moine Thrust Zone, NW Highlands, Scotland: Journal of the Geological Society, London, v. 145, p. 1-10.

Key, R.M., Clark, G.C., May, F., Phillips, E.R., Chacksfield, B.C. and Peacock, J.D., 1997, Geology of the Glen Roy District: Memoir of the British Geological Survey, HMSO.

Kinny, P. D. and Friend, C.R.L., 1997, U/Pb isotopic evidence for the accretion of different crustal blocks to form the Lewisian complex of northwest Scotland: Contributions to Mineralogy and Petrology, v. 129, p. 326-340.

Kinny, P.D., Friend, C.R.L., Strachan, R.A., Watt, G.R., and Burns, I.M., 1999, U-Pb geochronology of regional migmatites in East Sutherland, Scotland: evidence for crustal melting during the Caledonian Orogeny: Journal of the Geological Society, London, v. 156, p. 1143-1152.

Kinny, P.D., Friend, C.R.L. and Love, G.J., 2005, Proposal for a terrane-based nomenclature for the Lewisian Gneiss Complex of NW Scotland: Journal of the Geological Society, London, v. 162, p. 175-186.

Kneller, B.C. and Aftalion, M., 1987, The isotopic and structural age of the Aberdeen Granite: Journal of the Geological Society, London, v. 144, p. 717-721.

Krabbendam, M. and Dewey, J.F., 1998, Exhumation of UHP rocks by transtension in the Western Gneiss region, Scandinavian Caledonides. In: Holdsworth, R.E., Strachan, R.A., and Dewey, J.F. (eds.) Continental transpressional and transtensional tectonics: Geological Society, London, Special Publications, v. 135, p. 159–181.

Krabbendam, M. and Leslie, A.G., 2004, Lateral ramps and thrust terminations: an example from the Moine Thrust Zone, NW Scotland: Journal of the Geological Society, London, v. 161, p. 551-554.

Krabbendam, M., Leslie, A.G., Crane, A. and Goodman, S., 1997, Generation of the Tay Nappe, Scotland, by large-scale SE-directed shearing: Journal of the Geological Society, London, v. 154, p. 15-24.

Lambert, R.S.J. and McKerrow, W.S., 1976, The Grampian Orogeny: Scottish Journal of Geology, v. 12, p. 271-292.

Larsen, P.H. and Bengaard, H.J., 1991, Devonian basin initiation in East Greenland: a result of sinistral wrench faulting and Caledonian extensional collapse: Journal of the Geological Society, London, v. 148, p. 355–368.

Leslie, A.G. and Higgins, A.K., 1998, The Caledonian geology of Andrée Land, Eleonore Sø and adjacent nunataks, East Greenland: Danmarks og Grønlands Geologiske Undersøgelse Rapport - 1998/28, p. 11-27.

Leslie, A.G. and Nutman, A.P., 2003, Evidence for Neoproterozoic orogenesis and early high temperature Scandian deformation events in the southern East Greenland Caledonides: Geological Magazine, v. 140, p. 309-333.

Macdonald, R.L, Fettes, D.J. , Stephenson, D. and Graham, C.M., 2005, Basic and ultrabasic volcanic rocks from the Argyll Group (Dalradian) of NE Scotland: Scottish Journal of Geology, v. 41, p. 159-174.

Marcantonio, F., Dickin, A.P., McNutt, R.H. and Heaman, L.M., 1988, A 1800-million-year-old Proterozoic gneiss terrane in Islay with implications for the crustal structure evolution of Britain: Nature, London, v. 335, p. 62-64.

May, F. and Highton, A.J., 1997, Geology of the Invermoriston district: Memoir of the British Geological Survey, HMSO.

McCay, G.A., Prave, A.R., Alsop, G.I. and A.E. Fallick, A.E., 2006, Glacial trinity: Neoproterozoic Earth history within the British-Irish Caledonides. Geology, v. 34, p. 909-912.

McClay, K.R. and Coward, M.P., 1981, The Moine Thrust Zone: an overview. In: McClay, K.R. and Price, N.J. (eds.) Thrust and Nappe Tectonics: Geological Society, London, Special Publications, No. 9, p. 241-260.

McKerrow, W.S., MacNiocaill, C. and Dewey, J.F., 2000, The Caledonian Orogen redefined: Journal of the Geological Society, London, v. 157, p. 1149-1154.

McKie, T., 1990, Tidal and storm-influenced sedimentation from a Cambrian transgressive passive margin sequence: Journal of the Geological Society, London, v. 147, p. 785-794.

Millar, I.L., 1999, Neoproterozoic extensional basic magmatism associated with emplacement of the West Highland granite gneiss in the Moine Supergroup of NW Scotland: Journal of the Geological Society, London, v. 156, p. 1153-1162.

Moncrieff, A.C.M. and Hambrey, M.J., 1988, Late Precambrian glacially-related grooved and striated surfaces in the Tillite Group of central East Greenland: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 65,p. 183-200.

Muir, R.J., Fitches, W.R. and Maltman, A.J., 1994, The Rhinns Complex: Proterozoic basement on Islay and Colonsay, Inner hebrides, Scotland, and on Inishtrahull, NW Ireland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 85, p. 77-90.

Myers, J.S., 1987, The East Greenland Nagssuqtoqidian mobile belt compared with Lewisian Complex. In: Park, R.G. and Tarney, J. (eds.) Evolution of the Lewisian and Comparable Precambrian High Grade Terrains: Geological Society, London, Special Publications, v. 27, p. 235-246.

Mykura, W., 1991, Old Red Sandstone. In: Craig, G.Y. (ed.) Geology of Scotland (3rd edition): Geological Society, London. p. 297-346.

Noble, S.R., Hyslop, E.K. and Highton, A.J., 1996, High precision U-Pb monazite geochronology of the c.806 Ma Grampian Shear Zone and the implications for the evolution of the Central Highlands of Scotland: Journal of the Geological Society, London, v. 153, p. 511-514.

Oliver, G.J.H., 2001, Reconstruction of the Grampian episode in Scotland: its place in the Caledonian Orogeny. Tectonophysics, v. 332, p. 23-49.

Olsen, H., 1993, Sedimentary basin analysis of the continental Devonian basin in North-East Greenland: Bulletin Grønlands Geologiske Undersøgelse, No. 168, 80pp.

O'Nions, R.K., Hamilton, P.J. and Hooker, P.J., 1983, A Nd isotope investigation of sediments related to crustal development in the British Isles: Earth and Planetary Science Letters, v. 63, p. 229-240.

Park, R.G., 1994, Early Proterozoic tectonic overview of the northern British Isles and neighbouring terrains in Laurentian and Baltica: Precambrian Research, v. 68, p. 65-79.

Park, R.G., 1995, Palaeoproterozoic Laurentia-Baltica relationships: a view from the Lewisian. In: Early Precambrian processes. Coward, M.P. and Ries, A.C. (eds.): Geological Society, London, Special Publications, No. 95, p. 211-224.

Park, R.G., 2005, The Lewisian terrane model: a review: Scottish Journal of Geology, v. 41, p. 105-118.

Park, R.G., Tarney, J. and Connelly, J.N., 2001, The Loch Maree Group: Palaeoproterozoic subduction–accretion complex in the Lewisian of NW Scotland: Precambrian Research, v. 105, p. 205-226.

Park, R.G., Stewart, A.D. and Wright, D.T., 2002, The Hebridean Terrane. In: Trewin, N.H. (ed.) The Geology of Scotland: The Geological Society, London, p. 45-80.

Pickett, E.A., Hyslop, E.K. and Petterson, M.G., 2006, The Green Beds of the SW Highlands: deposition and origin of a basic igneous-rich sedimentary sequence in the Dalradian Supergroup of Scotland: Scottish Journal of Geology, v. 42, p. 43-57.

Piasecki, M.A.J., 1980, New light on the Moine rocks of the Central Highlands of Scotland: Journal of the Geological Society, London, v. 137, p. 41-59.

Pidgeon, R.T. and Compston, W., 1992, A SHRIMP ion microprobe study of inherited and magmatic zircons from four Scottish Caledonian granites. In: Brown, P.E. and Chappell, B.W. (eds.) The second Hutton symposium on the origin of granites and related rocks: Geological Society of America, Special Papers, v. 272, p. 473-483.

Powell, D., Baird, A.W., Charnley, N.R. and Jordon, P.J., 1981, The metamorphic environment of the Sgurr Beag Slide, a major crustal displacement zone in Proterozoic, Moine rocks of Scotland: Journal of the Geological Society, London, v. 138, p. 661-673.

Prave, A.R., 1999, The Neoproterozoic Dalradian Supergroup of Scotland: an alternative hypothesis: Geological Magazine, v. 136, p. 609-617.

Pringle, J., 1940, The discovery of Cambrian trilobites in the Highland Border rocks near Callander, Perthshire (Scotland): Report of the British Association for the Advancement of Science, v. 1, p. 252.

Rainbird, R.H., Hamilton, M.A. and Young, G.M., 2001, Detrital zircon geochronology and provenance of the Torridonian, NW Scotland: Journal of the Geological Society, London, v. 158, p. 15-27.

Rankin, D.W., Drake, A.A. Jr., Glover, L. III, Goldsmith, R., Hall, L. M., Murray, D.P., Ratcliffe, N.M., Read, J.F., Secor, D.T. Jr. and Stanley, R.S., 1989, The Appalachian-Ouachita Orogen in the United States: In: Hatcher, R.D.Jr., Thomas, W.A. and Viele, G.W. (eds.) The geology of North America. p. 7-100.

Read, H.H., 1961, Aspects of the Caledonian magmatism in Britain: Liverpool and Manchester Geological Journal, v. 2, p. 653-683.

Rex, D.C. and Gledhill, A.R., 1981, Isotopic studies in the East Greenland Caledonides (72°-74°N) - Precambrian and Caledonian ages: Rapport Grønlands Geologiske Undersøgelse, v. 104, p. 47-72.

Roberts, D., Melezhik, V.M. and Heldal, T., 2001, Carbonate formations and early NW-directed thrusting in the highest allochthons of the Norwegian Caledonides: Evidence of a Laurentian ancestry: Journal of the Geological Society, London, v. 159, p. 117-120.

Robertson, S. and Smith, M., 1999, The significance of the Geal Charn-Ossian steep belt in basin development in the central Scottish Highlands: Journal of the Geological Society, London, v. 156, p. 1175-1182.

Rogers, G. and Dunning, G.R., 1991, Geochronology of appinitic and related granitic magmatism in the W Highlands of Scotland: constrainsts on the timing of transcurrent fault movement: Journal of the Geological Society, London, v. 148, p. 17-27.

Rogers, G., Dempster, T.J., Bluck, B.J. and Tanner, P.W.G., 1989, A high-precision age for the Ben Vuirich granite: implications for the evolution of the Scottish Dalradian Supergroup: Journal of the Geological Society, London, v. 146, p. 789-798.

Rogers, G., Hyslop, E.K., Strachan, R.A., Peterson, B.A. and Holdsworth, R.E., 1998, The structural setting and U-Pb geochronology of Knoydartian pegmatites in W Inverness-shire: evidence for Neoproterozoic tectonothermal events in the Moine of NW Scotland. Journal of the Geological Society, London. v. 155, p. 685-696.

Rogers, G., Kinny, P.D., Strachan, R.A., Friend, C.R.L. and Patterson, B.A., 2001, U-Pb geochronology of the Fort Augustus granite gneiss, constraints on the timing of Neoproterozoic and Paleozoic tectonothermal events in the NW Highlands of Scotland: Journal of the Geological Society, London, v. 158, p. 7-14.

Rollin, K.E., 1994, Geophysical correlation of Precambrian rocks in northern Britain. In: Gibbons, W. and Harris, A.L. (eds.) A revised correlation of Precambrian rocks in the British Isles: Geological Society, London, Special Report, No. 22, p. 65-74.

Ryan, P.D. and Soper, N.J., 2001, Modelling anatexis in intra-cratonic rift basins: an example from the Neoproterozoic rocks of the Scottish Highlands: Geological Magazine, v. 138, p. 577-588.

Sanders, I.S., van Calsteren, P.W.C. and Hawkesworth, C.J., 1984, A Grenville Sm-Nd age for the Glenelg eclogite in north-west Scotland: Nature, London, v. 312, p. 439-440.

Sandiford, M. and Hand, M., 1998, Controls on the locus of Phanerozoic intraplate deformation in central Australia: Earth and Planetary Science Letters, v. 162, p. 97-110.

Scrimgeour, I and Close, D., 1999, Regional high pressure metamorphism during intracratonic deformation: the Petermann Orogeny, central Australia: Journal of Metamorphic Geology, v. 17, p. 557-572.

Seranne, M., 1992, Devonian extensional tectonics versus Carboniferous inversion in the northern Orcadian basin: Journal of the Geological Society, London, v. 149, p. 27-37.

Shaw, R.D., Zeitler, P.K., McDougall, I. and Timgate, P., 1992, The Paleozoic history of an unusual intracratonic thrust belt in central Australia based on ^{40}Ar-^{39}Ar, K-Ar and fission track dating: Journal of the Geological Society, London, v. 149, p. 937-954.

Shellnutt, J.G., Dostal, J., and Keppie, J.D., 2004, Petrogenesis of the 723 Ma Coronation sills, Amundsen basin, Arctic Canada: implications for the break-up of Rodinia: Precambrian Research, v. 129, p. 309-324.

Smith, M., Robertson, S. and Rollin, K.E., 1999, Rift basin architecture and stratigraphical implications for basement-cover relationships in the Neoproterozoic Grampian Group of the Scottish Caledonides: Journal of the Geological Society, London, v. 156, p. 1163-1173.

Smith, M.P. and Robertson, S., 1999, The Nathorst Land Group (Neoproterozoic) of East Greenland – lithostratigraphy, basin geometry and tectonic history: Danmarks og Grønlands Geologiske Undersøgelse Rapport, 1999/19, p. 127-143.

Smith, M.P., Rasmussen, J.A., Robertson, S., Higgins, A.K. and Leslie, A.G., 2004, Lower Palaeozoic stratigraphy of the East Greenland Caledonides: Geological Survey of Denmark and Greenland Bulletin, v. 6, p. 5-28.

Smith, R.L., Sterans, J.E.F. and Piper, J.D.A., 1983, Palaeomagnetic studies of the Torridonian sediments, NW Scotland: Scottish Journal of Geology, v. 19, p. 29-45.

Snyder, D.B. and Flack, C.A., 1990, A Caledonian age for reflectors within the mantle lithosphere north and west of Scotland: Tectonics, v. 9, p. 903-922.

Sønderholm, M. and Tirsgaard, H., 1993, Lithostratigraphic framework of the Upper Proterozoic Eleonore Bay Supergroup of East and North-East Greenland: Bulletin Grønlands Geologiske Undersøgelse, v. 167, 38 pp.

Soper, N. J., 1994a, Was Scotland a Vendian RRR junction?: Journal of the Geological Society, London, v. 151, p. 579-582.

Soper, N.J., 1994b, Neoproterozoic sedimentation on the northeast margin of Laurentia and the opening of Iapetus: Geological Magazine, v. 131, p. 291-299.

Soper, N.J. and Hutton, D.H.W., 1984, Late Caledonian sinistral displacements in Britain: Implications for a three-plate model: Tectonics, v. 3, p. 781-794.

Soper, N.J. and Woodcock, N.H, 2003, The lost Lower Old Red Sandstone of England and Wales: a record of post-Iapetan flexure or Early Devonian transtension?: Geological Magazine, v. 140, p. 627-647.

Soper, N.J., Strachan, R.A., Holdsworth, R.E., Gayer, R.A. and Greiling, R.O., 1992, Sinistral transpression and the Silurian closure of Iapetus: Journal of the Geological Society, London, v. 149, p. 871-880.

Soper, N.J., Harris, A.L. and Strachan, R.A., 1998, Tectonostratigraphy of the Moine Supergroup: a synthesis: Journal of the Geological Society, London, v. 155, p. 13-24.

Soper, N.J., Ryan, P.D. and Dewey, J.F., 1999, Age of the Grampian orogeny in Scotland and Ireland: Journal of the Geological Society, London, v. 156, p. 1231-1236.

Stephens, W.E. and Halliday, A.N., 1984, Geochemical contrasts between late Caledonian granitoid plutons of northern, central and southern Scotland: Transactions of the Royal Society of Edinburgh: Earth Sciences, v. 75, p. 259-273.

Stephenson, D. and Gould, D., 1995, British regional geology: the Grampian Highlands (4th edition): (London: HMSO for the British Geological Survey.)

Stephenson, D., Bevins, R.E., Millward, D., Highton, A.J., Parsons, I., Stone, P. and Wadsworth, W.J., 1999, Caledonian Igneous Rocks of Great Britain: Joint Nature Conservation Committee. v. 17 p. 1-648.

Stewart, A.D., 1991, Geochemistry, provenance and climate of the Upper Proterozoic Stoer Group in Scotland: Scottish Journal of Geology, v. 26, p. 89-97.

Stewart, A.D., 2002, The later Proterozoic Torridonian rocks of Scotland: their sedimentology, geochemistry and origin: Geological Society, London, Memoir, No. 24.

Stewart, M., Strachan, R.A. and Holdsworth, R.E., 1999, Structure and early kinematic history of the Great Glen Fault Zone, Scotland:. Tectonics, v. 18, p. 326-342.

Stoker, M.S., van Weering, T.C.E. and Svaerdborg, T., 2001, A mid-late Cenozoic tectonostratigraphic framework for the Rockall Trough. In: Shannon, P.M., Haughton, P.D.W. and Corcoran, D.V. (eds.) The petroleum exploration of Ireland's offshore basins: Geological Society, London, Special Publication, No. 188, p. 411-438.

Stone, P., 1995, Geology of the Rhinns of Galloway: Memoir of the British Geological Survey, HMSO.

Stone, P., Floyd, J.D., Barnes, R.P. and Lintern, B.C., 1987, A sequential back-arc and foreland basin thrust duplex model for the Southern Uplands of Scotland: Journal of the Geological Society, London, v. 144, p. 753-764.

Stone, P., Green, P.M., Lintern, B.C., Simpson, P.R. and Plant, J.A., 1993, Regional geochemical variation across the Iapetus Suture zone: tectonic implications: Scottish Journal of Geology, v. 29, p. 113-121.

Storey, C.D., Brewer, T.S. and Parrish, R.R., 2004, Late Proterozoic tectonics in northwest Scotland: one contractional orogeny or several?: Precambrian Research, v. 134, p. 227-247.

Strachan, R.A., 1986, Shallow-marine sedimentation in the Proterozoic Moine Succession, Northern Scotland: Precambrian Research, v. 32, p. 17-33.

Strachan, R.A., Harris, A.L., Fettes, D.J. and Smith, M., 2002, the Highland and Grampian terranes. In: Trewin, N.H. (ed.) The geology of Scotland: The Geological Society, London, p. 81-148.

Tanner, P.W.G., 1995, New evidence that the Lower Cambrian Leny Limestone at Callander, Perthshire, belongs to the Dalradian Supergroup, and a reassessment of the 'exotic' status of the Highland Border Complex: Geological Magazine, v. 132, p. 473-483.

Tanner, P.W.G. and Evans, J. A., 2003, Late Precambrian U-Pb titanite age for peak regional metamorphism and deformation (Knoydartian orogeny) in the western Moine, Scotland: Journal of the Geological Society, London, v. 160, p. 555-564.

Tanner, P.W.G. and Sutherland, S., 2007,. The Highland Border Complex, Scotland: a paradox resolved: Journal of the Geological Society, London, v. 164, p. 111-116.

Tanner, P.W.G., Johnstone, C.S., Smith, D. and Harris, A.L., 1970, Moinian stratigraphy and the problem of the Central Ross-shire inliers: Bulletin of the Geological Society of America, v. 81, p. 299-306.

Tanner, P.W.G., Leslie, A.G. and Gillespie, M.R., 2006, Structural setting and petrogenesis of the Ben Vuirich Granite Pluton of the Grampian Highlands: a pre-orogenic, rift-related intrusion: Scottish Journal of Geology, v. 42, p. 113-136.

Tarney, J. and Jones, C.E., 1994, Trace element geochemistry of orogenic igneous rocks and crustal growth models: Journal of the Geological Society, London, v. 151, p. 855-868.

Thirlwall, M.F., 1981,. Implications for Caledonian plate tectonic models of chemical data from volcanic rocks of the British Old Red Sandstone: Journal of the Geological Society, London, v. 138, p. 123-138.

Thirlwall, M.F, 1982, Systematic variation in chemistry and Nd-Sr isotopes across a Caledonian calc-alkaline volcanic arc: implications for source materials: Earth and Planetary Science Letters, v. 58, p. 27-50.

Thirlwall, M.F., 1988, Geochronology of Late Caledonian magmatism in northern Britain: Journal of the Geological Society, London, v. 145, p. 951-967.

Thomas, C.W., Graham, C.M., Ellam, R.M. and Fallick, A.E., 2004, ^{87}Sr/^{86}Sr chemostratigraphy of Neoproterozoic Dalradian limestones of Scotland and Ireland: constraints on depositional ages and time scales: Journal of the Geological Society, London, v. 161, p. 229-242.

Thomas, P.R., 1979, New evidence for a Central Highland root zone. In: Harris, A.L., Holland, C.H. and Leake, B.E. (eds.) The Caledonides of the British Isles — reviewed: Geological Society, London, Special Publications, No. 8, p. 205-211.

Thrane, K., 2002, Relationships between Archean and Palaeoproterozoic crystalline basement complexes in the southern part of the East Greenland Caledonides: an ion microprobe study: Precambrian Research, v. 113, p. 19-42.

Tirsgaard, H. and Sønderholm, M., 1997, Lithostratigraphy, sedimentary evolution and sequence stratigraphy of the upper Lyell Land group (Eleonore Bay Supergroup) of East and North-east Greenland: Geology of Greenland Survey Bulletin, v. 178, 60pp.

Tollo, R.P. and Hutson, E.H., 1996, 700 Ma rift event in the Blue Ridge province of Virginia: A unique time constraint on pre-Iapetan rifting of Laurentia: Geology, v. 24, p. 59-62.

Tollo, R.P., Aleinikoff, J.N., Bartholomew, M.J. and Rankin, D.W., 2004, Neoproterozoic A-type granitoids of the central and southern Appalachians: intraplate magmatism associated with episodic rifting of the Rodinian supercontinent: Precambrian Research, v. 128, p. 3-38.

Torsvik, T.H., Smethurst, M.A., Van der Voo, R., Trench, A., Abrahamsen, N. and Halvorsen, E., 1992, Baltica: A synopsis of Vendian-Permian palaeomagnetic data and their palaeotectonic implications: Earth-Science Reviews, v. 33, p. 133-152.

Trewin, N.H. and Rollin, K., 2002, In: Trewin, N.H. (ed.) The geology of Scotland: The Geological Society, London, p. 1-25.

Turnbull, M.J.M., Whitehouse, M.J. and Moorbath, S., 1996, New isotope age determinations for the Torridonian, NW Scotland: Journal of the Geological Society, London, v. 153, p. 955-964.

Van Breemen, O., Aftalion, M., Pankhurst, R.J. and Richardson, S.W., 1979, Age of the Glen Dessary syenite, Inverness-shire: diachronous Paleozoic metamorphism across the Great Glen: Scottish Journal of Geology, v. 15, p. 49-62.

van Staal, C.R., Dewey, J.F. MacNiocall, C. and McKerrow, W.S., 1998, The Cambrian-Silurian tectonic evolution of the northern Appalachian and British Caledonides: history of a complex west and southwest Pacific-type segment of Iapetus. In: Blundell, D.J. and Scott, A.C. (eds.) Lyell: the past is the key to the present: Geological Society, London, Special Publication, No. 143, p. 199-142.

Vance, D., Meier, M. and Oberli, F., 1998, The influence of high U-Th inclusions on the U-Th-Pb systematics of almandine-pyrope garnet: Results of a combined bulk dissolution, stepwise-leaching, and SEM study: Geochimica et Cosmochimica Acta, v. 62, p. 3527-3540.

Watson. J.V., 1984, The ending of the Caledonian orogeny in Scotland: Journal of the Geological Society, London, v. 141, p. 193-214.

Waldron, J.W.F. and van Staal, C.R., 2001, Taconian orogeny and the accretion of the Dashwoods block: A peri-Laurentian microcontinental microcontinental in the Iapetus Ocean: Geology, v. 29, p. 811-814.

Watt, G.R. and Thrane, K., 2001, Early Neoproterozoic events in East Greenland: Precambrian Research, v. 110, p. 165-184.

Watt, G.R., Kinny, P.D. and Friderichsen, J.D., 2000, U-Pb geochronology of Neoproterozoic and Caledonian tectonothermal events in the East Greenland Caledonides: Journal of the Geological Society, London, v. 157, p. 1031-1048.

Winchester, J.A., 1988, Later Proterozoic environments and tectonic evolution in the northern Atlantic lands. In: Winchester, J.A. (ed.) Later Proterozoic stratigraphy of the northern Atlantic regions: Blackie, Glasgow, p. 253-270.

Whitehouse, M.J., 1989, Sm-Nd evidence for diachronous crustal accretion in the Lewisian complex of NW Scotland: Tectonophysics, v. 161, p. 245-256.

Whitehouse, M.J. and Bridgwater, D., 1999, Palaeoproterozoic evolution of the Outer Hebridean Lewisian Complex, northwest Scotland: constraints from ion microprobe zircon geochronology: EUG 10th Session A07:3A. Abstracts.

Wright, A.E., Tarney, J. Palmer, K.F., Moorlock, B.S.P. and Skinner, A.C., 1973, The geology of the Angmassalik area, East Greenland and possible relationships with the Lewisian of Scotland. In: Park, R.G. and Tarney, J. (eds.) The early Precambrian of Scotland and related rocks of Greenland: University of Keele, p. 157-177.

Wright, D.T. and Knight, I., 1995, A revised chronostratigraphy for the lower Durness group: Scottish Journal of Geology, v. 31, p. 11-22.

Yoshinobu, A.S., Barnes, C.G., Nordgulen, Ø., Prestvik, T., Fanning, M. and Pedersen, R.B., 2002, Ordovician magmatism, deformation, and exhumation in the Caledonides of central Norway: An orphan of the Taconic orogeny?: Geology, v. 30, p. 883-886.

LIST OF CAPTIONS FOR FIGURES AND PLATES.

FIGURES

Figure 1 Latest Neoproterozoic template for the various segments of the Laurentian margin discussed in this text. The line of Iapetan separation is shown, along with suggested positions for Baltica, Barentsia and Siberia. The locations of Western, Central and eastern Svalbard are modified after Soper *et al.* (1992) and Gee and Teben'kov (2004). The inset projection shows location of the Scottish 'Promontory' (S) within a wider global continental plate reconstruction for Pannotia, note the alternative orientation shown for Baltica. GGF, Great Glen Fault; HB, Highland Border; MT, Moine Thrust; OIT, Outer Isles Thrust; SBT, Sgurr Beag Thrust; Sh, Shetland.

Figure 2 Simplified geological map of Scotland omitting small areas of outcrop and dike swarms. The inset shows the major terranes of Scotland after Strachan et al. (2002). M – Loch Maree Group.

Figure 3 Comparison of the Mesoproterozoic to Ordovician successions of Scotland (A) and East Greenland (B and C), shaded areas on the map. The successions are shown with reference to their relative position on the inboard to outboard location on the evolving continental margin of Laurentia. The timing of orogenesis (Scandian, Grampian etc.) in each sector is shown schematically. Ap, Appin Group; Arg, Argyll Group; D, Durness Group; Dal, Dalradian; D,GB, Dava Glen Banchor succession; EBSG, Eleonore Bay Supergroup; Gr, Grampian Group; HF, Hagen Fjord Group; KH, Kap Holbæk Formation; KOF, Kong Oscar Fjord Group; Kr, Krummedal; M, Målebjerg Formation; M, Moine Supergroup; MS, Morænesø Formation; RIV, Rivieradal Group; S, Slottet Formation; SH, Southern Highland Group; St, Stoer Group; T, Tillite Group; To, Torridon Group; ZS, Zebra 'series'.

Figure 4 Record of the geological evolution of the Scottish sector of Laurentian from the post-Grenvillian amalgamation of Rodinia until post-Caledonian time. The principal comparable events recorded on the East Greenland sector are included here for reference but see greater detail included in Figure 6. BV, Ben Vuirich Granite; CC, Carn Chuinneag Granite; PA, Port Askaig Tillite; SBT, Sgurr Beag Thrust; TV, Tayvallich Volcanics.

Figure 5 Reconstruction of the Paleoproterozoic belts and Archean cratons of the North Atlantic region. Amma, Ammasalik; NAC, North Atlantic Craton; Nag, Nagssugtoqidian; (after Buchan et al., 2000).

Figure 6 Correlation of the Neoproterozoic to Lower Paleozoic Laurentian stratigraphy of the Scotland and the central Fjord region of East Greenland. The correlation is structured around the dated global record of Neoproterozoic glacials and a tentative but chronologically unconstrained set of important flooding surfaces identified in the Neoproterozoic depositional record. The timing of the principal orogenic events is shown schematically. B.B., Boulder Bed.

Figure 7 Selected frequency distribution diagrams for detrital zircon ages determined for the Dalradian Supergroup of Scotland and its basement (after Cawood et al., 2003).

Figure 8 Map of the principal Grampian and Scandian structural features in the Northern and Grampian Highlands of Scotland along with the principal Ordovician and Siluro-Devonian intrusions (*cf.* Fig. 2). The cross-section along the line A-B illustrates the gross structural architecture of each region and overall pattern of structural divergence that results in this part of the Caledonian Orogen.

Figure 9 Schematic early Ediacaran paleogeography (A) for the Laurentian 'Scottish Corner' along with possible crustal cross-sections at this time. Note the suggestion for a change in the dominant polarity of Iapetan faulting on the onboard parts of the margin across the Foyers Cairngorm lineament (*cf.* Smith et al., 1999). Schematic crustal cross sections for the fjord region of central East Greenland (B) and for Kronprins Christian Land (C) are added for comparison. See discussion in text.

Figure 10 Schematic sections A, B and C illustrating the Ordovician to Silurian plate tectonic evolution of the 'Scottish Corner' on the Laurentian continental margin. In the inset addition to section C, end-Silurian (*c.* 410 Ma) juxtaposition of Avalonia against the Midland Valley was achieved along a major terrane boundary now expressed as the Southern Upland Fault. BV, Ben Vuirich Granite; C-O, Cambro-Ordovician shelf succession; GB, Glen Banchor 'High'; GGF, Great Glen Fault; HBF, Highland Boundary Fault; IS, Iapetus Suture; Mo, Moine Supergroup; MTZ, Moine Thrust Zone; MVA, Midland Valley Arc; MVT, Midland Valley Terrane; NT, Naver Thrust; OIT, Outer Isles Thrust; SUF, Southern Upland Fault; To, Torridonian; TV, Tayvallich volcanics.

PLATES

Plate 1A View north across Loch Glencoul, northwest Scottish Highlands. The Ben More Thrust is one of the principal thrusts developed within the Assynt culmination in the Moine Thrust Zone (Caledonian front) and here places Lewisian Gneisses in the Ben More Thrust Sheet onto Cambrian Quartzites and Lewisian Gneisses of the foreland. The Moine Thrust (*s.s.*) lies structurally above and to the right in the view shown. The summit is 450 m above the loch. BGS Photograph No. P000965.

Plate 1B Typical banded Scourian (Paleoproterozoic) Lewisian TTG orthogneiss, Achmelvich Bay, northwest Scottish Highlands. The mafic enclave identified in the photograph has a longest dimension of approximately 80 cm. BGS Photograph No. P513590.

Plate 1C View east-northeast across Suilven mountain in the northwest Scottish Highlands. The unconformity between the horizontally bedded early Neoproterozoic Torridonian sandstones which make up the mountain and the underlying ‘cnoc and lochan’ terrain of the Paleoproterozoic Lewisian Gniesses is clearly demonstrated. The near summit (Caisteal Liath, 731 m) lies some 550 m above the surrounding plain. BGS Photograph No. P000827

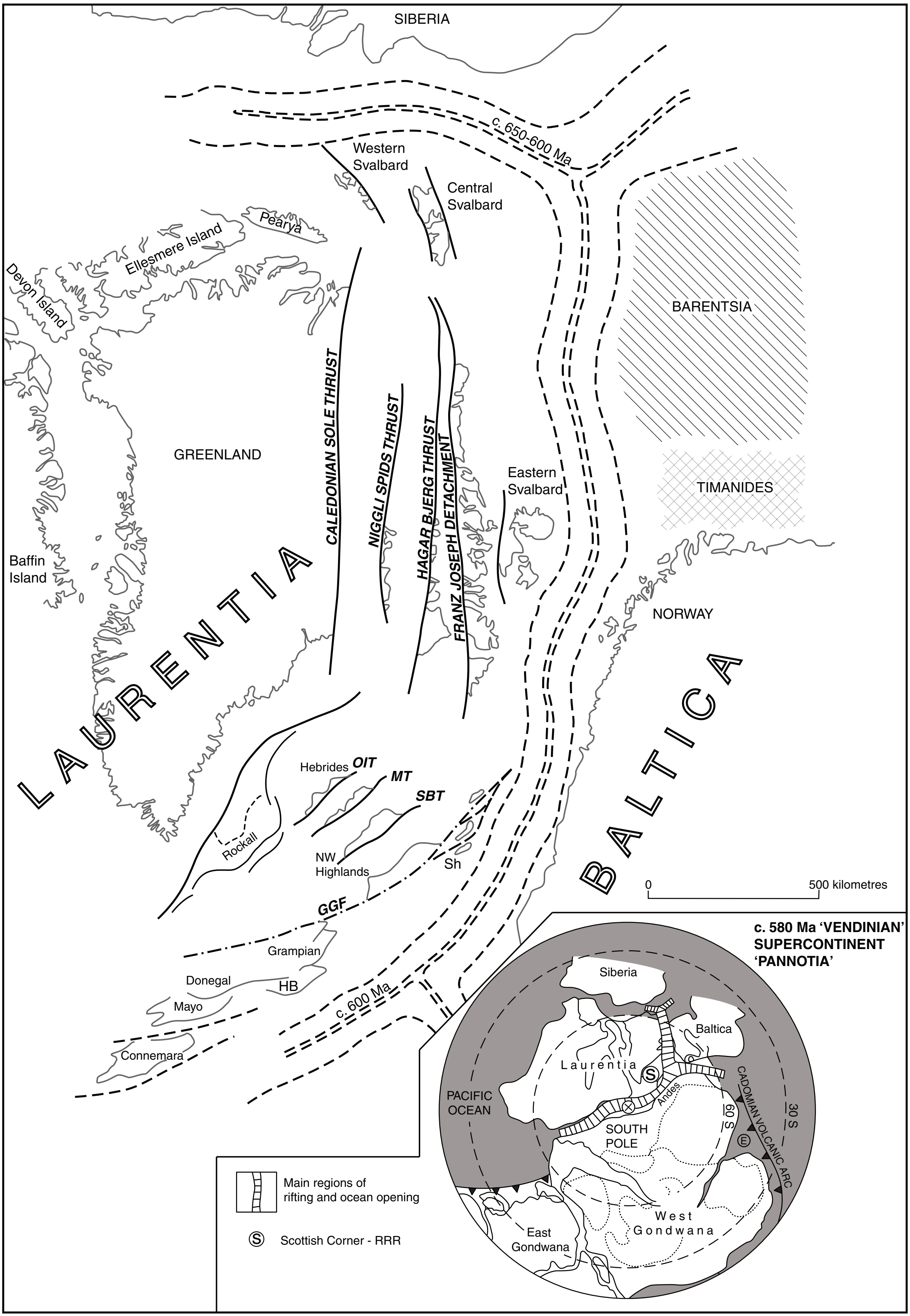
Plate 1D Interlayered cross-bedded psammitic and striped semipelitic rocks belonging to the Glenfinnan Group of the early Neoproterozoic Moine Supergroup, Loch Cluanie, Wester Ross, Northern Highlands. Hammer shaft is approximately 35 cm long. Photograph, JR Mendum, BGS.

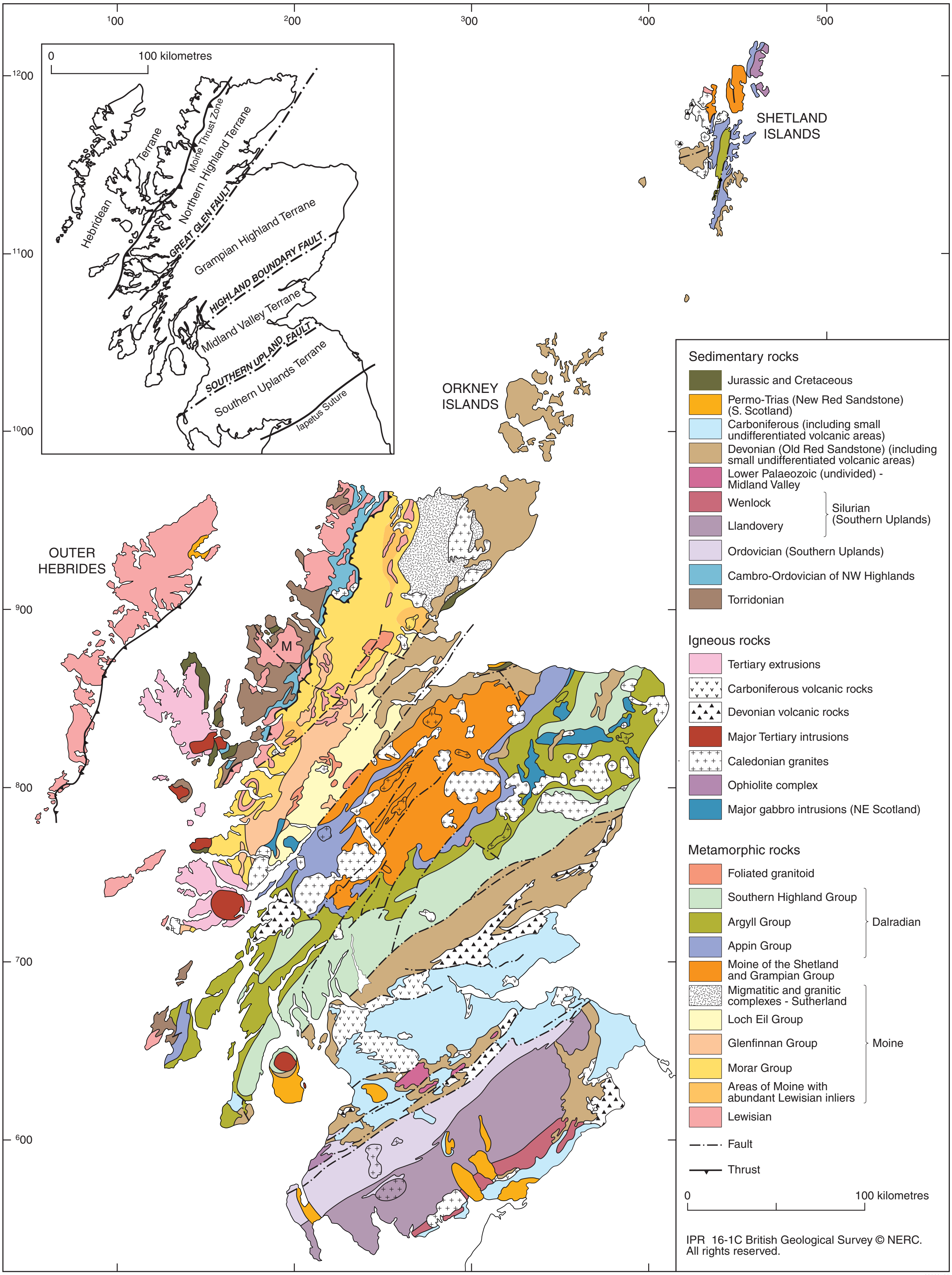
Plate 2A Roadside exposure of the Neoproterozoic (c. 870 Ma) West Highland Granite Gneiss along with the mafic sheets intruded into the granite prior to Knoydartian deformation and metamorphism at c. 820 Ma. Invermoriston, Wester Ross, Northern Highlands. The thickest of the mafic sheets is approximately 40 cm thick. BGS Photograph No. P579984. The inset shows the strongly foliated granite gneiss. Coin is 2cm in diameter, BGS Photograph No. P580522.

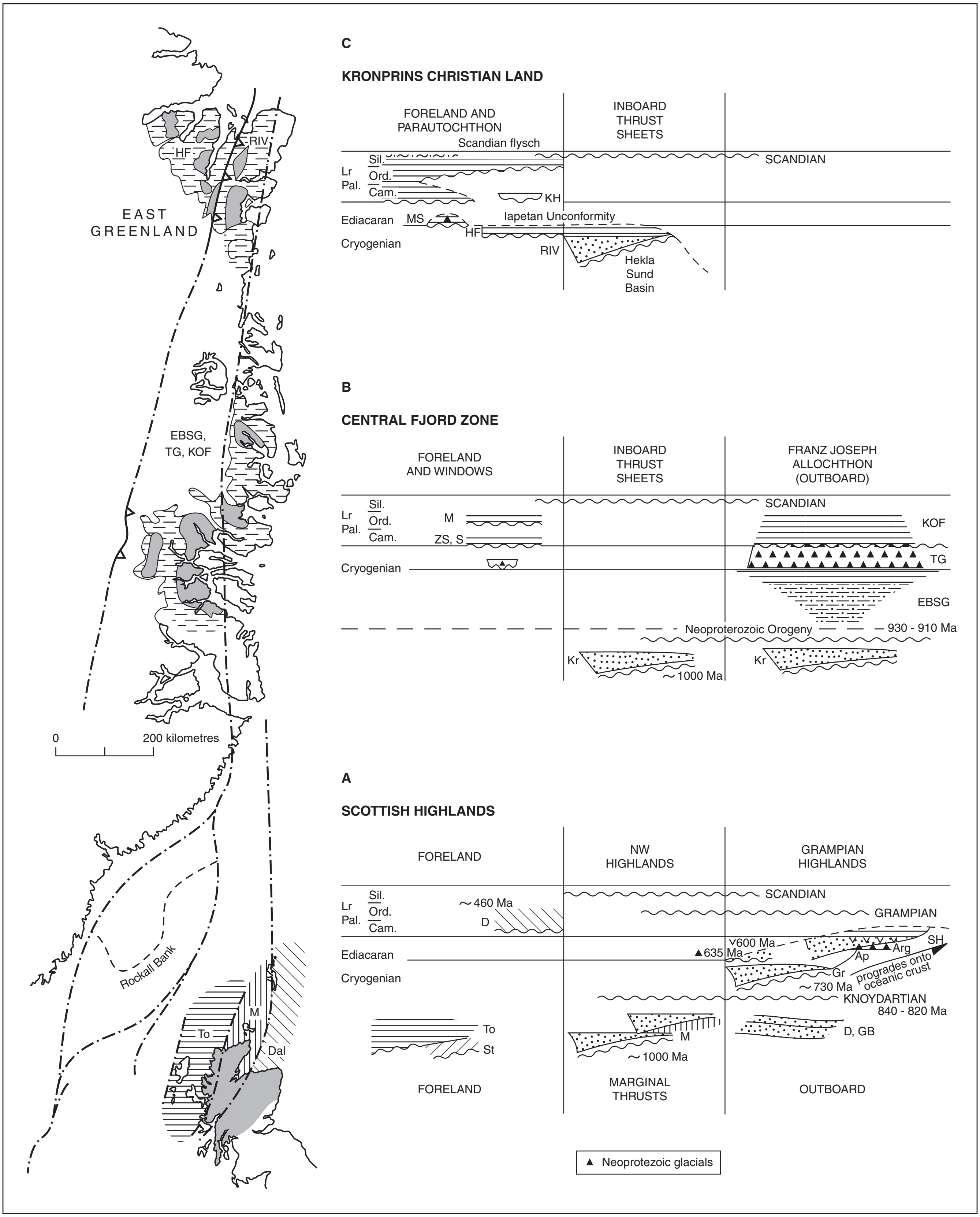
Plate 2B Prominently ribbed and graded late Neoproterozoic psammitic turbidites; the more micaceous uppermost parts of each layer preferentially erode giving a distinctive ‘sawtooth’ profile at outcrop. Grampian Group Dalradian, Ben Alder, central Grampian Highlands. Hammer shaft is approximately 35 cm long, BGS Photograph No. P605180.

Plate 2C Diamictite in the Port Askaig Tillite Formation; cleaved and containing large clasts mainly of granite. Argyll Group Dalradian, Islay, southwest Scottish Highlands. The hammer shaft is approximately 40 cm long, BGS Photograph No. P215702.

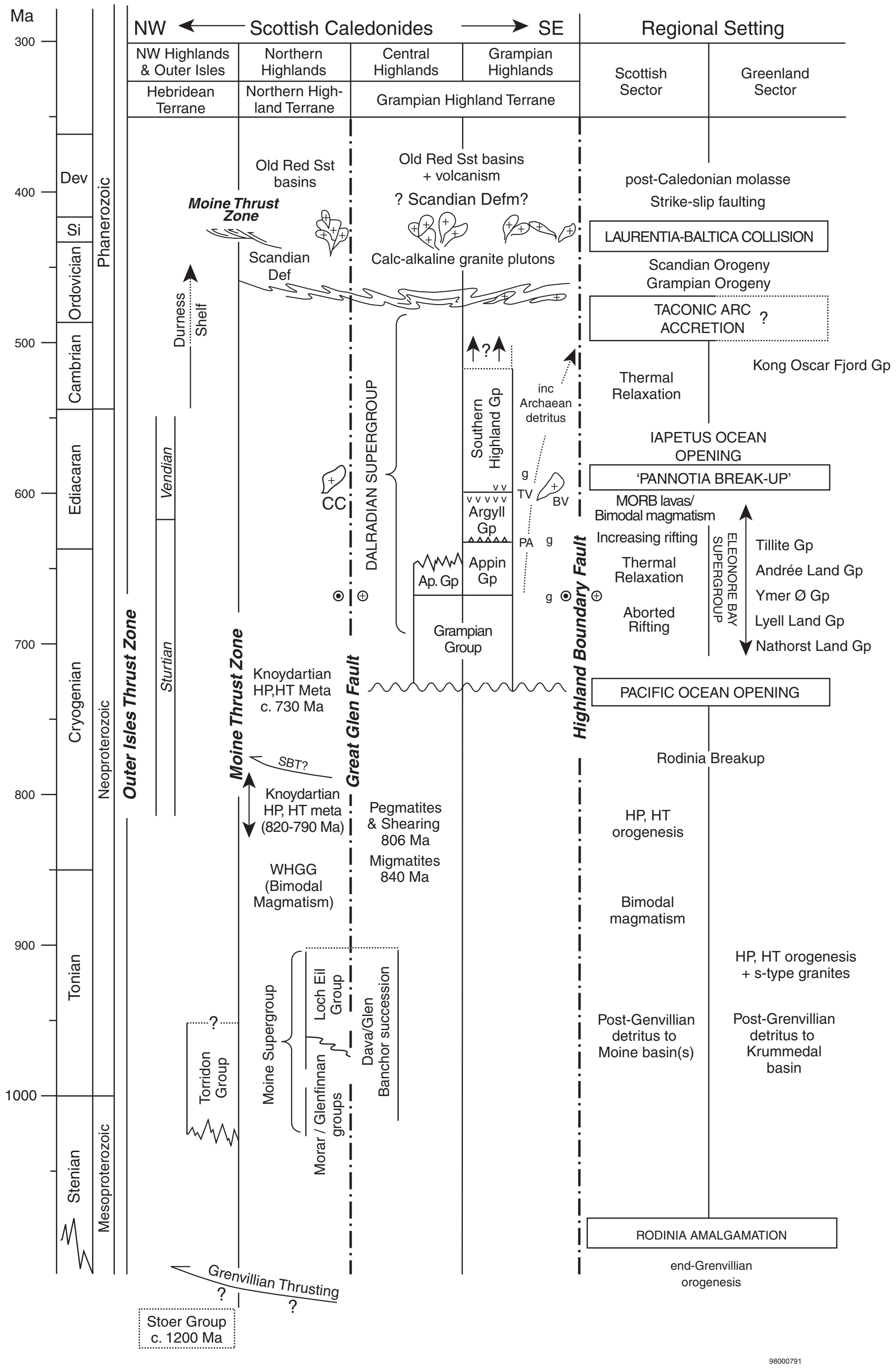
Plate 2D Basaltic pillow lavas of the Vendian Tayvallich Volcanic Formation. Argyll Group Dalradian, coast south west of Tayvallich, Argyll, southwest Scottish Highlands. The hammer shaft is approximately 40 cm long, BGS Photograph No. P219459.

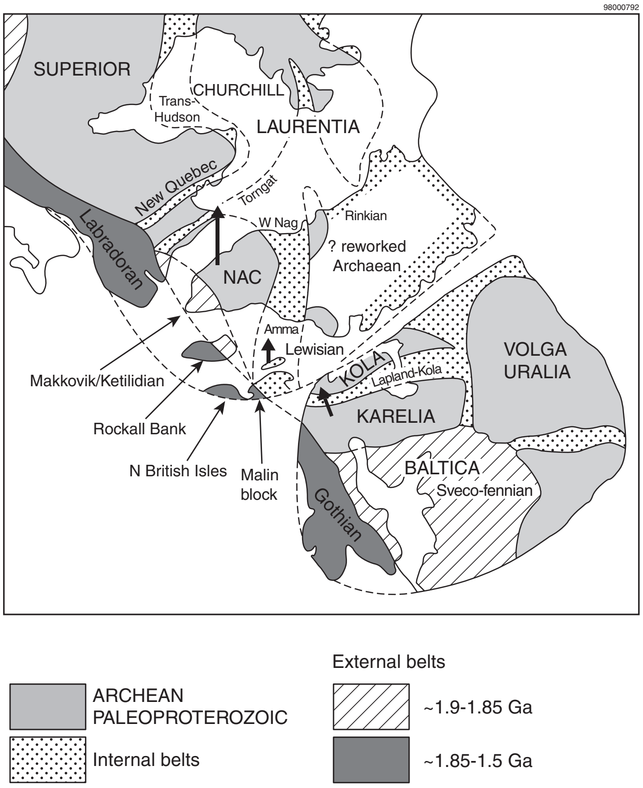

SIBERIA
c. 650-600 Ma
Western Svalbard
Central Svalbard
Pearya
Ellesmere Island
Devon Island
BARENTSIA
CALEDONIAN SOLE THRUST
NIGGLI SPIDS THRUST
HAGAR BJERG THRUST
FRANZ JOSEPH DETACHMENT
GREENLAND
Eastern Svalbard
TIMANIDES
Baffin Island
NORWAY
LAURENTIA
BALTICA
Hebrides
OIT
MT
SBT
Rockall
NW Highlands
Sh
0
500 kilometres
GGF
Grampian
Donegal
HB
Mayo
c. 600 Ma
Connemara
c. 580 Ma 'VENDINIAN' SUPERCONTINENT 'PANNOTIA'
Siberia
Baltica
Laurentia
S
Andes
PACIFIC OCEAN
SOUTH POLE
60 S
30 S
CADOMIAN VOLCANIC ARC
E
West Gondwana
East Gondwana
Main regions of rifting and ocean opening
S Scottish Corner - RRR
98000788

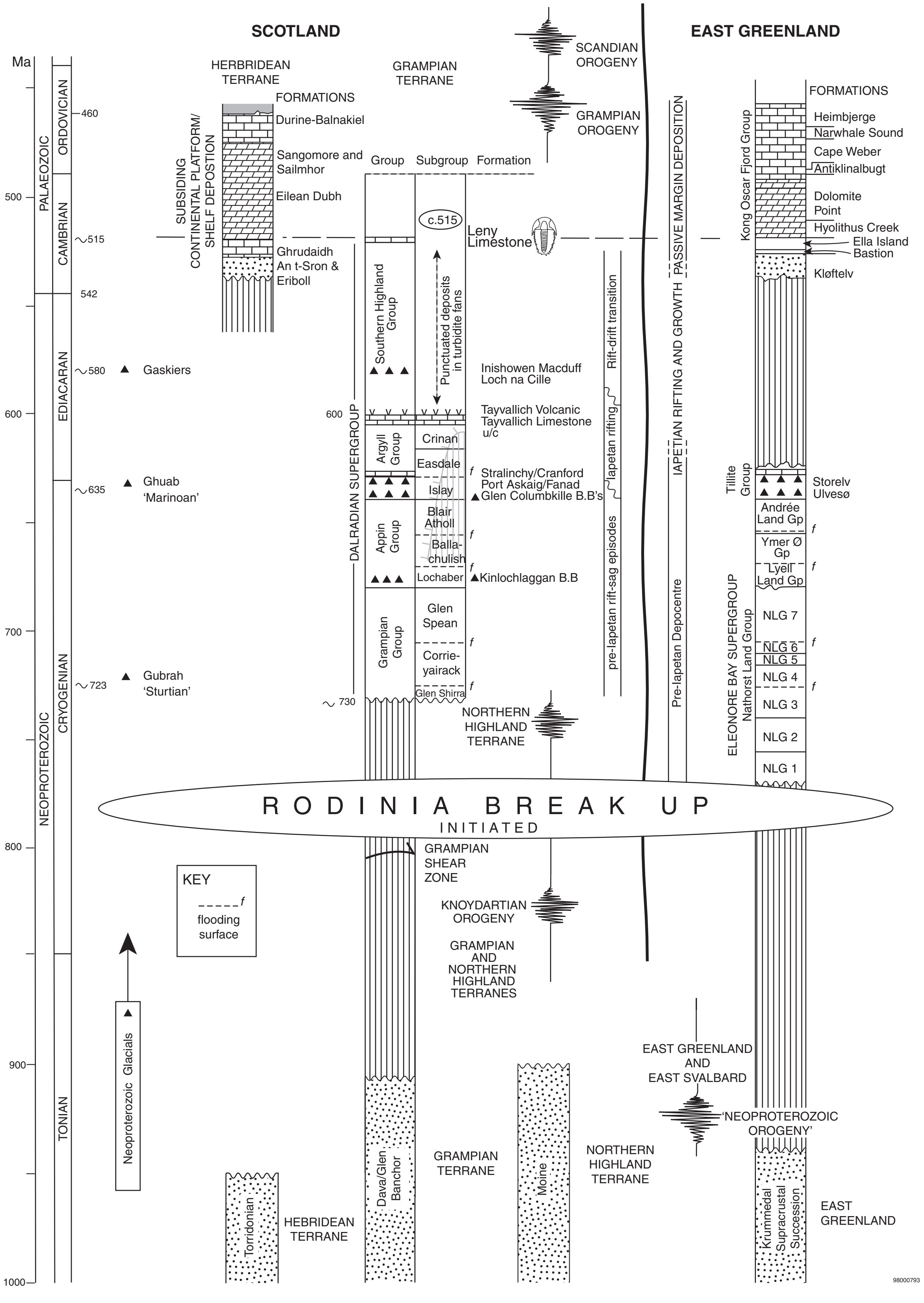

100
200
300
400
500
1200
1100
1000
900
800
700
600
0
100 kilometres
Hebridean Terrane
Moine Thrust Zone
Northern Highland Terrane
GREAT GLEN FAULT
Grampian Highland Terrane
HIGHLAND BOUNDARY FAULT
Midland Valley Terrane
SOUTHERN UPLAND FAULT
Southern Uplands Terrane
Iapetus Suture
SHETLAND ISLANDS
ORKNEY ISLANDS
OUTER HEBRIDES
M
Sedimentary rocks
Jurassic and Cretaceous
Permo-Trias (New Red Sandstone) (S. Scotland)
Carboniferous (including small undifferentiated volcanic areas)
Devonian (Old Red Sandstone) (including small undifferentiated volcanic areas)
Lower Palaeozoic (undivided) - Midland Valley
Wenlock
Llandovery
Silurian (Southern Uplands)
Ordovician (Southern Uplands)
Cambro-Ordovician of NW Highlands
Torridonian
Igneous rocks
Tertiary extrusions
Carboniferous volcanic rocks
Devonian volcanic rocks
Major Tertiary intrusions
Caledonian granites
Ophiolite complex
Major gabbro intrusions (NE Scotland)
Metamorphic rocks
Foliated granitoid
Southern Highland Group
Argyll Group
Appin Group
Dalradian
Moine of the Shetland and Grampian Group
Migmatitic and granitic complexes - Sutherland
Loch Eil Group
Glenfinnan Group
Morar Group
Areas of Moine with abundant Lewisian inliers
Moine
Lewisian
Fault
Thrust
0
100 kilometres
98000789

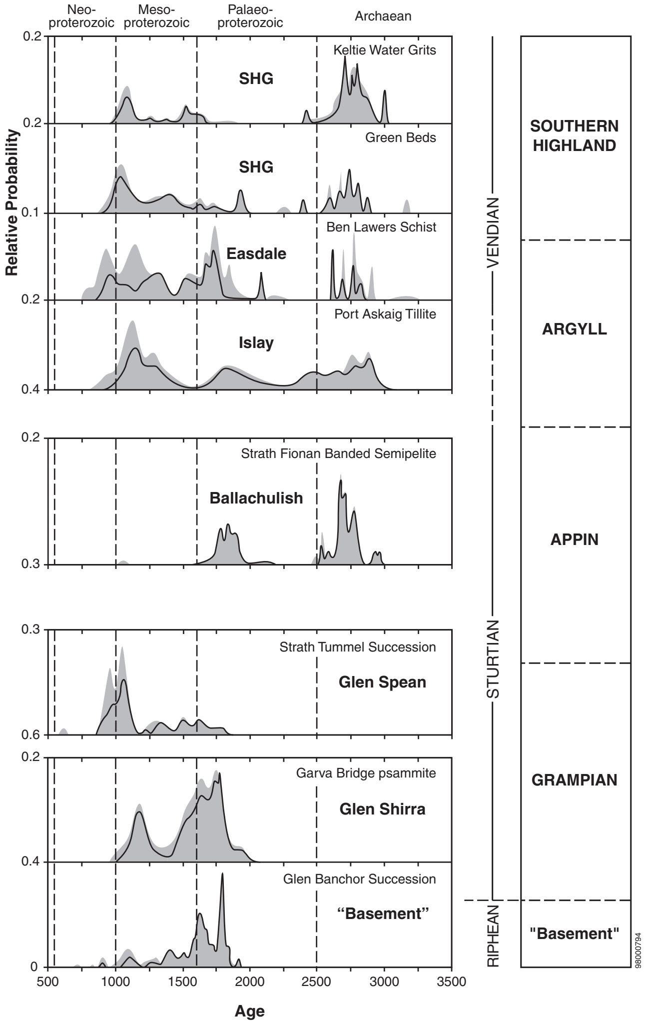

EAST GREENLAND
HF
RIV
EBSG, TG, KOF
0
200 kilometres
Rockall Bank
To
M
Dal
C
KRONPRINS CHRISTIAN LAND
FORELAND AND PARAUTOCHTHON
INBOARD THRUST SHEETS
Scandian flysch
SCANDIAN
Lr Pal.
Sil.
Ord.
Cam.
KH
Ediacaran
MS
Iapetan Unconformity
HF
Cryogenian
RIV
Hekla Sund Basin
B
CENTRAL FJORD ZONE
FORELAND AND WINDOWS
INBOARD THRUST SHEETS
FRANZ JOSEPH ALLOCHTHON (OUTBOARD)
SCANDIAN
Lr Pal.
Sil.
Ord.
Cam.
M
ZS, S
KOF
TG
Cryogenian
EBSG
Neoproterozoic Orogeny
930 - 910 Ma
Kr
1000 Ma
Kr
A
SCOTTISH HIGHLANDS
FORELAND
NW HIGHLANDS
GRAMPIAN HIGHLANDS
SCANDIAN
Lr Pal.
Sil.
Ord.
Cam.
460 Ma
D
GRAMPIAN
600 Ma
SH
Ediacaran
635 Ma
Ap
Arg
Cryogenian
Gr
730 Ma
progrades onto oceanic crust
KNOYDARTIAN
840 - 820 Ma
To
St
M
1000 Ma
D, GB
FORELAND
MARGINAL THRUSTS
OUTBOARD
▲ Neoprotezoic glacials

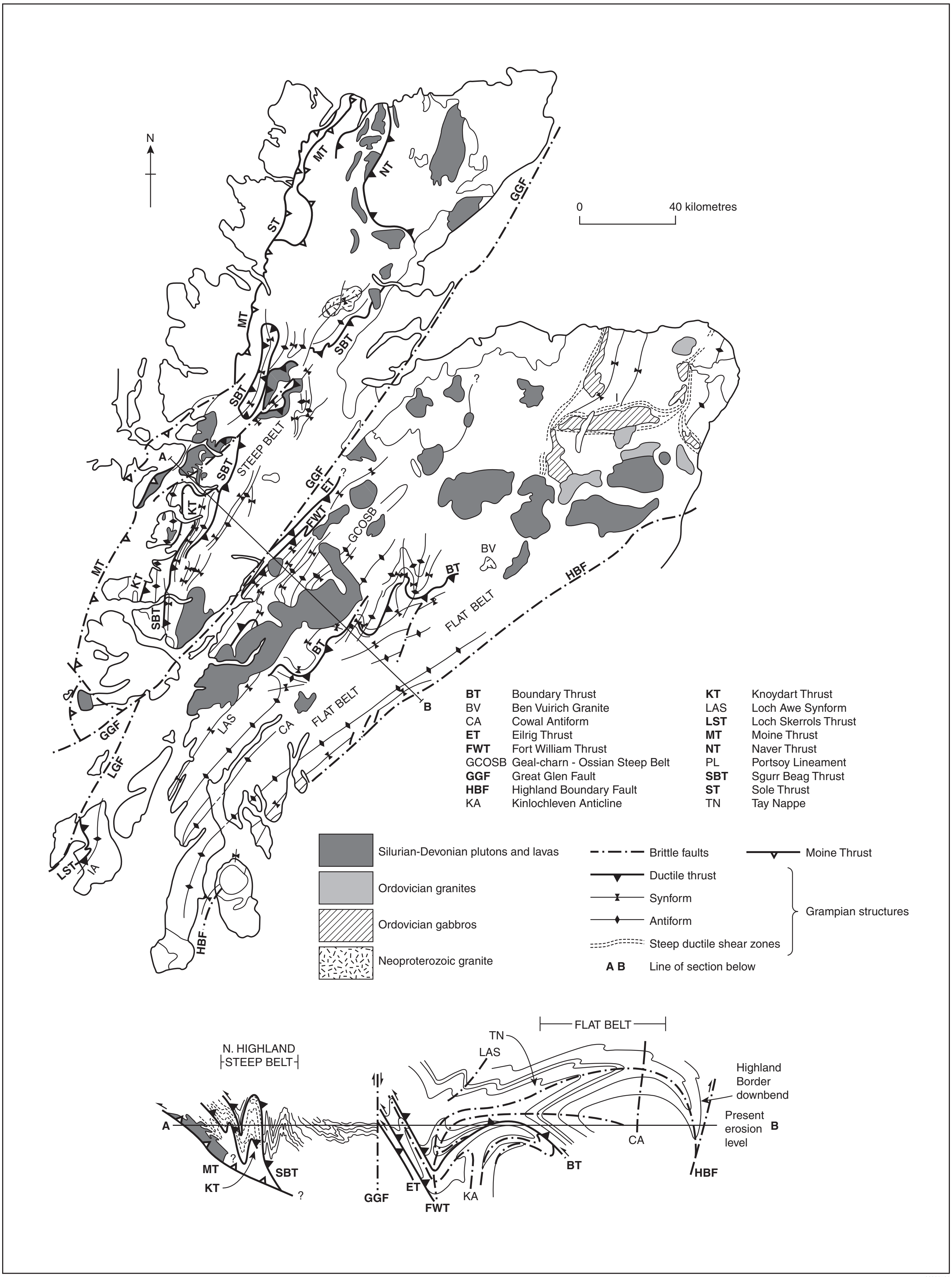
98000790


Ma
300
400
500
600
700
800
900
1000
Dev
Si
Ordovician
Cambrian
Ediacaran
Cryogenian
Tonian
Stenian
Phanerozoic
Neoproterozoic
Mesoproterozoic
NW
Scottish Caledonides
SE
Regional Setting
NW Highlands & Outer Isles
Northern Highlands
Central Highlands
Grampian Highlands
Hebridean Terrane
Northern Highland Terrane
Grampian Highland Terrane
Scottish Sector
Greenland Sector
Old Red Sst basins
Old Red Sst basins + volcanism
Moine Thrust Zone
? Scandian Defm?
Scandian Def
Calc-alkaline granite plutons
Durness Shelf
Vendian
Sturtian
Outer Isles Thrust Zone
Moine Thrust Zone
Great Glen Fault
Highland Boundary Fault
DALRADIAN SUPERGROUP
CC
Southern Highland Gp
Argyll Gp
Appin Gp
Ap. Gp
Grampian Group
inc Archaean detritus
g
TV
BV
PA
g
g
Knoydartian HP,HT Meta c. 730 Ma
SBT?
Knoydartian HP, HT meta (820-790 Ma)
Pegmatites & Shearing 806 Ma
Migmatites 840 Ma
WHGG (Bimodal Magmatism)
Moine Supergroup
Loch Eil Group
Morar / Glenfinnan groups
Dava/Glen Banchor succession
Torridon Group
?
Grenvillian Thrusting
?
?
Stoer Group c. 1200 Ma
post-Caledonian molasse
Strike-slip faulting
LAURENTIA-BALTICA COLLISION
Scandian Orogeny
Grampian Orogeny
TACONIC ARC ACCRETION
?
Thermal Relaxation
Kong Oscar Fjord Gp
IAPETUS OCEAN OPENING
'PANNOTIA BREAK-UP'
MORB lavas/ Bimodal magmatism
Increasing rifting
Thermal Relaxation
Aborted Rifting
ELEONORE BAY SUPERGROUP
Tillite Gp
Andrée Land Gp
Ymer Ø Gp
Lyell Land Gp
Nathorst Land Gp
PACIFIC OCEAN OPENING
Rodinia Breakup
HP, HT orogenesis
Bimodal magmatism
HP, HT orogenesis + s-type granites
Post-Genvillian detritus to Moine basin(s)
Post-Grenvillian detritus to Krummedal basin
RODINIA AMALGAMATION
end-Grenvillian orogenesis
98000791

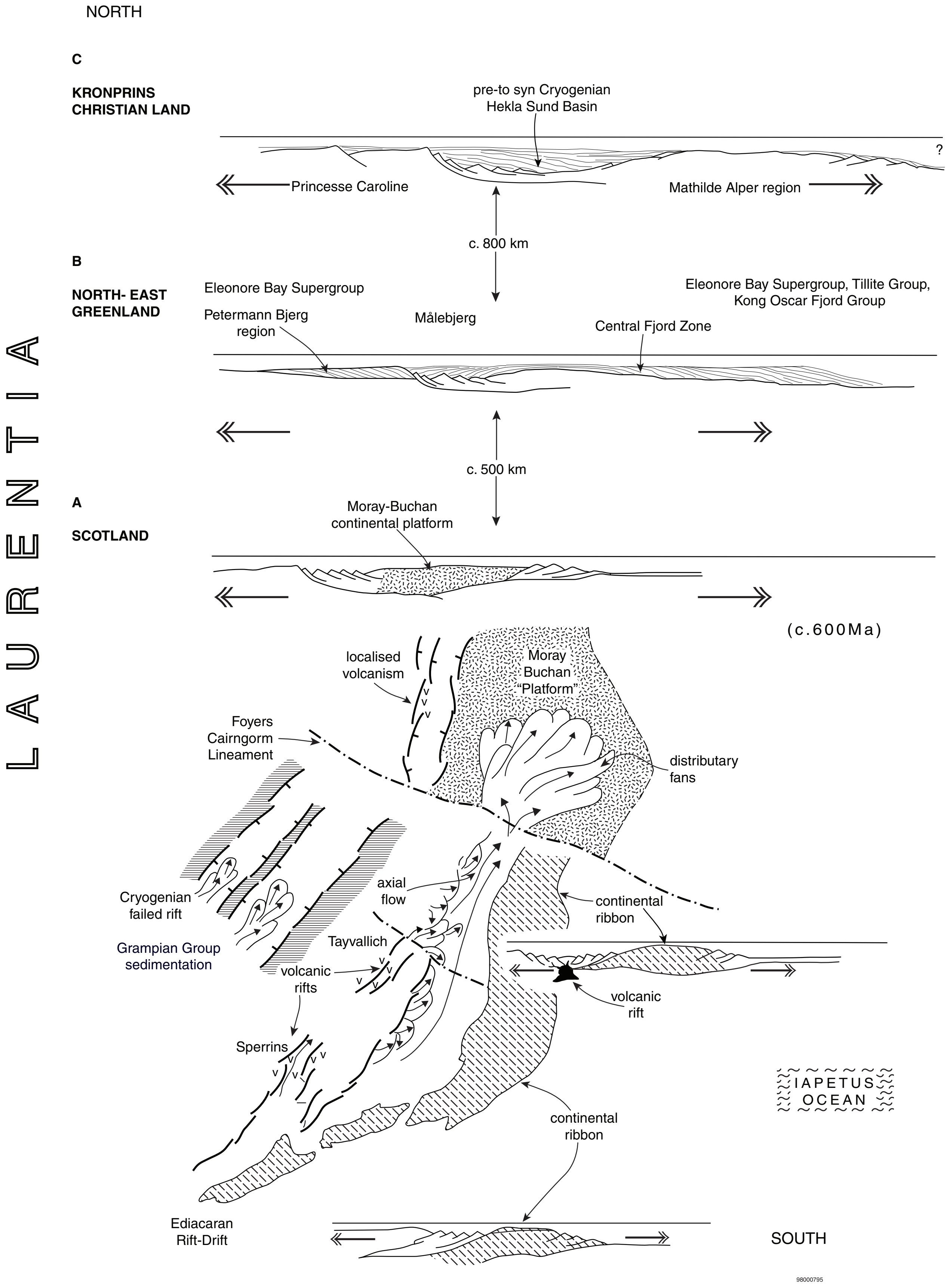

98000792
SUPERIOR
CHURCHILL
Trans-Hudson
LAURENTIA
New Quebec
Torngat
Labradoran
W Nag
Rinkian
? reworked Archaean
NAC
Amma
Lewisian
KOLA
Lapland-Kola
VOLGA URALIA
KARELIA
BALTICA
Sveco-fennian
Gothian
Makkovik/Ketilidian
Rockall Bank
N British Isles
Malin block
ARCHEAN PALEOPROTEROZOIC
Internal belts
External belts
~1.9-1.85 Ga
~1.85-1.5 Ga

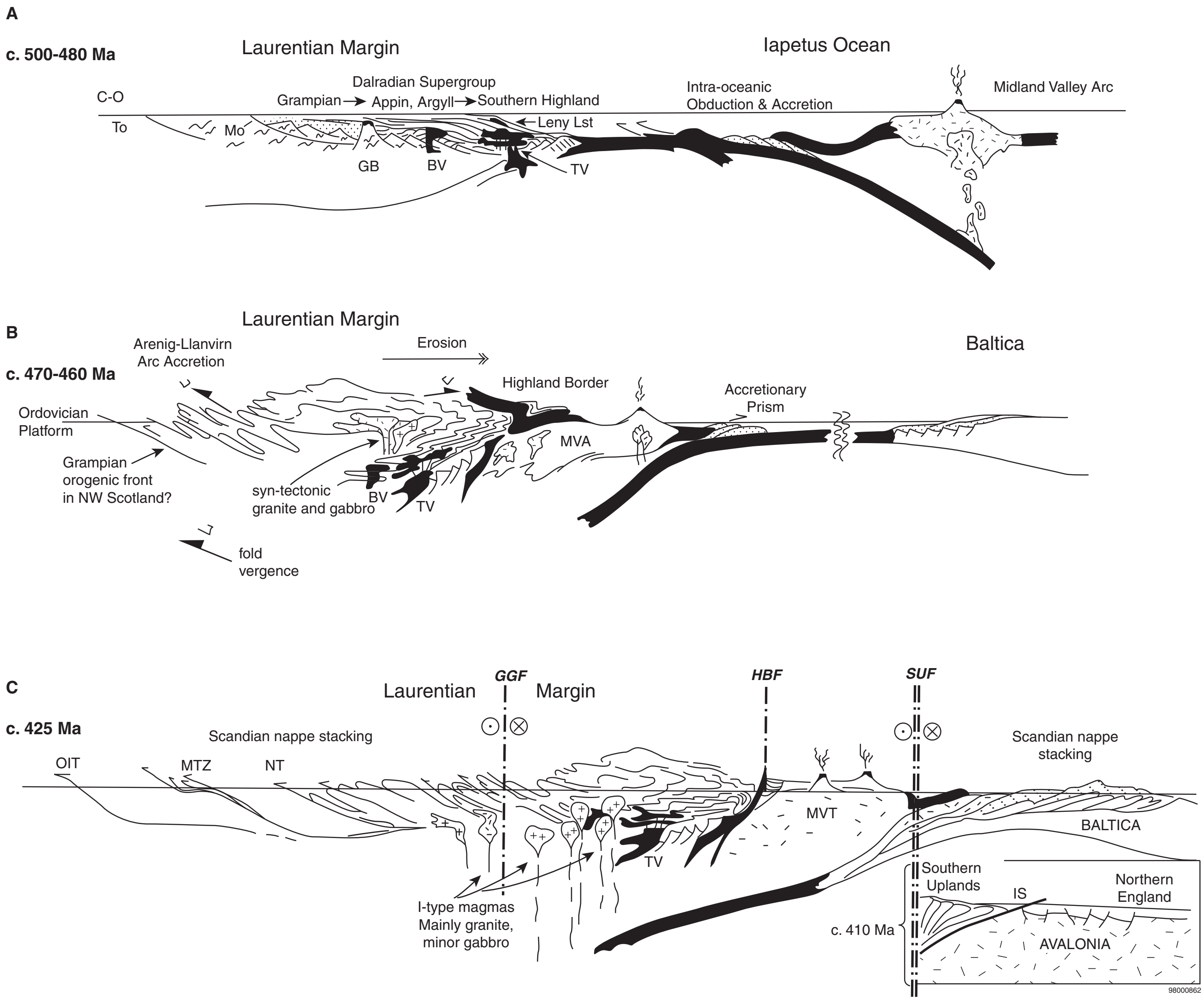

SCOTLAND
EAST GREENLAND
Ma
PALAEOZOIC
ORDOVICIAN
CAMBRIAN
NEOPROTEROZOIC
EDIACARAN
CRYOGENIAN
TONIAN
460
500
515
542
580
600
635
700
723
730
800
900
1000
Gaskiers
Ghuab
'Marinoan'
Gubrah
'Sturtian'
Neoproterozoic Glacials
KEY
f
flooding surface
HERBRIDEAN TERRANE
FORMATIONS
Durine-Balnakiel
Sangomore and Sailmhor
Eilean Dubh
Ghrudaidh
An t-Sron &
Eriboll
SUBSIDING CONTINENTAL PLATFORM/ SHELF DEPOSTION
GRAMPIAN TERRANE
Group
Subgroup
Formation
c.515
Leny Limestone
Southern Highland Group
Punctuated deposits in turbidite fans
DALRADIAN SUPERGROUP
Argyll Group
Appin Group
Grampian Group
Crinan
Easdale
Islay
Blair Atholl
Balla-chulish
Lochaber
Glen Spean
Corrie-yairack
Glen Shirra
Inishowen Macduff
Loch na Cille
Tayvallich Volcanic
Tayvallich Limestone
u/c
Stralinchy/Cranford
Port Askaig/Fanad
Glen Columbkille B.B's
Kinlochlaggan B.B
SCANDIAN OROGENY
GRAMPIAN OROGENY
NORTHERN HIGHLAND TERRANE
Rift-drift transition
Iapetan rifting
pre-Iapetan rift-sag episodes
PASSIVE MARGIN DEPOSITION
IAPETIAN RIFTING AND GROWTH
Pre-Iapetan Depocentre
RODINIA BREAK UP
INITIATED
GRAMPIAN SHEAR ZONE
KNOYDARTIAN OROGENY
GRAMPIAN AND NORTHERN HIGHLAND TERRANES
FORMATIONS
Kong Oscar Fjord Group
Heimbjerge
Narwhale Sound
Cape Weber
Antiklinalbugt
Dolomite Point
Hyolithus Creek
Ella Island
Bastion
Kløftelv
Tillite Group
Storelv
Ulvesø
Andrée Land Gp
Ymer Ø Gp
Lyell Land Gp
ELEONORE BAY SUPERGROUP
Nathorst Land Group
NLG 7
NLG 6
NLG 5
NLG 4
NLG 3
NLG 2
NLG 1
EAST GREENLAND AND EAST SVALBARD
'NEOPROTEROZOIC OROGENY'
Torridonian
HEBRIDEAN TERRANE
Dava/Glen Banchor
GRAMPIAN TERRANE
Moine
NORTHERN HIGHLAND TERRANE
Krummedal Supracrustal Succession
EAST GREENLAND
98000793

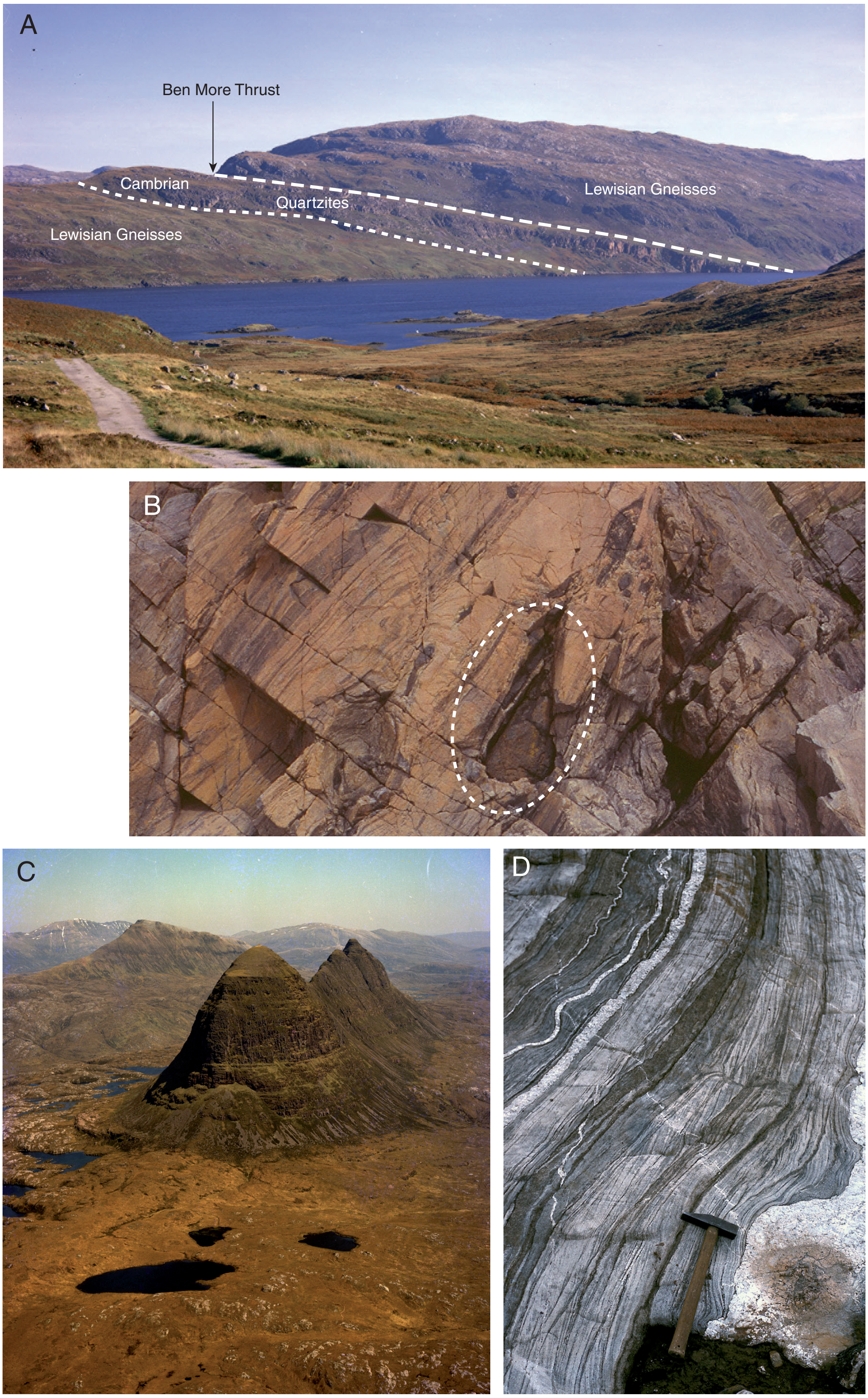

Neo-proterozoic
Meso-proterozoic
Palaeo-proterozoic
Archaean
Relative Probability
0.2
Keltie Water Grits
SHG
0.2
Green Beds
SHG
0.1
Ben Lawers Schist
Easdale
0.2
Port Askaig Tillite
Islay
0.4
0.2
Strath Fionan Banded Semipelite
Ballachulish
0.3
0.3
Strath Tummel Succession
Glen Spean
0.6
0.2
Garva Bridge psammite
Glen Shirra
0.4
Glen Banchor Succession
"Basement"
0
500
1000
1500
2000
2500
3000
3500
Age
VENDIAN
STURTIAN
RIPHEAN
SOUTHERN HIGHLAND
ARGYLL
APPIN
GRAMPIAN
"Basement"
98000794


N
0 40 kilometres
ST
MT
NT
GGF
SBT
STEEP BELT
A
KT
ET
FWT
GCOSB
BV
BT
FLAT BELT
HBF
B
LAS
CA
LGF
LST
IA
?
BT Boundary Thrust
BV Ben Vuirich Granite
CA Cowal Antiform
ET Eilrig Thrust
FWT Fort William Thrust
GCOSB Geal-charn - Ossian Steep Belt
GGF Great Glen Fault
HBF Highland Boundary Fault
KA Kinlochleven Anticline
KT Knoydart Thrust
LAS Loch Awe Synform
LST Loch Skerrols Thrust
MT Moine Thrust
NT Naver Thrust
PL Portsoy Lineament
SBT Sgurr Beag Thrust
ST Sole Thrust
TN Tay Nappe
Silurian-Devonian plutons and lavas
Ordovician granites
Ordovician gabbros
Neoproterozoic granite
Brittle faults
Moine Thrust
Ductile thrust
Synform
Antiform
Steep ductile shear zones
Grampian structures
A B Line of section below
N. HIGHLAND
STEEP BELT
FLAT BELT
TN
LAS
Highland
Border
downbend
Present
erosion
level
A
B
MT
KT
SBT
GGF
ET
FWT
KA
BT
CA
HBF
?

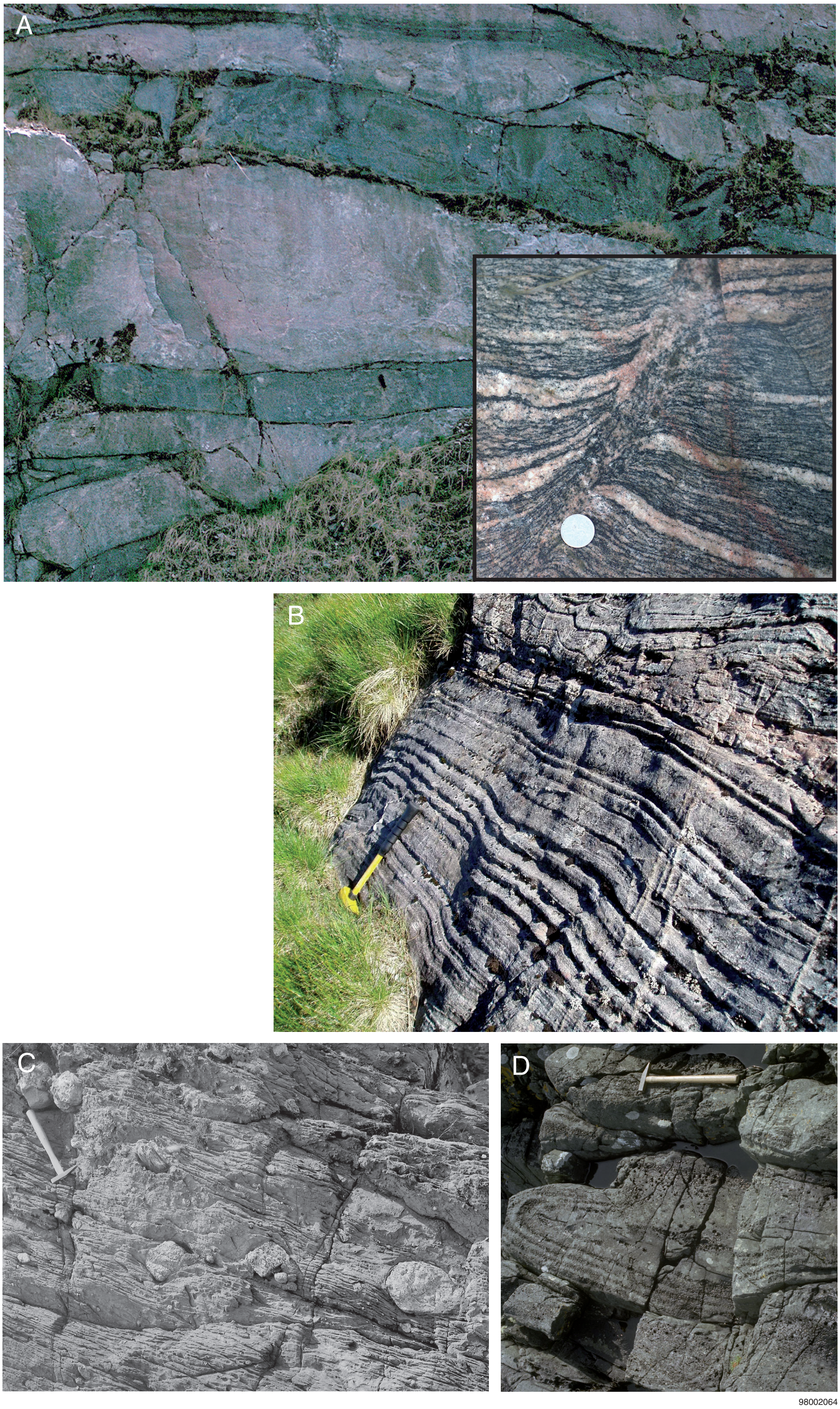
98000796


NORTH
C
KRONPRINS CHRISTIAN LAND
pre-to syn Cryogenian Hekla Sund Basin
?
Princesse Caroline
Mathilde Alper region
c. 800 km
B
NORTH- EAST GREENLAND
Eleonore Bay Supergroup
Eleonore Bay Supergroup, Tillite Group, Kong Oscar Fjord Group
Petermann Bjerg region
Målebjerg
Central Fjord Zone
c. 500 km
A
SCOTLAND
Moray-Buchan continental platform
LAURENTIA
(c.600Ma)
localised volcanism
Moray Buchan "Platform"
Foyers Cairngorm Lineament
distributary fans
axial flow
continental ribbon
Cryogenian failed rift
Grampian Group sedimentation
Tayvallich
volcanic rifts
volcanic rift
Sperrins
IAPETUS OCEAN
continental ribbon
Ediacaran Rift-Drift
SOUTH
98000795


A
c. 500-480 Ma
Laurentian Margin
Iapetus Ocean
Dalradian Supergroup
Grampian → Appin, Argyll → Southern Highland
C-O
To
Mo
Leny Lst
GB
BV
TV
Intra-oceanic
Obduction & Accretion
Midland Valley Arc
B
c. 470-460 Ma
Laurentian Margin
Arenig-Llanvirn
Arc Accretion
Erosion
Highland Border
Accretionary
Prism
Baltica
Ordovician
Platform
Grampian
orogenic front
in NW Scotland?
syn-tectonic
granite and gabbro
BV
TV
MVA
fold
vergence
C
c. 425 Ma
Laurentian
GGF
Margin
HBF
SUF
Scandian nappe stacking
OIT
MTZ
NT
MVT
TV
Scandian nappe
stacking
BALTICA
I-type magmas
Mainly granite,
minor gabbro
Southern
Uplands
IS
Northern
England
c. 410 Ma
AVALONIA
98000862


A
Ben More Thrust
Cambrian
Quartzites
Lewisian Gneisses
Lewisian Gneisses
B
C
D

98002063


A
B
C
D
98002064