The Geology of the Isles of Skye and Raasay

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Typeset by David Bell

Guide, excursions and other resources available Online

www.skyegeology.com

Front Cover

View towards the NW from Ord on the west coast of Sleat, across Loch Eishort with the southern cliffs of Strath composed of Lower Jurassic Pabay Shale Formation strata (right, middle ground), Strathaird composed of Middle Jurassic Great Estuarine Group strata capped by Paleocene lavas (left, middle ground) and, in the distance, the Cuillin Hills, the remnants of a Paleocene intrusive centre. Photograph courtesy of Christine Bell (May 2017).

Back Cover

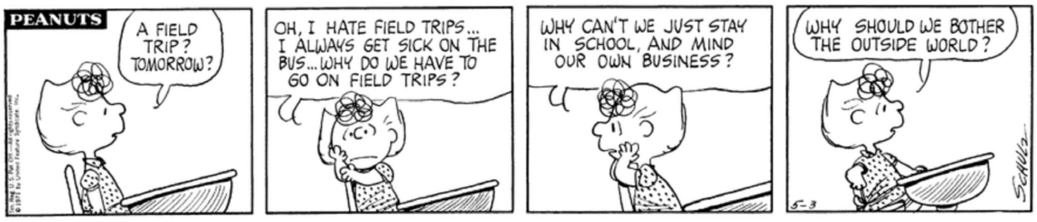
The Kilt Rock, south of Staffin on the east coast of Trotternish, comprising the cliff-forming eroded remnant of a Paleocene olivine dolerite sill of the Little Minch Sill Complex, emplaced into Middle Jurassic Valtos Sandstone Formation strata of the Great Estuarine Group. The illusion to a kilt is based upon the vertical prismatic joints (locally columnar) resembling the pleats of a kilt, further heightened by their variation in colour.

Forward

This Second Edition of *The Geology of the Isle of Skye* now includes the neighbouring Isle of Raasay, hence the new title. To all who have a love of field geology, I hope it will encourage you to visit these islands and inspire you to make your own observations.

Acknowledgements

This account of the geology of the Isles of Skye and Raasay has benefited greatly from time spent in the field with many friends and colleagues over the last forty years. In particular, I thank Iain Allison and Ian Williamson for putting up with my company over the years and giving freely of their time, energy, advice and friendship. Henry Emeleus was a mentor and friend throughout much of my career, teaching me the importance of field observations: it is my privilege to acknowledge Henry's role in my geological education.



Brian Bell, Cuillin Hills (2016)

“Ruari’s after takin’ a great lump of them jolly gees to the hills and then he’ll be after collectin’ some cattle from Rhuna and he’s sayin’ you’ll get with them if you’ve a mind” she informed me. (Morag always expressed quantity in ‘lumps’ whether she was speaking of manure, cheese or humanity). I accepted with alacrity even though, as I told Morag, I had no idea what ‘jolly gees’ might be.

“Jolly gees? Why, they’re thon fellows who hammer little bits off the hills and then fancy they can tell the Lord Himself how the Earth was made,” Morag replied.

“Geologists!” I exclaimed. She nodded.

…

“There they go,” she muttered resentfully, pointing through the window at the straggling party of men, each armed with a capacious rucksack, who were picking their way down to the shore.

“Don’t you like them?” I asked carelessly.

“Like them? Indeed I do not!” she replied with unaccustomed vehemence. “Climbing like spiders all over the hills and tap, tap, tappin’ with their little hammers. One of these days we’ll wake up in the mornin’ and find no hills left.

…

The hills for which we were bound looked cold and remote, their wintry peaks appearing to jostle one another for a glimpse of the morning sun. ….. The geologists stared towards them speculatively, their minds no doubt occupied with formations and faults, bridging the gap of millions of years.

…

Later in the day we returned to pick them up.

…

It was not long before we met two of the geologists tottering down towards us, carrying between them a heavy sack. ….. He gestured towards the heavy bag which had been dropped on first seeing us. “Here,” he instructed Ruari imperiously, “you can carry that down to the boat and put it aboard.”

“My God! That sack’s so heavy you’d think it was stones they had in it” he grumbled.

“It is stones,” answered Lachy, who was more familiar with the ways of geologists.

“Stones?” Ruari almost spat. “I’ll give them stones if they try to play tricks like that on me,” he threatened. He looked at me for confirmation.

“Of course they’re stones,” I told him, my face breaking into a smile at his outraged expression.

…

“Ruari,” I began timorously, feeling it incumbent on me to say something, “they were not just ordinary stones. These men were not playing a joke on you. They’re samples,” I floundered as Ruari bent his chilly gaze on me, “specimens for studying,” I faltered.

“Is that so?” asked Ruari in somewhat mollified tones. I nodded.

“Yes, these men are students,” I persevered. “They get a degree for this sort of thing.”

From *The Hills Is Lonely* by Lillian Beckwith (Lloyd) (1959)

Resident in Elgol and on Soay (1942-1962)

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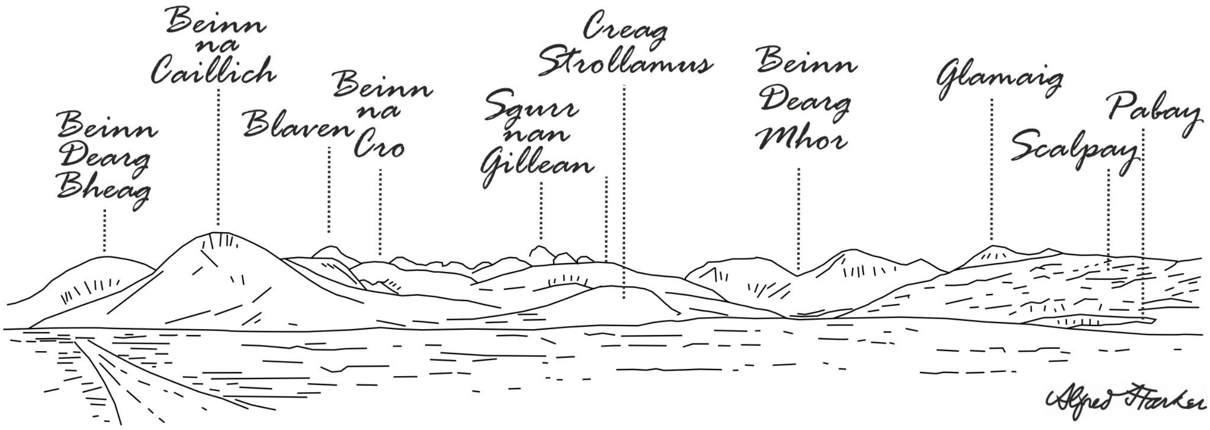
Chapter 1 Introduction

Some introductory comments on the format of the guide, early studies of the geology of Skye and Raasay, a summary of the geology, and Skye and Raasay through space and time.



1.A Prologue

The Isle of Skye, located in the Inner Hebrides, off the west coast of Scotland, is justifiably one of the Earth's greatest geological attractions. The diversity of rocks, their generally well-exposed character and comparative ease of access, combine to attract both lone geologists and organised parties from near and far. Adjacent to Skye is the Isle of Raasay, which compliments many of the geological units on Skye and adds many of its own. In this rewrite of the original guide (Bell & Harris, 1986), our understanding is brought up-to-date and includes many new field excursions and localities. New versions of maps are included, together with numerous figures and field photographs. The associated excursions are also available as an online resource.

Visitors should be aware that Scotland is justifiably a popular tourist destination, especially the majestic Inner Hebrides, and so advanced planning will be required at certain times of the year. Spring through to early Summer (late March - mid June) and Autumn (September - mid October) can often be the best times to visit; away from the peak of the Summer tourist season, and when the infamous midge (*Culicoides impunctatus)* is most active and annoying, especially on rare cloudy and wet days (Hendry, 2011).

The format of the guide follows that of the original, with an outline of the geology, from the oldest rocks to the youngest. Also included are: a lexicon of some geological terms (Appendix A); a list of place names with Gaelic and Norse translations and Ordnance Survey grid locations (Appendix B); and details of cited publications (Appendix C).

Excursions are published as an online resource and can be downloaded as pdf files. Each excursion is self-contained, including relevant maps, figures, and field photographs. For each excursion, there is an outline of the main geological features that are encountered, the type of terrain involved, a likely duration, any access issues, the distance involved, and an indication of the availability of vehicle parking. Access and parking availability can change, for better or worse; consequently, group excursions with coaches or multiple cars may wish to research conditions in advance.

In this chapter is a brief history of research of both islands (1.B), useful to understand their place in the development of geological thinking, followed by a short synopsis of the geology of Skye and Raasay (1.C). In Chapter 2, there is a non-technical outline of geological terms and concepts, which will aid understanding of some of the terminology used throughout the guide. Where some terms and concepts are introduced in subsequent chapters, definitions and explanations are included.

It is hoped that this new edition of the guide will serve future generations of geologists, both amateur and professional, and to encourage visitors to this beautiful part of Scotland. Be sure to bring appropriate field clothes, as the weather can change in a matter of minutes, and a camera to capture the stunning scenery.

1.B A Brief History of Research

Skye and Raasay have been the subject of numerous geological studies over the last 200 years. Both islands have acted, and continue to act, as excellent training grounds for geologists, as well as providing a challenging outdoor laboratory for research workers in the fields of volcanic and sedimentary geology, mountain-building processes, and landforms and deposits associated with periods of glaciation (Figure 1-1 & Figure 1-2).

The earliest published studies include descriptions by (Macculloch, 1819), (Von Oeynhausen & Von Dechen, 1829) and (Forbes, 1845), which established that igneous rocks figure prominently in the structure of the island, although details of their distribution were not elucidated in detail, and that the action of glaciers has been important in sculpting the present-day topography.

During the second half of the Nineteenth century, detailed studies were undertaken in order to gain a better understanding of the nature and development of Skye's igneous and sedimentary rocks. Principal amongst these studies were the publications of Geikie ((Geikie, 1857); (Geikie, 1888b); (Geikie, 1897)) and Judd ((Judd, 1874); (Judd, 1878)). These investigations established the Jurassic age of strata in the district of Strath in central Skye and on Trotternish in north Skye, and the Paleocene age, formerly referred to as the Lower Tertiary, of the igneous rocks in central and northern Skye. Controversy arose between Geikie and Judd as to the age relations of the two principal Paleocene intrusive rock-types of gabbro and granite (Oldroyd & Hamilton, 1997), as well as the style of eruption of the associated lavas, with both central and fissure mechanisms being suggested (Walker, 1995).

Following on from these studies, research on Skye entered a new phase, dominated by the monumental work of Alfred Harker. Invited by Sir Archibald Geikie, then the director of the Geological Survey of Great Britain, Harker undertook a detailed investigation of the Paleocene igneous rocks that crop out in the central mountainous part of the island. He spent seven field seasons, between 1895 and 1901, preparing detailed geological maps and collecting material for laboratory studies. Each year he was assisted in the field by the famed Skyeman and Cuillin climber, John MacKenzie. In 1904 Harker published his findings in the classic volume *The Tertiary Igneous Rocks of Skye* (Harker, 1904). As a result of his investigations, Harker settled many of the arguments between Judd and Geikie, in favour of the latter, namely that the gabbros pre-date the granites and that the lavas were erupted from fissures. He also made important observations on the Quaternary glacial landforms and deposits that are an integral part of today's landscape.

By the end of the Nineteenth century the detailed mapping of the Moine Thrust Zone, initiated by Peach and Horne of the Geological Survey in 1883, had reached Skye and Clough (in (Peach, et al., 1907) and (Peach, et al., 1910)) went on to show that these Lower Palaeozoic tectonic features were preserved in a complex fashion in the SE part of the island, on the Sleat Peninsula, and in the district of Strath.

Also as part of the Geological Survey's investigations, Woodward, Barrow and Wedd (in (Peach, et al., 1910)) and Lee (Lee, 1920) mapped the extensive development of Triassic and Jurassic strata that crops out on Skye and Raasay, deposited in the Hebrides/Minch Basin (in some publications subdivided into the Sea of the Hebrides-Little Minch and Inner Hebrides basins).

Thereafter, until the late 1940s, relatively little research was conducted, with the confidence that the results of the Geological Survey were thorough, up-to-date and final. Since then, literally hundreds of papers have been published on all aspects of the geology of Skye and Raasay and the rate of their production shows little sign of diminishing. Relevant papers are referred to throughout this publication.

1.C Geological Synopsis

On the basis of both geological and topographic features, Skye can be divided into three distinct parts (Figure 1-1 and Figure 1-2): the Sleat Peninsula; north and west-central Skye, including the peninsulas of Trotternish, Waternish, Duirinish and Minginish; and, the mountainous tract that forms the central portion of the island, the Cuillin Hills and the Red Hills.

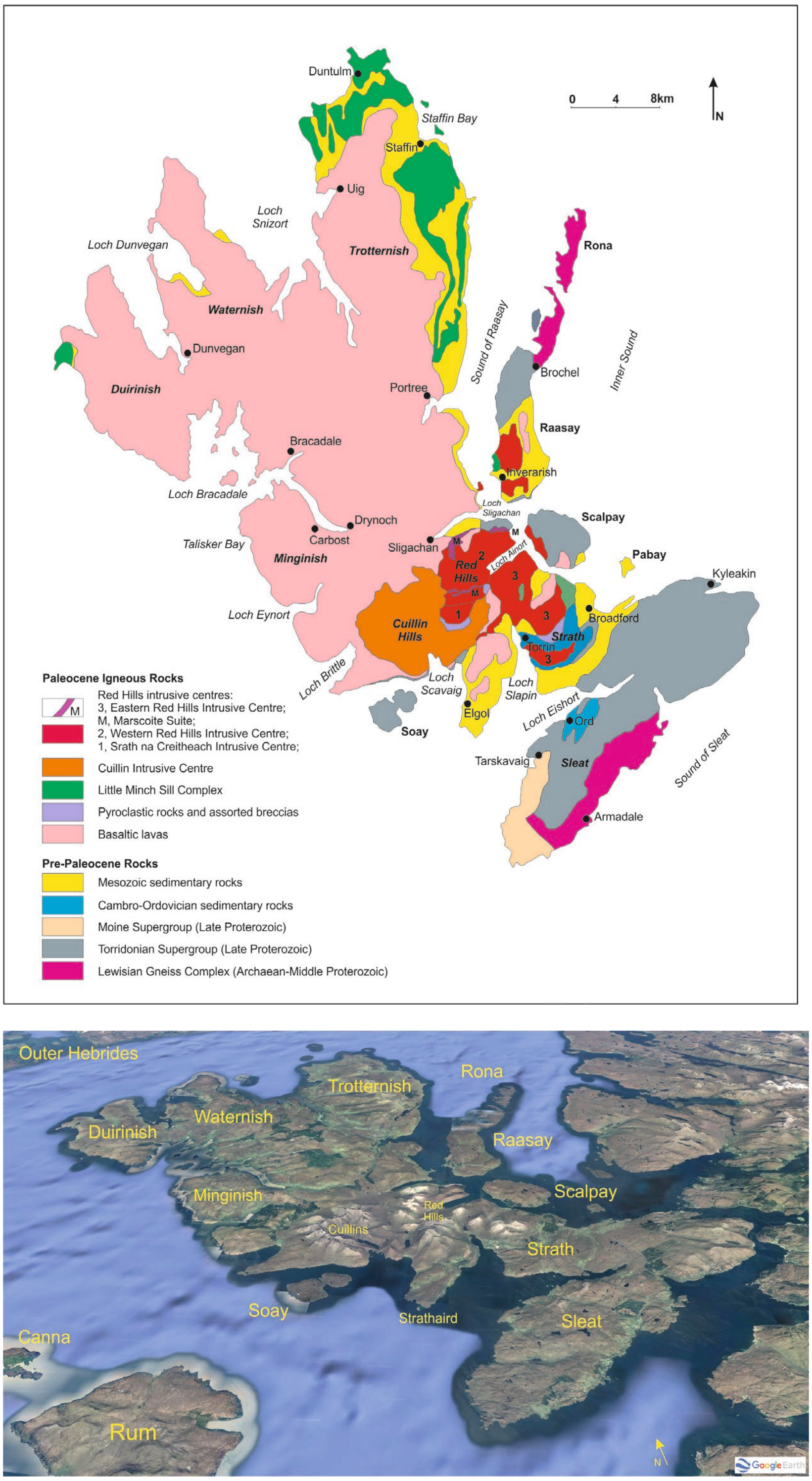
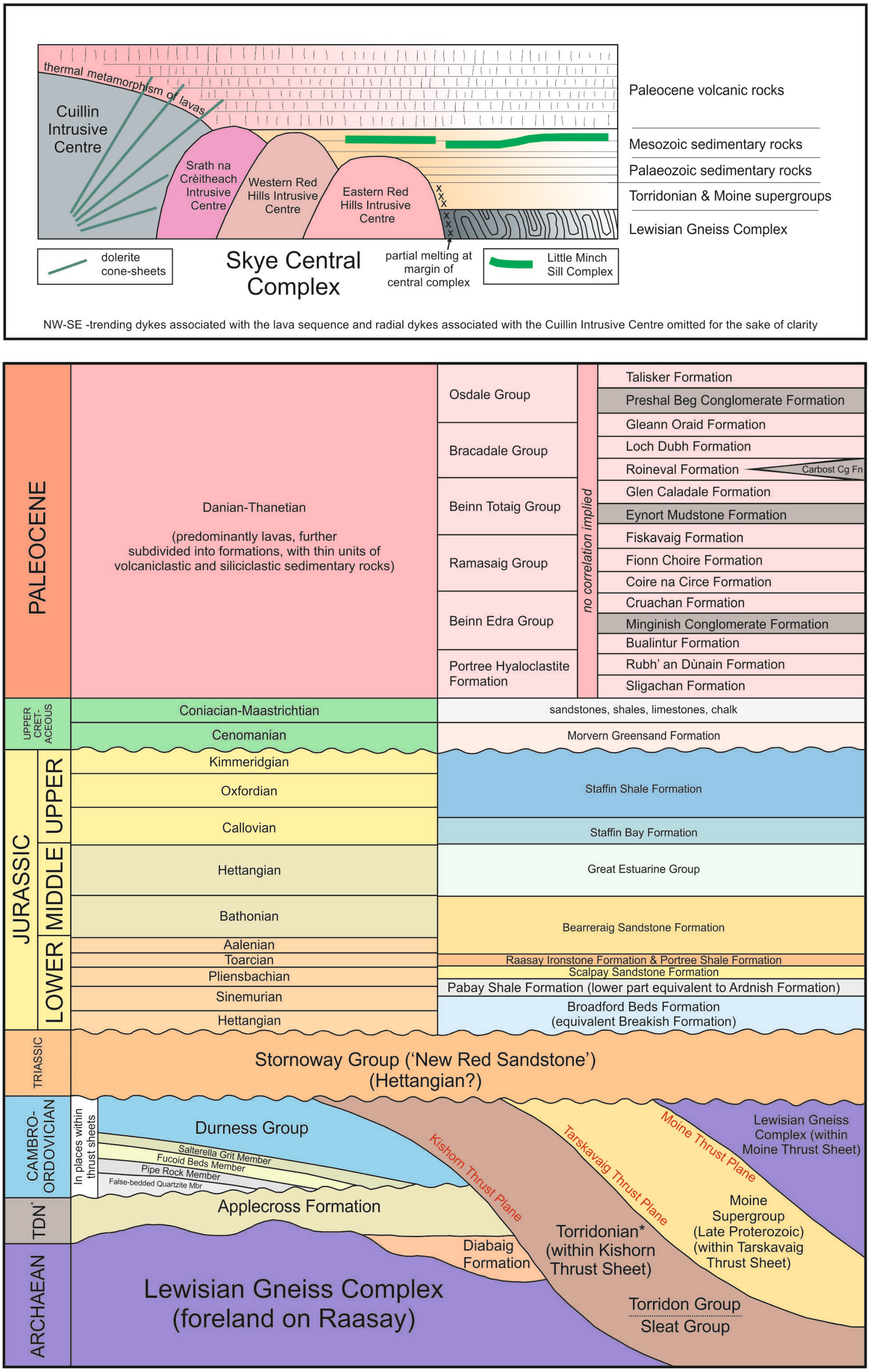


Figure 1-1 – General geological map and oblique Google Earth© image of Skye and Raasay.



*Torridonian Supergroup, commonly referred to as 'Torridonian' (Late Proterozoic)

Figure 1-2 – Fantasmagram for Skye and Raasay geology. Quaternary deposits are omitted.

The Sleat Peninsula, in the SE part of Skye, is composed of the Archaean Lewisian Gneiss Complex (Figure 1-3), Late Proterozoic (or Neoproterozoic) Torridonian (Supergroup) sedimentary rocks (Figure 1-4), Late Proterozoic Moine (Supergroup) pelites and psammites (Figure 1-5), and Cambro-Ordovician sedimentary rocks (Figure 1-6) (Chapter 3). The field relationships of these units are complicated due to extensive thrusting events associated with the Caledonian Orogeny, which took place during Lower Palaeozoic time and involved the transportation of large (thrust) sheets of these lithologies, north-westwards over a foreland consisting of the Lewisian Gneiss Complex, Torridonian sedimentary rocks and Cambro-Ordovician strata. The present-day, mature topography is glacial in origin, with numerous rounded hills up to 300m OD (Ordnance Datum) in the southern half of the peninsula, and in excess of 700m OD in the NE, where Torridonian sedimentary rocks crop out.

The Lewisian Gneiss Complex also crops out in the northern part of Raasay and on Rona, unconformably overlain (on Raasay) by Torridonian sedimentary rocks. A thick sequence of Torridonian strata crops out to the south of the Cuillin Hills and on the island of Soay.

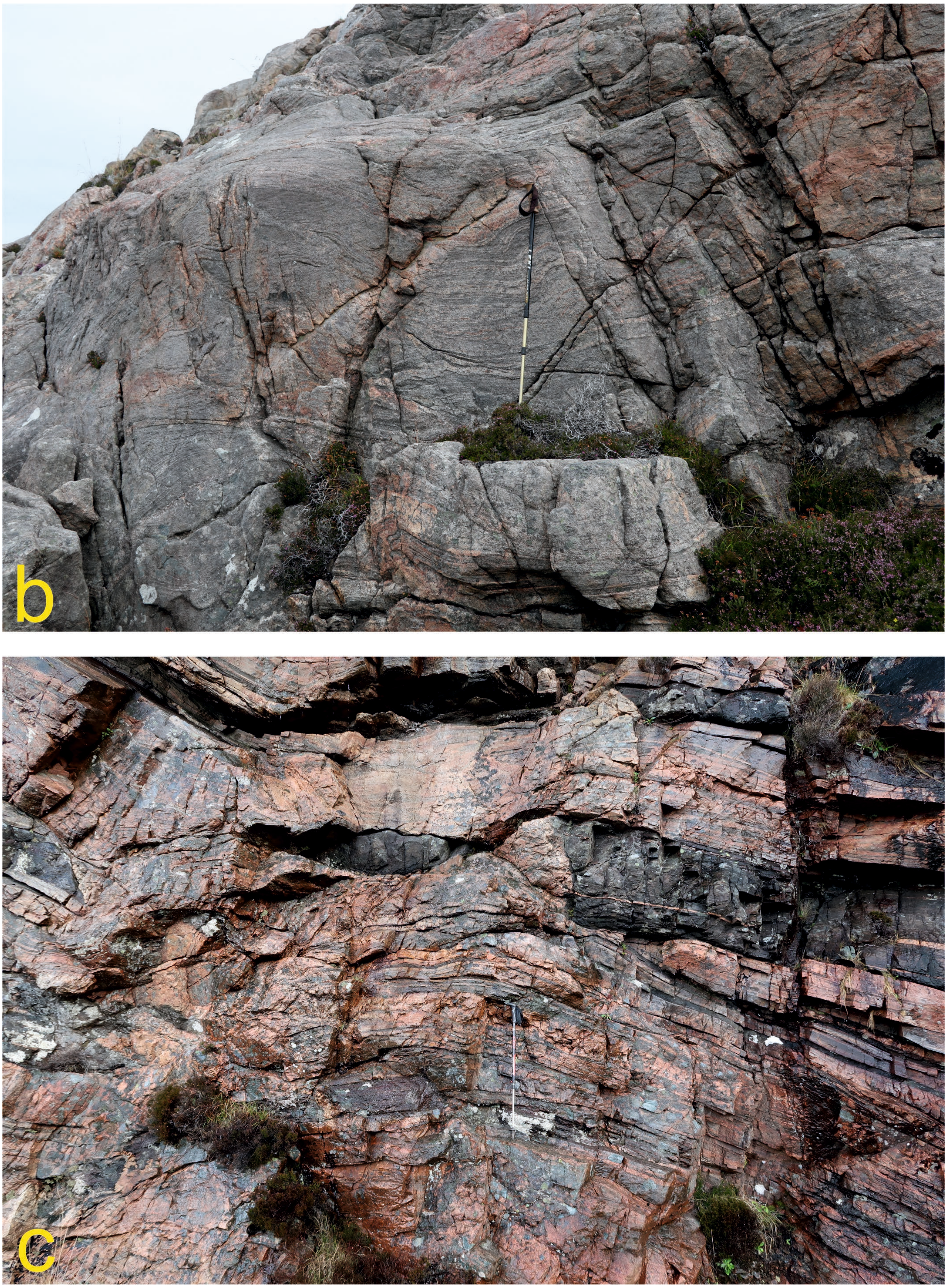


Figure 1-3 – (a) Lewisian Gneiss Complex forming rounded hills on the island of Rona, north of Raasay, with Applecoss on the Scottish Mainland in the distance, view towards the east; (b) exposure of the Lewisian Gneiss Complex, SW of Beinn na h-Iolaire, north Raasay, pole *c.* 1m long; and, (c) detail of Lewisian Gneiss Complex, Loch Arnish, north Raasay, comprising interleaved orange-weathered felsic (quartz-feldspar) layers and dark mafic (ferromagnesian mineral rich) layers, pole *c.* 1m long.

Figure 1-4 – (a) Inclined Applecross Formation (Torridon Group) strata on the island of Soay, south of the Cuillin Hills, with the island of Rum in the distance, view towards the south; and, (b) distorted laminae due to seismically-induced liquefaction within Loch an Uach(-dair) Member (Diabaig Formation, Torridon Group) feldspathic sandstones, NW of Loch Beag, Brochel, Raasay, pole *c.* 1m long.

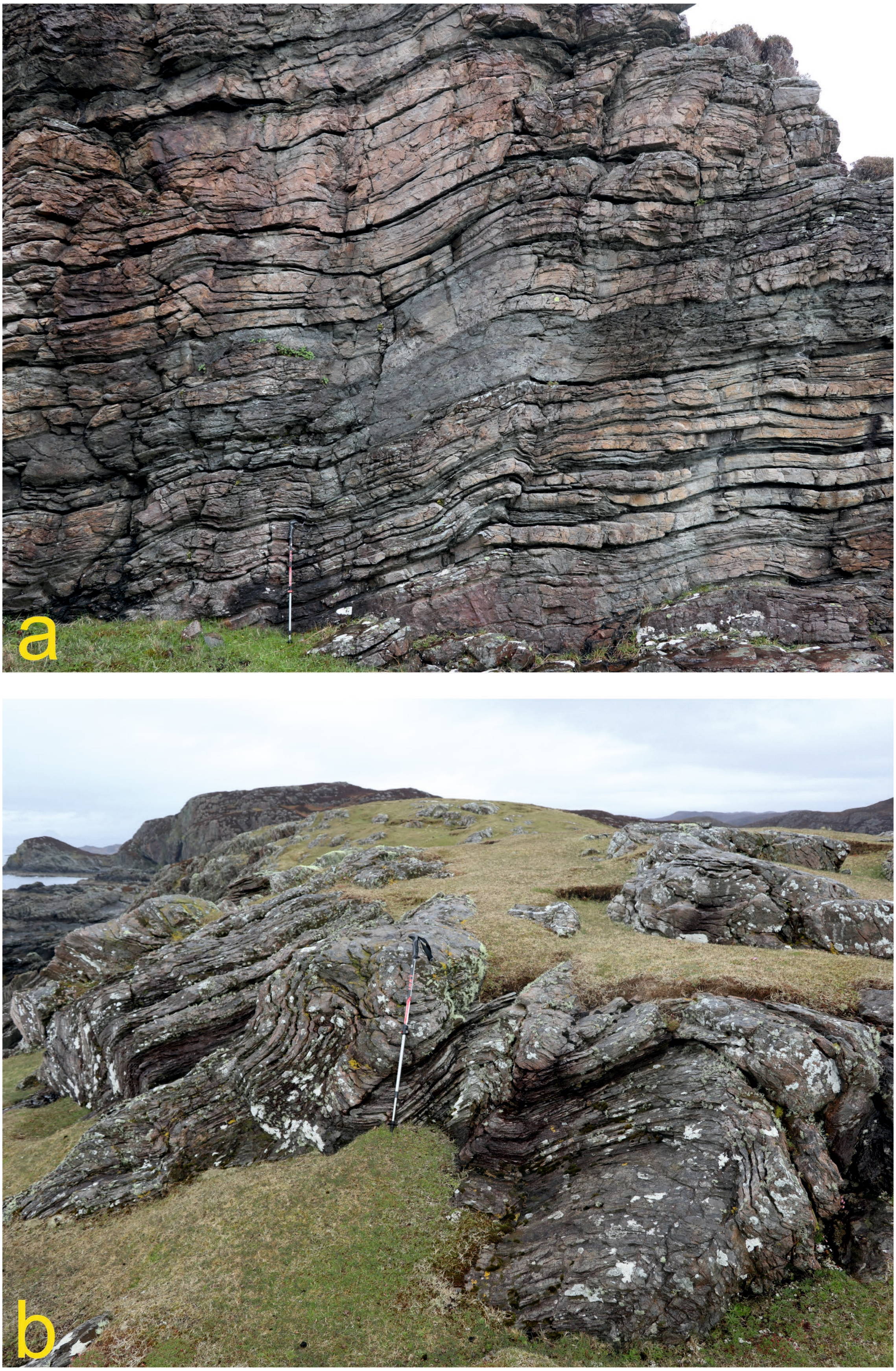


Figure 1-5 – Folded Moine Supergroup meta-sedimentary rocks (psammites and pelites): (a) Camas Daraich, SE Sleat; and, (b) Point of Sleat, pole *c.* 1m long.

Figure 1-6 – (a) Pale Cambrian sandstones ('quartzites') of the Eriboll Sandstone Formation forming the Sgiath-bheinn an Uird – Sgiath-bheinn Chrosabhaig ridge on the west side of the Sleat Peninsula, view towards the east across lochs Slapin and Eishort from Strathaird; and, (b) vertical, thermally metamorphosed Strath Suardal Formation limestones on the east side of Loch Slapin, Strath, intruded by a NW-SE -trending Paleocene dyke, view towards the west with Strathaird and, beyond, the Blà-bheinn – Clach Glas – Garbh-bheinn ridge.

North and west-central Skye, comprising the peninsulas of Trotternish, Waternish, Duirinish and Minginish, consist of a stepped, plateau-type topography indented by large sea-lochs, such as Loch Dunvegan and Loch Snizort. Here, Jurassic sedimentary rocks crop out locally (Chapter 4), mainly along the east coast of Trotternish, but also, for example, at Neist Point (Rubha na h-Eist) and Waterstein Head on Duirinish (Figure 1-7), and are capped by a large thickness of Paleocene lavas with rare interbedded pyroclastic, volcaniclastic and sedimentary rocks (Chapter 5). In north Skye, the entire sequence has a synclinal form, with its axis trending approximately north-south, giving rise to steep scarp slopes on the east and west sides of this part of the island. A similar relationship between Jurassic strata and Paleocene lavas occurs on Raasay and on Strathaird in central Skye.

The Jurassic sedimentary rocks comprise (Lower – Middle Jurassic) shallow marine units (Broadford Beds Formation, Pabay Shale Formation, Scalpay Sandstone Formation, Raasay Ironstone Formation, Portree Shale Formation and Bearreraig Sandstone Formation), which give way, up sequence, to the Middle Jurassic Great Estuarine Formation, deposited in a fluctuating coastal environment. A return to fully marine conditions led to the deposition of the Upper Jurassic Staffin Bay Formation and Staffin Shale Formation.

These Jurassic sequences unconformably overlie locally preserved terrestrial Triassic strata, conglomerates, sandstones, shales and caliches (fossil soils) of the Stornoway Group, mainly in Strath and on Raasay. Also locally preserved are thin sequences of Upper Cretaceous marine sandstones, shales and limestones, unconformably overlain by Paleocene lavas, for example on Strathaird and in central Raasay.

The lavas are predominantly of basaltic composition, with lesser amounts of more evolved types such as hawaiite, mugearite, benmoreite and trachyte, which are more common towards the top of the preserved sequence. The lavas were erupted from a linear fissure system, trending NW-SE, now represented by a significant regional dyke swarm, the Skye Main Dyke Swarm (Figure 1-8). At and close to the base of the volcanic sequence are pillowed lavas, hyaloclastites, and various pyroclastic units. Interbedded with the lavas are conglomerates, sandstones and shales, with the finer-grained units containing plant fragments.

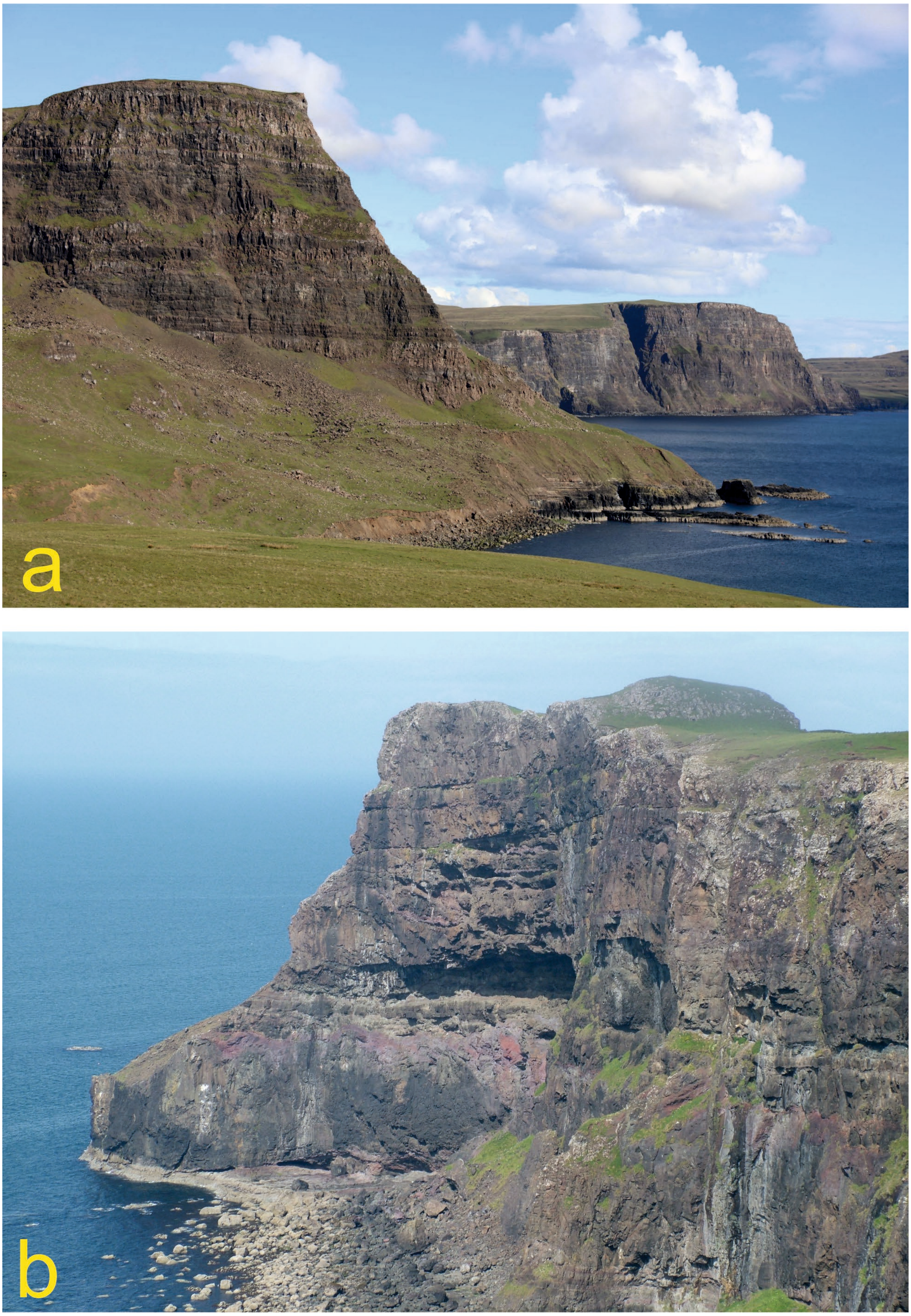


Figure 1-7 – (a) Paleocene lavas forming Waterstein Head, overlying Middle Jurassic Great Estuarine Group strata (at sea-level) at the northern end of Moonen Bay on Duirinish, view towards the SE from Camas nan Sìdhean; and, (b) cliffs at Rubha Cruinn on the north side of Talisker Bay, where the thick mugearite lava at sea-level has a conspicuous reddened top, height of cliff *c.* 120m, view towards the west.

Figure 1-8 – (a) Triassic Stornoway Group terrestrial conglomerates in SE Raasay, with Dùn Caan in the distance, view towards the north, pole *c.* 1m long; (b) Lower Jurassic Pabay Shale Formation strata on the north side of Loch Eishort, intruded by NW-SE -trending Paleocene dykes of the regional swarm, viewed from Ord on the Sleat Peninsula; and, (c) Middle Jurassic Bearreraig Sandstone Formation strata forming the inland cliff of Druim an Aonaich on the east side of Raasay, overlain by a remnant of the lava field forming the flat-topped summit of Dùn Caan, view towards the SW.

Intruded into the Jurassic sedimentary rocks of Trotternish and Duirinish, and only rarely into the lavas, are sills of Paleocene age (Chapter 8), ranging from relatively homogeneous dolerites through to olivine-dominated picrites with well-developed mineral layering. Due to the contrast in hardness between the sills and the enclosing sedimentary rocks there is the development of spectacular coastal cliffs of columnar-jointed igneous material capping the relatively softer Jurassic strata. The most famous example occurs on the east coast of Trotternish, *c.* 2km south of Staffin, referred to as the Kilt Rock (Figure 1-9).

Figure 1-9 – The Kilt Rock, composed of a horizontal columnar-jointed dolerite sill intruded into Middle Jurassic sedimentary rocks (Valtos Sandstone Formation) on the east coast of Trotternish, view towards the NW from Rubha nam Brathairean. The waterfall is discharging from Loch Mealt, located a few tens of metres inland.

Another feature that involves the Jurassic sedimentary rocks and the Paleocene lava sequence on Trotternish is an extensive tract of landslipped material, which developed during the Quaternary Period (Chapter 10). This N-S -trending escarpment runs from north of Portree to Sròn Vourlinn, west of Flodigarry, and includes the spectacular cliffs of The Storr, Beinn Edra and The Quiraing (Figure 1-10).

Figure 1-10 – The inland escarpment of lavas forming The Storr on Trotternish, with associated landslipped (Holocene) masses of lava forming the pinnacles to the east (right), including the Old Man of Storr and Needle Rock. View towards the north.

A third geographic area, arguably giving rise to the most spectacular scenery, is the mountainous tract that forms the central portion of the island. Here, Paleocene intrusive rocks, younger than the plateau lavas, are dominant and strongly control the local topography (Chapter 6). At the present level of erosion, the rock-types gabbro (*s.l.*) and granite (*s.l.*) are the most significant (Figure 1-11). The rugged horseshoe-shaped mass of the Cuillin Hills (strictly, *Cuillin*) rises to almost 1000m OD, with spectacular summits, for example, Gars-bheinn (895m OD) in the south, Sgùrr Alasdair (992m OD) in the central part of the ridge, and Sgùrr nan Gillean (964m OD) in the north, and is built of coarse-grained, basic and ultrabasic rock-types, typified by gabbros, troctolites and peridotites. In strong lithological and topographic contrast are the younger rocks of the Red Hills, comprising intrusive silicic rocks, located to the NE of the Cuillin Hills and exhibiting a more rounded, subdued topography. The Red Hills reach their maximum height in the summits of Glamaig (775m OD) (Figure 1-12) and Marsco (736m OD). The topographic contrast between the basic and ultrabasic rocks of the Cuillin Hills and the silicic intrusions of the Red Hills is most obvious in the vicinity of Glen Sligachan, which is flanked to the west by various gabbros and troctolites and to the east by granites and felsites.

Figure 1-11 – Panorama across Loch Bracadale from the southern end of Duirinish, with lavas forming the island of Wiay and the NW part of Minginish, with the gabbro-dominated Cuillin Hills (right) and the granite-dominated Red Hills (left) in the distance. View towards the SE.

Figure 1-12 – The granite-dominated double summit of Glamaig (An Coileach to the left and Sgùrr Mhairi to the right), with both summits comprising a thin cap of hornfelsed basaltic lavas. In the distance, to the right, is the summit of Sgùrr nan Gillean of the Cuillin Hills, and, to the left, are gabbros forming the peak of Garbh-bheinn (with snow patches) and various Red Hills granites. View towards the SW from Churchton Bay on Raasay.

The topography of the Cuillin Hills and the Red Hills is of glacial origin, formed during the Quaternary Period, with classic examples of corries, arêtes and horns, with associated tarns. In the surrounding lower ground are examples of various types of associated glacial deposits.

The island of Raasay contains many of the geological features of north Skye, with a thick sequence of Jurassic sedimentary rocks overlain by a thin remnant of the lava sequence on Dùn Caan (444m OD) (Figure 1-13). In the south of the island, Torridonian sedimentary rocks (Chapter 3) are overlain by a sequence of Triassic and Jurassic sedimentary rocks (Chapter 4). Paleocene sills of dolerite and picrite are also present (Chapter 8), although their relationship to their host Jurassic strata is not clear. A significant part of south and central Raasay comprises two major outcrops of a Paleocene granite sill, emplaced into Jurassic sedimentary rocks (8.E).

Figure 1-13 – The east coast of Raasay viewed towards the north from Rubha na Leac. The nearby promontory with the waterfall is composed of Lower Jurassic Ardnish Formation strata, mainly sandstones. In the distance, Middle Jurassic Bearreraig Sandstone Formation strata form the significant inland cliffs of Druim an Aonaich. The prominent flat-capped summit of Dùn Caan (444 m OD) is composed of Paleocene basaltic lava(s).

The northern part of Raasay consists of a thick sequence of Torridonian sedimentary rocks unconformably overlying the basement Lewisian Gneiss Complex (Figure 1-14) (Chapter 3). Both units have not been involved in the thrusting events of the Caledonian Orogeny and, consequently, are regarded as being part of the foreland, i.e. not significantly involved in the Moine Thrust Zone. These units are separated from the Jurassic and Paleocene rocks to the south by the SW-NE - trending Screapadal Fault.

Figure 1-14 – Lewisian Gneiss Complex exposed in a road-cut at Loch Arnish in north Raasay, with Creag an Eòin and Beinn na h-Iolaire in the distance, composed of similar material. View towards the NE.

A further similarity with the geology of north Skye takes the form of major landslips on the east side of the island at Beinn na Leac and Hallaig (Figure 1-15).

Figure 1-15 – View of central Raasay, viewed south from the summit of Dùn Caan (444m OD). Immediately to the south are crags of dolerite, most likely a sill, giving rise to obvious scree. Further south, forming the spine of the island, left (east) of Loch na Mna, are crags composed of Middle Jurassic Bearreraig Sandstone Formation strata. Below these crags, to the left (east) and all the way down to the coast, much of the rock is landslipped (Holocene). The obvious peninsula on the east coast of Raasay is Rubha na Leac, composed of Triassic strata. In the far distance, beyond Raasay, is the island of Scalpay, beyond which is Skye with the obvious summits of Beinn na Caillich and Beinn Dearg Mhòr.

Taken as a whole, a significant proportion of the major rock units that make up the complex geology of Scotland are present on Skye and Raasay, from the foreland sequence of the Lewisian Gneiss Complex and Torridonian strata on Raasay (Chapter 3), the tectonically complex thrust sheets of Lewisian gneiss, Torridonian sedimentary rocks, Moine psammites and pelites and Cambro-Ordovician sedimentary rocks in SE Skye (Chapter 3), through the unconformably overlying Triassic and Jurassic sedimentary rocks (Chapter 4), to the myriad of extrusive and intrusive igneous rocks of Paleocene age (Chapter 6, Chapter 7 & Chapter 8). Chapter 9 deals with the Late Palaeogene and Neogene, an interval dominated by weathering and erosion.

Exposures of many of the rock units on Skye and Raasay have been further enhanced by significant glacial erosion during the Quaternary Period (Chapter 10), revealing remarkably fresh and extensive exposures, especially in the mountainous parts of central Skye (Figure 1-16).

Figure 1-16 – Coir' a' Ghrunnda, viewed towards the SW, with the island of Soay and, in the distance, Rum (right) and Eigg (left). The near-complete exposure of various gabbroic rocks forming the so-called 'boiler plates' of the corrie floor was sculpted by glaciers. On the flat vegetated ground beyond the mouth of the corrie is an obvious moraine consisting of significant boulder-sized erratics of various types of gabbro, deposited when the glacier retreated. David Bell for scale.

1.D Skye and Raasay Through Space and Time

The further back in (geological) time we go, the relationship of the crustal block that today's Skye and Raasay is part of, to adjacent areas, becomes less clear. Oceans have opened and closed, sedimentary basins have developed, been buried, some deformed and metamorphosed, mountain belts have formed and been eroded, and volcanoes have erupted lavas and pyroclastic deposits. Glaciations in more recent time have significantly contributed to today's topography and the formation of some of the youngest deposits that partially blanket older units.

Unravelling this myriad of processes is a significant challenge and our understanding is far from complete. However, we can make reasonable estimates of (paleo-)geographic location, in terms of palaeo-latitude, and the overall make-up of the crustal block on which Skye and Rassay resides, at key times (Figure 1-2). Below, are outlines of snapshots in geological time for key parts of Skye and Raasay's history, some, those furthest back in time, necessarily very general.

The crystalline basement, the Lewisian Gneiss Complex, formed over a period in excess of 1.5 b.y. and involved an unknown number of continental crust -forming intrusive, deformation and metamorphic events. The more these rocks are studied, especially in terms of their radiogenic isotopic signatures, the more complex they appear to be. It is likely that today's configuration of these bewilderingly complicated basement gneisses involved many originally disparate fragments of continental crust brought together through significant lateral (and vertical) movements.

The unconformably overlying Torridonian Supergroup continental sedimentary rocks formed on this stabilised craton in the Late Proterozoic, in a sedimentary basin, or basins, defined on its western margin by the so-called Minch Fault, and possibly on the east by a fault later modified during the Lower Palaeozoic Caledonian Orogeny. Sedimentation occurred over a period of *c.* 50 m.y., from *c.* 1000 Ma through to *c.* 950 Ma ((Park, et al., 2002); (Krabbendam, et al., 2021)) in a variety of terrestrial environments, alluvial, fluvial and lacustrine, in an equatorial latitude, on a landscape devoid of vegetation.

The Late (Neo) Proterozoic Moine Schists (psammites, pelites), restricted to the Moine Thrust Zone on the Sleat Peninsula, were wholly involved in the Caledonian Orogeny and are not recognised, in their current configuration, as part of a foreland sequence (i.e. rocks not involved in an orogenic belt). There has been much debate as to the relationship between the Torridonian Supergroup strata and the Moine Schists throughout NW Scotland, with the current view (Krabbendam, et al., 2021) that both are components of a mega sequence, the Wester Ross Supergroup, deposited in a foreland basin to the Grenville Orogen(ic) Belt. Essentially the Torridonian and Moine sequence differ only in terms of grade of metamorphism and location within (and outwith) the Caledonian Orogenic Belt. (Krabbendam, et al., 2021) suggest that the Moine Schists on the Sleat Peninsula, which are attributed to the so-called Tarskavaig Group, are part of the basal sequence of the Wester Ross Supergroup.

The youngest unit of the foreland Hebridean Terrane comprises Cambro-Ordovician clastic and carbonate deposits, formed on the southern margin of the Laurentian Craton, flanked to the south by the Iapetus Ocean. These Lower Palaeozoic marine shelf deposits were formed in a tropical climate, just south of the (palaeo-) equator (Park, et al., 2002).

The ensuing Caledonian Orogeny saw the closure of the Iapetus Ocean, during which the various thrust sheets (nappes) of the Moine Thrust Zone, comprising dismembered parts of the foreland lithologies, including psammites and pelites of the Late Proterozoic Moine Supergroup, were translated towards the NW during the so-called Scandian Event, bringing together the Hebridean and Northern Highland terranes as Laurentia collided with Gondwanaland ((Park, et al., 2002); (Krabbendam, et al., 2021)).

There is then a substantial hiatus in the rock record, during which there was significant weathering and erosion of the Lower Palaeozoic and older rocks. During the Early Mesozoic Triassic Period, *c.* 250-200 Ma, continental sedimentation occurred in the fault-bounded Hebrides Basin, when global sea-level was generally low and Scotland was located distant from the margin of the Laurussian portion of the mega-continent, Pangaea, which formed after collision of Laurentia and Gondwanaland (Glennie, 2002). The palaeo-latitude was *c.* 15-30°N and the climate resulted in desert and semi-desert environments.

Sedimentation continued into the Jurassic, *c.* 200-145 Ma, when sea-level was generally high and there was a change to marine and lacustrine conditions of deposition (Hudson & Trewin, 2002). A marine strait opened, with incursions from the south, separating the cratonic areas of Greenland and Fennoscandia. The palaeo-latitude was *c.* 37°N, the climate was seasonal, with warm dry summers and cool wet winters, and the (sediment source) hinterland was vegetated. Marine conditions continued into the Cretaceous Period, poorly represented on Skye and Raasay.

The Paleocene Epoch was dominated by volcanic and associated intrusive activity ((Bell & Williamson, 2002); (Emeleus & Bell, 2005)). A significant lava field developed, with several interludes of terrestrial, mainly alluvial, fluvial and lacustrine sedimentation. Pyroclastic rocks are poorly represented. Magma was fed from a NW-SE -trending fissure system, now represented by a significant dyke swarm. A sill complex was emplaced into, predominantly, the Middle and Upper Jurassic strata of northern Skye. The Skye Central Complex, consisting of ultrabasic, basic and silicic intrusions, formed when voluminous quantities of magma(s) gained access to the shallow crust through pre-existing crustal weaknesses. Eruptive units associated with the predominantly basaltic Cuillin Intrusive Centre and the silicic Srath na Crèitheach, Western Red Hills and Eastern Red Hills intrusive centres are also recognised. These large intrusions caused deformation and contact metamorphism of the Pre-Paleocene country-rocks.

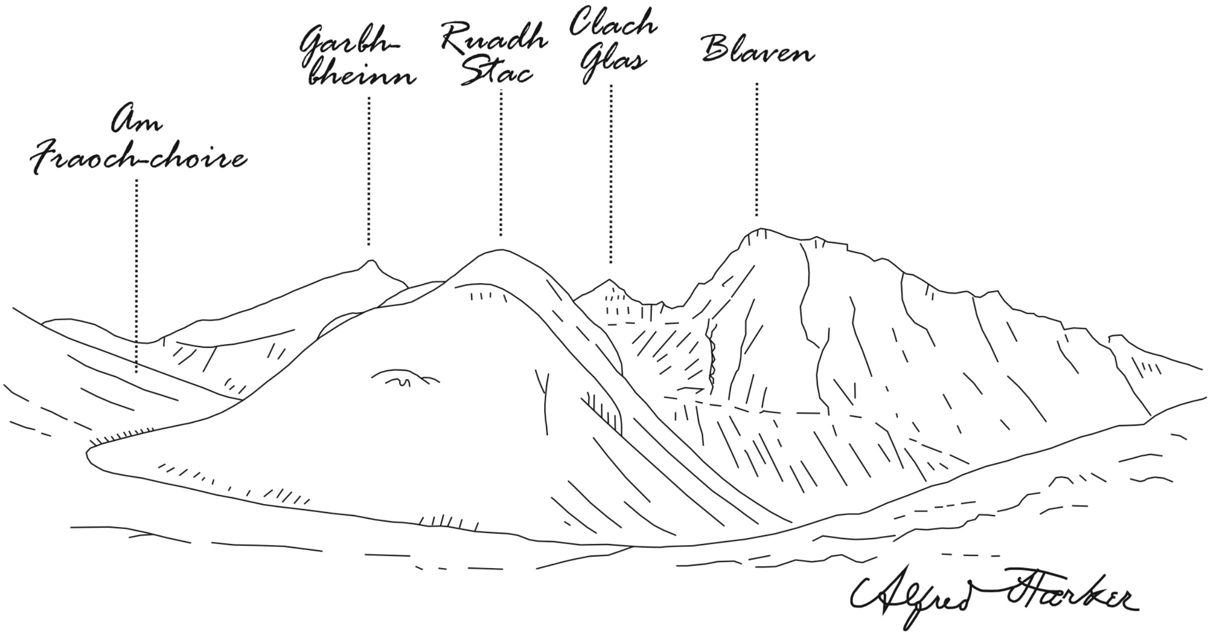
Thereafter, throughout much of the Eocene and Oligocene epochs, into the Neogene Period, there was considerable weathering and erosion, prior to a deterioration in the climate at the start of the Quaternary Period at *c.* 2.5 Ma, with the onset of intervals (stadial(s)) of glacial conditions (stades) and intervening interstadials (or interstades) (Ballantyne & Lowe, 2016).

The succeeding Holocene Epoch saw a moderating of the climate and a gradual warming of NW Scotland, with its attendant gradual population by nomads that migrated north as the climate permitted.

Chapter 2 Rocks: Igneous, Sedimentary and Metamorphic

Geologists traditionally

classify rocks as being igneous, sedimentary or metamorphic. Some rocks do not fit easily into this three-fold scheme but are relatively uncommon.



2.A Igneous Rocks

Igneous rocks result from the cooling and solidification of magma, commonly involving the crystallisation of silicate minerals. Magma is a general term used to describe high temperature (750-1200°C) silicate (Si-Al-O –dominated) liquids generated within (the) Earth's crust or underlying mantle. At its simplest, magmas produced by melting in Earth's mantle are typically of a low silica type, referred to as basaltic magma, whereas magmas produced by the melting of typical continental crust, of the type that underpins NW Europe, are of the high silica type, referred to as rhyolitic or silicic magma. Melting of mantle and crustal rocks to produce magmas can be attributed to a variety of mechanisms, including an influx of heat, the addition of H_2O (which lowers the melting temperature of rocks), or a reduction in pressure (much in the same way water boils at a lower temperature at lower pressures: water boils at the summit of Mount Everest at around *c.* 70°C!).

As magma ascends towards Earth's surface due to its natural buoyancy, it starts to lose heat and will crystallise minerals. If the magma flows out ('erupted' or 'emplaced') non-explosively onto Earth's surface it will produce a lava. When erupted into water, especially deep water, the lava takes on a distinctive morphology, or shape, and is referred to as pillow(ed) lava, with reference to the pillow-like masses that make up the lava. Eruption onto land tends to result in tabular (sheet-like) or ribbon-like lavas, such as we see on present-day Hawaii. Most commonly, lavas are formed from basaltic magma and crystallise the common silicate minerals olivine, clinopyroxene and plagioclase, together with Fe-Ti oxides. Crystals that grow in the magma as it ascends through the crust will typically be quite large (several millimetres across, and potentially more than a centimetre) due to the relatively slow rate of cooling; rapid cooling upon reaching Earth's surface will result in the remainder of the magma crystallising small (sub-millimetre) crystals, which are referred to as being fine-grained. Large crystals (phenocrysts) in a fine-grained groundmass (matrix) are called phenocrysts and the overall textural arrangement is referred to as being porphyritic.

Explosive eruption of magma will produce a pyroclastic (Greek, 'fire broken') rock, whereby the magma disintegrates by the violent expulsion of dissolved volatiles, producing glassy tephra (fragmental material), which can range in size from fine particles (ash) through lapilli, to large fragments (bombs or blocks). Fragmentation of magma can be the result of other processes, for example when magma encounters water-saturated ground, which also causes it to fragment explosively. Pyroclastic deposits, after burial, will be compacted and hardened into beds (i.e. layers), for example, ash will be transformed into the rock-type called tuff.

Magma doesn't necessarily make it to Earth's surface and can commonly cool and crystallise within the crust, typically the uppermost few kilometres. Igneous rocks formed in this way are referred to as being intrusive, giving rise to minor intrusions if the amount of magma is relatively small, or major intrusions (or plutons) if relatively large. There is no firm line between what we might call a minor intrusion or a major intrusion. The larger an intrusion, the slower the magma cools and crystallises, and the larger the resultant crystals. The shapes of intrusions, be they minor or major, will depend upon a variety of poorly understood factors. Intrusions are revealed to us due to erosion, over substantial periods of time, removing the rocks into which the magma has been injected, or intruded.

Minor intrusions are typically tabular in shape, laterally extensive, but only of the order of a few metres, up to a few tens of metres, thick. They are commonly classified as dykes if the magma has been injected into vertical fractures (or fissures) within the crust; or as sills if the fractures are near-horizontal (commonly resulting in intrusions parallel to the (near-) horizontal stratification of the sedimentary rocks that commonly act as host to the magma). Cone-sheets are a type of minor intrusion particularly common within the Hebridean Province, with conical geometries, with their apices at depth.

Major intrusions typically constitute significant volumes of magma, typically hundreds of cubic kilometres, and potentially orders of magnitude greater. How space is made available for the accumulation of such significant volumes of magma within the crust is still not fully understood but is likely to include mechanical disruption of the crustal rocks into which the magma is injected (intruded), as well as the melting (and assimilation) of these country-rocks, or their accumulation as fragments (xenoliths) within the resultant intrusions. It is likely that the accumulation of magma to form a major intrusion will involve multiple intrusive events, aggregating to form these large volume intrusions.

2.B Sedimentary Rocks

The second category we need to consider is sedimentary rocks: created by the formation of layers, or beds, of material at the Earth's surface. Three subdivisions are recognised: clastic, chemical and organic. Clastic sediments are accumulations of material originally transported as fragments or grains by water, wind or ice, then deposited as the transporting fluid slows down (in the case of water and wind) or melts (in the case of ice). Examples of environments in which water can transport (and ultimately deposit) sediment grains are river channels, along coastlines, in lakes, and in the sea. The faster water or wind flows, the larger the particles or grains that can be transported; as these transporting fluids slow down, grains, largest first, are deposited. Names are given to clastic deposits depending upon their average grain size, ranging from so-called fine-grained deposits, dominated by mud, and referred to as mudstones and shales after burial and consolidation into rock by a variety of processes including compaction and expulsion of pore water, through siltstones and sandstones, to conglomerates and breccias that are dominated by large fragments, rounded and angular, respectively. A wide variety of features can develop in clastic sediments during their deposition, which help geologists to determine the environment of deposition (for example, river channel, lake, estuary, beach, or marine). Marine sediments typically contain abundant fossils, which also tell much about the environment of deposition and age of sedimentary rocks.

Chemical sedimentary rocks are those which are precipitated from water, typically seawater, the most common being limestone and dolostone. As with clastic sedimentary rocks, a variety of features develop in these deposits during deposition, which help us to determine details as to how they formed. Fossils are commonly present and can help to determine precise ages of the deposits.

Organic sedimentary rocks form by the accumulation (and lithification – i.e. change into rock - after burial) of plant and animal debris. Plant materials include roots, leaves and wood fragments, and ultimately will be transformed into peat (with shallow burial) or coal (with significant burial). Typically, organic sediments accumulate in swamps and mires, for example on the floodplains of rivers or coastal fringes. Organic-rich marine sediments form by the accumulation of algae and plankton and are a major source of oil and gas when heated sufficiently during burial.

2.C Metamorphic Rocks

The third category is the so-called metamorphic rocks: igneous and sedimentary rocks that have been modified by the agents of pressure and/or temperature. Significant burial (kilometres to tens of kilometres) and compression will lead to originally tabular beds of igneous and sedimentary rocks being folded and the transformation of the original minerals into new assemblages of minerals that are stable under the ensuing pressure and temperature. Such rocks are referred to as regional metamorphic rocks, as they develop over large areas or regions, and are only seen at the Earth's surface because of subsequent large-scale uplift and erosion. The compressive stresses involved will cause the new minerals that form to grow with an alignment perpendicular to the compressive stress responsible for the folds and is referred to as a fabric, cleavage or schistosity.

Adjacent to intrusions, especially major intrusions, the dominant modifying agent is heat and the metamorphic rocks that form are referred to as being contact metamorphic rocks, or hornfels. Fabrics (alignment of minerals) do not typically form in these thermally altered rocks, as compressive stresses are not large at the time of intrusion of the magma. Rarely, the heat from intrusions can be sufficient to cause the so-called country-rocks immediately adjacent to the margin of the intrusion to melt, resulting in the formation of (a limited amount of) magma that may migrate away from where it was produced, or simply cool down and crystallise, commonly as sheets and veins.

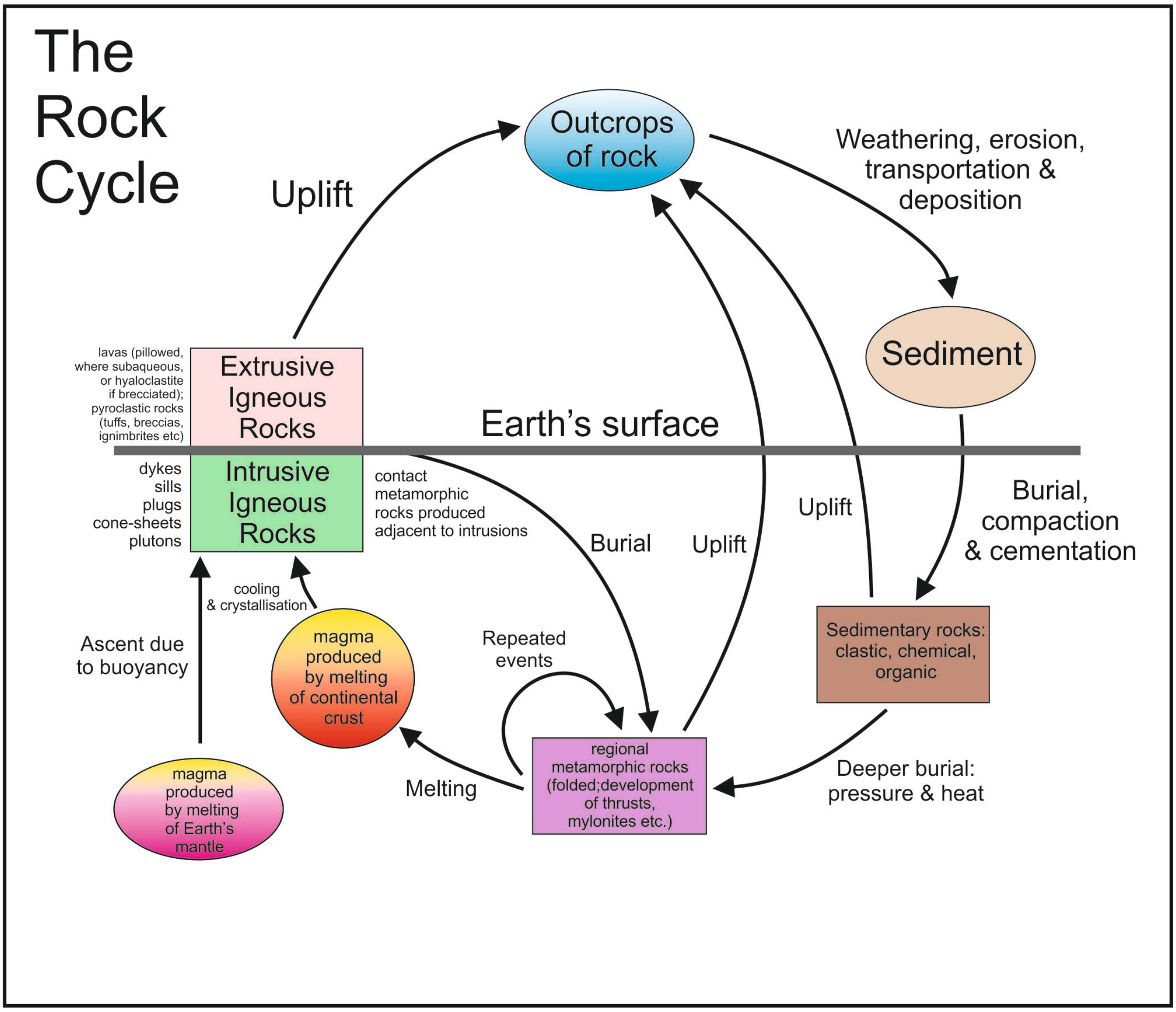
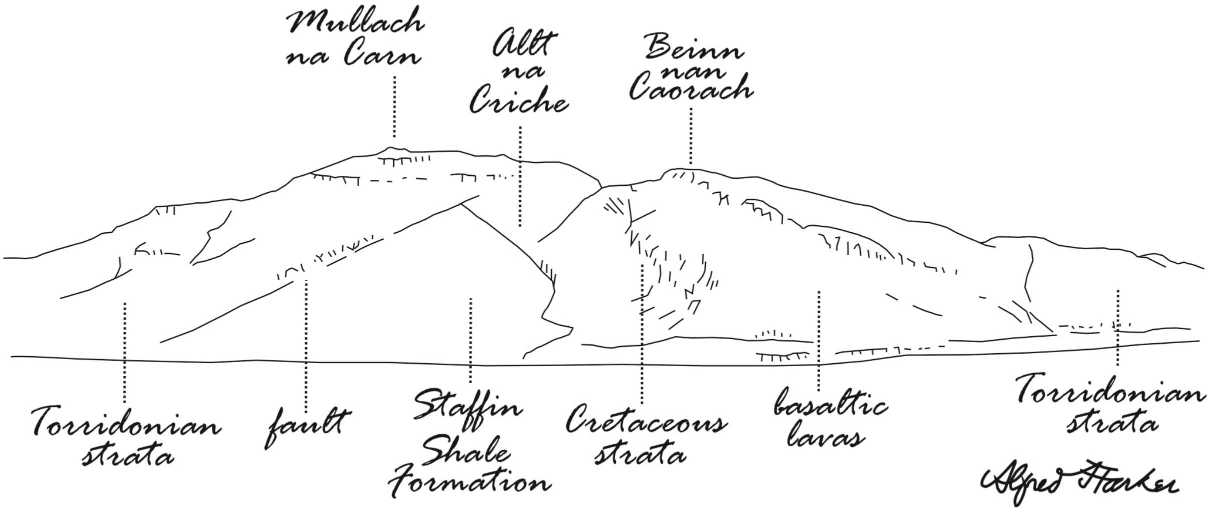


Figure 2-1 – The Rock Cycle.

Chapter 3 Precambrian and Palaeozoic Rocks

On Raasay, Archaean basement gneisses of the Lewisian Gneiss Complex are overlain by Late (or Neo-) Proterozoic terrestrial strata of the Torridonian Supergroup ('Torridonian') and constitute part of a foreland (in situ) crustal block. These units also form part of the Moine Thrust Zone on the Sleat Peninsula on Skye, where they, together with Late Proterozoic Moine Supergroup ('Moine') strata (schist, psammite, pelite) and Cambro-Ordovician marine strata, are components of thrust sheets that developed during the Palaeozoic Caledonian Orogeny.



3.A Introduction

Skye and Raasay are located at the southern end of the Moine Thrust Zone (MTZ), on the NW margin of the Caledonian Mountain (or Orogenic) Belt ((Peach, et al., 1907); (McClay & Coward, 1981); (Park, et al., 2002)). At its simplest, to the NW of the MTZ is the foreland suite of rocks of the Hebridean Terrane, comprising the basement Archaean Lewisian Gneiss Complex (3.B), unconformably overlain by Late Proterozoic Torridonian Supergroup strata of predominantly fluvial and lacustrine facies (3.C) and Early Palaeozoic (Cambro-Ordovician) marine strata comprising relatively pure quartz-dominated sandstones, shales, and limestones and dolostones with chert concretions (3.E). To the SE is the Northern Highlands Terrane, dominated by Late Proterozoic ('Moine') schists. The basement gneisses of the Hebridean Terrane have a complex history and there is still much debate as to the make-up of its various components and how these relate to other high grade metamorphic rocks in the North Atlantic region (Figure 3-1; Figure 3-2).

The landscape unconformity between the Lewisian Gneiss Complex and the Torridonian strata has considerable relief, with the boundary approaching, in places, a vertical attitude, indicating steep-sided palaeo-valleys on the gneissose landscape in the Proterozoic Eon. The unconformity below the Cambro-Ordovician sequence has virtually no relief.

During the Caledonian Orogeny (*c.* 500-400 Ma), the Moine schists, a thick, complex sequence of quartz- and feldspar-rich meta-sedimentary rocks (psammites) and mica-rich meta-sedimentary rocks (pelites) (3.D), which can be correlated with units within the Torridonian sequence (Krabbendam, et al., 2021), were thrusted/translated towards the NW over the foreland sequence.

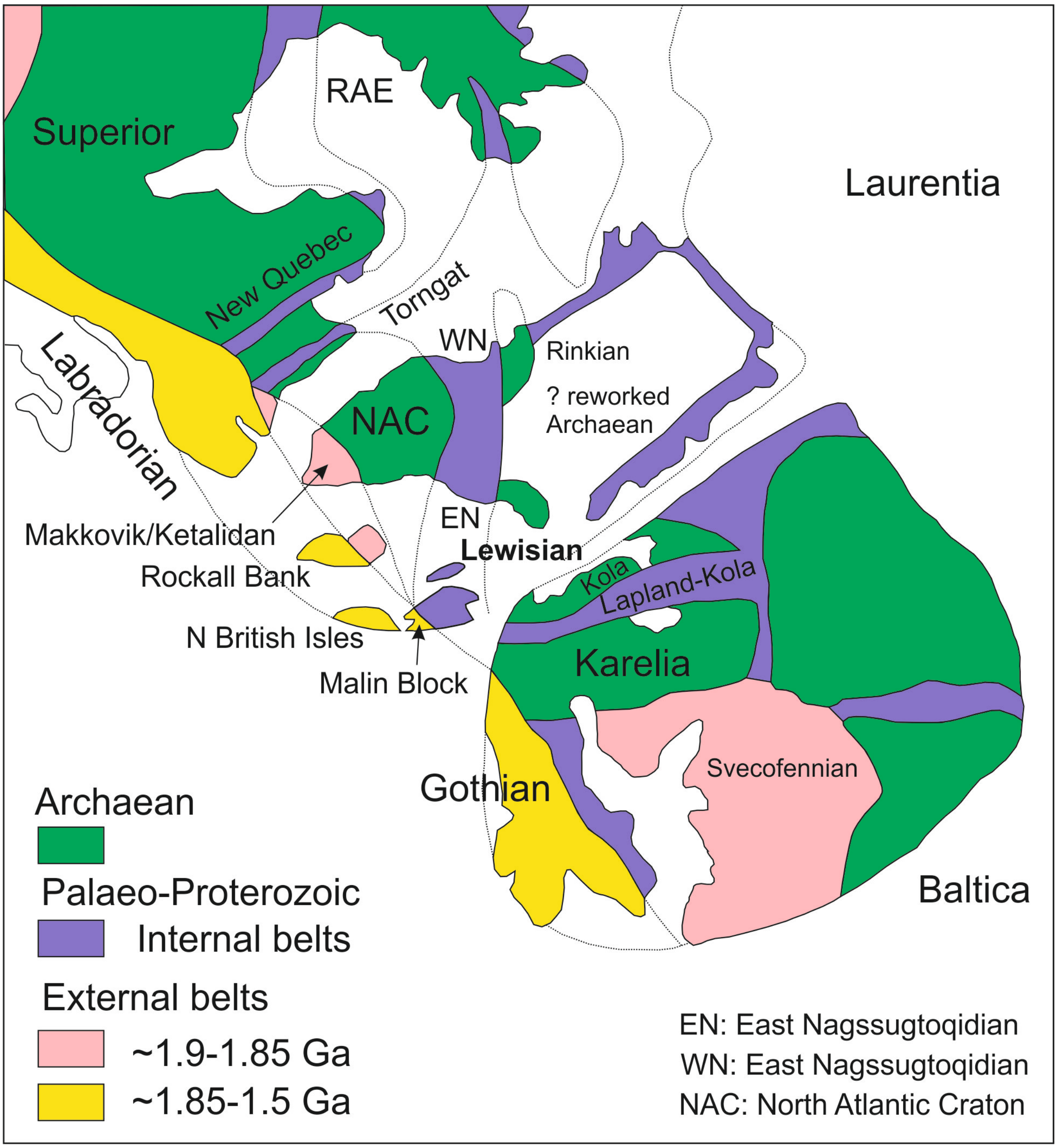


Figure 3-1 – Proterozoic plate reconstruction for Skye and Raasay (after Buchan *et al.* 2000).

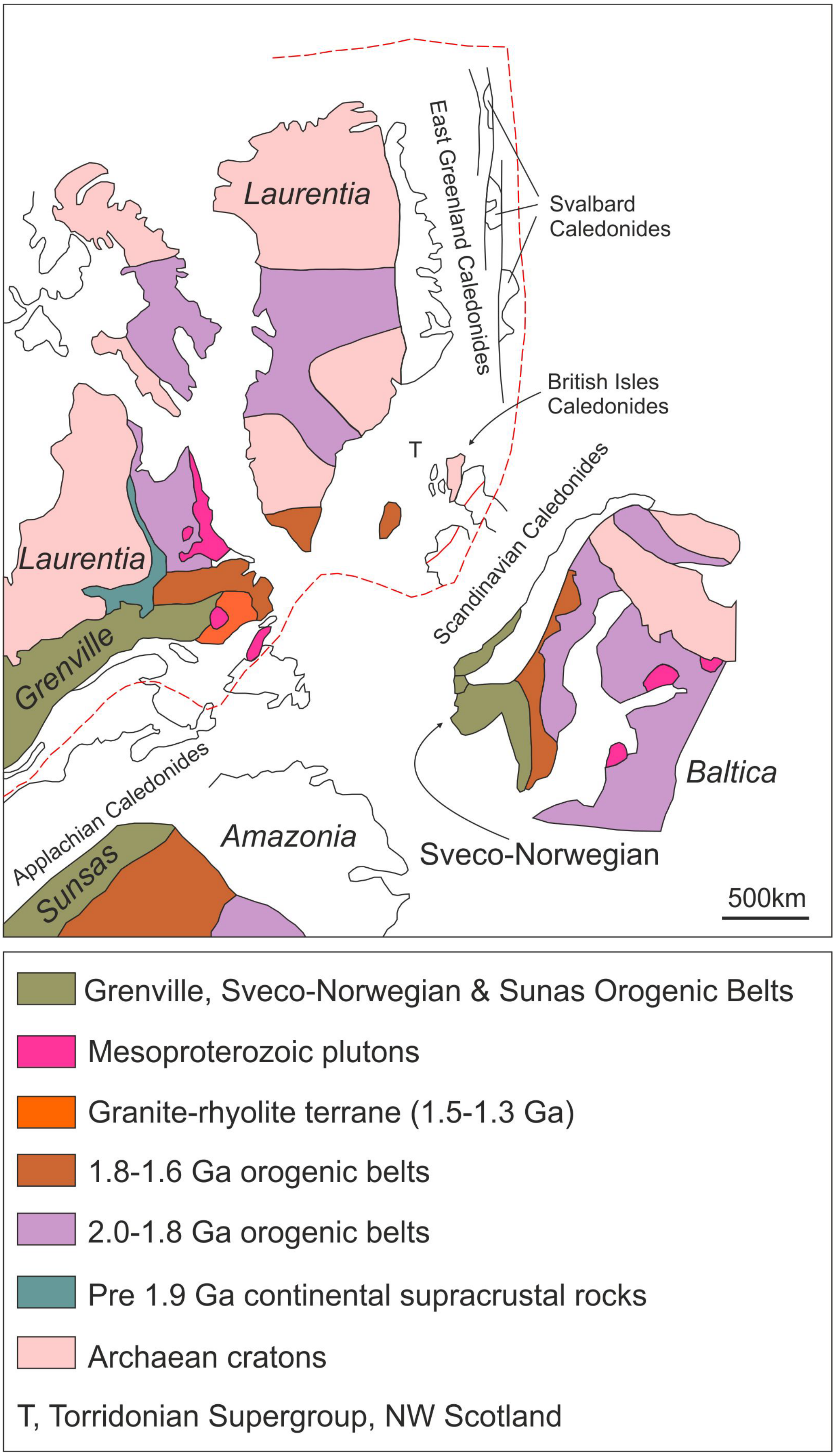


Figure 3-2 – Proterozoic plate reconstruction for Skye and Raasay (after various sources).

The Moine meta-sedimentary rocks are everywhere in tectonic/thrusted contact with rocks of the foreland sequence, the so-called 'belt of complication' (Peach, et al., 1907), or Caledonian Front. Within the belt of complication, the units of the foreland sequence, together with the Moine schists, are in complex thrusted contact relationships, most usefully illustrated in cross-sections. The various thrust faults, or damage zones, comprise intensely deformed rocks, ranging from mylonites to cataclasites (Brodie, 2007). Displacements on these thrusts range from a few kilometres, up to 30 km (McClay & Coward, 1981).

On Skye, thrusted rocks of the foreland sequence crop out on the Sleat Peninsula, in the district of Strath, and as far west as Camasunary Bay, the island of Soay, and the north side of Soay Sound. All of the units outlined above have, in some way, been modified and transported during the Caledonian Orogeny. However, on Raasay, the Lewisian Gneiss Complex is unconformably overlain by Torridonian strata and neither unit appears to have been significantly affected by the orogeny.

In Sections 3.B to 3.E, below, are details of the main Archaean, Late Proterozoic and Early Palaeozoic lithologies, including their stratigraphic and structural relationships; there is still significant and vigorous debate as to the details of these relationships ((Peach, et al., 1910); (Bailey, 1955); (Gass & Thorpe, 1976); (BGS, 2002); (Trewin & Rollin, 2002); (Krabbendam, et al., 2021)).

Unconformably overlying these units are Mesozoic rocks: Triassic, Jurassic and (minor) Cretaceous strata of the Hebrides Basin (Chapter 4). Paleocene volcanic rocks, predominantly lavas, comprise the final main stratigraphic sequence (Chapter 5). Various Paleocene intrusions disrupt these volcanic rocks, as well as virtually all of the Pre-Paleocene units, and range from significant bodies of gabbro and granite (Chapter 6), a significant dyke swarm (Chapter 7) and a sill complex (Chapter 8).

3.B The Lewisian Gneiss Complex

The oldest rocks preserved on Skye and Raasay are gneisses of the Archaean to Mid Proterozoic Lewisian Gneiss Complex, the bulk of which are exposed in north Raasay (Figure 3-3), Rona, and on the east side of the Sleat Peninsula between Isle Ornsay in the north and Ard Thurinish in the south. Thin bands of similar material crop out on the west side of the Sleat Peninsula, near Tarskavaig. Exposure on Raasay is relatively good, with abundant glacially moulded surfaces, whereas on Skye it is typically limited to the coast and a few river-sections and road-cuts. These rocks have been investigated in detail by ((Peach, et al., 1907); (Peach, et al., 1910); (Bailey, 1955); (Cheeney & Matthews, 1965); (Matthews, 1967); (Matthews & Cheeney, 1968)). In addition, an intrusion-bound mass crops out at Creagan Dubh, in Strath, and rare xenoliths of gneiss occur within the Marscoite Suite ring-dyke within the Western Red Hills Intrusive Centre (6.F).

Figure 3-3 – Typical exposure of the Lewisian Gneiss Complex in north Raasay, viewed towards the NNE across Loch an Uachdair. In the immediate area, around the shore of the loch, the bedrock is poorly exposed Torridonian Supergroup strata that unconformably overlie the Lewisian Gneiss Complex.

At its simplest, the Lewisian Gneiss Complex in NW Scotland constitutes a small part of continental crust that includes the Laurentian Shield of North America and Greenland, and the Scandinavian/Baltic Shield of NW Europe ((Park, et al., 2002)). One interpretation proposes that the Lewisian Gneiss Complex is part of an Early Proterozoic (orogenic or collisional) belt within a supercontinent comprising a number of amalgamated crustal terranes and can be correlated with the Nagssugtoqidian Belt of Greenland (Figure 3-1) ((Park, et al., 2002) and references therein).

Original high-grade (granulite facies) Scourie gneisses (named after a village, Scourie, on the Scottish Mainland, where first identified) are grey, coarse-grained, banded or massive, and of granodioritic, tonalitic or trondhjemitic composition, i.e. granitoid intrusions. The main minerals, in addition to quartz, alkali feldspar and plagioclase, are pyroxene and/or amphibole. Additional lithologies include meta-sedimentary gneisses. Subsequent structural/metamorphic events and intrusive events (the so-called Scourie Dykes) are recognised (Trewin & Rollin, 2002):

[YOUNGEST]
Laxfordian amphibolite facies metamorphic event and granite/pegmatite intrusion (2.1-1.5 Ga)
Emplacement of Scourie Dykes (2.2-2.4 Ga)
Inverian retrograde (to amphibolite facies) metamorphic event (2.4-2.5 Ga)
Post-Badcallian pegmatites (*c.* 2.5 Ga)
Badcallian (granulite facies) metamorphic event(s) (*c.*2.5 Ga)
Formation/emplacement of (Scourian) granitoid intrusions and rare sedimentary units (*c.* 2.8-3.1 Ga)
[OLDEST]

The NW-SE -trending Scourie Dyke Swarm (2.2-2.4 Ga) was deformed and metamorphosed, along with its host Scourie gneisses, during the Laxfordian event (named after a location, Laxford Bridge, on the Scottish Mainland, where first identified), which resulted in the development amphibolite facies mineral assemblages in original (predominantly) dolerite intrusions. Deformation comprised the development of a strong NW-SE -trending fabric, which was subsequently folded, resulting in segmentation/boudinage of the originally planar intrusions. Granitic and granodioritic pegmatites are another common feature of the Laxfordian gneisses and cross-cut the deformed and metamorphosed Scourie dykes. Although forming a useful chronological framework, there are considerable uncertainties as to the timing and regional significance of these events, with the possibility that the present-day configuration of the Lewisian Gneiss Complex occurred relatively late in the Proterozoic and that the various recognised terranes were subjected to earlier and (presently) uncorrelatable metamorphic and structural events (*cf.* (Love, et al., 2010)).

The Lewisian Gneiss Complex on Raasay (and its northern neighbour, Rona) is part of the Hebridean Terrane, or foreland, located NW of the Moine Thrust Zone, and is unconformably overlain by sedimentary rocks of the Torridonian Supergroup (Figure 3-3) (e.g. (Park, et al., 2002)) (3.C). These gneisses are attributed to the Southern Laxfordian Belt, which crops out on the Scottish Mainland between Gruinard Bay and Loch Torridon and which underwent regional metamorphism, or reworking, during a Laxfordian tectonic/metamorphic event (*c.* 2.1-1.5 Ga) ((Park, et al., 2002)).

The Raasay gneisses are locally migmatitic and contain discontinuous layers/bands of basic-ultrabasic material (Figure 3-4). The foliation/layering typically has a NW-SE strike, with a highly variable dip. Granitic sheets and pegmatites of Laxfordian character are relatively common, indicating affinities with the southern outcrop(s) of the Scottish Mainland. Several dykes of the NW-SE -trending Paleocene Skye Main Dyke Swarm dissect the gneisses of north Raasay and Rona, giving rise to significant clefts and coastal inlets.

Figure 3-4 – Typical banded gneiss of the foreland Lewisian Gneiss Complex in north Raasay, in a road-cut at Loch Arnish, south of Rubha Croin at [NG 5913 4763]. The predominantly orange rocks are quartz-alkali feldspar -dominated granitic gneiss, and the dark bands, commonly forming discontinuous (boudinaged) masses, are mafic gneiss, dominated by amphibole and plagioclase. Pole *c.* 1m long.

The gneisses on the Sleat Peninsula have suffered some degree of tectonic transport: the material on the east side of the peninsula sits above the Moine Thrust Plane (3.F) and constitutes a significant portion of the large Moine Thrust Sheet, which can be traced northwards along the west coast of the Scottish Mainland (Figure 3-5). Within the Moine Thrust Sheet on Skye, (Matthews & Cheeney, 1968) recognise the axial trace, dipping to the east, of the so-called Knock Synform (3.D). This Lower Palaeozoic structure can be traced from Knock Bay to Isle Ornsay and causes a repetition in rock-types from NW to SE. These flaggy rocks are granitic to intermediate in composition and are typically devoid of zones of mylonite, a feature more readily noted in the material around Tarskavaig. Gneissose banding is well developed, with layers consisting of quartz, alkali feldspar and plagioclase, and layers rich in chlorite, hornblende and actinolite. The thickness of individual bands is extremely variable, ranging from a few millimetres up to several tens of centimetres.

Figure 3-5 – Typical banded gneiss of the Lewisian Gneiss Complex within the Moine Thrust Sheet on the east side of Knock Bay, east coast of the Sleat Peninsula. The small-scale banded character of the gneiss may, in part, be due to Moine Thrust Zone deformation events. Pole *c.* 1m long.

Associated with these gneisses are smaller masses of more mafic hornblende-chlorite gneiss, most common in the area around Isle Ornsay. These rocks possibly represent metabasites, i.e. originally basaltic igneous rocks, which have undergone deformation and metamorphism during the development of the Lewisian Gneiss Complex in Proterozoic times (*cf.* the Scourie dykes, above). It is not uncommon to find developed within these mafic rocks, hornblende crystals up to 5cm in length, together with garnet porphyroblasts.

(Matthews, 1967) describes several zoned ultramafic pods that occur within the gneiss between Knock Bay and Isle Ornsay that consist of cores of talc and dolomite (commonly with magnetite), rimmed by succeeding zones of actinolite and biotite. Most of these pods tend towards lenticular forms, parallel to the foliation of the enclosing gneiss, with lengths of up to 3m and length:breadth ratios of approximately 5:1. It is concluded that the pods formed by reaction between ultramafic intrusions and the country-rock gneisses during a period of regional metamorphism (either in Proterozoic or Lower Palaeozoic times).

Also of probable igneous origin is a band of highly-altered serpentinite that trends NE-SW between Knock Bay and Camascross, which can be traced along strike for a distance of at least 2km. The serpentinite weathers to a rusty orange and is best exposed on the ridge to the west of Loch Baravaig. Serpentine and Fe-carbonates dominate this rock, which also contains stringers of magnetite up to several millimetres wide.

The gneiss to the west of the Moine Thrust, at Tarskavaig, and further south on the north side of Gleann Meadhonach, shows a much greater degree of deformation. It lies above the Tarskavaig

Thrust (and the associated Caradal and Lamascaig faults) and has been intensely deformed. This is best observed on the coast *c.* 1.5km south of Tarskavaig Bay, where the gneisses are intimately associated with Moine psammites and pelites (3.D).

At Creagan Dubh in the district of Strath, *c.* 6km west of Broadford, a small intrusion-bound inlier of gneiss is preserved between two of the granites of the Eastern Red Hills Intrusive Centre (6.G). It has an outcrop area of approximately 0.5km^2 and a faulted contact to the NW against Jurassic strata (4.C). Lying unconformably above the gneiss are hydrothermally-altered basaltic lavas of Paleocene age (5.D). The unconformity is somewhat irregular, but can be traced from the base of Creagan Dubh, NE to where it is exposed in the Allt na Teangaidh (Figure 3-6). The gneiss has a strong mineral banding/foliation, with alternating quartz-feldspar -rich and mafic portions and is, locally, brecciated or agmatitic. In thin-section, there is evidence that a melt phase developed: abundant micrographic intergrowths of quartz and alkali feldspar are present, suggesting that sufficient heat was available during the Paleocene to enable partial fusion to take place. Furthermore, breakdown of primary mafic minerals such as pyroxene and amphibole has occurred, resulting in the extensive development of secondary chlorite and epidote.

Figure 3-6 – Pale grey gneiss of the Lewisian Gneiss Complex exposed in the Allt na Teangaidh at [NG 5913 2455]. Its location, adjacent to granites of the Eastern Red Hills Intrusive Centre, has led to considerable (Paleocene) hydrothermal alteration, which has significantly affected its appearance. Pole *c.* 1m long.

The only other direct evidence of the Lewisian Gneiss Complex basement below Skye is the presence of gneiss xenoliths within the ferrodiorite intrusion of the Marscoite Suite of the Paleocene Western Red Hills Intrusive Centre (6.F). These xenoliths are up to 5m across, with quartz, sodic plagioclase and alkali feldspar in the pale bands, and pyroxene (± amphibole) within the darker bands. Most of these xenoliths occur in Harker's Gully, on Marsco. A two-pyroxene granulite xenolith occurs within the ferrodiorite intrusion at the head of the Allt Coire nam Bruadaran (Thompson, 1981).

3.C The Torridonian Supergroup

The Late Proterozoic Torridonian Supergroup sedimentary rocks (Figure 3-7), hereafter referred to informally as the Torridonian, were deposited in a rift valley system in the middle of a supercontinent, Rodinia (Park, et al., 2002); closure of the Iapetus Ocean during the Palaeozoic reactivated associated normal faults into thrust faults and the Torridonian strata and other spatially-associated units were involved in the complex compressional tectonics of the Moine Thrust Zone (Sections 3.A & 3.F). The outcrop (and associated subcrop) of the Torridonian extends from the Moine Thrust Zone, NW to the Minch Fault (Figure 3-8). Their distinctive, generally red-brown, coloration is due to the presence of abundant hematite cement. Mineralogically, the sandstones are plagioclase-rich arkoses, being predominantly derived from the subjacent basement Scourie grey gneisses (3.B). Hereafter, they will be referred to as sandstones.

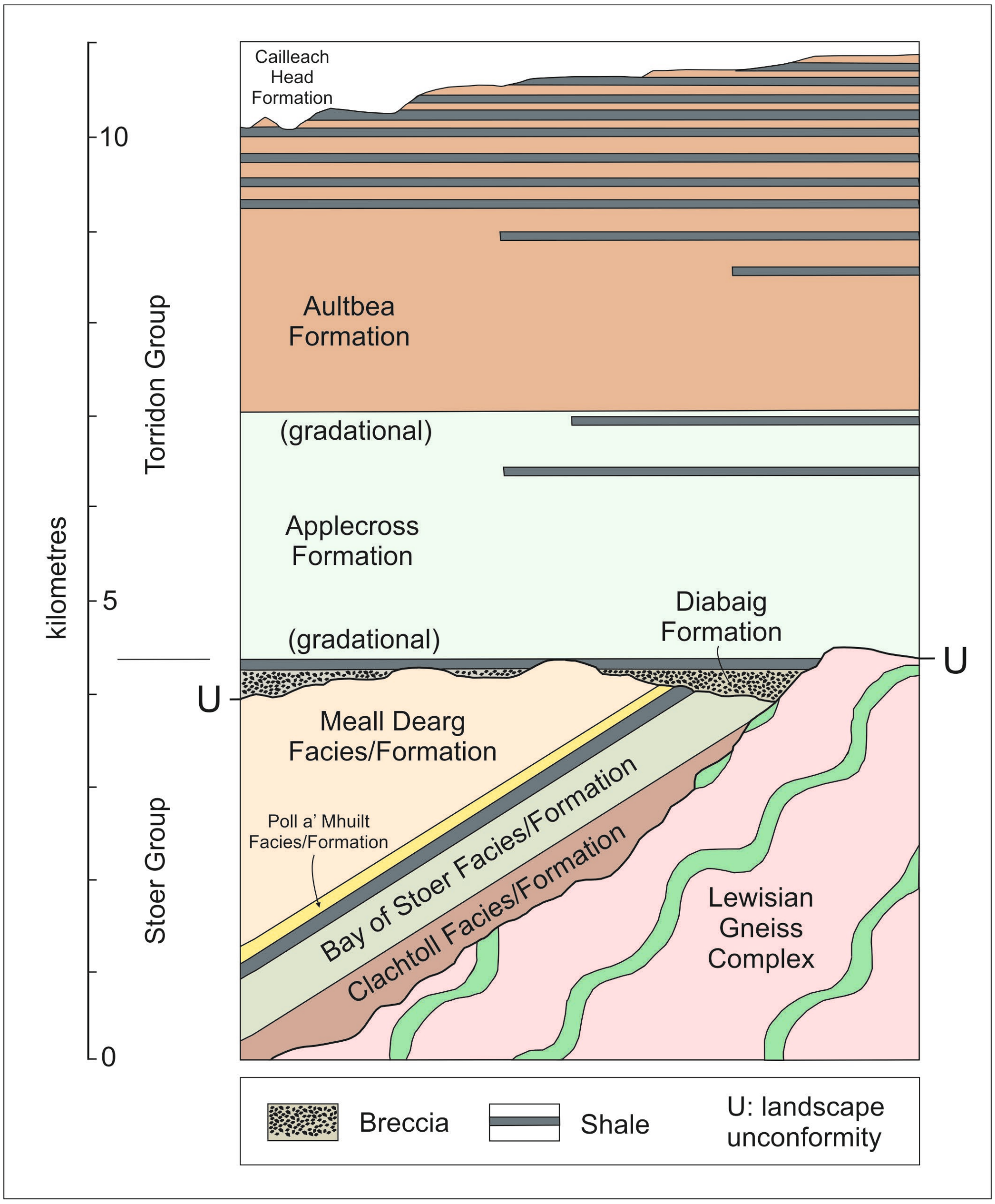


Figure 3-7 – Lithostratigraphy of the Torridonian Supergroup (after various sources).

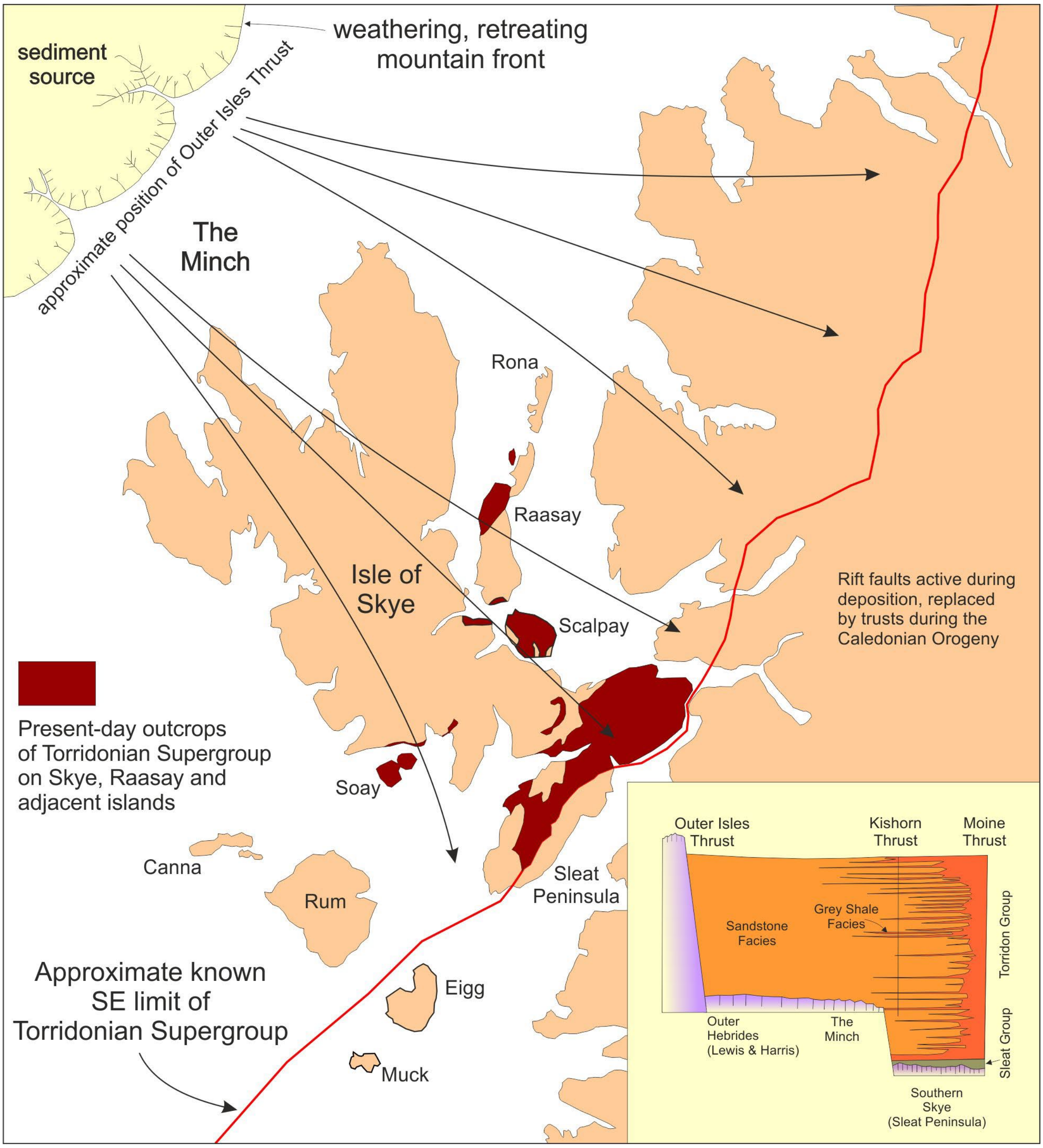


Figure 3-8 – Map depicting outcrops of Torridonian strata on Skye and Raasay (after various sources).

Age determinations for the three recognised groups within the Torridonian are not easily achieved (Park, et al., 2002). A limestone within the Stoer Group yields a Pb isotopic age of 1199 ± 70 Ma (Turnbull, et al., 1996), and phosphate concretions within the Diabaig Formation at the base of the Torridon Group yield a Rb-Sr isotopic age of 994 ± 48 Ma and a Pb isotopic age of 951 ± 120 Ma (Turnbull, et al., 1996). These data suggest a considerable age difference between the two groups, possibly as much as 200 m.y. There are no reliable isotopic ages for the so-called Sleat Group, only identified within the Kishorn Thrust Sheet on the Sleat Peninsula, although stratigraphic relationships indicate it is older than the Torridon Group.

Climatic conditions during the deposition of the Torridonian are indicated from the rock record (Park, et al., 2002). For the Stoer Group, muddy sandstones in the Clachtoll Formation and massive siltstones in the Poll a' Mhuilt Member are interpreted to be very similar to present-day vertisols, soils with a high clay content that shrink and swell as their water content changes, and which are most commonly formed in warm, sub-humid or semi-arid climates. Consequently, a low latitude (within *c.* 30° of the equator), an annual rainfall in the range 300-1200mm and periods of (Summer) drought are implied. Palaeomagnetic data, and bulk-rock mineralogy and geochemistry point towards a similar interpretation. Given the age of the Torridonian Supergroup, weathering and erosion of the source rocks occurred on a landscape devoid of vegetation, very different to the present-day.

The overall tectonic-depositional model proposed by (Stewart, 1982), summarised by (Park, et al., 2002), for the Stoer Group, but also applicable to the Sleat and Torridon groups, involves a rift environment. The western margin of the basin is interpreted as the Minch Fault and the eastern margin a (precursor) fault that ultimately may have been transformed into the Moine Thrust Plane (Figure 3-9). The overall width of the basin was *c.* 80km and it received quartz and feldspar-rich detritus from the erosion of the (Lewisian Gneiss Complex) basement (3.B). During the deposition of the Applecross Formation strata, the dominant sediment transport direction was from the west, possibly influenced by movements on the Minch Fault.

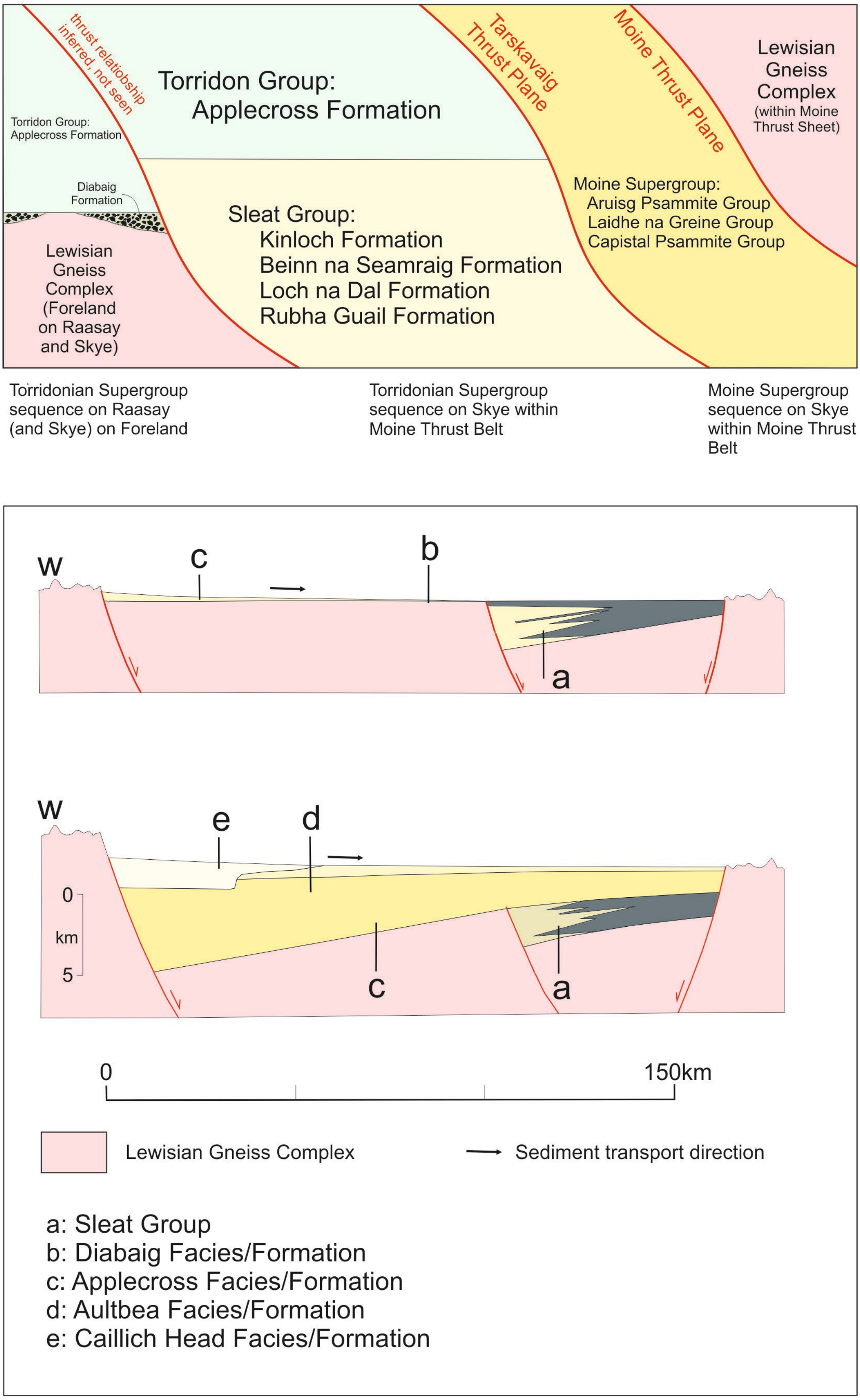


Figure 3-9 – Distribution of Torridonian Supergroup strata on Skye and Raasay and a tectonic model for deposition (after Park *et al.* 2002).

On Skye, four main outcrops have been identified (Figure 3-8): (1) on the Sleat Peninsula, west of the Moine Thrust Plane; (2) in the district of Strath, south of Broadford; (3) in the area north of the Western Red Hills, between Sconser and Maol na Gainmhich, including the islands of Scalpay and Longay; and, (4) in the area south of the Cuillin Hills, between Camasunary Bay and Soay Sound (including Soay). On Raasay, Torridonian strata (*s.l.*) unconformably overlie the Lewisian Gneiss Complex in the north of the island and also crop out in the southernmost part of the island.

A number of major subdivisions within the Torridonian are recognised (summarised from (Park, et al., 2002)) and references therein) (Figure 3-7):

1. *The Stoer Group:* a *c.* 2km thick sequence of red beds, ranging in grade from conglomerate through to mudstone. Various facies, or depositional characteristics, are recognised, including: (a) a breccia facies, deposited in alluvial fans on a basement gneiss topography with up to 300m of relief, with basal boulder beds of very local derivation, together with units containing rounded clasts suggesting kilometre-scale transport; (b) a muddy sandstone facies, a distal equivalent to the breccia facies, consisting of red-brown, massive sandstones and mud-rich sandstones and siltstones with desiccation cracks, deposited in mudflats; (c) a conglomerate facies, deposited in shallow, braided channels, with normal-graded, trough cross-bedded, coarse-grained sandstones and associated conglomerates; (d) a laminated sandstone facies, comprising mm-scale laminae of sandstone that define laterally-persistent, low-angle cross-bedded units up to 10m thick, together with more massive sandstones with erosional bases, deposited in migrating subaqueous barchanoid (crescent-shaped) dunes and high-energy flood-water systems, respectively; (e) the so-called Bay of Stoer Facies, red, trough cross-bedded sandstones with abundant soft-sediment deformation structures, deposited in a braided fluvial system; (f) the so-called Poll a' Mhuilt Facies, consisting of red, laterally-extensive, metre-scale, fine-grained sandstones and siltstones with wave ripples and desiccation cracks, deposited in ephemeral lakes, and intercalated with the Bay of Stoer Facies; and, (g) the so-called Meall Dearg facies, comprising planar cross-bedded and planar bedded sandstones with wave-rippled surfaces, very similar to the Bay of Stoer Facies.

These various facies are clearly spatially and temporally related. For example, the breccia facies forming alluvial fan deposits, located at or near to the base of the sequence, adjacent to basement palaeo-highs (i.e. hills at the time of sediment deposition). The conglomerate and laminated sandstone facies may be explained in terms of boulder and gravel fans fringing high ground, interfingered with fluvial deposits of ephemeral river systems, subsequently overwhelmed by a subaqueous barchanoid dune field. Abrupt changes in palaeo-flow directions and sporadic lacustrine deposits within predominantly fluvial intervals may be due to syn-depositional faulting, causing disruption to the drainage system.

2. *The Sleat Group:* up to 3.5km of coarse-grained, grey sandstones and lesser amounts of grey shales, taking its name from the Sleat Peninsula on Skye. These strata occur only within the Kishorn Thrust Sheet on Skye and are demonstrably older than the overlying, conformable Torridon Group. Due to their location within the Moine Thrust Belt, these strata have been regionally metamorphosed, up to lower greenschist facies, whereby original hematite is replaced by magnetite, hence their grey coloration. These strata are, however, not significantly deformed. A number of formations are recognised:

[TOP]
The Beinn na Seamraig and Kinloch formations: Two sequences of strongly distorted, cross-bedded sandstones (Beinn na Seamraig: coarse-grained; Kinloch: fine-grained). Typically, metre-thick sequences with ripple lamination, interbedded with grey shales. Interpreted as braided river deposits with intercalated lacustrine or shallow marine strata.

The Loch na Dal Formation: Dark grey siltstones with laminae of coarse to very coarse sandstone, most likely of lacustrine or shallow marine origin, overlain by fluvial to deltaic channel-fill, trough cross-bedded sandstones.

Rubha Guail Formation: Coarse green sandstones due to chlorite and epidote (formerly referred to as the *Epidote Grit Formation*), with trough cross-stratification, together with laminated, fine-grained sandstones and siltstones with wave ripples and desiccation cracks. Interpreted as the products of an alluvial fan prograding from the flank of a basement high into a lake.
[BASE]

Pebbles within the Sleat Goup deposits are typically of silicic igneous rock lithologies, or of granitic gneiss, and have been relatively locally derived from an upper crustal source.

3. *The Torridon Group*: This sequence unconformably overlies the Stoer Group and also sits directly upon the Lewisian Gneiss Complex. The palaeo-topographic relief on the unconformity is substantial, up to *c.* 600m. A number of formations are recognised:

[TOP]
The Cailleach Head Formation: Not represented on Skye or Raasay, this formation has a restricted outcrop on the Scottish Mainland and comprises sandstones and shales interpreted to have formed by deltas prograding into freshwater lakes.

Aultbea Formation: Not represented on Skye or Raasay, consisting of medium-grained, red, trough and planar cross-bedded sandstones deposited in a braided river system towards the toe of an alluvial fan. The channels were typically very shallow, typically < 10m, and deposition occurred on transverse sand bars.

Applecross Formation: Coarse-grained, red, trough and planar cross-bedded, fluvial sandstones, typically with pebbles of various porphyritic igneous rocks and jasper. Grain-size grade diminishes towards the transitional top of the formation into the Aultbea Formation. Soft-sediment deformation features are relatively common, including within-bed synclines connected by cusps and folded cross-stratification, that are attributed to seismically-induced liquefaction, or quicksand development. Interbedded shales are interpreted as lacustrine deposits.

Diabaig Formation: Four facies are recognised: (a) alluvial fan breccias, mantling the basement and infilling palaeo-valleys, dominated by clasts of gneiss; (b) fluvial, channel-filling trough and planar cross-bedded tabular sandstones, with wave-rippled surfaces, typically a few decimetres thick, with thin layers of red siltstone; (c) lacustrine, finely-laminated, grey shales with desiccation cracks and wave-rippled, fine-grained sandstones; and, (d) lacustrine, massive (i.e. ungraded) impure sandstones, up to several decimetres thick, with ripple laminations, interbedded with shales with desiccation cracks.
[BASE]

On Raasay, the Torridonian sequence ranges from breccias through to sandstones, siltstones and mudstones, and belong to the Diabaig and Applecross formations (Figure 3-10). Three 'local' depositional facies are recognised.

Figure 3-10 – Coarse red sandstones of the Torridonian (Supergroup) Applecross Formation, with large-scale cross stratification and distorted laminae due to seismically-induced liquefaction, or quicksand development, in a small (near-to-road) crag north of Glame, at *c.* [NG 5640 4395]. Pole *c.* 1m long.

A basal facies, typically red or grey, comprising alluvial fan breccias, transported by water over a landscape with significant topography, dominated by boulder conglomerate and breccia, together with cobble and pebble conglomerate and very coarse sandstone. These very poorly stratified rocks are interpreted to have formed by relatively minor amounts of sediment transport and represent the eroded products of the underlying basement gneisses. Two sequences are recognised: a red basal facies, the Torran Member (at least 60m thick), and a grey basal facies, the Brochel Member (at least 130m thick). These rocks have been attributed to the Diabaig Group.

Overlying the basal facies are two sequences: the Loch an Uach(dair) Member (up to 500m thick), also attributed to the Diabaig Group, overlain by the Leac-stearnan Member (up to 1,500m thick), part of the Applecross Formation.

Both are dominated by the so-called Red Facies, but with minor amounts of the Grey Facies. The Red Facies, the consequence of abundant hematite cement, is dominated by coarse to medium grade sandstones, together with a lesser amount of shale. Large-scale cross bedding is common, together with examples of highly disrupted bedding, interpreted to be the product of seismically-induced liquefaction, or quicksand development. This facies is clearly fluvial in character and the overall architecture of the facies indicates that the rivers were of the braided type. The Grey Facies, due to the quartz and chlorite content of the rocks, is dominated by shale and a lesser amount of sandstone. The presence of small-scale cross bedding, ripples and desiccation cracks are indicative of lacustrine or shoreline environments of deposition.

On Skye, a number of sequences in separate outcrops are recognised ((Peach, et al., 1907); (Peach, et al., 1910); (Clough & Harker, 1904)).

The Torridonian strata of the Sleat Peninsula are preserved within the Kishorn Thrust Sheet and are exposed in the tract of ground between Kyleakin, on Loch Alsh, in the NE, and Loch a' Ghlinne (4km NW of Ardvasar), in the SW. These rocks form an important part of the (within-thrust-sheet) Lochalsh Syncline, which is overturned towards the west. The axial plane of this structure can be traced from Loch na Beiste, south of Kyleakin, to the Sound of Sleat (at Meall Port Mealary). West of this line, the strata are the correct way up and show few signs of deformation, whereas to the east they are inverted, and in places heavily fractured and contain a cleavage.

The lowest exposed part of the sequence in the Sleat Group is the Rubha Guail Formation, formerly the Epidote Grit Formation, which crops out on the Sound of Sleat at, for example, Meall Port Mealary, where approximately 100m of strata are preserved (Figure 3-11). The original name of this formation is derived from the presence of epidote and epidotised feldspar, commonly as constituents of pebbles, which represent eroded debris from the Lewisian Gneiss Complex (3.B). The sequence comprises very coarse to medium grade sandstones, as well as mudstones and shales, deposited from fast-flowing, braided rivers and in shallow lakes, respectively.

Figure 3-11 – Deformed Rubha Guail Formation strata close to the Moine Thrust at Dùnan Ruadh on the Sound of Sleat. Pole *c.* 1m long.

Above the Rubha Guail Formation is a sequence of alternating coarse- and fine-grained sandstones, the Loch na Dal Formation, with abrupt variations in grain-size (Figure 3-12) (Peach, et al., 1910).

These rocks are best exposed on the NE side of the loch of that name, on the east coast of the Sleat Peninsula. Thicknesses of individual units are very variable, ranging from a few centimetres, up to 3m. The presence of desiccation cracks, ripple-structures and fine laminations lead (Sutton & Watson, 1964) to conclude that these sediments were deposited in some form of intertidal environment.

Figure 3-12 – Steeply inclined, fine-grained, laminated sandstone of the Loch na Dal Formation, west side of Loch na Dal at [NG 7039 1468]. Pole *c.* 1m long.

The Beinn na Seamraig Formation is dominated by fluvial channel, thick-bedded sandstones that commonly have well-developed cross-bedding, with foresets up to half a metre in height (Figure 3-13). Disturbance structures are common, with distorted laminae that take the form of upward-facing peaks separated by broad, rounded synclines (Sutton & Watson, 1964). The mechanism of formation of these structures is thought to be seismically-induced liquefaction during dewatering. Interbedded with these sandstones are thin beds of grey shale, most likely a lacustrine facies.

Figure 3-13 – Torridonian (Supergroup) Beinn na Seamraig Formation sandstones on the north side of the Broadford-Kylerhea Road at the Bealach Udal at *c.* [NG 7581 2072], with thoroughly distorted stratification due to seismically-induced liquefaction during dewatering. Pole *c.* 1m long.

At the top of the Sleat Group is the Kinloch Formation (Figure 3-14). It is best exposed north of the Kylerhea River and Glen Arroch, and can be traced south as far as Gleann Meadhonach. Its lower boundary, with the Beinn na Seamraig Formation, is transitional, being defined as where the various units, both coarse- and fine-grained, become thicker (Peach, et al., 1910). Current bedding and disturbance structures are common (Sutton & Watson, 1964). At the top of the formation there is a return to thin-bedded, fine-grained sandstones and siltstones, which alternate with thick sandstone units ((Peach, et al., 1910); (Sutton & Watson, 1964)).

Figure 3-14 – (a) Torridonian (Supergroup) Kinloch Formation sandstones forming the area NW of Beinn na Caillich (right of summit), south of Kyleakin, view towards the SW from the north side of Loch Alsh (on the Scottish Mainland); and, (b) inverted Kinloch Formation strata, indicated by truncated erosion surfaces, at the summit of Sgùrr na Coinnich, south of Beinn na Caillich, view up Loch Alsh towards ENE.

The overlying Applecross Formation of the Torridon Group is dominated by reddish-brown, medium-grained sandstones, with a few intercalations of fine-grained material (Figure 3-15). These strata are exposed over a wide tract of ground running from Lusa and Kyleakin in the north, to Loch Eishort in the south. Along the NW side of this area, the sequence is unconformably overlain by Mesozoic strata. Applecross Formation rocks are also found along with Cambro-Ordovician strata in the area around Ord, on the west side of the Sleat Peninsula, and are interpreted as part of a sequence below the Kishorn Thrust Plane.

Figure 3-15 – Inverted (younging downward), fractured Applecross Formation sandstones within the Moine Thrust Belt south of the Ord River at [NG 6157 1305]. Pole *c.* 1m long.

Below the strata of the Applecross Formation that crop out in the district of Strath, south of Broadford, are Cambro-Ordovician dolostones, in a thrusted relationship. Evidence for this relationship is less obvious in the Creag Strollamus and Coire-chat-achan areas, west of Broadford, where, again, both rock-types crop out.

Foreland Torridonian sandstones, not within the Moine Thrust Zone, are preserved on the islands of Scalpay and Longay, NW of Broadford Bay, and between Sconser and Maol na Gainmhich in the vicinity of Loch Sligachan. In the SW part of Scalpay, the Torridonian strata belong to the Mullach nan Carn Member of the Diabaig Formation and comprise laminated siltstones and sandstones. Conformably overlying these strata is the Sithean Glac an Ime Member of the Applecross Formation, consisting of red-brown, very coarse to medium grade sandstones, together with thin beds of conglomerate. The same member crops out to the NW, at the southern end of Raasay, and to the east, on Skye, between Sconser and Maol na Gainmhich. On all three islands, the Sithean Glac an Ime Member is unconformably overlain by Triassic Stornoway Formation strata (4.C). It is likely that the Lewisian Gneiss Complex occurs at no great depth (3.B).

The only other outcrops of Torridonian strata, all considered to be part of the foreland sequence, occur on the island of Soay, and on Skye south of the Cuillin Hills between Eilean Reamhar and An Leac, on Soay Sound (Figure 3-16) and in Camasunary Bay (Figure 3-17). The outcrops on Soay and (to the north) on Skye belong to the Leac-stearnan and Bheinn Bhreac members of the Applecross Formation. The Leac-stearnan Member comprises pale brown, coarse to medium grade sandstones with thin, red-grey shales and siltstones. The overlying Bheinn Bhreac Member is of similar character, differing in that it contains distinct beds of conglomerate, with cobbles and pebbles of quartzite, felsite, andesite and jasper. Cross bedding, ripple structures, remobilised sediment in the form of neptunian dykes, and water-escape features are present within these rocks. From their general appearance it is possible to correlate them with the Applecross Group. (Clough & Harker, 1904) suggest that these rocks lie to the west of the Moine Thrust Zone and have not suffered tectonic transport.

Figure 3-16 – Torridonian (Supergroup) Bheinn Bhreac Member (Applecross Formation) coarse-grained, cross-stratified sandstones, thin conglomerates and shales, intruded by irregular Paleocene basalt and dolerite sheets, east of An Leac on Soay Sound at *c.* [NG 4440 1712]. View towards the NW.

The Camasunary Bay outcrops comprise two unconnected, locally restricted and stratigraphically poorly-constrained sequences, attributed to the so-called Sgùrr na Stri and Blaven (Blà-bheinn) members (BGS, 2005). These strata dip at a shallow angle to the NW and consist of massive sandstones, together with uncommon very coarse sandstones in the east side of the bay, and fine sand and silt-rich material on the west side of the bay, especially on the west bank of the Abhainn Camas Fhionnairigh in Camasunary Bay and south of Sgùrr na Stri. (Figure 3-17).

Figure 3-17 – Torridonian (Supergroup) Sgùrr na Stri Member rippled siltstones and fine-grained sandstones, west side of Camasunary Bay at *c.* [NG 5095 1828], view towards the south.

(Clough & Harker, 1904) attribute these strata to the Diabaig Formation; however, (Beard & Drake, 2007), on the basis of interpreting a small outcrop of thermally metamorphosed dolostone in Camasunary Bay as being of Cambro-Ordovician age, rather than of Jurassic age (BGS, 2005), conclude that the Torridonian strata are separated from the dolostones by the Kishorn Thrust Plane and therefore belong to the Applecross Formation. These Torridonian strata have, in places, been subjected to intense thermal effects by the adjacent Cuillin Intrusive Centre (6.D), resulting in rheomorphism and partial melting of material up to 100m from the margin of the intrusive centre.

3.D The Moine Supergroup

On the west side of the Sleat Peninsula (Peach, et al., 1907) and (Peach, et al., 1910) recognise a series of low-grade (greenschist facies) schistose rocks that they call the Tarskavaig Moine Series, of (presumed) Late Proterozoic age (Figure 3-18; Figure 3-19; Figure 3-20; Figure 3-21; Figure 3-22). Directly below these psammites and pelites is a thin strip of mylonitised gneiss of the Lewisian Gneiss Complex (3.B), below which is the Tarskavaig Thrust Plane. The thrust plane defines a complex synform (Figure 3-18), below which are Torridonian strata (3.C) of the Kishorn Thrust Sheet. The field geologists of the British Geological Survey debated as to whether or not the Tarskavaig Moine schists could simply be metamorphosed equivalents of Torridonian strata (3.C) ((Peach, et al., 1907); (Peach, et al., 1910)), but could not reach a unanimous decision ((Strachan, et al., 2010)). However, more recent analysis by (Krabbendam, et al., 2021) indicates some form of equivalence and that the Torridonian and Moine rocks differ only in terms of metamorphic grade and degree of deformation.

Limited field evidence suggests that the depositional environment was tidal to shallow marine (Strachan, et al., 2010). The source of the original sands and muds, producing, during metamorphism, the psammites and pelites, is not thought to have been from the Lewisian Gneiss Complex. Rather, on the basis of the relatively young isotopic ages of detrital zircon crystals in the Moine rocks, derivation of the sediment was from a younger 'source', for example, the *c.* 1 Ga Grenville Orogenic Belt ((Trewin & Rollin, 2002); (Strachan, et al., 2010)) (Figure 3-2).

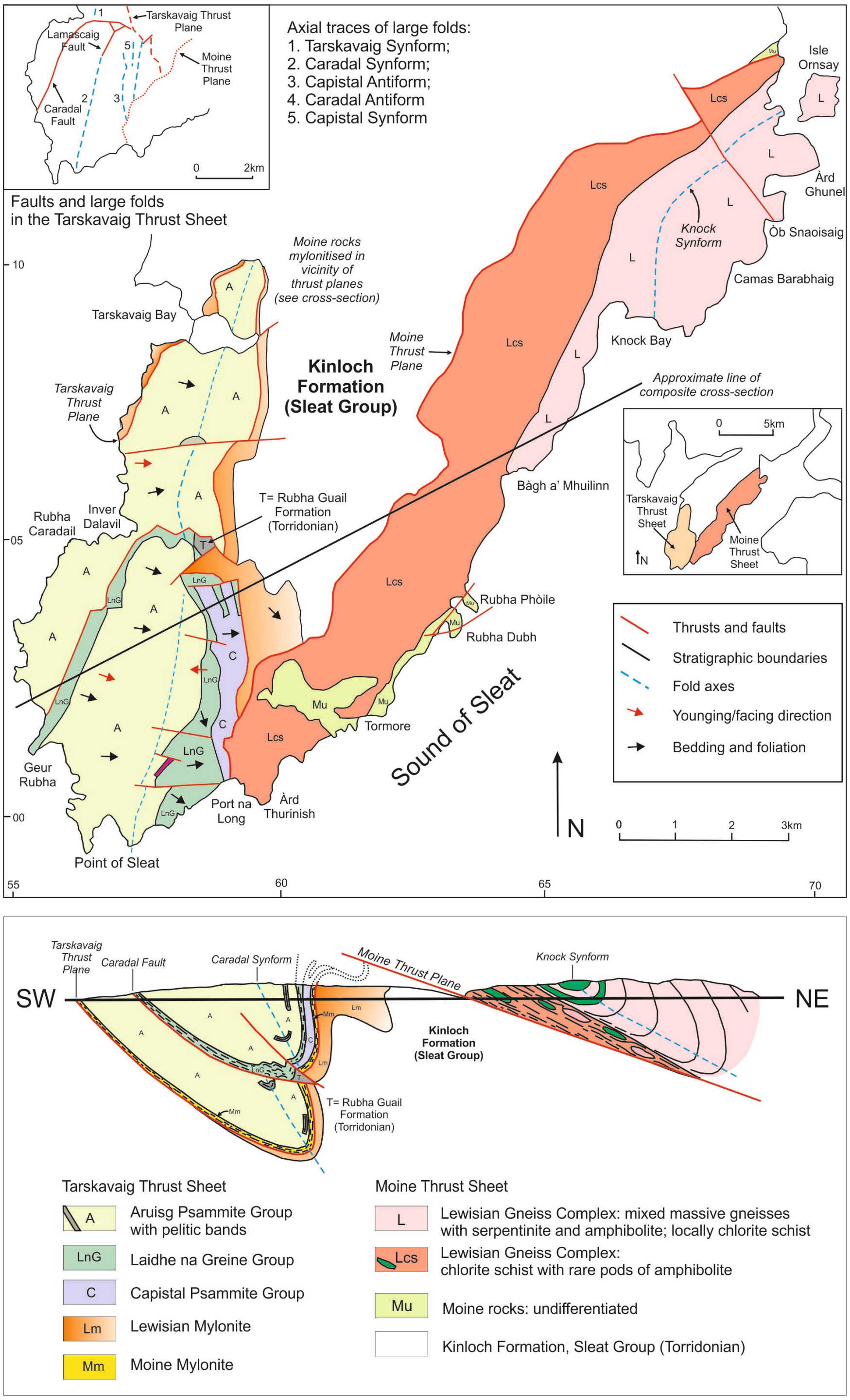


Figure 3-18 – Simplified geological map and composite cross-section illustrating the main lithological and tectonic components of the Tarskavaig and Moine thrust sheets in the southern part of the Sleat Peninsula (after Cheeney & Matthews 1965).

Figure 3-19 – Folded psammites and minor pelites of the Aruisg Psammite Group (Moine Supergroup) at the Point of Sleat (NW of the lighthouse).

Figure 3-20 – Detail of synform dominated by psammite layers of the Aruisg Psammite Group (Moine Supergroup) at the Point of Sleat (NW of the lighthouse). Pole c. 1m long.

Figure 3-21 – Inverted (younging downward) psammites of the Aruisg Psammite Group, with well-developed cross stratification, west of the summit of Sithean Mòr at c. [NG 5970 0780]. Coin c. 24mm across.

Figure 3-22 – Inverted (younging downward) psammites of the Aruisg Psammite Group, with well-developed normal grading, west of the summit of Sithean Mòr [NG 5970 0780]. Coin c. 24mm across.

A detailed investigation by (Cheeney & Matthews, 1965) concluded that a stratigraphic column and a correlation between the Tarskavaig Moine Series and Torridonian rocks on the Sleat Peninsula can be made using characteristic features such as cross-stratification and graded bedding:

[MOINE THRUST PLANE]
Aruisg Psammite Group (= Beinn na Seamraig Formation)
Laidhe na Greine Group (= Loch na Dal Formation)
Capistal Psammite Group (= Rubha Guail Formation, formerly Epidote Grit Formation)
MYLONITISED LEWISIAN GNEISS
[TARSKAVAIG THRUST PLANE]

In this correlation, the use of the terms 'Group' and 'Formation' are clearly of little significance.

The Capistal Psammite Group overlies mylonitised gneiss of the Lewisian Gneiss Complex and contains rare pelitic beds near its base, which increase in number near the transitional contact with the overlying Laidhe na Greine Group. The middle unit of the Tarskavaig Moine sequence, the Laidhe na Greine Group, consists of psammites, semi-pelites and pelites, some of which show well developed graded bedding. A return to dominant psammites is recorded in the overlying Aruisg Psammite Group, with pelites only locally developed. Cross bedding is present, although tectonic deformation has commonly destroyed these features.

Various generations of folds are present within the Moine rocks, including a set of early, large, isoclinal folds, the Capistal Antiform and the Capistal Synform (Figure 3-18). The Capistal folds and the younger/subsequent generation of smaller Doire na h-Achlais folds, developed before the main movement(s) on the Tarskavaig Thrust Plane, as some of the brecciated rocks within the thrust plane contain (fragments of) Doire na h-Achlais folds. The Tarskavaig Thrust Plane was then folded by the later Caradal folds, giving rise to the Tarskavaig Synform, the Caradal Synform and the Caradal Antiform (Figure 3-18). Small folds, named the Port a' Chuil and Conjugate Folds by (Cheeney & Matthews, 1965), have been recognised to post-date the Caradal folds. Following this, movement on the Moine Thrust Plane occurred, involving the westward tectonic transport of gneiss of the Lewisian Gneiss Complex (3.F) (Figure 3-18).

The timing of the multiple deformation and metamorphic events that have affected the Moine Supergroup rocks of NW Scotland has been investigated in detail using a variety of isotopic techniques ((Strachan, et al., 2010); (Dewey, et al., 2015)), but is not yet fully understood. The first orogenic event has been dated at *c.* 930 Ma, followed by a magmatic-intrusive event at *c.* 870-860 Ma. A so-called Knoydartian orogenic event has been dated at *c.* 780-825 Ma. This was followed by the Caledonian Orogeny, which involved three recognised phases: Grampian (at *c.* 470 Ma), Scandian (at *c.* 430 Ma), and Acadian (at *c.* 400 Ma), when final closure of the Iapetus Ocean occurred (3.F).

3.E Cambro-Ordovician Sedimentary Rocks

The youngest group of rocks that are part of the Hebridean Terrane are of Cambrian and Ordovician (Cambro-Ordovician) age (Park, et al., 2002). These strata unconformably overlie the Torridonian Supergroup (3.C) and the Lewisian Gneiss Complex (3.B) and were also involved in the Lower Palaeozoic (Caledonian) orogenic events of NW Scotland. On Skye, these rocks occur as a foreland sequence around Ord, on the west side of the Sleat Peninsula (all units except the Strath Suardal Formation), and as units within the Moine Thrust Zone on the Sleat Peninsula and in the district of Strath. A very small outcrop of marble in Camasunary Bay is also attributed to the Cambro-Ordovician sequence.

At its simplest, the sequence was deposited within the inner part of a shelf in relatively shallow water during a marine transgression on the southern passive margin of Laurentia, bordered to the south by the Iapetus Ocean (Figure 3-23). The palaeo-latitude was just south of the equator and the climate was tropical. The Eriboll Sandstone Formation and the An t-Sron Formation comprise various clastic units, whereas the overlying Durness Group are marine carbonates (dolostones) formed because of low sediment run-off from the continental interior.

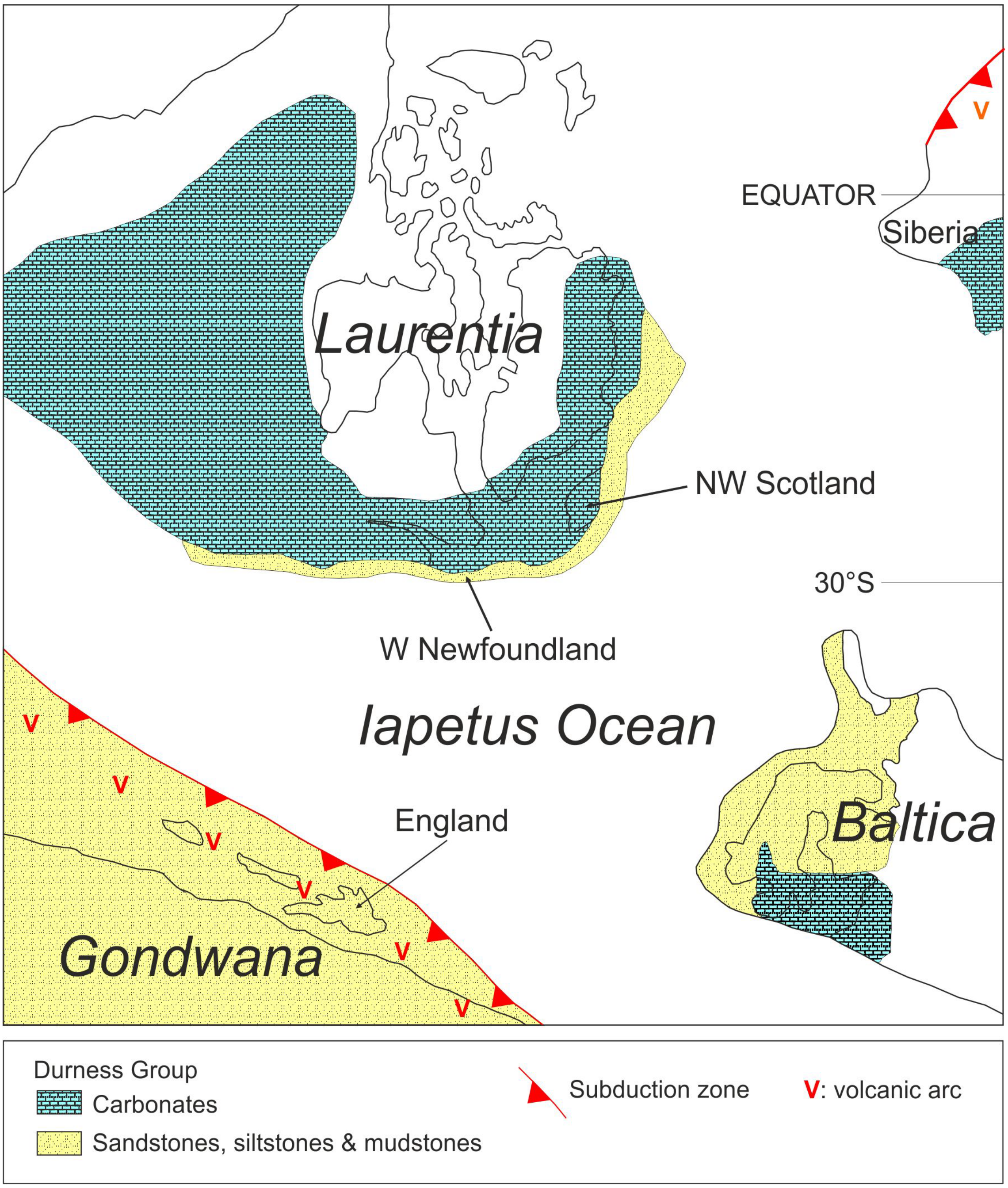


Figure 3-23 – Palaeogeographic interpretation illustrating depositional facies during Lower Cambrian times (after McKerrow *et al.* 1991).

The main stratigraphic sequence is summarised in Figure 3-24 ((BGS, 2002)). The units up to and including the Eilean Dubh Formation are of Early to Middle Cambrian age, whereas those above are of Early to Middle Ordovician age (up to the Llanvirn Series) (Figure 3-24).

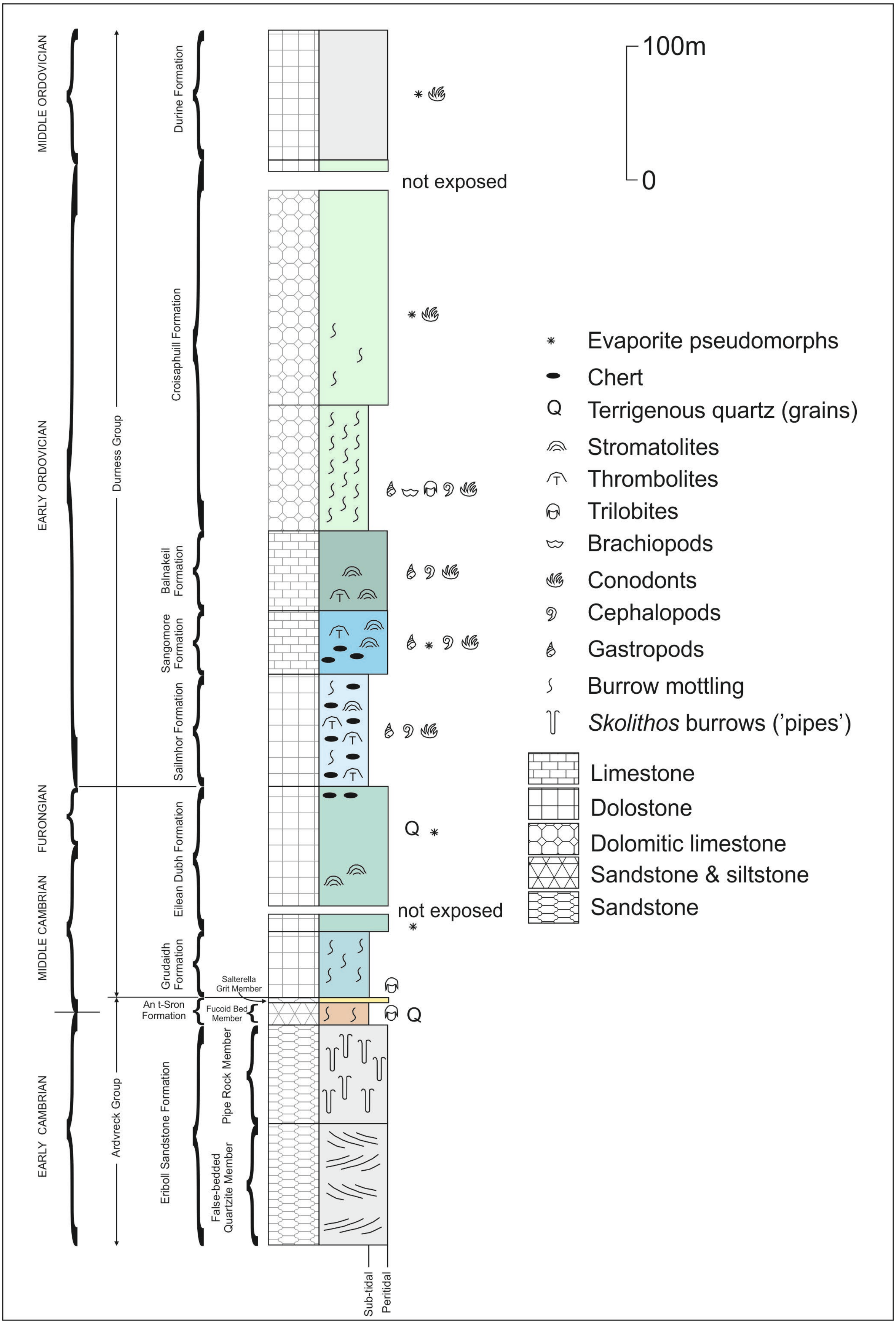


Figure 3-24 – Cambro-Ordovician lithostratigraphy (after various sources).

In summary, the various units (from oldest to youngest) have the following characteristics (Park, et al., 2002) (Figure 3-24; Figure 3-25):

False-bedded Quartzite Member (Eriboll Sandstone Formation): distinctly white sandstones; thin basal conglomerate; tidal channel and shoreface sandstones (commonly referred to as a 'quartzite' due to the effects of pressure solution and the introduction of significant silica cement) with conspicuous current cross bedding; uncommon wave ripples; barrier-island to tidal-flat environment of deposition;

Pipe Rock Member (Eriboll Sandstone Formation): distinctly white sandstones; characterised and easily recognised by the presence of the trace-fossils, *Skolithos,* comprising narrow (3-10mm diameter), vertical cylindrical burrows, and *Monocraterion,* funnel- or trumpet-shaped burrows (up to 3cm diameter) with internal curved laminae (spreite); both trace-fossils may be attributable to the same creature, with the spreite developing as escape features during periods of sediment inundation; pipe lengths may be related to sediment deposition rates, typically several cm up to *c.* 1m; bioturbation has usually destroyed any original stratification; barrier-island to tidal-flat environment of deposition;

Fucoid Bed Member (An t-Sron Formation): brown (ferruginous) dolomitic siltstones with thin interbedded shales and sandstones; bedding-parallel, sand-filled *Planolites* burrows (the 'fucoids' or seaweed of the original (Peach, et al., 1907) (mis-)interpretation); rare trilobites, brachiopods and molluscs; planar-laminated, low-angle cross bedding and normal grading; storm-dominated tidal environment of deposition;

Salterella Grit Member (An t-Sron Formation): white, coarse-grained sandstone ('quartzite') and uncommon feldspathic sandstones; conical shells of *Salterella*; *Skolithos* trace-fossils (see Pipe Rock Member, above); rare trilobites; dolomitic shales towards top of member; shallow marine transgressive and regressive environments of deposition;

Ghrudaidh Formation (Durness Group): mid to dark grey, structureless and mottled dolostones (possibly due to bioturbation *or* variable extent and degree of dolomitisation *or* intra-formational thrombolites (in which microbial communities trap, bind and cement grains)); uncommon oolitic and bioclastic grainstones; rare stromatolites; upper laminated facies with desiccation cracks; low-energy, sediment-starved, sub-tidal shelf;

Eilean Dubh Formation (Durness Group): pale grey, laminated dolostones, commonly porcellaneous; various forms of stromatolites (stratiform, digitate, dome, hemi-spheroidal) and thrombolites (tabular and bun-shaped); intra-formational breccias; nodular, lenticular and tabular cherts; locally ripple cross-bedded; three members recognised (Kyle, Stromatolite and Solmar); low-energy, sediment-starved, sub-tidal shelf;

Sailmhor Formation (Durness Group): dark grey dolostones; mottled and colloquially referred to as 'Leopard Rock' due to adjacent coarse- and fine-grained materials, possibly due to either bioturbation or diagenesis; various forms of stromatolites and thrombolites; white and pink diagenetic cherts, commonly with concentrically-layered nodular textures preserving original stromatolite structures; laminated facies; breccia-filled fissures, some extending into the subjacent

Eilean Dubh Formation, due to development of karstic surface; low-energy, sediment-starved, sub-tidal shelf;

Sangomore Formation (Durness Group): pale to dark grey, structureless dolostones; thin peloidal limestones; stratiform and hemi-spheroidal stromatolites; thin beds and nodules of chert; intraclast breccias; oolitic grainstones; collapse breccias and deformed beds due to dissolution of interbedded evaporates; shallow subtidal to emergent setting, supratidal sabkha.

The uppermost units of the Durness Group, the Balnakeil, Croisaphuill and Durine formations, do not occur on Skye.

The Eriboll Sandstone Formation (Figure 3-26) forms the most obvious topographic features (Figure 1-6), with a prominent ridge of hills east of Ord, the most recognizable summits being Sgiath-bheinn an Uird and Sgiath-bheinn Chrosabhaig, both of which are distinctly white and achieve heights in excess of 250m OD Small outcrops of quartzite occur in Glen Boreraig in the southern part of the district of Strath, as well as at Coire-chat-achan, to the SW of Broadford.

The Fucoid Bed Member (Figure 3-27) typically forms smooth grassy ground and hollows where not exposed, as seen on the west side of Sgiath-bheinn an Uird, or as isolated rusty brown exposures of siltstone.

The Salterella Grit Member lies conformably above the Fucoid Bed Member on the west sides of Sgiath-bheinn Togabhaig and Cnoc na Fuarachad, as well as from the coast, *c.* 900m ESE of the islet of Sgeir Gormul in Loch Eishort, inland, along the west side of the Sgiath-bheinn an Uird ridge. Exposures are also present in the bay at Ord.

The Durness Formation dolostones (Figure 3-28) crop out east and north of Ord, and in a tract west of the quartzite ridge from east of Rubha Ard Ghormul to the Ord River.

The Strath Suardal Formation (Figure 3-25) dolostones crop out in a broad arcuate tract in the district of Strath, from Bealach a' Ghlinne, south of Broadford, to the shore of Loch Slapin. Various members are recognised, although their precise field relationships are complicated by the presence of various thrusts within the Moine Thrust Zone and by Paleocene intrusions, including the large elongate granite that crops out on Beinn an Dubhaich (6.G.5). Tectonic boundaries between these dolostones and the structurally-overlying (Torridonian) Applecross Formation strata (3.C) have been modified by the intrusion of the granite. However, the passive intrusion of the granite post-dates the generation of the overall antiformal structure defined by the Cambro-Ordovician strata in Strath, which has been attributed to both Caledonian thrusting events and earlier intrusive events (Longman & Coward, 1979) (3.F). Thermal metamorphism and localised metasomatism by the granite add further to the complications of these strata (6.H) and their recognition as distinct stratigraphic units.

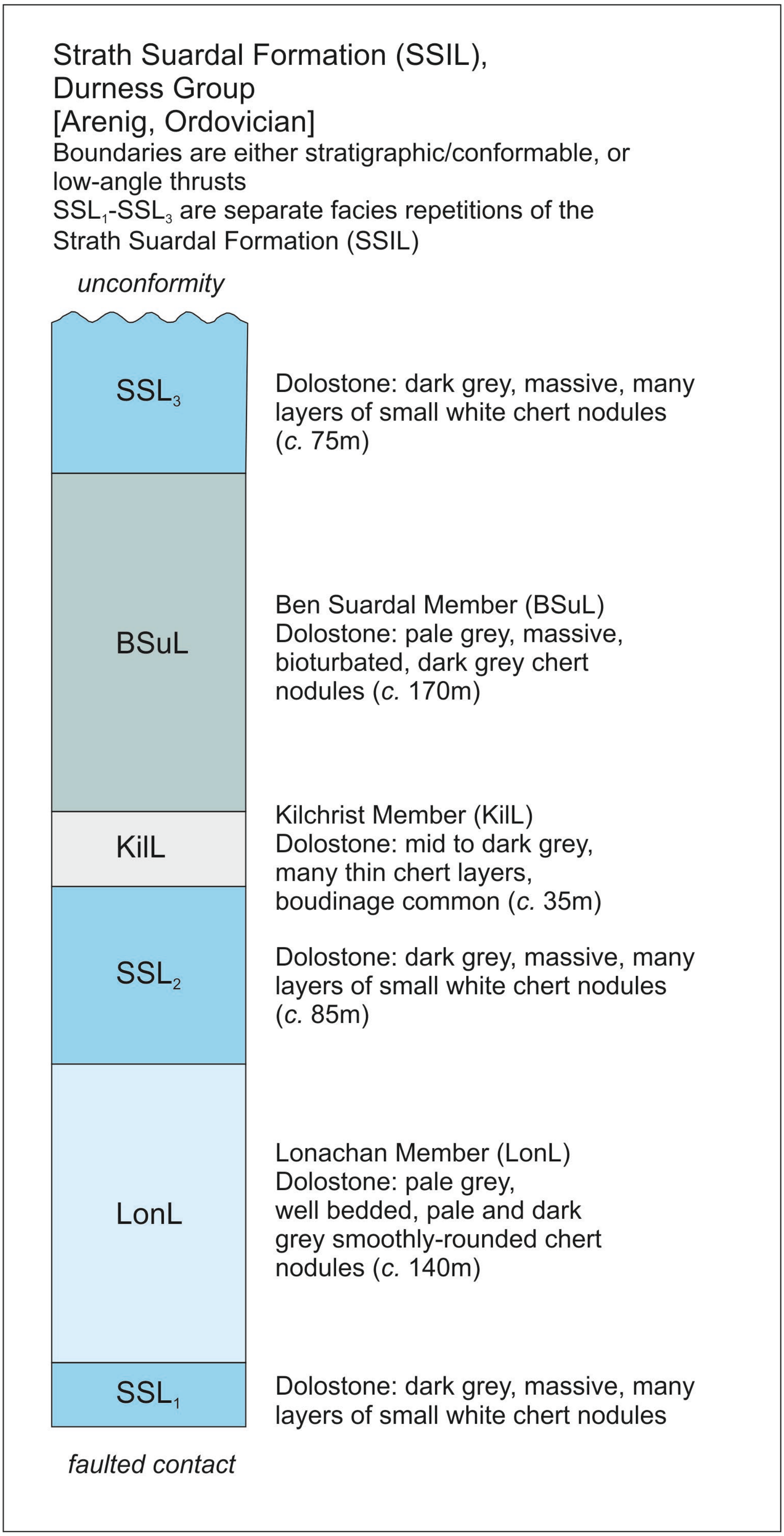


Figure 3-25 – Strath Suardal Formation lithostratigraphic column (after BGS 2002).

Key features of the members are:

Lonachan Member: pale grey dolostone; well-bedded; pale and dark grey, smooth-rounded chert nodules;

Kilchrist Member: pale to mid-grey dolostone; abundant thin chert layers, many with boudinage;

Ben Suardal Member: pale grey dolostone; massive; bioturbated; dark grey chert nodules.

Between these distinct members are intervals of dark grey massive dolostone with (many) layers of small white chert nodules. Interpretation of the depositional environment of these members follows that of the Durness Group strata that crop out on the Sleat Peninsula, where original features of the sequence are better preserved and are largely unaffected by the thermal effects of the Paleocene intrusions.

Small patches of Cambro-Ordovician strata are preserved around Creag Strollamus, west of Broadford, where they are in a thrusted contact relationship with Torridonian sedimentary rocks (3.C). Details of their field relationships are difficult to discern due to a lack of good exposure at certain critical locations, and it is not possible to conclude whether the dolostones have been thrust over the Torridonian strata, or *vice versa.*

A small outcrop of marble in Camasunary Bay, only a few metres across, is also attributed to the Cambro-Ordovician sequence (Beard & Drake, 2007). The identification of chert nodules and stringers, together with the development of abundant calc-silicate minerals, formed during thermal metamorphism (6.D), is used to argue that the original rock was a dolostone and that a more likely age for the original lithology is Cambro-Ordovician, similar to material within the Moine Thrust Zone exposed further east in the district of Strath, rather than a Jurassic age (cf. (Peach, et al., 1910)). Consequently, the contact between the metamorphosed dolostone and the surrounding Torridonian strata is a thrust plane, with the latter structurally above the former, as is the case for the Kishorn Thrust Plane, which crops out NW of Bheinn Shuardail in the district of Strath (3.F).

Figure 3-26 – Bedding surface of the Pipe Rock Member (Eriboll Sandstone Formation) with near-circular cross-sections through pipes, on north side of Camas Chathabhaig, opposite Eilean Gaineamhach an Arda [NG 6221 1403]. Hammer *c.* 30cm long.

Figure 3-27 – Steeply-inclined, orange-weathering sandstones of the Fucoid Bed Member, forming a small inter-tidal ridge in Camas Chathabhaig, opposite Eilean Gaineamhach an Arda, *c.* [NG 6210 1391]. Coin *c.* 24mm across.

Figure 3-28 – Durness Group strata on the south side of Camas Chathabhaig, *c.* [NG 6199 1385]. Pole *c.* 1m long.

3.F The Moine Thrust Zone

Compressional tectonics during the Caledonian Orogeny (470-400 Ma) caused major folding and thrusting of the various Hebridean Terrane units (Lewisian Gneiss Complex (3.B); the Torridonian Supergroup (3.C) and Cambro-Ordovician sedimentary rocks (3.E)), together with rocks of the Moine Supergroup (3.D), resulting in a complex zone of deformation (Figure 3-29; Figure 3-30; Figure 3-31). On Skye, several nappes, or thrust sheets, have been recognised ((Peach, et al., 1907); (Peach, et al., 1910); (Bailey, 1955)). The Lewisian Gneiss Complex and Torridonian Supergroup strata on Raasay are, essentially, undisturbed by the folding and thrusting events.

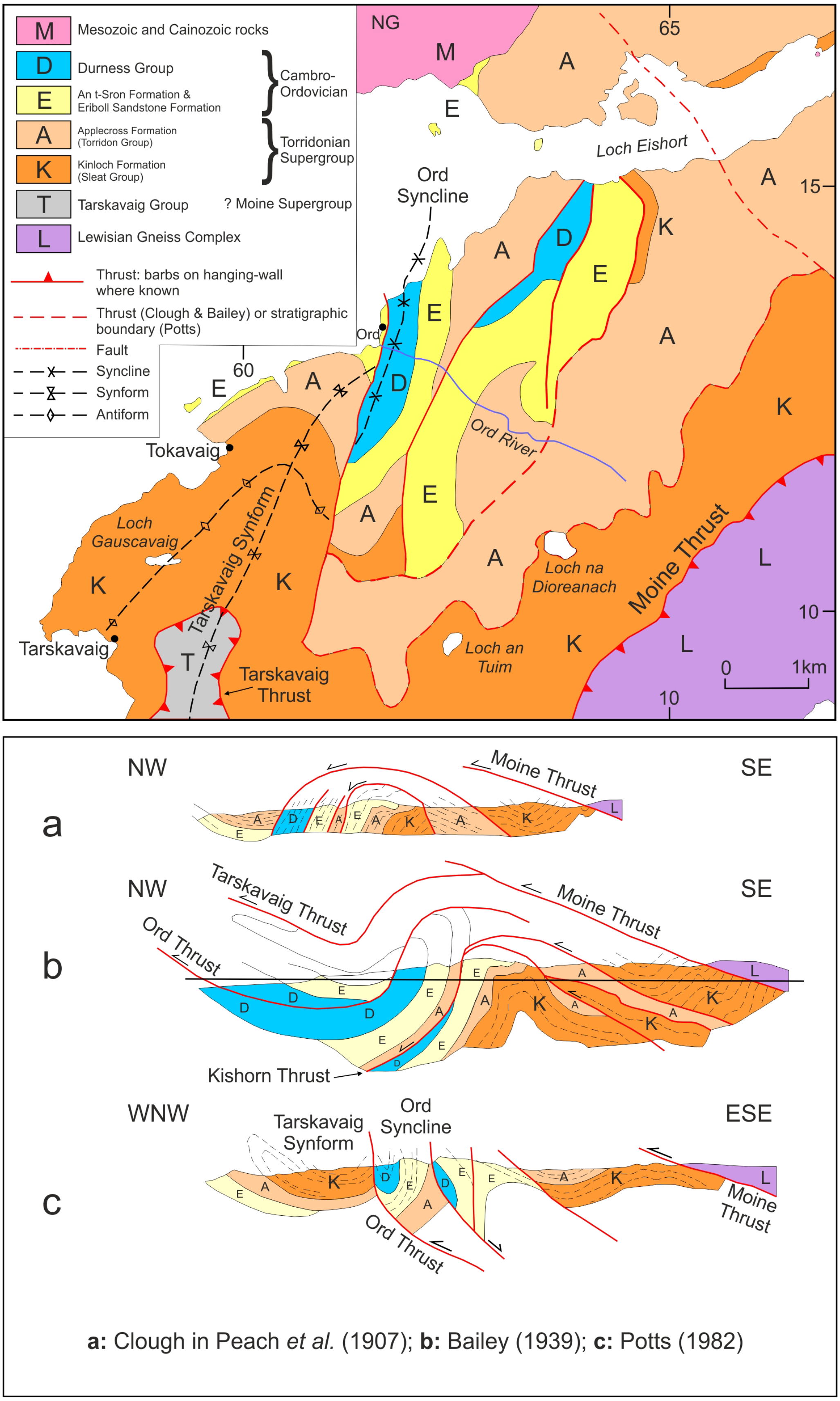


Figure 3-29 – Simplified geological map and differing cross-section interpretations illustrating the main lithological and tectonic components of the Tarskavaig and Moine thrust sheets in the central part of the Sleat Peninsula between Ord and Tarskavaig (after Emeleus & Bell 2005).

Figure 3-29 and Figure 3-31 illustrate in cross-section the key relationships between the various units within the Moine Thrust Zone on the Sleat Peninsula and in the district of Strath. The complex, faulted sequence of red-weathering Torridonian and white/pale Cambro-Ordovician strata that crops out around Ord on the west side of the Sleat Peninsula is defined/outlined by the Kishorn Thrust Plane (more likely thrust planes) (Bailey, 1955) below the Kishorn Thrust Sheet (Nappe). These strata are considered to be part of the foreland sequence ((Peach, et al., 1910); (Bailey, 1955)), although it is evident that they have been both folded and faulted (BGS, 2002). Further to the NW, in the district of Strath, the Kishorn Thrust Plane occurs on the flanks of Bheinn Shuardail, with the Cambro-Ordovician strata considerably modified by folds and faults. (Beard & Drake, 2007) interpreted an outcrop of marble in Camasunary Bay, *c.* 12km WSW of Bheinn Shuardail, as being of Cambro-Ordovician age. It is surrounded by Torridonian strata and, therefore, the boundary between the two units is, most likely, the Kishorn Thrust Plane.

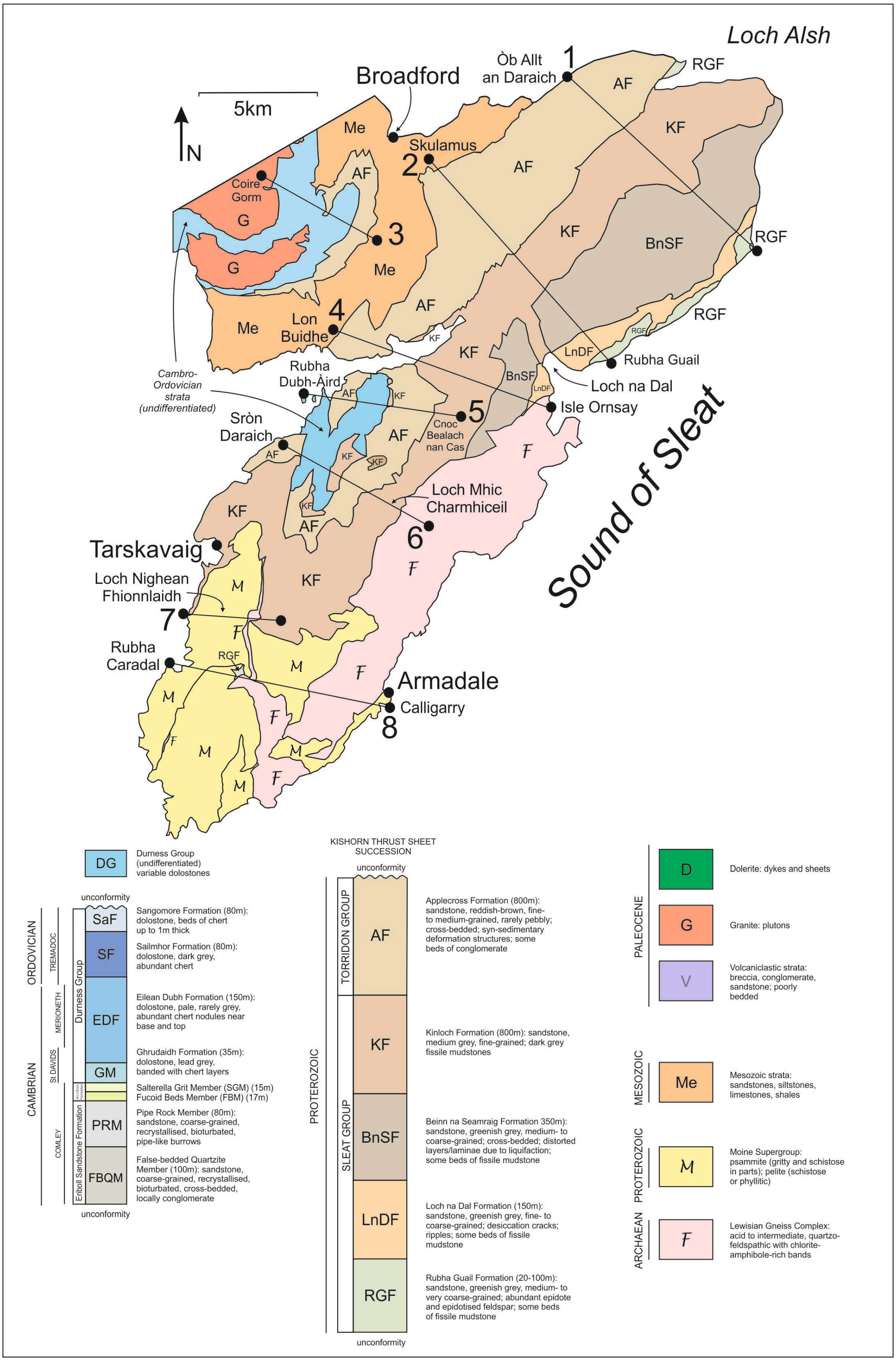


Figure 3-30 – Simplified geological map of the main lithological and tectonic components of the Sleat Peninsula and the district of Strath, with locations of schematic cross-sections in Figure 3.31.

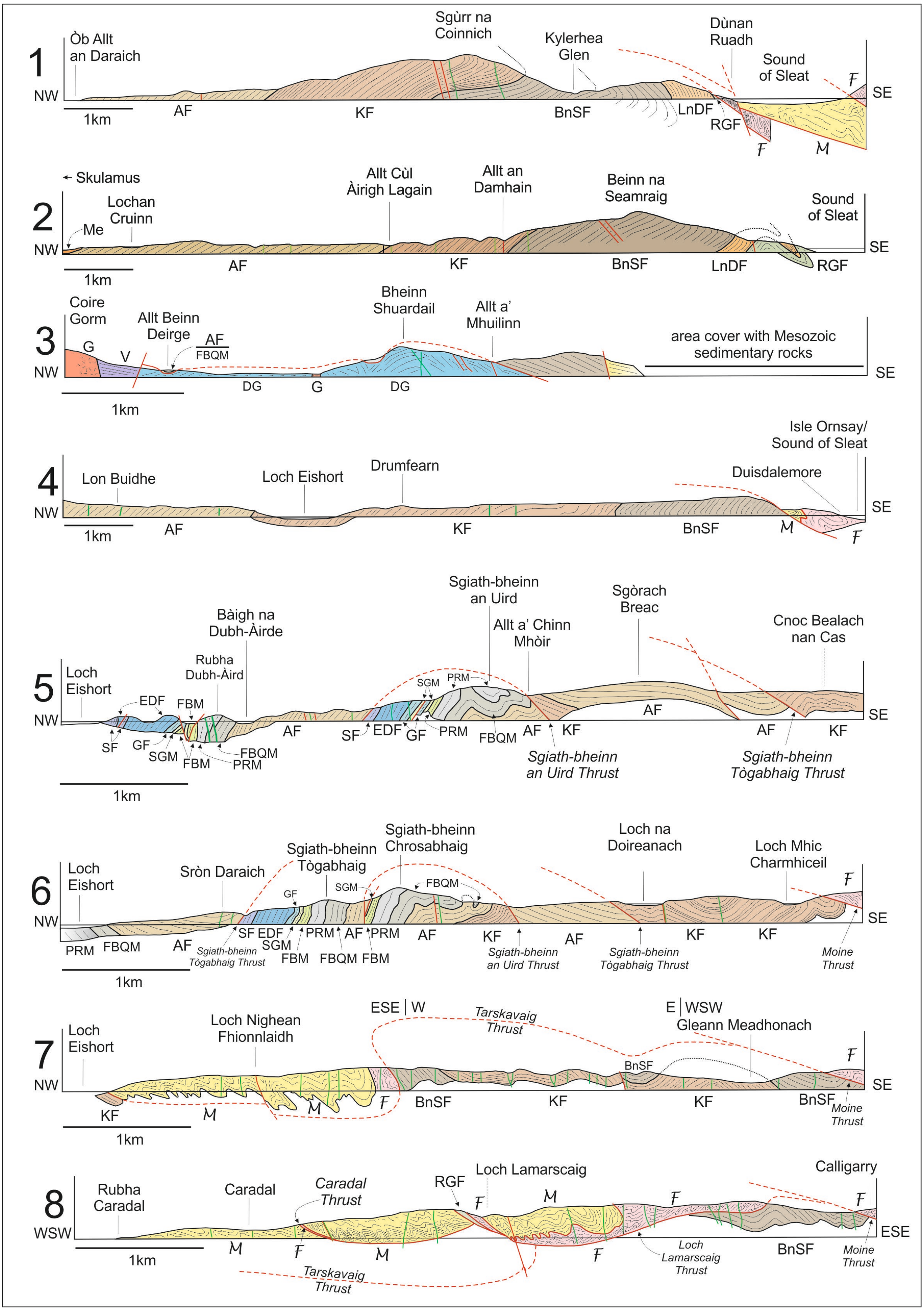


Figure 3-31 – Simplified cross-sections illustrating the main lithological units and tectonic components of the Sleat Peninsula and the district of Strath (after Peach *et al.* 1910). See Figure 3.30 for locations of lines of section and key.

The structurally-lowest thrust sheet is the Kishorn Nappe, dominated by the large recumbent Lochalsh Syncline, which is composed of a very thick sequence of (grey, greenish-grey or buff) Torridonian strata of the Sleat and (Lower) Torridon groups, together with gneiss of the Lewisian Gneiss Complex and Cambro-Ordovician strata. The colour difference between the Torridonian strata within the Kishorn Nappe and the red-weathering units in the foreland sequence can be attributed to incipient metamorphism (Bailey, 1955). This colour difference is evident within the folded Torridonian strata within the Kishorn Nappe (Sections 1 & 2 in Figure 3-31): the strata on the (lower) right-way-up limb, which dip towards the NW, are reddish-brown, whereas the SE-dipping strata of the (upper) inverted limb are grey or green (Peach, et al., 1910).

The overlying Tarskavaig Nappe (Cheeney & Matthews, 1965) comprises a complex series of thrust sheets of mylonitised quartz-feldspar -rich metasedimentary rocks, of low regional grade (greenschist facies), the so-called Tarskavaig Moine Series (3.D) (Figure 3-18). Unconformably below these Tarskavaig Moine rocks, within the Tarskavaig Nappe, are mylonitised gneisses of the Lewisian Gneiss Complex (3.B). Two thrust planes within the Tarskavaig Moine rocks are recognised, the Caradal and Lamascaig thrusts (Cheeney & Matthews, 1965) (Figure 3-18). The Moine Thrust Plane defines the top of the Tarskavaig Nappe, above which is the Moine Nappe, composed of gneiss of the Lewisian Gneiss Complex (3.B), together with a minor component of strongly foliated, lineated and folded Moine psammites and pelites (Figure 3-32) (Law & Potts, 1987). The gneiss has a relatively strong planar fabric and contains abundant epidote and chlorite, together with porphyroblasts of amphibole. It weathers relatively easily and, therefore, is generally poorly exposed. Both mylonite and (younger) cataclastite fault rocks are recognised at the base of the Moine Nappe (Figure 3-33).

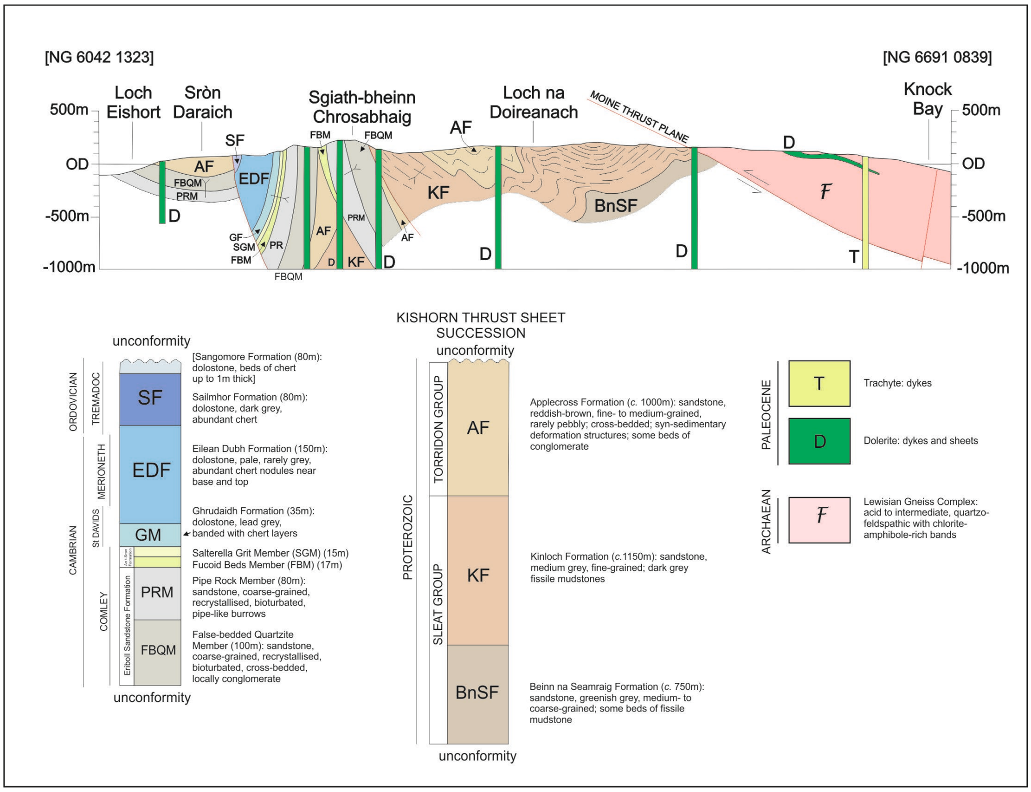
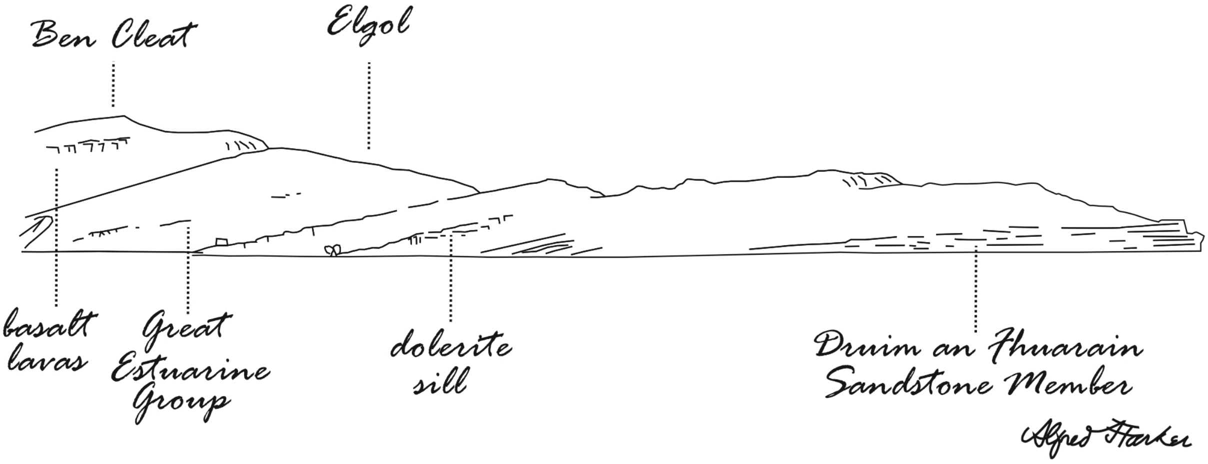


Figure 3-32 – Simplified cross-section for the main lithological units and tectonic components between Ord and Knock Bay on the Sleat Peninsula (after BGS 2002).

Figure 3-33 – Mylonitised gneiss within the Moine Thrust Plane/Zone at the contact between the Moine Thrust Sheet and underlying Torridonian (Supergroup) strata (not seen in this view) of the Kishorn Thrust Sheet in the Allt Duisdale [NG 6832 1274]. Pole *c.* 1m long.

Chapter 4 Mesozoic Sedimentary Rocks

Succeeding the Early Palaeozoic Caledonian Orogeny there is little preserved evidence of any igneous or sedimentary events on Skye and Raasay until the Early Mesozoic Triassic Period. Prior to the deposition of these strata, significant uplift and erosion took place and exposed all of the units of the foreland suite of rocks of the Hebridean Terrane and the Moine Thrust Zone. The crust stabilised and in Early Triassic times a new sedimentary basin developed due to a period of rifting that continued through the Jurassic, producing a detailed story of sedimentation, first in a terrestrial environment and subsequently in marine and estuarine settings.



4.A Introduction

Following the Caledonian Orogeny (*c.* 500-400 Ma), when Laurentia collided with Avalonia-Baltica and the Iapetus Ocean was eliminated, a new stable continental mass, Laurussia, formed (Cocks & Torsvik, 2011). The resultant uplift enabled significant weathering and erosion of the foreland sequence rocks (Chapter 3) (Trewin & Thirlwall, 2002), with the detritus contributing to Devonian (Old Red Sandstone) and younger deposits. Further continental amalgamation in the Late Carboniferous of Laurussia and Gondwanaland, with the elimination of the Rheic Ocean, led to the formation of the supercontinent, Pangea ((Glennie, 2002); (Cocks & Torsvik, 2011)). By Triassic time, *c.* 250-200 Ma, the area now represented by NW Scotland was well within Pangaea, far from any continental margin, and sedimentation was of terrestrial character (so-called ‘red beds’) and, consequently, the preserved sequences are virtually non-fossiliferous. The term New Red Sandstone is commonly used to describe these Triassic strata, distinguishing them from the older, similarly red, clastic sequences of (Devonian) Old Red Sandstone strata. Global sea-level was generally relatively low. The palaeo-latitude of Scotland was somewhere in the range 15-30°N and the climate resulted in desert to semi-desert environments, akin to today’s Arabia and the Sahara (Glennie, 2002).

Deposition occurred within *en echelon* half grabens aligned along the west coast of Scotland, from the Shetland Isles to offshore NW Ireland (Glennie, 2002). The Skye and Raasay sequences were deposited towards the eastern margin of the Minch (or Hebrides) Basin and are attributed to the Stornoway Formation, named after key outcrops located on Lewis in the Outer Hebrides ((Steel, 1971); (Steel & Wilson, 1975a)).

Sedimentation was typically in fault-influenced alluvial fans, with coarse-grained sediment transported eastwards into and across the Minch Basin, becoming progressively finer-grained (sand-rich). Mud-flow, stream-flow and braided stream deposits are also present and indicate periodic wetter intervals.

By Jurassic time, *c.* 200-145 Ma, Scotland was at a palaeo-latitude of *c.* 35°N, located at the southern opening of a marine strait that separated the Precambrian shields of Greenland and Fennoscandia and which connected the Arctic Sea to an island-studded epeiric sea covering most of Europe (Hudson & Trewin, 2002). Sea-level was relatively high and this inland sea connected southwards to the Tethys Ocean. Marine incursion(s) took place from the south, with sedimentation ranging between estuarine conditions through to fully marine deposition. The climate was seasonal, with warm dry summers and cool wet winters. Shallow seas led to relatively humid conditions. The hinterland was vegetated, at times relatively lush.

Much of present-day Scotland was an emergent landmass, with marginal extensional basins (Figure 4-1 and Figure 4-2). The half-graben extensional basin associated with the Skye and Raasay Triassic outcrops, the Minch/Hebrides Basin, flanked along its western margin by the Minch Fault, continued to subside during the Jurassic Period. The Camasunary-Skerryvore and Screapadal faults, which transect Skye and Raasay, respectively, played a role within the basin during sedimentation (Figure 4-2). Much of the sediment was delivered from the east, being particularly coarse and in high volumes during the Middle Jurassic, with deltas building out into the sea. Marine carbonate deposits developed throughout the Jurassic, although pure limestones are absent. Shales are, strictly, silty or of very fine sand grade, with common mica, and are typically ferruginous in character.

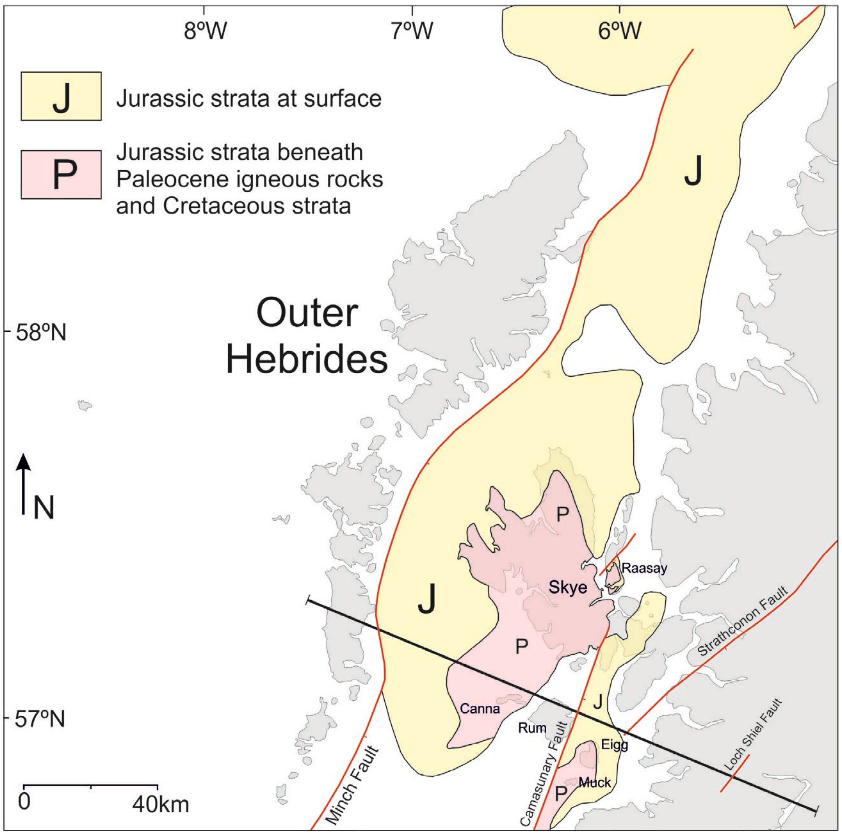


Figure 4-1 – Distribution of Jurassic strata on Skye, Raasay and the surrounding area (after Hudson & Trewin 2002).

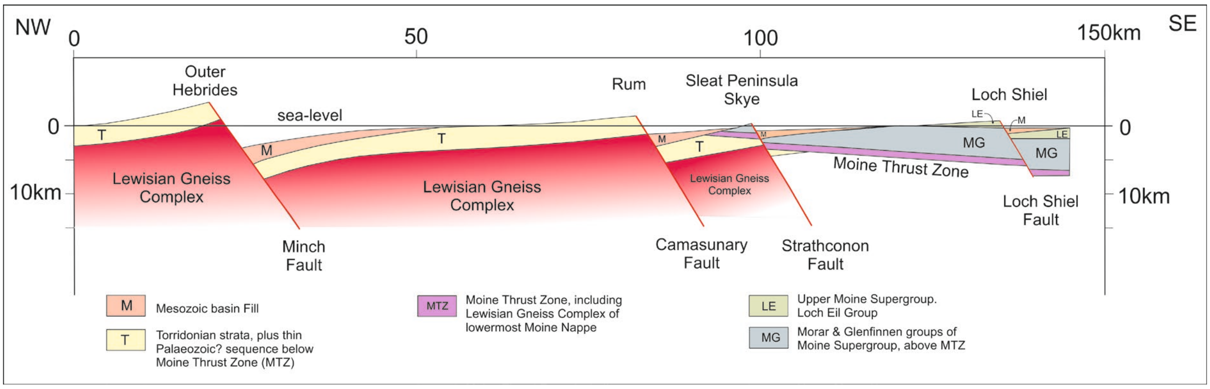


Figure 4-2 – Simplified schematic cross-section of Jurassic basin(s) in the Hebrides along line indicated in Figure 4.1 (after Hudson & Trewin 2002).

The most complete sequence of Jurassic sedimentary rocks in NW Scotland is preserved on Skye; a more restricted sequence of Lower and Middle Jurassic strata occurs on Raasay (Figure 4-3). A considerable amount of research has been undertaken on these rocks and, consequently, details of their sedimentation and palaeo-ecology are relatively well understood and extensively reviewed (e.g. (Morton & Hudson, 1995); (Hudson & Trewin, 2002)). The account given here draws significantly from these excellent summary publications. Of note, significant dinosaur footprint trackways and body fossils, preserved in Middle Jurassic coastal (estuarine) deposits on Trotternish of north Skye (e.g. (Andrews & Hudson, 1984); (Clark, et al., 1995); (Brusatte & Clark, 2015); (Brusatte, et al., 2015); (Brusatte, et al., 2016); (dePolo, et al., 2018)), have received much attention in recent years.

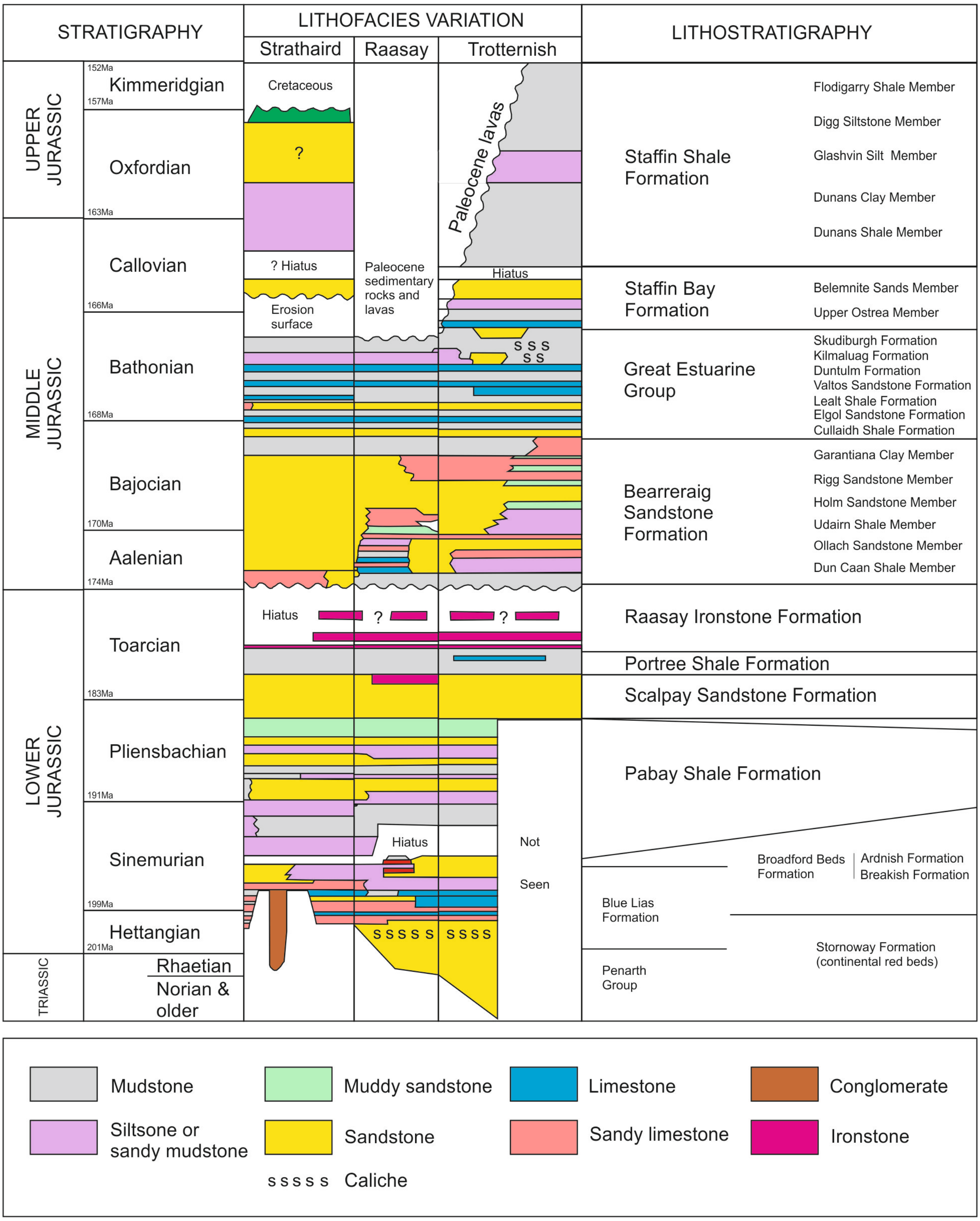


Figure 4-3 – Skye & Raasay Jurassic lithostratigraphy (after Emeleus & Bell 2005).

4.B Triassic Sedimentary Rocks

The Stornoway Formation sequences are interpreted as having been deposited in one or more alluvial fan systems, involving debris flow, stream flood and braided stream transport. Deposits associated with playas (flat-lying areas periodically inundated with water that either filtrates into the ground or is evaporated, as evidenced by the development of mud-cracked mudstones and laminated sandstones) and floodplains, in which coarse-grained sandstones with fining-upward motifs are deposited in fluvial channels and associated overbank environments, are also recognised (Steel, et al., 1975). Caliche profiles, or calcretes, are also preserved, and are essentially soils that cap the fine-grained units within the floodplain deposits, whereby well-developed carbonate cements bind the sediment grains together. Sedimentation occurred along the western faulted margin of the Minch/Hebrides Basin; the Camasunary-Skerryvore Fault, which transects Skye and the Screapadal Fault on Raasay, possibly playing significant roles (Figure 4-4).

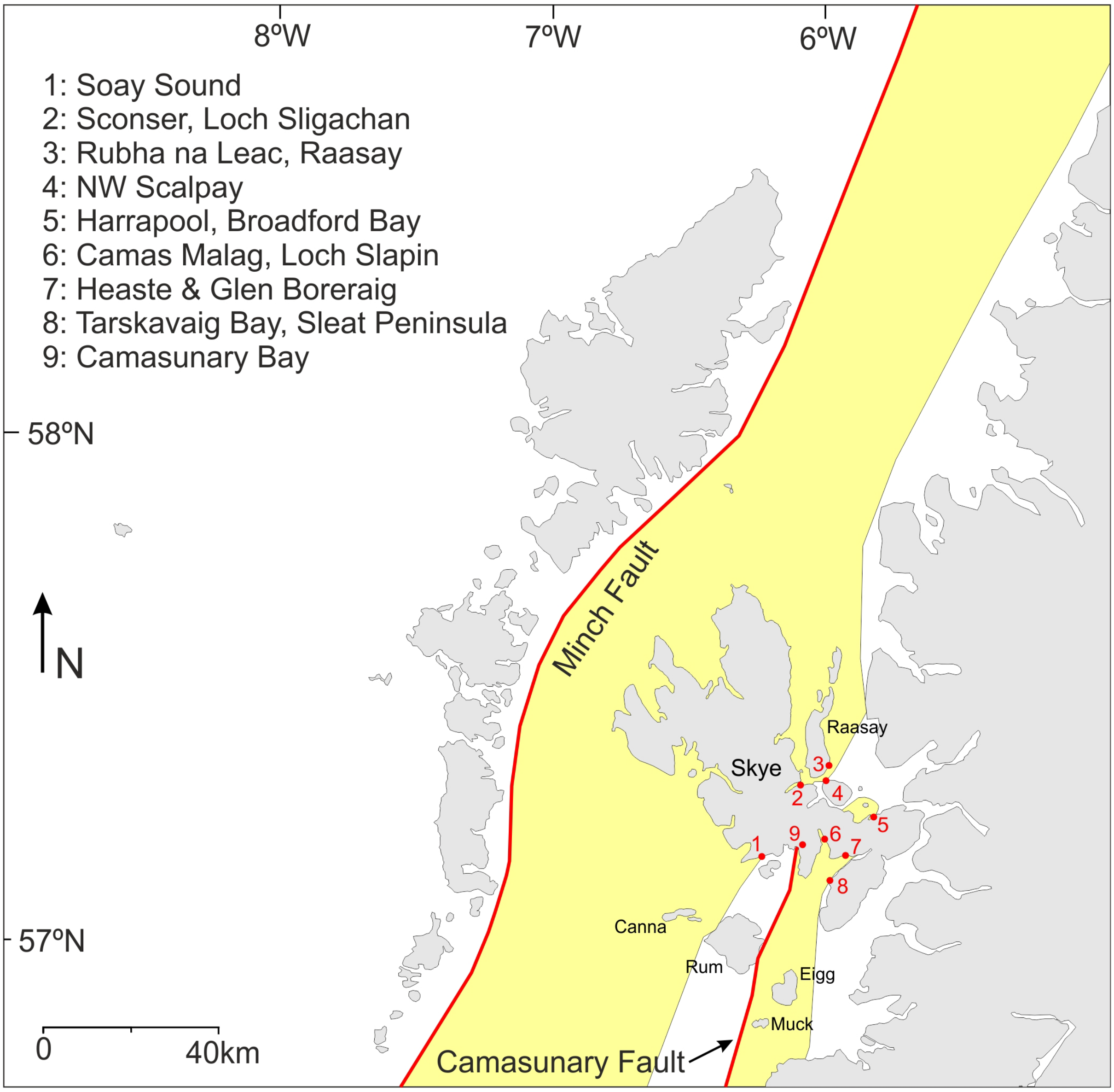


Figure 4-4 – Distribution of Triassic strata on Skye, Raasay and surrounding area (after various sources).

These strata crop out chiefly in the district of Strath on Skye and in south Raasay (Figure 4-5). Small, isolated outcrops occur: on the north side of Soay Sound at An Leac; in Camasunary Bay; between Glamaig and Loch Sligachan; in NW Scalpay; and, around Tarskavaig Bay on the west side of the Sleat Peninsula. Three isolated bodies of carbonate-cemented breccias, dominated by clasts of Torridonian strata, in north Raasay may also be of Triassic age.

Figure 4-5 – Triassic sedimentary sequence at Rubha na Leac on the east coast of Raasay [NG 6000 3820]. View NE towards Applecross on the Scottish Mainland.

In the district of Strath, overlying Torridonian and Cambro-Ordovician strata, are a series of red shaly marls, red and dull green sandstones, and conglomerates containing fragments of Torridonian sandstone and Cambro-Ordovician dolostone (Figure 4-6) ((Peach, et al., 1910); (Steel, et al., 1975); (Nicholson, 1978)). These strata are non-fossiliferous but are of presumed Triassic age on the basis of their distinctly continental character/motif, which allows them to be correlated with occurrences elsewhere in NW Scotland.

Figure 4-6 – Triassic conglomerate, comprising cobbles and pebbles of Cambro-Ordovician Durness Group dolostone (which unconformably underlie these strata) in a red, calcareous, sand- to silt-grade matrix. Upper part of the Allt nan Leac valley in Glen Boreraig (south of Beinn an Dubhaich), Strath [NG 6080 1809]. Pole *c.* 1m long.

The sequence preserved in the district of Strath crops out along the flanks of the broad arcuate syncline that runs from Harrapool, south of Broadford Bay, south to Boreraig, on the north side of Loch Eishort, as well as on the northern margin of the antiform that runs over Bheinn Shuardail. Small patches of material associated with the Harrapool Syncline occur along the Broadford to Kyleakin road, around Broadford Bay. These rocks are everywhere overlain by Lower Jurassic strata.

Barrow (in (Peach, et al., 1910)) summarises the following sequence from the Allt an Daraich, on the east side of the road, just north of Heaste:

[TOP]
Marl, greenish at top, abruptly changing below to reddish, with concretionary patches of green and red sandstone (0.5m)
Fine hard greenish sandstone, slightly calcareous (1.0m)
Greenish marl, changing to red, passing into a chocolate-coloured sandstone at its base (1.5m)
Detrital limestone, mainly inorganic (0.3m)
Green and mottled marl (1.0m)
Green sandstone
Conglomerate
[BASE]

Variations on this general theme are readily noted throughout the district of Strath, for example, at the top of Glen Boreraig, where a conglomerate with a calcareous matrix is the dominant rock-type

(Figure 4-6), whereas in the vicinity of Loch Buidhe on the east side of Gleann Shuardail, argillaceous rock-types are more common.

The sequence on Soay Sound comprises a lower breccia and conglomerate sequence, with clasts up to 20cm across of Cambro-Ordovician dolostone, quartzite and dark grey chert in a calcareous sandy to sandy pisolitic limestone matrix (Figure 4-7). Interbedded with these rudaceous deposits are discontinuous lenses of coarse-grained red sandstone and conglomerates with clasts of Torridonian sandstone. Calcrete layers/horizons occur within the sequence. Overlying these strata are yellow calcareous pebbly sandstones with interbedded, variegated siltstones and shales, limestones and beds of lignite. The sequence is unconformably overlain by the Lower Jurassic Broadford Beds Formation (4.C).

Figure 4-7 – Triassic strata, predominantly conglomerates and sandstones, An Leac, Soay Sound [NG 4400 1693]. View towards west. Pole *c.* 1m long.

(Nicholson, 1978) describes a sequence of interbedded sandstones, siltstones and mudstones, referred to as rhythmites, deposited from density currents of turbid water, together with conglomerates that were spread into lakes by storms, from SE of Camas Malag on the east side of Loch Slapin (Figure 4-8). These coarse- and fine-grained rocks, with a total thickness of *c.* 10m, are defined as the Camas Malag Formation and unconformably overlie Cambro-Ordovician Durness Group dolostones (3.E).

Figure 4-8 – Triassic Camas Malag Formation strata, comprising inclined, thinly-bedded, very fine sandstones, siltstones and mudstones on the eastern shore of Loch Slapin, south of Camas Malag near the outflow of the Allt na Garbhain [NG 5840 1860].

Three (definite) outcrops of Stornoway Formation strata occur on Raasay: two of these are located NE of Rudha na Cloiche in the south of the island, the third, beautifully exposed on the east coast, in the area around the peninsula of Rubha na Leac (Figure 4-5). These clastic deposits range between cobble conglomerate/breccia and siltstone and are associated with caliche deposits. The clasts within the conglomerates include: Torridonian sandstone (3.C); Cambro-Ordovician sandstone/quartzite and dolostone (3.E); schist (recognisably from the Moine Supergroup (3.D); (rare) Lewisian gneiss (3.B); aplite (uniformly medium-grained granitic rock); and, vein quartz.

Three outcrops of coarse, poorly-bedded breccia, *possibly* of Triassic age, occur in north Raasay: at Brochel; on the unnamed hill NW of Brochel; and, NW of Loch an Uachdair. The deposit at Brochel comprises unbedded breccia dominated by sub-angular to sub-rounded boulders and cobbles of Torridonian sandstone (3.C) in a carbonate cement. The ovoid outcrop is *c.* 80m long and surrounded by *in situ* Torridonian strata. Gneiss, although cropping out nearby and located at no great depth (3.B), is conspicuously absent as a clast lithology.

The two other outcrops are similar in character; the one nearby and to the NW of Brochel is elliptical and *c.* 150m long, and is surrounded by Lewisian Gneiss (3.B). It, too, is dominated by clasts of Torridonian sandstone, with only rare fragments of gneiss close to its margin. The third outcrop is NW of Loch an Uachdair, is *c.* 25m across, and of similar character to the Brochel outcrop.

These breccias have previously been interpreted as Paleocene vent infills (Selley, 1966). However, the lack of any igneous materials, the fact that Lewisian Gneiss fragments are essentially absent, their (poorly-) bedded character, and the presence of an abundant carbonate cement, suggest that they may be interpreted as coarse sedimentary breccias, and (only by comparison) of Triassic age.

The outcrops north of Glamaig comprise a *c.* 15-20m thick sequence of poorly-exposed conglomerates, sandstones, shales, (variegated) marls and calcretes (Peach, et al., 1910). Clast lithologies include Cambro-Ordovician sandstone/quartzite and dolostone (3.E), and Torridonian sandstone (3.C), set in a red-brown, sand-rich matrix.

In NW Scalpay, at Eilean Leac na Gainimh and Rubh' a' Chinn Mhòir, *c.* 50m of conglomerates unconformably overlie Torridonian strata (3.C) and dip at *c.* 30° towards the NW (Peach, et al., 1910). The clasts within the conglomerates include: Torridonian sandstone (3.C); Cambro-Ordovician sandstone/quartzite and dolostone (3.E); (rare) Lewisian gneiss (3.B); and, vein quartz.

The main Tarskavaig outcrop of Triassic conglomerates unconformably overlies Torridonian strata (3.C) and is located (inland) *c.* 600m NE of Tarskavaig Bay (Peach, et al., 1910). Clast lithologies include: pink-stained Cambro-Ordovician sandstone/quartzite and dolostone (3.E); Torridonian sandstone (3.C); and, red and black (Cambro-Ordovician) chert, all set in a matrix that ranges between a medium- to coarse-grained sand(stone) and a limestone. Of note, the nearby Torridonian strata are disrupted by fractures/fissures that are filled with (? Triassic) carbonate. The skerries of Sgeir Fhada and Sgeir Biodaig in Tarskavaig Bay are formed of similar conglomerates (Peach, et al., 1910).

4.C Jurassic Sedimentary Rocks

The Jurassic strata of NW Scotland can be subdivided into three parts: Lower, Middle and Upper (Figure 4-3). The oldest Jurassic age rocks on Skye, attributable to the Hettangian Stage, may be of continental ('red bed') character, deposited just prior to the generally accepted rise in sea-level, marine incursion, and deposition of marine sandstones, limestones and shales that characterise the Lower Jurassic sequence ((Morton & Hudson, 1995)). The Lower-Middle break is defined by a sea-level fall in the Toarcian, whereas the Middle-Upper break is taken as where there is a major sea-level rise in the Early Callovian. At its simplest, the Lower Jurassic marine sequence is the product of a Late Triassic - Early Jurassic marine transgression, followed by a change to lagoonal to estuarine, partly non-marine, conditions in the Middle Jurassic (Aalenian to Bathonian), before returning to fully marine conditions after an Early Callovian marine transgression that lasted until the Kimmeridgian ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)).

The subsequent burial history of the Jurassic strata by the substantial Paleocene volcanic sequence (Chapter 5) has not significantly modified these rocks and many of their original characteristics (for example, fossil aragonite, low reflectance vitrinite fragments, and pale spores) have survived. Thermal alteration has, however, taken place close to members of the Skye Regional Dyke Swarm (Chapter 7) and the various intrusions of the Little Minch Sill Complex in north Skye (Chapter 8), as well as the major intrusions of central Skye (Chapter 6), where the sequence on Strathaird has been subjected to recrystallisation and warping.

In the Inner Hebrides, the Early/Lower Jurassic sequence, commonly referred to as the Lias Group, has been subdivided into a number of formations: the Breakish Formation, the Ardnish Formation, the Pabay Shale Formation, the Scalpay Sandstone Formation, the Portree Shale Formation and the Raasay Ironstone Formation (Figure 4-3).

The Early Jurassic sediment was derived from the Scottish Mainland, together with the Hebrides Platform, to the west. The thin and calcareous character of the lowermost units, the Breakish and Ardnish formations, imply a low relief to the Scottish Mainland (Hudson & Trewin, 2002) (Figure 4-9).

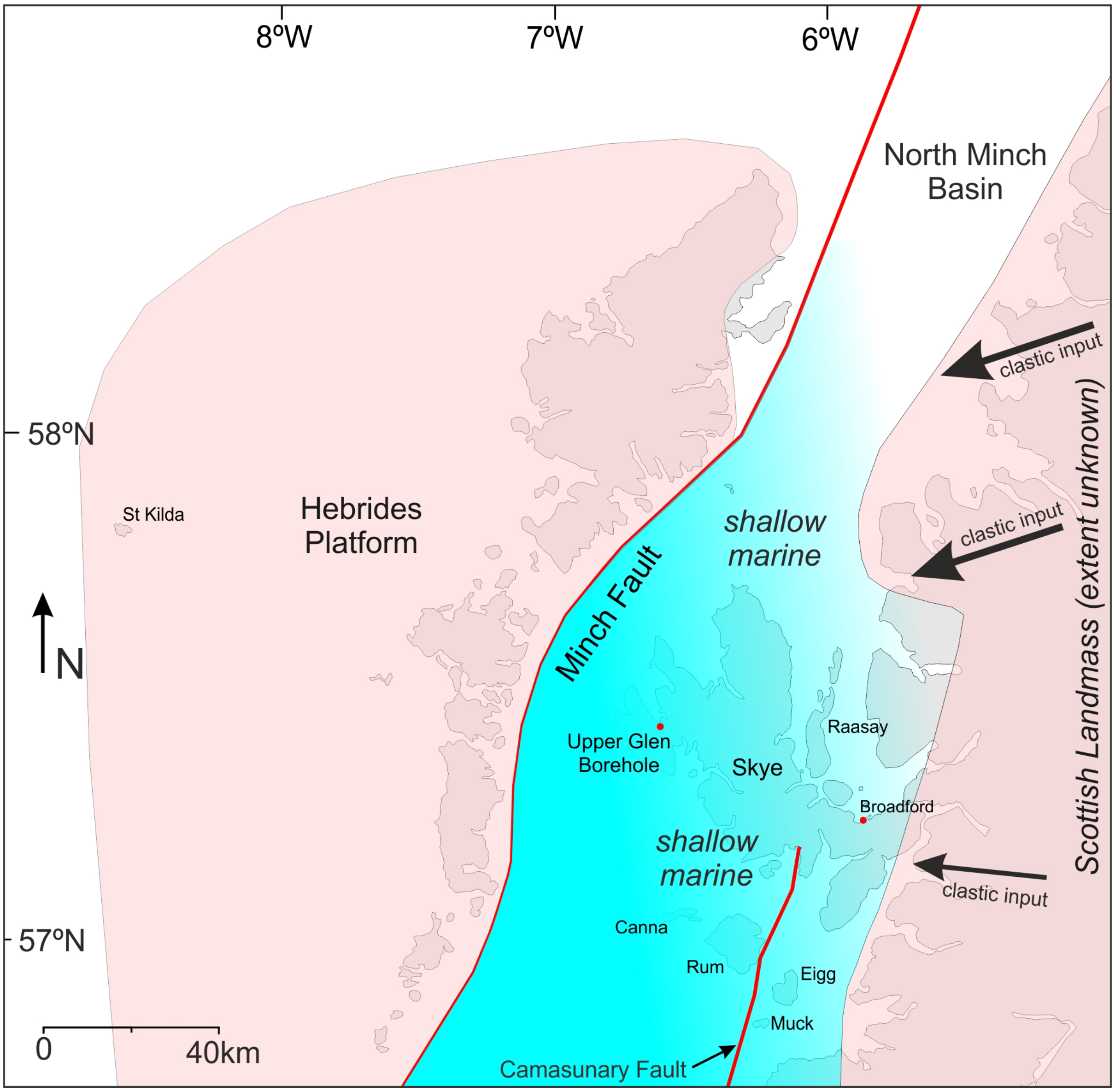


Figure 4-9 – Early Jurassic (Pliensbachian) palaeo-geographic map/interpretation (after Hudson & Trewin (2002)).

The Breakish Formation (formerly Lower Broadford Beds) on Skye comprises up to 65m of marine sandstones, limestones and shales that are underlain by red sandstones in central Skye, which may also be of very early Jurassic (Hettangian) age. Significant lithostratigraphical units include the Ob Lusa Coral Bed, near to the base of the type-section at Breakish on the east side of Broadford Bay (Figure 4-10), with compact colonial colonies of *Liostrea murchisoni,* which formed close to the palaeo-shoreline. Approximately 20m further up the sequence, the (Ob) Breakish Coral Bed contains branching colonies of the coral, *Thecosmilia martini,* forming a small patch reef. Also present within the formation are oolitic limestones, inferring a warm, shallow sea, with sustained water movement. The clay mineralogy is montmorillonite, which implies derivation from the weathering of basic igneous rocks in the sediment source area (Amiri-Garroussi, 1977). On Raasay (Figure 1-13), the Breakish Formation contains more limestones, with good examples of mid-Hettangian ammonites. The formation is onlapped by younger strata, suggesting the presence of an island within the basin (Hudson & Trewin, 2002).

Figure 4-10 – Ob Lusa Coral Bed of the Breakish Formation on the west side of Ob Lusa, Breakish [NG 6998 2498]. Coin *c.* 20mm across.

The overlying Ardnish Formation (formerly Upper Broadford Beds) is 50-80m thick and comprises similar lithologies, but without limestones, and with more abundant micaceous siltstones and shales, commonly ferruginous and commonly bioturbated. Also present are thin beds of ironstone and discrete sandstones such as the Hallaig Sandstone Member in SE Raasay. Distinctive, abundant bivalves, *Gryphaea arcuata,* the 'Devil's toenail(s)', are present, as is the ammonite, *Arnioceras.* The Formation is well-exposed at Ardnish on the east side of Broadford Bay (Figure 4-11). Relative to the underlying Breakish Formation, the Ardnish Formation represents a more offshore, relatively deeper-water facies. The presence of an oolitic ironstone, with the mineral bertherine (chamosite), implies a greater run-off of water (with both solid and dissolved load) from the hinterland, possibly due to a wetter climate. The clay mineralogy is illite-kaolinite, which implies that the weathered material from the source area no longer involved basic igneous rocks (Amiri-Garroussi, 1977). Significantly, at the head of Loch Slapin, the Ardnish Formation unconformably overlies a karstic-surfaced sequence of Durness Group dolostones, indicating a palaeo-shoreline at this time (Figure 4-11).

Figure 4-11 – Base of the Lower Jurassic Ardnish Formation on the east shore of Loch Slapin, north of the outflow of the Allt nan Leac [NG 5847 1838]. Below the angular unconformity are pale Cambro-Ordovician Durness Group dolostones forming the planar surface in the near ground. The lowest units in the Jurassic sequence are thin-bedded limestones and shales, with abundant oyster shells (*Gryphaea arcuata*). View towards south. Pole *c.* 1m long.

The overlying Pabay Shale Formation is a sequence of dark grey, ammonite-bearing, predominantly bioturbated siltstones and very fine-grained sandstones, typically ferruginous and mica-rich, together with thin sandstone units ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)) (Figure 4-12). The hinterland contributed significant amounts of vegetable matter to the sediment load. Calcareous and sideritic concretions are relatively common, some containing ammonites and *Gryphaea arcuata*. Towards the top of the formation, mica-rich sandstones are more common and one unit, the Suisnish Sandstone Member, with a type-section near Suisnish on the north side of Loch Eishort on Skye, forms a distinct correlatable sequence.

Figure 4-12 – Pabba Shale Formation forming the cliffs on the east shore of Loch Slapin north of Rubha Suisnish. View from Stac Suisnish, towards NNE. Beinn na Caillich in the distance.

The Pabay Shale Formation has a gradational boundary with the overlying marine Scalpay Sandstone Formation, which takes its name from the island of Scalpay, NW of Broadford Bay ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)). It also occurs in SE Raasay (Figure 4-13), from its faulted contact with the Triassic Stornoway Formation, south of Beinn na Leac, to North Fearns (Figure 4-13). On Trotternish, it occurs in difficult-to-access sections north and south of Portree: in the cliff sections north of Rubha na h-Àirde Glaise and at Udairn, respectively. These tidal-influenced sandstones are the product of a significant influx of sediment into the shallowing basin due to uplift of the hinterland, undergoing periods of storm conditions. It contains distinctive shells of the scallop *Pseudopecten aequivalvis,* together with large calcareous concretions. Bioturbation is common. Interbedded with the sandstones are thin beds of siltstone and mudstone and, locally, at the top of the formation, an ooidal limestone (ironstone). The top of the Scalpay Sandstone Formation is within the Toarcian Stage.

Figure 4-13 – Scalpay Sandstone Formation strata on the SE coast of Raasay, south of Rubha na Leac. The dominant lithologies are locally cross-bedded bioturbated marine sandstones and siltstones. The crags in the background are composed of the Druim an Fhurain Sandstone Member of the Bearreraig Sandstone Formation.

The main lithostratigraphic unit within the Toarcian (Figure 4-3) is the regionally-developed Portree Shale Formation, a sequence of dark, fossiliferous, marine shales, up to 14m thick, deposited during a period of significant sediment starvation in the basin (Figure 4-14) ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)). Above these relatively deep marine strata is the Raasay Ironstone Formation, a bertherine-oolite unit up to 2.5m thick (Figure 4-15), which was mined on Raasay between 1912 and 1919. The ironstone contains ammonites, for example *Dactylioceras,* along with belemnites, the latter commonly with evidence of wear, possibly due to bottom currents.

Figure 4-14 – Belemnite- and ammonite-bearing dark grey shales forming a bedding surface of Toarcian Portree Shale Formation strata on the locally exposed floor of the abandoned opencast quarry [NG 5652 3651] east of the No. 1 Mine Entrance on Raasay at [NG 5649 3653]. Ruler 30cm long.

Figure 4-15 – Deep marine Toarcian Raasay Ironstone Formation strata forming low crags NW of the abandoned opencast quarry [NG 5652 3651] east of the No. 1 Mine Entrance on Raasay at [NG 5649 3653]. The dominant lithology is a bertherine-oolite ironstone. Pole *c.* 1m long.

Thereafter, there was a major hiatus in sedimentation, before the end Toarcian (and younger) Middle Jurassic (Figure 4-3; Figure 4-17) Bearreraig Sandstone Formation, which comprises, on

Strathaird, the thick shallow marine Druim an Fhuarain Sandstone Member and the overlying marine Garantiana Shale Member.

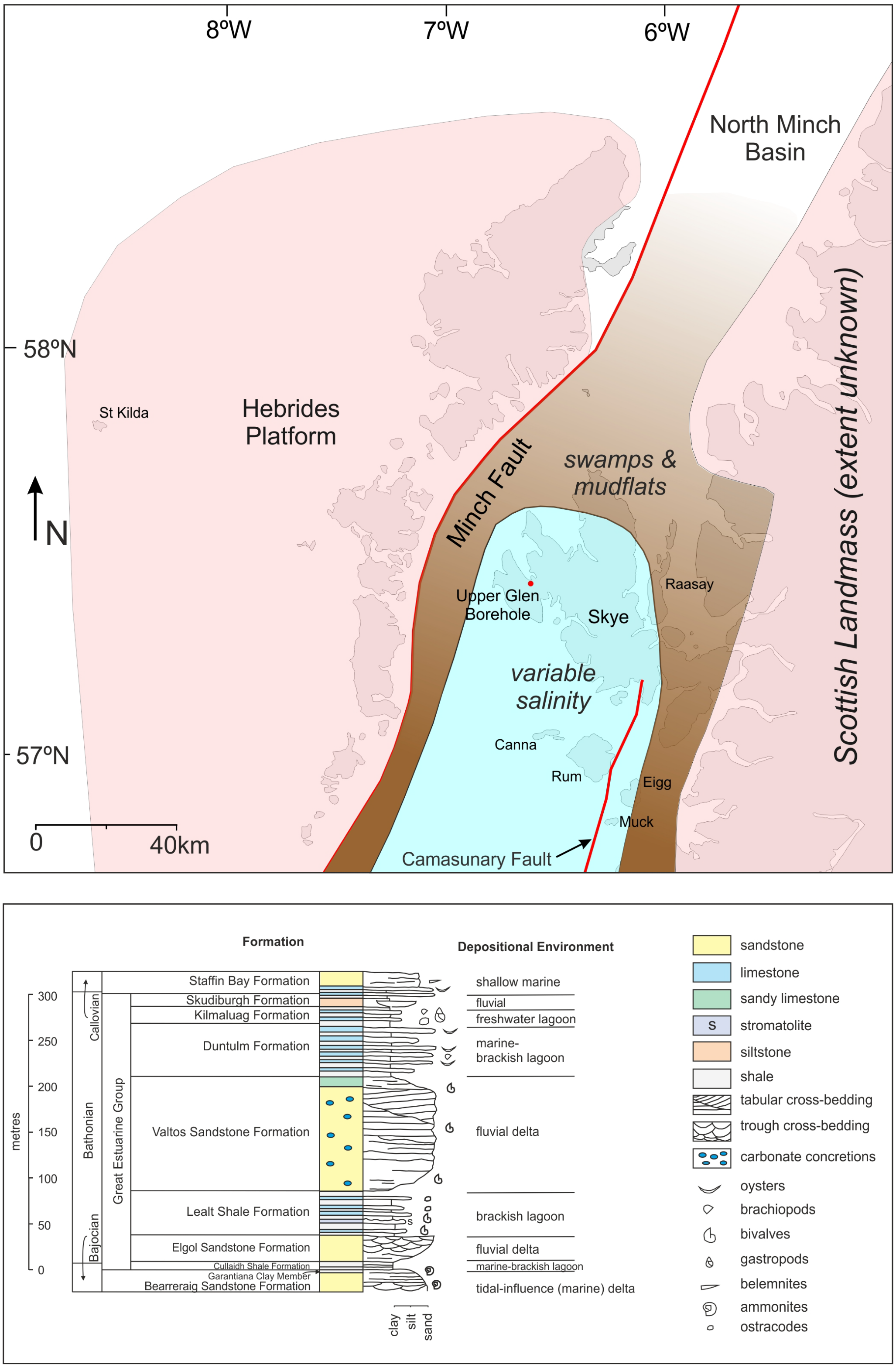


Figure 4-16 – Middle Jurassic (Bathonian) palaeo-geographic map/interpretation (after Hudson & Trewin (2002)) and lithostratigraphy of the Great Estuarine Group.

The commonly cliff-forming shallow marine Bearreraig Sandstone Formation of the Aalenian and Bajocian stages (Figure 4-3) on Skye achieves a thickness of almost 500m (Hudson & Trewin, 2002) and, therefore, is the thickest sequence of sandstones in the British Jurassic. Palaeo-current indicators such as cross-stratification indicate variable directions of sediment input into the basin which, in conjunction with significant facies changes over short distances, imply a complex sedimentation history involving differential subsidence and hinterland uplift. A number of members are defined from the type-section on the east coast of Trotternish: the Ollach Sandstone Member (oldest); the Udairn Shale Member; the Holm Sandstone Member; the Rigg Sandstone Member; and, the Garantiana Clay Member (youngest). On Raasay, the Bearreraig Sandstone Formation forms significant inland cliffs north and south of the Screapadal (Figure 4-17). Here, at the base of the formation, the Dùn Caan Shale Member is recognised. The other significant outcrop of the Bearreraig Sandstone Formation on Skye, on Strathaird, has not been formally subdivided to the same extent and only two members are recognised: the spectacularly cross-bedded Druim an Fhuarain Member and the Garantiana Clay Member (Figure 4-18; Figure 4-19). Within the calcareous Druim an Fhuarain Member, south of Elgol, the cross-bedding is unimodal and, within the troughs, are U-shaped burrows (*Diplocraterion*). Shell fragments are common, as is bryozoan and crinoidal debris.

Figure 4-17 – Crags of the Druim an Fhuarain Sandstone Member of the Bearreraig Sandstone Formation inland from the east coast of Raasay at Creag na Bruaich, south of Eaglais Breige. These Middle Jurassic tidally-influenced shallow marine sandstones form a spectacular exposure with at least 100m of near-vertical relief. Note incipient landslip failure at north (right-hand) end of the cliff.

Figure 4-18 – Large-scale cross-stratification of the Druim an Fhuarain Member of the Bearreraig Sandstone Formation at Spar Cave, Glasnakille, east coast of Strathaird. View towards the north.

Figure 4-19 – Detail of large-scale cross-stratification of the Druim an Fhuarain Member of the Bearreraig Sandstone Formation at Spar Cave, Glasnakille, east coast of Strathaird. Pole *c.* 1m long.

The sequence contains abundant marine fossils, with superb specimens of ammonites, belemnites and bivalves, many within concretions. These fossils occur both in life position and as fragments or debris in shell-rich beds. Drifted plant material is also common, some of which is fusainized (charcoalified), indicating forest fires in the hinterland.

The depositional environments of these tidally-generated, cross-bedded sandstones and subordinate shales are attributed to a period of significant sea-level fluctuation, with regressive (falling sea-level) periods of tide-dominated delta construction, and transgressive (rising sea-level) periods of estuary development ((Mellere & Steel, 1996); (Archer, et al., 2019)). During the regressive interval(s), in the lower part of the formation (Ollach Sandstone and Udairn Shale members), tidally-dominated deltas built out into the sea, with deposition of pro-delta (i.e. at the front or seaward part of the delta) bioturbated shales and siltstones, tidally-influenced, delta-front, planar, cross-bedded sandstones, and delta-plain, fine-grained sandstones deposited within fluvial channels. During transgressive phase(s), in the upper part of the formation (Holm Sandstone and Rigg Sandstone members), estuarine, tidally-influenced channel-fill sandstones were deposited. Bioturbated tabular sandstones at the top of the Trotternish sequence were deposited in a pro-delta shelf, possibly below fair-weather wave-base.

The top of the Bearreraig Sandstone Formation is typically a high-energy, coarse-grained, shell-rich sandstone, in places a granule-grade conglomerate. The overlying Upper Bajocian Garantiana Clay/Shale Member (Figure 4-20) records an abrupt facies change and is dominated by dark grey, ammonite-bearing, marine mudstones, marking a widespread marine transgression and deprivation of the source of coarse-grained sediment. This Member is commonly absent in the Trotternish section.

Figure 4-20 – Thermally-altered (hornfelsed) thinly-laminated, pyritiferous shales and siltstones of the Garantiana Clay/Shale Member, below a dolerite sill, south of Elgol, west coast of Strathaird [NG 5152 1350]. Ruler 30cm long.

The Middle Jurassic (Bathonian) Great Estuarine Group (Figure 4-3 and Figure 4-16) forms a geographically-widespread, distinct, highly variable sequence of members that record a number of different (non-marine) facies within a lagoon-estuary setting, including fluvial delta, marine-brackish lagoon, freshwater lagoon and fluvial ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)). The laterally-extensive nature of most of the units implies that the basin behaved as a single entity, not compartmentalised into sub-basins.

The base of the sequence comprises the dark grey, fissile, organic-rich Cullaidh Shale Formation (Figure 4-21). It is most likely transitional from the underlying marine Garantiana Shale Member of the Bearreraig Sandstone Formation. The type locality, at Elgol on Strathaird, has a sparse non-marine fauna of mytilid bivalves, freshwater to brackish water ostracods, and fish scales (Hudson & Trewin, 2002). Deposition of these sediments was in an anoxic environment and the total organic carbon content is *c.* 5%. This member is commonly absent in the Trotternish section, but, where present, for example at Rigg and Invertote, has a marine fauna and is represented by carbonaceous limestones and shales with washed-in lignitic material (Harris, 1989).

Figure 4-21 – Fissile, organic-rich, dark grey shales of the Cullaidh Shale Formation, exposed on the beach at Elgol, Strathaird, on the foreshore immediately west of the school building and north of where the Allt Port na Cullaidh flows into Loch Scavaig [NG 5163 1367]. Exposure is temporal, at times good, but can also be poor. Pole *c.* 1m long.

The Cullaidh Shale Formation transitions through increasingly bioturbated siltstones and fine-grained sandstones into the Elgol Sandstone Formation, which comprises a non-fossiliferous, coarsening-upward, deltaic sequence (Harris, 1989). Sediment input was predominantly from the north. At Elgol, small-scale cross-bedding was generated by small sand waves migrating down the front of a lobate delta (Figure 4-22). Calcareous concretions are absent. The top of the formation is marked by a granule conglomerate, formed by wave-winnowing.

Figure 4-22 – Gently-inclined pale sandstones of the Elgol Sandstone Formation exposed on the west side of Strathaird at Elgol, *c.* 150m north of where the Allt Port na Cullaidh flows into Loch Scavaig [NG 5161 1378]. View towards east.

The overlying fossiliferous Lealt Shale Formation has a sharp base and comprises two members: the (lower) Kildonnan and the (upper) Lonfearn. The type-section is exposed in the Lealt River, where it enters the sea at Inver Tote. Here, the section is intruded by sills of the Little Minch Sill Complex (Chapter 8) and is not easily accessed. A more accessible section crops out on the west side of Strathaird, north of Port na Cullaidh. The Kildonnan Member was deposited in a brackish lagoon, with mussels (*Praemytilus*), together with fragments of sharks and plesiosaurs. A particularly obvious (up to *c.* 30cm thick) cyanobacterial stromatolite is present at the top of the sequence and contains pseudomorphs after gypsum, indicating an episode, most likely brief, of desiccation (Figure 4-23).

Figure 4-23 – Stromatolite in the KIldonnan Member of the Lealt Shale Formation, in the bay north of Port na Cullaidh at Elgol, on the west side of Strathaird [NG 5168 1409]. Coin *c.* 24mm across.

The Lonfearn Member comprises shales and thin shelly (rarely oolitic) limestones. At the base, the bivalves indicate brackish-marine conditions, above which the sequence contains shallow fresh-to-brackish water conchostracans (clam shrimps). Pavements with desiccation cracks indicate periodic emergence. Dinosaur (sauropod) tracks occur within/upon a laminated shaly limestone in the sequence at Rubha nam Brathairean on the east coast of Trotternish (dePolo, et al., 2018).

The gradual transition into the overlying (commonly cliff-forming) Valtos Sandstone Formation (Figure 4-24; Figure 4-25) is marked by the incoming of siltstones and sandstones, together with beds dominated by shells of the bivalve, *Neomiodon.* The best exposures occur on the east coast of Trotternish, in the vicinity of Valtos (Bhaltos). On Strathaird, the formation crops out on the east-facing coast at Dùn Liath, north of Glasnakille. Poor exposures occur on Raasay, SW of Screapadal, above the cliff-line of Druim an Aonaich. The formation occurs in a variety of deltaic facies, from pro-delta silts deposited on the floor of a lagoon through to delta-top deposits of calcite-cemented granule conglomerate and cross-bedded *Neomiodon* (-bearing) biosparite (i.e. bioclastic limestone). The complex deltaic sequence developed in several stages, involving advances and retreats into lagoons (indicated by the interbedding of arenaceous and argillaceous units), and varies significantly with location, with sand-rich facies on Trotternish and finer-grained material on Strathaird. Mineralogical variations suggest multiple sediment sources. Within the nearshore lagoonal deposits of this formation, emergence is indicated by dinosaur remains and trackways ((Clark, et al., 1995); (Clark & Barco Rodriguez, 1998)).

Figure 4-24 – Pale Valtos Sandstone Formation strata intruded by members of the Little Minch Sill Complex at Valtos (Bhaltos) on the east coast of Trotternish.

Figure 4-25 – Pale sandstones with bedding-parallel carbonate concretions of the Valtos Sandstone Formation in a near-to-road exposure at Dùn Dearg, north of Valtos on the east coast of Trotternish [NG 5136 6428]. Hammer *c.* 60cm long.

One of the key characteristics of the Valtos Sandstone Formation at Valtos (but not on Strathaird) is the presence of large (decimetre-scale), carbonate-cemented, post-depositional concretions (or nodules or doggers). They are interpreted to have grown after a degree of compaction of the sequence from cool (*c.* 40°C) meteoric water at burial depths of *c.* 250 m over periods of hundreds of thousands to a few million years (Wilkinson, 1992). The source of the carbonate was the abundant shells of *Neomiodon.*

The transitional boundary with the overlying Duntulm Formation is marked by interbedded shales and limestones containing *Neomiodon,* above which are marginal marine (brackish) strata, including limestones that contain the oyster *Praeexogyra hebridica,* together with bivalves such as *Placunopsis* and the mussel *Modiolus.* Algal nodular limestones formed on the partially exposed margins of the lagoons, and there were also periodic influxes of coarse clastic sediment. The best exposures on Skye occur at the type-section, on the coast SW of Duntulm, at Cairidh Ghlumaig, on Trotternish (Figure 4-26).

Also preserved within the sequence at Cairidh Ghlumaig are dinosaur (sauropod) trackways (ichnites) within/upon beds of calcareous sandstone and limestone, which may have been submerged at the time of formation (Brusatte, et al., 2015). The foot (pes) prints, and possibly forelimb (manus) prints, occur both in positive (convex) relief (hypo-relief), i.e. casts of the footprints, and impressed (negative or concave) relief (epi-relief), i.e. moulds of the footprints. The casts tend to preserve more detail of the shape and features of the footprints, whereas the moulds are typically poorly defined due to present day (active) tidal erosion, many with the appearance of shallow potholes.

On Strathaird, the formation contains algal (cyanobacterial) nodular limestones with calcified (*Cayeuxia*) filamentous structures similar to that found in modern cyanobacteria and most likely formed along the coasts of lagoons (Hudson & Trewin, 2002).

The transitional boundary with the overlying freshwater-lagoonal Kilmaluag Formation (Figure 4-27; Figure 4-28) is marked by the loss of oysters within the fossil assemblage; in the uppermost bed of the Duntulm Formation there are only fragments of shells. The type-section occurs NE of Kilmaluag at the northern end of Trotternish, on the coast at Port Gobhlaig. The Kilmaluag Formation contains abundant ostracods and conchostracans within shales and marls; sandstones only occur in the Trotternish outcrops. Emergence is marked by desiccation cracks. Also present in uncommon shell-rich beds is the bivalve, *Unio,* and the freshwater gastropod, *Viviparus.* The formation is also noted for the remains of various reptiles, including lizards, crocodiles and turtles, amphibians, and mammals that inhabited the lagoons and surrounding area ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)).

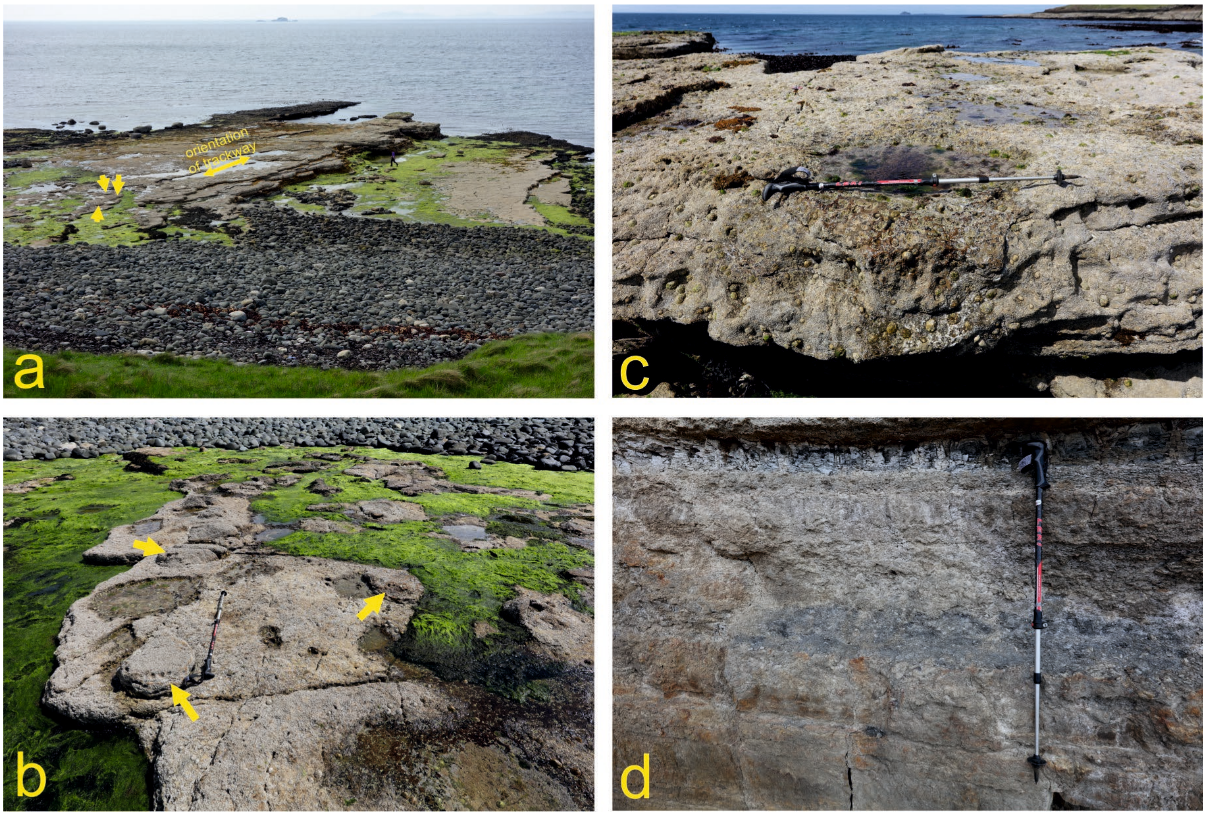


Figure 4-26 – (a) Duntulm Formation strata at the type-section, Cairidh Ghlumaig, Duntulm, at the northern end of Trotternish [NG 4100 7384], with indication of location and orientation of sauropod pes(= foot) prints (= ichnites); (b) bedding surface with main trackway of fossil footprints (ichnites) in hypo-relief indicated by arrows, pole *c.* 1m long; (c) section through bed with detail of sauropod convex hypo-relief pes (i.e. foot) print, pole *c.* 1m long; and, (d) shaly mudstones and siltstones with with abundant oyster (*Praeexogyra hebridica*) shells, pole *c.* 1m long.

Figure 4-27 – Field view of Kilmaluag Bay, north Trotternish, composed of Kilmaluag Formation strata. View towards the south.

Figure 4-28 – Desiccation cracks in siltstones of the Kilmaluag Formation, south side of Port Gobhlaig, north of Balmaqueen at the northern end of Trotternish [NG 4369 7510]. Ruler 30cm long.

The uppermost unit of the Great Estuarine Group, the Skudiburgh Formation, is composed predominantly of alluvial strata and has a gradational boundary with the underlying Kilmaluag Formation (Figure 4-29). The type-section occurs at Poll an Staimh, below Dùn Skudiburgh, west of Uig (Figure 4-29). Poor exposures of purple-red mudstones (possibly due to thermal metamorphism) also occur on the west coast of Strathaird, in the vicinity of Glen Scaladal. The dominant lithologies are mottled (green and red, other colours less common) non-fossiliferous mudstones, with sand- and silt-grade intercalations, together with caliches marked by the presence of calcareous concretions. Deposition was most likely on floodplains, with coarser sediment deposited from overbank flood events (Andrews, 1985). After the deposition of the Skudiburgh Formation, there was a marine transgression, which led to the deposition of the Upper Jurassic (Callovian to Kimmeridgian) Staffin Bay and Staffin Shale formations ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)).

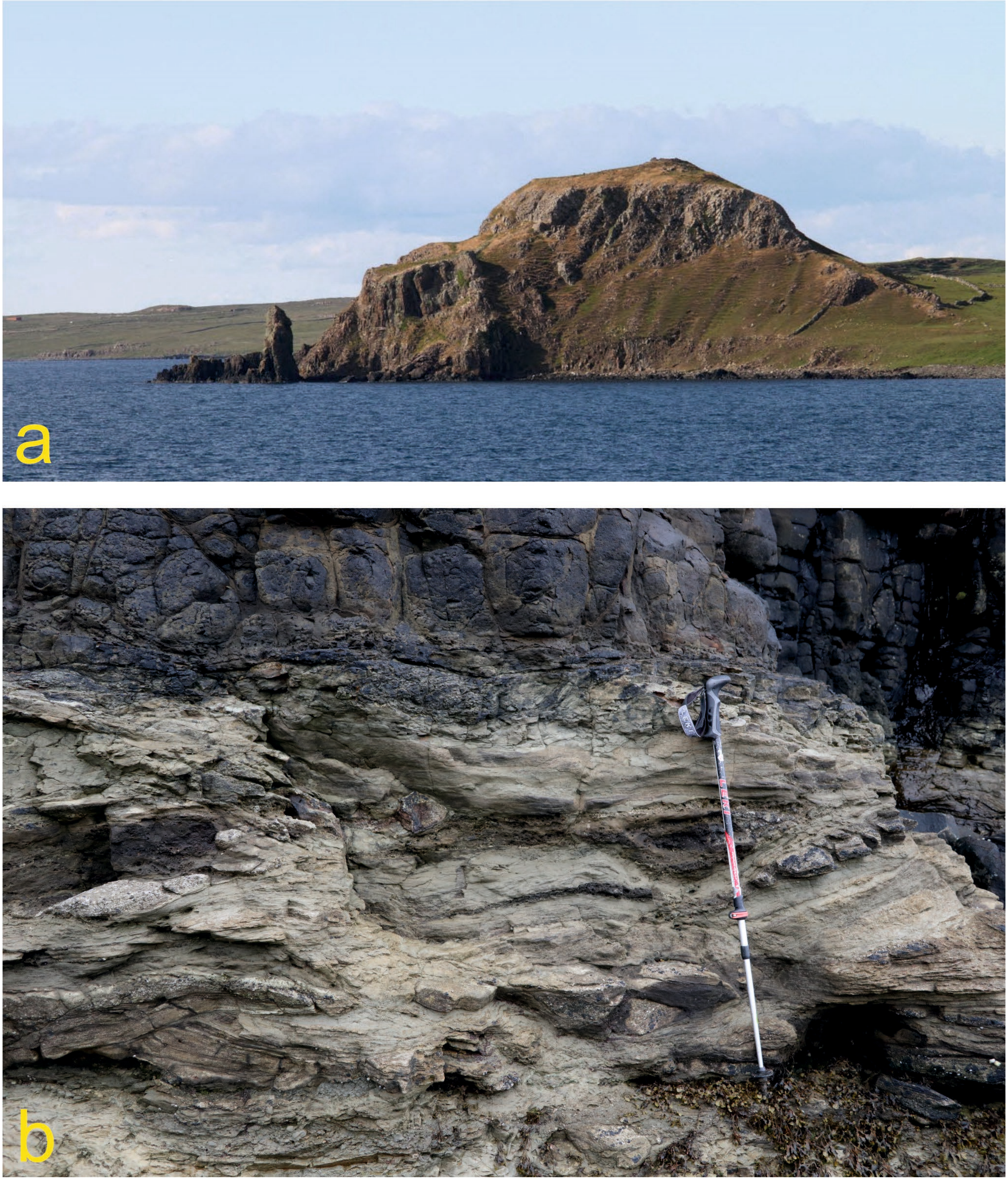


Figure 4-29 – (a) Field view of Stack of Skudiburgh and Dùn Skudiburgh, Trotternish [NG 3741 6472], composed of Skudiburgh Formation strata intruded by a sill of the Paleocene Little Minch Sill Complex; and, (b) Detail of pale, laminated, channelised Skudiburgh Formation strata, intruded by thin stringers of (overlying) sill material, pole *c.* 1m long.

Throughout the Upper Jurassic, sedimentation occurred in a deep marine environment and was dominated by dark shales, claystones and siltstones, with periodic deposition of turbidite sands, possibly initiated by basin-margin uplift leading to increased erosion (Figure 4-30). Anoxic conditions prevailed, resulting in the strata having high total organic contents, appropriate for hydrocarbon generation.

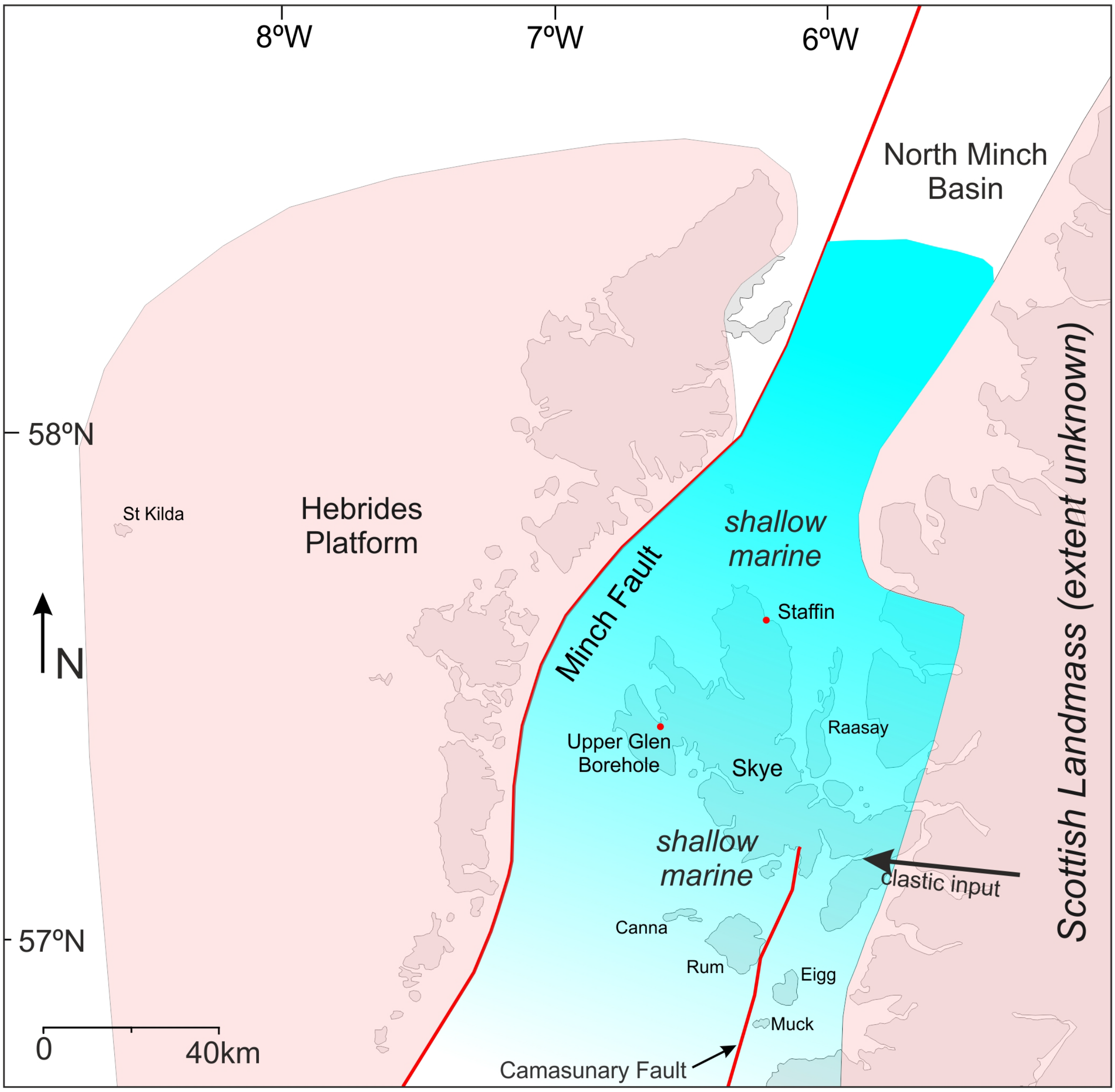


Figure 4-30 – Late Jurassic (Kimmeridgian) palaeo-geographic map/interpretation (after Hudson & Trewin (2002)).

The type-section of the Early Callovian Staffin Bay Formation occurs on Trotternish. The base of the sequence, the Upper Ostrea Member, is taken as a thin shell-rich bed with the bivalves, *Neomiodon* and *Isognomon,* marking a lagoonal transgression (Figure 4-31). Oysters are relatively rare, suggesting that the name of this member is (somewhat) inappropriate. The main lithologies are siltstone, mudstone and shale, with aragonite bivalves (Figure 4-32. The overlying Belemnite Sands Member was deposited as an offshore bar within the lagoon in which the Upper Ostrea Member was deposited. It does not, for the most part, contain belemnites, hence also being (in part) inappropriately named. However, near the top of the Belemnite Sands Member, belemnites are extremely abundant within a glauconitic (marine) sandstone containing siderite nodules. Pleisiosaur remains are described by (Clark, et al., 1995). On Strathaird, the formation comprises the bioturbated Càrn Mòr Sandstone Member (Sykes, 1975).

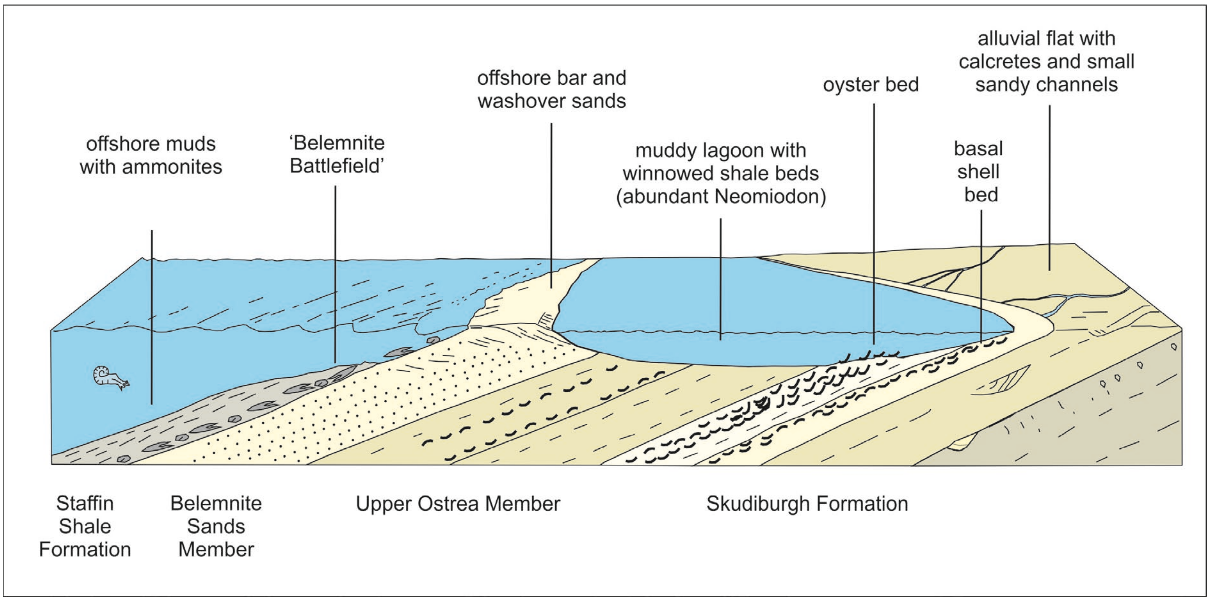


Figure 4-31 – Staffin Shale Formation facies interpretation, representing a transgression over the fluvial and alluvial Skudiburgh Formation at the top of the Great Estuarine Group (after Hudson & Trewin 2002). The Upper Ostrea Member indicates a first lagoonal transgression, followed by the shoreward migration of an offshore sand-bar (the Belemnite Sands Member), and final flooding at the base of the Staffin Shale Formation, with numerous belemnites washed up the seaward slope of the bar. Not to scale.

Figure 4-32 – Staffin Bay Formation shales on the coast at Digg at the northern end of Staffin Bay. Pole *c.* 1m long.

The Mid Callovian to Early Kimmeridgian Staffin Shale Formation was deposited in fully marine conditions and is dominated by shales, mudstones and siltstones at the type-locality on the Trotternish (Figure 4-33) ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)). Ammonites, belemnites and benthic bivalves are abundant and permit a detailed biostratigraphic analysis and interpretation. *Thalassinoides, Planolites* and *Chondrites* burrows disrupt fine-scale lamination. Septarian concretions are abundant towards the top of the sequence (Figure 4-34). A number of (haphazardly named) lithostratigraphic units are identified: the Dunans Shale Member (oldest); the Dunans Clay Member; the Glashvin Silt Member; the Digg Siltstone Member; and, the Flodigarry Shale Member (youngest). The exposures are complicated by faults, being located at the toe of still-active rotational landslips (10.G) due to the overlying (inland) Paleocene lavas (Chapter 5). On Strathaird, the units are coarser-grained, typically siltstones and sandstones (Figure 4-35): the Tobar Ceann Siltstone Member (oldest); the Scaladal Sandstone Member; the Camasunary Sandstone Member; and, the Camasunary Siltstone Member (youngest). Within the Trotternish outcrops, the presence of bentonitic clays is taken to infer a volcanic (tephra) input into the basin (Knox, 1977).

Figure 4-33 – Typical exposures of Staffin Shale Formation strata on the east coast of Trotternish north of Digg, east of Loch Sheanta [NG 4735 6990]. View is north, towards Eilean Flodigarry.

Figure 4-34 – Steeply-inclined, dark grey, fissile shales with carbonate concretions of the Staffin Shale Formation, partially obscured by boulders of dolerite on the east coast of Trotternish north of Digg, east of Loch Sheanta [NG 4730 6976]. Pole *c.* 1m long.

Figure 4-35 – Inclined, parallel-bedded shales and siltstones of the Staffin Shale Formation intruded by NW-SE -trending Paleocene dykes of the Skye Main Dyke Swarm at the southern end of Càrn Mòr on the west coast of Strathaird [NG 5220 1548].

No Jurassic strata younger than Early Kimmeridgian are preserved on Skye. The sequence on Raasay is restricted to the Lower and Middle Jurassic and is less complete and typically less well exposed ((Morton & Hudson, 1995); (Hudson & Trewin, 2002)).

4.D Cretaceous Sedimentary Rocks

Outcrops of Cretaceous sedimentary rocks on Skye and Raasay are very limited. Where their presence is suspected, they are generally overstepped by Paleocene lavas (Chapter 5). However, outcrops have been noted on Skye on the north side of Soay Sound, on Strathaird, and at Strollamus. On Raasay, there is one poorly exposed outcrop on the west side of Dùn Caan.

On Strathaird, between Slat Bheinn and the Kilmarie to Camasunary Bay footpath, a sandy limestone (chalk) unit grades downwards into a coarse-grained calcareous sandstone, containing fragments of Upper Jurassic sandstone. This material forms a sequence *c.* 2m thick and is considered (on the basis of lithology) to be of Upper Cretaceous age, although no clearly identifiable fossils have been recorded. Better evidence is obtained from the strata at Strollamus, where a limestone (chalk) bed, on top of a coarse-grained calcareous sandstone, occurs above Upper Jurassic sandstones. These rocks are exposed in the Allt Eoghainn, where fragments of the bivalve *Inoceramus* occur in a limestone, in a sequence that is up to 5m thick (Figure 4-36) ((Peach, et al., 1910); (BGS, 2005)).

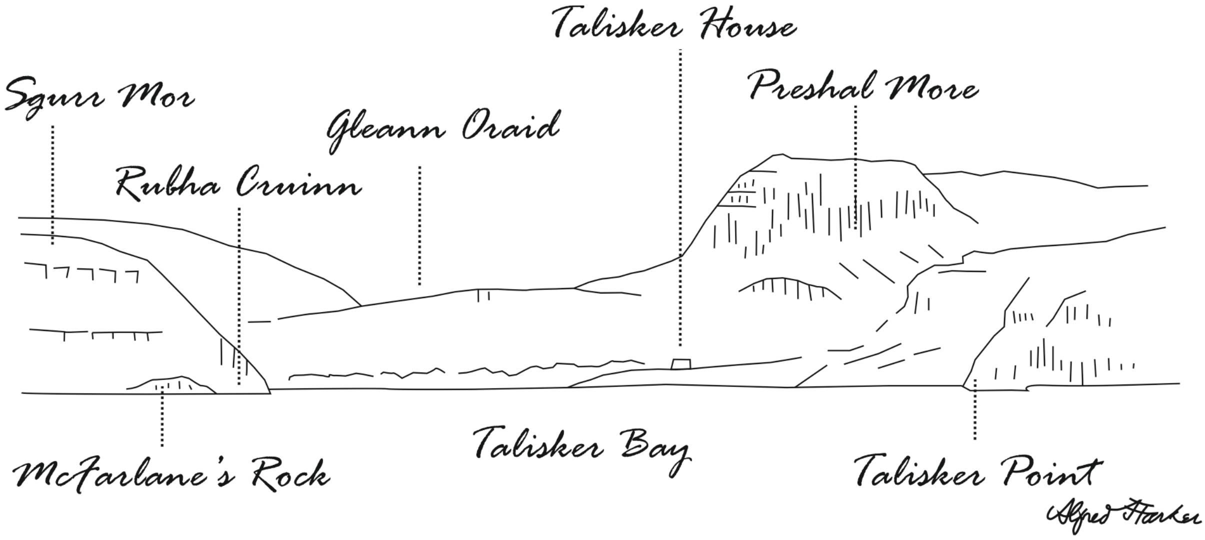
Figure 4-36 – Upper Cretaceous calcareous sandstones and limestones exposed in the Allt Eoghainn (with trees, below power lines) and a parallel unnamed stream to the east (nearest), west of Creag Strollamus in Strath [NG 5984 2626].

The Soay Sound outcrop occurs unconformably above Lower Jurassic Broadford Beds Formation strata (4.C) and is attributed to the Cenomanian (Upper Cretaceous) Morvern Greensand Formation (BGS, 2005). This difficult-to-access coastal sequence comprises only a few metres of strata, consisting of dominant medium-grained, red and green (glauconitic) sandstones, together with thin, laterally discontinuous, coarse-grained sandstones, siltstones and shales.

Similar glauconitic greensands of the Morvern Greensand Formation, less than 2m thick, are poorly exposed in the vicinity of the tourist path on the west side of Dùn Caan on Raasay (BGS, 2006a), below a remnant of the Paleocene lava sequence (5.D).

Chapter 5 The Skye Lava Field

Following the complex formation and filling of the Mesozoic Hebrides Basin, a major rifting event commenced in the Early Selandian (stage) of the Paleocene Epoch as a precursor to the commencement of ocean floor spreading in the NE Atlantic Ocean. On Skye and Raasay, this major magmatic event started with the construction of a lava field, erupted from fissures now expressed by a NW-SE -trending dyke swarm, predominantly into a terrestrial environment.



5.A Introduction

The post-Jurassic to pre-Paleocene rock record on Skye and Raasay is limited to small, scattered outcrops of Upper Cretaceous (Cenomanian) strata (4.D). The succeeding strata, volcanic and sedimentary, on both islands are of Paleocene age, although a precise and accurate age is yet to be determined. The base Paleocene angular unconformity is complicated, with a wide variety of underlying pre-Paleocene rocks present. There is very little relief on the unconformity, suggesting that the pre-volcanic landscape was relative subdued, although evidence for a true peneplain is lacking (Figure 5-1). The base of the lava field is not always above present-day sea-level.

Figure 5-1 – Base lava field unconformity, with rubbly basaltic breccia (hyaloclastite) of the An Leac Member (Rubha an Dùnain Formation) intruded by basalt and dolerite sheets, overlying Mesozoic strata (at base of cliff) on the north side of Soay Sound at Suidhe na h-Inghne, west of the outflow of the Allt na Meacnaish [NG 4367 1688]. View towards west.

The fossil record is poor, as the relatively uncommon interbedded sedimentary rocks are of terrestrial character, with only pollen and spore data providing a useful age indication (Jolley, 1997). The dominant volcanic rocks of the Skye Lava Field are lavas of basaltic composition, which are also difficult to age date by any of the available radiogenic isotope schemes (Emeleus & Bell, 2005). Currently, the best estimate for the commencement of the volcanism, based on palynological data from fine-grained lithologies, is *c*. 58 Ma (Jolley, 1997) - younger than the 60.53 ± 0.08 Ma age by radiometric age dating using the ^{206}Pb-^{238}U technique on zircons in material from the Rum Central Complex and also identified as clasts in conglomerates interbedded with lavas close to the base of the lava sequence (Hamilton, et al., 1998). A radiometric age date for (potentially close to) the end of the volcanism of 58.91 ± 0.18 Ma is based upon the ^{40}Ar-^{39}Ar technique using anorthoclase crystals in a trachytic tuff close to the interpreted top of the preserved sequence (Emeleus & Bell, 2005). This end-of-volcanism age is corroborated by a near-identical age of 58.91 ± 0.07 Ma for material from the Cuillin Intrusive Centre, which intrudes and therefore post-dates the eruption of the main sequence of the lava field (Hamilton, et al., 1998).

Using the radiometric age constraints outlined above, which give a very crude duration of *c.* 1.6 ± 0.2 million years, together with an estimated thickness for the lava field of at least 1,500m, an eruption rate of 2.2×10^{-3} km^3. yr^{-1} has been determined (Hamilton, et al., 1998).

The Paleocene volcanic rocks on Skye and Raasay, as well as those of similar age further south on the island of Mull (Figure 5-2), comprise remnant lava plateaux formed in response to a major phase of lithospheric extension and magmatism in the NE Atlantic region starting at *c.* 61 Ma, which ultimately led to ocean-floor spreading between NW Europe and Greenland at *c.* 55 Ma. Iceland, to the NW and located on the active spreading centre, represents an over-productive part of the magmatic system, where a discrete upwelling from a deeper level in the mantle, a so-called mantle plume or hotspot, coincides with the spreading centre (e.g. (White & McKenzie, 1989); (Brooks, 2011)).

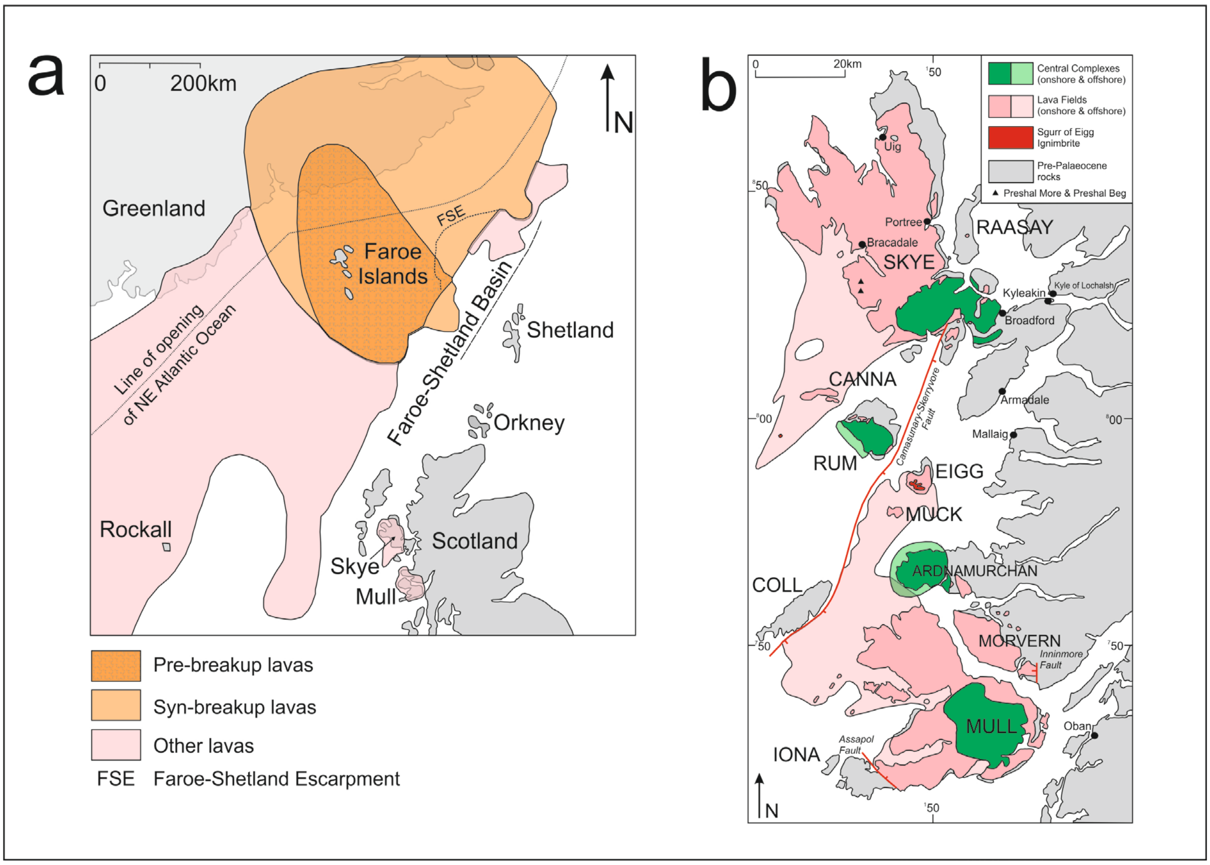


Figure 5-2 – (a) Palaeo-geographic reconstruction at *c.* 55Ma, as ocean floor spreading commenced in the NE Atlantic, indicating the locations of the Skye and Mull lava fields on the western seaboard of Scotland, relative to the lava sequences of East Greenland and the Faroe Islands (after (Larsen, et al., 1999)); and, (b) Schematic map illustrating the onshore and offshore distributions of the Paleocene lava fields and intrusive centres on the western seaboard of Scotland (after (Emeleus & Bell, 2005)).

The compositions of the lavas range from basalt, through hawaiite, mugearite and benmoreite, to trachyte. The dominant parental basaltic magma was neither distinctly alkaline nor tholeiitic, but rather was of a transitional character (Thompson, et al., 1972). Of significance, one volcanic unit, preserved on the twin summits of Preshal More and Preshal Beg in Minginish, at what appears to be the highest preserved stratigraphic level in the lava field, is compositionally distinct, and is of tholeiitic basalt (Essen, et al., 1975). There is a stratigraphic break below this lava, essentially a landscape unconformity, which is therefore interpreted as indicating a significant time break in the volcanism. The composition of this volcanic unit shares key characteristics with intrusive units of the Cuillin Intrusive Centre (Chapter 6) and a genetic relationship can be inferred (Bell & Williamson, 2013).

The fissure feeders to the lava pile are now represented by the myriad of dykes of the NW-SE - trending regional dyke swarm, the Skye Main Dyke Swarm (Chapter 7), which have compositions that match those of the effusive rocks. Other minor intrusions, the cone-sheets of the Cuillin

Intrusive Centre (6.B.10), may also have vented to surface, although direct evidence has not been preserved.

The lava field developed, almost exclusively, in a terrestrial (or subaerial) environment, with only rare pillowed lavas and hyaloclastites, both indicating subaqueous volcanism. Such volcanic rocks occur near to the base of the sequence in the area around and north of Portree Bay, and at An Leac on Soay Sound (Figure 5-3).

Figure 5-3 – Hyaloclastite between Craig Ulatota and Fiurnean, north of Portree, Trotternish [NG 51213 48383]. Pole *c.* 1m long.

Construction of the lava field was intermittent and involved periods during which (contemporaneous) weathering and erosion occurred, represented by weathered rock profiles (palaeosols) and minor unconformities, respectively. Interbedded with the lavas are various clastic sedimentary rocks, either fine-grained lithologies such as mudstone, shale and siltstone, interpreted to have been deposited in ephemeral lakes, or various conglomerate-sandstone-mudstone-coal sequences associated with fluvial systems that also developed during hiatuses in the volcanic activity. More difficult to interpret are clastic units that contain abundant volcanic material, which may either be pyroclastic or volcaniclastic in character. Units that are clearly pyroclastic rocks have been identified but are comparatively uncommon.

The siting of the lava field appears to have been controlled, or at least influenced, by the crustal extension and thinning events that occurred in the Mesozoic Era, when Triassic and Jurassic strata were deposited in the Hebrides Basin (Chapter 4). Significant pre-volcanic uplift of the area around the Skye Central Complex (Chapter 6) occurred, resulting in the volcanic rocks directly overlying the basement Lewisian Gneiss Complex (3.B) in the Eastern Red Hills in the district of Strath, whereas they overlie Torridonian strata (3.C) on the north side of Soay Sound, and overlie Jurassic sedimentary rocks more distal from the central complex in north Skye. At its simplest, the closer to the central complex, the greater the amount of early Paleocene uplift and associated erosion there has been. The cause of this pre-volcanic uplift may be attributed to the effects of magma generation and upwelling, which ultimately produced the Skye Central Complex (Chapter 6). The magma source that fed the volcanic and intrusive activity subsequently switched off below Skye, possibly when ocean floor spreading and the formation of new oceanic lithosphere commenced between the Faroe Islands and East Greenland at *c.* 55 Ma (Figure 5-2) (Larsen, et al., 2014).

At the commencement of the volcanic activity, Skye and Raasay were located at a latitude not greatly different from that of the present-day and the climate was warm temperate to sub-tropical, as evidenced by the pollen and spore record preserved in the interbedded sedimentary rocks (Jolley, 1997), and by the well-developed weathered tops, or palaeosols, to some of the lavas (Figure 5-4), and red beds, some of which are interpreted as lateritised pyroclastic or volcaniclastic rocks ((Emeleus, et al., 1996); (Bell, et al., 1996)). The pollen and spores recovered from the interbedded sedimentary units were derived from a variety of plants, including trees typical of low and high altitudes, which may imply an altitudinal variation of the volcanic landscape during the growth of the lava field (Jolley, 1997). The main types are pines and ferns from humid montane conifer forests with fern understories and associated riverside or riparian shrubs and trees (Jolley, 1997). Hickory (*Carya*), walnut (*Juglans*), oak (*Quercus*) and chestnut (*Castanea*) trees also grew on the lava field, typically at a low altitude. As the lava field aggraded/grew, the oldest units were buried, to depths of several hundreds of metres. Persistence of low altitude pollen and spore assemblages in parts of the sequence imply a subsidence rate similar to the rate of aggradation.

Figure 5-4 – Orange and grey weathered tops to lavas and thin sedimentary units within the Fiskavaig Formation on the north side of Talisker Bay at Rubha Cruinn, Minginish [NG 3100 3086].

During burial, the volcanic units were infiltrated by hydrothermal fluids, fuelled by the heating of (meteoric) groundwater. Emplacement of the central complex also contributed to the development of hydrothermal convection cells within the lava field (6.D; 6.H). Fluid-rock interaction was extensive, resulting in the precipitation of amygdale minerals in original gas cavities (vesicles) and the infilling of fractures to form mineral veins. The dominant minerals precipitated from these hydrothermal fluids during the construction of the lava field are of the zeolite group, including laumontite, mesolite, analcite, chabazite and thomsonite, together with various carbonates. As these fluids reacted with the primary minerals in the lavas, various secondary hydrous minerals formed, including chlorite, epidote, smectite and saponite. The nature of the hydrothermal systems is dealt with in more detail in sections 6.D and 6.H.

5.B Characteristics of the Volcanic Rocks

Most of the lavas, in terms of their compositions, can be recognised from a combination of their field characteristics. Exposures in the high inland escarpment of Trotternish and the spectacular coastal cliffs of Waternish, Duirinish and Minginish (Figure 1-1) offer the best opportunities to understand the three-dimensional characteristics, or architecture, of the lavas.

The main magmatic trend of the Skye lavas is from a 'primitive' transitional to mildly alkaline (olivine) basalt, through hawaiite, mugearite and benmoreite, to an 'evolved' trachyte. The one exception to this lineage is the spectacular columnar-jointed and distinctly tholeiitic basalt lava of the Talisker Formation at Talisker on Minginish.

Stratigraphic terms used in this section are explained in detail in Section 5.D and are included here merely to provide orientation.

The basaltic lavas can form both simple planar sheet-like bodies, commonly with well-developed cooling joints (Figure 5-5) (see below), as well as compound (or pahoehoe) lavas (Figure 5-6), the latter developing by shallow subsurface injection or intrusion and flow of magma below an already-solidified top surface of the flow through lava tubes, eventually leading to the distal part of the flow where the magma extrudes as toe-like lobes. In cross-section, the compound lavas have a stratified appearance, although the individual layers, which in reality are more ribbon-like in shape, are not laterally continuous. Simple sheet lavas are typically less than 5m thick, whereas the lobes of the compound lavas are commonly less than 2m thick but contribute to a lava with multiple stacked lobes and with an overall thickness that may be > 10m.

Figure 5-5 – A thick, prismatically-jointed sheet-like basaltic lava (with recent rockfalls) capping a sequence of compound basaltic lavas and thin sheet-like basaltic lavas of the Beinn Edra Formation on Sròn Vourlinn at the northern end of The Quiraing on Trotternish [NG 4520 7138].

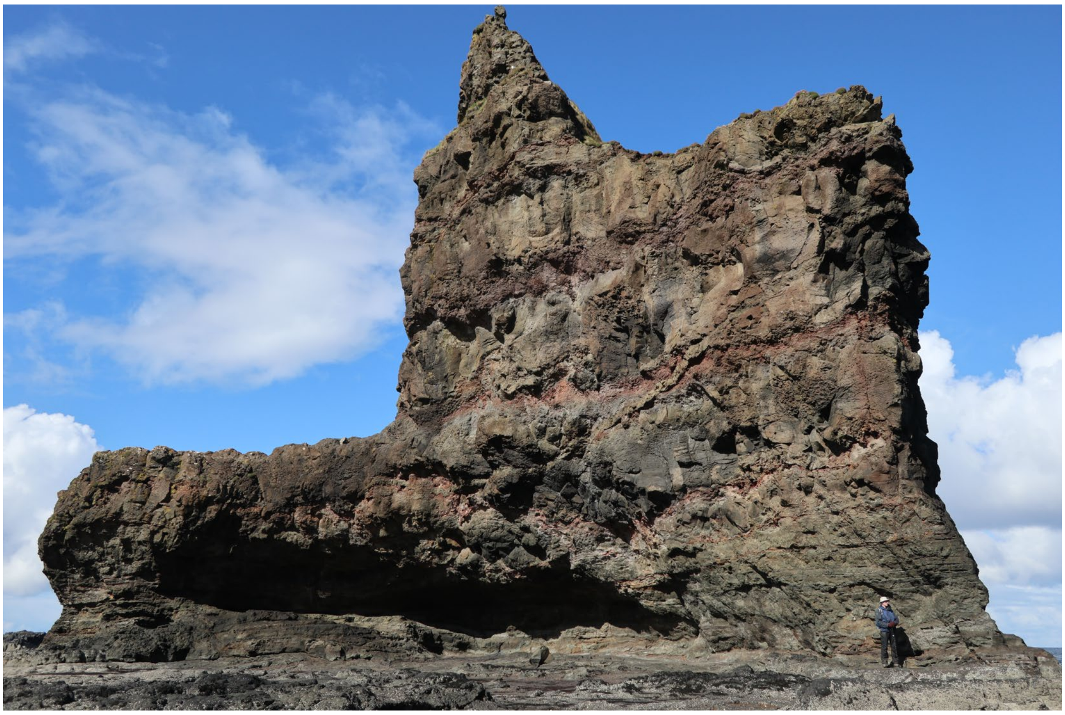


Figure 5-6 – Section on An Stac on the south side of Talisker Bay, Minginish, illustrating the internal architecture of an inflated pahoehoe (compound) lava (Glen Caladale Formation), comprising invasive sheets/lobes through which magma flowed, subsurface, during the construction of the lava [NG 3111 2997]. The thin red intervals are the product of weathering between eruptions and represent significant time breaks in the volcanism. Iain Allison for scale.

Identification of the top surfaces of these predominantly terrestrial, or subaerial, lavas is best achieved through the recognition of fossil soils, also variously referred to as palaeosols, laterites and boles, the thickness of which is, in part, a measure of the duration available for weathering between individual eruptions as the lava sequence aggrades (Figure 5-4 and Figure 5-6). Consequently, during periods of relatively rapid and near-continuous eruption, these products of weathering do not develop or are poorly represented. Basaltic lavas with abundant plagioclase phenocrysts are typically more massive, or structureless, and are thicker (Figure 5-7).

Figure 5-7 – Plagioclase macroporphyritic basalt lava, Dùn Ard an t-Sabhail, Minginish [NG 3188 3331]. Coin *c.* 24mm across.

Similarly, lavas of basaltic composition that become impounded in (i.e. restricted by) (palaeo-) valleys can achieve significant thicknesses, an extreme example being the intra-canyon tholeiitic basalt lava of the Talisker Formation that forms the twin summits of Preshal More and Preshal Beg on Minginish, which was originally > 120m thick and has well-developed cooling joints in the form of a lower colonnade of regularly-spaced hexagonal joints formed by controlled cooling through the floor and walls of the palaeo-valley, and an upper entablature of wavy joints that formed in response to the irregular ingress of surface waters as the displaced drainage system of the palaeo-valley re-established itself (Figure 5-8) (Bell & Williamson, 2013). Rare, very primitive lavas have also been recognised within the lower/older part of the lava field on Minginish and are described as picritic basalts, typically with obvious relatively fresh green olivine micro-phenocrysts in a fine-grained, dark groundmass (Bell & Williamson, 1994).

Figure 5-8 – Preshal More, viewed from the north side of Gleann Oraid [NG 3330 3000]. The thick intra-canyon basaltic lava that forms Preshal More overlies a thin sequence of sedimentary rocks, the Preshal Beg Conglomerate Formation, both of which are laterally restricted by the palaeo-topography that developed in the underlying Gleann Oraid Formation, exposed on the Stockval ridge to the east (left side of image).

Lavas of more evolved composition, such as hawaiite and mugearite, typically have a greater volume and many are 8 to 12m thick, some up to 20m (Figure 5-9). They have significant lateral persistence, despite their crystallisation from more viscous magmas. The uncommon thickness (relative to area covered) of these laterally extensive lavas suggests high effusion rates and their maintenance of magmatic temperatures. The relatively rare benmoreite and trachyte lavas are typically thick. On Minginish, the benmoreite of Cnoc Dubh Heilla is at least 30m thick (Figure 5-10), and the trachyte of Cnoc Scarall (Figure 5-11) in Glen Eynort is in excess of 100m thick. The thickness of the latter may have been accentuated through ponding, and/or its development as a dome-shaped mass, laterally restricted by the viscous nature of the magma. Evidence of flow termination is not common, although in cliff sections thinning of sheet-like lavas can be recognised but may be through lateral sections, as the lava utilised the palaeo-topography and drainage system of the land surface.

Figure 5-9 – Classic step or trap topography of sheet-like hawaiite and mugearite lavas of the Arnaval Member of the Gleann Oraid Formation on Arnaval and the Na Huranan ridge on the north side of Gleann Oraid [NG 3445 3172] (near and middle ground) and on Macleod's Tables on Duirinish (in the distance).

Figure 5-10 – Cnoc Glas Heilla benmoreite lava of the Arnaval Member of the Gleann Oraid Formation, Portnalong [NG 3500 3448]. Viewed towards the SE.

Figure 5-11 – The Cnoc Scarall trachyte lava of the Cnoc Scarall Member of the Gleann Oraid Formation on the east side of Glen Eynort [NG 3892 2860]. View towards the NE, with Cuillin Hills in the distance.

Secondary hydrothermal minerals infilling fractures, and filling original gas cavities (vesicles) to form amygdales, are ubiquitous but are best developed within the thinner, more primitive lava types, such as alkali (olivine) basalt (Figure 5-12). Pipe amygdales are relatively common where lavas have over-ridden palaeosols and mudstones. Amygdale minerals include calcite, quartz, analcime, and the zeolites, chabazite, stilbite, mesolite, thomsonite, gyrolite and apophyllite. The distribution of amygdale minerals is related to both depth of burial and the effects of the younger central complex (Chapter 6). The hydrothermal fluid(s) responsible for the precipitation of the vein and amygdale minerals was of meteoric origin and was also responsible for changes to the primary (magmatic) mineralogy of the lavas, involving the formation of hydrous minerals, including chlorite, epidote, smectite and saponite. Emplacement of the Cuillin Intrusive Centre led to the development of metamorphic olivine and orthopyroxene in lavas close to the margin of the various gabbro intrusions, with (contact metamorphic) temperatures in excess of 900°C.

Figure 5-12 – Amygdaloidal basaltic lava within the landslipped block forming the Old Man of Storr rock pillar on Trotternish [NG 5000 5400]. Hammer *c.* 30cm long.

Hawaiite and mugearite lavas are generally less vesicular, indicating lower concentrations of dissolved magmatic volatiles in the parent magma, responsible for vesicle development upon exsolution as the confining pressure drops below its critical value; however, some trachytes are distinctly vesicular (i.e. with no mineral infills of the gas cavities), for example the thick lava (of the Sleadale Member of the Gleann Oraid Formation) on the north side of Preshal Beg.

Palaeosols (or laterites or boles) form the uppermost part of some of the lavas and are a useful feature that enables individual lavas (both simple and compound) to be distinguished (Figure 5-4; Figure 5-6; Figure 5-13 and Figure 5-14). This material ranges in colour from dark chocolate-brown through dull reddish-brown to bright ocherous red, and from grey to mauve, and is indicative of subaerial weathering during the Paleocene in a warm temperate climate with moderate to high rainfall on free-draining ground. Commonly the palaeosols are obscured inland but are well exposed in the inland escarpments and in the sea cliffs (Figure 5-13 and Figure 5-14). They are generally not well preserved close to the Cuillin Intrusive Centre and the Red Hills granites, where pervasive hydrothermal alteration has commonly reduced lavas and palaeosols to dull grey structureless rocks.

Figure 5-13 – Bright orange lateritised (mugearite) lava top (palaeosol) within the Fiskavaig Formation on the north side of Talisker Bay [NG 3056 3088].

Figure 5-14 – Dull red/mauve lateritised lava top (palaeosol) within the Beinn Edra Formation of The Quiraing section, Trotternish [NG 4500 6960].

The thickness of palaeosols varies considerably. The tops to some lavas are merely stained a reddish brown, with no obvious palaeosol development, although, more typically, lavas are separated by a few millimetres to several centimetres of apparently structureless, massive material. Less commonly, thicker palaeosols preserve rhizolith-like structures where mineral matter has replaced plant roots. Such features are taken to indicate that the palaeosols formed *in situ.* Some of the thickest and best developed palaeosols occur in association with thin mudstones and are generally preserved as lensoid bodies on the undulating, eroded tops to lavas and palaeosols, and indicate minor reworking of soil and volcanic ash by running water, most likely rainwater run-off rather that organised fluvial systems. Commonly, the thicker palaeosols, with or without associated mudstone, are directly overlain by thick, differentiated lavas, hawaiite or mugearite, suggesting prolonged periods between eruptions. Particularly good examples are seen at Talisker Bay (Figure 5-13), Beinn nan Dubh Loch, Fiskavaig and Biod Mòr in west-central Skye.

Palaeosol-like layers with indistinct bedding and rudimentary pisolitic structure, commonly containing pristine minerals such as sanidine, biotite and pyroxene, are interpreted as the product of contemporaneous weathering of crystal and vitric tuffs and not a consequence of deep-weathering of *in situ* lava (Bell, et al., 1996). Examples are relatively common and include an easily-accessed, roadside example within a landslipped mass close to Lochan nan Dùnan in northern Trotternish, between Digg and Flodigarry (Figure 5-15).

Figure 5-15 – Weathered basaltic tuff within the landslipped section of lava field material (Beinn Edra Formation) at Lochan nan Dùnan, between Digg and Flodigarry on Trotternish [NG 4662 7070]. Lens cap *c.* 6cm across.

Flow structure (or 'flow banding') is best, but not exclusively, developed within the more evolved lavas, and such fabrics are generally parallel to the dip of the lava. The commonest type of flow structure is due to the alignment of groundmass and microphenocryst feldspars, which impart an obvious fissility (planar fabric) and banded appearance to the rock and is a useful aid to field identification; flow-alignment of plagioclase macrophenocrysts is not generally noted. Where the base of a lava is irregular, folds within the foliation are common. An excellent large-scale example is the mugearite lava at McFarlane's Rock, north of Talisker Bay (Figure 5-16). Systematic and abrupt changes in the inclination of flow structure and cooling joints are present at several localities. Usually, an otherwise flat to low-angle orientation is replaced by a near-vertical one. This may indicate either a lava dipping in an intrusive manner under its own surface or reflect the possibility of the lava having flowed over uneven topography. There are many examples, including those seen at Loch Dubh, and Cnoc Scarall and Coir' an Rathaid on Minginish.

Figure 5-16 – Flow fabric within (coastal exposures) of the McFarlane's Rock mugearite lava (of the McFarlane's Rock Member of the Fiskavaig Formation), north of Talisker Bay [NG 3014 3110]. Ruler 30cm long.

Flow direction can be established, albeit on a local scale, where the base of a lava has over-ridden unconsolidated material, such as sediment. There are good examples in lavas overlying the Minginish Conglomerate Formation in the Allt Mòr south of Loch Eynort (see also Section 5.C, below). There, the lava has both 'nosed' into soft sediment, incorporating strings of sandy material, and developed inclined flame-like masses of sediment along its base. Flow direction may also be indicated by inclined or deflected pipe amygdales and by discoid amygdales.

Some basalt, hawaiite and mugearite lavas have brecciated tops, typical of a'a-type flows; this autoclastic material can easily be misidentified as monolithological pyroclastic breccia. Typically, such a'a-type lavas are indicative of cooler, volatile-depleted magma at some distance from its point of eruption. A mugearite at Rubha Cruinn on the north side of Talisker Bay, illustrates this very well and also shows a basal breccia carpet.

The extent to which columnar joints (or 'jointing') are developed in lavas appears to depend, amongst other things, on the composition of the magma. The best examples of columnar joints are usually found in tholeiitic basalt or tholeiitic olivine basalt lavas, and one of the best examples of a columnar-jointed lava on Skye is the tholeiitic basalt that forms Preshal More and Preshal Beg, SE of Talisker Bay on Minginish, where these lava remnants are over 120m thick (Figure 5-17). Each outcrop has a (lower) colonnade in which near-vertical columns are typically six-sided (hexagonal) and between 0.3 and 1m across. Pentagonal and heptagonal columns have also developed but are not common. The overlying entablature shows a complex, highly irregular joint pattern; a thin zone, characterised by a sub-horizontal flow-foliation, separates the colonnade from the entablature. Curved ball-and-socket joints commonly divide the columns of the colonnade along their length. Inclined columns at several localities indicate the proximity of the sidewalls of the (palaeo-) valley in which the magma ponded, but which subsequently have been removed by erosion (Bell & Williamson, 2013).

Figure 5-17 – South face of Preshal More illustrating a thick well-developed entablature of near-vertical (typically hexagonal) columns overlain by, with a sharp near-horizontal contact, an entablature of irregular (or wavy) columns. The scree comprises fragments of columns from both facies of the lava [NG 3319 2984].

True columnar joints are less common within the unevolved alkali (olivine) basalt lavas, which are generally characterised by more irregular blocky or prismatic joints. Imperfect columnar joints are commonly present in hawaiite and mugearite lavas, and less common in lavas of more evolved composition such as trachyte.

Present-day weathering characteristics are also a useful field indicator of lava type (Figure 5-18). The minerals in basaltic lavas tend to degrade more readily, for example olivine, than those in the more evolved lavas such as hawaiite and mugearite. Coupled to the more obviously amygdaloidal and usually coarser-grained nature of olivine basalt lavas, are their degradation and a tendency to form hollows on lower ground, or terraced slopes between more resistant (and compositionally evolved) lavas. Within individual lavas, the amygdaloidal top and base weather more readily than the massive centre, resulting in typical, so-called step- or trap-featuring.

Figure 5-18 – Thin, easily-weathered, compound basaltic lavas (on the lower ground) overlain by thicker, less-weathered, impersistent hawaiite lavas with prismatic joints (Sleadale Member, Gleann Oraid Formation), on Ben Scaalan on the south side of Minginish [NG 3358 2633].

Pillowed lavas are comparatively rare and do not have substantial thicknesses or lateral extents within the Skye Lava Field. Discrete pillows and small clusters of pillows occur in association with the basal sequence of hyaloclastites (see below) north of Portree, within the Portree Hyaloclastite Formation, for example, between Craig Ulatota and Fiurnean (Figure 5-19) where access is relatively good, and between Sìthean a' Bhealaich Chumhaing and Rubha na h-Àirde Glaise where access is more challenging. In addition, an interval several metres thick, close to, but not at, the base of the lava sequence is dominated by pillow-structured lava in the cliffs of Creag Mhòr on the north side of Loch Portree (Figure 5-20). In essence, the sequence from Creag Mhòr, northwards, records an early period in the lava field's development (Beinn Edra Formation, see Section 5.D) when magma-water interactions, most likely in a lacustrine setting, resulted in various hydro-volcanic deposits, including hyaloclastite, volcaniclastic sandstones, siltstones and mudstones, and pillowed lavas, together with sheet flows where interaction and fragmentation did not significantly occur. Another location where the base of the Skye Lava Field is exposed is at An Leac, on the north side of Soay Sound. Here, similar lithologies occur, but are difficult to access in the coastal cliffs (Figure 5-1).

Figure 5-19 – A discrete pillow within a matrix of basaltic hyaloclastite of the Portree Hyaloclastite Formation near the summit of Fiurnean, Trotternish [NG 5143 4908]. Ruler 30cm long.

Figure 5-20 – Stacked pillows within a lava close to the base of the Beinn Edra Formation at the SW end of Creag Mhòr, NE of Portree [NG 5052 4470]. Ruler 30cm long.

Individual lavas can have (localised) pillowed facies due to their eruption into shallow bodies of water, interpreted as lakes and river channels. One of the best examples is the intra-canyon lava that forms the twin summits of Preshal More and Preshal Beg. On the NE side of Preshal More and the SW side of Preshal Beg the base of the lava is a complex assemblage of pillowed material, together with localised development of hyaloclastite (Figure 5-21).

Figure 5-21 – Hyaloclastite facies at the base of the Preshal More lava, Talisker Formation, on the north side of Preshal More [NG 3340 3004]. Pole *c.* 1m long.

The mineralogy of the lavas follows a logical progression from olivine-clinopyroxene-plagioclase -dominated (alkali olivine) basalt through hawaiite, mugearite and benmoreite by fractional crystallisation, to alkali feldspar -dominated trachyte. Similarly, the tholeiitic basalt lavas evolve through intermediate types to quartz-alkali feldspar dominated rhyodacite and rhyolite (Figure 5-22).

Lava type	Mineralogy and petrography
Alkali basalt and transitional olivine basalt (both commonly mapped as olivine basalt)	Phenocrysts and microphenocrysts of olivine (Fo_{87-70}), plagioclase (An_{70-55}) and rare clinopyroxene. Groundmass of plagioclase laths, commonly ophitic diopsidic augite/titanaugite ($En_{43}Fs_{14}Wo_{43}$) and minor titanomagnetite and apatite. Chrome-spinel as inclusions in olivine and rarely as microphenocrysts.
Picrobasalt	Abundant phenocrysts of olivine (Fo_{89-85}) enclose chrome-spinel. Matrix of olivine, plagioclase laths, ophitic diopsidic augite and titanomagnetite. Groundmass minerals of similar composition to alkali basalt.
Hawaiite	Phenocrysts of compositionally zoned plagioclase ($An_{51-45)}$, olivine (Fo_{75-50}) and rarer augite ($En_{45}Fs_{10}Wo_{45}$). Abundant microphenocrysts of magnetite. Groundmass of plagioclase ($An_{60}Ab_{39}Or_{1}$-$An_{15}Ab_{80}Or_{5}$), ophitic to subophitic clinopyroxene ($En_{38}Fs_{20}Wo_{42}$), minor biotite, amphibole, apatite and interstitial alkali feldspar ($An_{2}Ab_{60}Or_{38}$). Plagioclase phenocrysts and xenocrysts up to 25mm long in 'Big Feldspar' varieties.
Mugearite	Phenocrysts of zoned olivine (Fo_{40-18}), plagioclase (An_{60-30}) and iron-rich clinopyroxene . Groundmass of flow-aligned plagioclase laths ($An_{22}Ab_{68}Or_{10}$), equigranular clinopyroxene ($En_{38}Fs_{16}Wo_{46}$), apatite needles and granular titanomagnetite, with minor Fe-rich olivine, biotite, amphibole and interstitial alkali feldspar. Uncommon 'Big feldspar' variants.
Benmoreite	Abundant microphenocrysts of flow-aligned, zoned plagioclase (andesine-oligoclase) and anorthoclase. Fine-grained groundmass of flow-aligned alkali feldspar and sodic plagioclase laths, granular clinopyroxene and magnetite, and apatite needles. Rare olivine, typically serpentinised.
Trachyte	Phenocrysts of anorthoclase or sodic sanidine ($An_{1}Ab_{48}Or_{51}$), Fe-rich clinopyroxene ($En_{21}Fs_{33}Wo_{46}$) and rare olivine (Fo_{20}) and microphenocrysts of apatite. Abundant small flow-aligned sodic alkali feldspar laths, and interstitial sodic pyroxene and amphibole.
Tholeiitic olivine basalt	Sparse microphenocrysts of zoned olivine (Fo_{91-55}) and plagioclase (An_{90-66}). Groundmass of plagioclase laths (An_{82}), clinopyroxene ($En_{43}Fs_{12}Wo_{45}$), olivine and homogeneous titanomagnetite. Minor apatite and amphibole. Calcium-poor pyroxene absent.
Tholeiitic basalt	Rare phenocrysts of plagioclase (An_{87-76}) and altered olivine. Fine-grained plagioclase laths (An_{72}), granular aggregates of augite ($En_{47}Fs_{12}Wo_{41}$), rare pigeonite and opaque oxides. Interstitial glass, commonly altered to chlorite.
Tholeiitic basaltic andesite	Phenocrysts of plagioclase ($An_{57}Ab_{41}Or_{2}$ - $An_{30}Ab_{63}Or_{7}$), augite ($En_{43}Fs_{17}Wo_{40}$), and rare orthopyroxene ($En_{65}Fs_{31}Wo_{4}$). Fine-grained groundmass of plagioclase laths ($An_{40}Ab5_{6}Or_{4}$), granular clinopyroxene ($En_{40}Fs_{23}Wo_{37}$), magnetite and interstitial glass of sodic granite composition.
Tholeiitic andesite ('Icelandite')	Phenocrysts of plagioclase ($An_{60}Ab_{39}Or_{1}$ - $An_{38}Ab_{58}Or_{4}$), augite ($En_{42}Fs_{18}Wo_{40}$), orthopyroxene ($En_{66}Fs_{30}Wo_{4}$), titanomagnetite and apatite. Very fine-grained groundmass of plagioclase laths, magnetite grains and granular pyroxene.
Rhyodacite vitrophyre ('pitchstone')	'Phenocrysts' of plagioclase ($An_{32}Ab_{60}Or_{8}$), grid-twinned anorthoclase ($An_{6}Ab_{51}Or_{43}$), clinopyroxene ($En_{44}Fs_{18}Wo_{38}$), orthopyroxene ($En_{68}Fs_{29}Wo_{3}$), magnetite, ilmenite, apatite and rare quartz. 'Phenocrysts' (especially feldspar) commonly embayed. Groundmass of flow-banded glass, commonly devitrified to dusty, felsitic groundmass.

Figure 5-22 – Summary of mineralogy and petrography of lavas in the Skye Lava Field.

5.C Characteristics of the Interbedded Sedimentary Units

Interbedded with the estimated > 2,000m of lava field stratigraphy (see Section 5.D, below) are various non-marine clastic sedimentary units, ranging in grade from breccia and cobble/boulder conglomerate to mudstone, together with low-grade (lignite) coal. Some of these sequences are accorded formational status ((BGS, 2000); (BGS, 2002); (BGS, 2006a); (BGS, 2006b) (BGS, 2006c); (BGS, 2007)) and have been employed in defining stratigraphic subdivision schemes for various parts of the lava field (Section 5.D).

Although these sedimentary units, some of which are several metres thick, indicate hiatuses in the volcanism, they are not necessarily traceable over large distances. It is possible that whilst sediment deposition was occurring in one part of the lava field, weathering or erosion or volcanism was occurring elsewhere, as seen in many present-day, volcanically active areas. Beds of lignite attest to substantial periods of non-deposition of sediment and the accumulation of organic material, marginal either to fluvial or lacustrine systems. Marine sedimentary rocks do not form any part of the sequence and rare pillowed lavas (e.g. Figure 5-20) are interpreted to have formed in relatively shallow ephemeral lakes that developed on the lava field.

Figure 5-27 and Figure 5-35 provide details of sedimentary units that have been used to divide the lava field stratigraphy in north Skye (Anderson & Dunham, 1966) and on Minginish ((Williamson & Bell, 1994); (Bell & Williamson, 2013)).

Certain of the sedimentary sequences are typical siliciclastic units, whereas others are dominated by (Paleocene) volcanic material, both as large clasts and as matrix material, and are better referred to as being volcaniclastic sedimentary rocks, for example, volcaniclastic sandstone and volcaniclastic siltstone.

Stratification is common, typically with normal-graded profiles. Within many of the conglomerate and sandstone beds, cross-stratification indicates (local) transport direction, as does the localised imbrication of cobbles and pebbles. Other sedimentary structures include trough cross bedding, load casts, convolute lamination, minor ripples, and mudcracks.

Within the cobble and pebble population of the coarse-grained siliciclastic deposits, various lithologies from the Late Proterozoic Torridonian sequence (3.C) on Skye are recognised: coarse, green sandstone and siltstone from the Rubha Guail Formation; grey siltstones from the Loch na Dal Formation; reddish-brown sandstones of the Beinn na Seamraig and Kinloch formations; and, reddish-brown, medium-grained sandstones of the Applecross Formation. Also present are uncommon fragments of Cambrian sandstone (‘quartzite’) (3.E) and Moine psammite and pelite (3.D), also attributable to a Skye source. Of relatively local derivation are abundant clasts of various Paleocene volcanic lithologies: porphyritic and non-porphyritic variants of basalt, hawaiite, mugearite and trachyte, which either form a component of the clast assemblage in the siliciclastic conglomerates, or dominate units that are best described as volcaniclastic conglomerates.

Some of the cobbles and pebbles in the siliciclastic conglomerates are not recognised from any *in situ* outcrops on Skye and may be regarded as ‘exotic’ ((Williamson & Bell, 1994); (Bell & Williamson, 2013)). These include quartz-porphyritic felsite (or vitrophyre) and granophyric-textured granite, that petrographically match intra-caldera crystal (quartz)-rich ignimbrites and a granite (the so-called Western Granite of the Rum Central Complex), respectively. These rocks crop out >20km to the south on the island of Rum (Figure 5-2) and formed during the Paleocene as extrusive and intrusive units, respectively (Emeleus, 1997). The sedimentary motifs of these conglomerates are of fluvial character and, therefore, imply the development of a river system draining northwards from the unroofed Rum Volcano across the contemporaneously aggrading Skye Lava Field. The penecontemporaneous sedimentary sections at the Allt Geodh a' Ghàmhna and the Allt Mòr between Loch Brittle and Loch Eynort are important sequences with these conglomerates and are attributed to the Minginish Conglomerate Formation ((Williamson & Bell, 1994); (BGS, 2000)) (Figure 5-23 and Figure 5-24) (see also 5.D).

Figure 5-23 – Minginish Conglomerate Formation conglomerates and sandstones overlain by a basaltic lava of the Cruachan Formation in the Allt Geodh a' Ghàmhna [NG 3691 1966], between lochs Brittle and Eynort.

Figure 5-24 – Minginish Conglomerate Formation conglomerates overlain by a basaltic lava of the Cruachan Formation in the Allt Mòr [NG 3662 2056], between lochs Brittle and Eynort.

Other coarse-grained sedimentary units, dominated by boulders, cobbles and pebbles of locally derived volcanic lithologies are typically non-graded and poorly stratified, and are interpreted as the products of debris flow processes. Within such units, erosion surfaces are recognised, suggesting they comprise a number of rapidly deposited lobes. A good example occurs on the NE side of Preshal Beg, SE of Talisker Bay on Minginish. Here, within the Preshal Beg Conglomerate Formation, interpreted as having been deposited within a canyon system (Bell & Williamson, 2013), the dominant characteristics are those of (localised) debris flows (Figure 5-25), whereas elsewhere within the Formation, for example on the south side of the small satellite hill SE of Preshal Beg, fluvial facies conglomerates with internal stratification and grading are dominant.

Figure 5-25 – Coarse-grained, heterogeneous sedimentary unit of the Preshal Beg Formation, interpreted as a debris flow deposit, overlain by a columnar-jointed basalt lava of the Talisker Formation on the NE side of Preshal Beg [NG 3302 2797]. Ian Williamson for scale.

5.D Lithostratigraphy of the Lava Field

A usable and practical approach to subdividing the lava-dominated sequences of Trotternish, Waternish and Duirinish of north Skye was first used by (Anderson & Dunham, 1966) when they proposed five groups, separated by sedimentary units. The simple principle is that the sedimentary units represent (substantial?) hiatuses in the volcanism, during which, normal background sedimentation, mainly fluvial and lacustrine, re-established. If this principle/interpretation is correct, then the various subdivisions also have a chrono-stratigraphic significance; however, there is the distinct possibility that sedimentation in one part of the lava field could have been contemporaneous with weathering or erosion or volcanism elsewhere in the lava field.

On the basis of field observations reported in (Anderson & Dunham, 1966), (England, 1994) concluded that the overall structure of the lava field is a syncline that, in part, trends parallel to the NW-SE -trending Skye Main Dyke Swarm (Figure 5-26) (Chapter 7). The structure is attributed to the loading effect of the lava pile as it aggraded. Deviations away from this trend, towards N-S and NE-SW, are attributed to later tectonic processes in the Oligocene, possibly related to the N-S -trending Canna Fault (Figure 5-26).

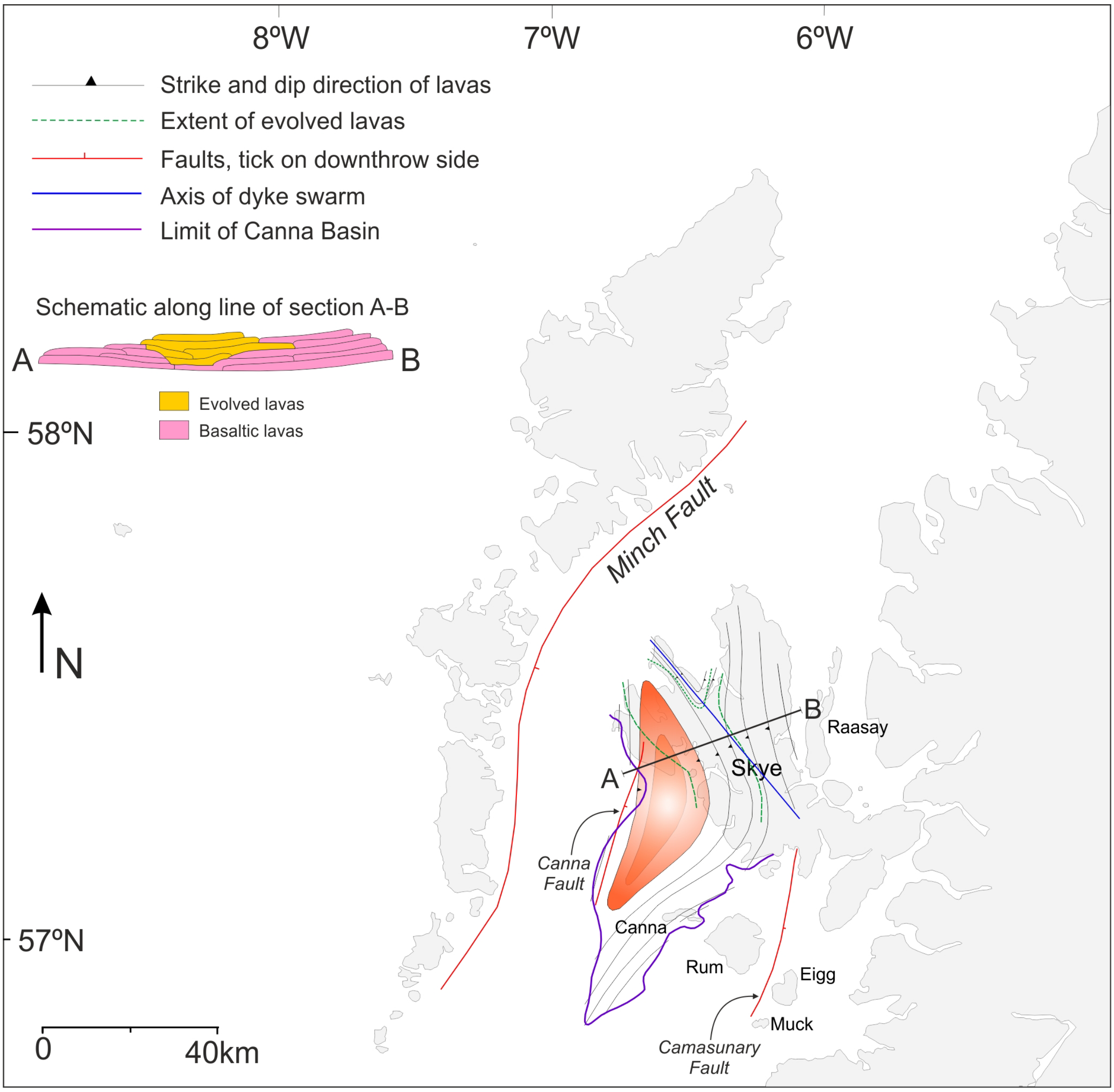


Figure 5-26 – Structural map of the Skye Lava Field illustrating a simplistic schematic cross-section with evolved lavas more abundant within the central part of the syncline (after England 1994).

The area documented by (Anderson & Dunham, 1966) was originally surveyed by the British Geological Survey between 1934 and 1939 by D. Haldane, J. Knox, T. R. M. Lawrie and T. Robertson, with G. V. Wilson as District Geologist; the 1966 memoir was an attempt to unify the field data collected by the field geologists involved. A subsequent formal addition to the lithostratigraphic framework of (Anderson & Dunham, 1966) was incorporated in a desk revision of the 1:50,000 maps published in the 2000s ((BGS, 2006b); (BGS, 2006c); (BGS, 2007)), with the recognition of a hyaloclastite-dominated basal unit north of Portree, the Portree Hyaloclastite Formation (Figure 5-27).

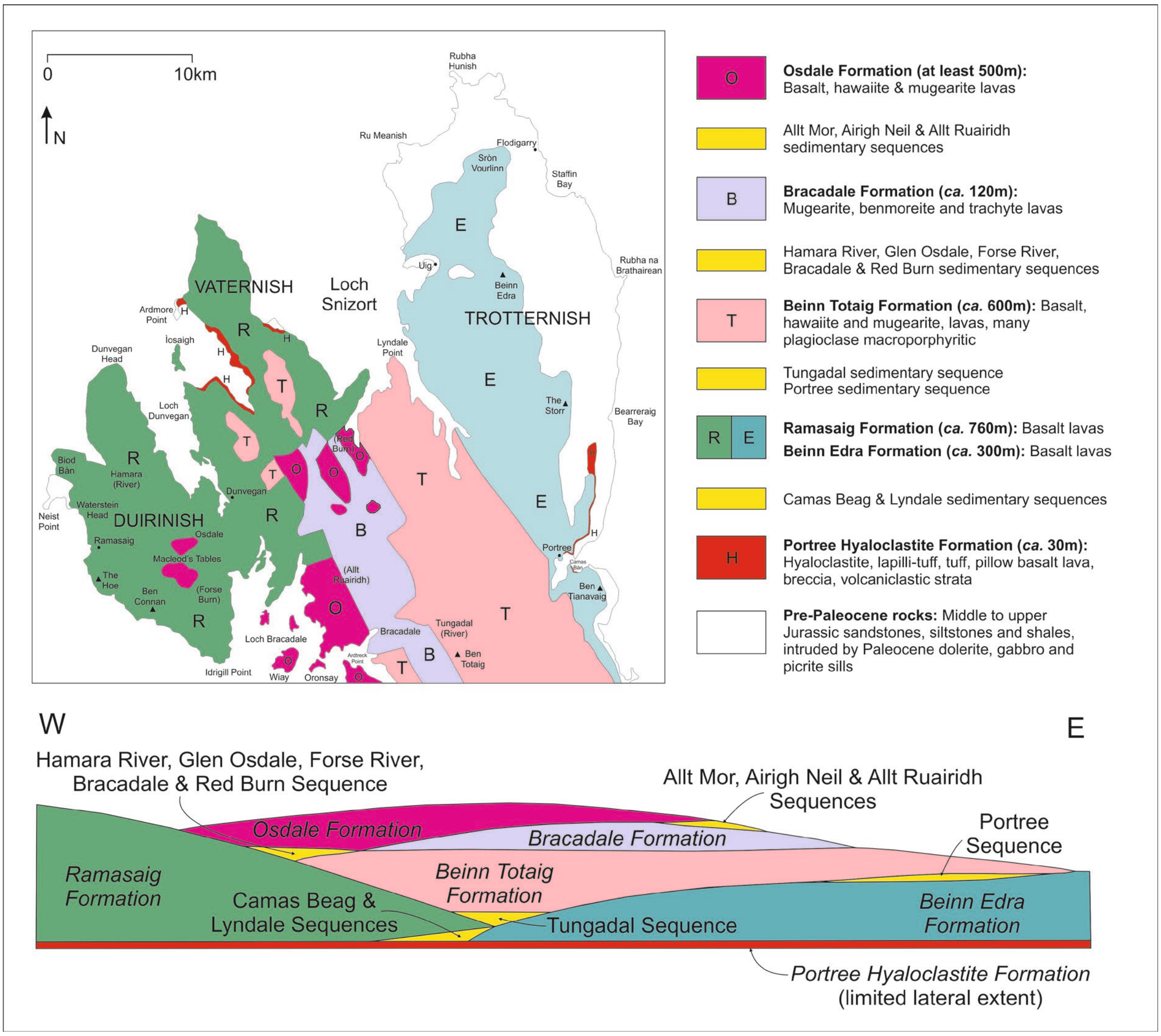


Figure 5-27 – Simplified schematic geological map and cross-section illustrating the distribution of the five lava formations and interbedded sedimentary sequences in North Skye (after (Anderson & Dunham, 1966)).

The Portree Hyaloclastite Formation is the oldest recognised subdivision of the lava field stratigraphy and is up to 30m thick. The best exposed and most continuous outcrops are located north of Portree, forming an inland set of crags between Sìthean a' Bhealaich Chumhaing and Fiurnean, including the crags of Craig Ulatota, along the eastern margin of the Beinn Edra Formation outcrop. Here, the base of the volcanic sequence is not exposed, with the underlying Lower and Middle Jurassic strata intruded by dolerite sills forming the coastal cliffs to the east (Chapter 8). The formation also crops out: further to the south at Rubha na h-Àirde Glaise; further west, in the east bank of a tributary of the Lòn Druiseach; poorly on the north side of Loch Portree, east of Toravaig; and, on the south side of Loch Portree at Camas Bàn (Figure 5-28). Other very small exposures occur where the base of the volcanic sequence is exposed in north Skye but are typically of poor quality and of a discontinuous nature, for example at Creagan na Sgalain on the north side of Tianavaig Bay, and south along the east-facing coast as far as Peinachorrain. Significant post-glacial landslips in north Skye have affected the basal part of the volcanic sequence (Chapter 10) and have significantly obscured the Portree Hyaloclasite Formation, although found as displaced fragments, for example at Staffin and Flodigarry.

Figure 5-28 – The Portree Hyaloclastite Formation on the west side of Camas Bàn, west of Vriskaig Point on the south side of Portree Bay [NG 4914 4256].

The sequence is relatively heterogeneous, with significant along-strike variation. Considering the main exposures, detailed above, the dominant lithology is hyaloclastite, essential a poorly stratified breccia composed of matrix-supported fragments of fine-grained to glassy basalt, commonly angular, up to 20cm across, but typically <5cm across, in a matrix of similar, much finer-grained or glassy material (Figure 5-29). The overall colour of the hyaloclastite is mid- to dark-brown, contrasting with the very pale/white zeolites and carbonate that has commonly been precipitated in voids throughout the rock. The larger fragments are crystalline, many with obvious chilled margins, whereas the smaller and interstitial fragments are fine-grained or, more typically, glassy. The fluids responsible for the precipitation of the interstitial hydrothermal minerals have also caused alteration of the original glass (sideromelane), to palagonite (a poorly understood low temperature alteration product formed when hydrothermal fluids reacts with (typically) basaltic glass producing, amongst other things, microscopic crystals of various types of clay).

Figure 5-29 – Detail of the Portree Hyaloclastite Formation on the west side of Camas Bàn, west of Vriskaig Point on the south side of Portree Bay [NG 4914 4256]. Hammer *c.* 30cm long.

Also present within the hyaloclastite are well-developed but isolated pillows of basalt, with chilled rinds and radially-disposed joints, typically set in a matrix of hyaloclastite (Figure 5-19), and relatively rare and discontinuous beds of fine-grained, plant-bearing, volcaniclastic sedimentary rocks, typically fine-grained sandstones, siltstones and mudstones. These clastic units have previously been described as tuffs, consisting of ash, lapilli and bombs (Anderson & Dunham, 1966), but show evidence of sedimentary transport and are also associated with low-grade, lignitic coals. Plant fragments within the volcaniclastic beds include *Ginkgo* (maidenhair) and *Equisetum* (horsetail). Spatially-associated flat-lying sheets of jointed, commonly amygdaloidal basalt and dolerite may be thin lavas or shallow-level intrusive bodies.

In north Skye, (Anderson & Dunham, 1966) have assigned the overlying lava-dominated sequence to five formations, separated by laterally-impersistent sedimentary units, as detailed in Figure 5-27. Although the principle applied is robust, the lack of continuous exposure and the variable nature of these sedimentary units may imply that the interpretation presented in Figure 5-27 is not, in all instances, correct. However, at a simplistic level, it has value, indicating hiatuses, even if only geographically-localised, in the aggradation of the lava field. Details of the dominant lava types in each formation (basalt, hawaiite, mugearite, benmoreite, trachyte) are summarised in Figure 5-27.

Clearly, the Beinn Edra and Ramasaig formations are, for the eastern and western parts of north Skye, respectively, the oldest sequences. Similarly, the upper part of the sequence appears to comprise, from oldest to youngest, the Beinn Totaig, Bracadale and Osdale formations. In map view the distribution of these formations is shown in Figure 5-27. The intervening sedimentary intervals comprise a wide variety of clastic lithologies, ranging between cobble conglomerate and mudstone, together with low-grade coals, all deposited in fluvial and/or lacustrine environments on a relatively subdued lava field topography. Plant remains, typically leaves, within the fine-grained lithologies include *Quercus, Corylus* and *Platanus,* oak, hazel and plane, respectively.

The 'type sections' for the five recognised formations are located as follows: the Beinn Edra Formation on Beinn Edra and along the east-facing escarpment of Trotternish (Figure 5-30); the Ramasaig Formation at Ramasaig on the west-facing sea-cliffs of Duirinish and, in general, on Duirinish and Waternish (Figure 5-31); the Beinn Totaig Formation, at the head of Glen Vidigill, NE of Loch Harport, and in a swath of land between Lyndale Point at the head of Loch Snizort Beag and Ben Lee, north of Loch Sligachan (Figure 5-32); the Bracadale Formation (Figure 5-33) in poorly exposed ground SW of the Beinn Totaig Formation, between Roineval (NE of the head of Loch Harport) and the moorland south of Blackhill, south of the head of Loch Greshhornish; and, the Osdale Formation, in the coastal area around Glen Ose at Loch Bracadale (Figure 5-34).

Figure 5-30 – Basaltic lavas of the Beinn Edra Formation, forming the east-facing inland cliffs of The Storr on Trotternish, intruded by typically less robust thin basalt and dolerite dykes that give rise to clefts within the crags [NG 4950 5400]. View towards the west.

Figure 5-31 – Basaltic lavas of the Ramasaig Formation, forming the west-facing coastal cliffs of Biod Bàn above Oisgill Bay on the west side of Duirinish [NG 1338 5000].

Figure 5-32 – Terraced basaltic lavas of the Beinn Totaig Formation, forming Ben Grasco, *c.* 4km west of Portree.

Figure 5-33 – Mugearite lavas of the Bracadale Formation, forming the crags of Creag Mhòr on the SE side of the Amar River, east of Bracadale, viewed towards the SE.

Figure 5-34 – Basaltic and mugearitic lavas of the Osdale Formation forming the summit of Healabhal Mhor (Macleod's Table North) on Duirinish, viewed towards the south [NG 2200 4451].

More recent investigations of the lava field on Minginish provide a considerably more detailed breakdown of the lithostratigraphy ((Williamson & Bell, 1994); (Bell & Williamson, 2013)) of that part of the Skye Lava Field, also using the principle of sedimentary interbeds indicating (local) hiatuses in the volcanism. Details are set out in Figure 5-35. Within the Minginish sequence, the most important stratigraphic break is at the base of the Preshal Beg Conglomerate Formation (Figure 5-25), which locally developed on a palaeo-land surface with significant topographic relief, and is overlain by an intra-canyon-style lava that was erupted/emplaced during the shield-building stage of the Cuillin Volcano, now represented by the various gabbros, troctolites, peridotites and minor intrusions of the Cuillin Intrusive Centre (Bell & Williamson, 2013) (Chapter 6).

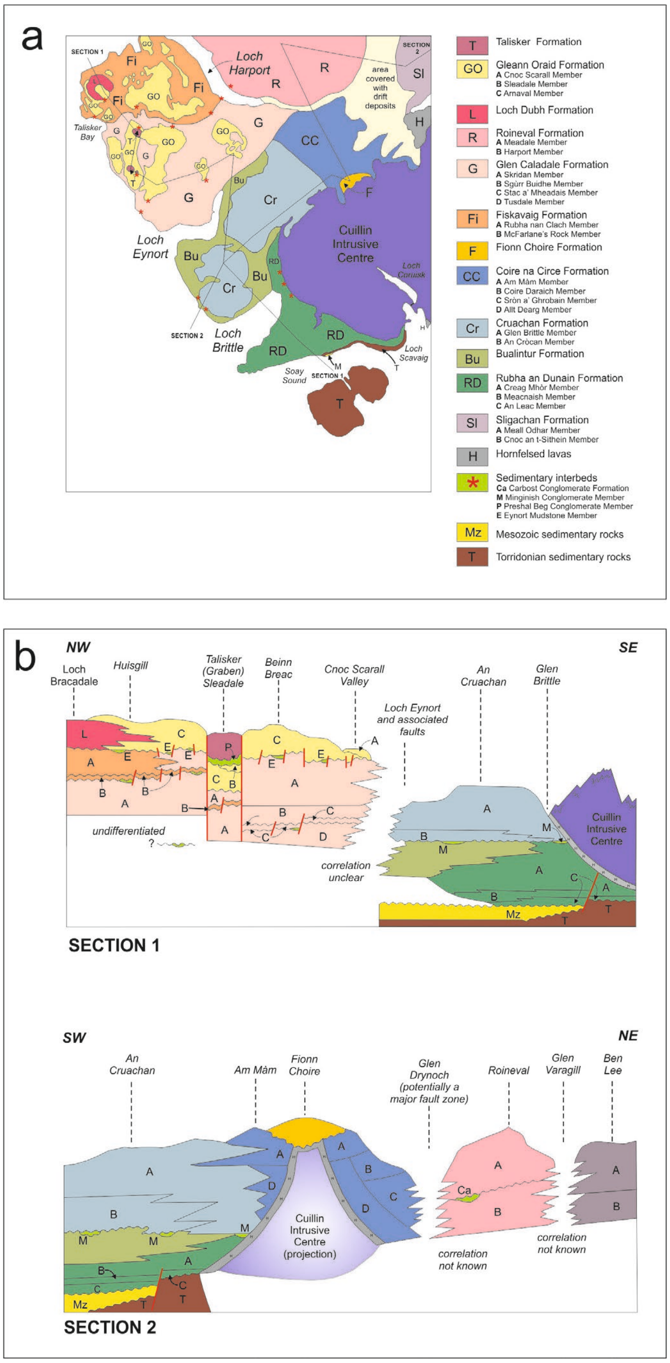


Figure 5-35 – Simplified schematic geological map and cross-sections illustrating the distribution of the twelve lava-dominated formations and interbedded sedimentary sequences on Minginish and adjacent areas (after BGS 2000).

Figure 5-35 illustrates schematically in map and cross-section views the main subdivisions of the Minginish sequence. Twelve lava-dominated formations are recognised, some of which can be further subdivided into members (BGS, 2000). All have been given local names, based upon their geographic distributions. The interbedded sedimentary-dominated units, also given formation status, are also detailed. The schematic cross-sections in Figure 5-35 are an attempt to illustrate the inter-relationships of all of these sequences, as best can be understood from the available inland and coastal exposures.

At the base of the sequence, exposed on the north side of Soay Sound at An Leac, where the Allt na Meacnaish enters the sea, the An Leac Member of the Rubha an Dùnain Formation comprises laterally impersistent units of intercalated volcaniclastic breccia and hyaloclastite, together with beds of volcaniclastic siltstone and sandstone (Figure 5-1 and Figure 5-36). In some respects, this member is similar to the Portree Hyaloclastite Formation of north Skye (see above), indicating subaqueous deposition, most likely in a lacustrine setting, possibly with associated pyroclastic activity. The member has a thickness of *c.*10-20m. It is here that the underlying Mesozoic sequence is exposed, as detailed in Chapter 4.

Above the An Leac Member are the first (oldest) lavas, attributed to the Meacnaish Member (Figure 5-36). The compositions of these lavas do not follow any simple progression with stratigraphic height; some of the oldest lavas in the sequence are mugearites.

Hiatuses in the volcanism are also evident from early in the aggradation history of the sequence, with the development of thin lacustrine shales and siltstones. The overlying Creag Mhòr Member consists of olivine ± plagioclase porphyritic and near-aphyric basaltic lavas, many with well-developed lateritic tops, with associated thin mudstones.

The two lowest lava-dominated formations, the Rubha an Dùnain and Bualintur formations (Figure 5-37), may interdigitate, and comprise a wide variety of lava types, both simple and compound, and range in composition from basalt through to mugearite. The hawaiite lavas, in particular, form strong features and can be traced laterally for significant distances, especially along the coastal sea cliffs between Loch Brittle and Loch Eynort. Porphyritic variants, mainly with olivine and/or plagioclase phenocrysts, are relatively common. Within the Bualintur Formation, for example at Sgùrr an Duine, there are thin, discontinuous beds of volcaniclastic breccia, conglomerate and sandstone, although inaccessible within the sea cliffs.

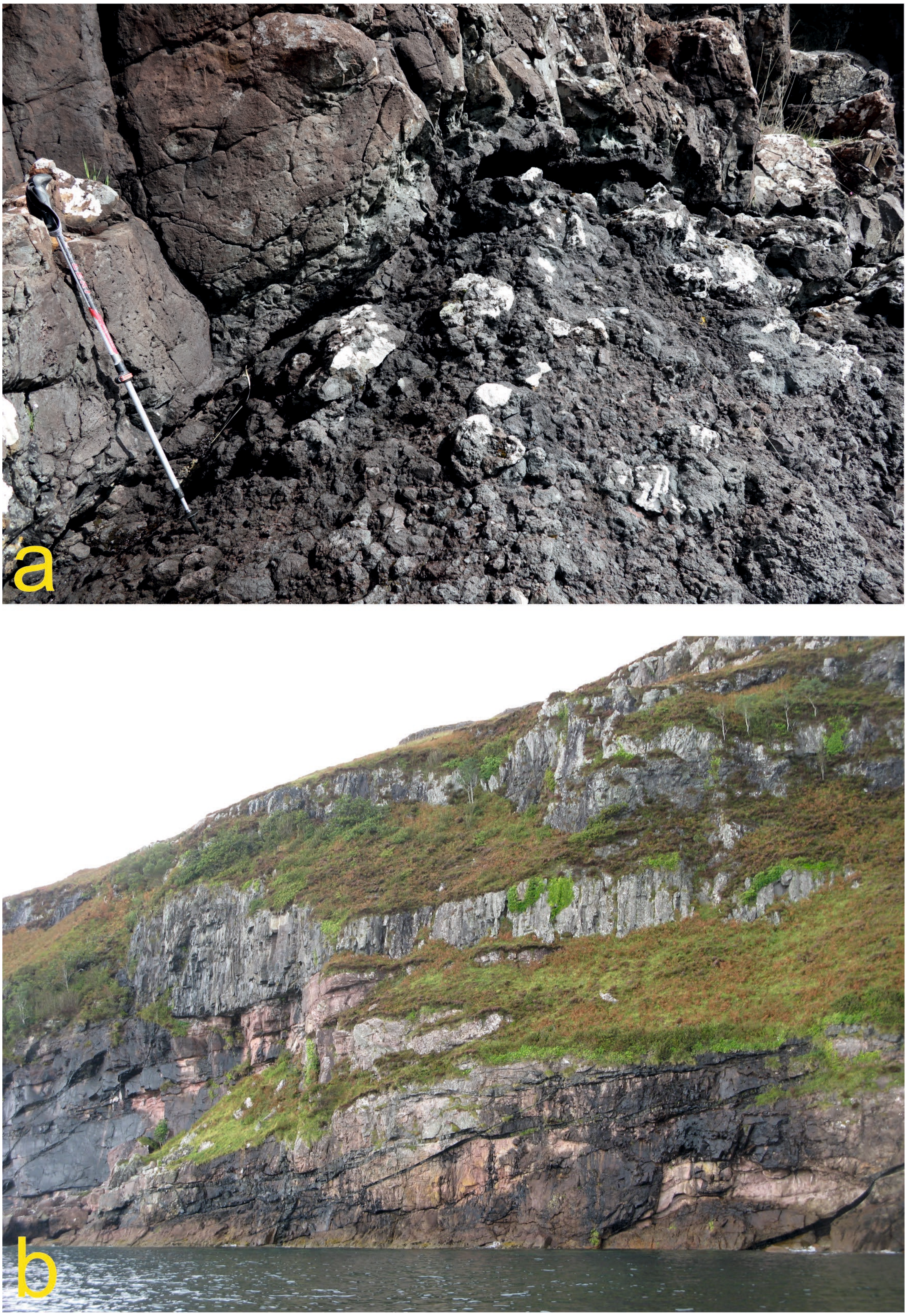


Figure 5-36 – (a) Volcaniclastic breccia (bottom right) intruded by a vesicular/amygdaloidal sheet of dolerite (top left) within the An Leac Member of the Rubha an Dùnain Formation, pole *c.* 1m long ; and, (b) prismatically-jointed evolved lavas (mugearites and hawaiites) of the Meacnaish Member (Rubha an Dùnain Formation) unconformably overlying pale orange Torridonian strata of the Bheinn Bhreac Member (Applecross Formation, Torridon Group) on the north side of Soay Sound [NG 4451 1714].

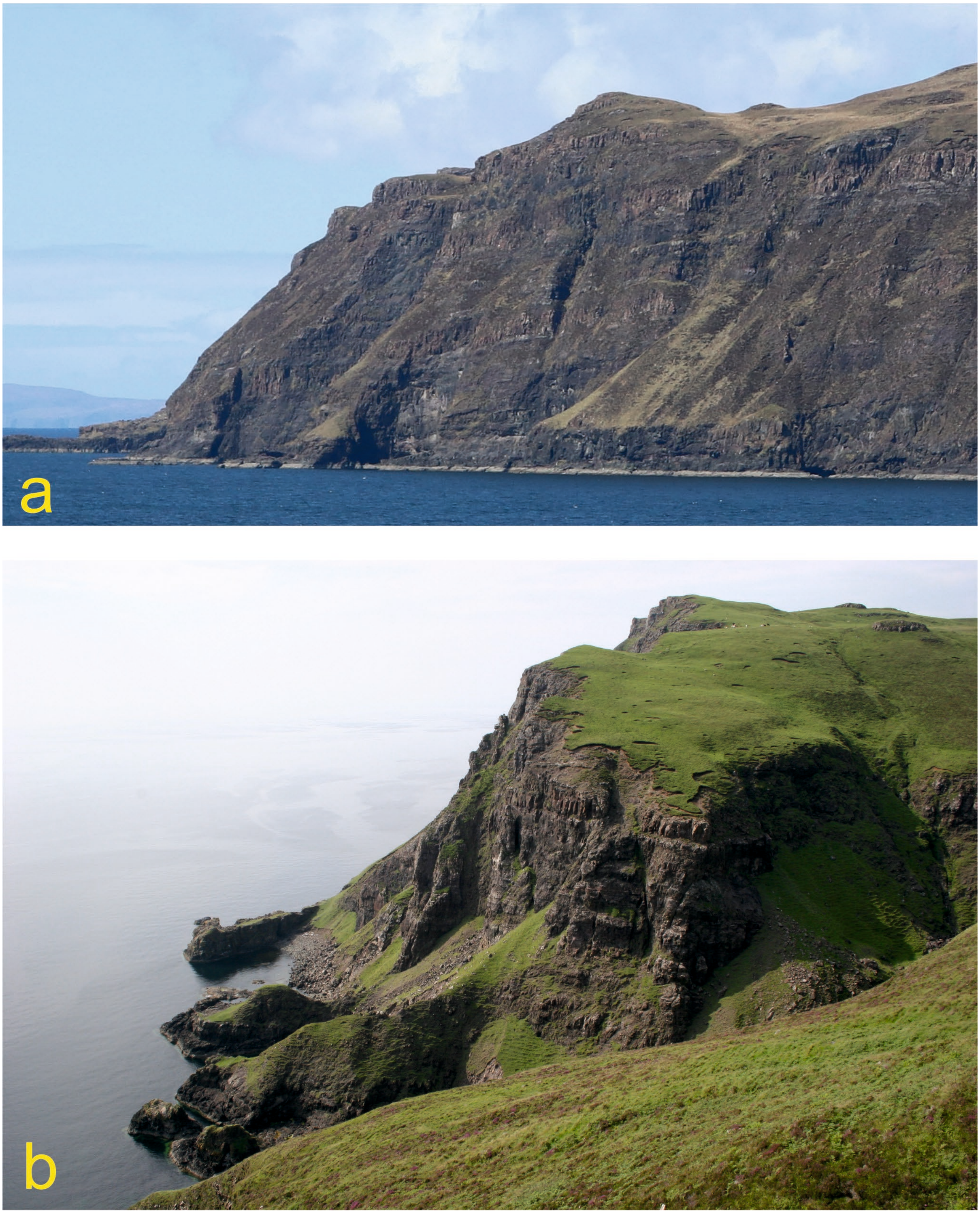


Figure 5-37 –Bualintur Formation lavas, mainly of basaltic and hawaiitic composition, some prismatic, forming the coastal cliffs: (a) Geodha na h-Airigh Mòire and below An Cròcan [NG 3821 1905]; and, (b) Sgùrr a' Ghobhainn, west of the Allt Mòr [NG 3639 2063]. Both views towards the NW.

The Minginish Conglomerate Formation comprises a complex sequence of clastic rocks of fluvial and debris flow associations, ranging from conglomerate through to mudstone, together with thin, low-grade lignitic coals of overbank/swamp/mire association. It overlies the Rubha an Dùnain and Bualintur formations and was deposited during a significant hiatus in the aggradation of the lava field. Three key sections/members are recognised, at Culnamean on the east side of Glen Brittle close to the margin of the Cuillin Intrusive Centre, and in the river sections of the Allt Geodh a' Ghàmhna and the Allt Mòr between Loch Brittle and Loch Eynort. Key features of the Allt Geodh a' Ghàmhna section are illustrated in Figure 5-38 and schematic sections for the Allt Mòr deposits, including the underlying and overlying volcanic rocks, are given in Figure 5-39. Field views are illustrated in Figure 5-23 and Figure 5-24. Clasts within the conglomerates, mainly rounded to sub-rounded cobbles and pebbles, are dominated by biotite and pyroxene-hornblende granophyric-textured granite, together with relatively rare quartz-porphyritic felsite. Given the relatively resistant-to-erosion character of both lithologies, it is evident that these clasts have been subjected to significant transport. Also present are similarly tough clasts of fine-grained laminated siltstone and coarse-grained haematite-stained arkose (feldspathic lith-arenite), the latter the more abundant type. The granite clasts match well the Western Granite/Granophyre on Rum (Figure 5-2), which pre-dates the lavas on Rum that are a southern extension of the Skye Lava Field (Emeleus & Bell, 2005). The felsite clasts do not have such a similarly good correspondence/match with the felsites that crop out on Rum, which are interpreted as ignimbrites ((Bell & Emeleus, 1988); (Emeleus & Bell, 2005)). Sedimentary units on Rum belonging to the Torridonian sequence and acting as the dominant country-rock to the Rum Central Complex, match well the sedimentary clasts within the Minginish Conglomerate Formation. Clasts of basalt, hawaiite and mugearite are present, but are rare. Thus, a southerly source for the Minginish Conglomerate Formation clasts can be inferred (Williamson & Bell, 1994).

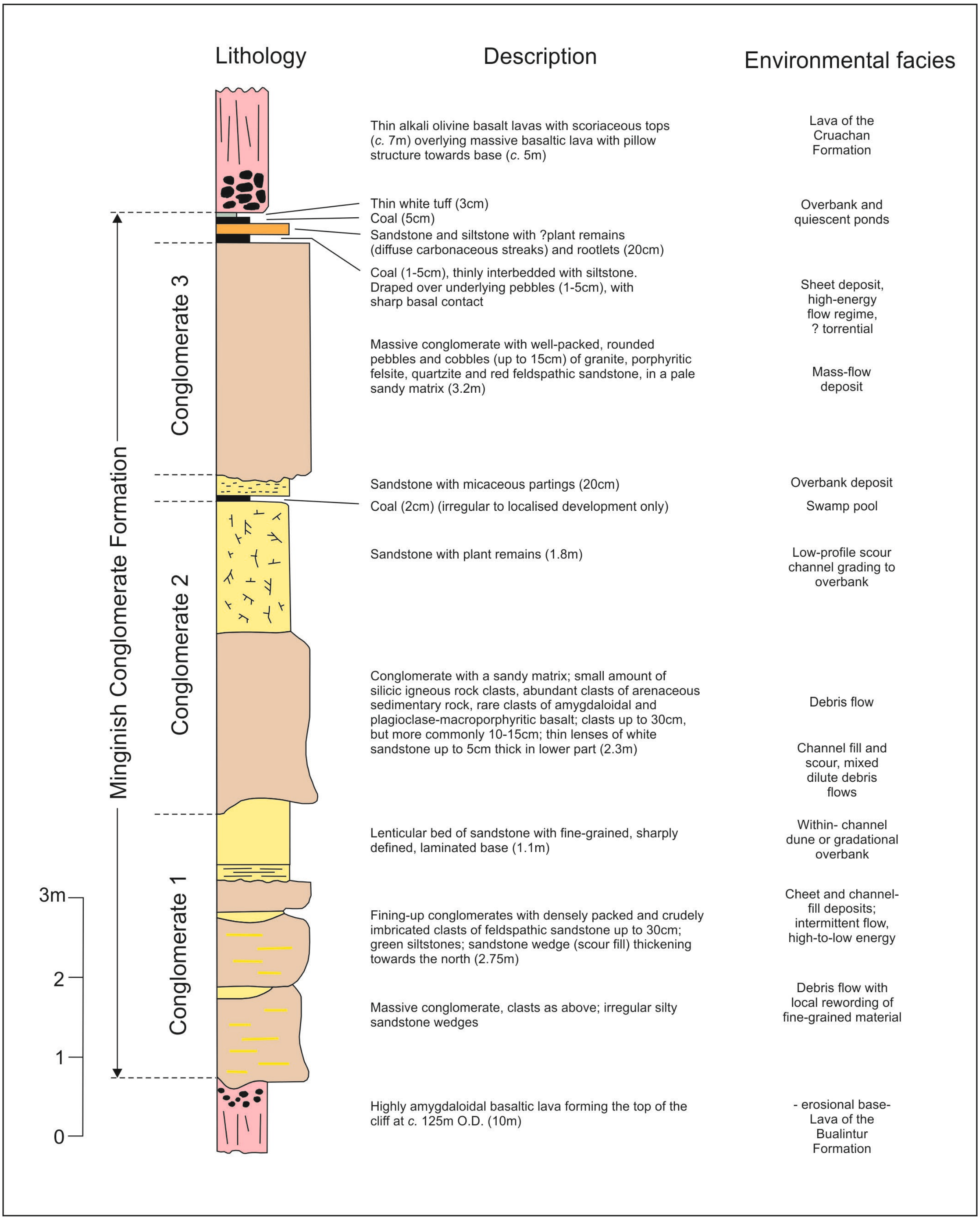
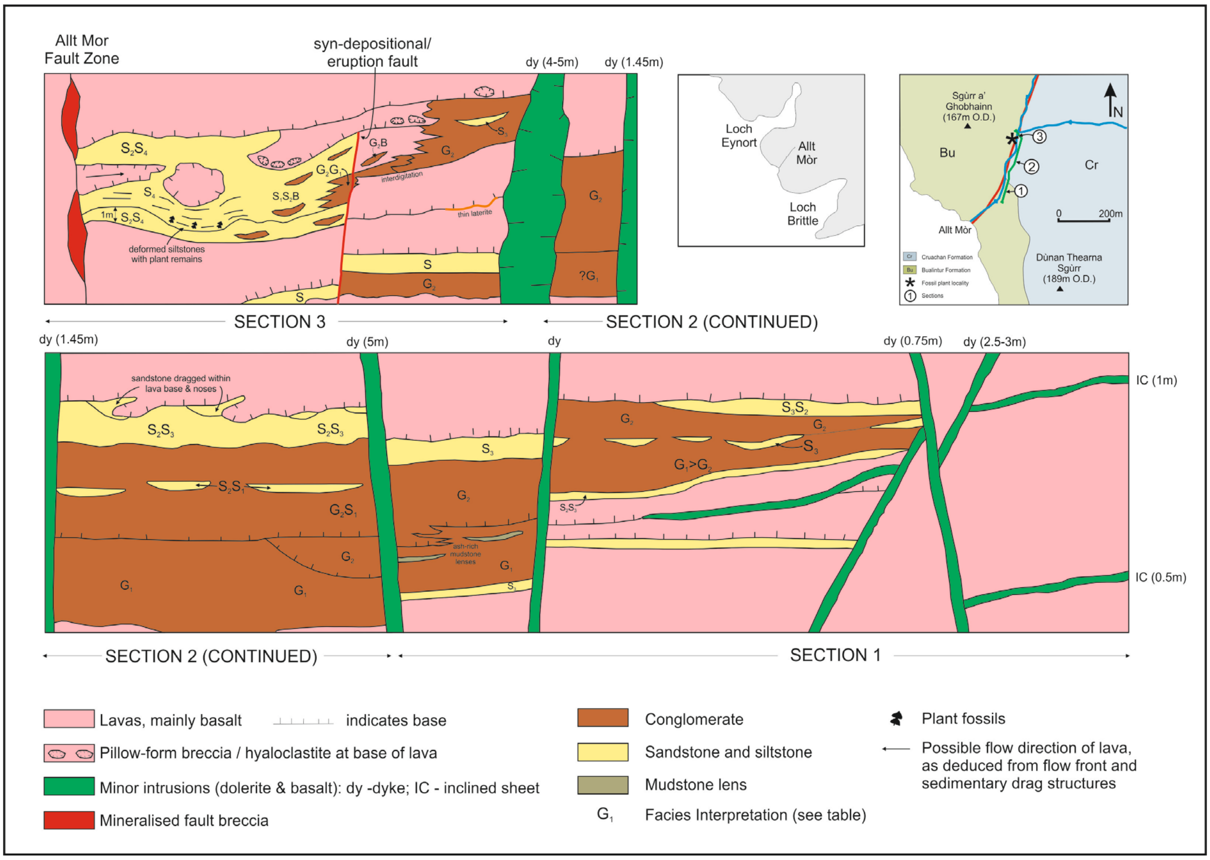


Figure 5-38 – Stratigraphical section for the Allt Geodh a' Ghàmhna Member of the Minginish Conglomerate Formation (based on Williamson & Bell 1994).



Code	Facies	Sedimentary structures	Interpretation
G1	Matrix-supported conglomerate	Massive to crudely-graded	Debris flow deposit
G2	Clast-supported conglomerate	**A:** weakly stratified, planar, normally-graded, locally imbricate **B:** Lenticular, trough cross-bedded	Sheet deposit or longitudinal bar Channel fill or scour
S1	Pebbly, silty coarse-grained sandstone	Massive	Dilute debris flow or avalanche deposit
S2	Fine- to coarse-grained, locally pebbly, sandstone	**A:** Trough cross-bedded, pebbles at base of troughs **B:** Trough cross-bedded, upper surfaces rippled, graded profiles	Within-channel dunes and lag deposits Within-channel dunes and channel fill and scour
S3	Fine- to medium-grained, silty sandstone	Planar cross-bedded	Linguoid and transverse bar or low-angle scour fills
S4		Massive to faintly sub-parallel laminated; plant remains	Channel infilling, relative quiescence, locally lacustrine
S5	Interbedded siltstones and mudstones	Thinly bedded to coarse inter-laminated; horizontal to wavy laminations	Similar to overbank deposits, but could be upper flow regime (waning current)
C	Coal	**A:** Bright, massive **B:** Dull to banded	Allocthonous, washed-in plant (mainly woody) remains Autochthonous,*in situ* vegetation; swamp/mire conditions

Figure 5-39 – Schematic sections (not to scale) within the Allt Mòr Member of the Minginish Conglomerate Formation and details of sedimentary facies and structures [NG 3660 2040] (based on Williamson & Bell 1994).

The overlying Cruachan Formation is separated from the Rubha an Dunain and Bualintur formations by the laterally-discontinuous Minginish Conglomerate Formation. The Cruachan Formation (Figure 5-40) is subdivided into two members, the Glen Brittle and An Crocan members, both dominated by interbedded basalt and hawaiite lavas. A single picritic basalt lava occurs in the Glen Brittle Member on An Cruachan (Bell & Williamson, 1994).

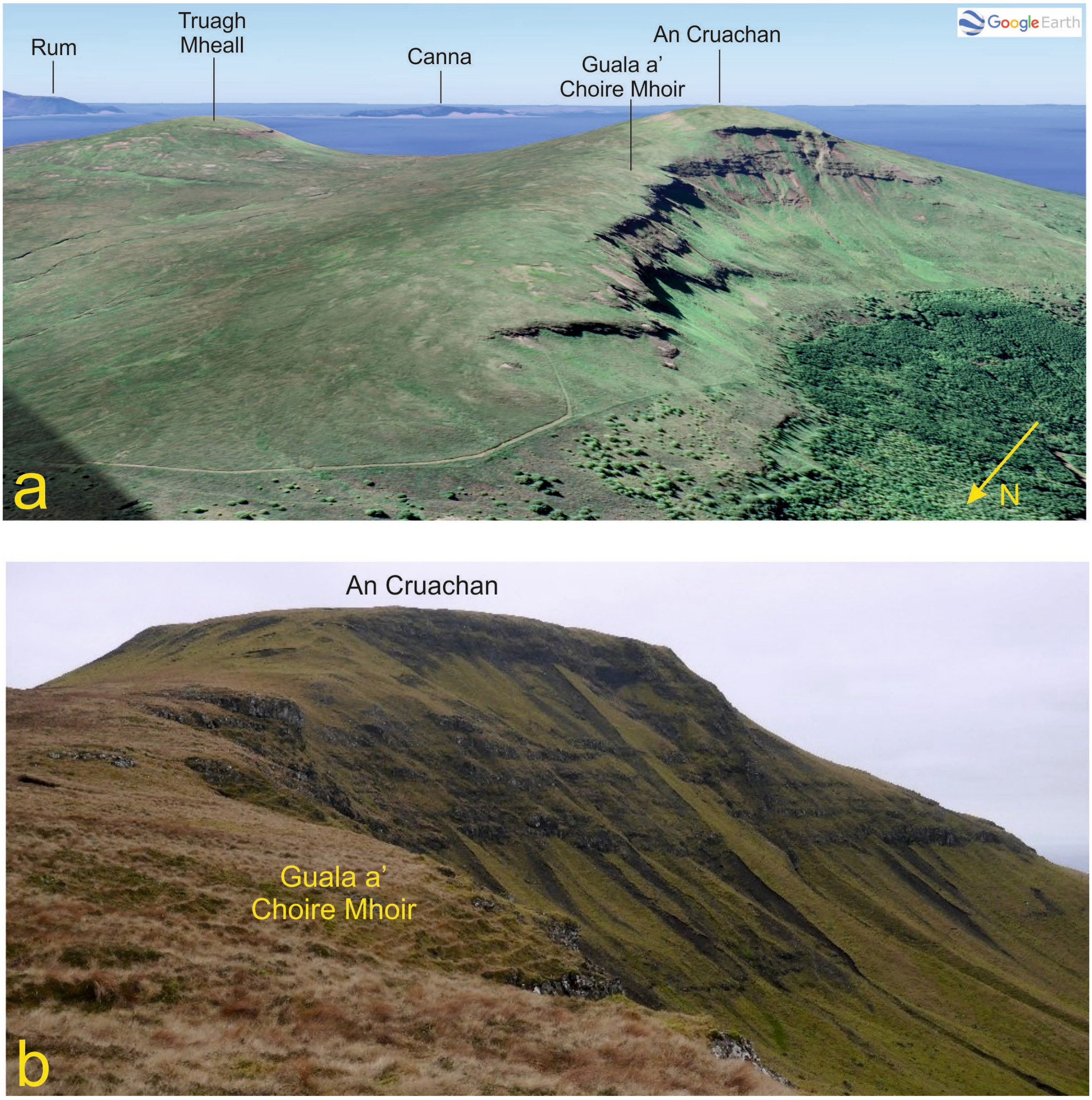


Figure 5-40 – (a) Oblique Google Earth© image of An Cruachan and Truagh Mheall, composed of Cruachan Formation (Glen Brittle Member) interbedded basalt and hawaiite lavas; and, (b) field view of An Cruachan and the crags of Guala a' Choire Mhoir, view towards the south [NG 3821 2251].

The Glen Caladale Formation is interpreted to be younger than the previously described sequences (Figure 5-35), although precise field relationships are not clear, mainly due to relatively poor exposure in the area around Loch Eynort. Four members are identified: Tusdale (oldest), Stac a' Mheadais, Sgùrr Buidhe and Skridan. Simple sheet and compound lavas of basalt, hawaiite and mugearite dominate, with olivine and plagioclase porphyritic variants being relatively common (Figure 5-41). A picritic basalt lava occurs towards the base of the Tusdale Member between Sgùrr Mòr and Sgùrr Beag. The Stac a' Mheadais Member is represented by a single sheet-like mugearite lava up to 25m thick and cropping out on the sea-cliff opposite Stac a' Mheadais (Figure 5-41). It overlies a distinctive red-brown laterite, has a brecciated, lateritised top and forms substantial inland exposures. The Stac a' Mheadais Member is overlain, locally, by thin sandstones, siltstones and mudstones, above which are simple and compound basalt and hawaiite lavas of the Sgùrr Buidhe Member. The hawaiite lavas can be traced from the sea cliffs where they crop out near to

Stac a' Mheadais, inland, forming bold escarpments between Glen Caladale and Tusdale, apparently terminating SE of Beinn na Cuinneig. The Skridan Member is dominated by compound olivine basalt lavas and, traced along the sea cliffs NW towards Talisker Bay, appear to interdigitate with lavas of the (younger) Fiskavaig Formation.

Figure 5-41 – Glen Caladale Formation in the coastal section below Sgùrr Buidhe, with amygdaloidal basaltic and hawaiitic lavas of the Sgùrr Buidhe Member, overlying a thick prismatic-jointed mugearite lava at the base of the cliff and on the islet of Stac a' Mheadais [NG 3318 2570]. View towards the SE.

Superb exposures of inflated pahoehoe (compound) lavas of the Glen Caladale Formation crop out on the south side of Talisker Bay, at Talisker Point, forming the tidal islet of An Stac and the adjacent coastal cliffs (Figure 5-6).

The Fiskavaig Formation, comprising the McFarlane's Rock and Rubha nan Clach members, crops out over a significant area north of Gleann Oraid, as far as Loch Bracadale and Loch Harport, and interdigitates with the upper part of the Glen Caladale Formation. The lower of the two members, the McFarlane's Rock Member, comprises compound basalt lavas, a prominent, prismatic-jointed mugearite, and hawaiite lavas with distinctive red-brown lateritic tops, best seen in the cliffs on the north side of Talisker Bay. The McFarlane's Rock Member is particularly well exposed at Rubha Cruinn, on the north side of Talisker Bay. The most spectacular of the evolved lavas is the mugearite that crops out on McFarlane's Rock and along the adjacent coastline, and which has very well-developed flow bands with complex fold patterns (Figure 5-16). The overlying Rubha nan Clach Member comprises interbedded compound basalt lavas and laterally extensive sheet hawaiite lavas (Figure 5-42).

Figure 5-42 – Fiskavaig Formation strata forming the promontory of Rubha Cruinn on the north side of Talisker Bay. The sequence comprises mainly basaltic and hawaiitic lavas of the Rubha nan Clach Member overlying the thick, flow-banded mugearite lava of the McFarlane's Rock Member (at the base of the cliff) with an obvious lateritic top (palaeosol) [NG 3038 3081].

The overlying Eynort Mudstone Formation (Figure 5-35), stratigraphically above the Rubha nan Clach Member in the area around Rubha nan Clach, but also stratigraphically above the Skridan Member of the Glen Caladale Formation in the area around Beinn Bhreac, was deposited after a prolonged period of intense weathering and erosion, followed by deposition of fine-grained sediments in a lacustrine setting (Figure 5-43). These siltstones and mudstones contain abundant volcanic material and are variably interbedded with carbonaceous shales, ironstones and impure lignitic coals. Exposures occur on Ben Scaalan, on Biod Mòr, in Gleann Oraid on the slopes of Arnaval and Stockval facing the glen, and on the southern slopes of Beinn nan Dubh-lochan above Loch an Sgùirr Mhòir. Four members are recognised (Williamson & Bell, 1994), based upon locally developed sequences: the Ben Scaalan Member, the Biod Mòr Member, the Gleann Oraid Member and the Loch an Sgùirr Mhòir Member. An easily accessed sequence is exposed in the Carbost Burn, south of the Talisker Distillery at Carbost, below a thick, sheet-like mugearite lava (Figure 5-43).

Figure 5-43 – A thick mugearite lava of the Glean Oraid Formation overlying the sedimentary sequence of the Eynort Mudstone Formation in the Carbost Burn, SW of Carbost [NG 3734 3101].

The overlying Gleann Oraid and Loch Dubh formations interdigitate in the area around Beinn nan Dubh-lochan and Loch Dubh. The Gleann Oraid Formation consists of three members, Arnaval (oldest), Sleadale and Cnoc Scarall (youngest?), and is dominated by relatively evolved lavas, hawaiites, mugearites and benmoreites, which form prominent summits and ridges, for example, Na Huranan, SE of Arnaval (Figure 5-44). Interbedded with these lavas, many with well-developed flow structure/banding, are compound basalt lavas. A single benmoreite lava forms the two hills, Cnoc Dubh Heilla and Cnoc Glas Heilla, south of Portnalong. The base of the Gleann Oraid Formation is not planar, and the initial lavas of the sequence appear to have ponded in depressions on the palaeo-land surface.

Figure 5-44 – Hawaiite and mugearite lavas of the Arnaval Member of the Gleann Oraid Formation, forming the summit area of Arnaval (centre) and the Na Huranan crags (right) on the north side of Gleann Oraid [NG 3450 3170]. View towards the north.

The Sleadale Member is represented by two units, a distinctive red-brown, lateritised trachyte tuff, up to 3m thick, with remarkably fresh anorthoclase and biotite crystals, overlain by a thick, vesicular porphyritic trachyte lava ((Bell & Williamson, 2013). The tuff crops out only NW of Preshal Beg on the south side of Sleadale, (Figure 5-45) whereas the trachyte lava occurs both north of Preshal Beg and to the SE of Preshal More on the north side of Sleadale.

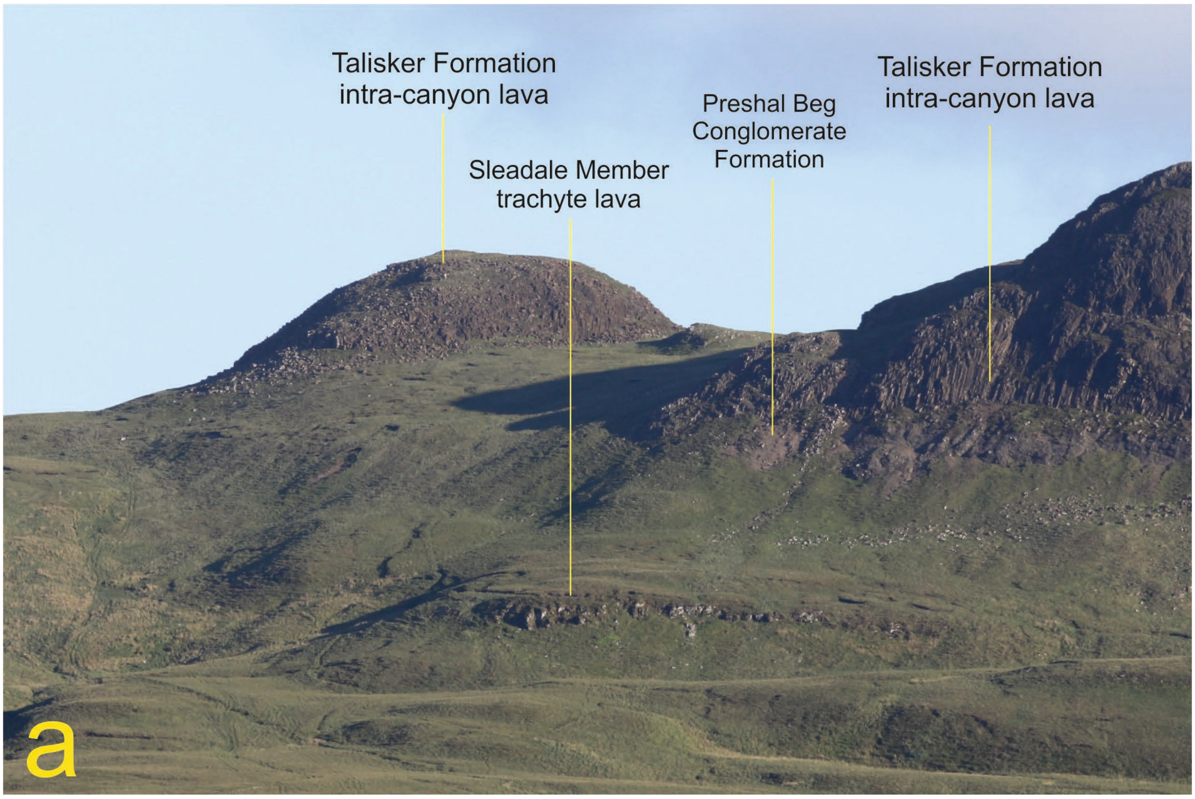


Figure 5-45 – (a) Sleadale Member (Gleann Oraid Formation) trachyte lava forming a distinct terrace on the north side of Preshal Beg, view towards the SE, and, (b) poorly exposed trachyte tuff of the Sleadale Member [NG 3255 2825], in the nameless stream NW of Preshal Beg, below a prismatic-jointed trachyte lava, in the distance, to the SE, is Preshal Beg.

The Cnoc Scarall Member is an isolated, ponded, compound lava, at least 100m thick, of porphyritic trachyte. It is located on the east side of Glen Eynort, forming the twin summits of Cnoc Scarall (Figure 5-11), and overlies both the Arnaval Member of the Gleann Oraid Formation and the Skridan Member of the Glen Caladale Formation.

The Loch Dubh Formation, interdigitated with the Gleann Oraid Formation, comprises interbedded plagioclase-micro-porphyritic basalt and hawaiite lavas, together with a plagioclase-macro-porphyritic hawaiite lava that forms the broch-capped hill, Dùn Ard an t-Sabhail (Figure 5-10).

A major hiatus in the volcanism occurred after the eruption of the main plateau-building sequence (Bell & Williamson, 2013). The next preserved unit, the Preshal Beg Conglomerate Formation, was deposited locally in a steep-sided valley, or canyon, drainage system, carved out of the pre-existing plateau lava landscape (Figure 5-46; Figure 5-47; Figure 5-48; Figure 5-49). It consists of various coarse-grained sedimentary units, poorly sorted and typically unstratified breccias and conglomerates, of debris flow and fluvial channel association, together with fluvial channel and overbank sandstones, siltstones and mudstones (Figure 5-25). All are volcaniclastic in character, essentially devoid of siliciclastic material. Outcrops are restricted to the flanks of the twin summits of Preshal More and Preshal Beg, SE of Talisker Bay, in particular the NE side of Preshal Beg. Unlike the conglomerates of the Minginish Conglomerate Formation, the cobbles and pebbles are of local derivation and are solely of lava field lithologies, mainly basalt, hawaiite and mugearite, together with their scoriaceous and amygdaloidal variants.

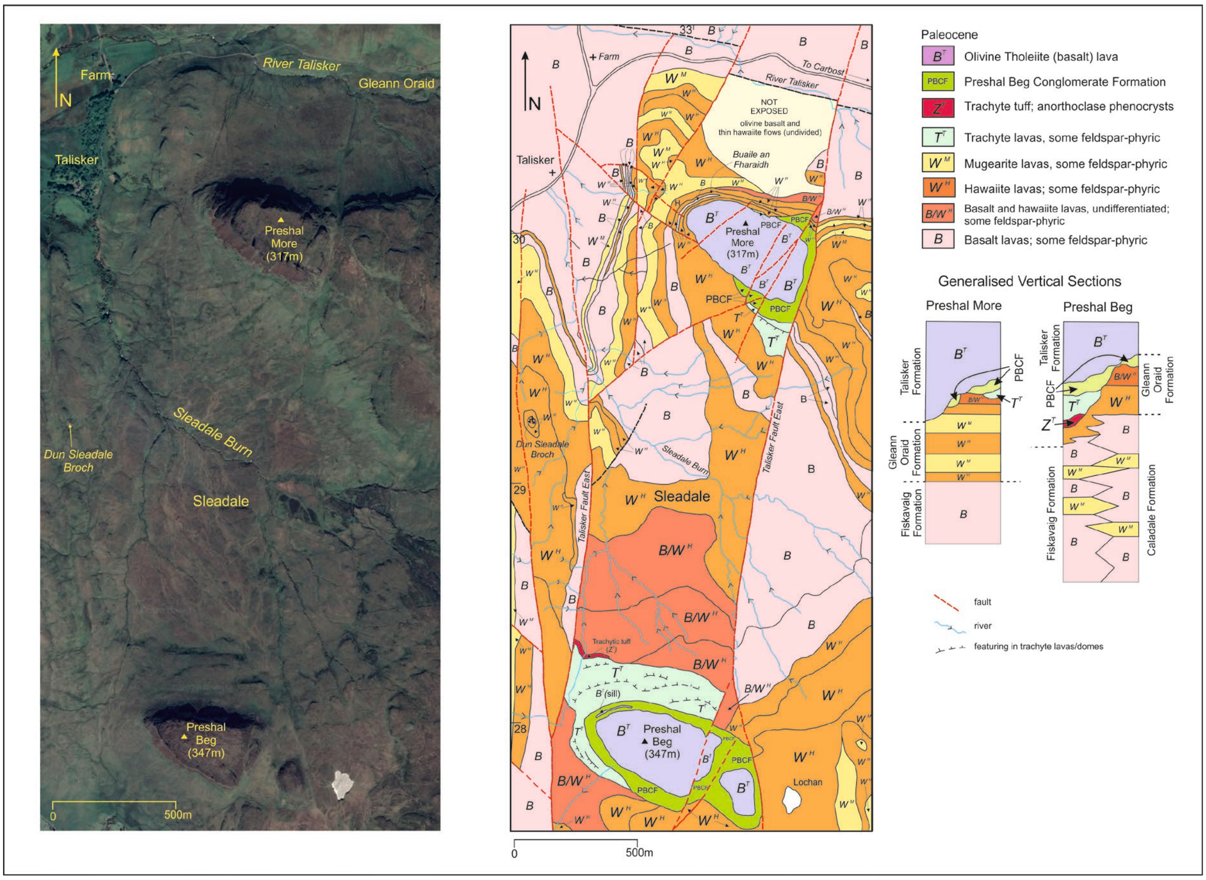


Figure 5-46 – Detailed geological map of the Preshal More – Preshal Beg area, Minginish (after Bell & Williamson 2013).

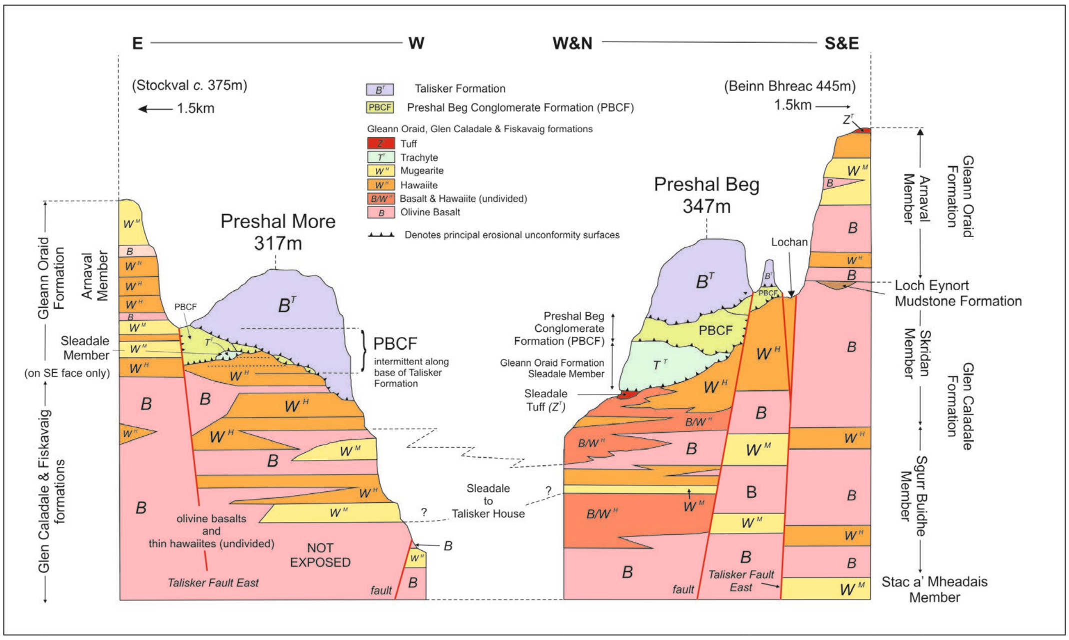


Figure 5-47 – Schematic geological cross-section of the Preshal More – Preshal Beg area illustrating general stratigraphic and structural relationships (after Bell & Williamson 2013).

The drainage system was then inundated by the intra-canyon tholeiitic basalt Talisker Lava, which has a thickness of at least 120m. The basal part of the lava has both pillowed and hyaloclastite facies (Figure 5-21), indicative of eruption into water. Differential weathering and erosion have led to a topography inversion, whereby the more resistant (to erosion) canyon-filling lava now forms the high ground and the relatively less resistant valley-wall lavas of the older plateau sequence form the present-day lower ground of Sleadale (Figure 5-8; Figure 5-49). The two main outcrops, forming the spectacular summits of Preshal More (Figure 5-8) and Preshal Beg (Figure 5-48), have significant colonnades defined by hexagonal-patterned columnar joints, above which are entablatures comprising less regular joint patterns. The transition between the two styles of joints is abrupt, with a thin intervening platy facies. On Preshal Beg, especially obvious on the south side of the hill, the entablature exhibits an intrusive/sheeted facies (Figure 5-49). The top of the lava is not preserved, although the flat summit area of Preshal Beg gives excellent access to the intrusive/sheeted facies of the lava, interpreted as being relatively close to the original top of the lava.

Figure 5-48 – South face of Preshal Beg, illustrating the main sub-units (Figure 5.49) of the intra-canyon Talisker Lava that forms the twin summits of Preshal More and Preshal Beg. View towards the north. 1: Basal (pillow) Facies; 2: Colonnade; 3: Platy Facies; 4: Entablature; 5: Entablature with intrusions.

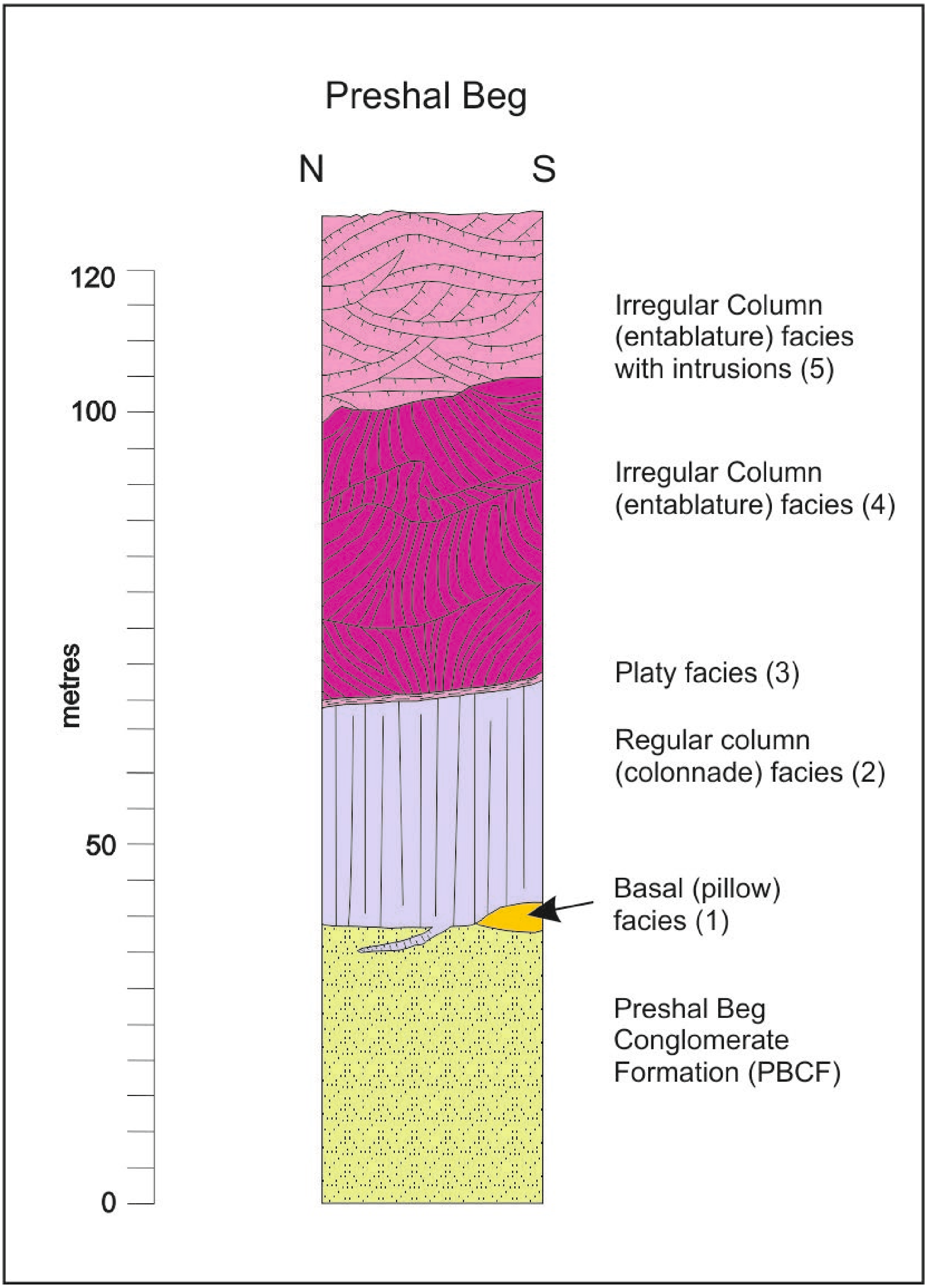


Figure 5-49 – Main sub-units of the intra-canyon Talisker Lava on Preshal Beg (see Figure 5.47).

The composition of the Talisker Lava is significantly different from the transitional to mildly alkaline basalt lavas that occur within the volumetrically dominant underlying sequence. It is of tholeiitic basalt composition, very similar to that of Mid Ocean Ridge Basalt (MORB) and, importantly, similar in composition to a significant proportion of the dykes of the Skye Main Dyke Swarm (Chapter 7) and the cone-sheets that intrude the various coarse-grained intrusions of the Cuillin Intrusive Centre (6.B.10). (Bell & Williamson, 2013) propose that the Talisker Lava was sourced from a Cuillin Volcano (Chapter 6), the superstructure of which has been removed by erosion since the end of the volcanism (Figure 5-50). The original extent of the lava is unknown, although the location of Preshal More and Preshal Beg *c.* 15km distant from the Cuillin Intrusive Centre indicates a minimum drainage path length, and which is considered to be very conservative, given that the nearby coastline is fringed with cliffs composed of the older plateau lava sequence.

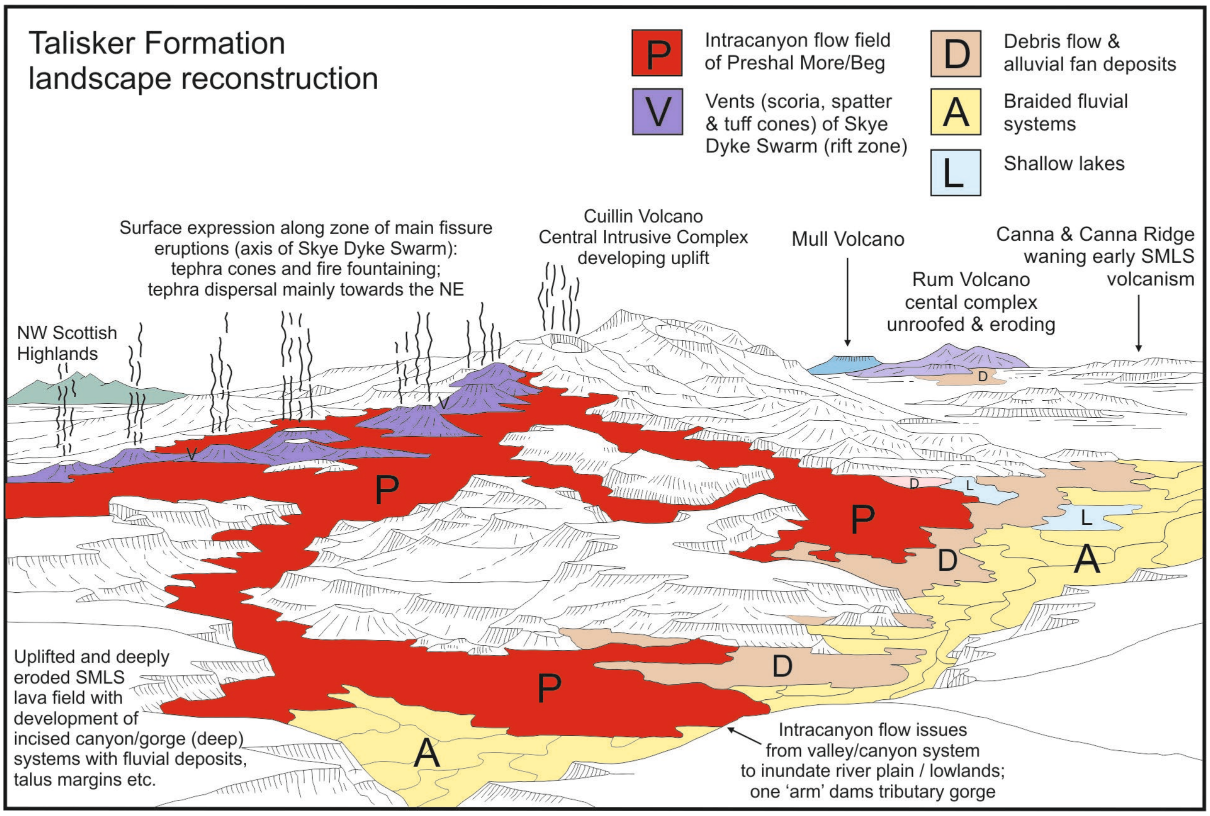


Figure 5-50 – Schematic Talisker Formation intra-canyon lava landscape reconstruction (after (Bell & Williamson, 2013)).

Correlations between the various subdivisions of the lava sequence on Minginish, outlined above, and the sequences north of Loch Harport and north of the Cuillin Hills have not been established, mainly due to poor exposure (Figure 5-35). The sequence north of Loch Harport has tentatively been assigned to two members, the Harport and Meadale members, of the Roineval Formation (BGS, 2000), characterised by interbedded compound basaltic lavas and sheet-like hawaiite lavas, together with laterally restricted (ponded?) plagioclase-porphyritic and near-aphyric mugearite lavas (Figure 5-51). The Roineval Formation is most likely separated from the Coire na Circe Formation (with four members: Allt Dearg (oldest), Sròn a' Ghrobain, Coire Daraich and Am Màm (youngest)), north of the Cuillin Hills, by a major fault zone in Glen Drynoch. Similarly, the Sligachan Formation, north of Loch Sligachan, is dominated by interbedded compound basaltic lavas and sheet-like hawaiite lavas, with an older Cnoc an t-Sìthein Member and a younger Meall Odhar Member, both poorly constrained.

Figure 5-51 – Roineval Formation plagioclase macro-porphyritic basaltic lava forming the plateau of Roineval, NE of the head of Loch Harport [NG NG 4180 3500]. View towards the north from the south side of Loch Harport.

The Fionn Choire Formation crops out in the Fionn Choire – Meall Odhar area on the NW side of the Cuillin Hills, accessed from the Bealach a' Mhàim, and comprises a complex sequence of fragmental deposits, both pyroclastic and volcaniclastic, together with amygdaloidal basalt, hawaiite and mugearite lavas. The compositionally evolved nature of much of the sequence has produced a distinctive landscape, significantly devoid of vegetation because of the nutrient-poor nature of these rocks (Figure 5-52). Although, superficially, the level of exposure looks good, much of it comprises frost-shattered scree and is not *in situ.* Exposure tends to be slightly better where the sequence is cut by dolerite and basalt minor intrusions, for example in the Allt Mòr an Fhinn Choire (Figure 5-53), some associated with the Cuillin Intrusive Centre to the south (Chapter 6) and some members of the NW-SE -trending Syke Main Dyke Swarm (Chapter 7). The interbedded basalt, hawaiite and mugearite lavas are not well exposed and their field relationships are difficult to determine.

Figure 5-52 – Distinctive vegetation-poor nature of the Allt Mòr an Fhinn Choire area in Fionn Choire, comprising silicic pyroclastic and volcaniclastic lithologies of the Fionn Choire Formation. View towards the south.

Figure 5-53 – Minor basaltic intrusions within silicic volcanic lithologies in the Allt Mòr an Fhinn Choire, Fionn Choire [NG 4519 2680]. View towards the west.

A variety of clastic lithologies are recognised, all hydrothermally altered with abundant secondary hydrous minerals such as epidote and chlorite, due to their proximity to the Cuillin Intrusive Centre (to the south) (6.D), including stratified lithic lapilli-tuffs (Figure 5-54), crystal-rich lapilli-tuffs (Figure 5-55), and relatively coarse unstratified (matrix-supported and clast-supported) breccias (Figure 5-56). Clasts within these deposits are of a variety of Paleocene lithologies, including basalt, hawaiite, mugearite and granite, together with sandstone, which may have been derived from the Late Proterozoic Torridonian Supergroup (3.C). The dominant crystals within the crystal-rich lapilli-tuffs are plagioclases, ranging between euhedral forms and angular fragments, some well over 1cm across. Matrix material to the lapilli-tuffs is very fine-grained and very altered, comprising original ash, together with silt and sand grade granular material. Also present, and potentially constituting a large part of the Fionn Choire Formation, are pale-weathering, distinctly banded units, commonly with abundant folds, that have been variously interpreted as rhyolite lavas (Harker, 1904), trachyte lavas (Thompson, 1967), and rhyolitic ignimbrites and trachytic-rhyolitic lava-like ignimbrites (Drake, 2014) (Figure 5-57).

Figure 5-54 – A stratified sequence of relatively crystal-rich lapilli-tuff, laminated lapilli-tuff (with local cross stratification) and more massive lapilli-tuff, Fionn Choire Formation, NW of Meall Odhar in the NE part of Fionn Choire [NG 4608 2685]. Pole *c.* 1m long.

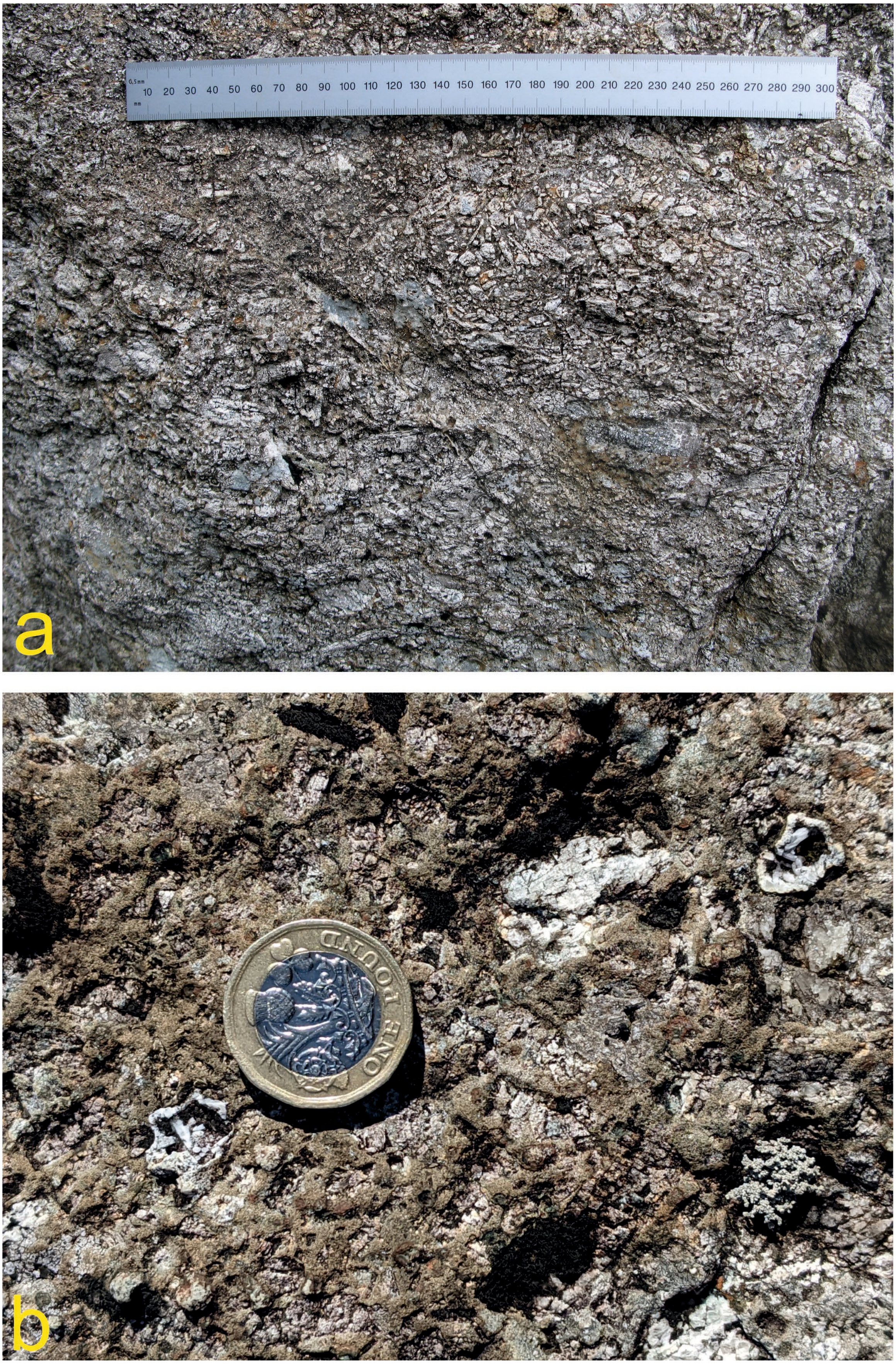


Figure 5-55 – (a) Crystal-rich tuff with pale plagioclase crystals in the Fionn Choire Formation, Fionn Choire, ruler 30cm long; and, (b) detail of crystal-rich tuff in the Fionn Choire Formation, Fionn Choire, coin *c.* 24mm across.

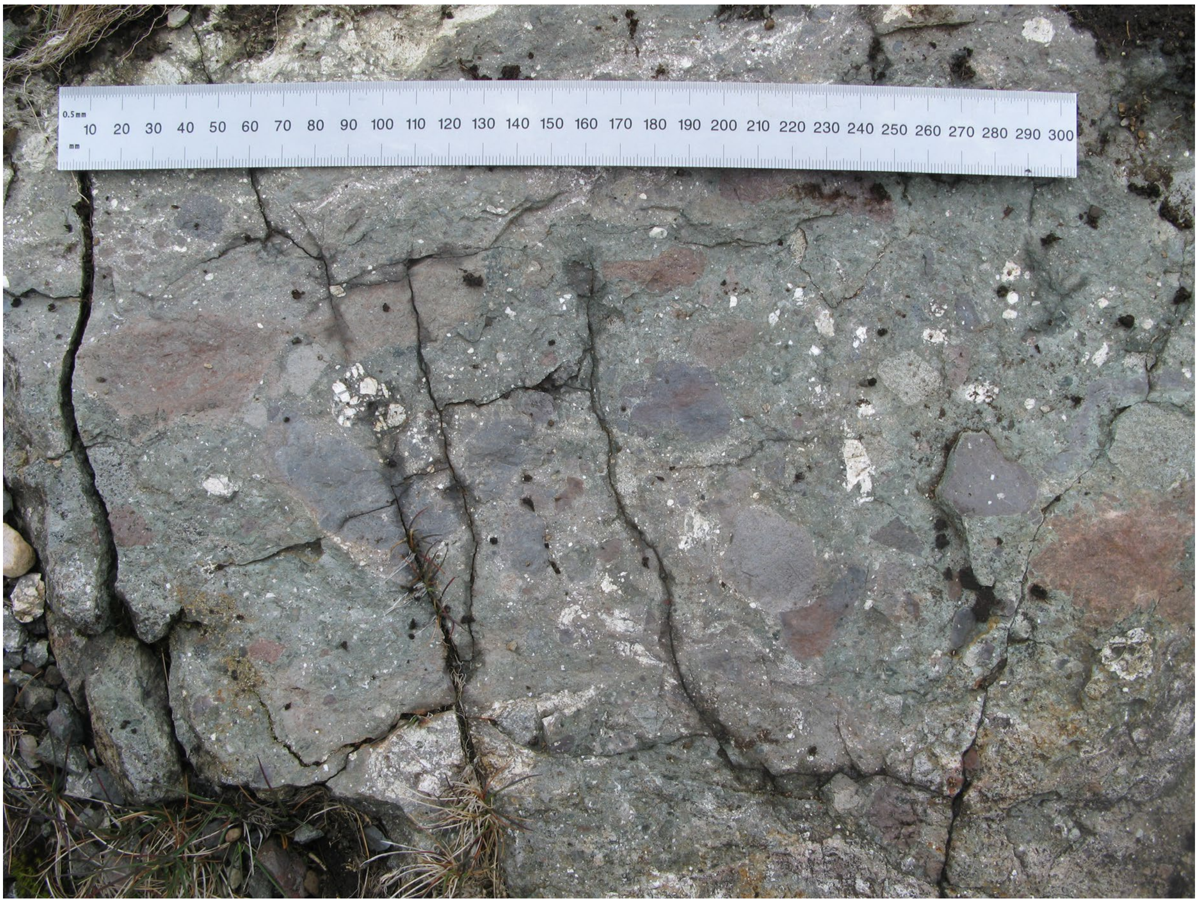


Figure 5-56 – Unstratified, polylithic breccia, with conspicuous angular to sub-angular fragments of lava lithologies, of the Fionn Choire Formation, Fionn Choire. Ruler 30cm long.

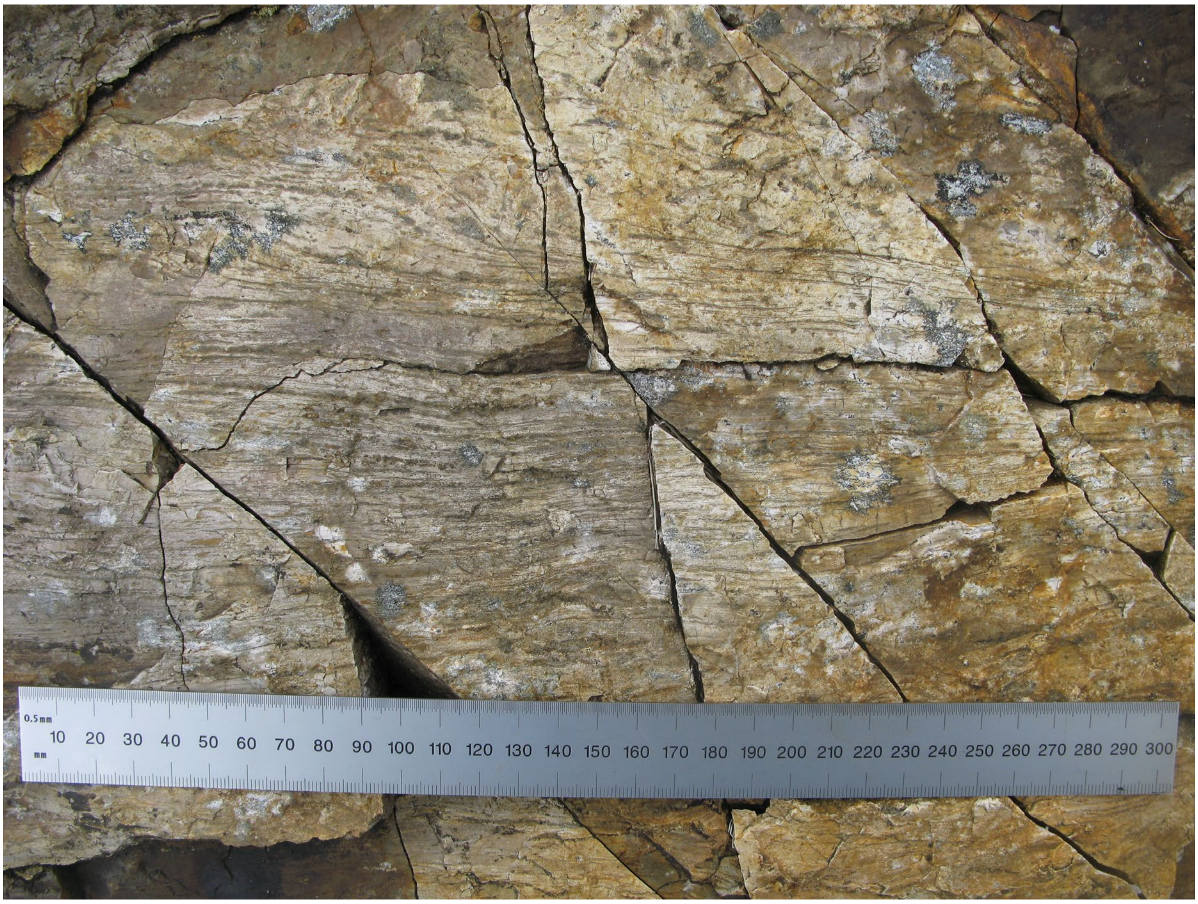


Figure 5-57 – Trachytic lava-like ignimbrite of the Fionn Choire Formation, with minor folds within its well-developed fabric [NG 4543 2665]. Ruler 30cm long.

Other relatively minor disparate outcrops of the lava field occur within central Skye: on Strathaird outliers form the summits of Ben Cleat and Ben Meabost, and from Ben Leacach north to Slat Bheinn, An Càrnach and An Stac; on Belig, NW of the head of Loch Slapin; on the south side of Sgùrr na Stri; at Creagan Dubh in the district of Strath; on the SW side of Creag Strollamus, west of Broadford; north of the summit of Beinn na Crò in the district of Strath; east of the Allt Stapaig in south Scalpay; and, on the summit ridge of Glamaig in the Western Red Hills.

Only the sequence on Strathaird has been examined in detail ((Almond, 1960); (Almond, 1964)). Here, a *c.* 300m thick sequence of lavas crops out over an area of *c.* 18km^2, overlying Jurassic and ?Cretaceous sedimentary rocks with a small amount of angular discordance. Both the Mesozoic strata and the Paleocene volcanic rocks have been flexed during the emplacement of the Cuillin Intrusive Complex, most obviously on An Stac, east of Blà-bheinn (Blaven) (Figure 5-58). (Almond, 1964) identified four units, as set out in Figure 5-59.

Figure 5-58 – Inclined basaltic lavas overlying poorly exposed Mesozoic strata forming An Stac. In the background, the lower slope of Blà-bheinn is composed of younger gabbros of the Cuillin Intrusive Centre. View towards the west from the head of Loch Slapin.

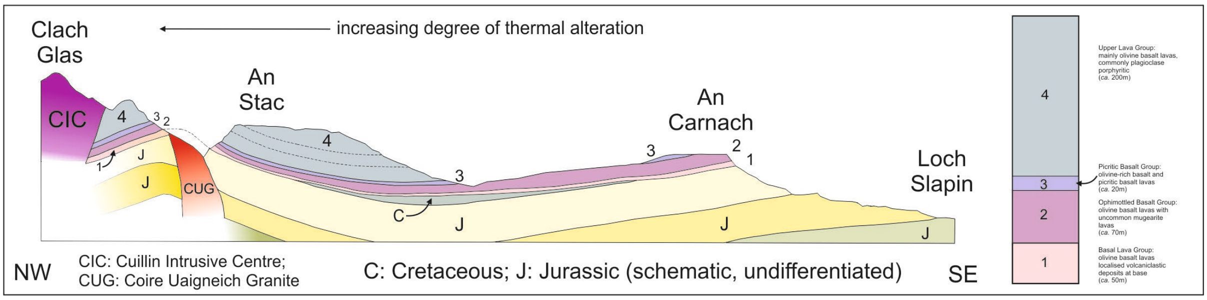


Figure 5-59 – Lava stratigraphy on Strathaird (after Almond 1964).

At the base of the sequence, at the northern end of the east-facing ridge of An Càrnach, Almond (1960) briefly describes fragmental rocks that are interpreted as being of pyroclastic origin, although possibly having undergone some form of sedimentary reworking. These rocks have subsequently been interpreted as silicic pyroclastic rocks (Drake & Beard, 2012), and subsequently (re)interpreted by the same authors (Drake, et al., 2017) as being an ejecta layer associated with some sort of meteorite impact that pre-dated the eruption of the lava field.

The close proximity of the lavas on Strathaird and south of Sgùrr na Stri (Figure 5-60) to the Cuillin Intrusive Centre has led to changes in the characteristics of the lavas, the replacement of brown weathered surfaces and red palaeosols by grey surfaces and reddish-brown palaeosols, respectively, and joints (including columnar joints) being sealed with hydrothermal minerals such as epidote, chlorite, various zeolites and carbonates. Secondary minerals have replaced primary (magmatic) minerals. (Almond, 1964) identified three zones of alteration/metamorphism within this thermal aureole of the intrusive complex and the development of new, non-magmatic features, as detailed in Section 6.D.

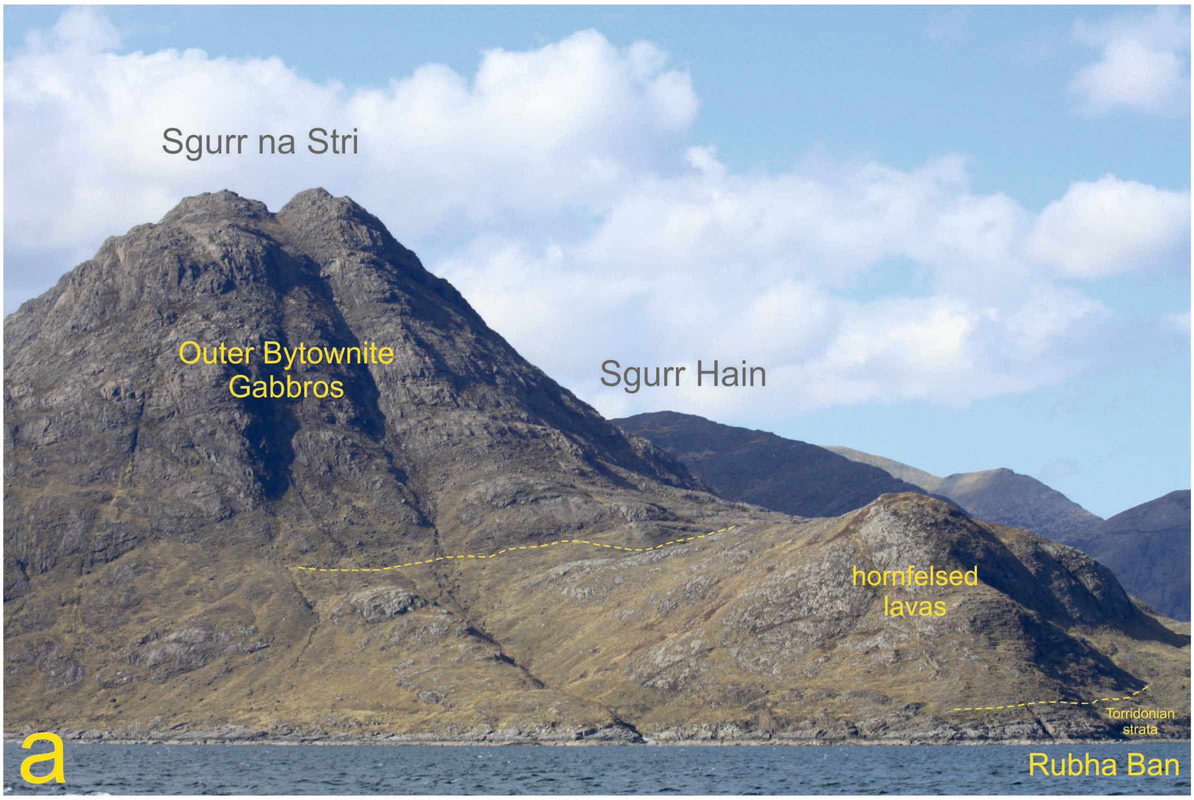


Figure 5-60 – (a) Hornfelsed basaltic lavas unconformably overlying Torridonian Supergroup strata, forming the low-lying southern part of the Sgùrr na Stri peninsula, view towards the north; and, (b) annotated oblique Google Earth© image of the Sgùrr na Stri peninsula.

Similar hydrothermally altered lavas crop out NW of the head of Loch Slapin on Belig, dipping at 30-40° towards the west, with obvious step or trap topography preserved (Figure 5-61). Where adjacent to the younger intrusions of the Cuillin Intrusive Centre and the granite that crops out south of Belig (Chapter 6), the rocks are intensely altered and recrystallized.

Figure 5-61 – Trap or step topography of basaltic lavas on Belig, NW of the head of Loch Slapin, dipping towards the west. View towards the NW.

At Creagan Dubh in the district of Strath, basaltic lavas unconformably overlie rocks of the Lewisian Gneiss Complex (Figure 5-62). The unconformity has some topographic relief. Similar to the lavas adjacent to the Cuillin Intrusive Centre on Strathaird and on Belig, they are intensely hydrothermally altered and the stratified character of the sequence is less obvious that in the main sequences in north and west-central Skye. Towards the top of the preserved sequence are laterally-discontinuous cobble and pebble conglomerates and volcaniclastic deposits. Of similar character, north of the summit of Beinn na Crò in the Eastern Red Hills, are relatively poorly-exposed hydrothermally-altered, hornfelsed lavas, intruded by gabbros and granites.

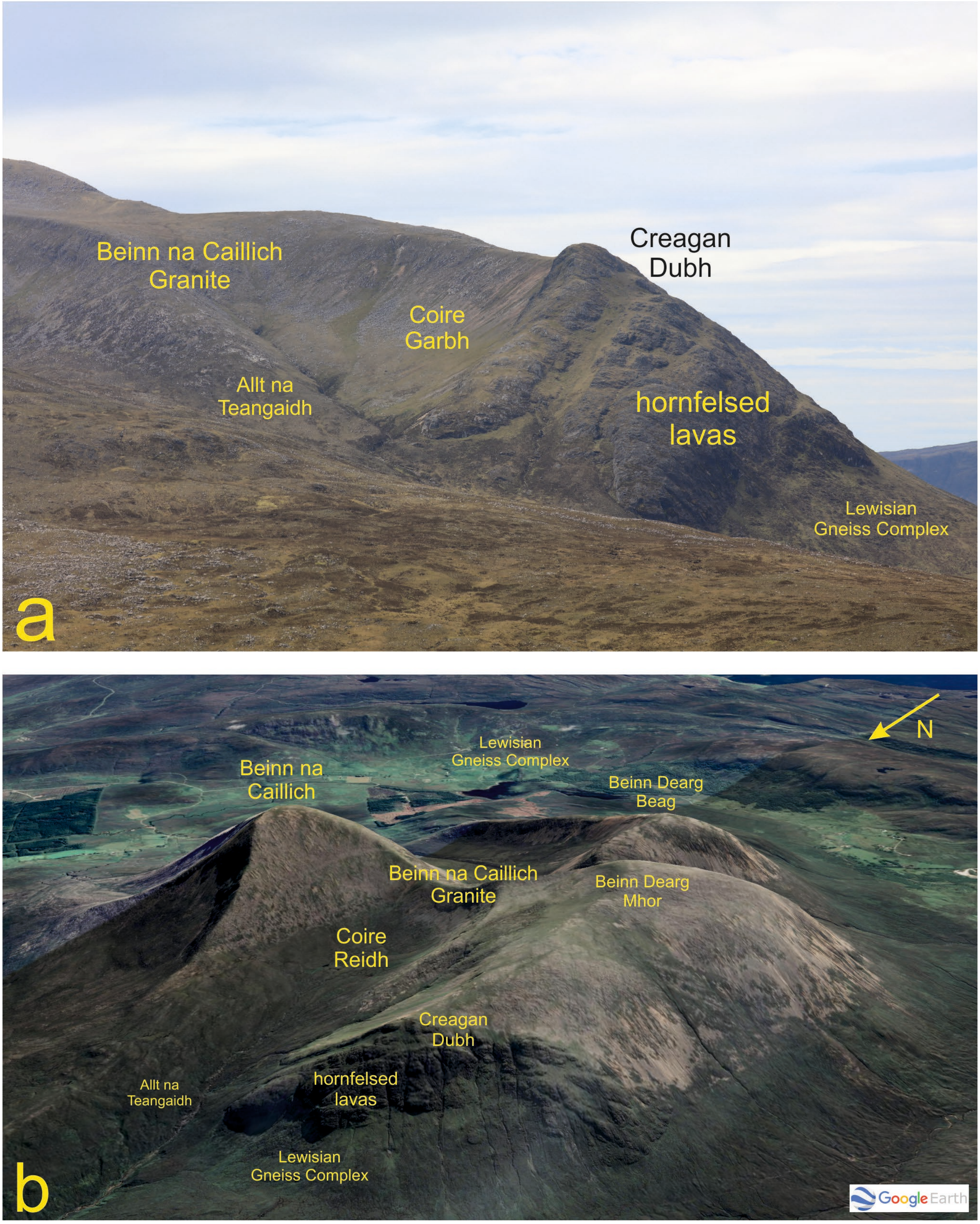


Figure 5-62 – (a) Hornfelsed basaltic lavas of Cregan Dubh overlying the (basement) Lewisian Gneiss Complex, view towards the south from Creag Strollamus; and, (b) annotated oblique Google Earth© image of the area centred on Creagan Dubh.

The lavas preserved in the vicinity of Creag Strollamus, west of Broadford, are moderately hydrothermally altered and lie unconformably upon either Torridonian strata, or, rarely, Cambro-Ordovician dolostones (King, 1953a). Amygdaloidal texture is relatively common, but the overall structure and orientation of the lavas are not clear. Interbedded pebble and cobble breccias and conglomerates crop out north of Loch Cùil na Creige, west of Creag Strollamus (Figure 5-63). The lavas on the south side of Scalpay, directly across Caolas Scalpay from Creag Strollamus, overlie Mesozoic strata and their stratified character is more obvious, with identifiable units dipping towards the SE (Figure 5-64).

Figure 5-63 – Matrix-supported pebble and cobble breccia/conglomerate interbedded with amygdaloidal basaltic lavas north of Loch Cùil na Creige, west of Creag Strollamus, with abundant clasts of orange-weathering Torridonian sandstone and white Cambrian quartzite (sandstone) [NG 6030 2600]. Pole *c.* 1m long.

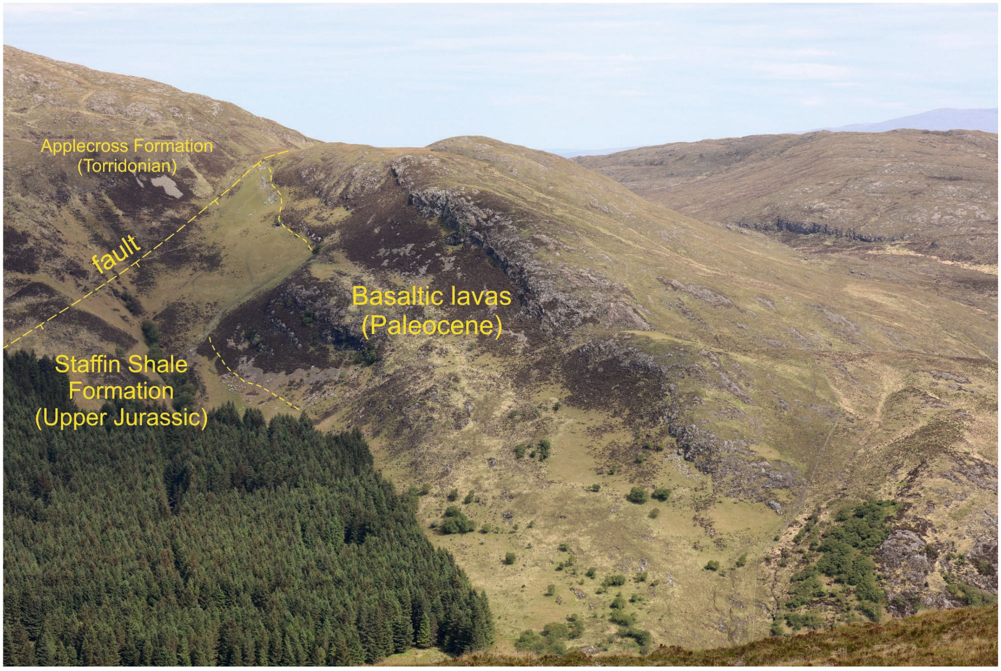


Figure 5-64 – Trap topography of dipping (towards the SE) basaltic lavas on the east side of the Allt Stapaig on Scalpay. View towards the NE from west of Creag Strollamus on Skye.

Much of the twin summits of Glamaig – Sgùrr Mhairi and An Coileach – south of Loch Sligachan in the Western Red Hills, are composed of similarly altered lavas, below which are younger granites of the Western Red Hills Intrusive Centre that are responsible for their general lack of primary features, as seen north of Loch Sligachan and over much of the ground to the north (Figure 5-65).

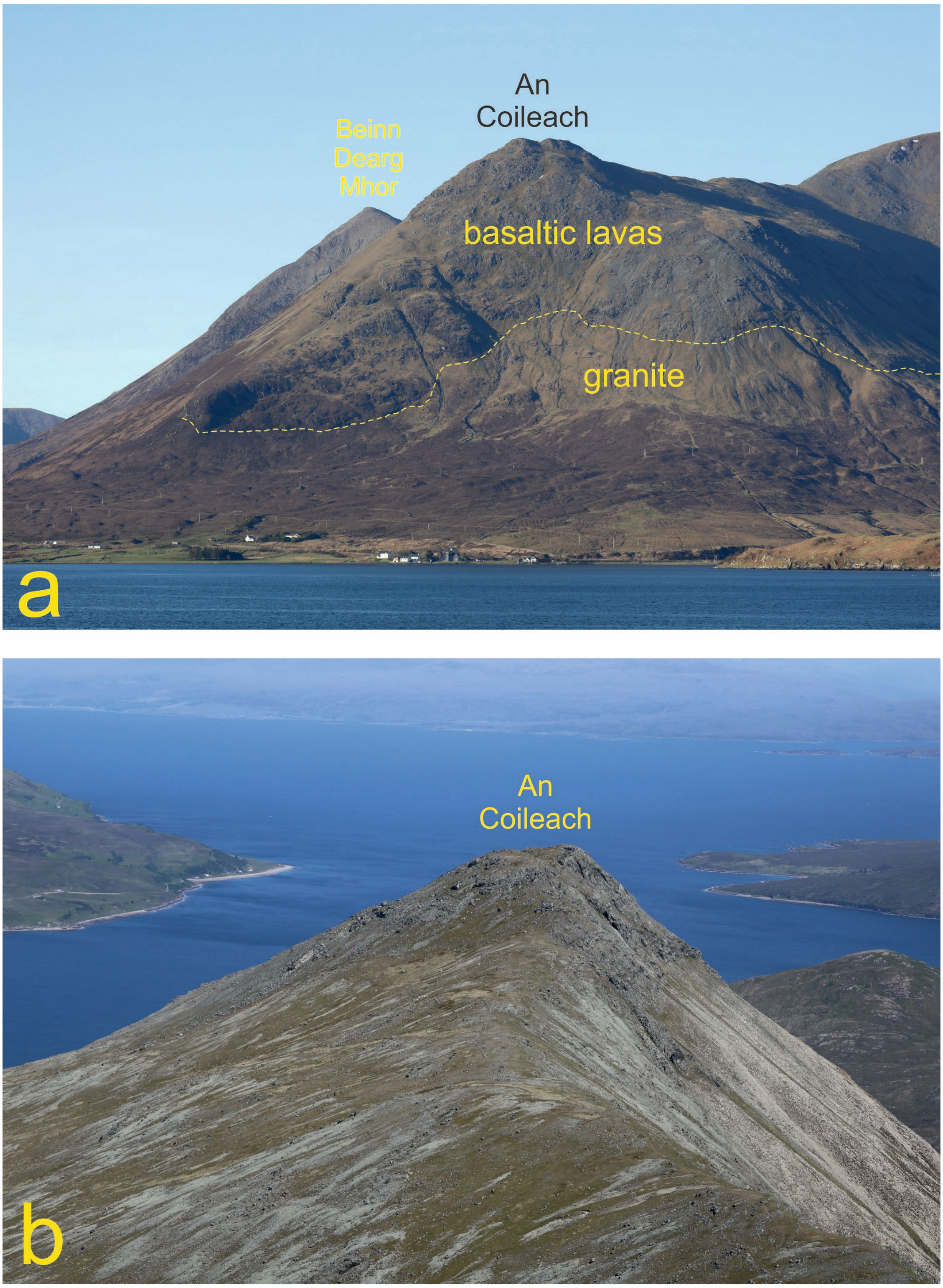


Figure 5-65 – Hornfelsed basaltic lavas forming an inclined cap to younger pale-weathering granites of the Western Red Hills Intrusive Centre on the An Coileach ridge of Glamaig, SE of Loch Sligachan: (a) view towards SW from Raasay House, Raasay; and, (b) from the summit of Sgùrr Mhairi (Glamaig) towards An Coileach.

On Raasay, a small outlier of the Skye Lava Field forms the conspicuous summit of Dùn Caan (Figure 5-66), consisting of at least two distinct lavas, the uppermost of which, forming the top crag, is distinctly (flow) banded. Below these lavas, most easily identified from loose scattered fragments on the path leading to the summit, is an interval of distinctly green glauconitic sandstone, the Cenomanian (Upper Cretaceous) Morvern Greensand Formation (4.D).

Figure 5-66 – Basaltic lavas forming the summit of Dùn Caan on Raasay. View towards the east across Loch na Meilich.

5.E The Srath na Crèitheach, Kilchrist and Belig Deposits

Pyroclastic and associated (volcani)clastic rocks occur throughout central Skye, in close spatial association with the central complex, and range from material that is unequivocally intrusive, to deposits that were clearly laid down under subaerial and subaqueous conditions. Historically, the term *agglomerate* has been used to embrace a significant proportion of these rocks (Harker, 1904), but, in line with present-day terminological usage, is essentially redundant, as a high proportion of the larger fragments in these rocks are non-magmatic in origin, hence the preferred usage of the non-genetic term *breccia*.

Three significant outcrops of fragmental rocks occur in central Skye, intimately associated with intrusions of the Cuillin Intrusive Centre and the Red Hills granites (Chapter 6): (i) Srath na Crèitheach; (ii) Kilchrist; and, (iii) north of Belig. The outcrop in Srath na Crèitheach comprises interbedded coarse-grained and fine-grained fragmental deposits in close association with large masses of gabbro (Jassim & Gass, 1970). The Kilchrist outcrop occupies the ground south of Beinn Dearg Bheag in the district of Strath, between Cnoc nam Fitheach and Creagan Fitheach. Here, the dominant materials are poorly- to unstratified, coarse-grained fragmental rocks with a diverse lithological range of angular to sub-rounded blocks, including various Mesozoic and older lithologies, various types of basalt and dolerite of presumed Paleocene age, together with crystal-rich and crystal-poor silicic ignimbrites, and thin, bedded silicic tuffs (Bell, 1985). The relationships of these rocks are obscured in part by a suite of younger hybrid intrusions, the so-called Kilchrist Hybrids (6.G.1), and a large granite intrusion, the Beinn na Caillich Granite, to the north (6.G.6). The outcrop north of Belig, forming the higher part of Coire Choinnich, is intruded by granite and the Marscoite Suite Ring-dyke of the Western Red Hills Intrusive Centre (6.F). It comprises unstratified, sub-angular to rounded blocks of various lithologies, including gabbro and dolerite, similar to that of the nearby intrusions of the Cuillin Intrusive Centre, Torridonian and Mesozoic sedimentary rocks and amygdaloidal basalt, similar to the country-rocks into which the intrusive centre was emplaced, and granite and various quartz and feldspar porphyritic silicic igneous lithologies that do not match any nearby outcrops (Bell, 1966).

The shapes of both the Srath na Crèitheach and Kilchrist outcrops are very strongly influenced by the distribution of adjacent younger intrusions and, consequently, caution needs to be exercised when considering the origin of these rocks. In addition, younger ring faults may have (significantly) controlled the outcrop pattern. At Srath na Crèitheach, the granites to the north are younger, whereas the gabbros to the west, south and east are older. At Kilchrist, the Kilchrist Hybrids to the west and east are younger, as is the granite to the north. However, the contact between the fragmental rocks and the Cambro-Ordovician Durness Group dolostones between Coire Beithe and Buaile nan Aodan, although poorly exposed, appears to take the form of an unconformity.

Srath na Crèitheach: The deposits that crop out at the northern end of Loch na Crèitheach, in Srath na Crèitheach, occupy an area of *c.* 2km^2 and have an estimated vertical extent of at least 200m and a 'stratigraphic' thickness of around 450m (Jassim & Gass, 1970) (Figure 5-67). These rocks were originally described by (Harker, 1904), who concluded that they represent a lens of agglomerate caught up in the gabbros of the Cuillin Intrusive Centre. In contrast, (Jassim, 1970) and (Jassim & Gass, 1970) suggest that this mass of fragmental material represents some form of vent infill that was deposited under subaerial and subaqueous conditions. At least twelve large 'slabs' of gabbro related to, or derived from in some way, the nearby Cuillin Intrusive Centre, are spatially associated with these clastic rocks. The descriptions presented below are largely taken from the studies of (Jassim, 1970) and (Jassim & Gass, 1970) (Figure 5-67).

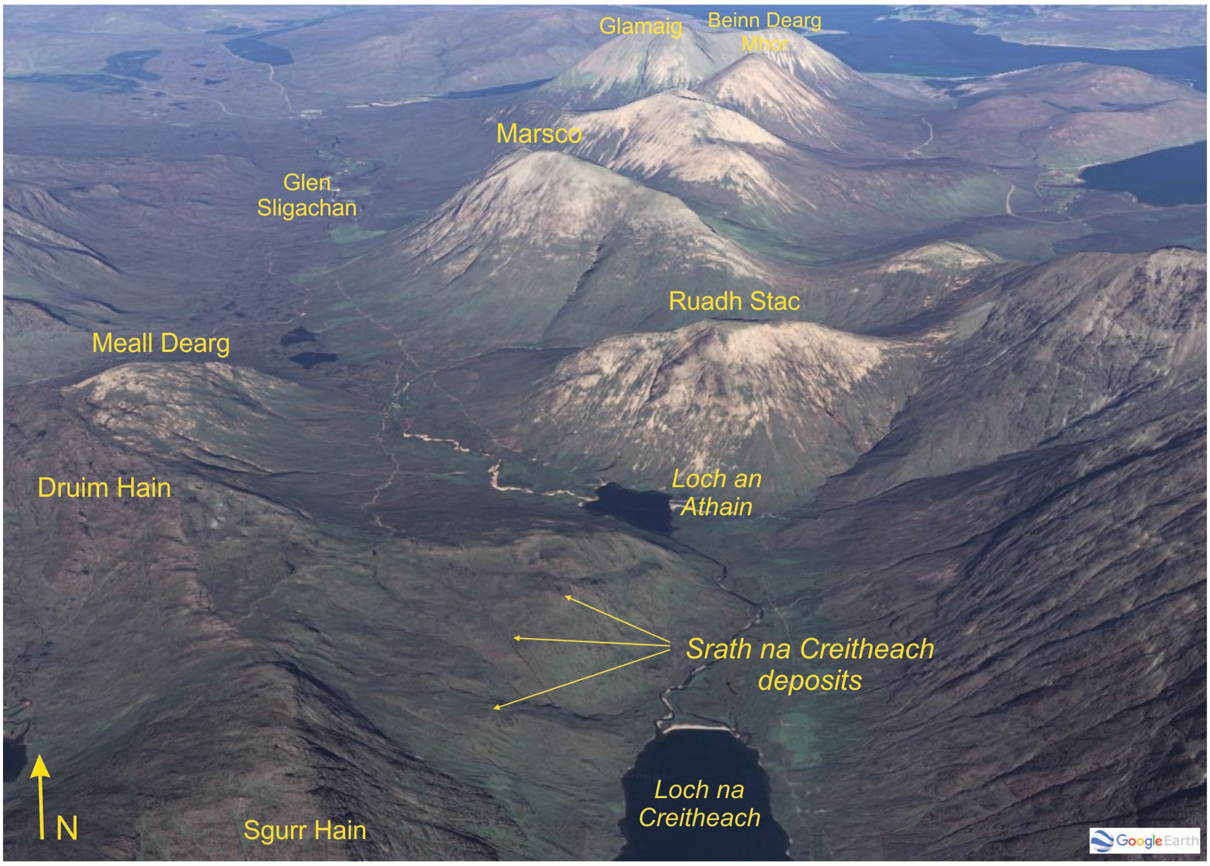


Figure 5-67 – Oblique Google Earth© image of Srath na Crèitheach area.

Along their western and southern margins, the Srath na Crèitheach fragmental rocks are in contact with layered gabbros of the Cuillin Intrusive Centre. This boundary has been identified as a steeply-inclined, arcuate ring-fault, in part because of the cross-cutting termination of the layering of the gabbros. The northern and eastern margins are against granites of the younger Srath na Crèitheach Intrusive Centre (Figure 5-68 and Figure 5-69).

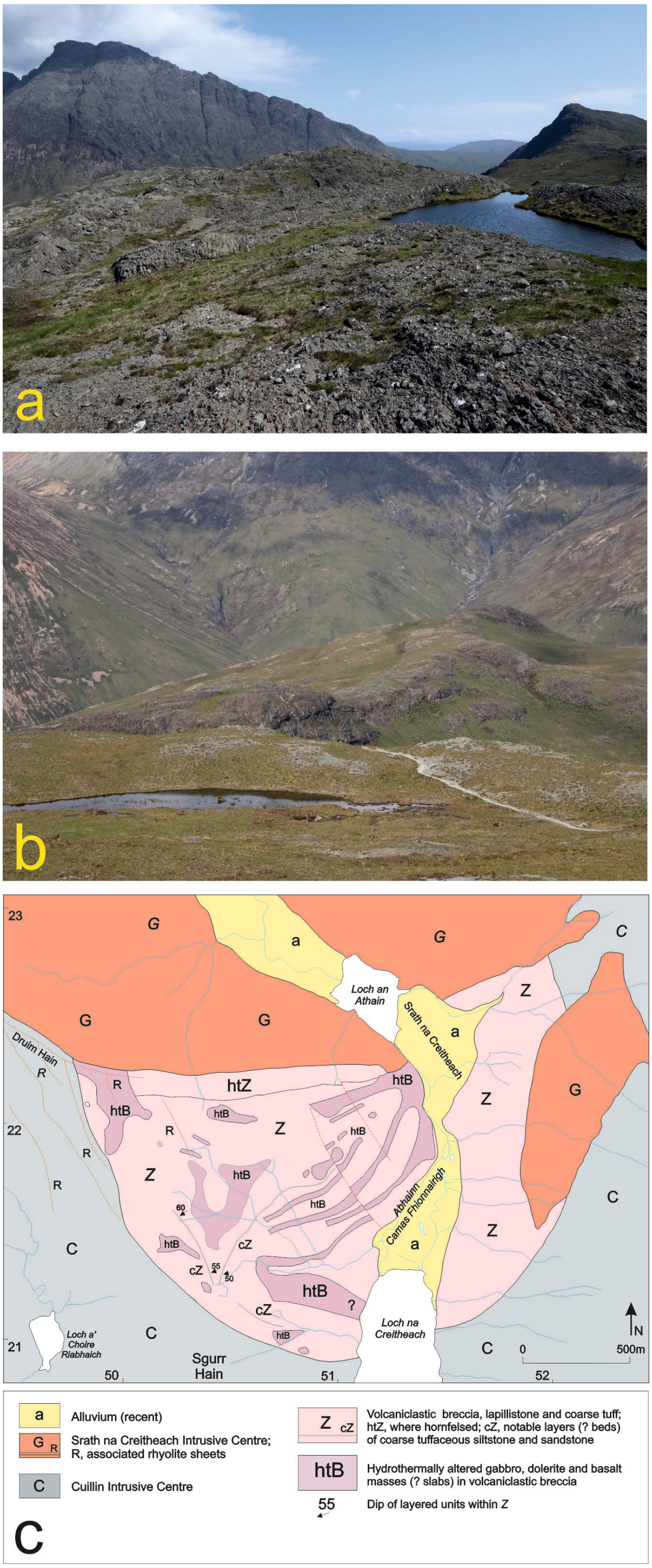


Figure 5-68 – Field views of the Srath na Crèitheach area: (a) the western end of outcrop, viewed east towards Blà-bheinn; and, (b) the eastern end of outcrop, viewed east towards Srath na Crèitheach; and, (c) simplified geological map of the Srath na Crèitheach area (after Jassim & Gass 1970).

Figure 5-69 – Typical coarse volcaniclastic breccia from the Srath na Crèitheach area, SE of Meall Dearg. Coin *c.* 24mm across.

The dominant breccia comprises uncommon sub-angular to sub-rounded metre-sized blocks and common sub-angular decimetre- to cm-sized fragments of various basic igneous rocks, basalt, dolerite and gabbro, set in a dark, chlorite-rich matrix of mm-sized comminuted material of similar type (Figure 5-70). Blocks of peridotite are also present, but are much less common, as are angular to sub-angular blocks of stratified volcaniclastic sandstone or tuff and plagioclase-porphyritic trachyte. Apparently laterally-continuous inclined beds, up to 10m thick, of mm-scale, stratified volcaniclastic sandstone and siltstone, or tuff, are also present and are composed of approximately equal proportions of crystals of plagioclase and rock fragments.

Figure 5-70 – Typical coarse volcaniclastic breccia from the Srath na Crèitheach area, SE of Meall Dearg. Coin *c.* 24mm across.

Within the same outcrop are several large gabbro (*s.l.*) 'slabs', ranging in length between 40m and 900m, which tend to stand proud of the surrounding breccia, and with typically sharp contacts. Strictly, most of the slabs are olivine-bytownite gabbros with megacrysts of calcic plagioclase (*c.* An_{85}) and, petrographically, are very similar to the Outer Bytownite Gabbros of the Cuillin Intrusive Centre (6.B.5) that crop out to the south and east. Layering is identified in one slab and is discordant to the margin of the slab. Brecciation and fragmentation of the slabs are common.

(Jassim & Gass, 1970) have outlined the events that they consider best explain the nature and distribution of the Srath na Crèitheach deposits. First, a large volcanic vent developed that broke through to the Earth's surface, disrupting the basic layered rocks of the Cuillin Intrusive Centre and the overlying lavas of the main plateau sequence. Subsequently, a caldera formed, and further explosive activity gave rise to subaerial and shallow subaqueous deposits of tuff, lapilli-tuff and agglomerate (their term) within this volcanic depression. Collapse of gabbro slabs and fragments of basaltic lava from the vent walls caused their entrapment within the sequence. Surface reworking of the tuffs then occurred. (Jassim & Gass, 1970) estimate that subsidence of the material by as much as 750-1000m subsequently took place along marginal ring-faults. Granites of the Srath na Crèitheach Intrusive Centre (6.E) were then emplaced.

An alternative scenario, suggested here, is that the various coarse-grained unsorted fragmental rocks, described above, are of epiclastic origin, essentially sedimentary breccias, formed by weathering and erosion of various volcanic basaltic lithologies, with localised low-energy subaqueous sedimentation of volcanic debris in shallow bodies of water, most likely ephemeral lakes, to produce the stratified volcaniclastic sandstones and siltstones. The mechanism by which the gabbro slabs were incorporated into these deposits is, however, not easily explained. It is possible that some type of vent-forming phase transported fragments of these rock-types to the surface, where they were subsequently incorporated into subaerial deposits by gravitational slumping on an irregular topography.

Kilchrist: The Kilchrist outcrop is dominated by polylithic breccias and comprise a heterogeneous assemblage of lithologies covering an area of *c.* 2km^2, in places relatively poorly exposed, with a stratigraphic thickness of at least 300m (Figure 5-71). Access is better in the Spring, Autumn and Winter due to the aggressive and rampant vegetation growth in the Summer. An unambiguous base to the sequence is not exposed, although is tentatively identified as the inferred boundary with the Cambro-Ordovician Durness Group dolostones (3.E) between Coire Beithe and Buaile nan Aodan, SE of Beinn na Caillich. Five main lithologies are recognised: (i) polylithic breccia; (ii) basaltic tuff; (iii) silicic tuff; (iv) ignimbrite; and, (v) masses of brecciated rhyolite (Figure 5-72 and Figure 5-73).

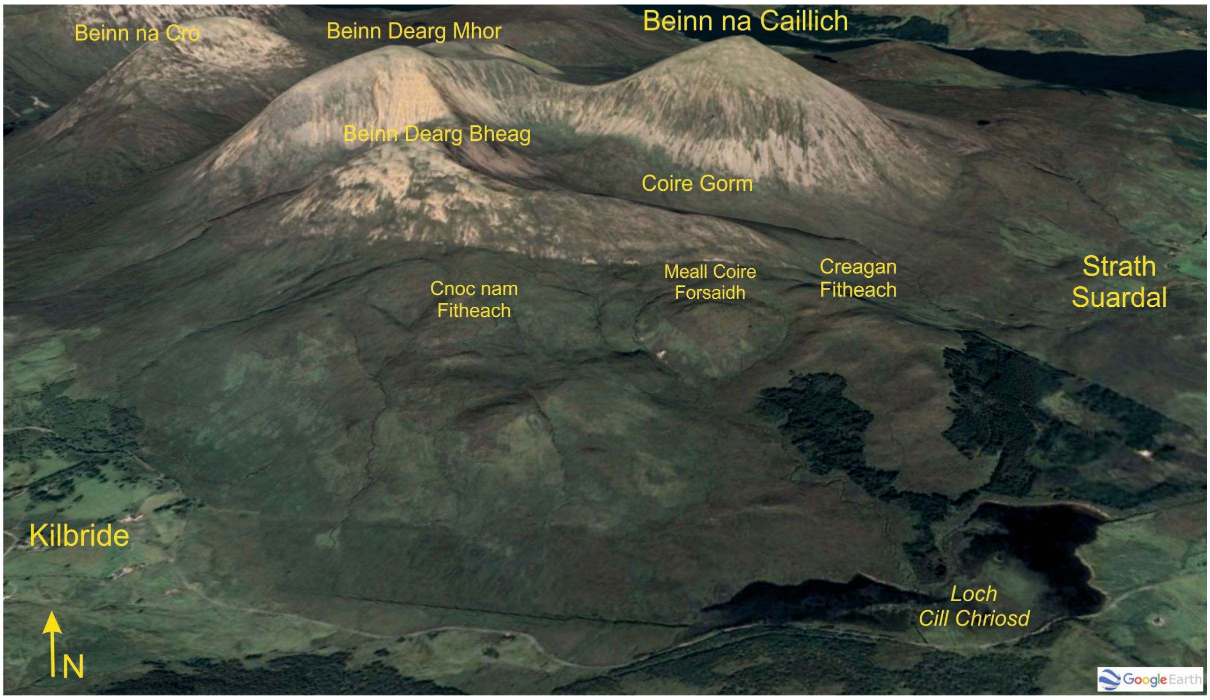


Figure 5-71 – Oblique Google Earth© image of Kilchrist area. View is towards the NW.

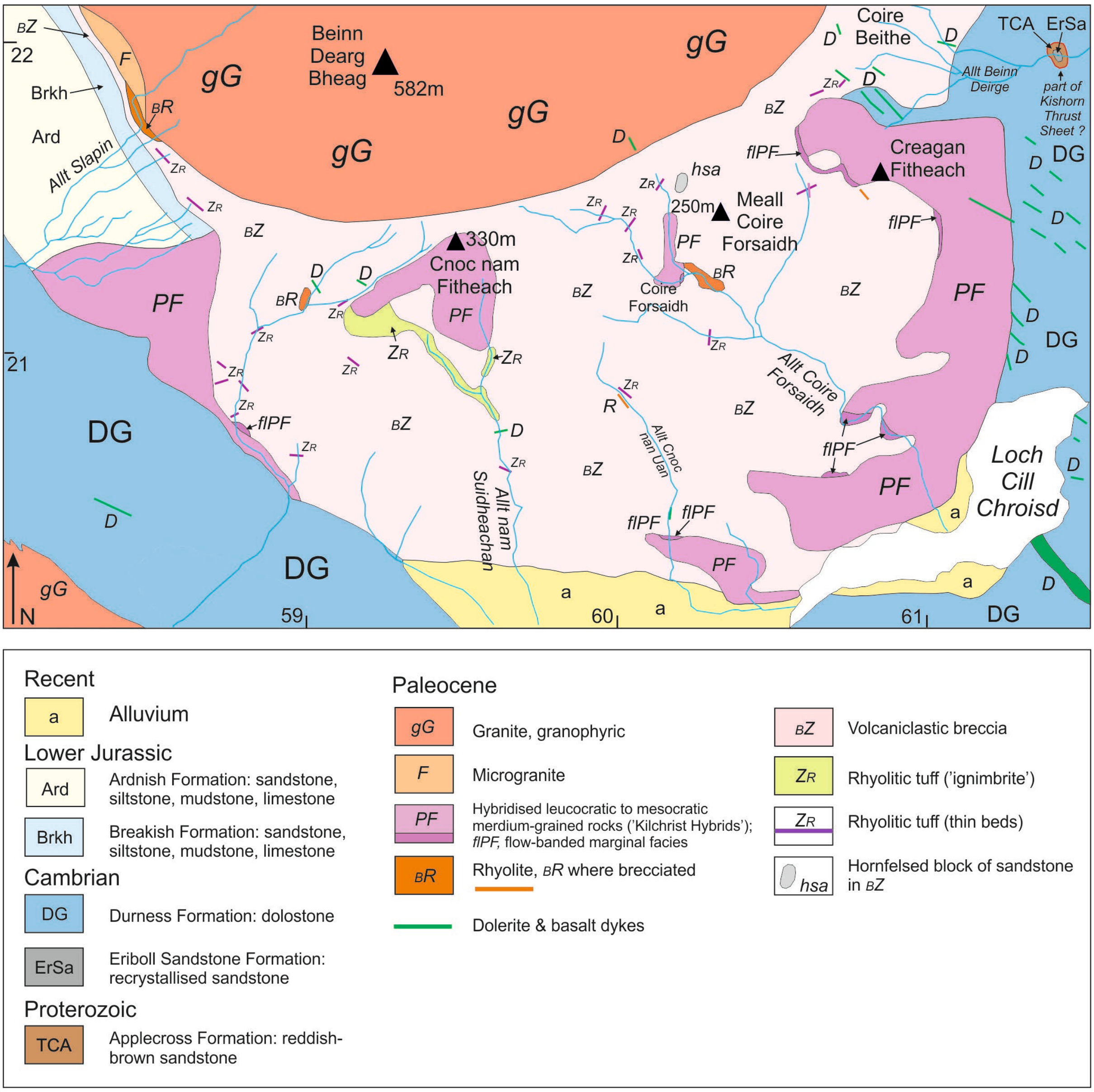


Figure 5-72 – Geological map of the Kilchrist area.

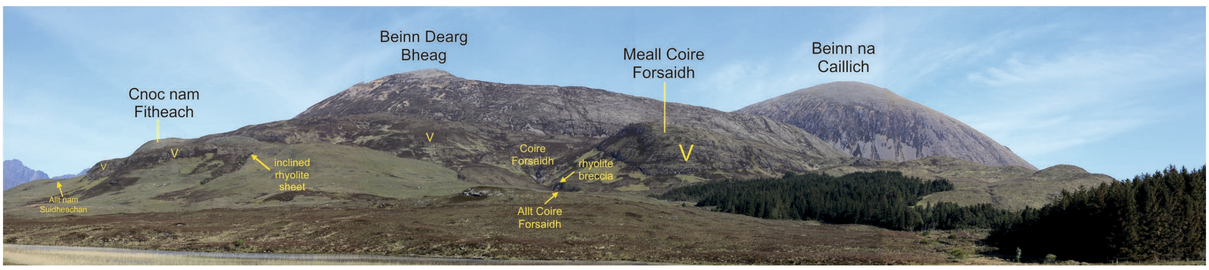


Figure 5-73 – Field view of the Kilchrist area. Much of the area is dominated by weakly stratified to massive polylithic volcaniclastic breccia (V). Also labelled are a rhyolite sheet and a mass of rhyolite breccia. Views towards the north from the Broadford to Kilbride road.

(i) The most abundant rock-type is coarse, unbedded, polylithic breccia (Figure 5-74). It is very poorly sorted and has been hydrothermally-altered by the nearby younger intrusions: the Kilchrist

Hybrids (6.G.1) and the large Beinn na Caillich Granite to the north (6.G.6). Only the least-altered material will be described.

Blocks that comprise the breccia are randomly distributed, range from sub-angular to rounded, and vary in size up to several metres across. Block-types recorded are: Torridonian sandstone and shale, Cambro-Ordovician sandstone/quartzite and dolostone, Jurassic limestone, sandstone and siltstone (Chapter 3), Paleocene basalt (including amygdaloidal and plagioclase-porphyritic variants), dolerite, gabbro, rhyolite, tuff (including ignimbrite), granite, vitrophyre, and pre-existing coarse- and fine-grained pyroclastic and volcaniclastic materials. Locally outcropping gneiss of the Lewisian Gneiss Complex (3.B) is not recognised as blocks in the breccia.

Figure 5-74 – Typical coarse-grained, polylithic, volcaniclastic breccia in the Kilchrist area. Coin *c.* 24mm across.

Generally, poor exposure limits the evidence of stratification, although subaqueous or subaerial deposition and reworking and erosion surfaces are evident, for example, north of Loch Cill Chriosd, in the Allt Coire Forsaidh, a 0.5m-thick reddened interval within the breccia consists of lithic clasts, typically up to 5cm across, set in a fine-grained, red-brown, volcaniclastic matrix, interpreted as the product of subaerial weathering and is, essentially, a poorly-developed palaeosol or laterite.

Block-supported and matrix-supported macro-textures occur throughout the breccia, indicating that the transport and depositional processes were variable. The general lack of stratification is taken as an indication that transportation was by some form of hyper-concentrated or debris flow mechanism.

(ii) Intercalated with the breccia are numerous thin layers of relatively fine-grained basaltic volcaniclastic material, with examples of grading from breccia to sand grade material over intervals of up to several tens of centimetres. These volcaniclastic sandstones are dull grey-green and contain sub-angular to sub-rounded basaltic clasts up to 10mm across. Erosional surfaces are also identified. A (mega-)block of Cambrian sandstone (quartz arenite)/quartzite, with shattered material at its margin, crops out north of Meall Coire Forsaidh and measures at least 60m by 30m.

(iii) Closely associated with the breccia and the beds of finer-grained basaltic volcaniclastic material are thin beds of silicic tuff or tuffaceous sandstone. Over twenty distinct exposures have been identified (Bell, 1985), although some may be lateral equivalents. Typically, they are less than 2.5m thick (and commonly less than 1m). Except for some of the deposits exposed in the crags south of Beinn Dearg Bheag, the tuffs/sandstones are visible and accessible only where cut by the numerous small unnamed streams that dissect the area.

These pale deposits commonly have irregular, weathered tops that, in some cases, are overlain by dark, fine-grained material, mainly volcaniclastic siltstones and sandstones. Bedding may be discerned in some instances, for example, two deposits NE of Meall Coire Forsaidh, whereas in others there is very little vertical (stratigraphic) variation in grain-size. The silicic character of these deposits is only readily identified in the least-altered units, where wispy fragments of rhyolitic material, up to 5mm long and with curved margins, are set in a fine-grained, clastic matrix. Angular crystals of quartz and, less commonly, alkali feldspar and plagioclase, are present, as are small xenoliths of various types of country-rock.

(iv) Ignimbrites in the Kilchrist district were first recorded by (Ray, 1960) and (Ray, 1966), who described material from two localities in the Allt nan Suidheachan - Cnoc nam Fitheach area (Figure 5-75). Both were interpreted by (Ray, 1960) and (Ray, 1966) to be intrusive, forming marginal facies of a micro-adamellite intrusion. This intrusion is interpreted here as the product of magma mingling, one of the Kilchrist Hybrids (6.G.1), involving basaltic and rhyolitic magmas, and is considered here to being unrelated to the ignimbrites. Both ignimbrite outcrops are interpreted by (Bell, 1985) to be extrusive.

Figure 5-75 – Detail of the ignimbrite in the Allt nan Suidheachan area [NG 5954 2087], with typical foliation (banding, or eutaxitic fabric) and angular xenoliths. Coin *c.* 24mm across.

The Cnoc nam Fitheach outcrop consists of four distinct sheets, with a total thickness of *c.* 4.5m, and is exposed in a small gully that flows SE into the Allt nan Suidheachan. This ignimbrite is relatively crystal-rich, has a strong eutaxitic fabric, and dips at an angle of *c.* 35° towards the NW. The deposit has a distinct base, with bedding defined by a eutaxitic fabric dipping at a very low angle towards the NE/north. This lower boundary is erosional, with the underlying breccia showing a slight amount of (Paleocene) lateritic weathering. Low-angle brittle faults, discordant to the fabric of the ignimbrite, cause the dip of the fabric to increase, up-section. These faults, of unknown displacement, have also acted as hydrothermal fluid conduits, causing extensive alteration of the adjacent ignimbrite for distances of a few centimetres. The resulting pale green, homogeneous rock has very few recognisable primary characteristics. At the top of this deposit, the fabric of the ignimbrite is distorted, with the formation of small, detached folds and cusp-shaped masses. Directly above this deposit is coarse breccia.

The ignimbrite exposed in the Allt nan Suidheachan is also inclined, but at a higher angle, *c.* 60°, to the NE. Essentially, it is a large slab of material 120–130m in length and between 10 and 20m thick. The fiamme that define the eutaxitic fabric of this ignimbrite have very high aspect ratios (length:thickness), not uncommonly 25:1, or more, indicating extreme compaction and welding.

Both ignimbrites contain xenoliths and crystals. Xenolith types include most of the pre-Paleocene and Paleocene lithologies that crop out within the district and are present as blocks within the breccias (see above). In the case of the crystals, there is abundant sanidine, perthitic alkali feldspar and quartz. The glass component of the ignimbrites is commonly dark brown (less often dark green) and is much altered and devitrified.

(v) Three discrete masses of brecciated quartz-alkali feldspar micro-porphyritic rhyolite are identified, all with obscure field relationships (due to a lack of good exposure) to the surrounding and volumetrically-dominant coarse, unbedded, polylithic breccias : (a) in a stream west of Cnoc nam Fitheach, *c.* 85m by 35m; (b) within the Allt Coire Forsaidh, south of Meall Coire Forsaidh, *c.* 115m by 40m, forming an obvious pale scar visible from afar and consisting of distinctly pale-weathering (grey-green) brecciated rhyolite with individual angular fragments typically a few centimetres across, rarely up to a decimetre (Figure 5-76); and, (c) in the stream bed and gorge walls of the Allt Slapin, consisting of apparently vertical masses of brecciated rhyolite, a few metres wide, with conspicuous banding and spherulitic texture within the fragments.

Figure 5-76 – Brecciated quartz-alkali feldspar micro-porphyritic rhyolite from the main exposure (scar) in Coire Forsaidh, east of the stream confluence. The clasts and the matrix material are hydrothermally altered, with the development of secondary chlorite, epidote and clay. Coin *c.* 24mm across.

All of these outcrops of brecciated rhyolite are hydrothermally altered, with the development of secondary chlorite, epidote and clay. In the Allt Coire Forsaidh outcrop, veins and disseminated crystals of pyrite have been altered to various iron oxides and hydroxides.

From the descriptions presented above, it is evident that a range of volcanic and volcanic-related products of the Kilchrist district can be readily distinguished and that it is not appropriate to group these highly variable accumulations under the essentially-redundant term *agglomerate*. Furthermore, the overall field relationships at Kilchrist can be better explained in terms of an incomplete ring-dyke intrusion of the so-called Kilchrist Hybrids that partially define the outcrop (shape) of the breccia and other spatially-associated lithologies. The gross character of the different types of material suggests that surface processes - subaqueous and/or subaerial - have dominated their mode of deposition and that within-vent processes, as suggested by (Harker, 1904), were not involved.

The numerous silicic tuffs, for example, together with the ignimbrites, are evidently extrusive in form and their deposition would have been on relatively irregular surfaces, strongly controlled by the voluminous breccia accumulations. The aspect ratios of the fiamme in the ignimbrites and the wispy rhyolitic fragments in the tuffs also suggest large degrees of compaction. Rheomorphism, in the form of secondary mass flowage, can occur in such deposits, and deposition on slopes is a critical aspect of features such as flow folds, cusps and slump structures, resulting in (lava-like) ignimbrites.

(Walker, 1975) suggested that a significant feature in the positioning and development of individual intrusive centres throughout the province, including Skye, was the emplacement of silicic diapirs high in the crust at an early stage. Such diapirs are considered important because they would considerably influence the development of fragmental material, i.e. breccias. (Walker, 1975) suggested that some of the so-called 'vent agglomerates' of (Harker, 1904) may in fact have been derived from shattered country-rock from roof-zones, together with chilled and disrupted material from the upper parts of these diapirs. Due to updoming, this material would exist at an elevated/shallow position in the crust and through erosion would be readily subjected to surface reworking processes. Thus, the agglomerates of (Harker, 1904), referred to here as polylithic breccias, are essentially sedimentary in character.

The lack of (Lewisian) gneiss fragments in the breccias possibly provides some evidence as to how high within the crust the top of such a silicic diapir was able to rise. The absence of this rock-type suggests that the zone of brecciation above the diapir was structurally above the gneiss at its pre-granite intrusion level within the crust.

Other occurrences of rhyolitic rocks, with somewhat ambiguous field relationships, occur along the margin of the Beinn na Caillich Granite north of the Kilchrist deposits and are exposed in the Allt Slapin and as far around the margin of the granite as the west-flowing tributaries of the Allt an t-Sratha Bhig in Srath Beag.

Belig: The breccias that crop out north of Belig were first described in detail and interpreted by (Harker, 1904) (Figure 5-77, Figure 5-78, and Figure 5-79). He identifies their contact with the basaltic lavas that form the summit of Belig as dipping towards the south and that the fragmental rocks, referred to by him as agglomerates, being intruded by younger granites. The dominant block types, typically sub-angular to sub-rounded and up to 0.5m across, are of basalt, dolerite and gabbro, together with a lesser amount of, but locally abundant, granite and quartz-porphyritic felsite, all set in a dark chlorite-rich matrix of comminuted material (Figure 5-80). Stratification is absent, although, locally, layers of grey silicic tuff is recognised.

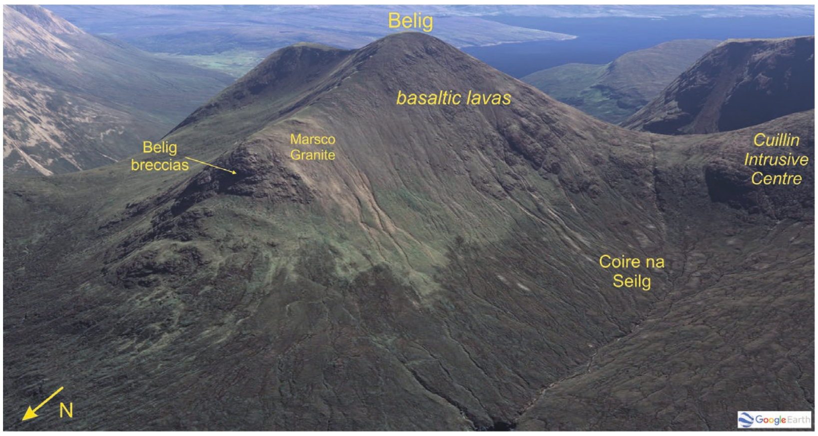


Figure 5-77 – Oblique Google Earth© image of the Belig area. View towards the SE.

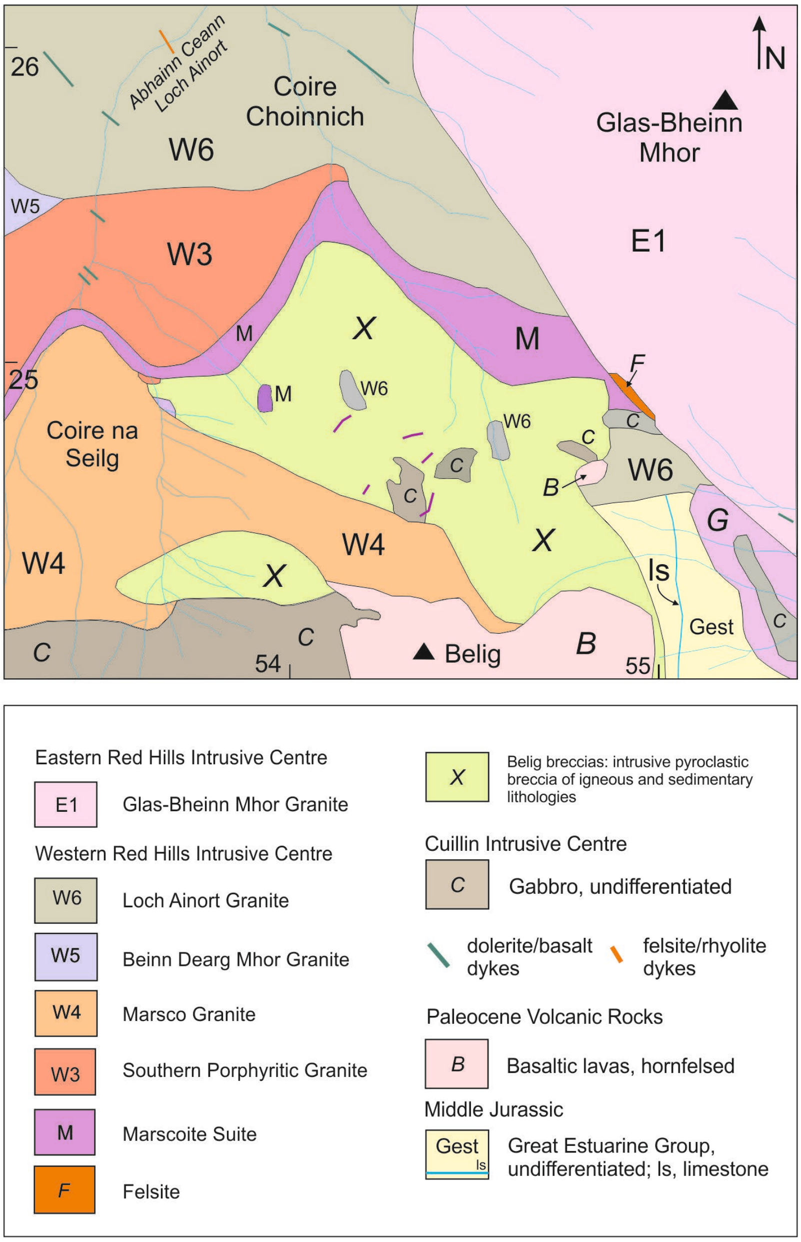


Figure 5-78 – Geological map of the Belig area illustrating the distribution of the breccias.

Figure 5-79 – Field view of the Belig area. View towards the SE from the head of Loch Ainort (see Figure 5.77).

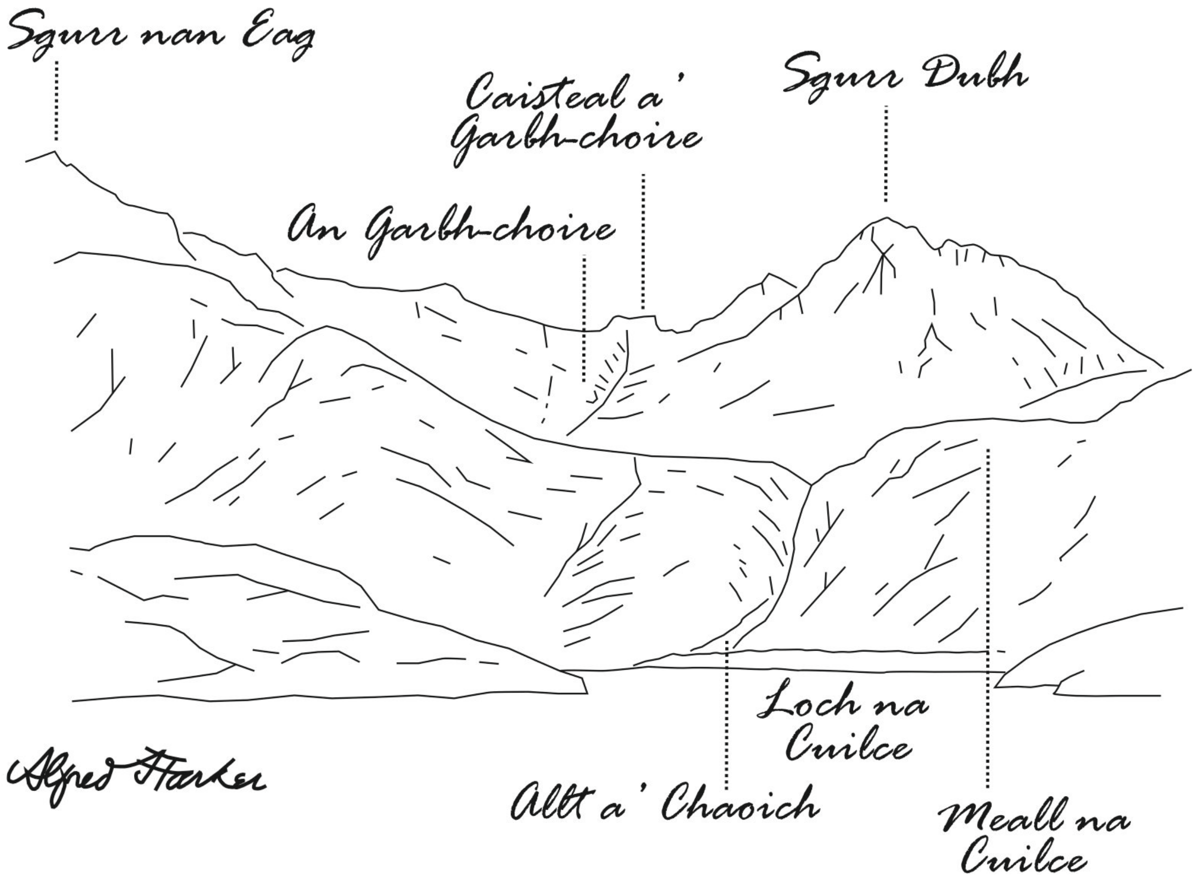
(Bell, 1966) re-examined these rocks and his description does not differ significantly from that of (Harker, 1904). Blocks of Torridonian and Mesozoic sedimentary rocks are also recognised, the former only occurring *in situ* at least 5km distant from the breccia outcrop. Some of the (mega-) blocks of gabbro and basalt are up to 50m across and are brecciated.

(Bell, 1966) interprets the Belig breccias as the product of disruption and fragmentation of pre-existing lithologies by degassing/devolatilisation of silicic magma(s) during their emplacement into the shallow crust, including (genetically related) early-crystallised felsite/granite. Fluidization caused rounding of previously formed fragments. In essence, these outcrops are interpreted as 'explosion' breccia(s).

Figure 5-80 – Typical unstratified Belig breccia, with sub-angular to sub-rounded clasts up to 0.5m across of pale granite and quartz-porphritic felsite, dark basalt, dolerite and gabbro, all set in a dark chlorite-rich matrix of comminuted material. Coin *c.* 24mm across; pole *c.* 1m long.

Chapter 6 The Skye Central Complex

After the development of the Paleocene lava plateau, magmatism became more focussed, leading to the development of the Skye Central Complex, consisting of sub-volcanic (shallow-emplaced) intrusive centres involving ultrabasic and basic units (the Cuillin Intrusive Centre) and granites (the Srath na Crèitheach, Western Red Hills and Eastern Red Hills intrusive centres). Although evidence for the surface manifestation of these shallow intrusive bodies is limited, it is possible to develop simplistic models for the links between intrusive and extrusive activity.



6.A Introduction

Following the Paleocene eruptive events that formed the Skye Lava Field (Chapter 5), much of the magmatism on Skye appears to have taken the form of intrusive activity. Volcanic rocks that formed contemporaneously with this intrusive activity are not recognised, other than one intracanyon basaltic lava at the top of the volcanic sequence on Minginish (5.D; Figure 5-46; Figure 5-47; Figure 5-48; Figure 5-49 and Figure 5-50). Such coeval eruptive products inevitably formed, but have been lost through tens of millions of years of weathering and erosion, especially during the Quaternary Period (Chapter 10) when severe glacial conditions ensued.

The laterally-extensive sequence of volcanic rocks (Chapter 5) that covers much of the older metamorphic and sedimentary sequences in central and north Skye (Chapter 3 & Chapter 4) was erupted from fissures, now represented by the NW-SE -trending Skye Main Dyke Swarm, together with other dykes with a variety of orientations. Crustal dilation, leading to the intrusion/emplacement of the dykes, reaches its maximum in the vicinity of the Cuillin Intrusive Centre. These intrusions are dealt with in Chapter 7, although their genetic link with the volcanic rocks and, indeed, the Skye Central Complex (this chapter), should be borne in mind.

This chapter deals with the major intrusions of Central Skye, the so-called Skye Central Complex (SCC). The SCC is a large composite intrusive complex that was emplaced into the Skye Lava Field and the underlying pre-Paleocene country-rocks, therefore at a relatively shallow depth below the contemporaneous land surface. Emplacement of the SCC post-dates most of the volcanic activity that produced the Skye Lava Field. However, as noted above, various lines of evidence indicate that the Cuillin Intrusive Centre (CIC), the oldest component of the SCC, was contemporaneous with and genetically linked to the intracanyon lava of the Talisker Formation of the lava field (5.D).

The surface expression of the SCC has long since been removed by weathering and erosion over the intervening *c.* 55 million years since the overall magmatic event ceased, including significant periods of glaciation in the Quaternary Period (Chapter 10). Erosion has, locally, removed several hundreds of metres of lava field stratigraphy, most significantly in the vicinity of the SCC. However, we are able to infer the possible nature of the 'Cuillin Volcano' by comparison with dissected volcanoes that have formed in a similar extensional tectonic environment, and in particular within the North Atlantic Igneous Superprovince. Figure 5-50 illustratates a possible palaeogeographic linkage between a 'Cuillin Volcano' and the intracanyon lava of the Talisker Formation.

The SCC has four major foci of intrusive activity, in order of decreasing age: (i) the Cuillin Intrusive Centre (CIC), a suite of (in plan view) annular intrusions of gabbro, troctolite and peridotite, which dominate the spectacular, glacially-sculpted Cuillin Hills (Figure 6-1); (ii) the Srath na Crèitheach Intrusive Centre (SnCIC), a suite of granites forming the red hills of Meall Dearg and Ruadh Stac in Srath na Crèitheach (Figure 6-2); (iii) the Western Red Hills Intrusive Centre (WRHIC), forming the granite hills on the SE side of Glen Sligachan, as far east as the area south of the head of Loch Ainort (Figure 6-3); and, (iv) the Eastern Red Hills Intrusive Centre (ERHIC), dominated by the granite hills SW of Broadford but also including the hills of Beinn na Crò, Glas-Bheinn Mhòr and Beinn an Dubhaich (Figure 6-4). The most diffuse of these foci of intrusive activity is the Eastern Red Hills Intrusive Centre, which comprises several discrete intrusions that were emplaced into various pre-Paleocene country-rocks.

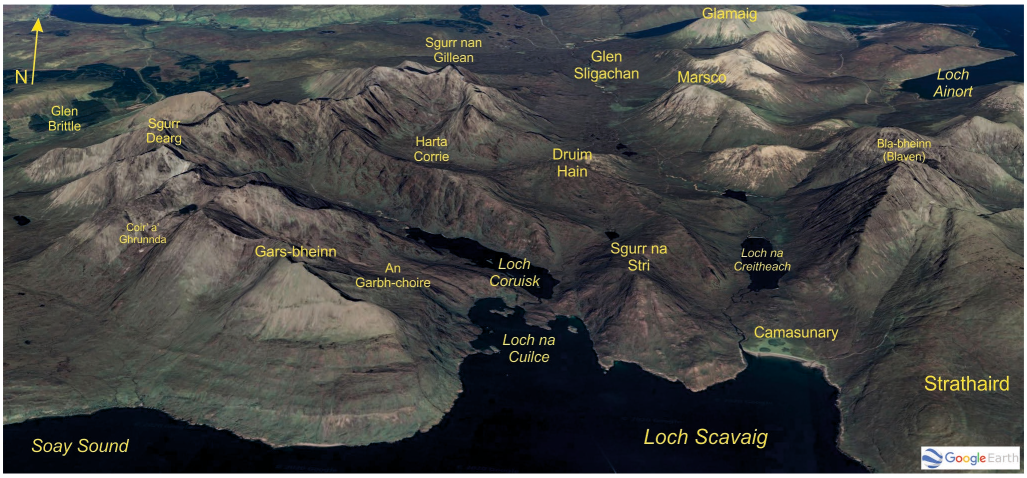


Figure 6-1 – Oblique Google Earth© image of the Cuillin Hills. View towards the NNE.

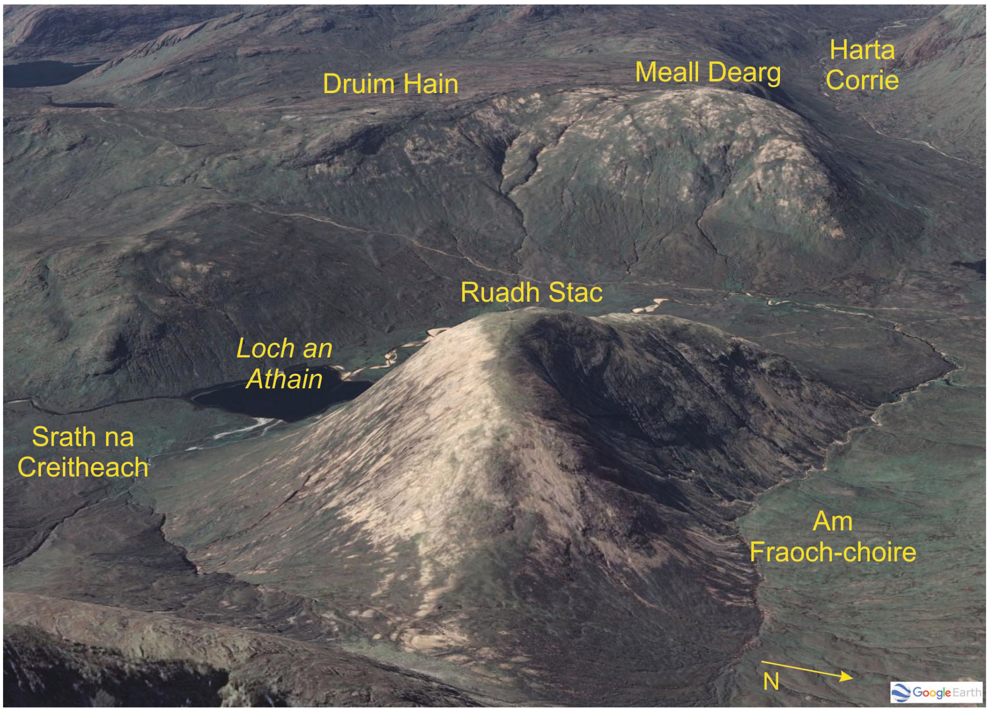


Figure 6-2 – Oblique Google Earth© image of the granites of the Srath na Crèitheach Intrusive Centre, forming the red hills, Ruadh Stac (near) and Meall Dearg (far). View towards the SW.

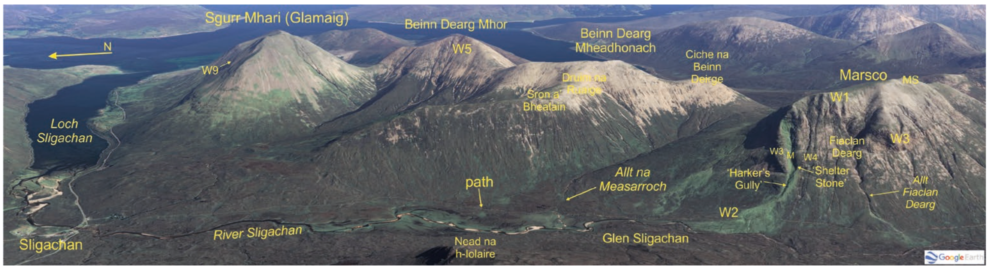


Figure 6-3 – Oblique Google Earth© image of the Western Red Hills Intrusive Centre. In the foreground (from left-to-right) are Glamaig, Beinn Dearg Mhòr, Beinn Dearg Mheadhonach and Marsco. View ENE towards the sea indent of Loch Ainort.

Figure 6-4 – Oblique Google Earth© image of the Eastern Red Hills Intrusive Centre. The three obvious summits (from left-to-right) are Beinn Dearg Bheag, Beinn Dearg Mhòr and Beinn na Caillich. View towards the west.

Age constrains for these intrusions are still relatively poor, with the most robust isotope-based age for the CIC being 58.91 ± 0.07 Ma for zircon crystals recovered from gabbro pegmatites from the CIC

(Hamilton, et al., 1998), and ages in the range 58.5 to 57 Ma for the granites from the Srath na Crèitheach and Western Red Hills intrusive centres (summarised in (Emeleus & Bell, 2005)). Sensibly younger ages, in the range 55-56 Ma, have been determined for a granite and a late-stage vitrophyre dyke from the Eastern Red Hills Intrusive Centre. As a general trend, as analytical techniques have improved over the last few decades, the time span for the whole magmatic event, embracing both the lava field and the SCC intrusions, has contracted and there is some degree of consensus that, from start to finish, it may have been of the order of 1 to 2 million years.

The nature of the SCC, at depth, has been modelled from gravity data, with a very localised positive Bouguer anomaly of 73 mgal (Bott & Tucson, 1973). This suggests, simplistically, that there must be a dense cylinder-shaped mass of material with an approximate diameter of 25km extending downwards, possibly to a depth of *c.* 15km (Figure 6-5). This is one of the largest positive gravity anomalies in the British Isles. The most likely (and obvious) lithology candidates are gabbro, troctolite and peridotite, with densities of at least 3,000 kg.m^{-3}, but possibly as high as 3,500 kg.m^{-3}, which contrasts with that of the basement country-rock gneisses (2,800 kg.m^{-3}). The granites, with a typical density of 2,600 kg.m^{-3}, do not extent to any great depth, perhaps as little as 1km, and their outcrop area, relative to that of the gabbros, troctolites and peridotites of the CIC, incorrectly make them appear to be of equal volumetric significance. (Bott & Tantrigoda, 1987) estimate that the granites may represent just 5 volume % of the overall intrusive mass.

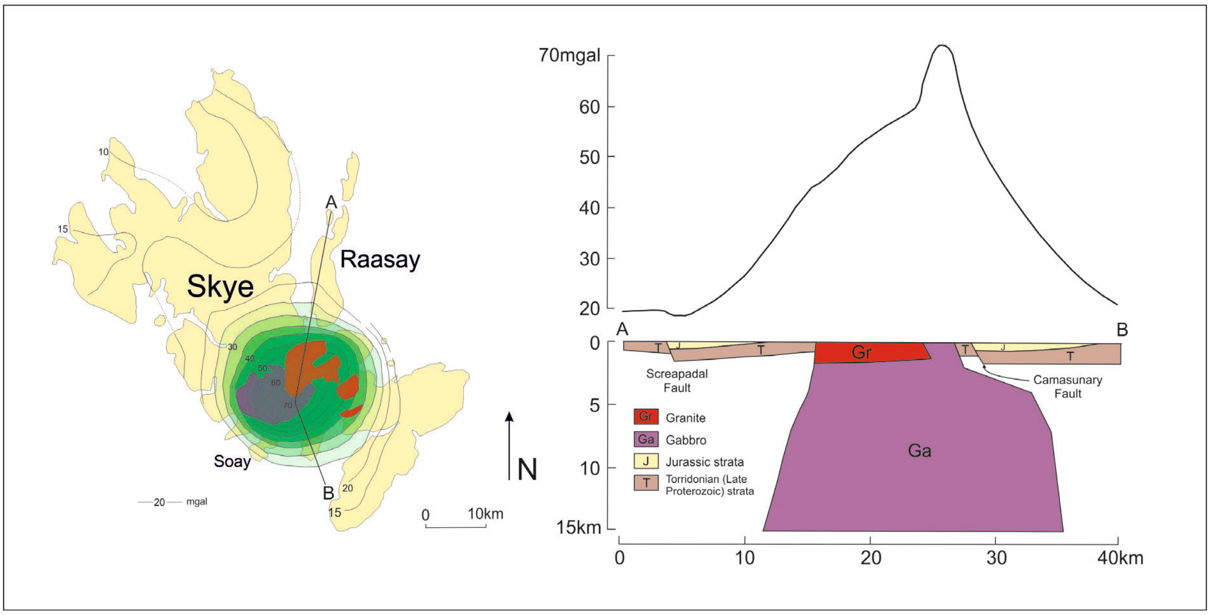


Figure 6-5 – Interpretation of the subsurface structure of the Skye Central Complex based upon gravity data (after Bott & Tucson 1973).

Local aerial magnetic data provide further insights regarding the nature of the postulated cylinder of mafic and ultramafic rock below the SCC (Brown & Mussett, 1976). In simple terms, the magnetic signature for the area over the outcrop of the CIC is negative, with values as low as -250nT, whereas the signature over the outcrop of the Red Hills granites is positive, up to +250nT (Figure 6-6). The granites, however, are not likely to have significantly contributed to the magnetic signature. Thus, the cylinder of basic/ultrabasic rocks modelled to explain the gravity anomaly has (at least) two discrete units or components, each acquiring their magnetic signature as they cooled through the Curie Temperature for magnetic minerals such as magnetite (500-600°C). The mass below the CIC was emplaced and cooled through the Curie Temperature when the Earth's magnetic field was negative, whereas the mass below the Red Hills cooled whilst the Earth's magnetic field was positive/normal. Field relationships indicate clearly that the positive polarity event was after the negative polarity event. Thus, at least two significant and discrete bodies of mafic/ultramafic magma were emplaced at depth during the lifetime of the SCC and bridged a time when the Earth's magnetic field reversed.

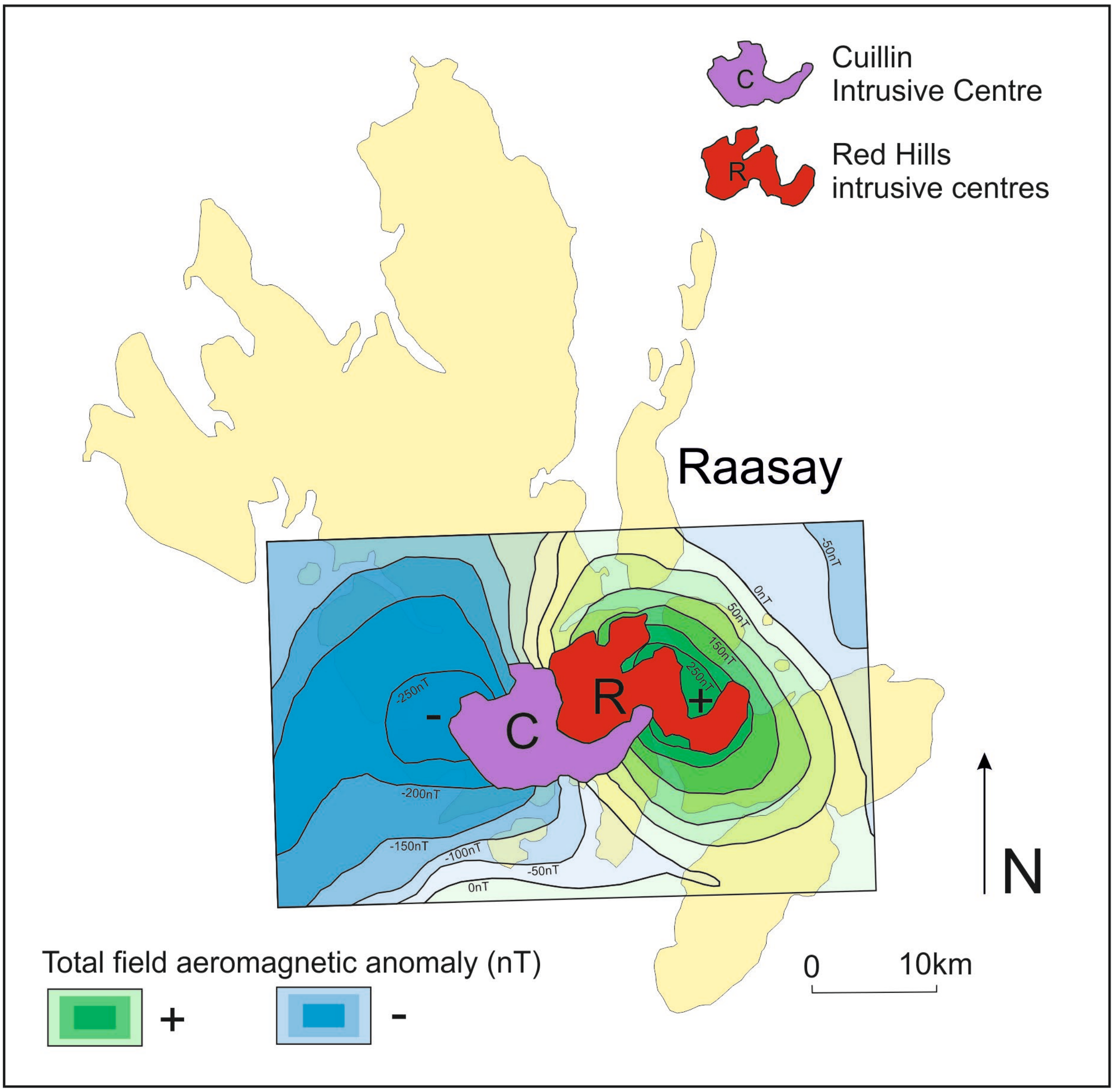


Figure 6-6 – Aeromagnetic data for the outcrop area of the Skye Central Complex, with discrete negative and positive signatures inferring two events that straddle a magnetic polarity reversal (negative, then positive) (after Brown & Mussett 1976).

Thus, the SCC, and other Paleocene central complexes throughout the Hebridean Igneous Province, may be interpreted as the product of the ascent to shallow crustal levels of large-volume pulses of mantle-derived, mafic(-ultramafic) magma, which most likely manifested itself at the contemporaneous Earth's surface with crustal doming and the development of a volcanic edifice (cf. (Walker, 1975)).

In plan/map view, the various gabbro, troctolite and peridotite intrusions of the CIC have annular outcrop patterns, disrupted (and effectively removed) in the NE quadrant by the younger granites of the Srath na Crèitheach and Western Red Hills intrusive centres (Figure 6-1). Where age relationships can be deduced, the intrusions are progressively younger from the marginal part of the intrusive centre, with the youngest being in the geographic centre, in the vicinity of Druim Hain. Common features within the various intrusions of the CIC include mineral layering/banding and pegmatites. However, some of the earliest/oldest gabbros lack obvious (extensive) mineral layering and have, locally, considerable ranges of crystal size over short (metre scale) distances. At depth, the margin of the CIC dips inwards, as do other inter-intrusion contacts, giving the entire centre a confluent cone-shaped geometry.

Spatially (and genetically) related to these large, coarse-grained intrusions is a suite of basaltic cone-sheets, mainly dolerite and basalt, some porphyritic, which has a focal point, at depth, coincident with the geographic centre of the CIC at Druim Hain (6.B.10). Also related to the CIC is the NW-SE -trending Skye Main Dyke Swarm, which cuts across it and has, in the vicinity of the intrusive centre, its maximum intensity in terms of number of intrusions and degree of crustal dilation. Compositionally and genetically, the cone-sheets and dykes are related.

The three Red Hills centres: Srath na Crèitheach, Western Red Hills and Eastern Reds Hills, comprise multiple intrusions with both ring-dyke and dome geometries. The Srath na Crèitheach and Western Red Hills intrusive centres lack any screens of country-rock between the intrusions, but with well-defined intrusion-intrusion contacts and with age relationships that can be deduced with confidence. The oldest of the three granitic centres, Srath na Crèitheach, is in contact with, and intrudes with rhyolitic dykes, the CIC (Figure 6-2). Part of the Western Red Hills Intrusive Centre is the so-called Marscoite Suite, which forms a composite ring-dyke with silicic, intermediate (ferrodiorite) and hybrid components, the last formed by the interaction and mingling/mixing of magmas of the first two components (Figure 6-3). The Marscoite Suite forms a distinctive ring-dyke that is particularly well exposed on Marsco, from where the (locally applicable) lithology name, marscoite, was given by (Harker, 1904).

The Eastern Red Hills Intrusive Centre is considerably more dispersed, with abundant country-rocks separating some of the intrusions. At its core is the late-stage, dome-shaped intrusion, the Beinn na Caillich Granite, which forms the three summits, Beinn na Caillich, Beinn Dearg Mhòr and Beinn Dearg Beag (Figure 6-4). To the west and NW are intrusions with little or no intervening country-rock, forming the summits of Beinn na Crò and Glas-Bheinn Mhòr, whereas to the south the Beinn an Dubhaich Granite forms a distinctive, elongate ridge and is intruded into Cambro-Ordovician dolostones (3.E), resulting in a complex, zoned, metamorphic (thermal) aureole (6.H). Genetically related to the Eastern Red Hills intrusions is a suite of composite sills, with silicic and intermediate components, together with, locally, zones of hybridised rocks formed by their interaction and mixing (6.G.7).

The Raasay Granite is a true sill, forming two significant outcrops. It is intruded into Jurassic strata and steps up-stratigraphy from where it crops out on the south coast of the island, as far north as Balmeanach (Figure 6-7). Locally, it is significantly faulted, with the fault planes giving rise to obvious topographic features. An outcrop of the Raasay Granite forms the headland of An Àird, on the Skye side of the Narrows of Raasay, east of The Braes. Granites also occur on the island of

Scalpay, with, in part, sheet-like geometries, intruded into Torridonian and Jurassic strata. Their relationships with the Western and Eastern Red Hills intrusive centres have not been established.

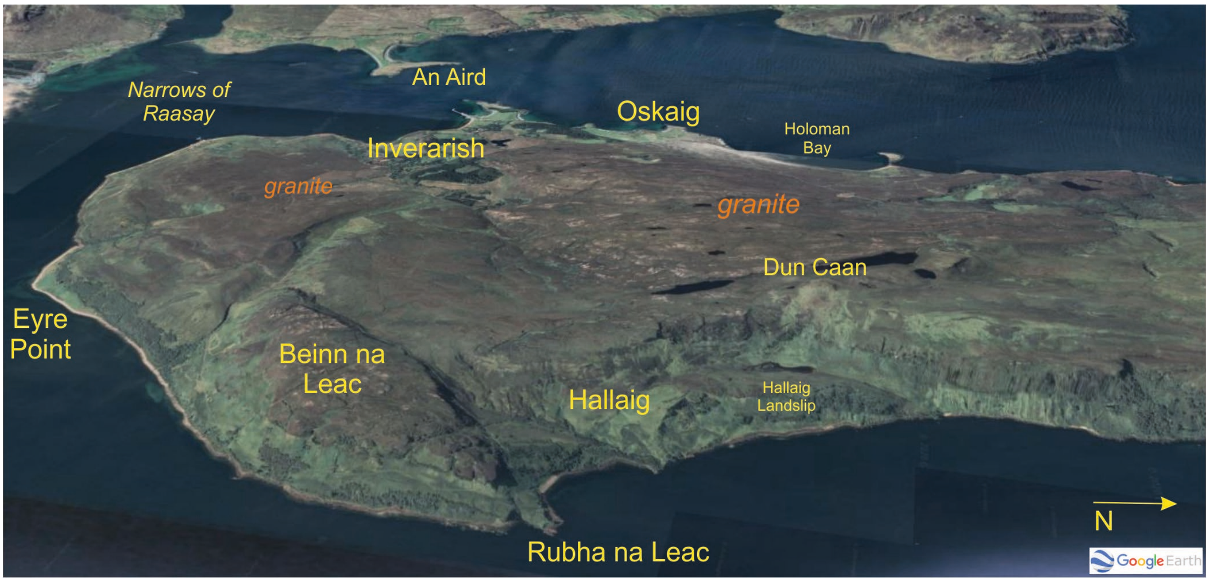


Figure 6-7 – Oblique Google Earth© image of the southern part of Raasay illustrating the nature of the outcrop of the pale, orange-weathered Raasay Granite between Inverarish and Dùn Caan and its (predominant) Jurassic sedimentary country-rocks on Beinn na Leac and along the east-facing coast (from Rubha na Leac, northwards). View towards the west.

The long-lived emplacement events of the SCC caused significant heating of the surrounding country-rocks. Where the predominantly gabbroic rocks of the CIC are in contact with basaltic lavas of the Skye Lava Field, the grade of contact metamorphism is very high, resulting in the formation of a zone of hornfels, with a metamorphic mineral assemblage including orthopyroxene and olivine, indicating temperatures in excess of 1,000°C (Ferry, et al., 1987). Furthermore, the whole-rock oxygen isotope signature of these rocks, typically with values of $\delta^{18}O < 0\%$, indicate significant hydrothermal interaction/reaction at these high temperatures, but not after cooling below *c.* 900°C (Ferry, et al., 1987). Distant from the margin of the SCC, the thermal effects were considerably less, although the effects of hydrothermal fluid circulation are still significant, in part due to burial of the earliest lavas as the lava field aggraded ((Forester & Taylor, 1977); (Ferry, et al., 1987)). The nature and products of these fluid-rock interactions are considered in detail in Section 6.D.

Where the CIC is in contact with Torridonian sedimentary rocks, as seen at the present-day level of erosion in Camasunary Bay, the thermal effects have caused partial melting of the sandstones and shales, with the obliteration of obvious primary features such as bedding. The resultant silicic melts have invaded less-altered Torridonian strata further from the margin of the intrusive centre, as well as early-crystallised marginal gabbros of the intrusive centre, resulting in spectacular multiple, cross-cutting networks of microgranitic/rhyolitic veins (6.D). One granite, the Coire Uaigneich Granite, has a ribbon-shaped outcrop pattern adjacent to the SE margin of the CIC, including in Camasunary Bay, and has geochemical and petrographic characteristics that suggest it is the product (at least in part) of the partial melting of Torridonian sedimentary material (6.C).

6.B The Cuillin Intrusive Centre (CIC)

The oldest major sub-volcanic group of rocks of Paleocene age preserved on Skye is referred to as the Cuillin Intrusive Centre (CIC) (Figure 6-8) and is dominated by coarse-grained basic and ultrabasic rock-types which, in part, exhibit igneous layering (stratification, banding). The CIC is *c.* 8km in diameter, with layering dipping towards a focal point below Meall Dearg, at the southern end of Glen Sligachan. The dip of rare, locally-developed layering in the Outer Gabbros (see below) is *c.* 10–20°, increasing to values of *c.* to 60–70° towards the centre in the Inner Gabbros (Figure 6-8). The NE portion of the complex has been removed by the subsequent intrusion of the granites of the Srath na Crèitheach and Western Red Hills intrusive centres. The dominant country-rocks, at the present level of erosion are lavas of the Skye Lava Field (Chapter 5), except in the SE quadrant, where Torridonian sedimentary rocks are exposed (Chapter 3).

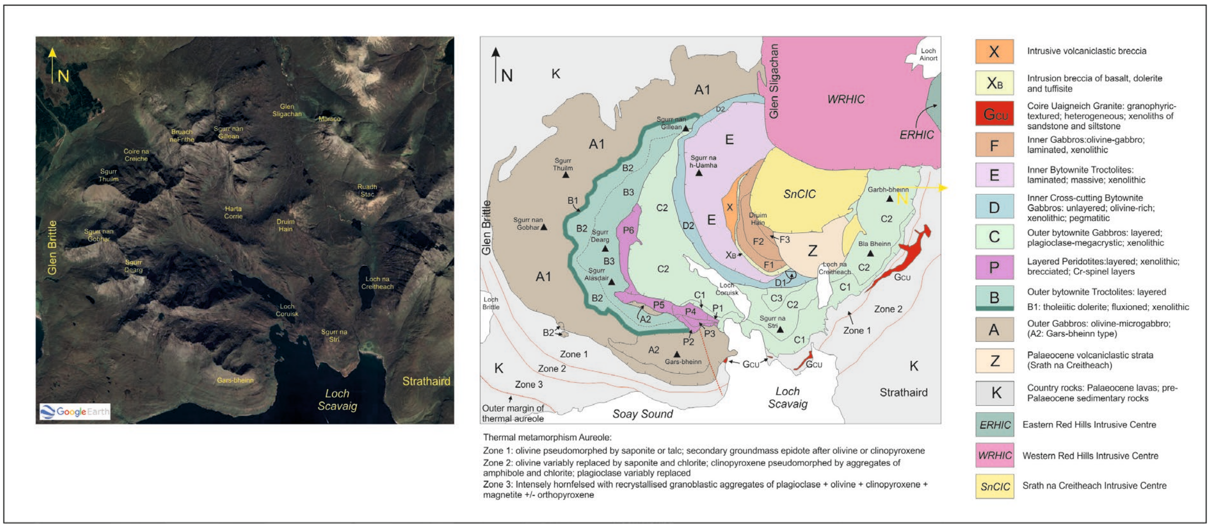


Figure 6-8 – Lithodemic units of the Cuillin Intrusive Centre (CIC) (based on BGS (2005) and Emeleus & Bell (2005)) and Google Earth© image of the same area.

Geographically, the complex has two distinct parts. The most prominent is that forming the main Cuillin ridge, running from Sgùrr nan Gillean in the north, to Gars-bheinn in the south, an arc which is concave to the east. The numerous peaks that constitute the main ridge are all just under 1000m OD and give rise to a very irregular alpine topography, mainly due to the inweathering and outweathering of minor intrusions, cone-sheets and dykes, that cut the various gabbros, troctolites and peridotites. On the convex side of the ridge, several corries are separated by buttress-like ridges, for example Coire Làgan and Coir' a' Ghrunnda separated by Sròn na Cìche. Two large drainage areas have developed within the amphitheatre east of the ridge: Harta Corrie in the north and Coir'-uisg in the south. These two areas are separated by the ridge of Druim nan Ramh, which lies to the north of Loch Coruisk.

The isolated, eastern part of the CIC forms the Garbh-bheinn - Blà-bheinn (Blaven) ridge, which lies to the east of Loch na Crèitheach. The main rock-units that have been identified within the Cuillin Hills (*s.s.*) can be traced into this eastern sector.

(Harker, 1904), in his classic memoir, describes the various types of basic and ultrabasic lithologies present within the CIC and concluded that they developed in response to the injection of several pulses of heterogeneous magma. Subsequently, it was suggested by (Stewart & Wager, 1947) that the layering present within these rocks developed in response to gravity stratification and crystal settling mechanisms. Work by Carr ((Carr, 1952); (Carr, 1954)), Weedon ((Weedon, 1956); (Weedon, 1961); (Weedon, 1965)), Zinovieff ((Zinovieff, 1958); (Wager & Brown, 1968)), J.D. Bell ((Bell, 1959); (Bell, 1966)), Hutchison ((Hutchison, 1964); (Hutchison, 1966b); (Hutchison, 1968)), (Wager & Brown, 1968), (Jassim, 1970), (Hutchison & Bevan, 1977), (Claydon & Bell, 1992) and (Brandriss, et al., 2014) has further added to the understanding of these rocks and forms the basis of some of the descriptions given below. A useful evolutionary intrusive stratigraphy (or lithodeme) is given in Figure 6-8 (modified from (BGS, 2005) and (Emeleus & Bell, 2005)).

Although various structural complexities are present within the Inner and Outer units, in general, the oldest members crop out around the margin of the intrusive centre, whereas the younger members are found towards the centre. It is likely that several periods of internal uplift and subsidence have modified any simple stratigraphy that may have existed.

In this scheme, the Inner Cross-cutting Bytownite Gabbro, formerly the Druim nan Ramh Eucrite of (Wager & Brown, 1968), is a significant intrusion, separating the Outer and the Inner units. (Zinovieff, 1958) suggested that the layered troctolites of the Outer and Inner units are, in fact, members of the same unit, and that large-scale faulting has brought about the apparent repetition in the sequence. Alternatively, it has been suggested ((Wager & Brown, 1968); (Wadsworth, 1982)) that this troctolite body is the Inner equivalent of the Outer Gabbros and Outer Bytownite Troctolites and represents a marginal unlayered facies of a second major phase in the development of the CIC. Insufficient detailed work has been undertaken to prove or disprove either of these models.

The dykes, cone-sheets and thick intrusive sheets associated with the CIC are described, separately, below (Chapter 7; 6.B.10; 6.B.11).

6.B.1 The Outer Gabbros (A)

This ring-shaped intrusion of heterogeneous coarse-grained lithologies forms a distinct marginal part of the CIC, on the western, convex side of the main Cuillin Ridge. The outer contact, against country-rock basaltic lavas, is only locally exposed, typically where cut by a water course, for example in the Allt a’ Choire Ghreadaidh on the east side of Glen Brittle. Well-developed layering (*s.s.* layers) is generally absent, and these rocks are believed to constitute some of the earliest units of the CIC.

On the basis of detailed field and mineralogical studies, (Weedon, 1961), (Hutchison, 1964) and (Hutchison & Bevan, 1977), identified two distinct rock-units within the Outer Gabbros in the southern part of the CIC, in the area between Coir’ a’ Ghrunnda and Loch Scavaig, including the summit area of Gars-bheinn. These are (Figure 6-8): (i) an Outer Marginal Gabbro (A1); and, (ii) a micro-gabbro (A2), the Gars-bheinn Gabbro (and its altered variant, the ‘Gabbro with Clouded Feldspars’ of (Weedon, 1961)) (Figure 6-9).

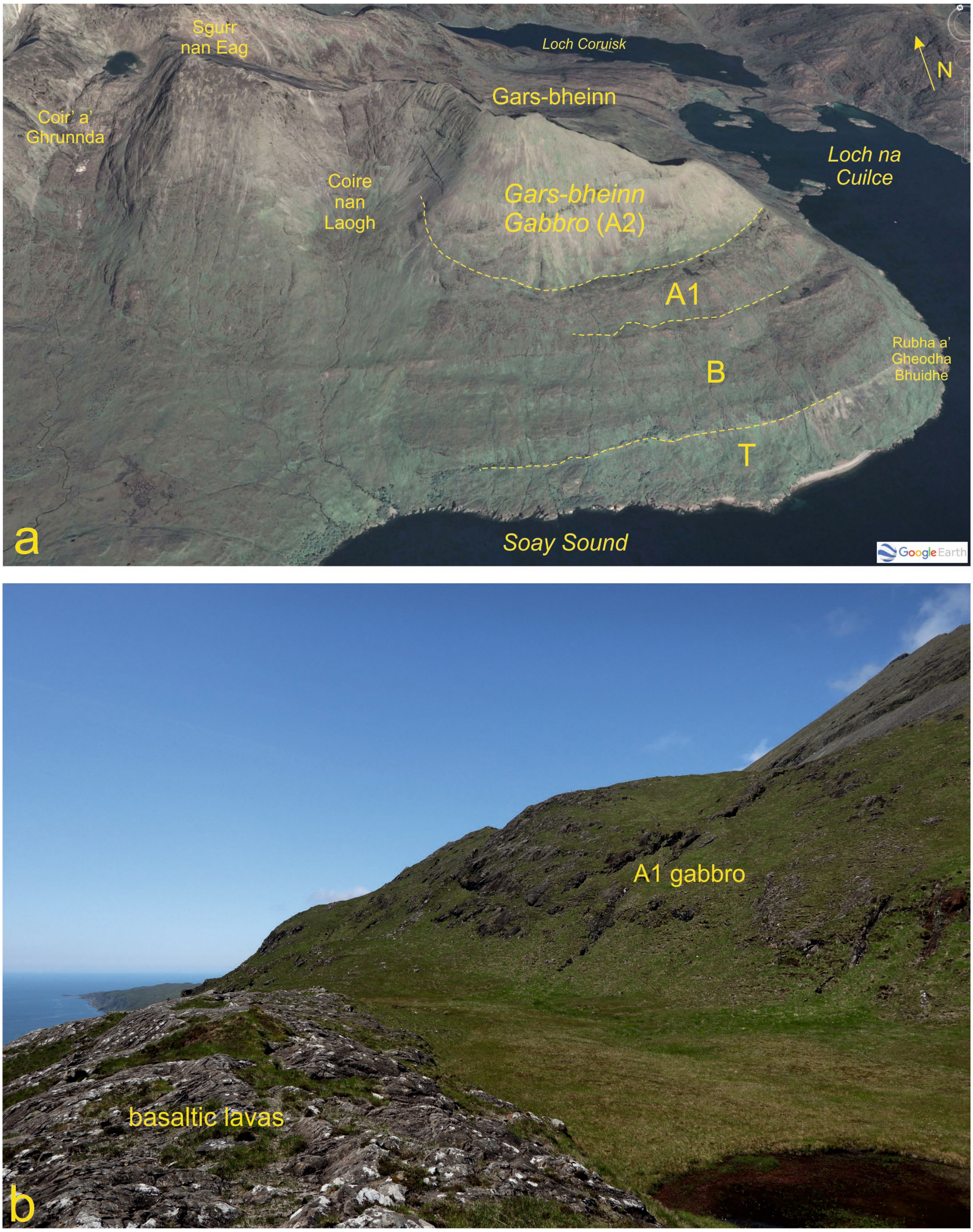


Figure 6-9 – (a) Oblique Google Earth© image towards the NE of the southern part of the Cuillin Hills indicating the approximate outcrop of the A1 and A2 gabbros on Gars-bheinn, together with hornfelsed basaltic lavas (B) unconformably overlying Torridonian strata (T); and, (b) field view towards the west along intrusive contact between the A1 gabbro and country-rock hornfelsed basaltic lavas.

Rare xenoliths of peridotite within the altered variant of A2 (i.e. with altered plagioclase crystals or 'clouded feldspars') north of the Allt Coir' a' Chruidh indicated to (Hutchison & Bevan, 1977) and (Bevan & Hutchison, 1984) that the A2 gabbro post-dates at least some peridotite intrusion(s).

The following descriptions are mainly from (Weedon, 1961).

The A1 Outer Gabbros have an outer contact with the country-rock lavas that is steeper than 40°, although it is not typically exposed along much of its outcrop and may (at the present level of erosion) dip, locally, inwards and outwards. These gabbros are relatively variable in character, typically unlayered with localised (gabbro) pegmatites, and comprise complex-zoned crystals of calcic plagioclase (up to An_{80}), magnesian olivine and relatively unaltered clinopyroxene.

The A2 Gabbro (Gars-bheinn Gabbro) crops out on the summit of that name (Figure 6-9), as well as on Sgùrr a' Choire Bhig, where it may be identified as a slightly-altered, fine-grained, smooth-weathering gabbro. It has a green coloration, particularly in the vicinity of darker, fine-grained, basic sheets that are present within the intrusion (see below). Where exposed, A2 has a sharp contact with A1 and 'B' gabbros/troctolites (Figure 6-8 and see below). Petrographically, the unaltered A2 gabbro is composed of plagioclase ($An_{65–68}$, but with cores as calcic as An_{74}), and clinopyroxene, in an ophitic textural arrangement. Interstitial patches are present: either glass, or sodic plagioclase, or alkali feldspar. The glassy material may possibly represent an extreme fractionate, with a composition close to that of granite. Northwards, the A2 gabbro grades (gradually) into its altered variant (the Gabbro with Clouded Feldspars of (Weedon, 1961); see below). The upper contact, to the south, with the A1 Outer Gabbros, however, is sharp, being marked by a distinct topographic depression (Figure 6-9).

The altered A2 gabbro (Gabbro with Clouded Feldspars) is very similar to the unaltered A2 gabbro but is distinguished from it by the alteration present within the plagioclase crystals, and in some pyroxenes. It is exposed in the area NE of Sgùrr nan Eag and Sgùrr a' Choire Bhig. The boundary between the unaltered and altered gabbros is not sharp. (Weedon, 1961) suggested that these differences may be due solely to the ingress of (hydrothermal) fluids at elevated temperatures, which were enriched in iron. The subsequent emplacement of the Layered Peridotites to the north (see below) may be important in this respect, being a potential source of heat to drive convective hydrothermal systems.

6.B.2 The Border Group (B1 and B2)

The presence of a Border Group of rocks (B1 in Figure 6-8) to the 'B' group of rocks was first proposed by (Zinovieff, 1958) and investigated in detail by Hutchison ((Hutchison, 1964); (Hutchison, 1968)). Its contact with the Outer Gabbros (6.B.1) is exposed in Coire Làgan on the buttresses on the south side of the corrie (i.e. the north side of Sròn na Cìche). The material at the outer margin of the Border Group is a tholeiitic basalt containing xenoliths of bytownite gabbro. Progressing away from the contact, to the east, the Border Group grades into a 'zone of wispy banding' (Hutchison, 1968) which, in general, persists for *c.* 30m, before grading into unlayered bytownite troctolites (B2 in Figure 6-8: the 'White Allivalite' of (Hutchison, 1968)) and layered bytownite troctolites (B3 in Figure 6-8). The zone of wispy banding dips steeply inwards (eastwards), at an average angle of 80°, and forms a boundary layer that can be traced for over 5km along strike, to the north and south ((Hutchison, 1968)). Some of the most spectacular exposures of these B2 bytownite troctolites form the expansive slab-like 'boiler plates' in Coir' a' Ghrunnda (Figure 1-16; Figure 6-10; Figure 6-11).

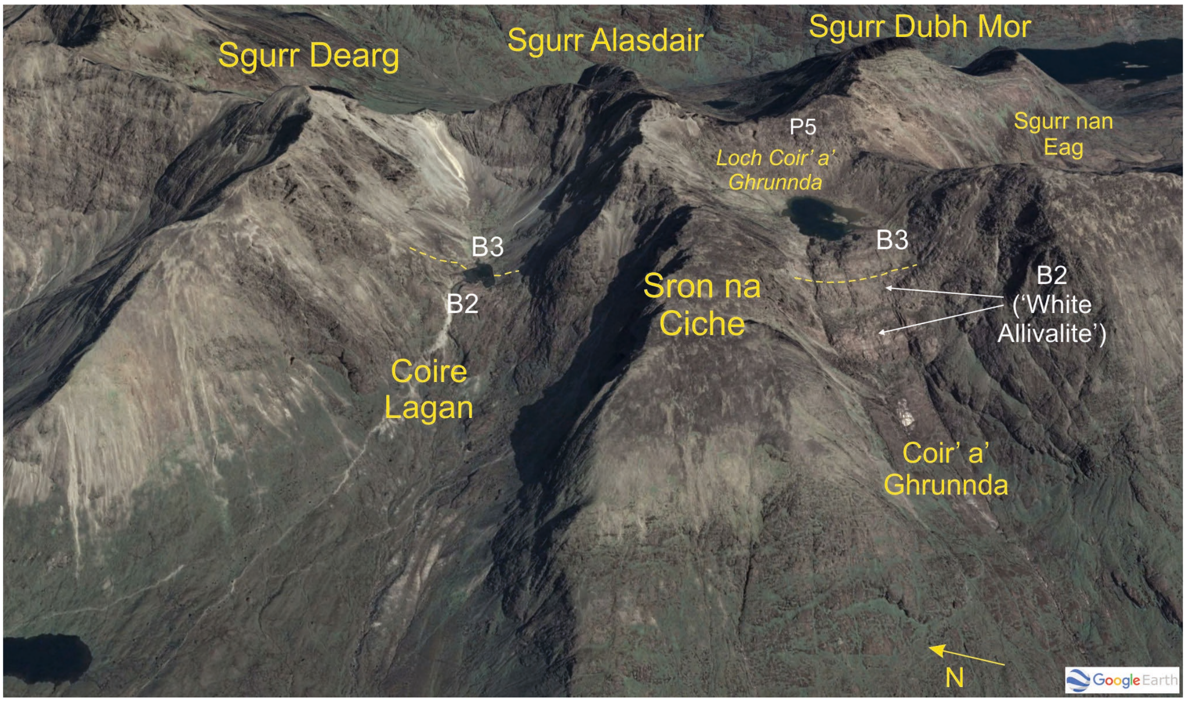


Figure 6-10 – Oblique Google Earth© image of the SW part of the Cuillin Hills, indicating the approximate outcrops of: B2 (Outer Unlayered Bytownite Troctolites or 'White Allivalite'); B3 (the Outer Layered Bytownite Troctolites); and, P5 (Layered Peridotites and Bytownite Troctolites). View towards the NE.

Figure 6-11 – Outer Unlayered Bytownite Troctolites (B2) (the 'White Allivalite') forming a glacially-sculpted 'boiler plate' in Coir' a' Ghrunnda, intruded by anastomosing basaltic minor intrusions.

The tholeiitic basalt at the margin of the Border Group contains olivine, two pyroxenes and intensely clouded plagioclases, with compositions of *c.* An_{57} (Hutchison, 1968). Progressing inwards (i.e. to the east) from the outer margin of the Border Group, the clouding within the plagioclase crystals diminishes and their compositions are more calcic (An_{85}). Textural variations are present within the zone of wispy banding, depending upon the inter-relationships of the pyroxenes and plagioclases. Crystal alignment textures are commonest near to the outer margin and die out inwards as the rock passes into coarse-grained, unlayered bytownite troctolite (B2).

The unlayered bytownite troctolite (B2; the 'White Allivalite') varies in width/thickness from 200m on the west side of Sgùrr Dearg, to 600m on the SW side of Sgùrr a' Mhadaidh. The incoming of (cumulus) olivine constitutes a demarcation between the unlayered bytownite troctolites (B2) and the subsequent rock unit, the layered bytownite troctolites (B3) (Figure 6-8). The inner contact of the unlayered bytownite troctolites (B2) dips inwards (to the east) at an angle of approximately 60°, but as its outer contact dips inwards at a steeper angle, this distinctive unit must thin upwards and outwards.

The unlayered bytownite troctolites are coarse-grained, locally pegmatitic rocks rich in plagioclase (cores of An_{90}, zoned to rims of An_{75}) intergrown with clinopyroxene. Olivine is present in amounts similar to that of clinopyroxene (10%), whereas orthopyroxene and Fe-Ti oxides are much less abundant. Cores of individual plagioclases tend to be euhedral, suggesting that at the time of emplacement, the magma had cooled below its liquidus temperature and contained a significant amount of plagioclase crystals. (Hutchison & Bevan, 1977) present evidence that the magma involved was picritic, rather than basic, as suggested by (Wager & Brown, 1968).

(Hutchison, 1968) envisaged the following steps in the development of the Border Group and the associated unlayered and layered bytownite troctolites within a funnel-shaped composite intrusion, requiring uplift of an (undefined) central block to create space for the incoming magma(s): (i) intrusion of a relatively thin sheet of tholeiitic basalt magma, with a cone–like geometry, possibly with entrained xenoliths, into intensely fractured Outer Gabbro(s), which cools and crystallises calcic plagioclases with random orientations; (ii) further intermittent injections of similar magma and associated uplift to produce the rocks within the 'zone of wispy banding' - localised more-hydrous magma produced the randomly-distributed pegmatites; (iii) further major uplift, interior to these marginal lithologies, associated with voluminous injection(s) of similar plagioclase-bearing basaltic magma, to produce the unlayered bytownite troctolites during periods of static crystallisation, and layered bytownite troctolites, with plagioclase-pyroxene and plagioclase-olivine cumulates, during periods when convective overturn and crystal accumulation took place, the latter banking up against the inner margin of the former.

6.B.3 The Outer Layered Bytownite Troctolites (B3)

The Outer Layered Bytownite Troctolites (B3) have an estimated thickness of 1800m and have been subdivided into five units (Zinovieff, 1958) (Figure 6-8; Figure 6-12). With the exception of the lowest unit (Unit 1), the basis of the divisions is plagioclase-pyroxene cumulates grading upwards into plagioclase-olivine cumulates, with the latter having good, small-scale layering. Plagioclase dominates throughout this group of rocks ($An_{82–87}$), along with olivine ($Fo_{81–84}$). (Zinovieff, 1958) identified two features used to distinguish the five units, namely, the general absence of layering and the presence of olivine only in small amounts at the base of each unit. Additionally, within the lowest part of the sequence, olivine constitutes approximately 40% of the rock, whereas in the highest part of the sequence it is only half this amount.

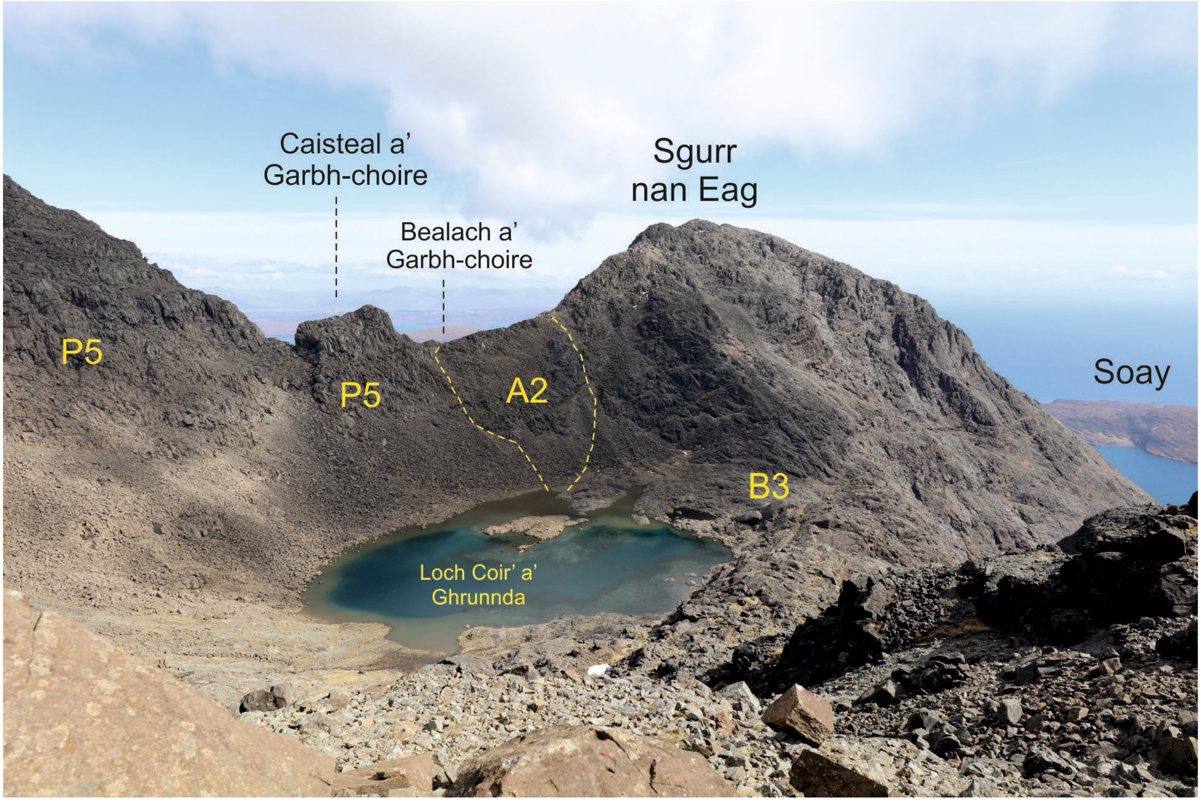


Figure 6-12 – Field photograph of the area around Loch Coir' a' Ghrunnda illustrating the distribution of: B3 (the Outer Layered Bytownite Troctolites); P5 (Layered Peridotites and Bytownite Troctolites); and, A2: Unlayered micro-gabbro. View towards the south across Loch Coir' a' Ghrunnda.

(Hutchison, 1968) and (Hutchison & Bevan, 1977) concluded that the Outer Layered Bytownite Troctolites (B3) are banked up against the unlayered bytownite troctolites of the Border Group (B2, see above) and constitute typical cumulates deposited (or accumulated) on the margin of a funnel-shaped magma chamber. (Hutchison & Bevan, 1977) suggested that the Unit 1 rocks, at the lowest exposed part of the sequence, may equate with the Unit 2 bytownite troctolites of the Layered Peridotites (6.B.4, below), with extensive ring-faulting bringing about the present-day field relationships. They envisage a series of events in which, after the formation of the Border Group rocks, there was a period during which olivine-rich cumulates (dunites) developed, and these were subsequently onlapped by peridotite cumulates (the Unit 1 rocks of the Layered Peridotites, see Section 6.B.4). This was followed by the development of bytownite troctolites when plagioclase started to crystallise and fractionate. The absence of pyroxene in the Unit 1 bytownite troctolites of the Outer Bytownite Troctolites suggests that these rocks are more likely related to the Layered Peridotites ((Wager & Brown, 1968); (Hutchison & Bevan, 1977)). The boundary between units 1 and 2 of the Outer Bytownite Troctolites, the latter rich in cumulus pyroxene, may represent the incoming of a new batch of magma.

With the downward faulting of the Layered Peridotites (6.B.4), relative to the Unit 1 rocks of the Outer Bytownite Troctolites and the Border Group rocks, the present distribution of rock-types may be explained.

6.B.4 The Layered Peridotites (P)

The Layered Peridotites are the oldest true ultrabasic cumulates (rocks formed by some mechanism of crystal accumulation) associated with the CIC (P in Figure 6-8). They are at least 500m thick, although the base of the sequence is not exposed, and crop out in an arcuate band running from the Allt Beag, which flows into Loch na Cuilce in the south, to Coireachan Ruadha in the north (Figure 6-13). In the lower part of An Garbh-choire, the peridotites are in direct, almost vertical, contact with Outer Gabbros (A1, 6.B.1), with the Border Group and associated bytownite troctolites (B, 6.B.2) absent. These relationships may be explained by a downward movement of a central portion of layered rocks (including the peridotites), bringing them into contact with the Outer Gabbros (A). The thermal role of the peridotites is discussed by (Wager & Brown, 1968), who suggest that the altered plagioclases present in the A2 micro-gabbro developed in response to the emplacement of this hot peridotite mass, although (Hutchison, 1966b) concludes that the clouding is a much later event.

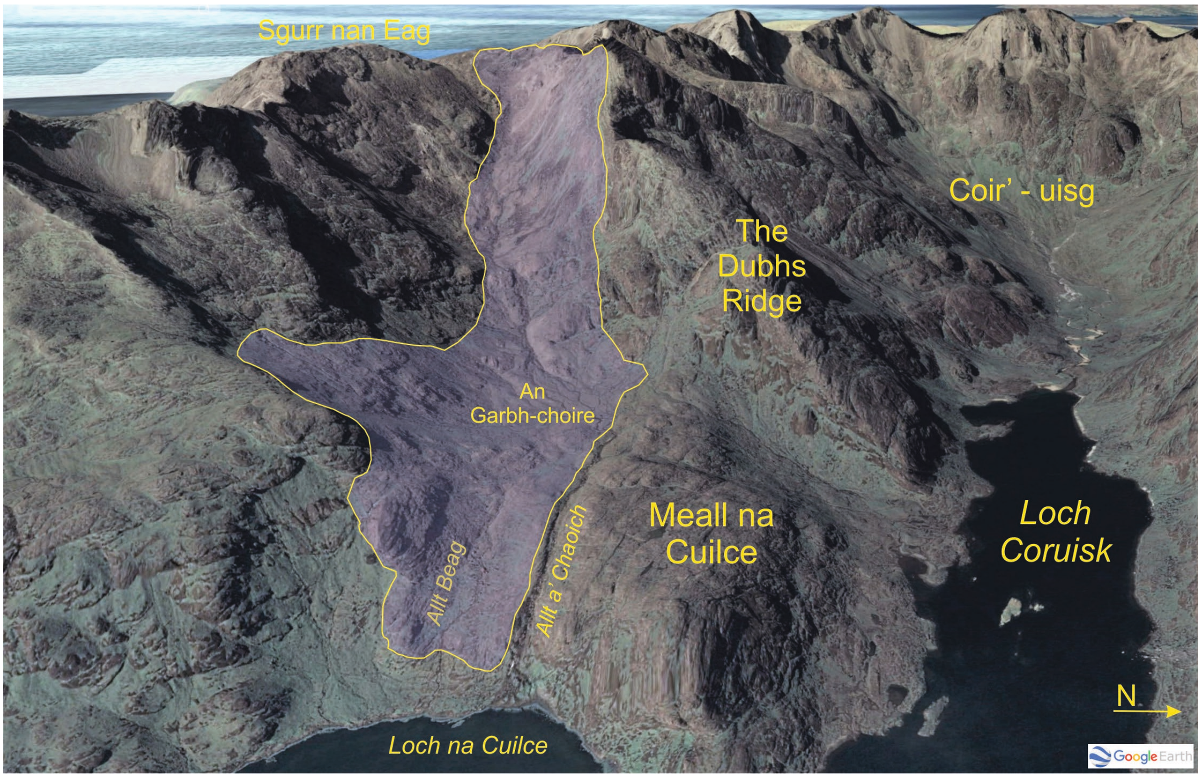


Figure 6-13 – Oblique Google Earth© image of the southern part of the Cuillin Hills, south of Loch Coruisk, indicating the approximate outcrop of the Layered Peridotites in An Garbh-choire (purple tint). View towards the west.

Details of the field relationships and petrology of the Layered Peridotites are given by Weedon ((Weedon, 1956); (Weedon, 1965)) and (Claydon & Bell, 1992). These olivine-rich rocks are relatively easily distinguished from gabbros and (plagioclase-rich) troctolites by their reddish-orange oxidation surfaces. Furthermore, the peridotites are relatively soft and easily eroded. They are readily accessed in An Garbh-choire, and in the area extending to the SE, south of the Allt a' Chaoich, but do not reach Loch na Cuilce. The outcrop continues to the west, across Caisteal a' Garbh-choire and Sgurr Dubh an Da Bheinn into the uppermost part of Coir' a' Ghrunnda (Figure 6-12) and north (east of the main Cuillin ridge) to Coireachan Ruadha. To the north of the outcrop, in the lower part of An Garbh-choire, the ground rises towards Meall na Cuilce, where rocks of the Outer Layered Bytownite

Gabbros (C in Figure 6-8) crop out. The nature of the contact between the peridotites and these bytownite gabbros is outlined, below.

(Weedon, 1965) identified three 'zones', each named after the dominant rock-types within it. They are: Zone I, dunites and peridotites; Zone II, 'allivalites' – now named bytownite troctolites and feldspathic peridotites (depending upon the amount of plagioclase present); and, Zone III, brecciation and segregation veins within Zone I and Zone II rocks.

Rocks of Zone I form the lowest part of the sequence. They are at least 200m thick and are exposed in the vicinity of the Allt Beag, near Loch na Cuilce (Figure 6-14). Layering is not particularly well-developed due to the dominance of equigranular olivine throughout. In the area nearest to Loch na Cuilce, the dominant rock-type is dunite (Figure 6-15), whereas to the west, further up-sequence, with the incoming of intercumulus plagioclase, are peridotites. The olivines have Mg-rich compositions, typically around Fo_{83}, and the interstitial plagioclase is An_{91} ((Hutchison & Bevan, 1977); (Bevan, 1982)). Apart from olivine and plagioclase, small quantities of chrome spinel, orthopyroxene and clinopyroxene are also present, uncommonly forming distinct (1–2cm thick) bands.

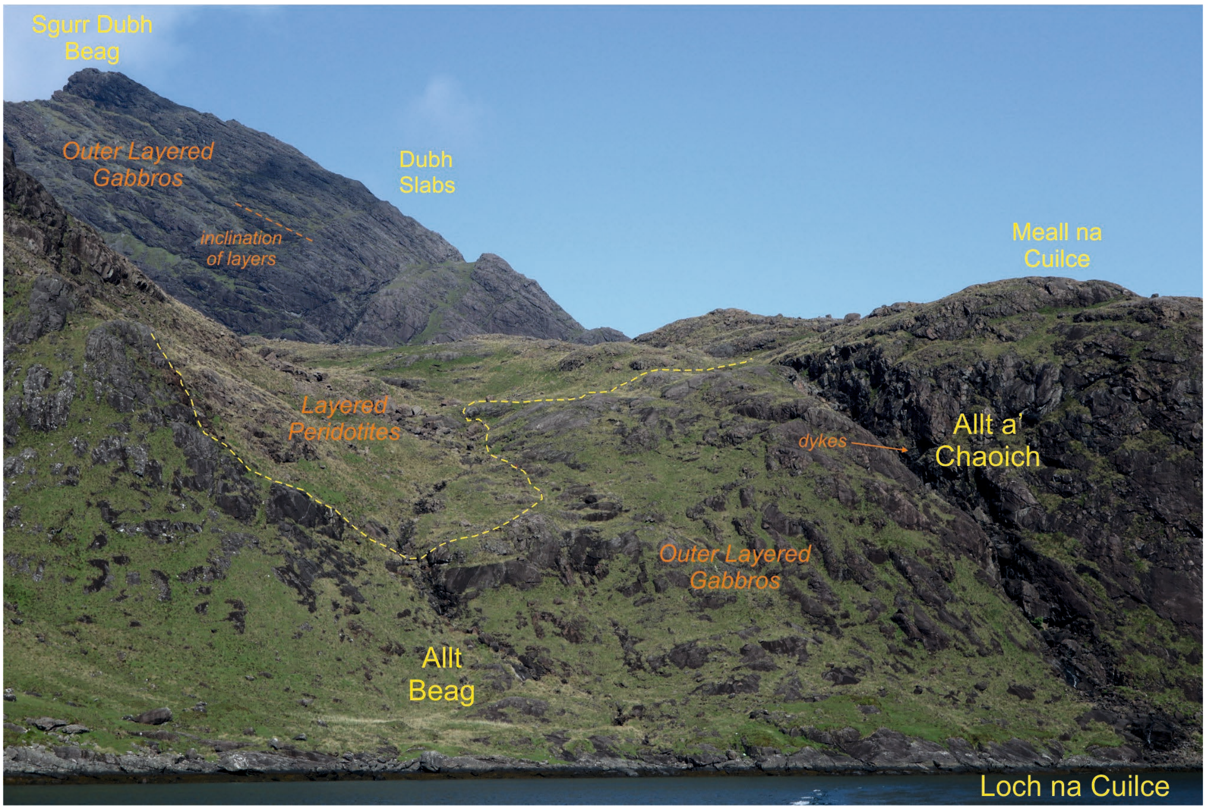


Figure 6-14 – Orange-red -weathering dunites of the Zone I Layered Peridotites south (left) of the Allt a' Chaoich, which flows into Loch na Cuilce. View towards the west.

Figure 6-15 – Dunites of the Zone I Layered Peridotites south of the Allt a' Choich. Compass *c.* 10cm long.

Zone II rocks are dominated by feldspathic peridotites and bytownite troctolites (allivalites of older literature). The presence of significant amounts of plagioclase produces excellent layering (Figure 6-16). These features are best observed between An Garbh-choire and Caisteal a' Garbh-choire. Features typically associated with cumulates are readily identified: mineralogically distinct layers, crystal size grading within layers, truncation of layers, slump structures, and 'cross-stratification'. Elongate, dendritic olivines are also present, forming a delicate interlocking structure most clearly seen on weathered surfaces. Layering becomes less obvious further up in the Zone II sequence, whereas small, rounded autoliths (fragments of genetically-related material; 'cognate xenoliths') are a common feature. Compositions of the olivines and plagioclases within the Zone II rocks have not been investigated in detail.

Figure 6-16 – Layered feldspathic peridotites of the Zone II Layered Peridotites in the lower part of An Garbh-choire. Pole *c.* 1m long.

The brecciation and segregation veins of feldspathic peridotite that constitute Zone III form an important component of the Zone I rocks around the headwaters of the Allt a' Chaoich (Figure 6-17 & Figure 6-18). These veins are typically 2–5cm wide and form an anastomosing series of stringers throughout the host rocks. Their presence suggests that a significant amount of post-depositional movement of inter-cumulus magma took place through the already-formed crystal (cumulate) pile. Further evidence of disturbance of the peridotites is seen in the form of slumps and folds within the succession, and in places layering dips atypically at angles in excess of 70° towards the middle of the intrusive centre, in the vicinity of Druim Hain.

Figure 6-17 – Zone III Layered Peridotites, comprising Zone I dunite and peridotite disrupted and invaded by veins of feldspathic peridotite, below the rock barrier in An Garbh-choire. View towards the NW.

Figure 6-18 – Typical Zone III veins of feldspathic peridotite in Zone I dunite, below the rock barrier in An Garbh-choire. Pole *c.* 1m long.

Subsequent ring-faulting along the inner margin of the Layered Peridotites most likely formed the magmatic disconformity between the Layered Peridotites and the overlying (younger) Outer Bytownite Gabbros (6.B.5).

In a re-investigation of the Layered Peridotites, (Claydon & Bell, 1992) added some new observations and interpretations to the excellent, robust observations of (Weedon, 1965). They identified six 'chronostratigraphic' units that comprise various layered olivine-rich cumulates, ranging from dunite through to feldspathic peridotite (Figure 6-8). The structurally lowest unit (P1) is dominated by dunite and contains abundant layers rich in chrome spinel. Other units contain plagioclase, both cumulus and intercumulus, and have excellent modal layering. Autoliths (cognate xenoliths) of various ultrabasic rock-types are common and typically accentuate the layering. Unit 4 (P4) is a heterogeneous breccia comprising plagioclase-dominated blocks in a matrix dominated by olivine, and olivine-dominated blocks in a matrix dominated by plagioclase. Block types vary from anorthosite through to dunite. Such breccias are most likely to be of intrusive origin and formed by the forceful injection of ultrabasic magma into ultrabasic rocks, the latter consequently disrupted and fragmented.

A number of unusual textural varieties of peridotite, as well as structures involving various ultrabasic rocks, are preserved within the Layered Peridotites (Claydon & Bell, 1992). For example, within Unit P5 on the south side of An Garbh-choire, structures that are approximately hemispherical and range in size from 15 to 200cm across, comprise dendritic intergrowths of poikilitic intercumulus plagioclase enclosing orientated cumulus olivine. Such structures most likely formed by nucleation and growth within a crystal mush from a hydrous, aluminous, ultrabasic magma. In addition, within Unit P5, along the interface of peridotite and troctolite layers, 'fingers' of peridotite penetrate into troctolite (Figure 6-19). These structures are interpreted as evidence that hot ultrabasic magma invaded pre-existing solid troctolite and eroded it by melting. From these and other observations it is now generally accepted that thick sequences of layered ultrabasic rocks, such as the Layered Peridotites of the Cuillin Intrusive Centre, were formed through the combined operation of a number of processes including crystal settling, *in situ* crystallisation, and the intrusion of sheets of hot magnesium-rich magma into pre-existing solid material of similar type.

Figure 6-19 – Irregular boundary between dark orange peridotite and pale layered troctolite in An Garbh-choire, where high-temperature peridotite magma has thermally eroded solid (crystallised) troctolite. Pole *c.* 1m long.

6.B.5 The Outer Bytownite Gabbros (C)

Detailed studies of this *c.* 1600m thick sequence of bytownite gabbros was undertaken by Carr ((Carr, 1952); (Carr, 1954)), Weedon ((Weedon, 1956); (Weedon, 1961)), (Zinovieff, 1958) and

(Jassim, 1970). On the basis of Carr's excellent work, three intervals or zones are recognised, each with distinct cumulus minerals. These are: Unit 1, plagioclase-olivine-clinopyroxene orthocumulates; Unit 2, olivine-rich adcumulates; and, Unit 3, olivine-magnetite adcumulates.

The Outer Bytownite Gabbros are exposed over a large sector of the complex, from SW of Sgùrr nan Gillean forming a crescent-shaped outcrop through Loch Coruisk, Sgùrr na Stri, Blà-bheinn (Blaven) and Garbh-bheinn (Figure 6-8). In the western part of the CIC, these bytownite gabbros are in contact with the Outer Bytownite Troctolites (B) and the Layered Peridotites (P), where a narrow, unlayered, marginal facies has been identified; in the vicinity of Sgùrr na Stri and in the Blà-bheinn - Garbh-bheinn sector, this unlayered facies is in contact with hornfelsed country-rock basaltic lavas. This boundary dips inwards at approximately 70°. Layering within the sequence dips towards the centre of the complex, and generally increases from values of *c.* 20° in the lowest (outer) parts of the sequence, to dips as high as 40° towards the top of the sequence, at the inner contact with the unlayered olivine-bytownite gabbros that form the ridge of Druim nan Ramh, north of Loch Coruisk (D2 in Figure 6-8, see also below). Generally, layering is more prominent towards the top of the sequence. The most easily accessed outcrops are those investigated by Carr (1952), in a traverse through Sgùrr na Stri and Sgùrr Hain (Figure 6-20; Figure 6-21; Figure 6-22; Figure 6-23).

Figure 6-20 – Layered Outer Bytownite Gabbros (C) north of Loch nan Leachd (northern end of Loch Scavaig), between the Scavaig River and the Bad Step. View towards the north.

Figure 6-21 – Detail of the layered Outer Bytownite Gabbros (C) north of Loch nan Leachd, between the Scavaig River and the Bad Step, with dark layers rich in olivine and pale layers rich in plagioclase. Note orange-weathered peridotite xenolith at top left. Pole *c.* 1m long.

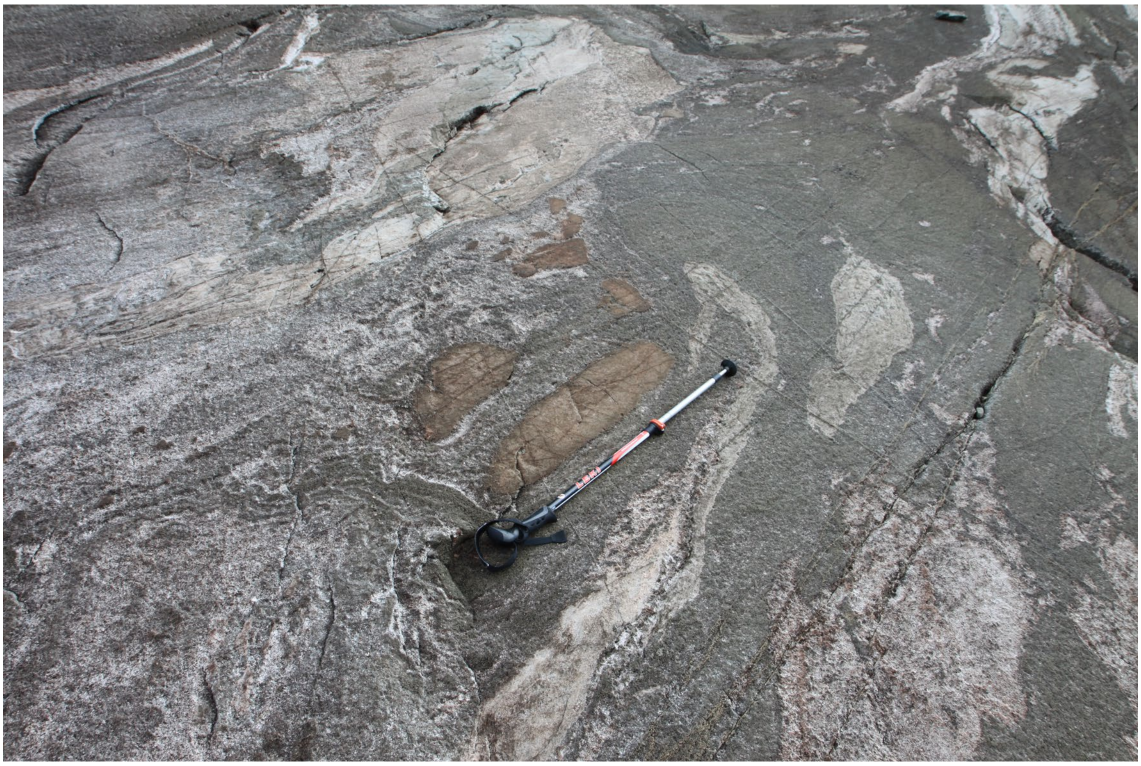


Figure 6-22 – Detail of the layered Outer Bytownite Gabbros (C) north of Loch nan Leachd, between the Scavaig River and the Bad Step, with elongate blocks/xenoliths of orange-weathered peridotite and pale troctolite. The host bytownite gabbro is relatively heterogeneous, with disrupted layering/banding and feldspathic veins. Pole *c.* 1m long.

Figure 6-23 – Well-developed mineral layering in the Outer Bytownite Gabbros (C) on Meall na Cuilce (between Loch Coruisk and Loch na Cuilce). Note xenoliths of orange-weathered peridotite at top left and the general northerly (top-right to bottom-left) dip of layering in the Outer Bytownite Gabbros *and* dolerite/basalt cone-sheets on Sgùrr na Stri in the distance. Shaft of hammer *c.* 30cm long.

Cryptic variation is present, to a minor extent, within these rocks, with plagioclase ranging from An_{75} in the lowest exposed part of Unit 1, to An_{67} at the top of Unit 3. Likewise, olivine varies from Fo_{74} to Fo_{67}. A significant and distinctive feature of these cumulates, especially in units 2 and 3, is the presence of 'calcic-phase phenocrysts' of plagioclase, with a relatively constant composition of An_{85} (Carr, 1952). It is likely that their presence indicates the incoming of a new batch of crystal-laden magma at that stage in the development of the intrusive centre.

(Carr, 1952) also discusses the presence of various types of 'blockstuff' (i.e. xenoliths) within the Outer Bytownite Gabbros. These are principally blocks of dunite and peridotite, but also includes bytownite troctolite, bytownite gabbro, gabbro, dolerite and basalt, and are found particularly in the Meall na Cuilce area ((Weedon, 1956); (Weedon, 1961)). Their incorporation into the Outer Bytownite Gabbros suggests that disturbance of already-consolidated material within the intrusive centre took place during magma emplacement/intrusion. This may have involved faulting, with (central) subsidence or marginal uplift taking place.

The inner margin of the Outer Bytownite Gabbros is marked by the strongly discordant D2 unlayered olivine-bytownite gabbro forming the ridge of Druim nan Ramh, which cuts across rocks of all three units.

(Brandriss, et al., 2014) concluded on the basis of a detailed investigation of the exposures illustrated in Figure 6-20, Figure 6-21 & Figure 6-22, that the layered character of the Outer Bytownite Gabbros is the result of repeated influxes of plagioclase porphyritic basaltic magma into the magma chamber, depositing their crystals on the contemporaneous floor of the chamber and producing what they refer to as ‘coarse-grained massive gabbro.’ During periods between these influx events, ‘normal’ crystal settling processes or *in situ* crystallisation produced the intervening layers of ‘fine-grained laminated gabbro.’ Interstitial melts trapped between the main cumulus minerals in both types of gabbro were partially expelled during compaction, typically more efficiently from the laminated gabbro. (Brandriss, et al., 2014) infer from geochemical data that the magma chamber was sheet-like and of relatively small volume. This model is in accord with that suggested by (Carr, 1952), some sixty years previously.

6.B.6 The Unlayered Olivine-bytownite Gabbro of Druim nan Ramh (D)

The unlayered olivine-bytownite gabbro that crops out on the ridge of Druim nan Ramh is a coarse-grained rock devoid of layering and has a semi-circular outcrop that separates the Outer and Inner groups of the CIC (Figure 6-24;Figure 6-25). It was first described by (Carr, 1952), who referred to it as an ‘invading eucrite'. Subsequent work by (Zinovieff, 1958) infers that this unit is a ring-shaped intrusion and suggests that the rocks interior and exterior to the intrusion can be correlated. On this basis, (Wager & Brown, 1968) suggested that large displacements of a central block took place prior to, and during, the injection of the unlayered olivine-bytownite gabbro. Such displacements, however, would have to be of the order of 1000m in an upward direction - contrary to the perceived general trend of central subsidence throughout the evolution of the intrusive centre.

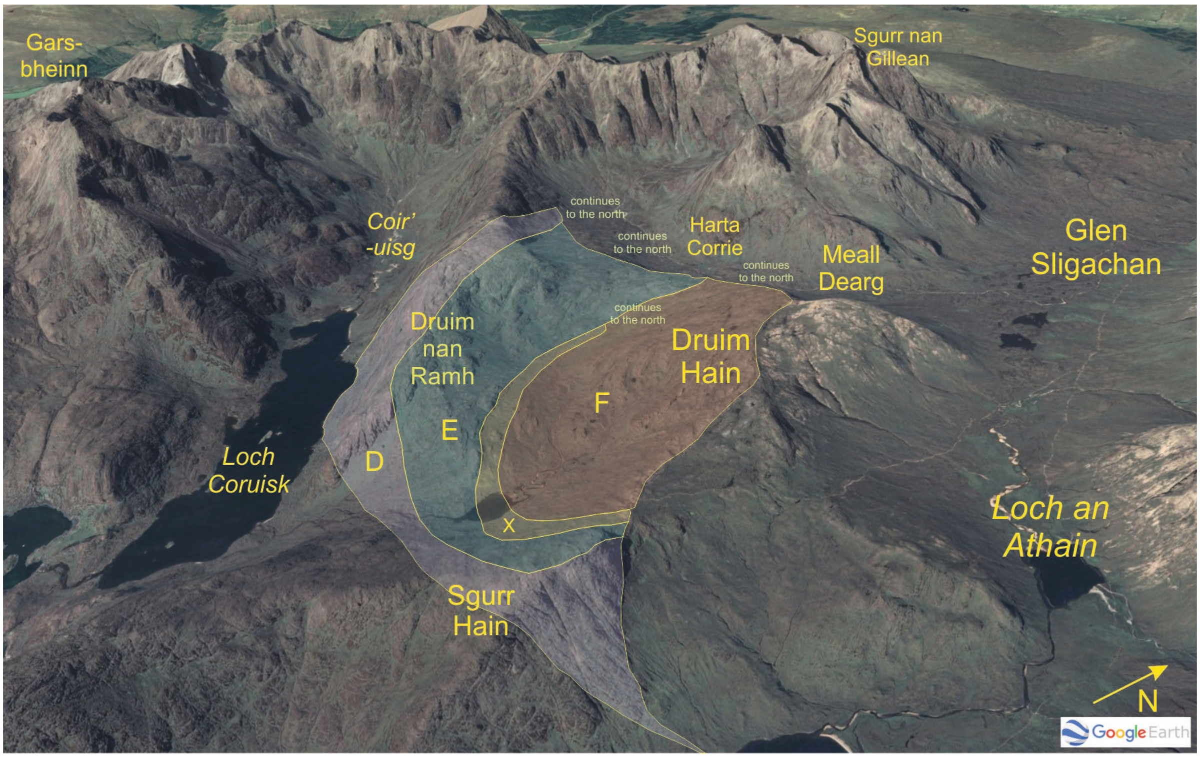


Figure 6-24 – Oblique Google Earth© image illustrating the outcrop of the unlayered olivine-bytownite gabbro of Druim nan Ramh (D), the Inner Bytownite Troctolites (E), the Inner Gabbros (F) and a zone of intrusion breccia (X). View towards the west. Oblique projection causes some distortion of outcrop geometry.

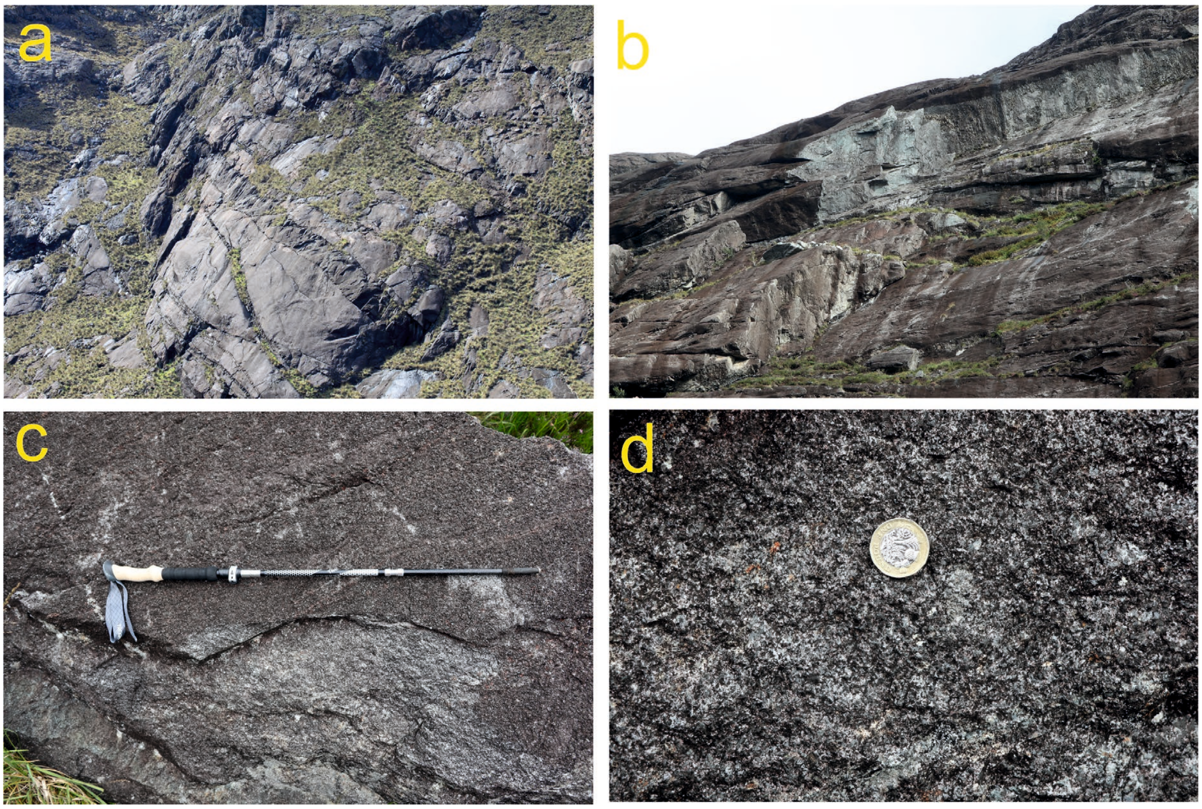


Figure 6-25 – Field images of the Unlayered Olivine-bytownite Gabbro of Druim nan Ramh (D): (a) intruded by dolerite cone-sheets, west of the Allt a' Choire Riabhaich (NE of Loch Coruisk); (b) collapsed surface, NE of Loch Coruisk; (c) typical weathered and fresh surfaces, pole *c.* 1m long; and, (d) typical fresh surface, coin *c.* 24mm across.

An alternative hypothesis is that this unlayered olivine-bytownite gabbro represents a marginal group of rocks and marks the onset of a second major phase of intrusive activity within the CIC, related to the development of the Inner Bytownite Troctolites (E, see 6.B.7, below) and the Inner Gabbros (F, see 6.B.8, below).

Irrespective of its status, the unlayered olivine-bytownite gabbro of Druim nan Ramh has almost vertical contacts and an average width, at the present level of erosion, of *c.* 200m. It is truncated to the SE, on the west side of Srath na Crèitheach, by volcaniclastic rocks, and to the north by the Marsco Granite of the Western Red Hills Intrusive Centre. It is best observed on Druim nan Ramh. The outer contact is extremely irregular, consisting of veins injected into the Outer Bytownite Gabbros. (Zinovieff, 1958) notes that individual veins are commonly enriched in one mineral, for example, olivine or pyroxene, suggesting that the magma was introduced as pulses of crystal-laden mush. Progressing inwards, a xenolithic facies is encountered, containing blocks/xenoliths of material from outer units, particularly bytownite troctolite and bytownite gabbro. The inner contact is much sharper, and it is possible to distinguish the unlayered olivine-bytownite gabbro from the Inner Bytownite Troctolites (Zinovieff, 1958).

The dominant mineralogy of the unlayered olivine-bytownite gabbro of Druim nan Ramh is calcic plagioclase ($An_{70–82}$) intergrown with clinopyroxene. Olivine and Fe-Ti oxides are also present but are not abundant.

6.B.7 The Inner Bytownite Troctolites and Inner Bytownite Gabbros (E)

Very little published information is available on the Inner Bytownite Troctolites. According to (Zinovieff, 1958), three units can be identified, which it is suggested are simply a repetition of part of the Outer Bytownite Troctolites (B, see 6.B.3, above). The estimated thickness of the sequence is of the order of 500m, and individual units consist of plagioclase-pyroxene cumulates at the base, grading upwards into finely laminated plagioclase-olivine cumulates. Where layering is present, it dips towards a focal point similar to that deduced for units of the outer sequences, i.e. below Meall Dearg, at the southern end of Glen Sligachan. These rocks are best examined on the high ground east of Sgùrr nan Gillean and in the vicinity of the summit of Sgùrr Hain.

The Inner Bytownite Gabbros are of the order of 450m thick and are exposed in Harta Corrie, where in direct contact with the Inner Bytownite Troctolites, which they overlie at a steep angle (Zinovieff, 1958) (Figure 6-26). Layering is not well developed and these rocks are truncated to the east by a large mass of breccia on Meallan Dearg, and to the NE by a faulted contact with the younger Inner Gabbros (F, see 6.B.8, below). Poor exposure, plus the effects of later intrusions, largely prevents a detailed investigation of these rocks.

Figure 6-26 – Field image of the Inner Bytownite Gabbros (E) on the NE side of Druim nan Rahm. Pole *c.* 1m long.

6.B.8 The Inner Gabbros (F)

The Inner Gabbros constitute the youngest group of cumulates preserved within the CIC. They are best exposed on the ridge of Druim Hain, west of Srath na Crèitheach, as, to the south, in Coire Riabhach, exposure is poor (Figure 6-27). Within the latter region, however, it is possible to identify a vertical shatter zone, approximately 50m wide, along which (it has been suggested by (Wager &

Brown, 1968) that) downward movement of the Inner Gabbros has brought them to their present position (Figure 6-28). (Carr, 1952) estimated that this displacement is of the order of 300m. Rocks within this zone are intensely crushed, resulting in a fragmental rock, a breccia that contains obvious fragments of peridotite. These shattered rocks are also cut by numerous irregular intrusions of dolerite and basalt.

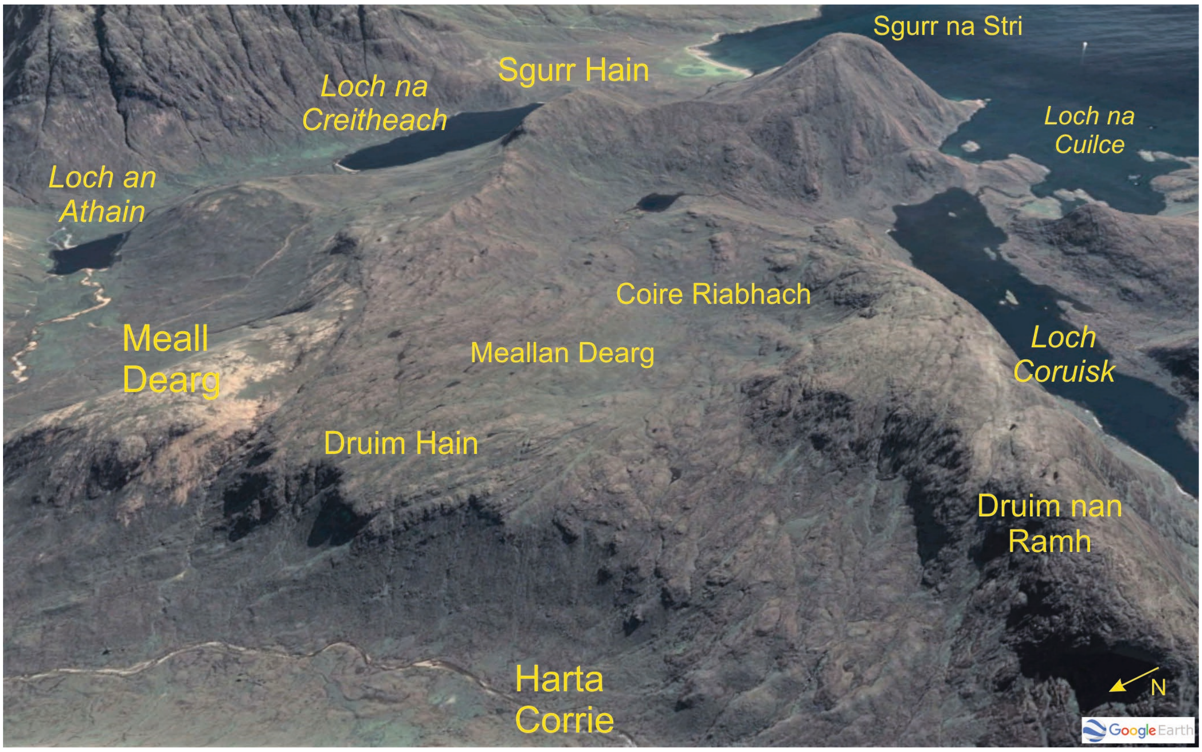


Figure 6-27 – Oblique Google Earth© image of the Druim Hain area.

Figure 6-28 – Field image of the Inner Gabbros (F) on Druim Hain. View is towards the NW, with Sgùrr nan Gillian as the right-hand pyramidal summit in the distance.

A recognisable sequence of gabbros, at least 750m thick, is preserved on Druim Hain (Figure 6-29; Figure 6-30).

The arcuate distribution of the layering is easily recognised (Figure 6-27), with the focal point lying below Meall Dearg to the north (Figure 6-27). The lowest rocks of the sequence show the weakest development of layering and constitute a thickness of at least 200m. The incoming of a distinct lamination marks the main portion of the layered sequence, at least 300m thick. These rocks exhibit excellent rhythmic layering, uncommonly showing mineralogical grading, with magnetite enrichment at the base of individual units, passing upwards into plagioclase-rich tops. The dip of the layers ranges from *c.* 30° in the lower parts of the sequence, up to 70° at the top of the preserved sequence. Normal cryptic variation is present within both the plagioclases and the olivines, with ranges of $An_{58–69}$ and $Fo_{58–66}$, respectively. Apatite also occurs as a cumulus phase, indicating that the magmas involved achieved relatively evolved compositions. The highest exposed rocks (SSE of Meall Dearg) have uncommon developments of coarse pegmatitic facies.

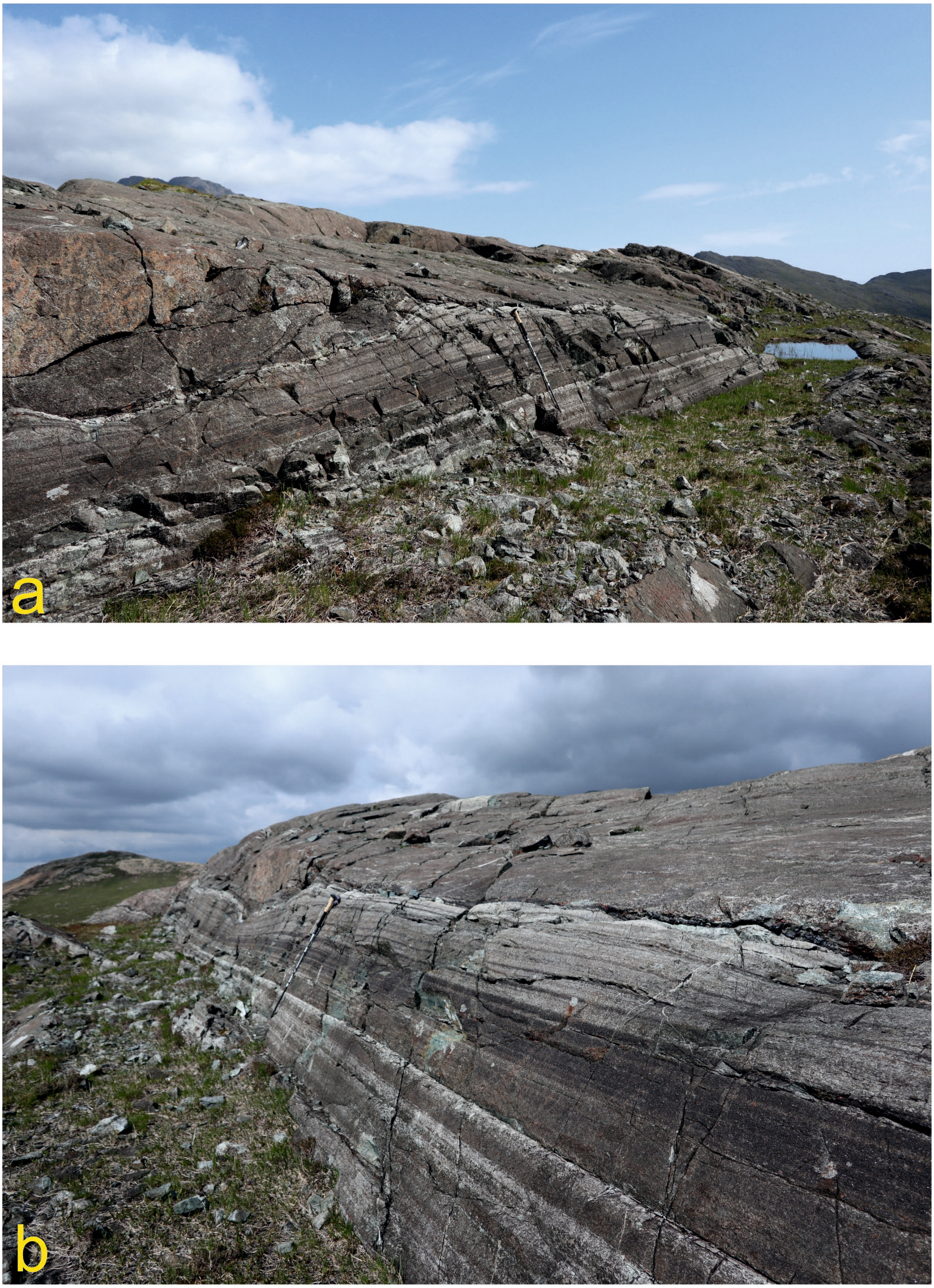


Figure 6-29 – Field images of (same exposure) of steeply inclined Inner Gabbros (F) on Druim Hain: (a) towards the NE; and, (b) towards the NW, with Meall Dearg in the distance. Pole *c.* 1m long.

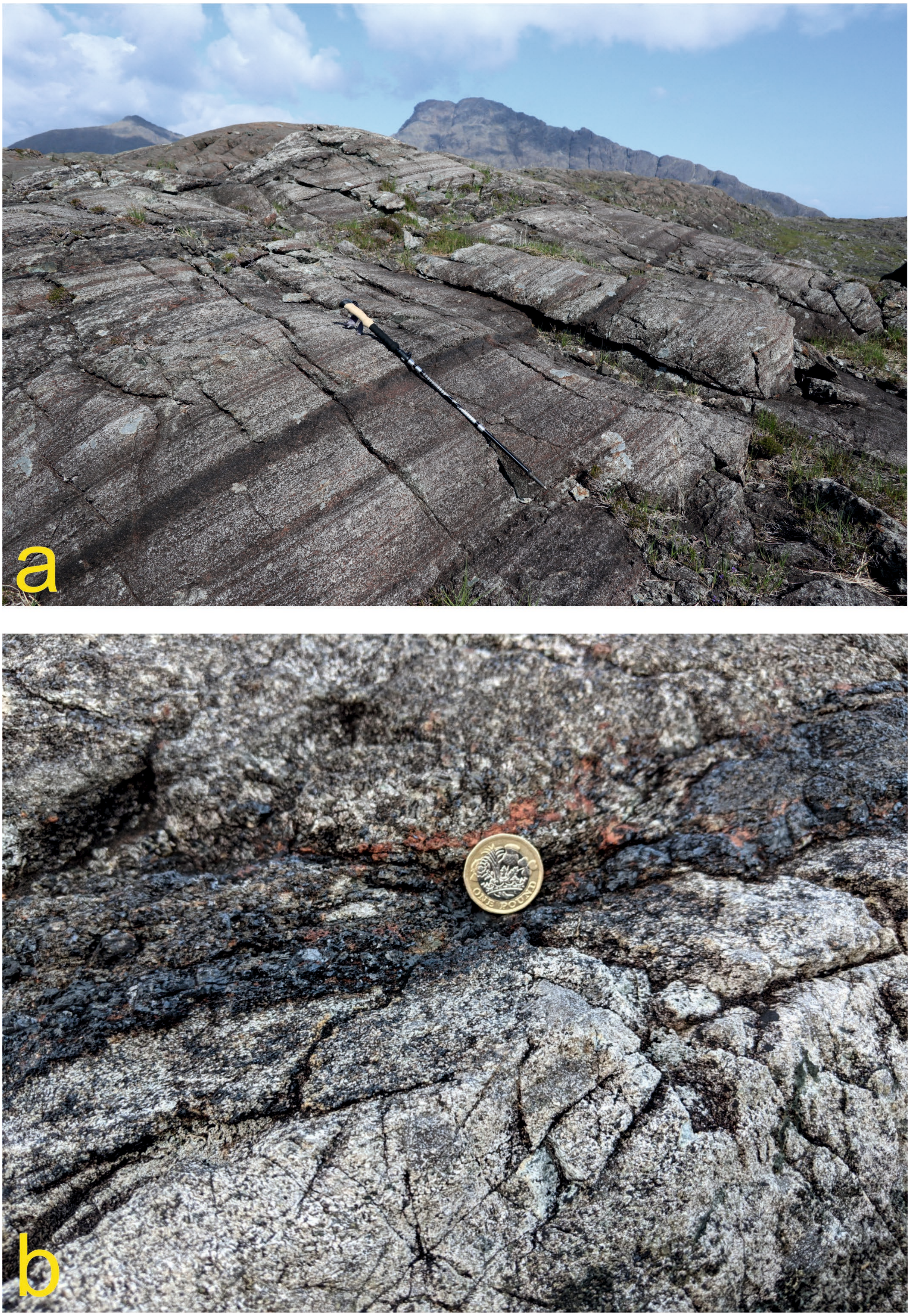


Figure 6-30 – Field images of the Inner Gabbros (F) on Druim Hain, with: (a) a prominent dark layer rich in magnetite, pole *c.* 1m long; and, (b) a thin layer dominated by magnetite, coin *c.* 24mm across.

The Inner Gabbros contain calcium-rich plagiocases (An_{85}), similar in character/composition to plagioclases ('calcic-phase phenocrysts') in the Outer Bytownite Gabbros, especially units 2 and 3 (see 6.B.5, above). Their presence suggests that the supply of new batches of crystal-laden (plagioclase-porphyritic) magma may have continued until at least this stage in the evolution of the intrusive centre. Xenoliths present within these gabbros include: peridotite, bytownite gabbro and dolerite.

Any coarse-grained basic or ultrabasic rocks that may have formed at a later stage than the (preserved portion of the) Inner Gabbros has subsequently been removed by erosion.

6.B.9 Volcaniclastic Pipes

(Zinovieff, 1958) describes over forty pipe-like masses of breccia throughout the western portion of the CIC (Figure 6-31). Other similar material has been identified in the eastern sector of the complex (Dundas, in a personal communication to J.D. Bell 1976), as well as to the south of the complex, on the north side of the Soay Sound (Harker, 1904).

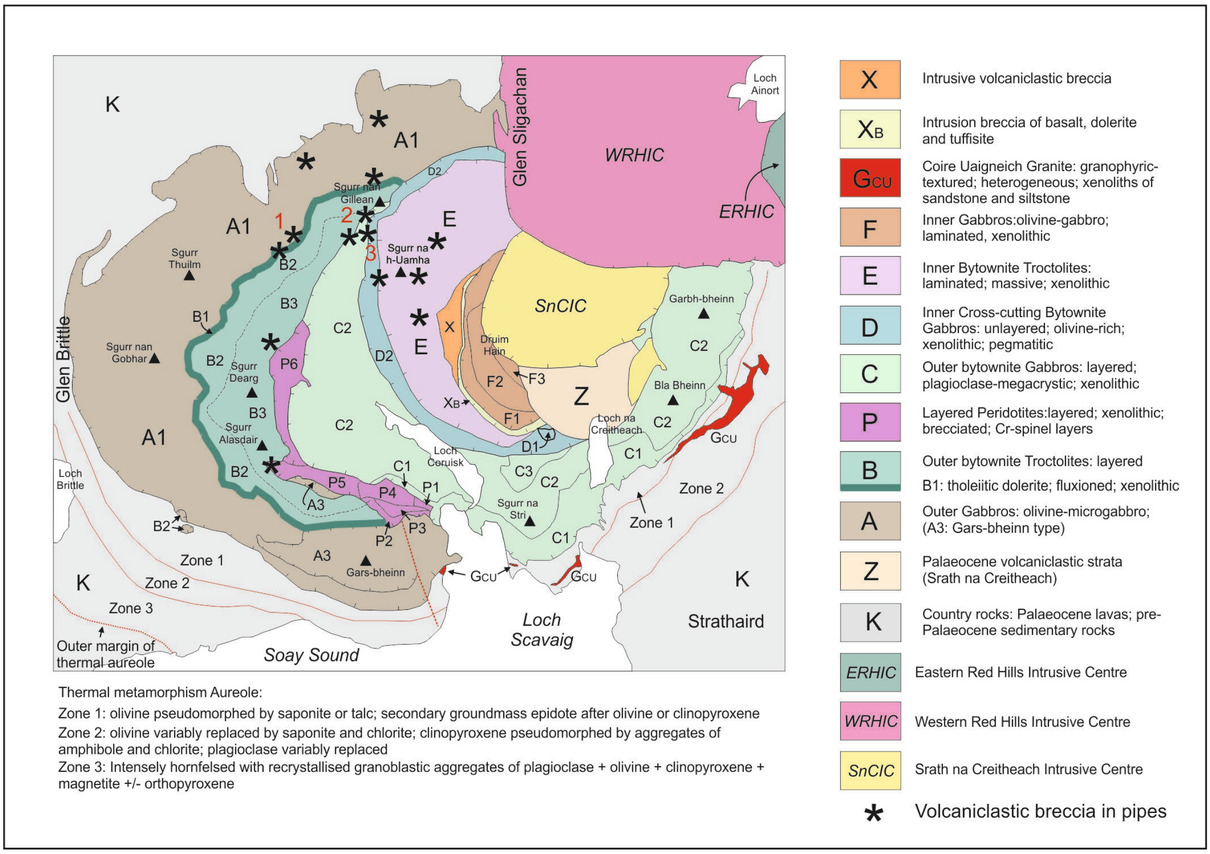


Figure 6-31 – Map showing the distribution of the (main) volcaniclastic pipes intruded into the CIC. 1, Coire na Creiche; 2, Sgùrr nan Gillean; 3, Lotta Corrie (see main text).

These masses of breccia pierce, and hence post-date, the various coarse-grained basic and ultrabasic rocks of the CIC. They are readily identified in the field by their distinctly fragmental appearance and consist of blocks of basic and ultrabasic rock-types set in a doleritic or fine-grained fragmental matrix (Figure 6-32; Figure 6-33).

Figure 6-32 – Field image of a volcaniclastic pipe in Harta Corrie, with angular blocks of basalt and dolerite in a basaltic matrix. Pole *c.* 1m long.

Figure 6-33 – Field image of a volcaniclastic pipe in Harta Corrie, with angular blocks of basalt and dolerite in a doleritic matrix. Coin *c.* 24mm across.

(Zinovieff, 1958) identifies three main groups of pipes: (1) the Coire na Creiche Group; (2) the Sgùrr nan Gillean Group; and, (3) the Lota Corrie Group (Figure 6-31). Other smaller, geographically localised groups are present throughout the Cuillin Hills.

The largest single outcrop is on Meallan Dearg, south of the lower part of Harta Corrie. Close to the outcrop margin, the most prominent blocks are of fine-grained fragmental rock, grading over a short distance, inwards, into a coarse, block-dominated breccia. The dominant block-types are of bytownite troctolite, bytownite gabbro and gabbro, commonly angular, set in a predominantly doleritic, but in places finer-grained fragmental, matrix. Crush zones are common.

The size, degree of rounding and sorting of the blocks within these pipe-like structures appears to depend upon the structural height at which the material exists. (Zinovieff, 1958) proposed the following model to explain the observed features. First, magma (dyke) injection causes brecciation of the coarse-grained (igneous) country-rocks, whilst under compression. Increased vapour pressure due to rapid cooling of this magma causes fluidisation of the blocks that have formed, transporting them upwards in a coherent fashion. During this process, abrasion of blocks, mixing, and further brecciation takes place, resulting in the development of fine-grained matrix material. Material of this type penetrates upwards to the highest structural levels (for example, on the upper parts of Sgùrr nan Gillean). Finally, the fluidised masses collapse, due to the lack of a sufficient pressure gradient to drive the system, resulting in the preserved textural characteristics.

The pipe on the southern slopes of Sgùrr na h-Uamha shows many of the features outlined above (Zinovieff, 1958). At its base, the dominant material is a coarse-grained breccia, with numerous associated basaltic and doleritic dykes. The matrix constitutes *c.* 10% of the total volume of the pipe. This passes upwards into a breccia with more rounded clasts, set in a fine-grained fragmental matrix. Material in the uppermost preserved part of the pipe is highly vesiculated, suggesting a final escape of gas from the system.

6.B.10 Cone-sheets of the Cuillin Intrusive Centre

Cone-sheets intrude the coarse-grained basic and ultrabasic rocks of the CIC, as well as the Coire Uaigneich Granite (see 6.C, below) and parts of the surrounding country-rocks. They have a focal point below Meall Dearg (at an estimated depth of 2–3km), at the southern end of Glen Sligachan. The Skye cone-sheets were first investigated by (Harker, 1904), who referred to them as inclined basic sheets. Subsequent work by (Bailey, et al., 1924) on Mull led to the use of the term cone-sheet (Figure 6-34).

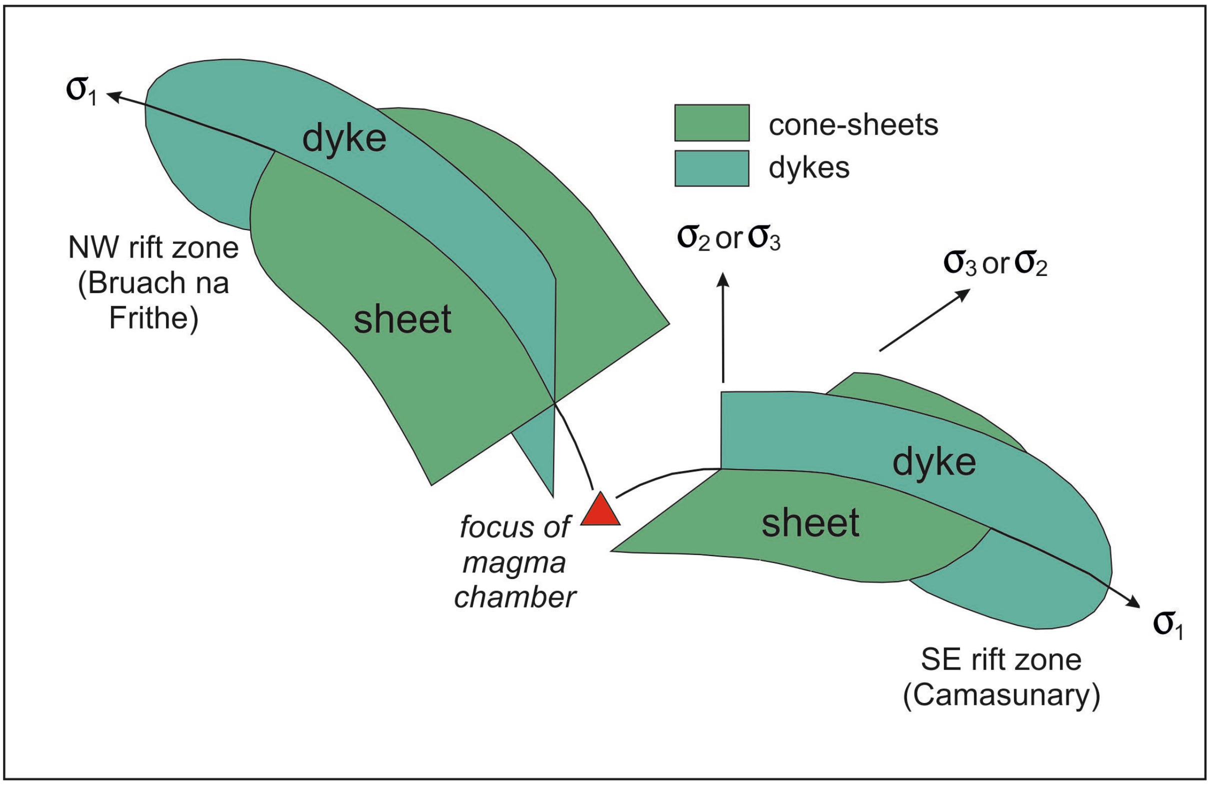


Figure 6-34 – Relationship between cone-sheets and the Main Dyke Swarm. Dykes are injected when the principal deviatoric stress axis, 3, is horizontal, and cone-sheets are injected when the principal deviatoric stress axis is vertical (after Walker 1993b and Emeleus & Bell 2005).

The cone-sheets are most common in the units immediately exterior and interior to the unlayered olivine-bytownite gabbro of Druim nan Ramh (see 6.B.6, above), where they dip inwards at an angle of 35–40°. Exterior to the olivine-bytownite gabbro, in 'lower stratigraphic/lithodemic units', they dip at shallower angles (10–20°), whereas in 'higher stratigraphic/lithodemic units' they dip at higher angles (50–65°). In general, the cone-sheets are concordant, or nearly so, with any layering present within the host basic and ultrabasic units of the CIC (Figure 6-35; Figure 6-36).

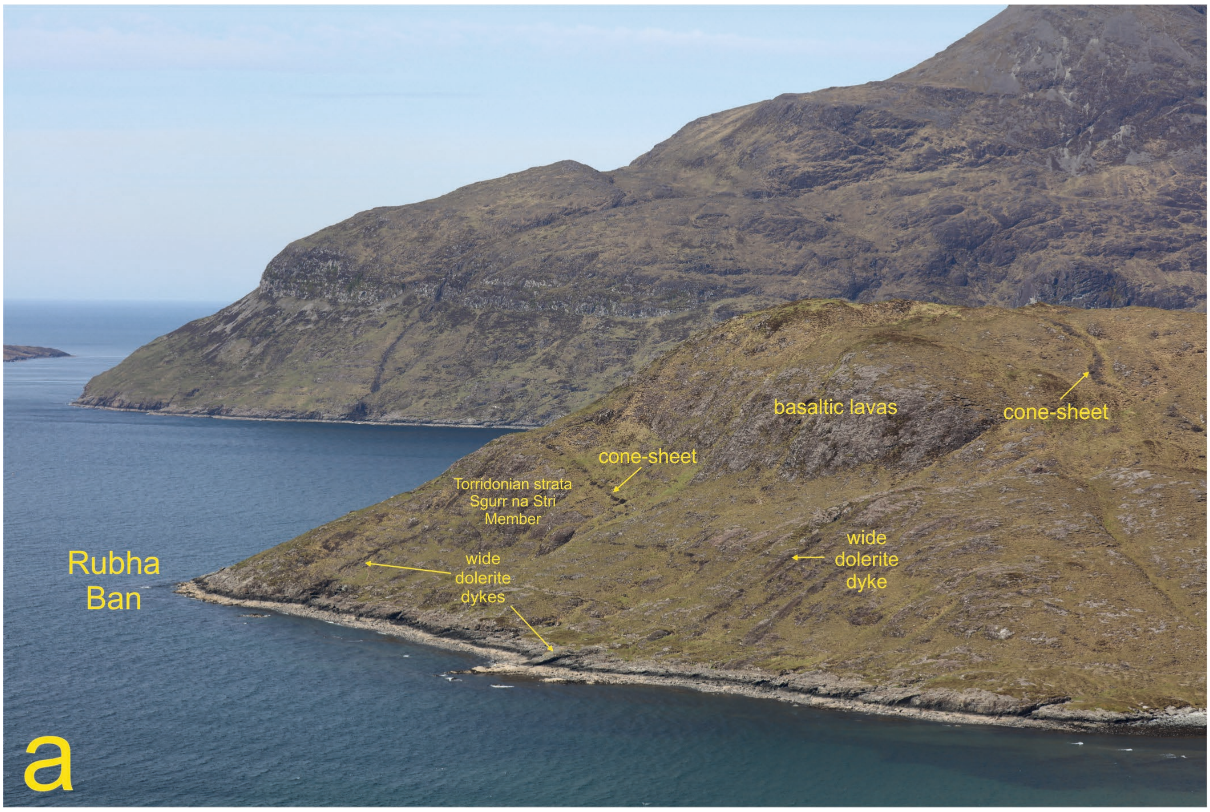


Figure 6-35 – Two thick cone-sheets intruded into Torridonian strata and basaltic lavas north of Rubha Bàn on the west side of Camasunary Bay. These cone-sheets are located in the 'SE Rift Zone'. Views towards the west.

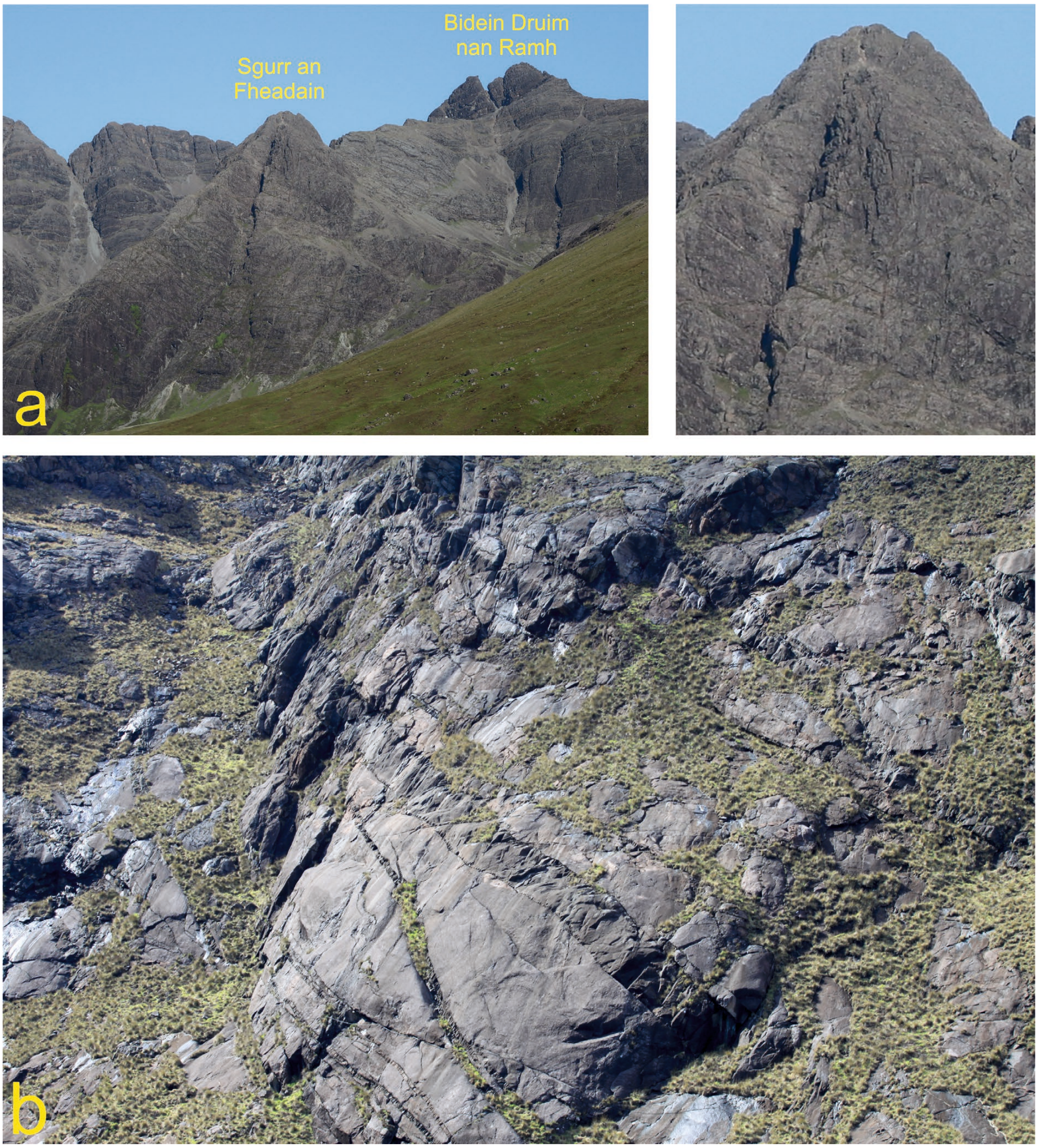


Figure 6-36 – (a) Thin, ribbon-like cone-sheets within Outer Gabbros (A) and Outer Bytownite Troctolites (B) on Sgùrr an Fheadain (centre and close-up of summit and Waterpipe Gully) and Bidein Druim nan Ramh (right of centre); and, (b) cone-sheets intruded into the Outer Bytownite Gabbros (C) between the Scavaig River and The Bad Step on the west side of Sgùrr na Stri.

Most of the cone-sheets are olivine-free, non-porphyritic dolerites with tholeiitic affinities and weather to a dark grey (Harker, 1904). They are generally less than 1m thick. The dominant minerals are plagioclase and augite, in an ophitic to sub-ophitic textural arrangement. (Harker, 1904) also reported xenocrysts of plagioclase and xenoliths of gabbro within some of these cone-sheets, for example, on Sgùrr a' Bhàsteir, on Druim nan Ramh, and, below the Inaccessible Pinnacle of Sgùrr Dearg.

A second variety of cone-sheet is the porphyritic dolerite type, also free of olivine. (Harker, 1904) recorded their presence in Coire' a' Chruidh and east of Gars-bheinn, both in the southern part of the Cuillin Hills. The phenocrysts within this type are zoned plagioclases, with compositions typical of the labradorite range, set in a groundmass of plagioclase, augite and Fe-Ti oxides. Locally, cone-sheets of this type contain phenocrysts of plagioclase up to 6mm in length, with rounded margins, set in a granulitic groundmass of plagioclase, augite and Fe-Ti oxides.

(Harker, 1904) also identified a porphyritic olivine dolerite variety, which is restricted to the Sgùrr Thuilm area in the Western Cuillin Hills. This type is relatively fine-grained and contains, in addition to olivine microphenocrysts, abundant phenocrysts of plagioclase.

A fourth type of cone-sheet, identified by (Harker, 1904), is similar to the dominant non-porphyritic dolerite noted above, but is, in contrast, more basic and contains abundant groundmass olivine and bytownite. This mineralogical difference is readily noted in the field as these intrusions weather to a distinctive rusty-red. The rock which forms part of the twin summit area of Blà-bheinn (Blaven) is a particularly good example of this type of cone-sheet.

(Bell, et al., 1994) investigated the geochemical evolution of the cone-sheets from a suite of samples in a traverse between Rubha Bàn, south of Sgùrr na Stri, north to Sgùrr Hain. The most primitive samples are of tholeiitic basalt, almost identical in composition to that of the intracanyon lava of the Talisker Formation on Minginish (5.D). Dykes from the axial zone of the Skye Main Dyke Swarm (Chapter 7) share the same compositional characteristics. Intra-suite compositional variation of the cone-sheets can be modelled in terms of low-pressure fractional crystallisation of olivine, clinopyroxene and plagioclase, with the most evolved composition(s) produced by 60% crystallisation of the most primitive composition. Trace-element and isotope geochemical data indicate that during fractional crystallisation of the cone-sheet magma(s), contamination by upper crustal country-rock material, most likely amphibolite facies gneisses of the Lewisian Gneiss Complex (3.B) occurred.

The cone-sheets pre-date the majority of the granites associated with the Skye Central Complex (SCC). However, cone-sheets do cut the Coire Uaigneich Granite (see 6.C, below) and this led (Richey, 1932) to conclude that granites of (distinctly) different ages are present within the SCC.

6.B.11 The Tholeiite Sheets of the Western Cuillin Intrusive Centre

Within the gabbros (*s.l.*) of the Western Cuillin Hills, several sheets of amygdaloidal tholeiitic basalt/dolerite and associated breccias were recognised by (Hutchison, 1966a). These rocks were originally described by (Harker, 1904), who concluded that they were remnants of the plateau lava sequence that had been incorporated into the gabbro by the foundering of large slabs into the magma chamber. (Bailey, 1952) re-investigated these rocks and suggested that they were normally-crystallised, medium- to fine-grained tholeiitic basalt intrusions. This conclusion was also reached by (Hutchison, 1966a) and it is mainly from this work that the following descriptions are taken.

Two suites of intrusions are recognised (Figure 6-37): an Outer Complex, consisting of three near-horizontal, N-S -trending sheets west of Coire na Banachdich associated with many more inwardly-inclined (50–60°) sheets forming the lower parts of Coire na Banachdich; and, an Inner (Main Ridge) Complex, consisting of numerous sheets also dipping inwards at 60°, which crop out along the main Cuillin Ridge.

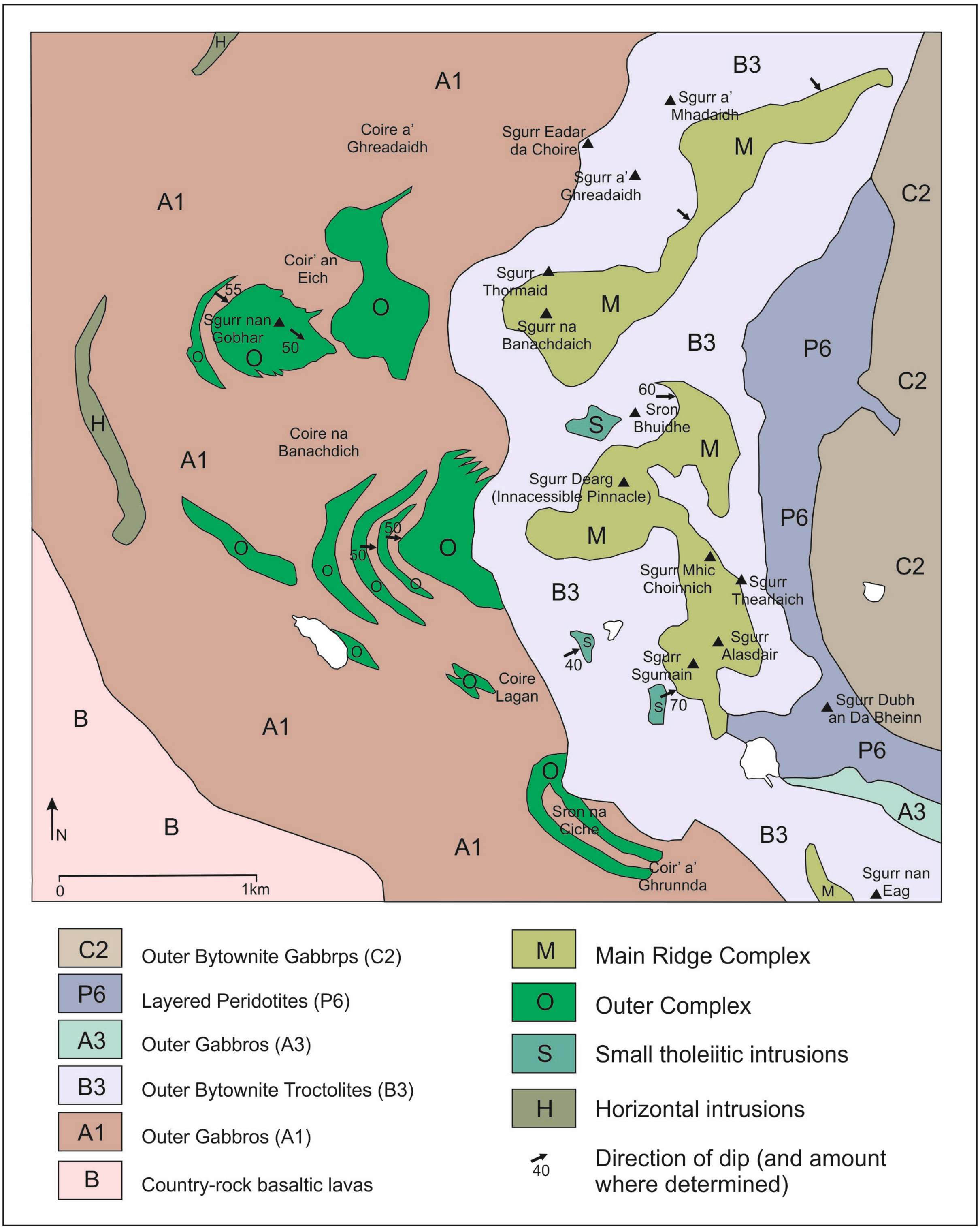


Figure 6-37 – Simplified geological map illustrating the distribution of the Outer Complex and Inner (Main Ridge) Complex tholeiite sheets (after BGS 2005).

Within the Outer Complex, marginal facies of the sheets are either distinctly fine-grained, or show no decrease in grain-size. These sheets predominantly intrude the Outer Gabbros (A, see 6.B.1, above). Xenoliths of local 'country-rock' intrusive rocks are common and columnar joints have locally developed.

Sheets belonging to the Inner Complex are intimately associated with various breccias, for example on Sgùrr Alasdair (Figure 6-38) and Sgùrr Sgumain, with tholeiitic basalt/dolerite acting as a matrix material. (Hutchison, 1966a) reported a diverse spectrum of rock-types, from 'welded' breccias (i.e. fragmental rocks with a coherent, crystalline basaltic matrix) to xenolithic intrusive basaltic rocks. These sheets intrude/cut rocks of the Border Group (see 6.B.2, above) and the Outer Bytownite Troctolites (see 6.B.3, above).

Figure 6-38 – Tholeiite sheet of the Inner (Main Ridge) Complex on Sgùrr Alasdair. View towards the NE from near to Loch Coir' a' Ghrunnda.

The non-xenolithic portions of the tholeiite sheets range from coarse-grained dolerite through to fine-grained basalt, the latter rarely containing phenocrysts of plagioclase. The groundmass is typically composed of plagioclase and augite in an ophitic to sub-ophitic arrangement. Amygdales and interstitial patches of quartz and secondary hydrous silicates, such as chlorite and epidote, are also present.

Alteration of the 'country-rocks' by the Outer Complex tholeiite sheets is evidenced by the sericitisation of plagioclase feldspars and the schillerization of pyroxenes, together with the replacement of olivine and clinopyroxene by serpentine and a fibrous amphibole, respectively.

According to (Hutchison, 1966a), these tholeiitic basalt and dolerite sheets released volatiles during emplacement, causing brecciation and fragmentation of their host-rocks. Vesiculation occurred as the confining pressure reached critical (low) values. Subsequently, vesicles were infilled by secondary (amygdale) mineral assemblages. It is likely that, in terms of composition and mode of emplacement, there is a close connection between these tholeiite intrusions, the cone-sheets (see Section 6.B.10, above) and the volcaniclastic pipes of the CIC (see Section 6.B.9, above).

6.C The Coire Uaigneich Granite

The only rock of truly granitic composition associated with the CIC is the Coire Uaigneich Granite. It crops out along the SE margin of the intrusive centre, between Sgùrr na Stri and Coire Uaigneich (Figure 6-39), in a narrow, discontinuous, ribbon-shaped outcrop, and is most easily examined on the beach on the west side of the Abhainn Camas Fhionnairigh on the west side of Camasunary Bay, where it forms a wave-washed platform. On these clean surfaces, variations between coarse- and fine-grained facies are readily noted, as are partially-digested xenoliths of sandstone (Figure 6-40). In hand-specimen, needles of hypersthene (typically replaced by bastite) are also conspicuous, in a pale granitic groundmass (Figure 6-41). SE of Sgùrr na Stri, the granite is intruded along the contact between Torridonian strata and metamorphosed basaltic lavas, and dips to the NW at an angle of between 35 and 50°. The only other place where the field relationships of the granite are easily examined is in Coire Uaigneich, itself, where it is intruded into Jurassic sedimentary rocks and basaltic lavas. Here, much of the outcrop is mantled by frost-shattered material.

Figure 6-39 – Pale-weathered Coire Uaigneich Granite cropping out in the upper part of the Abhainn nan Leac valley on the east side of Blà-bheinn (Blaven). The dark country-rocks on either side of the granite at the top of the valley are hornfelsed basaltic lavas. View towards the NNE.

Figure 6-40 – An elongate inclusion of fine-grained, metamorphosed sandstone, most likely derived from the Torridonian sequence that crops out in Camasunary Bay and the surrounding area (see Section 3.C), within typical Coire Uaigneich Granite on the west side of the Abhainn Camas Fhionnairigh, where it flows into Camas Fhionnairigh [NG 5093 1864]. Pole *c.* 1m long.

Figure 6-41 – Typical Coire Uaigneich Granite from the coastal exposures on the west side of the Abhainn Camas Fhionnairigh, where it flows into Camas Fhionnairigh. Original needles of hypersthene (now replaced by bastite, a variety of serpentine; Wager *et al.* 1953) set in a quartz-feldspar groundmass. The elongate, rounded inclusion is interpreted as being originally Torridonian sandstone (see Section 3.C) [NG 5093 1864]. Coin *c.* 26mm across.

Near to its margins, fine-grained facies of the granite are locally developed, grading over a short distance into coarser material towards the centre of the intrusion. Interpretations of the age relationship between the granite and the main units of the CIC differ: (Carr, 1952) concluded that it predates the CIC, whereas (Almond, 1960) suggests that it formed at a later stage.

The presence of sandstone xenoliths within the Coire Uaigneich Granite lead (Wager, et al., 1953) to study the intrusion in more detail in order to determine if there is a genetic relationship. Within the granite, itself, they identified quartz paramorphs (pseudomorphs with the same composition), after tridymite, and suggested that the whole-rock composition of the intrusion falls within the primary quartz field of the synthetic system Qz-Ab-Or, when $P_{TOTAL} = P_{H2O}$ (= 1kbar). Consequently, they concluded that this granite represents a partial melt of Torridonian sandstone (see 3.C, and 6.D, below). Experimental studies by (Brown, 1963) provide further evidence for this interpretation, suggesting that the melting events probably took place at a depth of *c.* 1km.

Meighan ((Meighan, 1976); (Meighan, 1979)) proposed an alternative model, suggesting that the intrusion originated via fractional crystallisation of a basaltic magma, possibly associated with the CIC, and subsequently underwent silicification. Important to his arguments are significant differences in the major- and trace-element chemistry between the granite and typical Torridonian sandstones from the surrounding area. Meighan ((Meighan, 1976); (Meighan, 1979)) also suggested that the so-called paramorphs of quartz, after tridymite, are, in fact, the hydrothermal replacement of plagioclase by quartz.

(Dickin & Exley, 1981) investigated the intrusion in detail using major-, trace- and isotope-element data. They concluded that the intrusion has not undergone a significant change in bulk composition, and that it formed by the mixing of two distinct magmas: one being a partial melt of Torridonian sedimentary material, the other a silicic differentiate of a basaltic magma (from a Cuillin magma chamber) enriched in incompatible elements such as Zr and Y. According to their data modelling, the mixing involved two parts of Torridonian melt for every part of the basaltic differentiate.

6.D Thermal Effects of the Cuillin Intrusive Centre

The emplacement of large volumes of basic and ultrabasic magma into the crust produced several changes in both the early-formed units of the CIC ((Ferry, 1985a) and in the surrounding country-rocks (Ferry, et al., 1987). Alteration was caused by a combination of the large amount of heat liberated by the crystallising magmas, and by the circulation of heated meteoric fluids (groundwater), mainly supercritical H_2O (Forester & Taylor, 1977).

As the various gabbros, troctolites and peridotites crystallised, hydrous fluids were able to gain access, along crystal boundaries and, on a larger scale, along fractures that formed in response to volume reduction and stress release during cooling. Most of the fracture networks that formed were subsequently sealed by the precipitation of hydrothermal minerals, commonly in complex assemblages, to form quasi-planar veins (Figure 6-42).

Figure 6-42 – Intensely altered/hornfelsed amygdaloidal basaltic lava (pyroxene hornfels, within the Inner Zone of Almond (1964), see Figure 6.49): (a) south of Gars-bheinn, adjacent to lochans [NG 4777 1763], coin *c.* 24mm across; and, (b) on the west side of the Abhainn Camas Fhionnairigh [NG 5087 1905], immediately SE of the margin of the CIC, hammer *c.* 30cm long.

Primary (magmatic) minerals locally underwent reaction with these fluids to form secondary talc, chlorite, montmorillonite, amphibole, biotite and magnetite. Less common was the formation of calcite, epidote, quartz, titanite, prehnite and garnet. The alteration process led to minor changes in the bulk composition of the original rocks, with the addition of relatively mobile elements such as K and Na, and a loss of Mg. Most of the mineralogical alteration occurred within the temperature range *c.* 450-550°C, with the most resistant mineral to alteration being clinopyroxene. However, stable isotope data (oxygen and hydrogen), for surviving magmatic minerals, indicate that fluid-mineral reaction occurred at higher temperatures, from *c.* 1000°C (i.e. just below the temperature that the basic and ultrabasic magmas had fully crystallised), down to *c.* 500°C. During this high-temperature period of fluid-mineral reaction, oxygen and hydrogen in the fluid equilibrated with oxygen and hydrogen in the minerals, but did not result in the formation of secondary hydrous minerals, which are not stable at such high temperatures, enabling the anhydrous magmatic minerals to survive, apparently unaltered ((Forester & Taylor, 1977); (Ferry, 1985a)).

Investigations into the nature of the (country-rock) Torridonian sedimentary rocks in Camasunary Bay by Almond ((Almond, 1960); (Almond, 1964)) and (Jassim, 1970) provide evidence of the significant amount of heat transferred from the Cuillin Intrusive Centre (CIC) into the country-rocks. Along the coastal exposures on the east side of Camasunary Bay and in the vicinity of where the track crosses the Abhainn nan Leac, 'normal' Torridonian strata are encountered, predominantly medium- to coarse-grained bedded sandstones and siltstones of the Blà-bheinn Member (3.C), intruded by dolerite and basalt (cone-)sheets.

In a traverse (from here), NW towards the margin of the CIC, these Torridonian strata preserve evidence of progressive alteration, most readily evident in the hummocky ground west of the small stream on the east side of An-t Sròn that flows into the Abhainn Camas Fhionnairigh on the west side of Camasunary Bay (Figure 6-43; Figure 6-44; Figure 6-45; Figure 6-46; Figure 6-47). Initially the rocks take on a slightly bleached appearance and in thin-section there is evidence that some recrystallisation has taken place. Within 100m of the margin of the CIC, for example, NE of the small outcrop of marble on the west side of the bay (see below), rheomorphism (mobilisation) of material within the Torridonian strata has taken place, resulting in pale, cross-cutting, rhyolitic/micro-granitic veins. This material is, in many ways, similar to that of the Coire Uaigneich Granite (6.C). These veins cut less-altered Torridonian strata and various dolerite and basalt minor intrusions. Some of the minor intrusions show evidence of distortion in the form of sinuous contacts at their margins, which reflect the non-brittle nature of the country-rock during their emplacement.

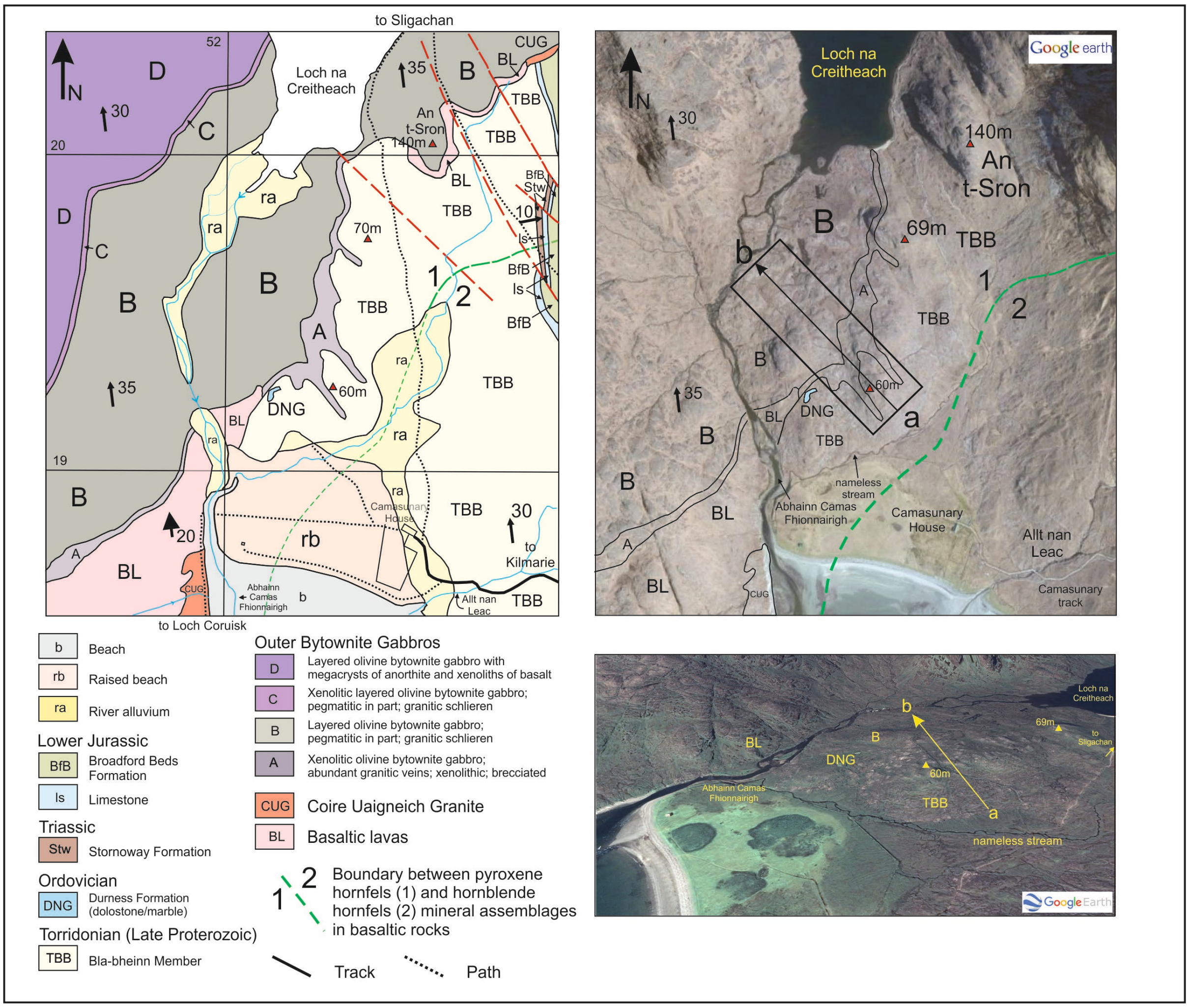


Figure 6-43 – Location of traverse in Camasunary Bay, where Torridonian strata (Blà-bheinn Member, see Section 3.C) are the dominant country-rocks, displaying increasing degrees of modification towards the margin of the CIC.

Figure 6-44 – Relatively unmodified Torridonian strata of the Blà-bheinn Member close to where the main Camasunary track crosses the Abhainn nan Leac via a wooden vehicle bridge [NG 5181 1862]. Ruler 30cm long.

Figure 6-45 – Torridonian strata of the Blà-bheinn Member cut by basaltic dykes with irregular margins at *c.* [NG 5144 1927]. Locally, the sedimentary material has deformed due to intense heating by the nearby CIC, causing it to start to flow. Note boudinaged character of the intrusion in the centre of the image. Pole *c.* 1m long.

Figure 6-46 – Brecciated and intensely veined Torridonian strata of the Blà-bheinn Member close to the margin of the CIC at *c.* [NG 5136 1941]. The veins are composed of microgranite. Pole *c.* 1m long.

Figure 6-47 – Relatively homogeneous unlayered Outer Bytownite Gabbros (C) cut by microgranite veins close to the margin of the CIC on a large, glacially-sculpted, slab-like exposure east of the Abhain Camas Fhionnairigh [NG 5104 1941]. Pole *c.* 1m long.

As the irregular 'boundary zone' of the Outer Bytownite Gabbros (see 6.B.5) with the country-rock Torridonian strata is crossed, the intensity and complexity of the cross-cutting rhyolitic/microgranitic veins increases and they are a common feature within the marginal gabbros of the CIC as far west as the Abhainn Camas Fhionnairigh.

Also within Camasunary Bay is a small outcrop of marble, originally attributed a Jurassic age (Peach, et al., 1910) (Figure 6-48). In a mineralogical study of this rock, (Wyatt, 1952) identified two high-temperature calc-silicate minerals, spurrite and rankinite. A subsequent assessment by (Beard & Drake, 2007), identified melilite, another high-temperature calc-silicate mineral, together with wollastonite, vesuvianite, tilleyite, andradite-grossular garnet, monticellite and perovskite, all indicative of extremely high-grade thermal metamorphism, within the so-called Sanidinite Facies and with a peak metamorphic temperature possibly in excess of 900°C at an assumed depth of no more than 1km. Metamorphism was not isochemical and the rock is better described as a skarn. The identification of chert nodules and stringers, similar to those in Cambro-Ordovician Durness Group dolostones within the Moine Thrust Zone exposed to the east in the district of Strath and on the Sleat Peninsula (3.E), together with the development of abundant calc-silicate minerals, is used by (Beard & Drake, 2007) to argue that the original rock was a dolostone with a more likely Cambro-Ordovician age. One inference of this interpretation is that the (not seen) contact between the metamorphosed dolostone and surrounding Torridonian strata (3.C) is a thrust plane, with the latter structurally above the former, as is the case for the Kishorn Thrust Plane, which crops out NW of Bheinn Shurdail (3.F).

Figure 6-48 – Metamorphosed dolostone (marble) in Camasunary Bay, interpreted to be part of the Durness Group (see Section 3.E), with a complex assemblage of high-temperature (calc-silicate) minerals [NG 5118 1922]. Pole *c.* 1m long.

The thermal effects of the CIC are also recorded by the mineralogy of the adjacent plateau lavas south of Sgùrr na Stri, in Camasunary Bay and on Strathaird ((Almond, 1960); (Almond, 1964)). (Hutchison, 1964) reports a similarly high grade of contact metamorphism within the amygdaloidal basaltic lavas adjacent to the margin of the CIC in the Allt a' Choire Ghreadaidh on the east side of Glen Brittle.

(Almond, 1964) defined three zones within the thermal aureole along the SE margin of the CIC (Figure 6-49). The highest grade of thermal metamorphism is defined as a pyroxene hornfels, with four textural types of basalt recognised, ranging from lavas that retain their igneous mineral textures, through to lavas where recrystallisation is almost complete, containing a mineral assemblage of plagioclase, clinopyroxene, orthopyroxene and (metamorphic) olivine, typical of Sanidinite Facies thermal metamorphism, which persists out to a distance of at least 200m from the contact. Temperatures were in excess of 900°C, possibly as high as 1,000°C (Ferry, et al., 1987). This gives way to basaltic lavas in the general range 200-1,000m from the margin of the CIC and defined as being hornblende hornfels, a subdivision of the Albite-epidote Facies, containing actinolite, chlorite, albite and epidote. Still further out, for a distance of at least 5km from the margin of the CIC, the lowest grade of metamorphism within the lavas along this sector of the country-rocks contains only chlorite, albite and epidote, and primary magmatic textures are reasonably well preserved. These relatively unaltered rocks have developed their secondary mineral assemblage largely due to burial and the circulation of heated meteoric/ground water due to the elevated temperatures caused by the various magmatic processes.

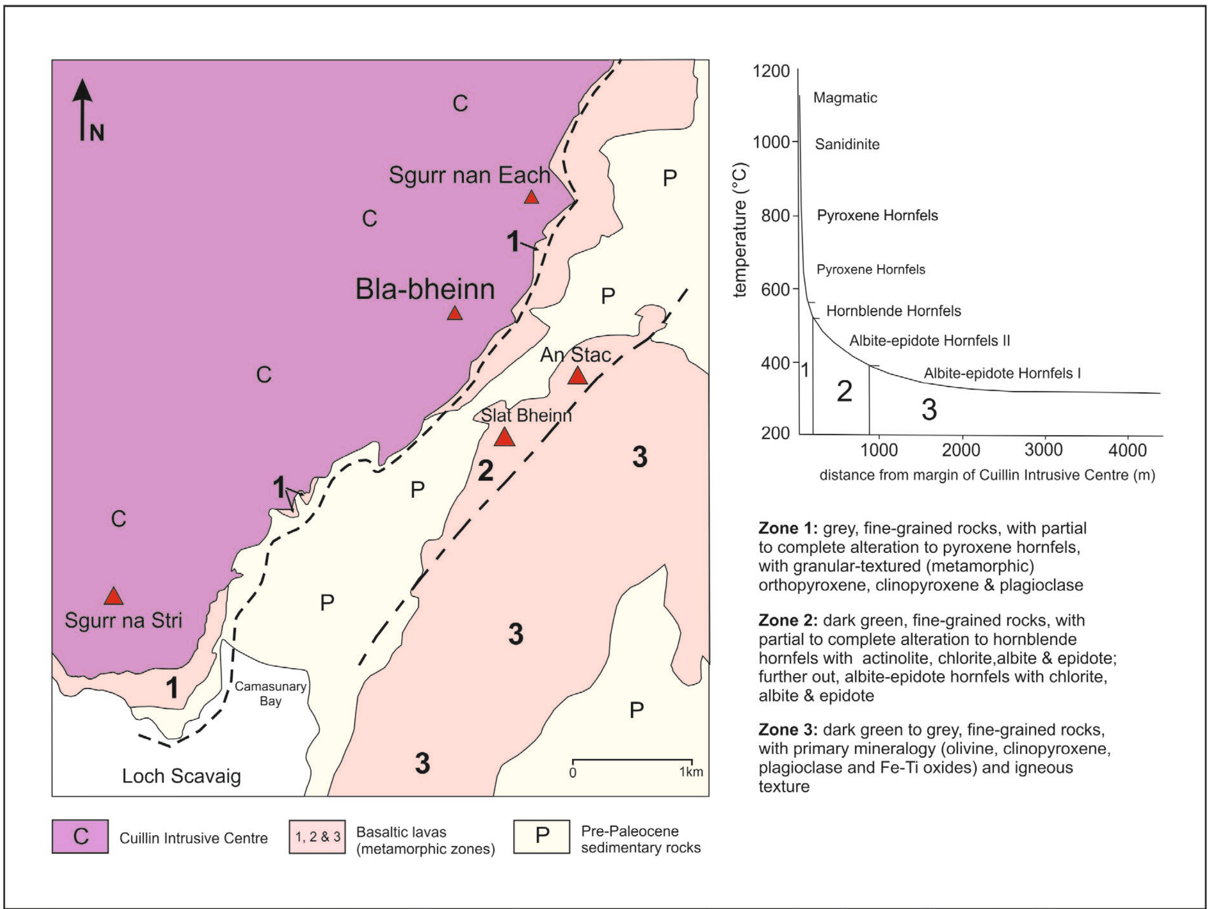


Figure 6-49 – Zones of thermal alteration within the basaltic lavas on Strathaird and south of Sgùrr na Stri (after Almond 1964).

The thermal metamorphism of the lavas along the western margin of the CIC has been investigated by (Ferry, et al., 1987) (Figure 6-50). The highest grade is within their Orthopyroxene-olivine Zone

(>900°C), defined by metamorphic olivine, orthopyroxene and biotite. The adjacent lavas are within the Amphibole Zone (400-900°C) and contain the amphiboles actinolite and edenite, together with chlorite, titanite, epidote, andradite and quartz. Still further out are rocks in the Smectite Zone (<400°C), containing saponite and carbonate, but lacking primary (i.e. magmatic) olivine and containing considerably less zeolites than in the Primary Olivine Zone, which comprises basaltic lavas dominated by magmatic minerals with original igneous textures. The extent of thermal metamorphism is strongly coupled to the degree of reaction and exchange between the rocks and circulating meteoric fluids, as deduced from their whole-rock $\delta^{18}O$ signatures. Furthermore, the anhydrous character of the Orthopyroxene-olivine Zone rocks indicates that any significant rock-fluid reaction did not occur after temperatures dropped below *c.* 900°C. To a significant extent, the metamorphic process was isochemical and the whole-rock compositions of the lavas have not been substantially modified (Ferry, et al., 1987).

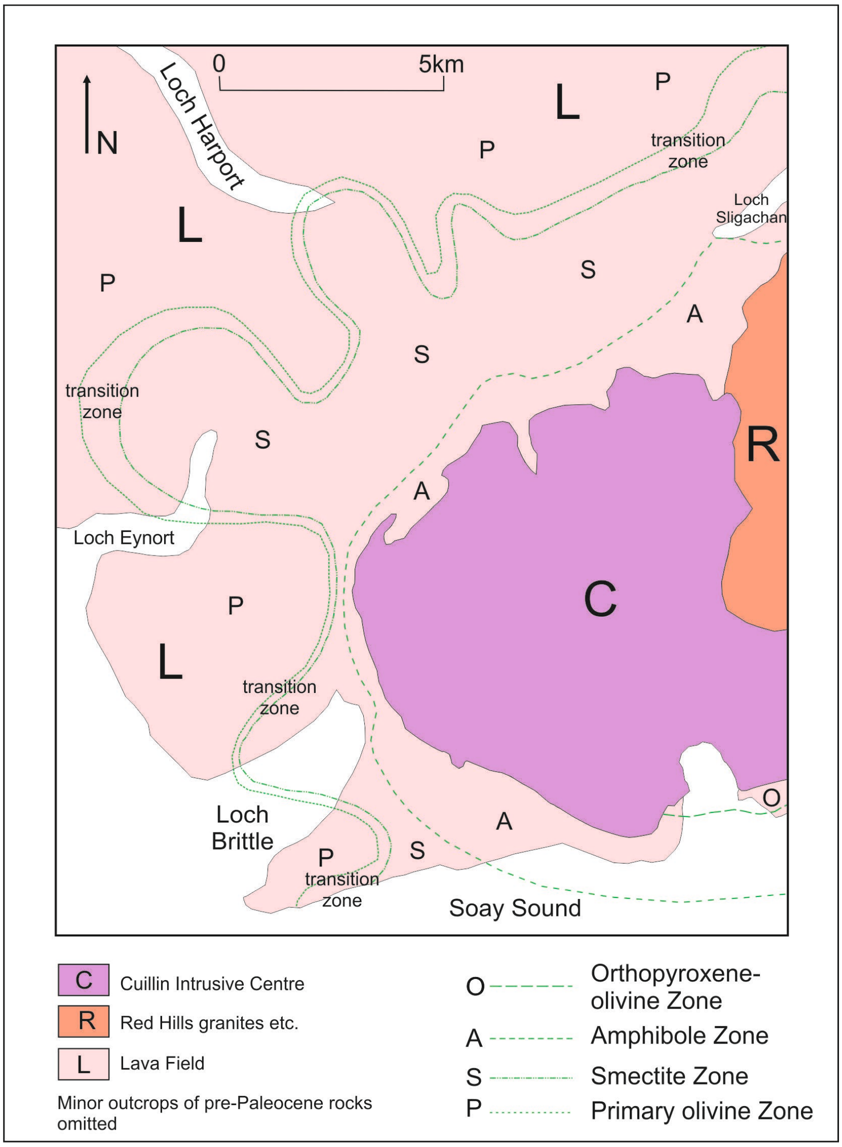


Figure 6-50 – Zones of thermal alteration in the basaltic lavas adjacent to the western margin of the CIC (after Ferry *et al.* 1987).

(Hutchison, 1964) identifies three locations on the western side of the CIC where its contact with country-rock basaltic lavas can be examined. At *c.* 400m WNW of the lochan NE of An Sgùman, there is a gradational contact, over a distance of *c.* 10m dipping inwards at *c.* 30°. Where the contact is traversed by the Allt Coire na Banachdich and the Allt a' Choire Ghreadaidh, an element of shearing is recognised in both the lavas and the adjacent gabbro. The hornfelsed lavas are dark grey and break with a splintery fracture. Amygdales, originally low-temperature minerals such as carbonate and chlorite, are replaced by resistant-to-weathering plagioclase cores surrounded by rims of granular olivine and clinopyroxene.

6.E The Srath na Crèitheach Intrusive Centre (SnCIC)

The Srath na Crèitheach Intrusive Centre (SnCIC) (Figure 6-51) is defined here as a group of three sub-volcanic granitic intrusions, the Meall Dearg, Ruadh Stac and Blaven granites, which post-date the Cuillin Intrusive Centre (6.B) and pre-date the Western Red Hills Intrusive Centre (6.F) (Figure 6-51). These intrusions, covering an area of *c.* 7km^2, crop out in Srath na Crèitheach, on the hills of Meall Dearg and Ruadh Stac, and on part of the west side of Blà-bheinn (Blaven) (Figure 6-52). The older, spatially-associated, volcaniclastic rocks that crop out to the south and west of the granites are discussed in Section 5.E.

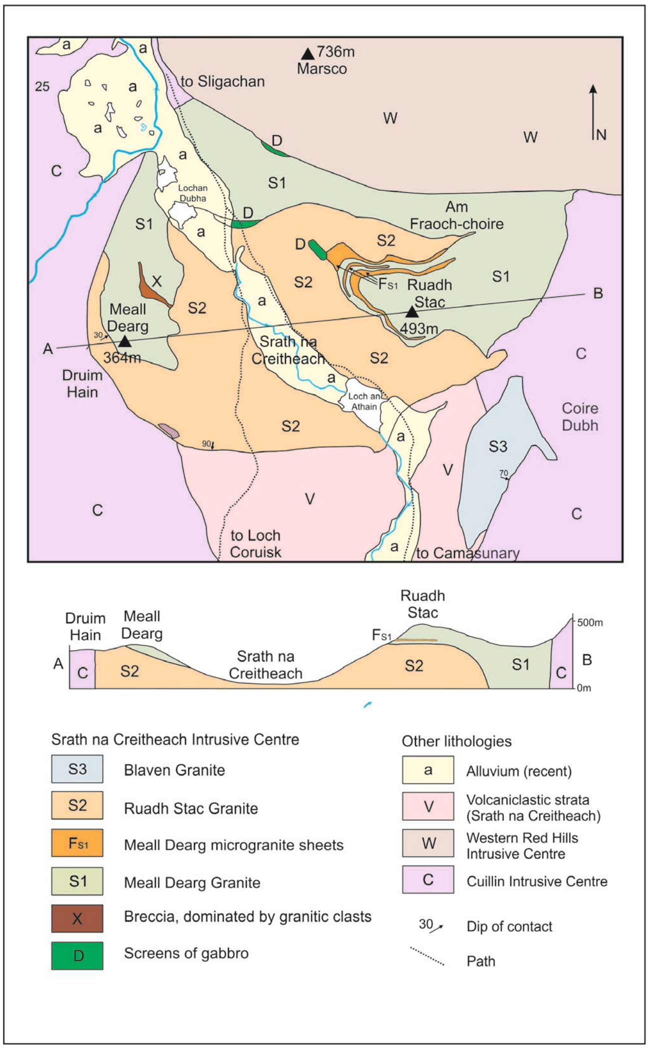


Figure 6-51 – Lithodemic units of the Srath na Crèitheach Intrusive Centre (SnCIC) (based on BGS (2005) and Emeleus & Bell (2005)).

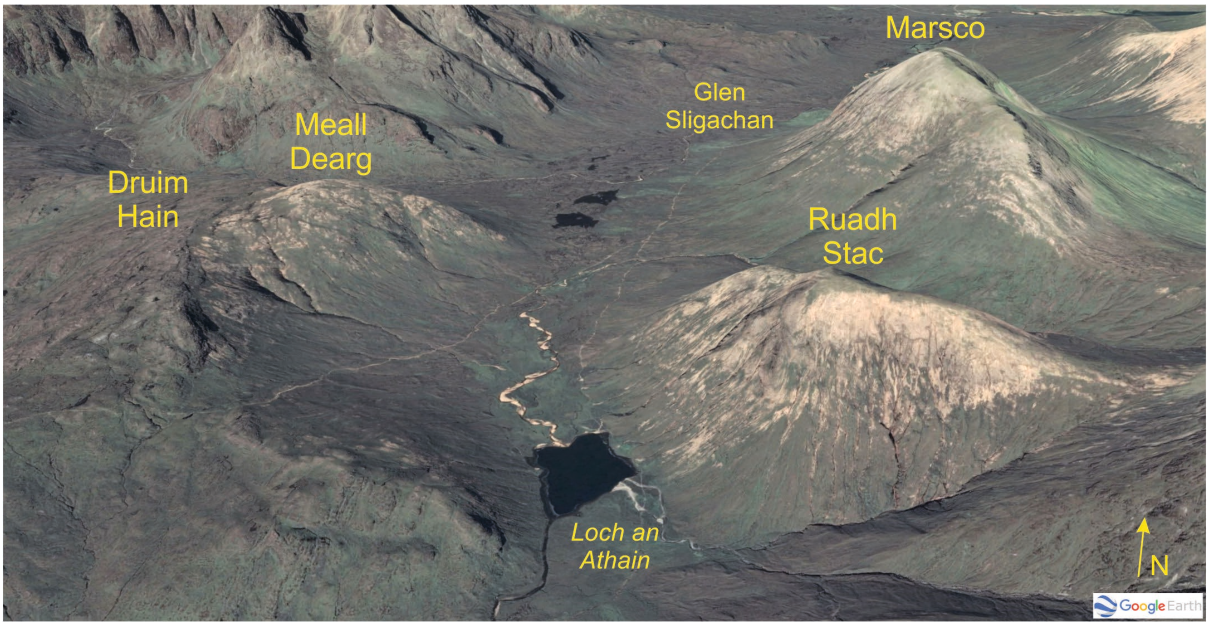


Figure 6-52 – Oblique Google Earth© image of the Srath na Crèitheach Intrusive Centre (SnCIC) area, with Ruadh Stac in the near ground, separated from Meall Dearg in the distance by the glacially-excavated valley of Srath na Crèitheach. View towards the north.

Very little published data are available on these granite intrusions. (Geikie, 1894), in a discussion of the time-relationships between the Cuillin gabbros (*s.l.*) and the granites of the Red Hills, provides evidence that the former pre-date the latter. He also notes that riebeckite is present within one of the granites exposed on Meall Dearg. The conclusions of Geikie are amplified by (Harker, 1904), who also delineates the outcrop of the 'riebeckite-bearing granophyre' on his unpublished 6 inch to 1 mile map. Anwar ((Anwar, 1950); (Anwar, 1955)) presents an analysis of a clinopyroxene (ferrohedenbergite) from the other granite exposed on Meall Dearg (see below). (Thompson, 1969) briefly examined the granites of the Srath na Crèitheach area and concluded that they define an older intrusive centre that is distinct from the Western Red Hills Intrusive Centre further north. He also concludes that two intrusions may be defined, referring to them as the Meall Dearg and Ruadh Stac granites. According to (Thompson, 1969), the dome-shaped Ruadh Stac Granite lies below the Meall Dearg Granite and pre-dates the latter. However, (Jassim, 1970) concludes that the reverse time-relationships can be discerned, with the Ruadh Stac Granite chilling against, and hence post-dating, the Meall Dearg Granite.

The descriptions presented below draw partly upon the studies of Thompson ((Thompson, 1965); (Thompson, 1969)) and (Jassim, 1970).

6.E.1 General Field Relationships

The three granites of the SnCIC post-date the basic and ultrabasic rocks of the Cuillin Intrusive Centre (CIC) (Figure 6-8; Figure 6-27). Typically, contacts are steep, or vertical, with the development of marginal chill facies, locally containing spherulitic aggregates involving quartz and alkali feldspar. Apophyses (offshoots) of the granite intrusions invade the surrounding gabbros (Figure 6-53). These two features are particularly well-developed at the margin of the Ruadh Stac Granite, south of the summit of Meall Dearg, at Druim Hain (Harker, 1904). Accordingly, the older gabbros are intensely altered over distances of 10–40m from the granite contact. The plagioclases are opaque and distinctly white, whereas the pyroxenes take on a greenish tinge, with the development of secondary chlorite and epidote. Xenoliths of altered gabbro are common within the marginal facies of the Blaven Granite, are less common in the Ruadh Stac Granite, and are absent from the Meall Dearg Granite.

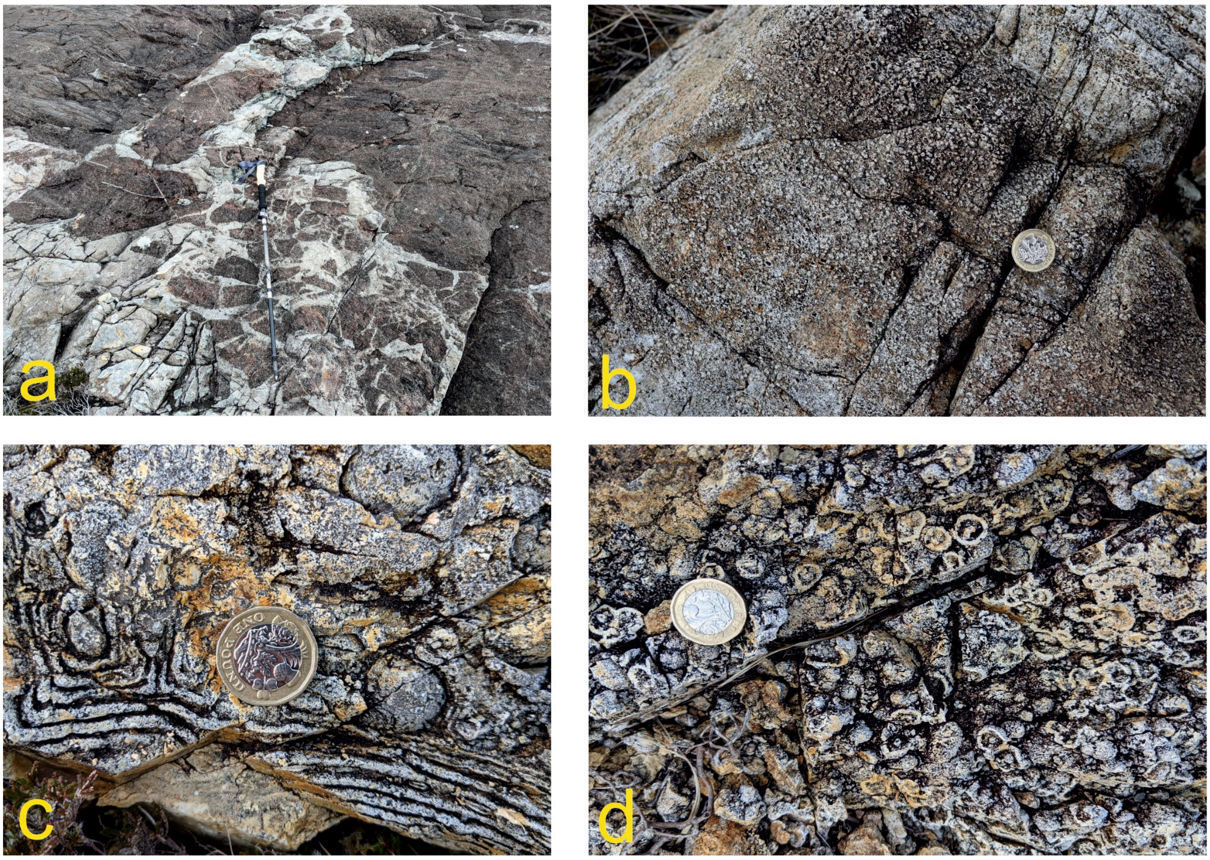


Figure 6-53 – (a) Pale rhyolitic apophysis of the Ruadh Stac Granite within Inner Layered Gabbros (F), with fragments of disrupted gabbro, on Druim Hain, pole *c.* 1m long; (b) spherulitic aggregates within an apophysis of the Ruadh Stac Granite, coin *c.* 24mm across; (c) detail of banded rhyolite within an apophysis of the Ruadh Stac Granite, coin *c.* 24mm across; and, (d) detail of spherulitic aggregates within an apophysis of the Ruadh Stac Granite, coin *c.* 24mm across.

The boundary between the Srath na Crèitheach and Western Red Hills intrusive centres runs along the southern face of Marsco at approximately 300m OD and is concave to the north. Along part of the contact a screen of crushed gabbro, approximately 400m long, separates the granites of the two centres. It is likely that this material was originally part of the Inner Gabbros, subsequently caught up in the younger granites.

The older volcaniclastic rocks, in the immediate vicinity of the granites, have been subjected to intense brecciation and alteration. The various components of the sequence within this crush zone have reacted differently, with fine-grained, fragmental material having the greatest degree of alteration. Marginal rhyolitic veins are common, cutting the volcaniclastic rocks and giving rise to areas of 'hybridisation'. This type of alteration is particularly well developed SW of Loch an Athain, where there is a 50m-wide zone consisting of fine-grained fragments of basic and ultrabasic material surrounded by large patches of quartz and alkali feldspar in a granophyric intergrowth, together with abundant plagioclase and hornblende.

6.E.2 The Meall Dearg Granite

This granite crops out on the upper slopes of Meall Dearg and Ruadh Stac (Figure 6-51). It is most easily examined on Ruadh Stac, where it clearly overlies the Ruadh Stac Granite (Figure 6-54). In general, the sheet-like Meall Dearg Granite dips to the east at an angle of *c.* 30°. It may be identified in the field by its whitish-brown coloration on weathered surfaces, whereas when fresh it has a pale green tinge. Two facies of the granite are recognised, occurring as interleaved sheets. These are: a fine-grained, hornblende-bearing granite; and, a younger, coarse-grained, pyroxene-bearing granophyre. The contact relationships between these closely associated, flat-lying sheets are most readily observed on the northern slopes of Ruadh Stac, when viewed from Marsco.

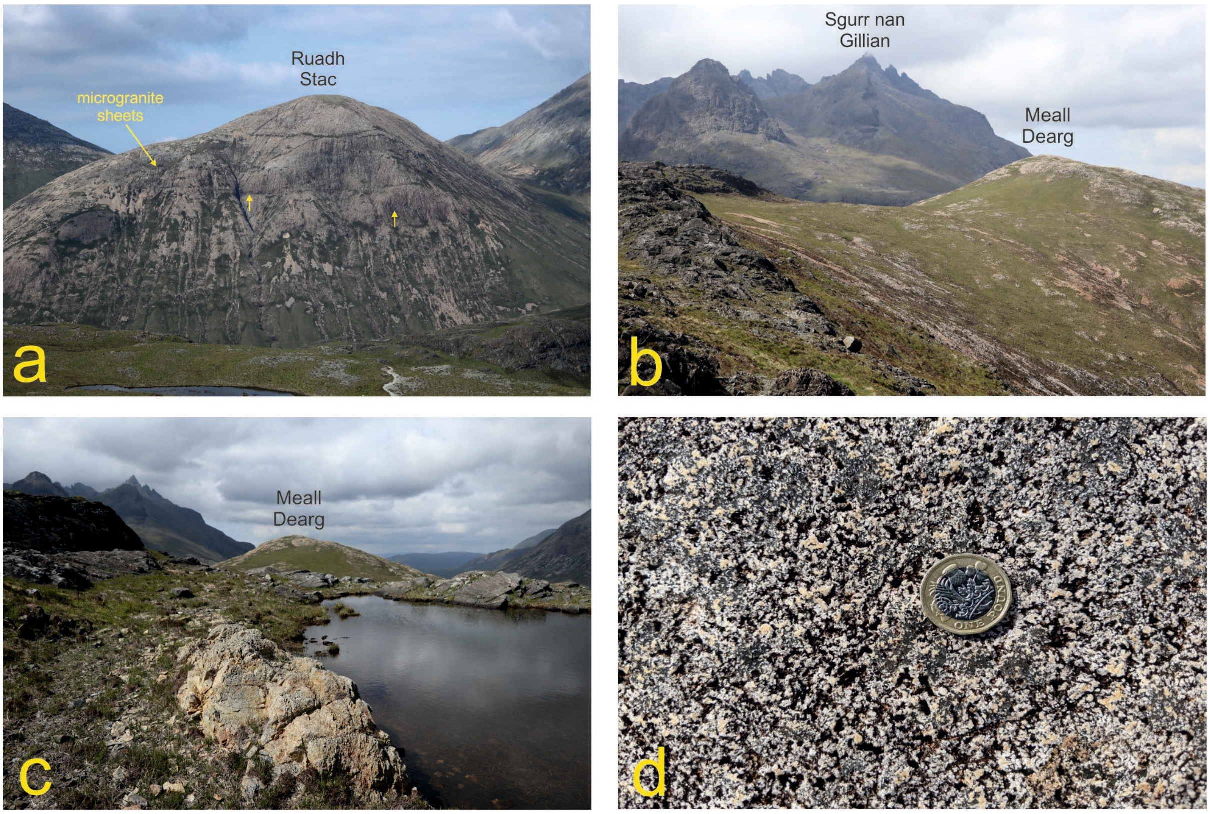


Figure 6-54 – (a) Ruadh Stac viewed from Druim Hain towards the ESE, with the younger Ruadh Stac Granite below the (older) Meall Dearg Granite, with a relatively horizontal contact (arrowed); (b) contact of pale Meall Dearg Granite with dark older Inner Gabbros on Druim Hain; (c) pale dyke-like offshoot of the Ruadh Stac Granite within Inner Gabbros on Druim Hain, with dome-shaped Meall Dearg in the middle distance; and, (d) typical medium-grained Meall Dearg Granite, coin 24mm across.

In detail, the hornblende-bearing variety, exposed halfway up the northern face of Ruadh Stac, consists of three distinct sheets. These sheets dip at a very shallow angle to the NE and are between 5 and 30m thick. The rock is aplitic, containing large needles of hornblende. Quartz dominates the rock, constituting up to 40% of the mode, together with approximately 10% of plagioclase-cored alkali feldspar phenocrysts, giving the rock a porphyritic appearance. (Jassim, 1970) suggests that some of the plagioclases have been derived from an older intrusion and are xenocrysts. In addition, xenoliths of gabbro and granite are present in various stages of digestion.

The pyroxene-bearing variety of the Meall Dearg Granite has a much coarser appearance and forms three sheets. The pyroxene is a Fe-rich monoclinic variety, ferrohedenbergite, which occurs in association with the Fe-rich olivine, fayalite (typically altered to chlorite + haematite). The groundmass is dominated by quartz and alkali feldspar in a granophyric intergrowth. These sheets have weathered more deeply than the hornblende-bearing variety and have a slightly paler/lighter appearance.

Although texturally distinct, the bulk mineralogies of the two varieties of the Meall Dearg Granite are very similar. The differences in the mafic mineral assemblages within the two facies are most easily attributed to differences in the relative H_2O contents of the magmas during crystallisation. (Thompson, 1965) reported the presence of fluorite as an abundant accessory mineral in both facies of the Meall Dearg Granite.

6.E.3 The Ruadh Stac Granite

The Ruadh Stac Granite has commonly been referred to as the “Riebeckite Granophyre" ((Geikie, 1894); (Anwar, 1955)), although more recent investigations ((Thompson, 1965); (Thompson, 1969); (Thompson, 1976)) indicate that the compositional range of the amphiboles is broader, from arfvedsonite to ferrorichterite.

This intrusion weathers, commonly deeply, to a pale brown, and underlies the Meall Dearg Granite (Figure 6-54), with intervening slabs of gabbro present along the contact (see below). It crops out on both Ruadh Stac and Meall Dearg, up to heights of 300m OD. Its base is not exposed. Fresh material is most readily examined in the stream beds of the Allt nam Fraoch-choire and the Allt Teanga Bradan, north and south of Ruadh Stac, respectively (Figure 6-52).

The textures present within this granite are extremely variable, from aplitic, through porphyritic, to granophyric. Sparse phenocrysts of subhedral perthite occur in a groundmass that is either typically granophyric or granitic in texture. Amphibole constitutes *c.* 5% of the rock.

6.E.4 The Contact Between the Meall Dearg and Ruadh Stac Granites

Although some uncertainty surrounds the time-relationships of these two granites, some field-relationships are not in dispute. For instance, the junction is readily identified because of the distinctly different weathering characteristics of the two intrusions; the Meall Dearg Granite has a rugged, irregular appearance, whereas the Ruadh Stac Granite is darker, more fractured, and weathers to much smoother surfaces (Figure 6-54). Secondly, gabbro slabs are locally present along the contact between the two intrusions.

A ‘needle-sharp’ contact just above the gabbro slabs on the NW slopes of Ruadh Stac indicated to (Jassim, 1970) that the Ruadh Stac Granite chilled against the Meall Dearg Granite. Thompson ((Thompson, 1965); (Thompson, 1969)) concluded the reverse relationship.

6.E.5 The Meall Dearg Breccias

On Meall Dearg, various breccias occur within the Meall Dearg Granite. They are considered by (Jassim, 1970) to be the result of volatile release closely associated with the incoming of the Ruadh Stac Granite. The main exposures are located *c.* 400m NE of the summit of Meall Dearg, trending NW-SE, with a width of 50–100m and a length of 300m, tapering at both ends into narrow dyke-like masses. The main upper part of this outcrop of breccia comprises relatively coarse-grained material, with blocks of conspicuously spherulitic-textured granite, which contrast with the finer-grained material with associated crush zones lower down on Meall Dearg. The fragments are readily identified as being ferrohedenbergite-bearing granite of the Meall Dearg Granite (see above).

Related to these rocks are numerous breccia dykes, generally less than 1m wide, which are common within the Meall Dearg Granite, but only rarely seen within the Ruadh Stac Granite. Inclusions in these dykes are similar to those in the breccias described above, set in a matrix of comminuted rhyolitic material.

6.E.6 The Blaven Granite

The Blaven Granite crops out on the lower, western slopes of Blà-bheinn (Blaven), from the northern end of Loch na Crèitheach, north to Coire Dubh **(**Figure 6-55**).** On its east side, the granite is in contact with rocks of the Outer Bytownite Gabbros (6.B.5), whereas to the west it intrudes various volcaniclastic rocks (5.E). Both contacts are steep, dipping to the NE.

Figure 6-55 – Field image of the Blaven (Blà-bheinn) Granite, intruded into Outer Bytownite Gabbros above (west side of Blà-bheinn). View towards the NE from Druim Hain.

A marginal facies of finer-grained material is commonly present, up to 10m wide. Along the granite-gabbro contact, numerous elongate slabs of extremely altered gabbro are present within the granite.

The Blaven Granite is generally pale when fresh, of medium grain-size (1–2mm) and contains phenocrysts of alkali feldspar. The dominant mafic mineral is a green hornblende, typically altered to chlorite, which occurs in irregularly shaped clots.

6.E.7 Shape and Mechanism of Intrusion of the Granites

From the studies of (Thompson, 1965) and (Jassim, 1970), it is clear that the Ruadh Stac Granite is dome-shaped and underlies the sheet-like Meall Dearg Granite. According to (Jassim, 1970), the Meall Dearg Granite has an 'inverted L' shape, forming an incomplete ring-dyke, with the steep limb located east of the summit of Ruadh Stac, against the Outer Bytownite Gabbros (6.B.5), and the flat-lying roof-rocks exposed on the summits of Ruadh Stac and Meall Dearg (Figure 6-51). The presence of two varieties of the Meall Dearg Granite (see above) indicates multiple injections of magma.

The almost-vertical, sheet-like shape of the Blaven Granite suggests that the level of erosion is deeper for this intrusion, when compared to the other granites of the SnCIC, with the outcrop pattern possibly being that of the limb of a very incomplete ring-dyke, or simply a dome-shaped intrusion.

6.F The Western Red Hills Intrusive Centre (WRHIC)

The Western Red Hills Intrusive Centre (WRHIC) (Figure 6-3; Figure 6-56; Figure 6-57) was first defined as a distinct intrusive centre by (Richey, 1932), when he distinguished the granites of the Glamaig-Marsco-Loch Ainort area from the younger Eastern Red Hills Intrusive Centre, west of Broadford (6.G). The centre covers an area of *c.* 35km^2 and, at the present level of erosion, is dominated by annular silicic intrusions of granite, granophyre and felsite/rhyolite. Significantly, one of the earliest members of the centre is the Marsco Summit Gabbro, constituting the only true basic intrusion. One other important feature of the centre is the presence of a group of rocks referred to as the Marscoite Suite, consisting of a narrow composite ring-dyke, comprising (units of) ferrodiorite (an Fe-enriched fractionate of a tholeiitic basalt magma), a felsite (the Southern Porphyritic Felsite/Rhyolite) and various hybrid rocks (‘marscoite’ and ‘glamaigite’), which were formed by magma-mingling/mixing processes.

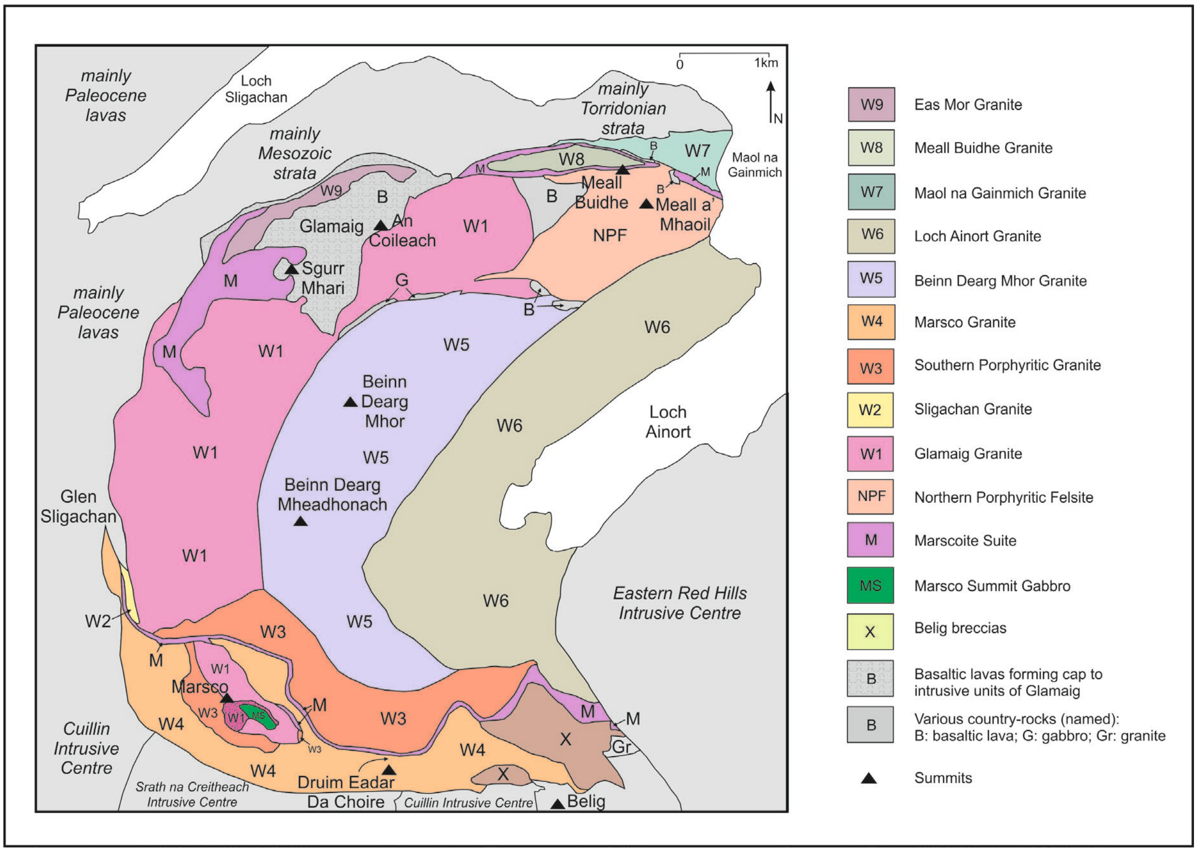


Figure 6-56 – Lithodemic units of the Western Red Hills Intrusive Centre (WRHIC) (based on BGS (2005) and Emeleus & Bell (2005)).

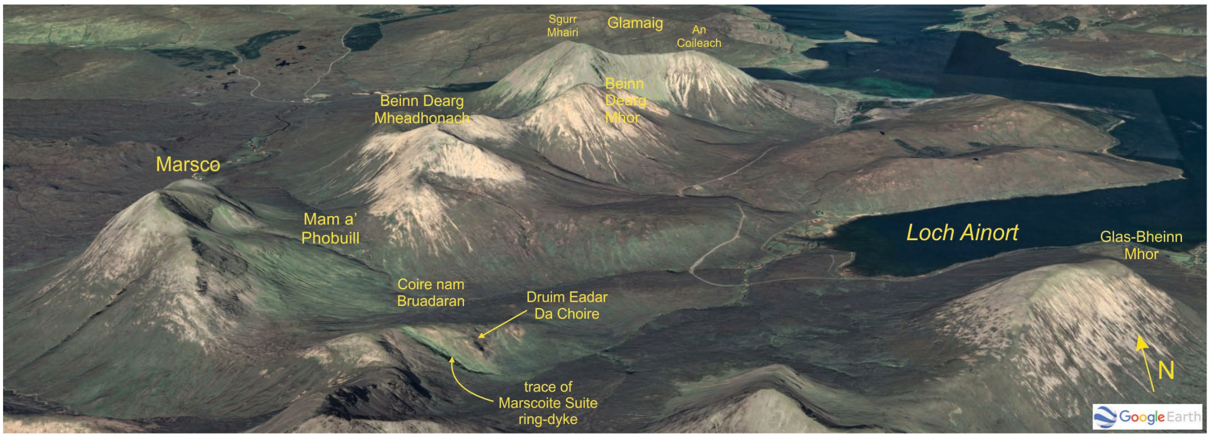


Figure 6-57 – Oblique Google Earth© image of the Western Red Hills Intrusive Centre (WRHIC) area. View towards the north.

A detailed investigation of the rocks of the Western Red Hills Centre was undertaken by Wager and his co-workers, commencing with a preliminary report by (Richey, et al., 1946) that discusses age relationships between the granites. The results of this investigation are presented by (Wager & Vincent, 1962), (Wager, et al., 1965), (Bell, 1959), (Bell, 1966)), (Thompson, 1965); and, (Thompson, 1969). Subsequently, (Thompson, 1980) suggested that aspects of the petrology of the granites, as well as the Marscoite Suite, may be explained in terms of magma-mingling/mixing processes throughout the development of the intrusive centre.

A summary of events comprises:

INTRUSIVE EVENTS	**PRINCIPAL ROCK-TYPE(S)**
[YOUNGEST]	
dykes	dolerite, vitrophyre (‘pitchstone’), aplite
Marsco Granite	plagioclase porphyritic fayalite ferrohedenbergite granite/granophyre
Meall Buidhe Granite	plagioclase porphyritic ferrohedenbergite amphibole microgranite/granophyre
Northern Porphyritic Felsite	quartz-alkali feldspar porphyritic felsite
Marscoite Suite	marscoite, ferrodiorite, glamaigite, felsite/rhyolite, andesinite
Southern Porphyritic Granite	quartz-alkali feldspar porphyritic felsite/ microgranite/granophyre
Glen Sligachan Granite	alkali feldspar porphyritic fayalite microgranite
Loch Ainort Granite	alkali feldspar porphyritic fayalite ferrodedenbergite granophyre
Beinn Dearg Mhòr Granite	alkali feldspar porphyritic fayalite ferrodedenbergite granophyre
Eas Mòr Granite	alkali feldspar porphyritic amphibole granophyre
Maol na Gainmhich Granite	arfvedsonite granite
Glamaig Granite	plagioclase porphyritic hastingsite biotite granite/granophyre
Marsco Summit Gabbro	(olivine) gabbro (altered)
[OLDEST]	

6.F.1 The Marsco Summit Gabbro

The Marsco Summit Gabbro forms a distinct cap to the SE part of the summit of Marsco (Thompson 1969) (Figure 6-56; Figure 6-58). It crops out as a relatively flat-lying sheet and is underlain by the Glamaig Granite, the first of the WRHIC granite intrusions (see below). Numerous veins of rhyolite from the Glamaig Granite have intruded and fragmented the gabbro, giving rise to zone of stoping several metres wide. In this zone, the gabbro is typically brecciated and metamorphosed, although in places there is a sharp, locally crenulate boundary.

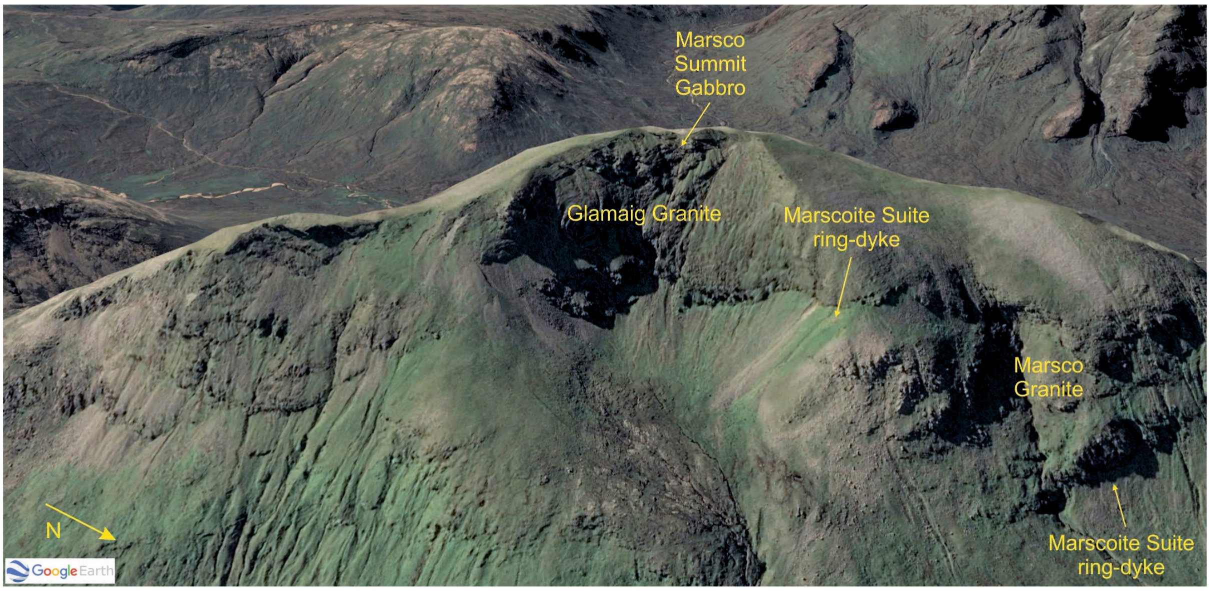


Figure 6-58 – Oblique Google Earth© image of the summit area of Marsco, indicating the outcrop of the Marsco Summit Gabbro. View towards the SW.

The gabbro has a distinct brown coloration and, unlike the gabbros of the CIC, is not intruded by cone-sheets (6.B.10). It is composed of clinopyroxene and plagioclase (with cores of An_{67-74}, zoned to rims of An_{50}, (Thompson, 1965)), in an ophitic arrangement. Olivine is not common and is typically altered. (Thompson, 1965) also reports the presence of orthopyroxene, Fe-Ti oxides, apatite and zircon, together with interstitial hornblende and biotite.

The presence of a fine-grained, marginal facies to this sheet, with sub-variolitic textures involving skeletal plagioclase phenocrysts, suggests that intense chilling of the basic magma occurred locally. This chilling, together with patches of coarse-grained gabbro that are fragmented by the Glamaig Granite, lead (Thompson, 1969) to conclude that prior to, and during, the intrusion of the granite, the Marsco Summit Gabbro was partly crystalline, but with pockets of melt still present.

6.F.2 The Glamaig Granite

The medium-grained, amphibole- and biotite-bearing granite that crops out over a broad tract of ground, *c.* 9km^2, running from Glamaig in the north, to Marsco in the south (Figure 6-56), was originally referred to as G1 by (Richey, et al., 1946) and (Wager, et al., 1948), but subsequently renamed the Glamaig Granite by (Wager, et al., 1965). The outer margin has the development of extensive crush planes within a porphyritic felsite chill facies and is thought to be vertical, as is the inner contact with the later/younger Beinn Dearg Mhòr Granite (Figure 6-59) (6.F.4). The normal, coarse-grained granite weathers to a dull grey, contains miarolitic cavities, and is characterised in the field by the presence of small, rounded to sub-angular, mafic inclusions (5–50mm) (Figure 6-60). These inclusions constitute up to 5 vol. % of the rock and are relatively evenly distributed throughout its mass. Typically, the larger inclusions have distinct outlines, whereas the smaller ones have less clearly defined margins and appear simply as clots or aggregates of mafic minerals. Also present are leucocratic inclusions of fine-grained material, up to 4m across, typically found within the central part of the intrusion. The Allt na Measarroch crosses the Glamaig Granite from close to its margin, through to its centre, and allows the examination of fresh material of the different types described above.

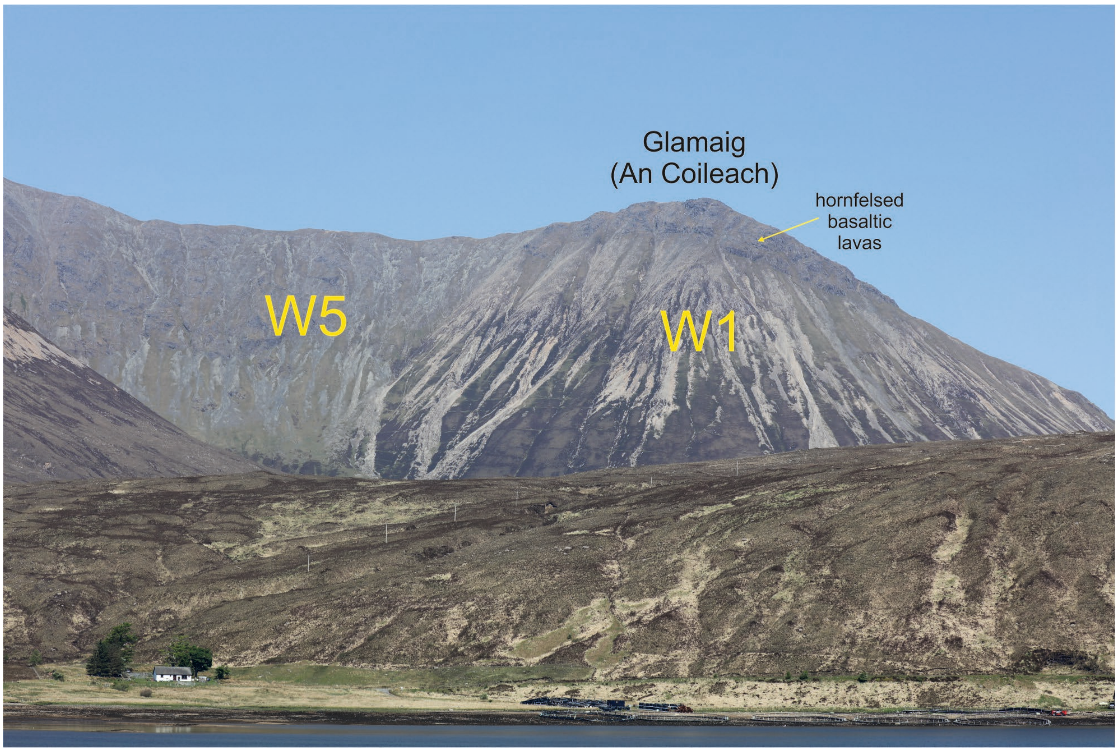


Figure 6-59 – The near-vertical contact between the Glamaig (W1, right-hand-side) and Beinn Dearg Mhòr (W5, left-hand-side) granites. A cap of hornfelsed country-rock basaltic lavas forms the summit of Glamaig (An Coileach) and dips top-left to bottom-right. View towards the west across Loch Ainort to the Beinn Dearg Mhòr - Glamaig ridge.

Figure 6-60 – Typical mafic inclusions (e.g. top, left of centre) within the Glamaig Granite in exposures in the Allt na Measarroch. Coin *c.* 24mm across.

In the Marsco area, the Glamaig Granite is overlain by the younger Southern Porphyritic Granite on the north side of the mountain. On the south side this relationship is reversed and the Glamaig

Granite is overlain by the Marsco Summit Gabbro (6.F.1). These relationships are illustrated in Figure 6-61.

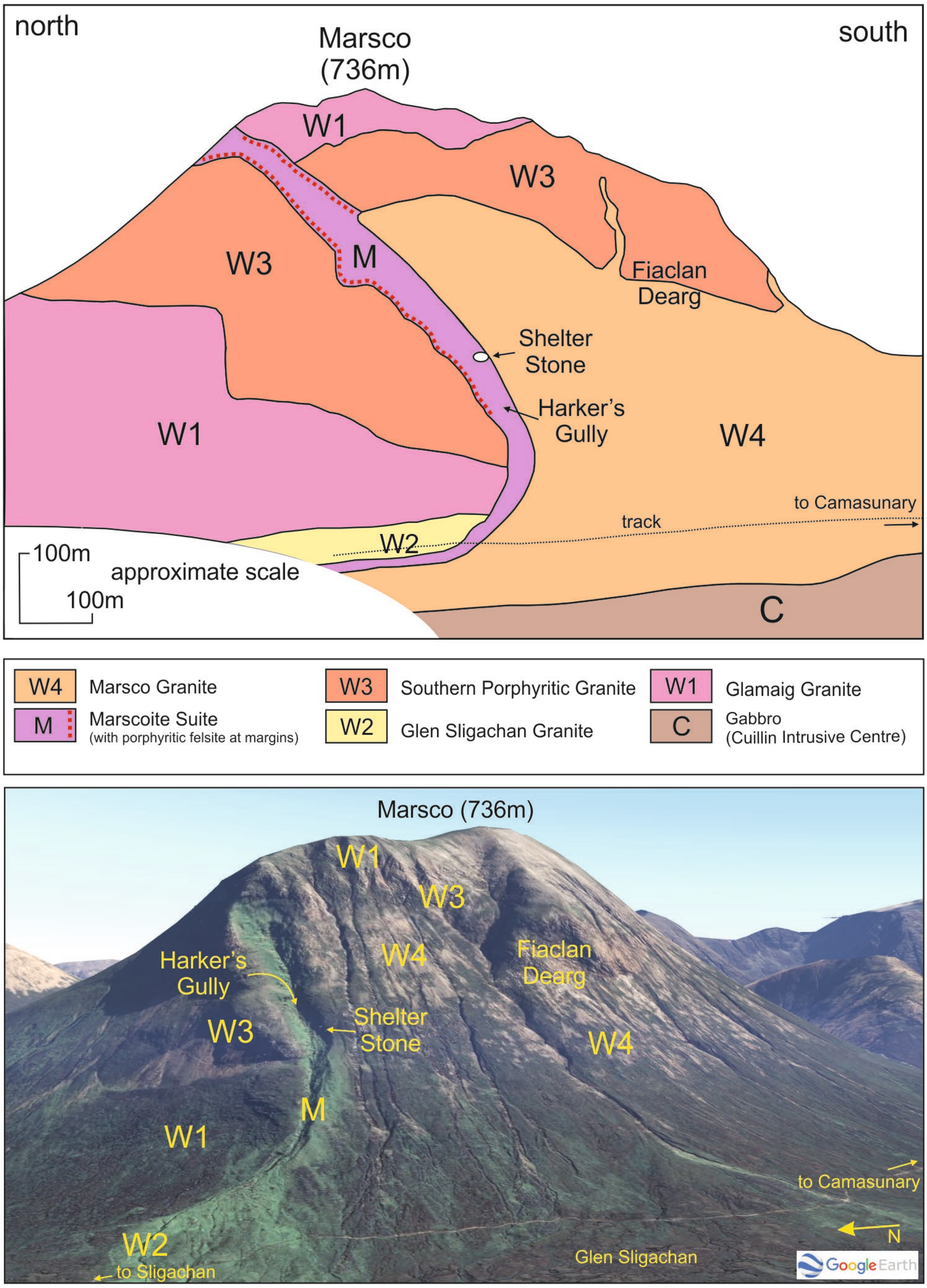


Figure 6-61 – Oblique Google Earth© image and schematic figure of the west side of Marsco illustrating the field relationships of the various granites and the Marscoite Suite Ring-dyke. View is towards the east.

In detail, the Glamaig Granite is dominated by equigranular quartz, alkali feldspar and plagioclase (2–8mm), together with small quantities of calciferous amphibole (hastingsite), clinopyroxene, biotite, Fe-Ti oxides and various other accessory minerals (Thompson, 1969). Detailed studies indicate that, on Marsco, the granite becomes more mafic in composition near to its contact with the Marsco Summit Gabbro, suggesting that 'contamination' of the silicic magma may have occurred.

(Thompson, 1980) suggests that the mafic inclusions dispersed throughout the volume of this granite were introduced in the form of basic magma, which was injected into the base of a magma chamber dominated by Glamaig-type silicic magma. One consequence of this interaction would be the net transfer of heat from the hotter basic magma into the cooler silicic magma, causing the latter to convect and further entrain the former.

6.F.3 The Maol na Gainmhich and Eas Mòr Granites

The Maol na Gainmhich and Eas Mòr granites were identified by (Wager, et al., 1965) as having formed early in the evolution of the WRHIC. However, no direct evidence of their age(s) relative to the Glamaig Granite is available, although it is evident that both granites were intruded before the Marscoite Suite (6.F.6).

The Maol na Gainmhich Granite is a coarse-grained, amphibole-bearing rock that contains only one feldspar, a potassium-rich variety (Figure 6-62). The amphibole is rich in alkalis and has been identified as arfvedsonite. This intrusion crops out north of Loch Ainort, in the ground south of Maol na Gainmhich, between Ceann a' Chreagain and the coast (Figure 6-56). In addition, the granite that crops out on the SW coast of the neighbouring island of Scalpay may be from the same intrusion (Wager, et al., 1965).

Figure 6-62 – Field image of coarse-grained, amphibole-bearing Maol na Gainmhich Granite. Coin *c.* 24mm across.

The Eas Mòr Granite crops out on the NW slopes of Glamaig, being accessible in the stream bed of the Eas Mòr, itself (Figure 6-63). It is characterised by phenocrysts of alkali feldspar, together with relatively abundant green hornblende, set in a fine-grained, quartz and alkali feldspar dominated, groundmass.

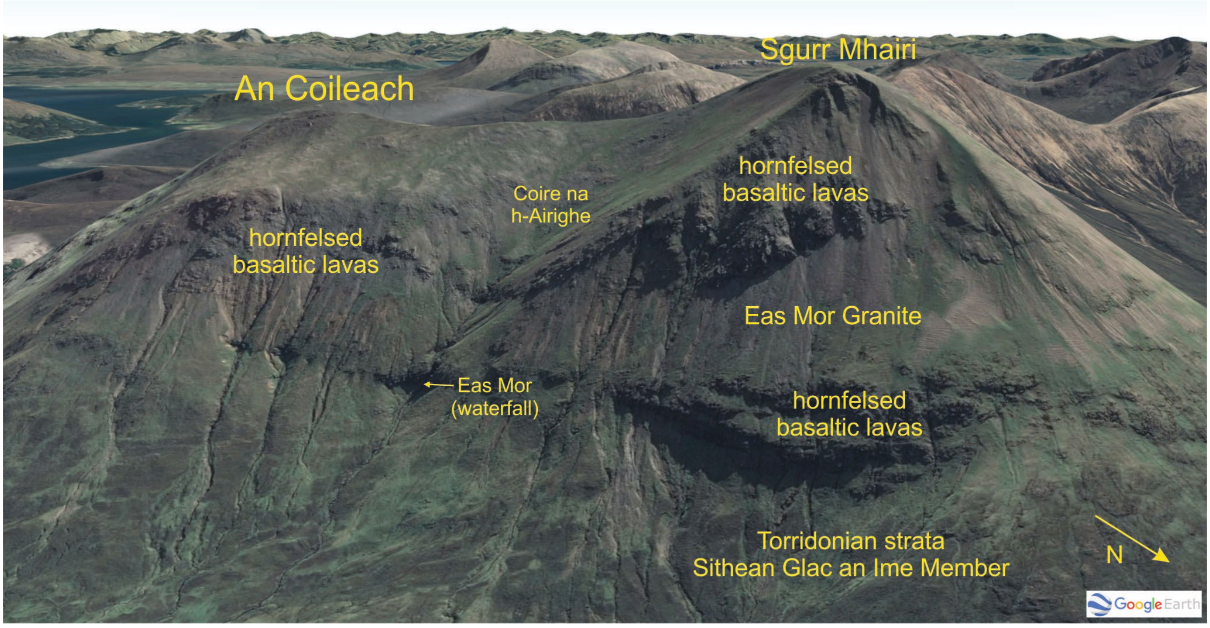
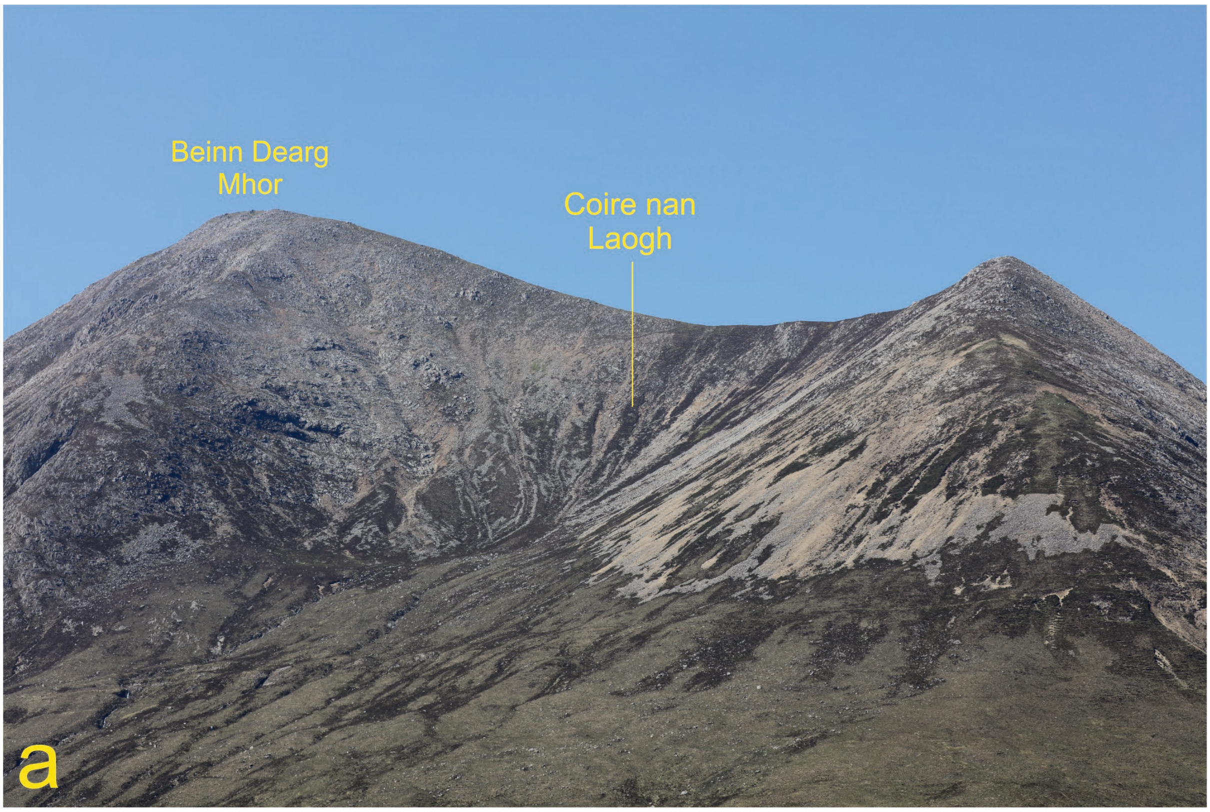


Figure 6-63 – Oblique Google Earth© image of the north face of Glamaig, with the relatively easily weathered Eas Mòr Granite, comprising a horizontal outcrop, with hornfelsed country-rock basaltic lavas above and below. View towards the SW.

6.F.4 The Beinn Dearg Mhòr and Loch Ainort Granites

The Beinn Dearg Mhòr Granite crops out on the Red Hill of that name (Figure 6-64), as well as on Ciche na Beinne Deirge and Beinn Dearg Mheadhonach, and was originally called the G2 granite by (Richey, et al., 1946). Its inner and outer margins are close to vertical (Figure 6-59) and locally show signs of crushing. Along its boundary with the Glamaig Granite, for example at Am Fuar-choire, it has a chill facies of porphyritic felsite/rhyolite, which clearly indicates the time-relationships between the two intrusions. At Màm a' Phobuill, the Beinn Dearg Mhòr Granite is fractured and altered by the later Southern Porphyritic Granite (6.F.5). Along its inner margin, for example in the Allt Mhic Mhoirein, the Beinn Dearg Mhòr Granite is fractured by the later Loch Ainort Granite (see below).



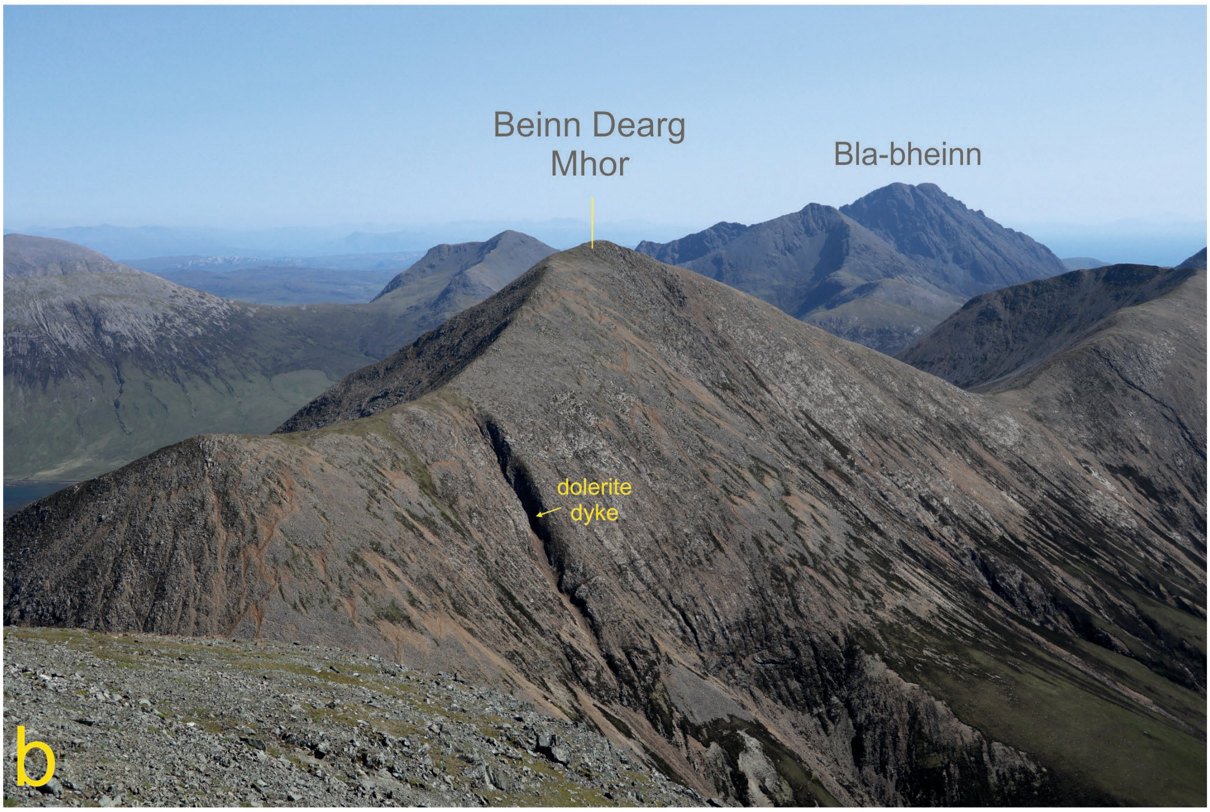


Figure 6-64 – (a) The east side of Beinn Dearg Mhòr, composed of the Beinn Dearg Mhòr Granite, view towards the SW from Gleann Torra-mhichaig; and (b) Beinn Dearg Mhòr viewed towards the south from Sgùrr Mhairi (Glamaig).

The Beinn Dearg Mhòr Granite weathers deeply, to a distinct rusty red, in sharp contrast to the grey coloration of the neighbouring, older Glamaig Granite (Figure 6-59). Fresh material is most readily examined in road-cuts at the southern end of Gleann Torra-mhichaig, where it is greenish-blue. It contains abundant phenocrysts of fresh, glassy anorthoclase, commonly in a glomero-porphyritic arrangement. The groundmass is composed of granophyric intergrowths of quartz and alkali feldspar. The most common ferromagnesian mineral is the Fe-rich clinopyroxene, ferrohedenbergite, together with some hornblende, Fe-Ti oxides, apatite and biotite. Olivine is not common but, where present, is typically serpentinised.

Around the northern margin of the Beinn Dearg Mhòr Granite, south of the Allt Mòr Doire Mhic-ùin, is a zone of disruption, with large slabs of crushed, altered gabbro forming part of a screen between it and the Glamaig Granite. These slabs were most likely entrained along the contact during the emplacement of the younger Beinn Dearg Mhòr Granite.

The Loch Ainort Granite crops out on the low ground around the head of Loch Ainort, between Maol Bàn in the north, and Coire Choinnich in the south, and is roughly L-shaped, with an area of *c.* 7km^2 (Figure 6-56; Figure 6-65;Figure 6-66). Crushing complicates its contacts with the Beinn Dearg Mhòr Granite to the west, the Northern Porphyritic Felsite (6.F.7) to the north, and the Southern Porphyritic Granite (6.F.5) to the south. It is truncated to the east by the oldest of the granites of the Eastern Red Hills Intrusive Centre, the Glas-Bheinn Mhòr Granite (6.G). In terms of its petrology, the Loch Ainort Granite is almost identical to the Beinn Dearg Mhòr Granite (see above). The zone of crushing in the northern part of the granite, between Druim nan Cleochd and Leathad Chrithinn, lead J.D. Bell ((Bell, 1959); (Bell, 1966)) to conclude that the two intrusions are part of the same mass, with upward movement of the inner Loch Ainort Granite, relative to the outer Beinn Dearg Mhòr Granite, bringing about the observed field relationships.

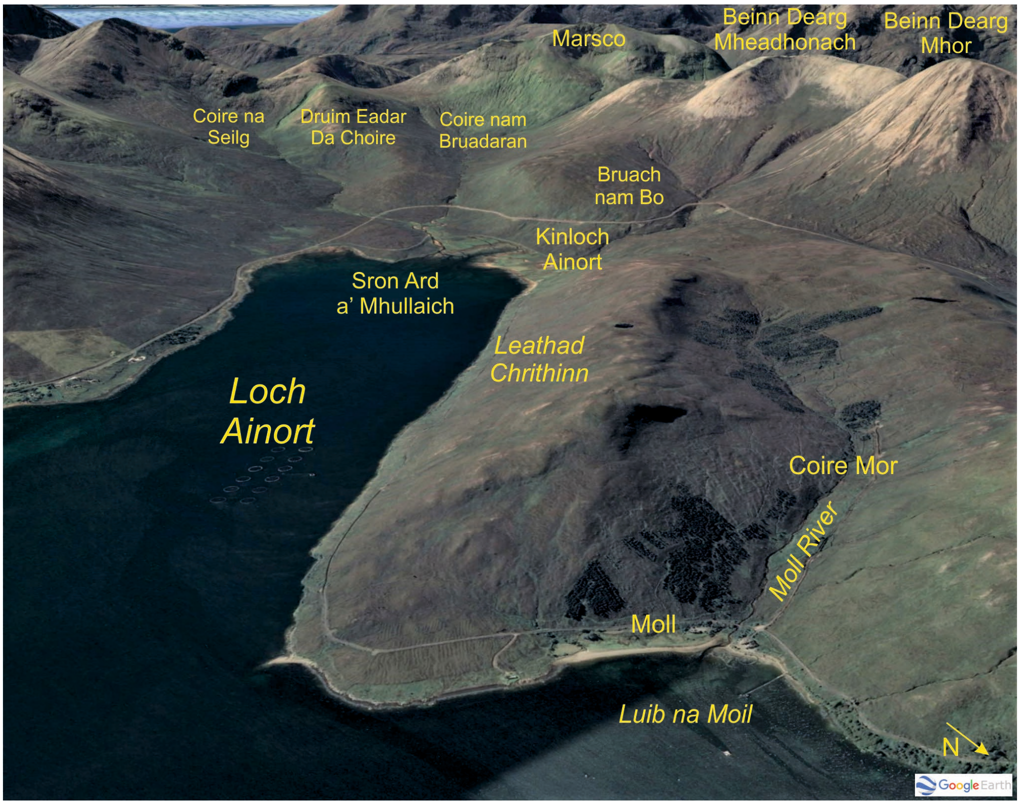


Figure 6-65 – Oblique Google Earth© image of the Loch Ainort area, with the Loch Ainort Granite cropping out on the NE side of the loch at Leathad Chrithinn. View towards the SW.

Figure 6-66 – Exposure of the Loch Ainort Granite forming the Eas a' Bhradain on the Allt Coire nam Bruadaran at the head of Loch Ainort.

In the vicinity of the Allt Coire na Cìche, J.D. Bell (Bell, 1966) identifies a fine-grained rock containing biotite and amphibole. It is light grey and may either constitute a separate sheet of material intruded between the Beinn Dearg Mhòr and Loch Ainort granites, or a marginal facies of one of them. A small intrusion of similar material is exposed SW of Sròn Ard a' Mhullaich, at the head of Loch Ainort. Essentially, these are porphyritic felsites/rhyolites, containing feldspar phenocrysts of the same type present in the granites. Locally, the felsites have gradational contacts with the granites.

6.F.5 The Glen Sligachan and Southern Porphyritic Granites

The Glen Sligachan Granite (Figure 6-56; Figure 6-61) has a very limited outcrop, *c.* 750m x 100m, along the northern side of the Marscoite Suite, at the base of Harker's Gully on Marsco (Figure 6-61). It weathers to a rusty brown, although when fresh is bluish-grey, with a distinctly porphyritic character. The phenocrysts of feldspar consist of plagioclase cores, rimmed with alkali feldspar, together with crystals that are purely alkali feldspar (microperthite). Both ferrohedenbergite and olivine (generally altered) are present in small quantities. This granite is most easily examined in the drift-covered, hummocky ground east of the path, at the foot of Harker's Gully (Figure 6-67). According to Thompson (1969), the Glen Sligachan Granite was approximately contemporaneous with the Southern Porphyritic Granite.

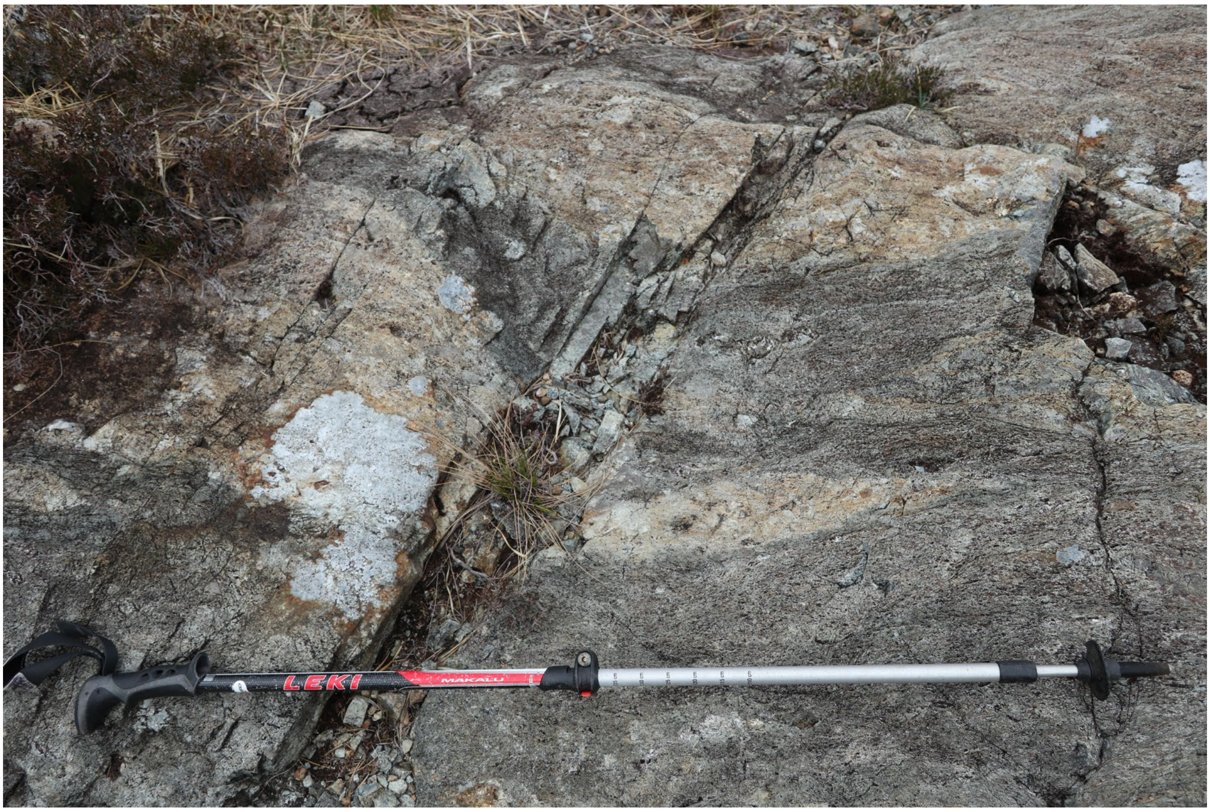


Figure 6-67 – Sheared Glen Sligachan Granite, east of the Sligachan – Camasunary path. Pole *c.* 1m long.

The Southern Porphyritic Granite (Figure 6-56; Figure 6-61) is exposed in a broad tract of ground north of the Marscoite Suite (6.F.6), between Màm a' Phobuill in the west and the Allt a' Mheadhoin in the east, and also to the south of the Marscoite Suite, at Fiaclan Dearg, on Marsco (Figure 6-68). Along the northern margin of the main outcrop, dipping at 60° to the south, the Southern Porphyritic Granite cuts the Glamaig, Beinn Dearg Mhòr and Loch Ainort granites, although well-defined contacts are not open to examination. The southern margin of this outcrop of the granite is almost vertical and there is an extensive development of a marginal chill facies of felsite/rhyolite (6.F.6). The outcrop of the Southern Porphyritic Granite south of the Marscoite Suite has the form of a ring-dyke roof fragment, lying below the older Glamaig Granite, and above the younger Marsco Granite (6.F.8).

Figure 6-68 – Contact between the Southern Porphyritic Granite (with wide-spaced joints; left side of exposure) and the Southern Porphyritic Felsite (with narrow-spaced joints; right side of exposure). NE side of Marsco, north of Harker's Gully (*c.* 100m above the Shelter Stone). Pole *c.* 1m long, located at contact.

This pale-weathering granite contains phenocrysts of quartz and clouded alkali feldspar, set in a granophyric groundmass. (Thompson, 1969) recorded the presence of small amounts of ferrohedenbergite, olivine, amphibole and biotite. Crushing is a common feature within the Southern Porphyritic Granite, and this led (Wager, et al., 1965) to suggest that a high H_2O pressure developed during its crystallisation.

The marginal felsite/rhyolite facies, along the contact with the Marscoite Suite, is referred to as the Southern Porphyritic Felsite and contains the same phenocryst assemblage as the closely related granite, but is set in a felsitic, or fine-grained to glassy, groundmass. (Wager, et al., 1965) concluded that the felsite constitutes a thin, separate sheet of material injected into the granite after it had been crushed, but whilst still hot. The felsite was most likely derived from the same magma source as the Southern Porphyritic Granite, but clearly cooled much faster and was most likely depleted in volatiles. The significance of the Southern Porphyritic Felsite, in relation to magma-mingling/mixing processes in the Western Red Hills Intrusive Centre, is discussed in Section 6.F.6.

6.F.6 The Marscoite Suite

The Marscoite Suite forms a partially preserved composite ring-dyke within the WRHIC and was first identified as a distinct group of rocks by (Wager, et al., 1965), and includes: porphyritic felsite/rhyolite, ferrodiorite, and the (locally named and used) hybrid rocks marscoite, glamaigite and dioritic glamaigite. The ring-dyke's main and most important outcrop forms a prominent gully on the NW side of Marsco (Figure 6-61; Figure 6-69; Figure 6-70). The hybrid nature of marscoite (see below) was first deduced by Alfred Harker (Harker, 1904) and, to honour his remarkable insight, the gully formed by the inweathering of the ring-dyke was informally named 'Harker's Gully' by (Wager, et al., 1965).

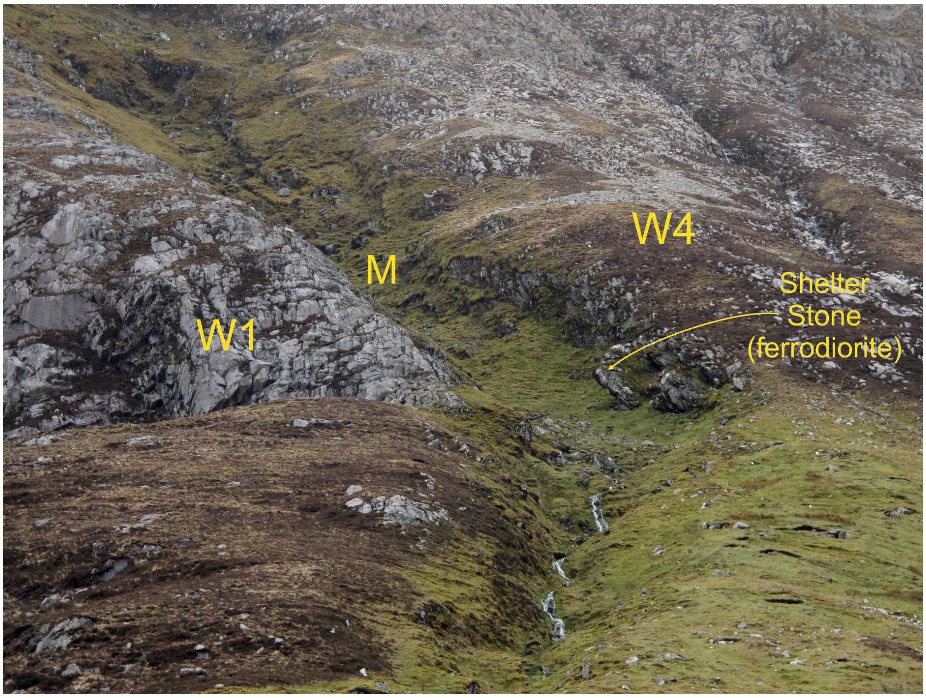


Figure 6-69 – The lower part of Harker's Gully on the NW side of Marsco, marking the location of the Marscoite Suite (M) of rocks forming part of a composite ring-dyke within the WRHIC. W1: Glamaig Granite; W4: Marsco Granite. The protruding rock on the south (right) side of the gully is the so-called Shelter Stone, composed of ferrodiorite.

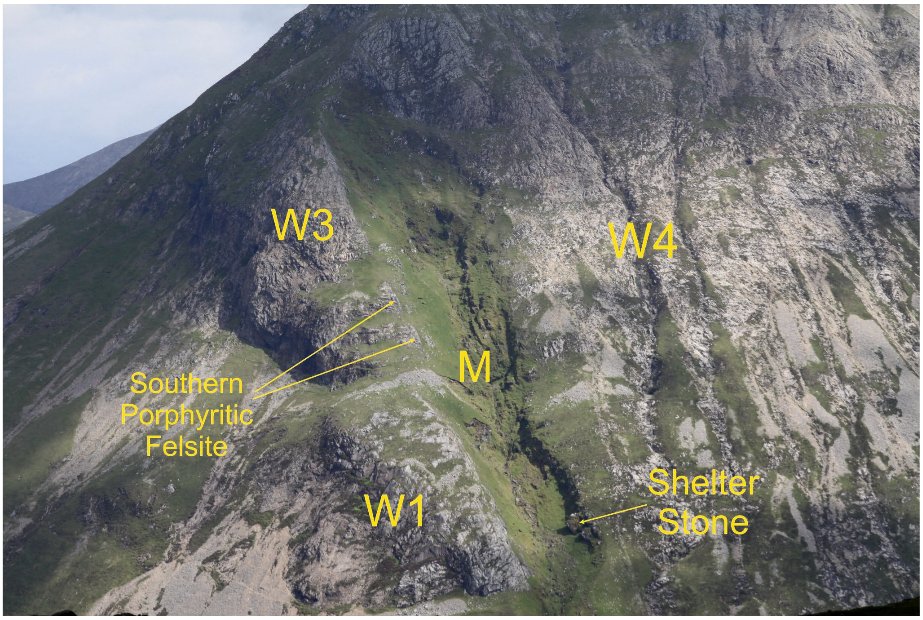


Figure 6-70 – The upper part of Harker's Gully on the NW side of Marsco, marking the location of the Marscoite Suite (M) of rocks forming part of a composite ring-dyke within the WRHIC. Southern Porphyritic Felsite indicated. W1: Glamaig Granite; W3: Southern Porphyritic Granite; W4: Marsco Granite. The protruding rock on the south (right) side of the gully is the so-called Shelter Stone, composed of ferrodiorite. View towards the east from the lower part of Fionn Choire.

In Harker's Gully, on the NW side of Marsco, (Wager, et al., 1965) were able to deduce the field relationships of the porphyritic felsite/rhyolite, the ferrodiorite and the marscoite units/lithologies

(Figure 6-69), and suggested that marscoite was formed by mechanical mingling/mixing of porphyritic felsite/rhyolite and ferrodiorite magmas. On the basis of simple calculations, (Wager, et al., 1965) concluded that the mixing of *c.* 65% of ferrodiorite magma (an Fe-enriched fractionate of tholeiitic basalt magma) and *c.* 35% of porphyritic felsite/rhyolite magma (the Southern Porphyritic Felsite, see Section 6.F.5) would result in a magma with the composition of marscoite. Confirmatory mineralogical evidence for the hybrid nature of marscoite is readily obtained from thin-section studies. For example, this fine-grained, grey rock contains xenocrysts of andesine (with rounded edges), orthoclase (with embayed margins, the so-called fingerprint texture) and quartz (fringed with either pyroxene or amphibole), all of which can be identified as phenocrysts in the postulated basic and silicic parents (the andesine in the ferrodiorite and the orthoclase and quartz in the porphyritic felsite).

The ferrodiorite tends to be the most easily weathered of the three lithologies and is responsible for the gully's development. Locally, it has well-developed spheroidal/doleritic/onion skin weathering, typical of mafic rocks (Figure 6-71) and occurs in two varieties: with or without distinct phenocrysts of andesine (zoned from An_{50} to An_{30}). The groundmass is composed of turbid crystals of alkali feldspar, interstitial quartz, inverted pigeonite, augite and olivine (Fo_{22}, typically altered to serpentine), together with accessory apatite, zircon, Fe-Ti oxides and pyrrhotite. Also present within the ferrodiorite intrusion are large (10–30cm) inclusions of andesinite, an essentially monomineralic lithology of plagioclase (andesine) crystals. These inclusions are also found within the marscoite but are much less common. Xenoliths of Lewisian Gneiss (3.B) occur within the ferrodiorite intrusion in Harker's Gully and in the Allt Coire nam Bruadaran (Figure 6-72). The mineralogy of the Southern Porphyritic Felsite is outlined in Section 6.F.5.

Figure 6-71 – Typical spheroidal weathering of ferrodiorite on the north side of Harker's Gully at the Shelter Stone level. Pole *c.* 1m long.

Figure 6-72 – Xenolith of banded gneiss within the ferrodiorite intrusion of the Marscoite Suite close to the base of Harker's Gully on the NW side of Marsco. Coin *c.* 24mm.

On the north side of Harker's Gully, the Southern Porphyritic Felsite, marscoite and ferrodiorite occur as relatively thin, steeply-inclined sheets, which constitute part of a large, outward-dipping, composite ring-dyke that can be traced, albeit discontinuously, from Marsco in the west, to Coire Choinnich in the east (Figure 6-73).

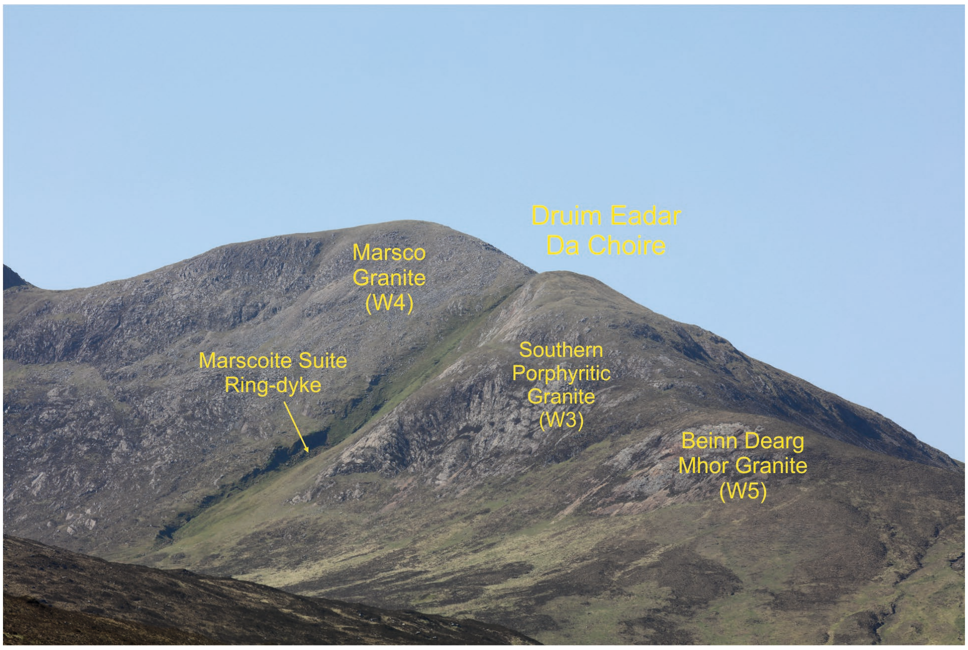


Figure 6-73 – Trace of the Marscoite Suite ring-dyke, forming a trench-like feature on the east side of Druim Eadar Dà Choire, flanked by the Southern Porphyritic Granite and the Marsco Granite. View towards the SW.

On Marsco, at the level of the so-called *Shelter Stone* (Wager, et al., 1965), the following field relationships can be deduced (Figure 6-74). First, marscoite chills against, and rarely veins, the

Southern Porphyritic Felsite, although their bulbous mutual boundary suggests that the latter had not totally crystallised. Second, the marscoite grades over *c.* 10m into porphyritic ferrodiorite, suggesting that the two intrusions were emplaced almost synchronously, and that *in situ* mingling/mixing (both mechanical and diffusional) has destroyed any sharp boundary that may have existed between the two.

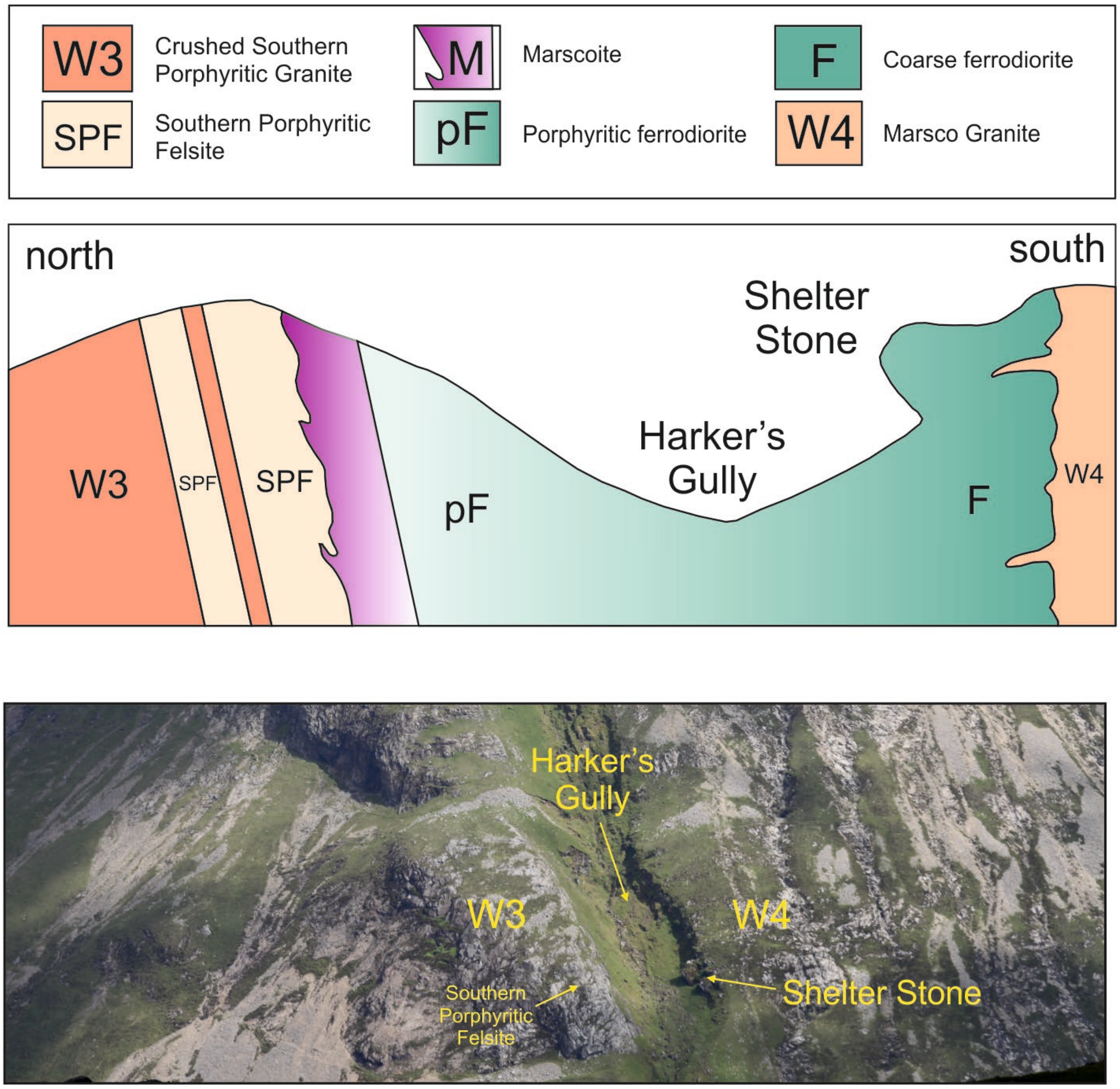


Figure 6-74 – Schematic cross-section through the Marscoite Suite at the level of the Shelter Stone in Harker's Gully on the NW side of Marsco (after Wager *et al.* 1965).

On the south side of the gully, the ferrodiorite is coarser-grained and non-porphyritic. Typical ferrodiorite forms the overhanging Shelter Stone (Figure 6-71; Figure 6-74). Also, on this side of the gully, the ferrodiorite is in contact with the Marsco Granite, one of the youngest of the Western Red Hills major granitic intrusions (see 6.F.8).

A subsequent investigation of these rocks by (Thompson, 1969) identified quartz xenocrysts within the ferrodiorite, suggesting that it, too, is a hybrid rock. Also, at the top of Harker's Gully, above the roof of the Marsco Granite, (Thompson, 1969) identified a complete (and symmetrical) section through this composite ring-dyke (Figure 6-75). The section consists of: felsite-marscoite-ferrodiorite-marscoite-felsite, and confirms the previously deduced sequence of intrusive events as: felsite, followed by marscoite, followed by ferrodiorite.

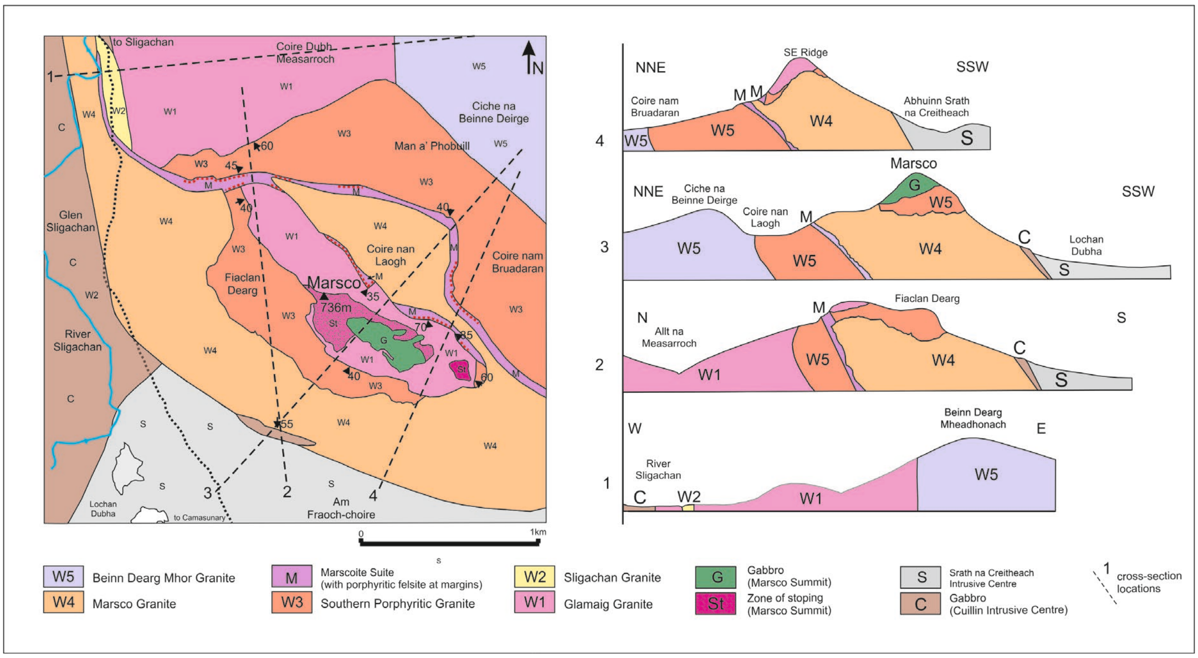


Figure 6-75 – Schematic cross-sections through the Marsco area (after Thompson 1969).

Members of the Marscoite Suite in the northern part of the WRHIC crop out as three separate intrusions, referred to by (Wager, et al., 1965) as the Glamaig, Meall Buidhe and Moll Shore intrusions (Figure 6-56; Figure 6-76). In addition to marscoite, two other (locally named and used) hybrid rocks are identified within these composite intrusions: glamaigite and dioritic glamaigite.

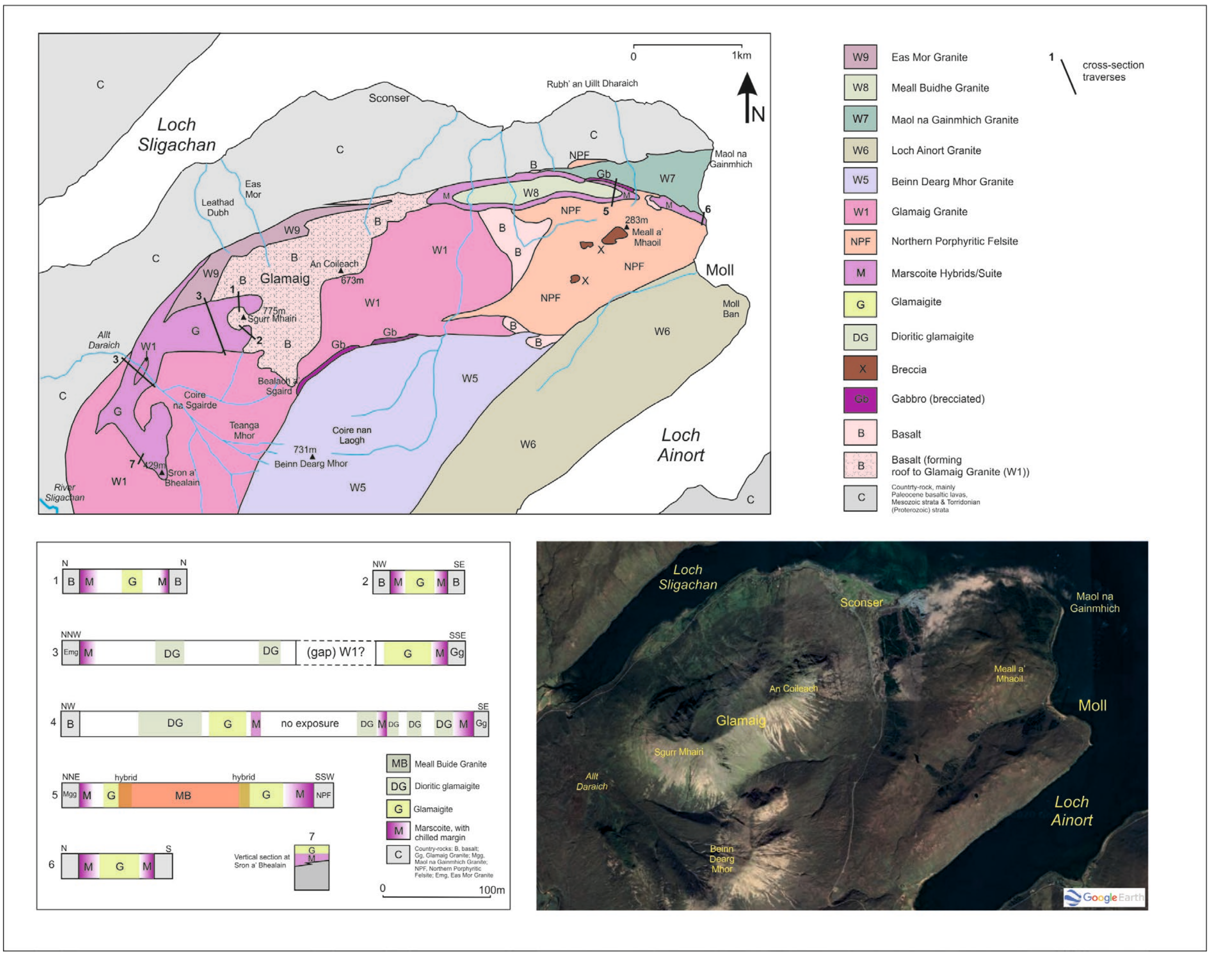


Figure 6-76 – Schematic cross-sections through Marscoite Suite in the northern part of the WRHIC (after Wager *et al.* 1965), and Google Earth© image of the same area.

The Glamaig hybrid Intrusion consists of an inclined sheet cutting the granites and lavas SW of the summit of Glamaig and on Sròn a' Bhealain. The attitude of this sheet is most readily determined in the Allt Daraich, where it dips at 45° to the NW. On Sròn a' Bhealain, the dip is much less, *c.* 5°, in the same general direction. The Meall Buidhe Hybrid Intrusion is exposed in the ground between the hill of that name and the Abhainn Torra-mhichaig, further west, and forms an almost-vertical sheet. The Moll Shore Hybrid Intrusion is, in many ways, similar, and is readily examined along the road-cuts south of Maol na Gainmhich. The disposition of these intrusions suggests that they have the same steep-sided, incomplete ring-dyke form as the Marscoite Suite exposed in the southern portion of the WRHIC (see above).

The margins of all three northern hybrid intrusions consist of chilled marscoite, which grades over *c.* 1m into 'normal' marscoite. 10–20m beyond, the rock takes on a heterogeneous, streaky (or net-veined) appearance, passing into, over the next 10m, a hybrid rock referred to by (Wager, et al., 1965) as glamaigite (Figure 6-77). This is a rock which (Harker, 1904) described as a xenolithic granophyre, believing it to have formed by the mixing of marscoite and a granitic magma (see below). Towards the centres of the three hybrid intrusions, a more homogeneous facies of glamaigite is preserved, which (Wager, et al., 1965) referred to as dioritic glamaigite. Sections through the three hybrid intrusions are of the symmetrical form: marscoite-glamaigite-dioritic glamaigite-glamaigite-marscoite.

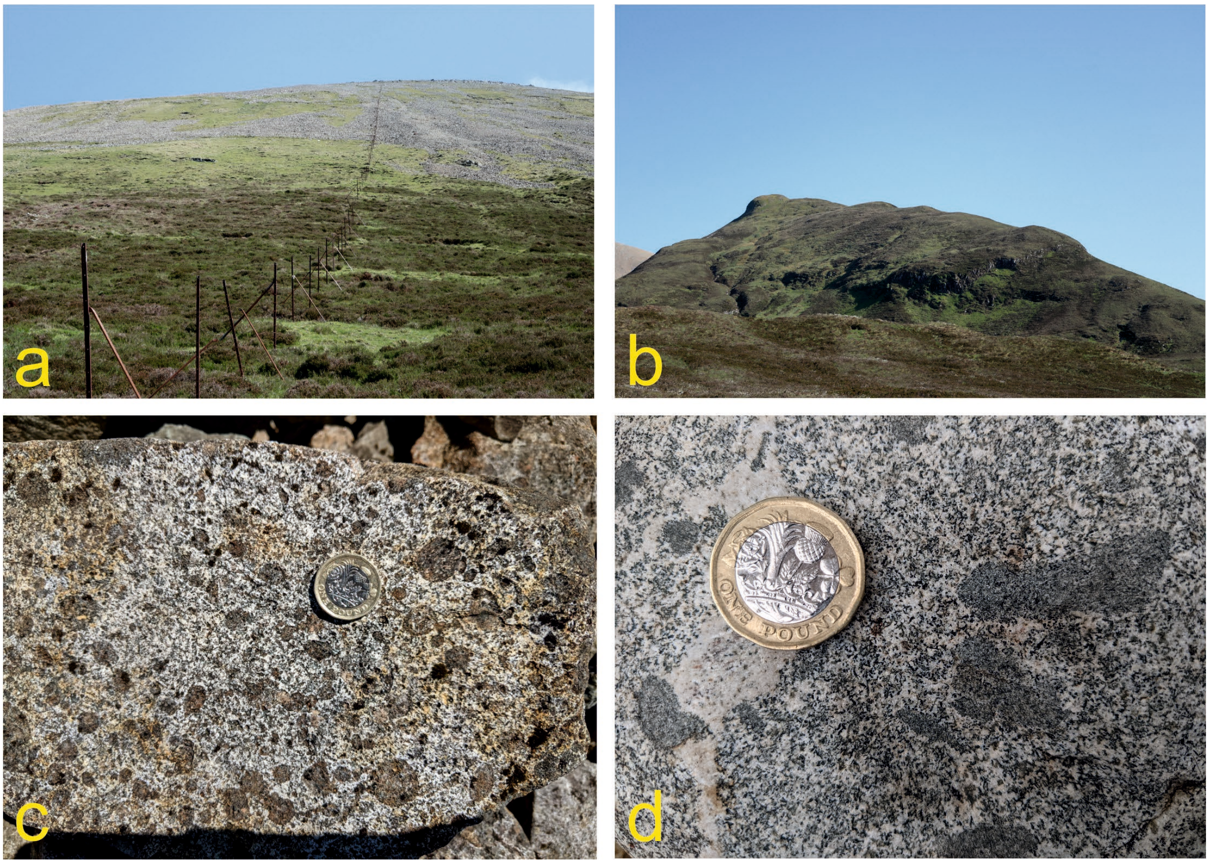


Figure 6-77 – (a) SW side of Glamaig, dominated by a scree of glamaigite; (b) north face of Sròn a' Bhealain, composed of an inclined sheet of glamaigite, view towards the SW from Glamaig; and, (c) & (d) hand specimens of glamaigite, comprising contrasting dark (mafic) and pale (silicic) components in an arrested state of mixing (hybridisation). Coin *c.* 24mm across.

In the centre of the glamaigite unit of the Meall Buidhe Hybrid Intrusion is a silicic intrusion, the Meall Buidhe Granite. The petrology of this somewhat variable granite is described in Section 6.F.7.

Xenoliths and xenocrysts are common within the northern marscoite-glamaigite intrusions. Andesinite is the commonest xenolith type, together with glomero-porphyritic patches of xenocrystic plagioclase. Also present are smaller, rounded masses of fine-grained basic material containing plagioclase phenocrysts with compositions of An_{50} and whole-rock compositions approximating to that of hawaiite.

From simple calculations, (Wager, et al., 1965) suggested that the northern marscoites of the Glamaig, Meall Buidhe and Moll Shore hybrid intrusions were generated by the mixing of *c.* 40% porphyritic felsite magma (Southern Porphyritic Felsite) with *c.* 60% basic (hawaiitic) magma.

The heterogeneous nature of the glamaigite intrusions suggests that they, too, have formed by various mingling/mixing processes. For example, detailed microscopic studies show that the dark patches characteristic of glamaigite, most readily identified on weathered surfaces, and the paler 'matrix' material have mineralogies similar to that of typical marscoite. Thus, glamaigite has at least two distinct parts, both essentially marscoites, and both containing xenocrysts of andesine, quartz and alkali feldspar. It is clear, therefore, that the heterogeneous and homogeneous forms of glamaigite have had long, complex histories.

6.F.7 The Northern Porphyritic Felsite and the Meall Buidhe Granite

The Northern Porphyritic Felsite (NPF) crops out over an area of *c.* 2km^2 south of Meall Buidhe and has many features in common with the Southern Porphyritic Felsite (see 6.F.6) (Figure 6-76; Figure 6-78). However, no equivalent granite can be correlated, at the present level of erosion, with this felsite. Similar to the Southern Porphyritic Felsite, the NPF contains phenocrysts of quartz and alkali feldspar (and in the same relative proportions) but differs in terms of its greater absolute amount of these phenocrysts. A further distinctive feature is the presence of small (2–10cm) fragments of basic material dispersed throughout the intrusion. This material is similar, but not identical, to the inclusions within the Glamaig Granite (6.F.2). The NPF has a thin crush zone where it is in contact with older country-rock basaltic lavas and the Glamaig Granite.

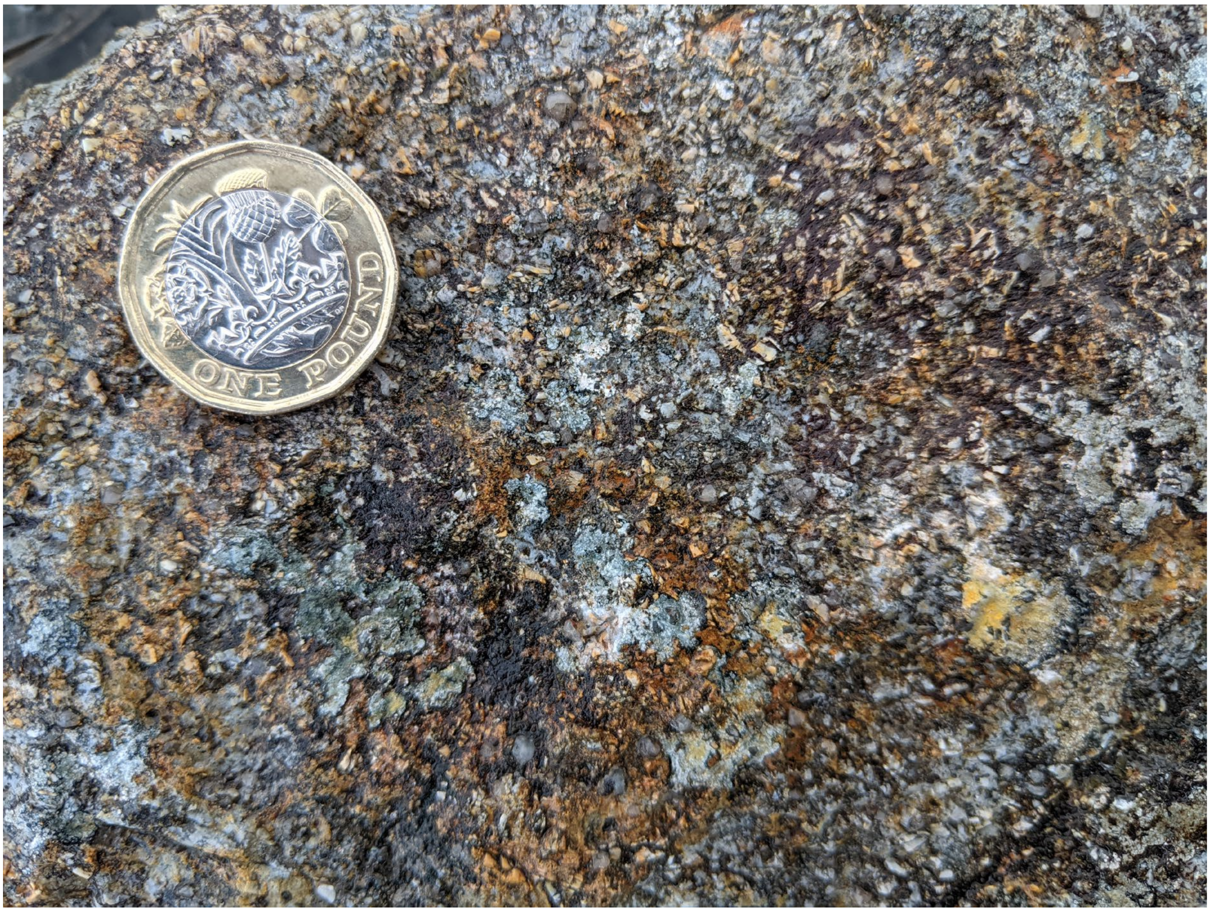


Figure 6-78 – Typical weathered surface of the Northern Porphyritic Felsite, with pink alkali feldspar and grey quartz phenocrysts. Coin *c.* 24mm across.

The Meall Buidhe Granite occurs within the northern marscoite-glamaigite Meall Buidhe Hybrid Intrusion (Figure 6-76), which crops out in the area between Meall Buidhe and the Abhainn Torra-mhichaig. The best exposures are in the Allt a' Bhealaich Bhric, where its close relationship with these hybrid rocks is readily noted. The Meall Buidhe Granite is a microgranite, containing phenocrysts of oligoclase rimmed with altered alkali feldspar, set in a groundmass dominated by quartz and alkali feldspar. Also present are small quantities of pyroxene, a green amphibole, a green biotite, and a small amount of serpentinised olivine. These mineralogical features led (Wager, et al., 1965) to conclude that this intrusion is similar to the Marsco Granite (6.F.8), the youngest of the granites of the WRHIC (see below).

6.F.8 The Marsco Granite

The Marsco Granite crops out on the southern and western sides of Marsco ((Wager, et al., 1965); (Thompson, 1969)) (Figure 6-79). It is readily identified by its non-porphyritic character, is pale blue when fresh (pale brown when weathered) and may be examined at the level of the Shelter Stone (Figure 6-69; Figure 6-70; Figure 6-74). The northern margin of this granite against the slightly older ferrodiorite intrusion of the Marscoite Suite/Ring-dyke (6.F.6) dips steeply to the south. These time-relationships are suggested by rare veins of Marsco Granite that penetrate the ferrodiorite, and by the disruption of members of the Marscoite Suite by the Marsco Granite in Coire nan Laogh. However, (Thompson, 1969) noted that where the Marsco Granite is in contact with ferrodiorite there is evidence that the latter had not completely crystallised. Along such contacts are hybrid rocks, suggesting that some form of mixing/interaction process has taken place, albeit locally. The flat-lying roof of the Marsco Granite crops out at *c.* 500m OD, below Fiaclan Dearg (Figure 6-79), although in places apophyses of the intrusion vein and stope the older, overlying Southern Porphyritic Granite at higher levels (Figure 6-61; Figure 6-69; Figure 6-70).

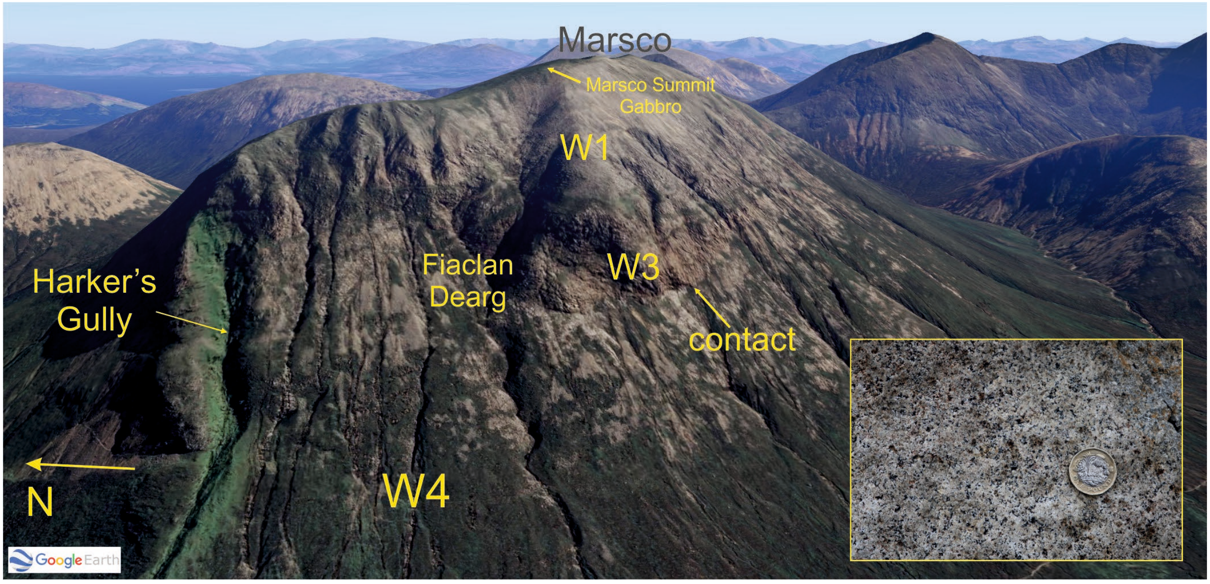


Figure 6-79 – Oblique Google Earth© image of the flat-lying contact between the (lower) Marsco Granite (W4) and the (upper) Southern Porphyritic Granite (W3) on Fiaclan Dearg on the west side of Marsco. W1: Glamaig Granite. View towards the east. Inset: field view of typical (non-porphyritic) Marsco Granite.

The primary mineralogy of the Marsco Granite consists of quartz, alkali feldspar and plagioclase (An_{24}), together with ferrohedenbergite and fayalite in the lower parts of the intrusion, and amphibole near to the roof zone. Accessory apatite, zircon, allanite and Fe-Ti oxides are also present. A significant feature of the Marsco Granite is miarolitic cavities, especially within the roof zone of the intrusion, which are lined with quartz, alkali feldspar, amphibole and Fe-rich mica (Thompson, 1969).

6.F.9 Mechanisms of Intrusion and Volcanic Processes

Emplacement mechanisms and possible links with volcanic processes of the intrusions of the WRHIC have been considered in detail by Thompson ((Thompson, 1969); (Thompson, 1980)), who makes the following observations: (i) two distinct structural groups of granites are present, one elongated

N-S (Glamaig, Beinn Dearg Mhòr and Loch Ainort granites), the other and later, oriented E-W (Figure 6-56), with members of the N-S group intruded sequentially inwards, whereas the E-W group were emplaced sequentially outwards; (ii) all of the intrusions are approximately co-focal about a point east of Loch Ainort; (iii) the outcrop patterns of the early granites have the appearance of steep-sided ring-dykes that have been disrupted and partially destroyed by later granites, whereas the later granites have shapes more akin to short arcs of circles, which taper towards their edges; and, (iv) permissive emplacement of the intrusions is strongly suggested by the general lack of disturbance of the surrounding country-rocks.

Thompson ((Thompson, 1969); (Thompson, 1980)) suggested the following cauldron subsidence model for the development of the WRHIC. After the formation of various breccias and the emplacement of the sheet-like Marsco Summit Gabbro (6.F.1), the first of the granites (the Glamaig Granite) was emplaced as a steep-sided mass in the Glamaig area. This was followed, along its concave side, by the Beinn Dearg Mhòr and Loch Ainort granites, which are petrographically and compositionally very similar. At this stage, it is postulated, that the subsided, central block was jammed against the country-rocks along part of the ring-fracture zone, possibly in the vicinity of Glen Sligachan. Successive tilting of this block about an E-W oriented axis permitted the intrusion of the various members of the Marscoite Suite (6.F.6) and the later granites. With each successive tilt of the block, similar, but not identical, intrusions would be emplaced in the northern and southern sectors of the intrusive centre. Thus, the distinctive differences between members of the Marscoite Suite preserved in the two parts of the WRHIC might be explained.

In their investigation of the Marscoite Suite, (Wager, et al., 1965) concluded that the mixing events associated with the hybrid rocks marscoite, glamaigite and dioritic glamaigite occurred within a deeper level magma chamber. They suggest that two compositionally contrasting magmas, a lower more basic magma (either ferrodioritic or hawaiitic) and an upper more silicic magma (porphyritic rhyolite/felsite), existed as discrete components within the chamber because of their different physical and chemical properties. Convective currents within each of these magmas caused mechanical mingling/mixing to take place along their mutual boundary/interface. The subsequent emplacement of batches of either the silicic magma, the basic magma, a homogeneous hybrid (marscoite), or a heterogeneous/inhomogeneous hybrid (glamaigite), in either the southern or northern sectors of the intrusive centre, provides a suitable mechanism for explaining the various complex rock associations described above.

(Thompson, 1980) and (Bell, 1983) suggest that these mixing events may have been triggered by the injection of primitive, basic magma into a chamber already containing either silicic magma or silicic magma ponded above a fractionating basic magma. Mixing between these contrasting magmas would produce the hybrids, marscoite and glamaigite.

Another feature of this type of mingling/mixing process would be the entrainment of blebs of the basic magma into the silicic magma. (Thompson, 1980) suggests that the basic inclusions that typify the Glamaig Granite (6.F.2) originated in this way. The same argument may be applied to the Northern Porphyritic Felsite (6.F.7), which, similarly, contains small inclusions/blebs of basic material.

The emplacement of these annular, hybrid intrusions (Glamaig Granite, marscoite and glamaigite) may also have initiated the foundering of a central caldera block. Such an event may have caused additional magma mingling and mixing. Heat transfer from the basic magma would cause extreme vesiculation of any unmixed silicic magma still present within the chamber, resulting in the intrusion of magma along ring-fractures and surface venting.

6.G The Eastern Red Hills Intrusive Centre (ERHIC)

The Eastern Red Hills Intrusive Centre (ERHIC) (Figure 6-80) is the last of the four recognised foci of sub-volcanic activity of Skye Central Complex and occupies the ground between Loch Ainort in the NW, and Heaste in the SE. This relatively large area contains numerous intrusive units, although a significant proportion of the rocks which crop out are pre-Paleocene in age (Chapter 3), acting simply as hosts to the intrusions.

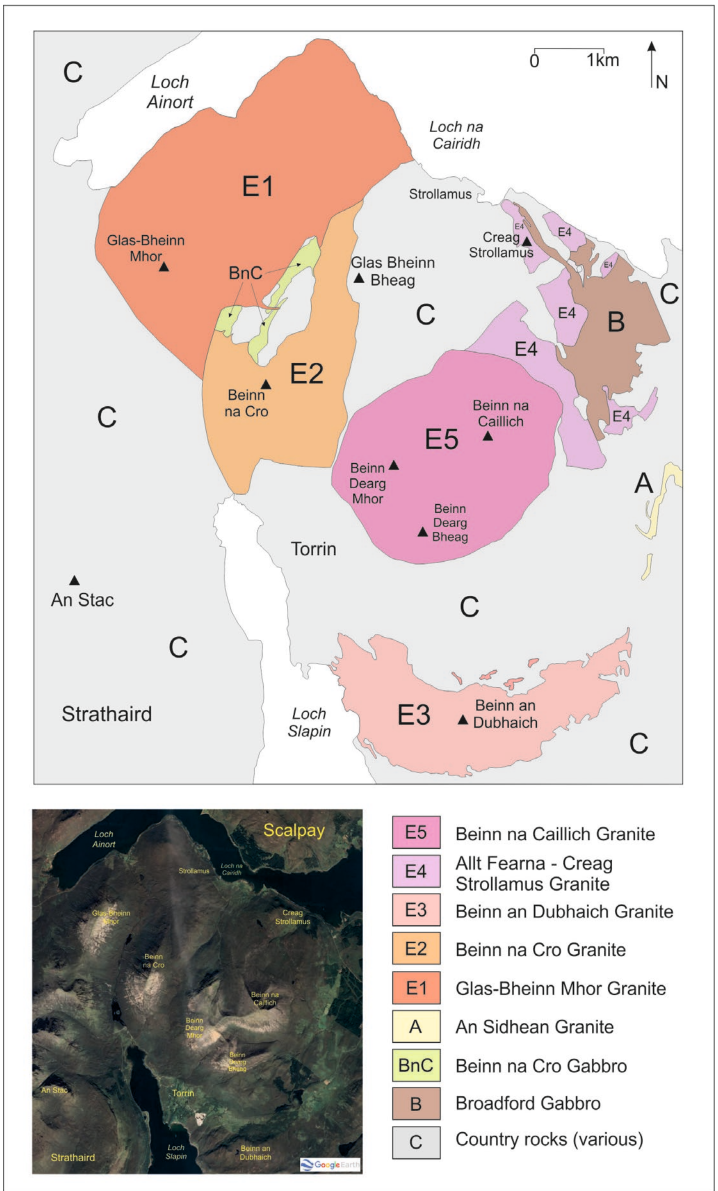


Figure 6-80 – Lithodemic units of the Eastern Red Hills Intrusive Centre (ERHIC) (based on BGS (2005) and Emeleus & Bell (2005)) and Google Earth© image of the same area.

The presence of a distinct intrusive centre in the area around Beinn na Caillich (now defined here as the Eastern Red Hills Intrusive Centre) was considered likely by (Harker, 1904), although he did not define in detail the various components. Further thoughts on the validity of an Eastern Red Hills Intrusive Centre were presented by (Richey, 1932), who defined an 'outer ring granophyre', composed of the granites exposed on Beinn na Crò and Beinn an Dubhaich, which surround the boss-shaped 'central mass' of Beinn na Caillich, also composed of granite. Richey also drew attention to a large suite of composite sills that form an incomplete arcuate belt, co-focal to the granite of Beinn na Caillich (Figure 6-81).

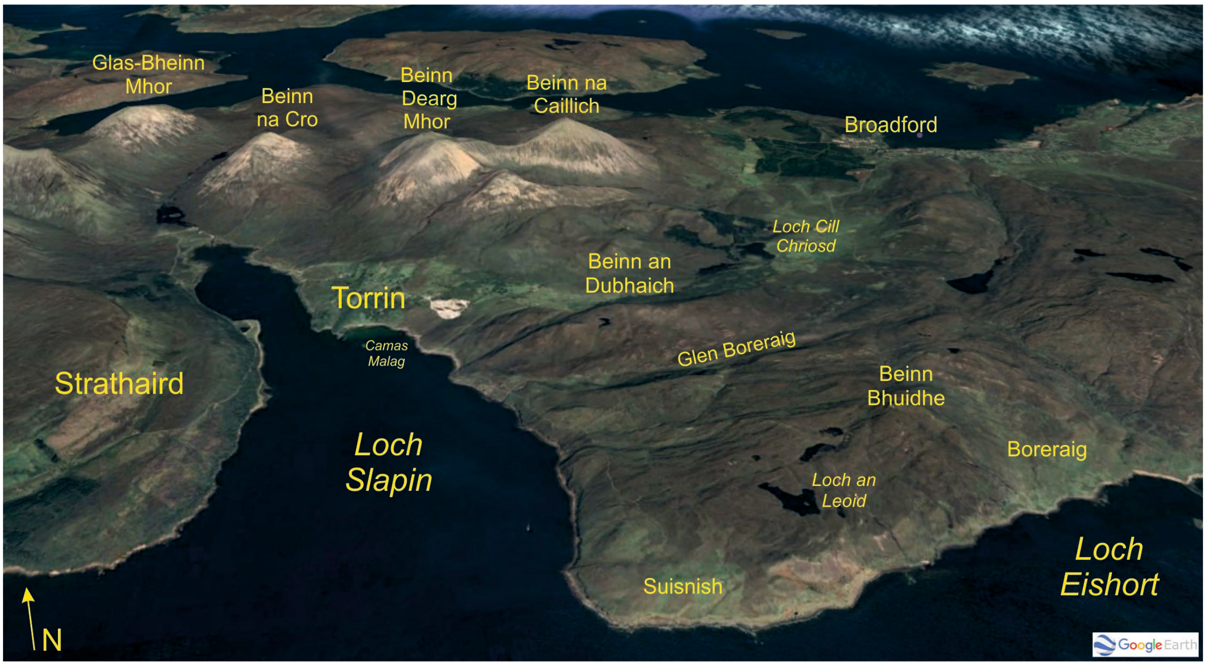


Figure 6-81 – Oblique Google Earth© image of the Eastern Red Hills district, SW of Broadford. View towards the north.

Subsequently, (Stewart, 1965) presented details of the time-relationships of the various units that he considered to be part of the intrusive centre. Similar to the Western Red Hills Intrusive Centre (6.F), unlayered gabbros pre-date the granites, although in this case an additional early intrusion is the Kilchrist Ring-dyke, formed by magma mingling/mixing. At a later stage, the large subvolcanic granites of the district (Figure 6-80) were emplaced, followed by a suite of composite sills and dykes.

J.D. Bell ((Bell, 1976)) outlined the time-relationships of the rock-units of the intrusive centre and the following table is modified from that work:

INTRUSIVE EVENTS	**PRINCIPAL ROCK-TYPE**
[YOUNGEST]	
dykes	Vitrophyre ('pitchstone'), felsite, dolerite, peridotite
Composite sills and dykes	granophyre, felsite, basalt, hybrid lithologies
Beinn na Caillich Granite	amphibole, biotite granite/granophyre, felsite
Beinn na Crò & Beinn an Dubhaich granites	amphibole, biotite granite/granophyre, felsite
Glas-Bheinn Mhòr Granite	amphibole, biotite granite/granophyre, felsite
Broadford Gabbro	gabbro (altered)
Beinn na Crò Gabbro	olivine gabbro/bytownite gabbro
Kilchrist Ring-dyke	mixed-magma (basaltic-silicic) hybrid lithologies
[OLDEST]	

6.G.1 The Kilchrist Ring-dyke

The Kilchrist Hybrids constitute five discrete outcrops of intrusive material in the area between Loch Cill Chriosd (Kilchrist) and Torrin, in the district of Strath, and were first described by (Harker, 1896) (Figure 6-82). Three of these, the Eastern, Western and Southern intrusions, form an incomplete ring-dyke that surrounds various pyroclastic and volcaniclastic rocks (5.E); exterior to the ring-dyke are country-rock Cambro-Ordovician and Jurassic sedimentary rocks (3.E & 4.C). The contacts of these three intrusions against the country-rocks dip steeply outwards, whereas the inner contacts against the pyroclastic and volcaniclastic rocks are relatively flat-lying and comprise fine-grained, more silicic material. The other two intrusions form steep-sided outcrops within the pyroclastic and volcaniclastic rocks and are referred to as the Cnoc nam Fitheach and Coire Forsaidh intrusions. Only the Eastern, Cnoc nam Fitheach and Coire Forsaidh intrusions form prominent topographic features; the first of which crops out on Creagan Fitheach, whereas the last two are exposed in the areas defined by their names (Figure 6-81; Figure 6-82; Figure 6-83). The relationships of the Eastern, Western and Southern intrusions, which are possibly (laterally) connected at depth, to those of Cnoc nam Fitheach and Coire Forsaidh, are obscure. The latter two masses do not appear to be related to a ring-dyke structure and may simply be discrete masses of the same material intruded into the central block of clastic rocks.

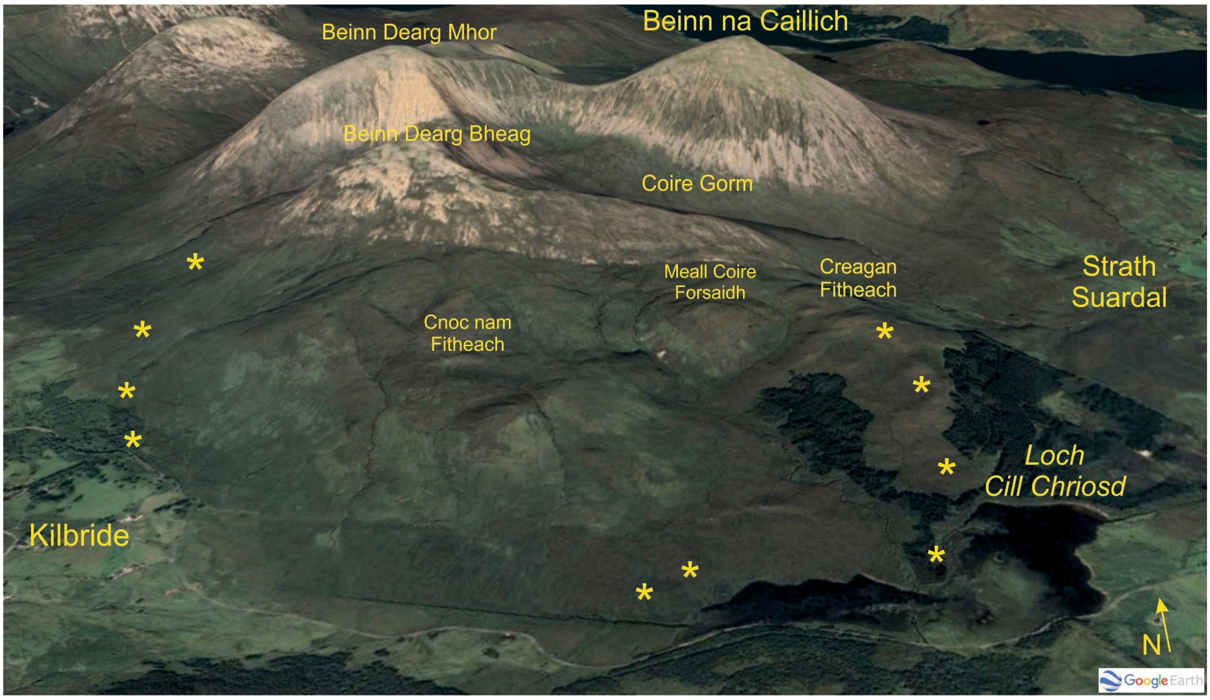


Figure 6-82 – Oblique Google Earth© image of the area south of the Beinn na Caillich, between Strath Suardal and Torrin, indicating the locations of the various parts of the Kilchrist Ring-dyke (*). View towards the north.

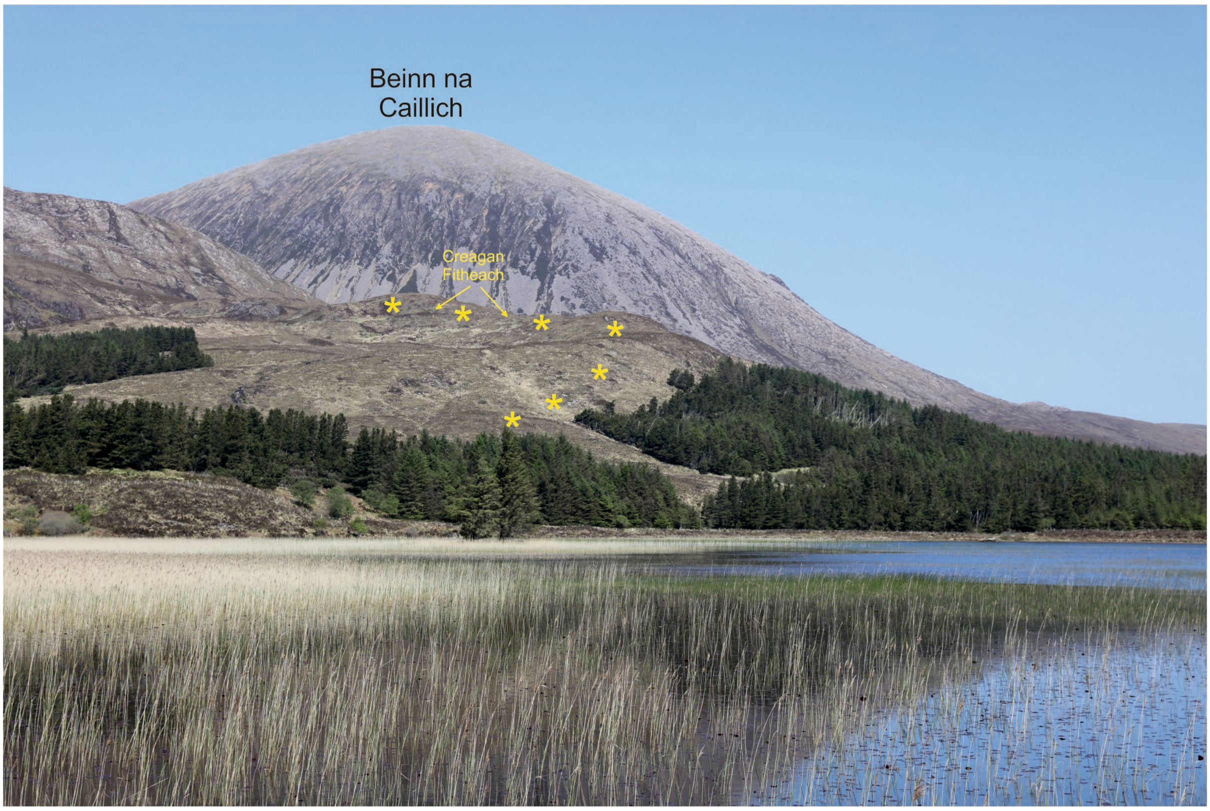


Figure 6-83 – The surface expression of the Eastern outcrop of the Kilchrist Ring-dyke, forming the ridge of Creagan Fitheach, north of Loch Cill Chriosd. In the distance is Beinn na Caillich, composed of part of the Beinn na Caillich Granite. View is towards the north from Loch Cill Chriosd.

The hybrid (mixed-magma) origin of the Kilchrist Ring-dyke is readily noted in the field. Particularly obvious in this leucocratic to mesocratic, medium-grained rock are anhedral crystals of quartz (2–4mm) fringed by clusters of amphibole and/or pyroxene, together with slightly larger (3–5mm), rounded crystals of white (altered) alkali feldspar. Also present are larger (up to 3cm) inclusions of fine-grained basic material with irregular and commonly diffuse margins (Figure 6-84), similar in many respects to the inclusions present within the Glamaig Granite of the WRHIC (6.F.1).

These hybrid rocks are also similar to the mixed-magma/hybrid rocks of the Marscoite Suite of the WRHIC (6.F.6), formed by the incomplete mixing (mingling) of basic and porphyritic silicic magmas, resulting in a hybrid magma in which the phenocrysts are out of equilibrium, hence their disequilibrium textural features. However, unlike the rocks of the Marscoite Suite, no basic and silicic rocks occur in obvious close spatial or temporal association with the Kilchrist Hybrids. However, narrow, flow-banded, marginal facies, some of which have compositions more silicic than the typical Kilchrist Hybrids, occur, for example, in one of the tributaries of the Allt Coire Forsaidh, along the inner margin of the Eastern Intrusion (Figure 6-84). This material may have been intruded prior to the main mixed-magma ring-dyke and represent some of the silicic parent involved in the mixing process. Also present within these fine-grained facies are fragments of the pyroclastic and volcaniclastic material, most likely entrained from the material interior to the ring-dyke.

Figure 6-84 – (a) Silicic (pale) and basaltic/mafic (dark) components of the Creagan Fitheach portion of the Kilchrist Ring-dyke north of Loch Loch Cill Chriosd (Kilchrist), coin *c.* 24mm across; and, (b) inner chill facies of the Eastern Intrusion of the Kilchrist Ring-dyke in the Allt Coire Forsaidh, SW of Creagan Fitheach, coin *c.* 24mm across.

On the basis of general field relationships, although no definite contacts are visible, the Kilchrist Ring-dyke may pre-date the late-stage Beinn na Caillich Granite (6.G.6) and constitutes a small, discrete, sub-volcanic centre that pre-dates the granite-dominated ERHIC (*s.s.*).

6.G.2 The Beinn na Crò Gabbro

The Beinn na Crò Gabbro is a coarse-grained, unlayered, basic intrusion with tholeiitic affinities, varying in composition between an olivine-poor gabbro and an olivine-rich bytownite gabbro. It consists of several thick sheets of relatively flat-lying material intruded into basaltic lavas along the N-S -trending ridge of Beinn na Crò. The Glas-Bheinn Mhòr Granite (6.G.4) has subsequently intruded and altered both the gabbro and the lavas and it is not, therefore, possible to determine the original extent of either unit.

The gabbro is most easily examined in the deep gullies NW of the summit of Beinn na Crò, where the complex sheet-like inter-relationships between the gabbro, lavas and granite are readily noted. Also present are numerous basic dykes that intrude the lavas and the gabbro but predate the Glas-Bheinn Mhòr Granite (Figure 6-85).

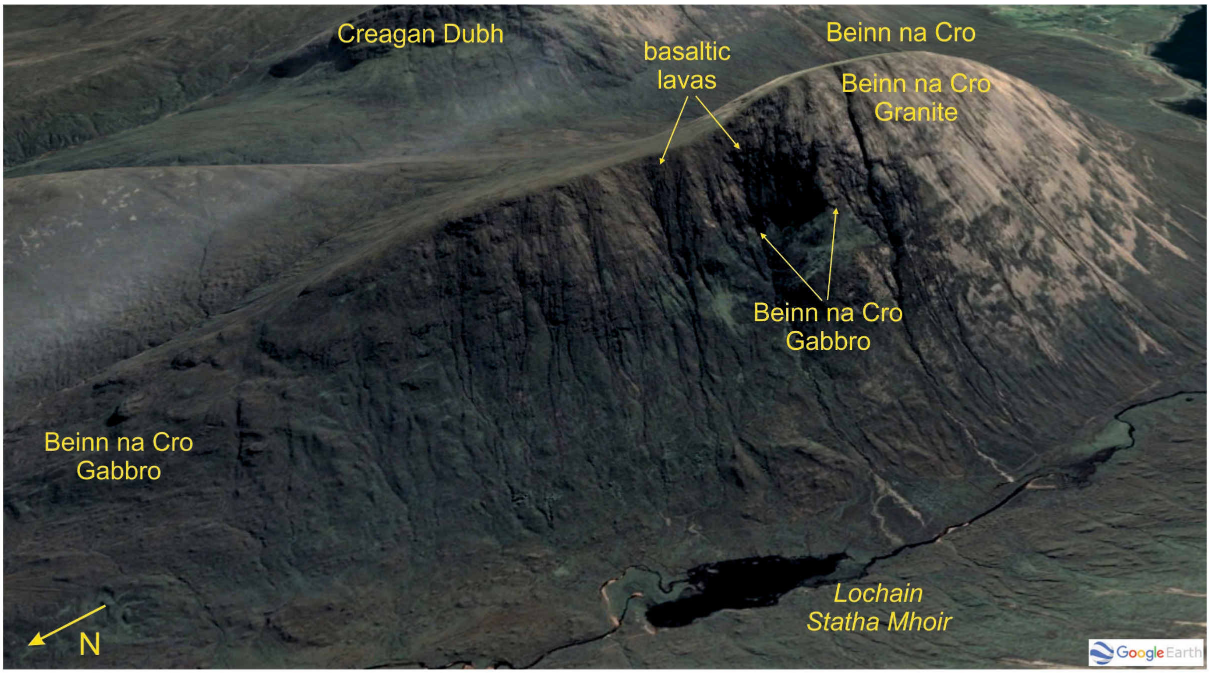


Figure 6-85 – Oblique Google Earth© image illustrating the locations of the Beinn na Crò Gabbro and country-rock basaltic lavas. View towards the SE.

6.G.3 The Broadford Gabbro

The Broadford Gabbro crops out over an area of *c.* 3km^2, WNW of Broadford (Figure 6-80). Along its eastern margin it is bound by Cambro-Ordovician and Jurassic strata, the latter in a faulted relationship, whereas further west the gabbro is cut by younger granites. In the area around Creag Strollamus, the field relationships are complicated by the presence of the Kishorn Thrust Plane (Chapter 3) and, consequently, there is some doubt about the shape of the intrusion (see below).

(Harker, 1904) mapped the area in detail and concluded that the gabbro is intimately associated with Cambro-Ordovician Durness Group dolostones (3.E) that crop out east of the Kishorn Thrust

Plane. Throughout its exposure, the gabbro contains numerous small (typically less than 50m across) enclosures of the carbonates, which form small topographic depressions within the harder igneous rock. (Harker, 1904) concluded that the intrusion is boss-shaped, with steeply inclined margins. In contrast, (King, 1953a) and (Bailey, 1954a) suggest that the gabbro is most likely sheet-like.

Along the northern slopes of Creag Strollamus, the gabbro extends to the NW as a dyke-like mass with a width of *c.* 200m (Figure 6-86). This elongate part of the intrusion tapers NW of Creag Strollamus and does not reach the coast. Towards the margins of the intrusion there are doleritic and basaltic facies. The common presence of 'acidified' and 'granite-veined' facies suggested to (King, 1953a) that some form of hybridisation process had taken place between the gabbro and younger granites.

Figure 6-86 – A profile (on the nearest horizon) of the dyke-like portion of the Creag Strollamus Gabbro on the NW side of Creag Strollamus, viewed towards the NE, with Scalpay on the opposite side of Loch na Cairidh.

The Broadford Gabbro is an unlayered, medium- to coarse-grained rock composed of clinopyroxene and zoned plagioclase in an ophitic to sub-ophitic arrangement (Figure 6-87). Unlike the gabbros of the Cuillin Intrusive Centre (6.B), olivine is not present. Local variations in the modal percentages of the two dominant minerals give rise to pyroxene- and plagioclase-rich facies. In general, the gabbro has been severely hydrothermally altered by the nearby younger granites, with the resultant development of secondary mineral assemblages. Commonly, pyroxene is replaced by aggregates of amphibole + chlorite + epidote. Marginal facies of the intrusion locally show the development of shearing and brecciation, possibly due to volatile release during intrusion.

Figure 6-87 – Typical Broadford Gabbro with dark aggregates of amphibole, chlorite and epidote replacing original clinopyroxene and white plagioclase *c.* [NG 6150 2610]. Coin *c.* 24mm across.

The mechanism of emplacement of this gabbro is not easily envisaged. (King, 1953a) suggested that it was formed by the metasomatic replacement of basaltic lavas. Such a hypothesis appears extremely unlikely for several reasons, especially because of thermal constraints.

Another mechanism, which alleviates the 'space problem' and provides a plausible way of explaining the intimate relationship between the gabbro and the enclosures of dolostone, is that basaltic magma was (to some extent) intruded into limestone voids or caves, which had developed at some previous stage. A similar explanation may be appropriate to explain some of the complex field relationships of the Beinn an Dubhaich Granite (6.G.5).

6.G.4 The Glas-Bheinn Mhòr Granite (E1)

The Glas-Bheinn Mhòr Granite is the first of the large sub-volcanic silicic intrusions of the ERHIC (*s.s.*). It crops out on the hill of that name and clearly cross-cuts members of the older WRHIC (for example, the Loch Ainort Granite and the Marscoite Suite, see Section 6.F) (Figure 6-88). The eastward extent of this granite has not been determined in detail, although it certainly crops out on the low ground west of the Beinn na Crò ridge. Its outer (western) margin is steeply inclined, dipping to the west, and can be traced from Sròn Ard a' Mhullaich, at the head of Loch Ainort, south to the col between Belig and Glas-Bheinn Mhòr (Bell, 1966).

Figure 6-88 – (a) Oblique Google Earth© image illustrating the location of the dull grey Glas-Bheinn Mhòr ridge, which is essentially the outcrop of the Glas-Bheinn Mhòr Granite; (b) the Glas-Bheinn Mhòr ridge, view towards NNE; and, (c) Glas-Bheinn Mhòr from the east side of Loch Slapin, view towards the NW.

In hand-specimen, the Glas-Bheinn Mhòr Granite weathers dull grey and is distinctly porphyritic, with phenocrysts of normally zoned plagioclase ($An_{20–27}$, (Bell, 1966)) set in a fine-grained groundmass that is composed of a granophyric intergrowth of quartz and alkali feldspar. The dominant mafic minerals are amphibole and brown mica, although primary pyroxene, commonly replaced by secondary amphibole, is recognised (Bell, 1966). Accessory apatite, zircon, titanite, Fe-Ti oxides and fluorite are also present.

Irregularly dispersed throughout the intrusion are small clots of mafic minerals, dominated by amphibole, brown mica and Fe-Ti oxides. These most likely represent partially digested inclusions of mafic material: a feature of other granites within the Skye Central Complex and discussed elsewhere in Chapter 6.

6.G.5 The Outer Granites

The outer granites of the ERHIC are defined here as consisting of the various coarse-grained silicic intrusions that crop out in the arcuate belt which runs from Beinn na Crò in the west, south to Beinn an Dubhaich, and thence around the eastern side of Beinn na Caillich to the Allt Fearna - Creag Strollamus area (Figure 6-80; Figure 6-81). These separate granite outcrops were tentatively grouped together by (Richey, 1932) and subsequent work by (Stewart, 1965) and (Bell, 1982) confirm this interpretation. These intrusions are slightly porphyritic, with phenocrysts of alkali feldspar and quartz, and contain hornblende and biotite. Depending upon the amounts of these ferromagnesian minerals, both grey and reddish-brown weathered surfaces occur. The country-rocks that host the different parts of this annular-shaped group of intrusions span a wide range in terms of lithology and age.

The three main intrusions are: (i) Beinn na Crò; (ii) Beinn an Dubhaich; and, (iii) Allt Feàrna - Creag Strollamus.

(i) Beinn na Crò Intrusion (E2): has a steep, outer contact against the older Glas-Bheinn Mhòr Granite (6.G.5) and an almost vertical contact against a screen of fragmental rocks and rhyolitic lavas on the east side of Srath Beag (5.E), that separates it from the younger Beinn na Caillich Granite (6.G.6) (Figure 6-89).

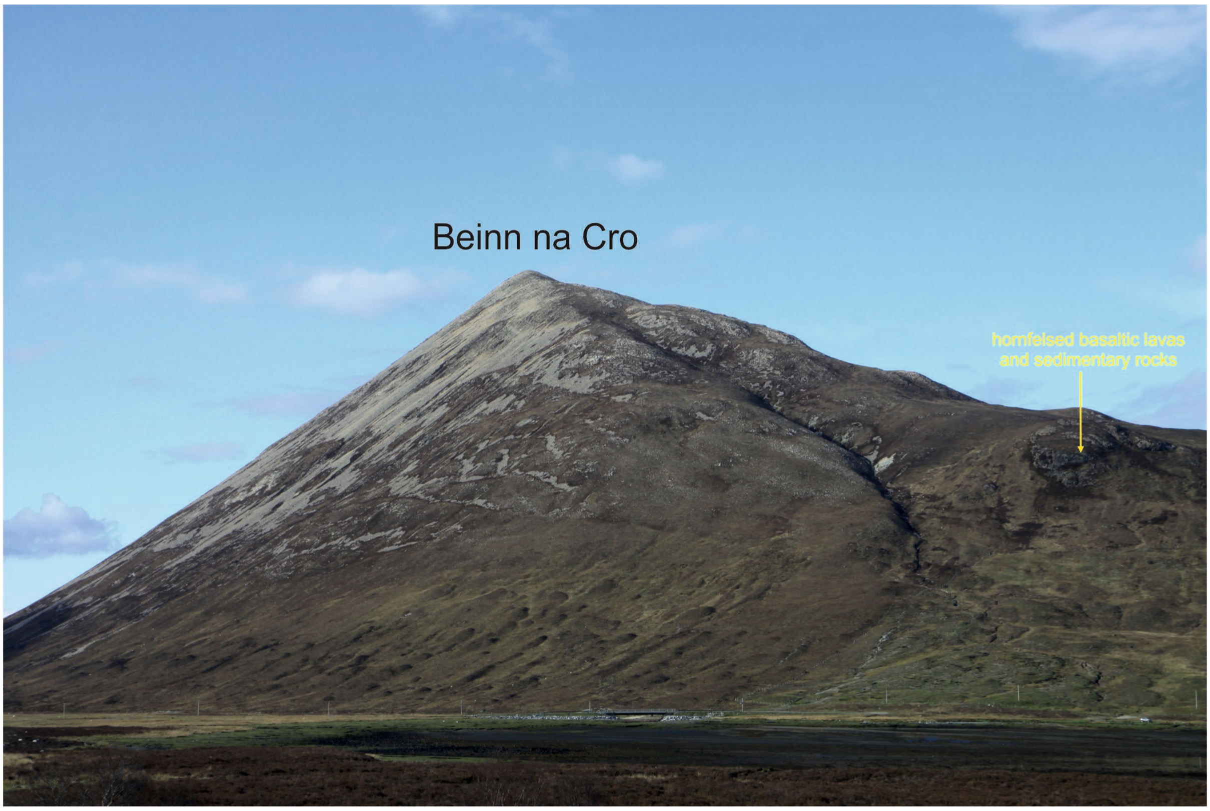


Figure 6-89 – Beinn na Crò from the west side of Loch Slapin, composed mainly of the Beinn na Crò Granite, here in contact with country-rock basaltic lavas and interbedded sedimentary units. View towards the north.

(ii) Beinn an Dubhaich Intrusion (E3): a much studied granite that is wholly intruded into a broad anticline of Cambro-Ordovician Durness Group dolostones (3.E) on the east side of Loch Slapin (Figure 6-90). Formation of the anticline predominantly pre-dates intrusion of the granite. The outcrop of the intrusion is significantly complicated by numerous enclosures of the country-rock dolostones (Figure 6-91). There is little evidence of stoping or tectonic disturbance associated with the intrusion of this granite. Older (Paleocene) dykes that cut the large enclosures of country-rock dolostones show little sign of deviation from the regional trend (Chapter 7). Local variations in the attitude of the granite - country-rock contact(s) have led to different interpretations being suggested for the general shape of the Beinn an Dubhaich Granite. (Harker, 1904) suggested that it was a steep-sided mass, and similar conclusions have been reached by (Stewart, 1965), (Raybould, 1973) and (Bell, 1982). In contrast, (King, 1960) and (Whitten, 1961b) favour a sheet-like structure, intruded along the Kishorn Thrust Plane, dipping at a shallow angle to the SE (Chapter 3). With the first interpretation, the enclosures of Cambro-Ordovician dolostone represent roof-pendants, whereas those who favour the sheet-like model suggest the dolostone enclosures represent irregularities in the Cambro-Ordovician ‘floor’, which lies below the base of the granite sheet. A drill hole through one of these enclosures of country-rock (reported in (Raybould, 1973)) encountered granite below, which adds support to the 'steep-sided contact' model. In addition, (Hoersch, 1979), on the basis of a ground magnetometer study, concluded that the intrusion is a steep-sided stock and extends to depth. (Hoersch, 1979) also suggested that lobes of the granite penetrate the area to the north. One other emplacement model worthy of consideration is that the granite’s shape is, in part, due to the emplacement of magma into voids of a previously formed cave system, a present-day feature of the Cambro-Ordovician dolostones and, by inference, a feature prior to the emplacement of the granite.

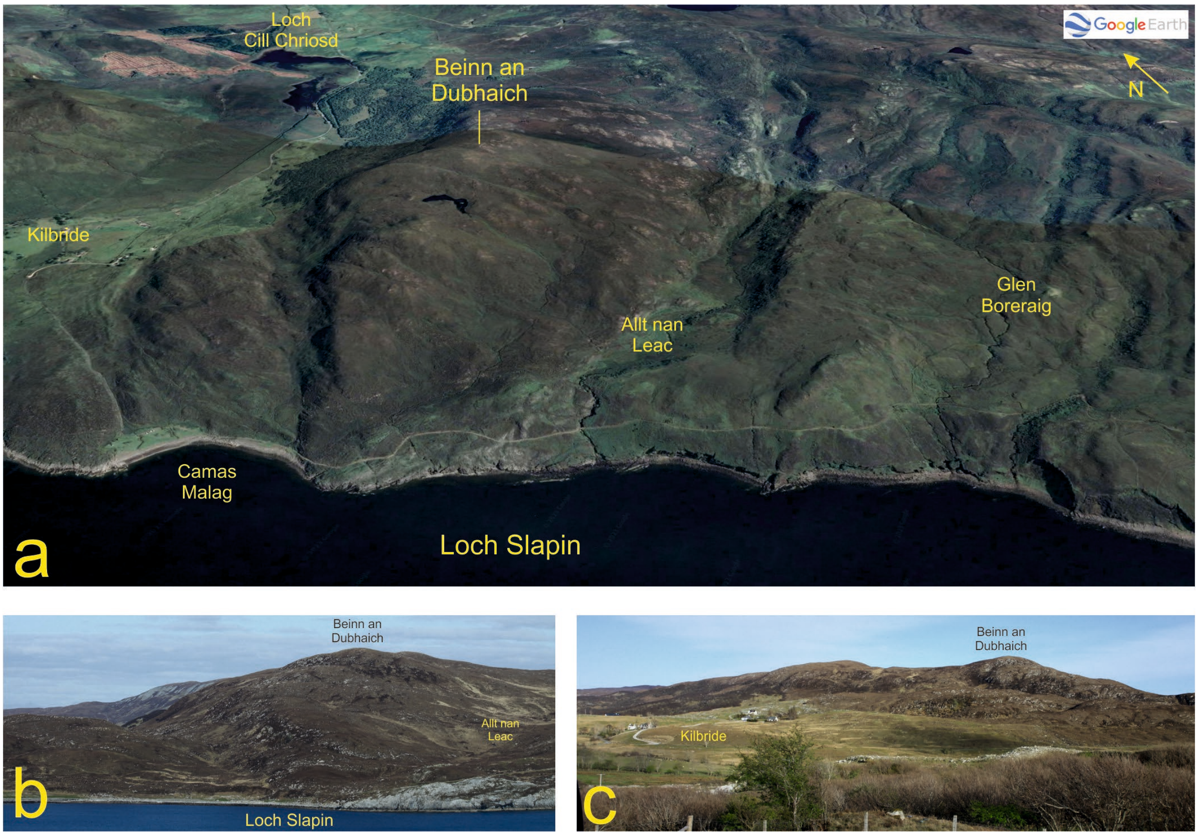


Figure 6-90 – (a) Oblique Google Earth© image of the E-W -trending Beinn an Dubhaich ridge viewed from the east side of Loch Slapin, with the granite forming the higher, dark, heather-clad ground, view towards the east; (b) Beinn an Dubhaich Granite (E3) forming the dark, heather-clad, high ground, with the more verdant lower ground comprising Cambro-Ordovician Durness Group dolostones to the north (left) and Jurassic strata to the south (right), view towards the east; and, (c) Beinn an Dubhaich Granite (E3) forming the dark, heather-covered, high ground, with the more verdant lower ground at Kilbride comprising Cambro-Ordovician Durness Group dolostones, view towards the south.

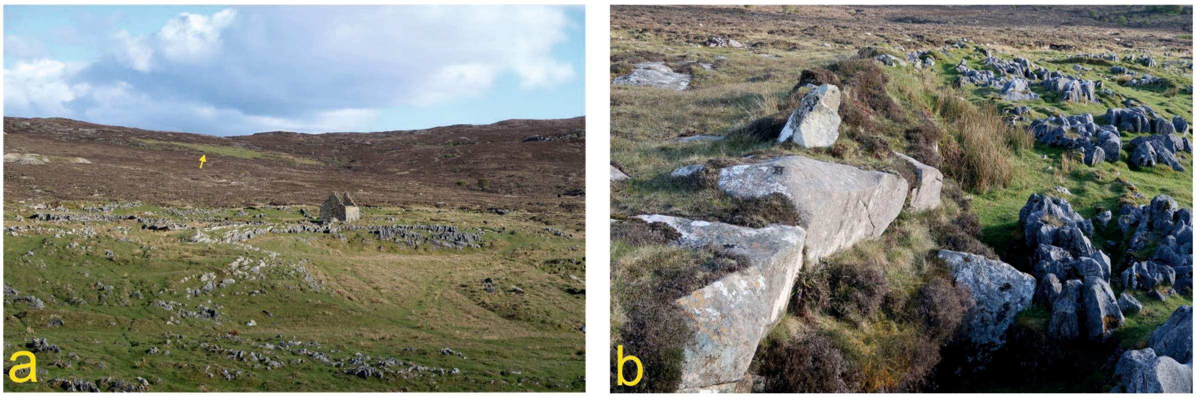


Figure 6-91 – (a) The margin of the Beinn an Dubhaich Granite (E3) at the old Manse at Kilchrist, SE of Loch Cill Chriosd, with the contrasting heather-dominated ground of the granite and the grass-dominated ground of the Cambro-Ordovician Durness Group dolostones at *c.* [NG 6160 2010], enclosure of dolostones in the far distance (arrowed), view towards the SW; and, (b) detail of granite (left) – dolostone (right) contact close to the old Manse at Kilchrist.

(Tilley, 1949) records the presence, locally, of alkali pyroxene -bearing marginal facies of the Beinn an Dubhaich Granite, associated with the development of contact skarns in the dolostone country-rocks (6.H) and (Raybould, 1973) identifies four distinct varieties of granite within the intrusion, namely: porphyritic microgranite, granophyre, pale green granite, and hornblende granite. (Tuttle & Keith, 1954) and (Tuttle & Bowen, 1958)) investigated the inversion temperatures of quartz and feldspar crystals from the intrusion and concluded that, during crystallisation, high-temperature features had been 'quenched-in', such as would be expected if the granite had crystallised from a rhyolitic magma, and had not been formed by lower-temperature metasomatic processes. The thermal and metasomatic effects of this granite on the surrounding country-rocks are outlined in Section 6.H.

(iii) Allt Feàrna - Creag Strollamus Intrusion (E4): consists of a number of small granite, microgranite and porphyritic felsite intrusions/outcrops that intrude various pre-Paleocene country-rocks, as well as the older Broadford Gabbro (6.G.2) (Figure 6-92). The boundaries of these masses are complicated by the presence of the Kishorn Thrust Plane, which dips at a shallow angle towards the east. (Harker, 1904) and (King, 1953a) note that, in places, granite has been intruded along the thrust plane. (King, 1953a) further suggests that much of the granite formed by *in situ* metasomatic replacement of original Torridonian strata (3.C), but this hypothesis was rejected by (Stewart, 1965) on several grounds, but principally because of vertical contacts between the granite, the Broadford Gabbro and Cambro-Ordovician dolostones, as seen in tributaries of the Allt Feàrna. Where granite and gabbro are in contact, zones of hybrid material have developed. The contact between the main intrusion of this granite (in the Allt Feàrna - Creag Strollamus area) and the Beinn na Caillich Granite (see below) may be traced from Buaile nan Aodan (SE of Beinn na Caillich), towards the plateau area around Lochain Beinn na Caillich, where it follows the sharp break in slope at *c.* 250m OD, west to Creagan Dubh. This change in slope provides the most useful field evidence as to the position of the boundary between these two granites. The Beinn na Caillich Granite (6.G.6) is commonly chilled against the older granite, thereby allowing the contact to be readily distinguished.

Figure 6-92 – Typical rusty-brown -weathering Creag Strollamus (Granite) Intrusion on the east side of Creag Strollamus at *c.* [NG 6080 2585]. Pole *c.* 1m long. View towards the north.

The irregularly-shaped silicic intrusion that crops out at An Sithean/Sidhean, SSW of Broadford, is considered to be part of the suite of outer granite intrusions and is, in places, extremely fine-grained, essentially a porphyritic felsite.

6.G.6 The Beinn na Caillich Granite (E5)

The Beinn na Caillich Granite is interpreted as the youngest of the large sub-volcanic intrusions of the ERHIC and crops out on the three prominent summits WSW of Broadford, Beinn na Caillich, Beinn Dearg Mhòr and Beinn Dearg Bheag (Figure 6-93). This intrusion has a near-perfect circular outline, although somewhat linear at Creagan Dubh, north of Beinn Dearg Mhòr (Figure 6-94). The contact of the Beinn na Caillich Granite with the surrounding country-rocks is typically steep and there is commonly the development of a fine-grained chill facies. Along its western, southern and eastern margins, the granite has intruded various pyroclastic and volcaniclastic rocks, whereas to the north it is in contact with basaltic lavas, and to the NE with the Creag Strollamus (Granite) Intrusion (6.G.5).

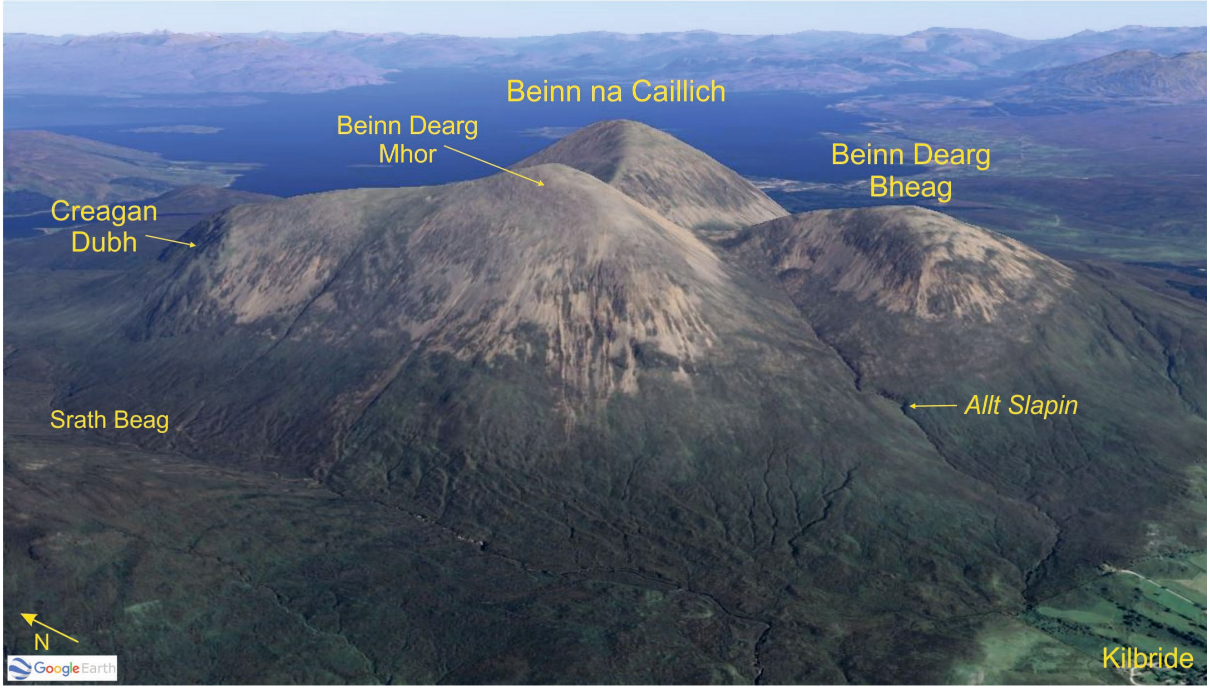


Figure 6-93 – Oblique Google Earth© image of the three summits, Beinn Dearg Mhòr (left), Beinn na Caillich (far centre) and Beinn Dearg Bheag (right), which constitute most of the outcrop of the Beinn na Caillich Granite. View is towards the NE.

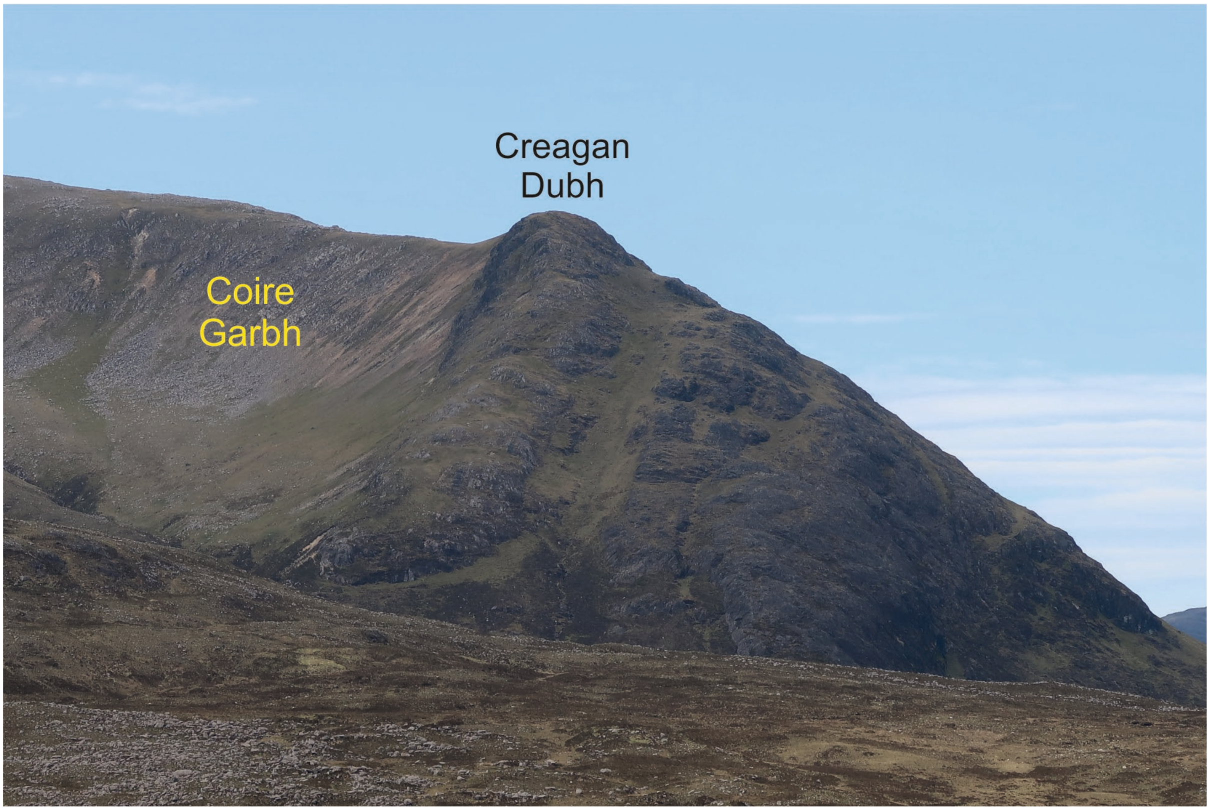


Figure 6-94 – The linear NW margin of the pale Beinn na Caillich Granite in Coire Garbh against basaltic lavas forming Creagan Dubh. View from Creag Strollamus, towards the SW.

Miarolitic cavities are a common feature of this intrusion. They are particularly well-developed in the summit areas of the three hills noted above, presumably because they are relatively close to the roof zone of the intrusion. Within these cavities are euhedral crystals of quartz, alkali feldspar and, uncommonly, fluorite. Two mineralogical facies of the granite are readily identified in the field. First, a normal, coarse-grained facies, consisting of phenocrysts (3–5mm) of quartz and alkali feldspar, set in a groundmass that is dominated by the development of a granophyric intergrowth involving the same two minerals. The alkali feldspar is generally clouded. Also present are laths of oligoclase ($An_{20–25}$). The main ferromagnesian minerals are hornblende and biotite, commonly occurring as small clusters associated with Fe-Ti oxides. Zircon, titanite and apatite are present as accessory minerals. The fine-grained chill facies of the intrusion is only exposed locally, and typically does not exceed 1-2m in width; it is most easily examined in the gorge at the head of the Allt Slapin, north of Torrin, where the stream cuts through the contact between the granite and various breccias. This marginal facies is a felsite which, locally, veins the country-rocks. Extreme chilling against the country-rocks has led to the development of spherulitic masses (1–2mm) composed of quartz and alkali feldspar set in a green felsitic (originally glassy) groundmass. The same feldspar phenocrysts as in the normal/dominant granite are present, although they are typically smaller (1–2mm). The main ferromagnesian minerals are microphenocrysts (0.5–1mm) of the Fe-rich clinopyroxene, ferrohedenbergite, and an almost pure Fe-olivine, fayalite. Alteration of the ferrohedenbergite to aggregates of chlorite, epidote and actinolite, and of the fayalite to serpentine and/or chlorite, are common.

The differences in the mafic mineral assemblages of the two facies of the granite (main and marginal) may be explained in terms of the bulk composition of the magma involved. Essentially, the silicic magma when intruded was close to its liquidus temperature, containing relatively few phenocrysts. Experimental studies suggest that, under such conditions, silicic magmas with low CaO contents and high Fe/Mg ratios will crystallise olivine and pyroxene in preference to hornblende and biotite. In addition, the volatile content/concentration will be low during the early stages of crystallisation and this will further restrict or prevent the formation of hydroxyl-bearing minerals. Subsequent crystallisation will decrease the Fe/Mg ratio of the magma and increase its relative CaO and volatile contents, with hornblende and biotite becoming the stable ferromagnesian minerals.

6.G.7 Composite Sills and Dykes

Composite sills and dykes constitute an important component of the ERHIC, cropping out over an arc at least 15km long, from Rubha Suisnish in the south, to Rubha na Sgianadin in the north, and possibly continuing onto Scalpay (Figure 6-80; Figure 6-81; Figure 6-95). The radius of the circle, of which this arc forms almost a half, is *c.* 5km and is co-focal with the centre of the Beinn na Caillich Granite (6.G.6), suggesting a close spatial (and genetic) relationship between the composite intrusions and the granite(s). These intrusions were first described in detail by (Harker, 1904), who noted over twenty discrete outcrops, all of which occur within strata of Lower Jurassic age (4.C).

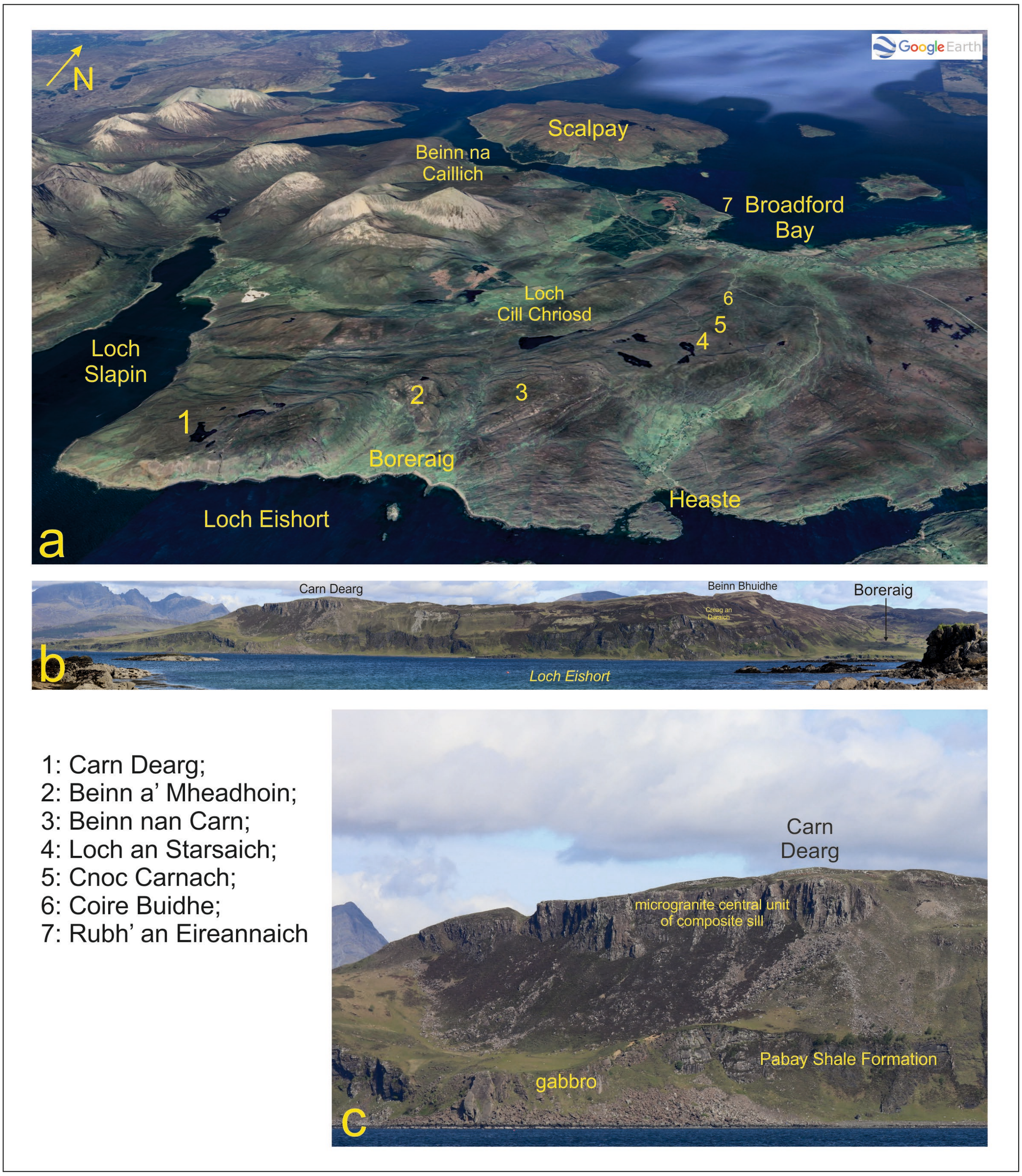


Figure 6-95 – (a) Oblique Google Earth© image of the district of Strath, indicating the (numbered) locations of the main composite sill outcrops; (b) coastal section on the north side of Loch Eishort between Càrn Dearg and Boreraig; and, (c) the composite sill of Càrn Dearg on the north side of Loch Eishort, with country-rock Lower Jurassic Pabay Shale Formation strata forming the coastal cliffs, together with a steep-sided gabbro intrusion that has produced much of the scree on the coast [NG 5980 1585], view towards the NW from Ord.

(Harker, 1904) identified various types of minor intrusions that are composed of silicic and basic components, in an intimate association. The suite of sills and dykes described here are referred to by (Harker, 1904) as being of the Cnoc Càrnach Type. They are typically composed of three distinct units: upper and lower basic portions that preserve evidence of chilling against the country-rock strata, and a central silicic portion (granophyre, microgranite or felsite) that shows no evidence of chilling against the fine-grained, basic material. All of the sills are either flat-lying, or dip at a shallow angle (*c.* 15°) towards a point below Beinn na Caillich. The basic components have thicknesses of 0.5–2.5m, whereas the silicic centres have much greater thicknesses, commonly 50m, or more. In many instances, erosion has removed the upper basic unit and the upper part of the silicic centre. For example, the sills that crop out on Càrn Dearg (Figure 6-95), Beinn nan Càrn and Cnoc Càrnoch, itself, are in part eroded down to this level. Numerous faults disrupt and complicate the (original) relatively simple field relationships of these intrusions.

Evidence for the intrusion of the silicic magma after the basic magma includes the presence of fragments of the latter within the former, together with veins of felsite and microgranite cutting the basic portions, for example, within the upper basic unit of the Cnoc Càrnach intrusion, along its western side.

The composite dykes associated with these sills may have acted as feeders. They have similar geometries, with marginal, fine-grained, basic portions flanking a thicker central silicic unit. Numerous examples of these dykes are preserved, with the intrusion at Loch Fada, north of Càrn Dearg, providing the most clear-cut evidence for the close genetic relationship between the dykes and the sills.

The formation of these intrusions is readily understood from a study of the petrography and whole-rock geochemistry of the *c.* 5m-thick composite sill that crops out at Rubh' an Eirèannaich, on the west side of Broadford Bay (Figure 6-96). The descriptions presented below are based on the studies of (Harker, 1904), (Buist, 1959), (Bell, 1982), (Bell, 1983) and (Bell & Pankhurst, 1993). The sill has upper and lower basaltic units (strictly of ferrobasaltic andesite composition), each 1.3–1.4m thick, and a central porphyritic felsite/rhyolite (*c.* 2.4m thick). Whole-rock Sr-isotope data indicate that the basaltic magma was generated by fractional crystallisation of a more primitive, basic magma and has also been contaminated by crustal material, and that the felsite has a significant crustal component, i.e. produced by melting of continental crust. Unlike the majority of the composite sills, boundaries between the basaltic and silicic parts are completely gradational, typically over a distance of 10-20cm. The upper and lower contacts with the Lower Jurassic country-rock strata exhibit strong chilling, producing a glassy (now partially/totally devitrified) material. This grades over a few millimetres into a fine-grained, dark grey rock that contains phenocrysts of labradorite and xenocrysts of oligoclase (with rounded edges) and alkali feldspar (exhibiting the so-called fingerprint texture, indicating disequilibrium), all set in a groundmass dominated by augite, plagioclase (andesine-labradorite) and Fe-Ti oxides. The central portion of the sill is composed of light grey to greenish-white porphyritic felsite/rhyolite, with phenocrysts of oligoclase and rare alkali feldspar, set in a felsitic groundmass composed of recrystallised quartz and alkali feldspar. Hydrothermal alteration of the central felsite is, in places, severe, as evidenced by the presence of secondary calcite, chlorite and pyrite. Between the contrasting basic and silicic rock-types, the 10-20cm -thick hybrid zones exhibit a complete compositional spectrum. Closest to the basic units, xenocrysts of oligoclase and alkali feldspar within the hybrid are set in a groundmass dominated by augite, plagioclase and Fe-Ti oxides. Towards the silicic centre of the sill, these minerals grade imperceptibly into phenocrysts (with no evidence of disequilibrium, such as rounding or magmatic corrosion), set in a felsitic groundmass.

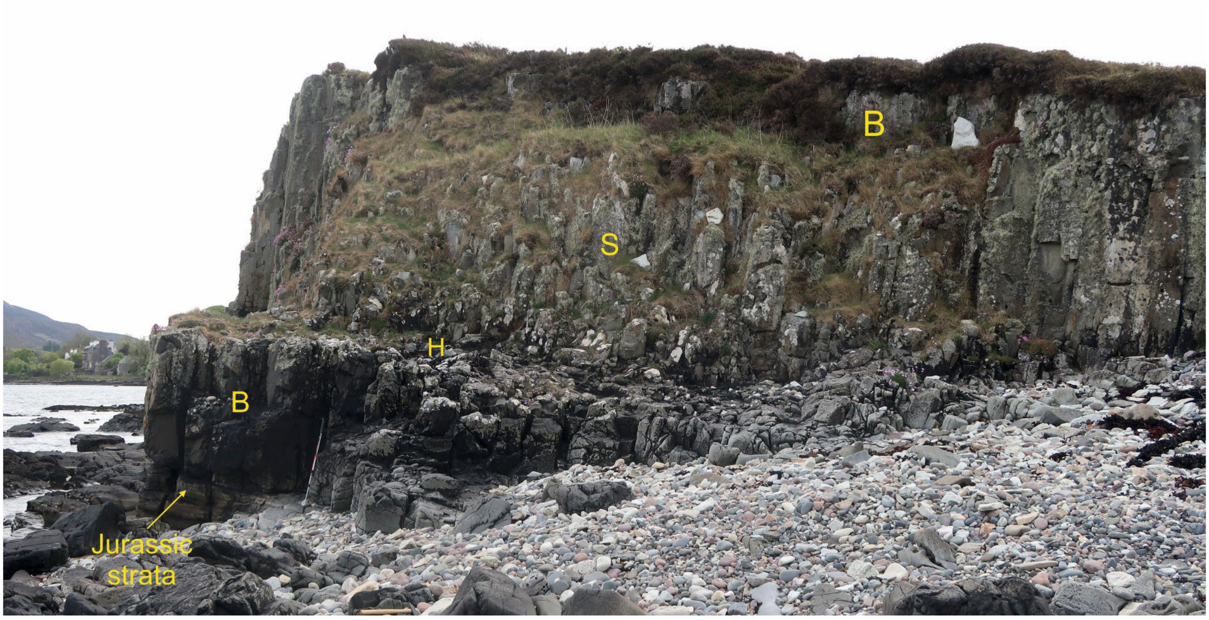


Figure 6-96 – The composite sill at Rubh' an Eiréannaich on the west side of Broadford Bay [NG 6458 2476]. B: basaltic lower and upper units; S: silicic (microgranite) central unit; H: hybrid zone. View towards the south. Pole *c.* 1m long.

These features suggest that two periods of hybridisation of basic and silicic magmas have taken place. First, there was the incorporation of a silicic magma into a basic magma, within a deeper-level magma chamber, resulting in the partial resorption of phenocrysts that were present within the silicic magma. The rounded and corroded oligoclases and alkali feldspars within the basic portions of the composite sill represent this process in an arrested state. The absence of quartz xenocrysts within the basic units suggests that either quartz was not present as a phenocryst phase in the silicic magma, or that it was totally dissolved during the mixing. The compositionally transitional zones formed either by *in situ* hybridisation, by diffusion between the two contrasting magmas after their emplacement, or by mixing prior to or during emplacement. Any fractional crystallization of the unmixed silicic magma occurred almost exclusively after mixing.

6.H Thermal and Metasomatic Effects of the Granites

The shallow emplacement of large volumes of silicic ('granitic') magma into the crust brought about several changes in both the surrounding country-rocks and the intrusive rocks that formed (Ferry, 1985b). Alteration processes were relatively short-lived, did not necessarily go to completion, and were caused by a combination of the large amount of heat liberated by the shallowly emplaced crystallising magmas and by the circulation of heated meteoric fluids, mainly supercritical H_2O.

As the various granites and finer-grained associated rocks, such as porphyritic felsites, crystallised, hydrous fluids were able to gain access, along crystal boundaries and, on a larger scale, along fractures that formed in response to volume reduction and stress release during cooling. Most of the fracture networks that formed were subsequently sealed by the precipitation of hydrothermal minerals, commonly in complex assemblages, to form quasi-planar veins.

Primary (magmatic) minerals, including amphibole, biotite, ferrohedenbergite/ferroaugite, fayalite, alkali feldspar, plagioclase, magnetite and ilmenite, locally underwent reaction with these fluids to form (common) secondary alkali feldspar, chlorite and montmorillonite. Less common was the formation of muscovite, calcite, epidote, prehnite, zeolite and pyrite. The alteration process led to minor changes in the bulk composition of the original rocks, with the addition of hydrogen, and a loss of Ca and Fe. Most of the mineralogical alteration occurred within the temperature range 350-450°C, mainly by solution-reprecipitation processes. However, mineral thermometry and barometry calculations suggest that certain minerals in the granites, clear alkali feldspar and plagioclase, Fe-Ti oxides, biotite, fayalite and, most likely, amphibole and ferrohedenbergite/ferroaugite, retain magmatic compositions, developed at temperatures in the range 650-750°C, and were unaffected by later, lower-temperature fluid-mineral reactions. These magmatic minerals have not isotopically equilibrated with hydrothermal fluids and have retained their magmatic stable isotopic (oxygen and hydrogen) signatures. However, the secondary minerals, listed above, have stable isotopic compositions that record fluid-mineral reactions that took place in the temperature range 350-450°C. Essentially, the granites retain two groups of minerals, those that are compositionally and texturally magmatic, and those that are compositionally and texturally of hydrothermal character.

Metamorphic and metasomatic effects caused by the various intrusions are recorded in the Cambro-Ordovician (3.E) and Jurassic strata (4.C) of the district. The features within the Durness Group Cambro-Ordovician strata are more obvious and more widespread.

The whole of the Beinn an Dubhaich and parts of the Allt Feàrna–Creag Strollamus intrusions of the outer suite of granites (6.G.5) are intruded into Cambro-Ordovician Durness Group dolostones. Both thermal metamorphic and metasomatic alteration of the carbonates have resulted, and these features are discussed in detail by Tilley ((Tilley, 1947); (Tilley, 1948a); (Tilley, 1948b); (Tilley, 1948c); (Tilley, 1949); (Tilley, 1951)), Hoersch ((Hoersch, 1977); (Hoersch, 1979); (Hoersch, 1981)) and Holness ((Holness, et al., 1989); (Holness, 1992); (Holness & Fallick, 1994)).

Apart from simple recrystallisation of dolomite within the dolostones, chert nodules within the dolostones have, to varying extents, been involved in metamorphic and metasomatic processes. (Hoersch, 1981) demonstrated that these nodules (70% quartz, 20% dolomite and 10% calcite) reacted with dolostone (99% dolomite and 1% calcite) to form reaction rims of calc-silicate minerals. In terms of incoming index minerals, which appear with increasing temperature as the contact with the granite is approached, (Hoersch, 1981) identified four distinctive zones: (1) talc-bearing (lowest temperature, 350–425°C); (2) tremolite-bearing (425–440°C); (3) diopside-bearing (440–520°C); and, (4) forsterite-bearing (highest temperature, 520–600°C) (Figure 6-97).

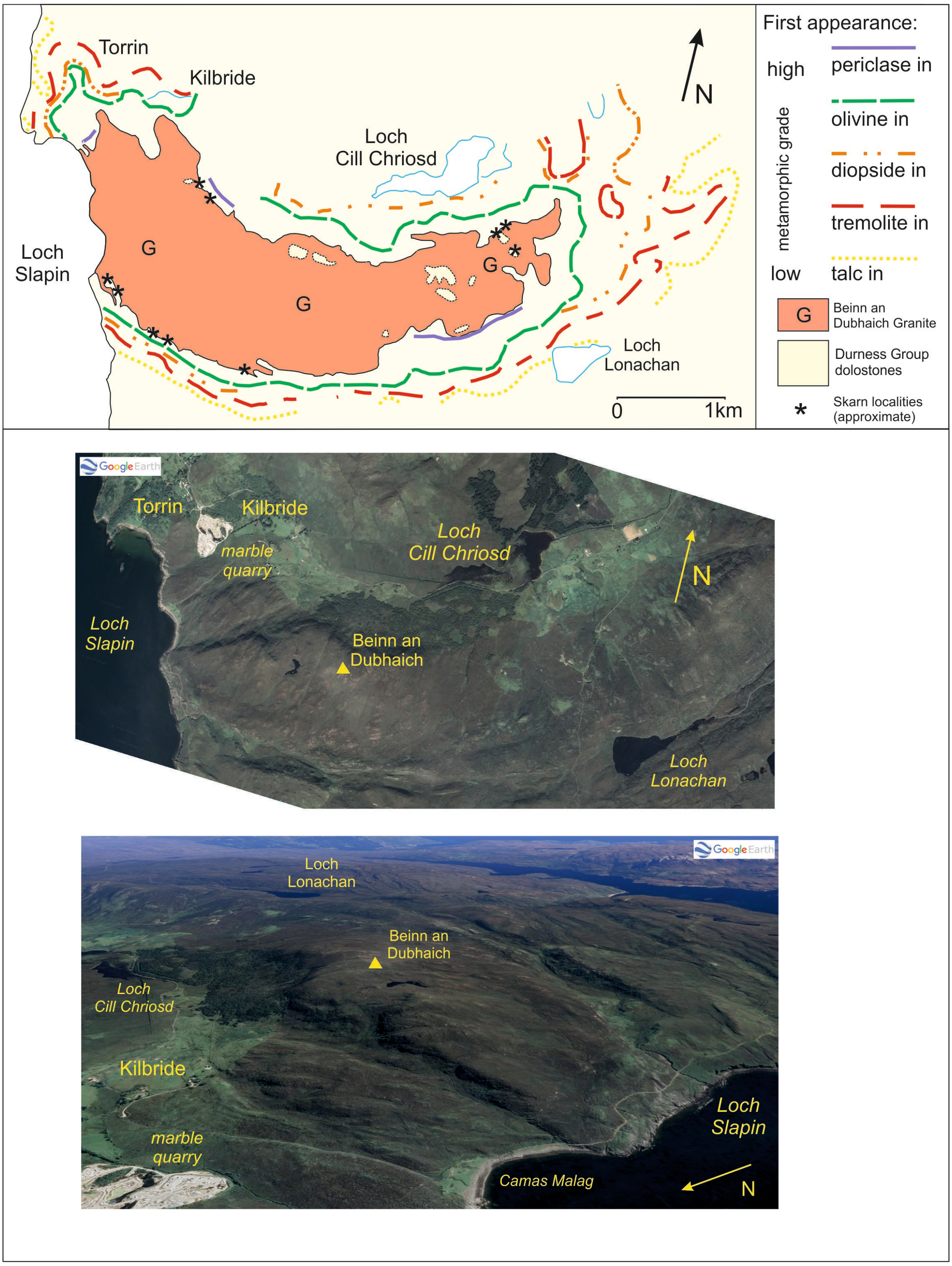


Figure 6-97 – Contact metamorphic zones within the Cambro-Ordovician Durness Group dolostones on the east side of the Beinn an Dubhaich (granite) Intrusion (after Holness *et al.* 1989).

(Holness, 1992) re-examined the rocks within the metamorphic aureole and concluded that the metamorphism of dolostones within the sequence does not differ significantly from that of the chert nodule -bearing dolostones studied by (Hoersch, 1981) and, in addition, recognised the development of periclase, formed by the breakdown of dolomite in the highest grade assemblage, but now completely pseudomorphed by brucite and minor magnetite.

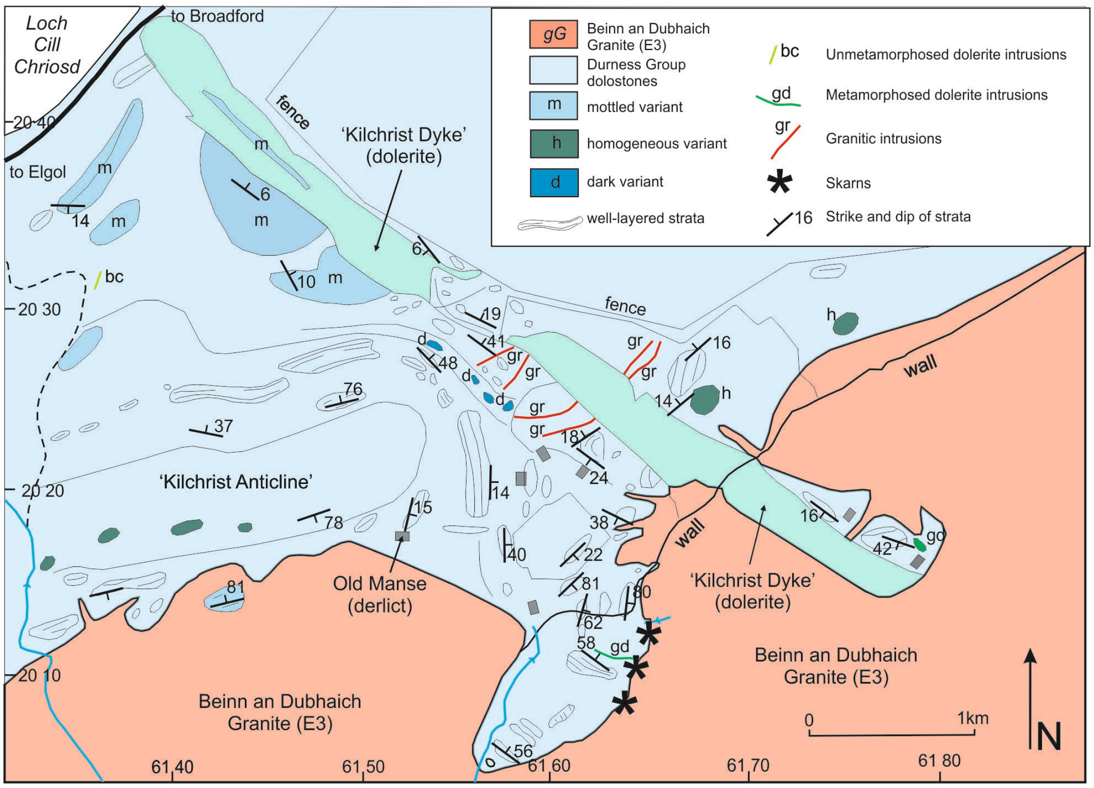
The first sign of metamorphism in the dolostones is the growth of talc and calcite at chert-dolostone (nodule-matrix) boundaries (Zone 1). This metamorphic reaction continues until one of the reactants (generally the chert nodule) is totally consumed. Within the second zone, tremolite develops, occurring within nodules irrespective of whether silica had been, or had not been, totally used up. Within the third zone, the incoming of diopside is typically at the expense of any talc remaining within the nodule structure, together with some of the tremolite. Finally, nearest the granite, small forsterite grains develop within diopside crystals (Zone 4). Within *c.* 100m of the granite contact, the nodules take the form of alternating layers of forsterite (plus a small amount of calcite) and pure calcite (Figure 6-98). (Tilley, 1951) suggested that this may be due to a Liesgang phenomenon (secondary nested rings or bands caused by rhythmic precipitation within a fluid-saturated rock), although (Hoersch, 1981) points out that these bands may be the product of original zonation patterns present within the nodules.

Figure 6-98 – Concentric alternating bands of forsterite (retrogressed to serpentine) and diopside within Zone 4 marbles from a large enclosure of country-rock, surrounded by granite, at the eastern end of the Beinn an Dubhaich Intrusion [NG 6184 1980]. Coin *c.* 24mm across.

Only the innermost isograd (separating the diopside and forsterite zones) can be traced with confidence in the field, running from the northern end of Loch Cill Chriosd (Kilchrist), east to the area south of Bheinn Shuardail, thence SW towards the area west of Loch Lonachan (((Hoersch, 1981); (Holness, et al., 1989)). Due to the discontinuous nature of the exposure, the other isograds cannot readily be traced. Furthermore, the sub-surface shape of the granite (6.G.5) may mean that distances from the boundary, at the present level of erosion, do not actually represent true distances from the contact (for example, consider the possibility that the granite occurs at no great depth below Bheinn Shuardail).

During the metamorphism, the pressure was *c.* 500bars (equal to a depth of *c.* 2km) and the temperature of the silicic/granitic magma was *c.* 750°C. Detailed mineralogical data and thermodynamic calculations indicate that the proportion of CO_2 present within the metamorphic fluid greatly influenced the reactions that took place (Hoersch, 1981). For the duration of the metamorphism, externally derived aqueous fluid infiltrated the dolostones, most likely along pre-existing fracture systems, but with the highest grade (olivine-bearing) rocks pervasively infiltrated (Holness, 1992).

Along the granite-dolostone contact, skarns developed locally, with widths typically less than 3m (Tilley, 1951) (Figure 6-99). They formed as a result of the movement of various species from the crystallising silicic magma and the heated country-rock dolostones, with deposition occurring within the contact zone. At the contact, the granite contains an alkali-rich pyroxene (in contrast to the normal mafic minerals, hornblende and biotite, see Section 6.G.5). (Tilley, 1949) considered the pyroxene to be the product of a net removal of Al from the granitic magma into the dolostone country-rocks. In order to form the various skarn mineral assemblages, outlined below, Si, Al, Fe, B and F (within a fluid phase) must have been supplied by the crystallising granite (Tilley, 1951).



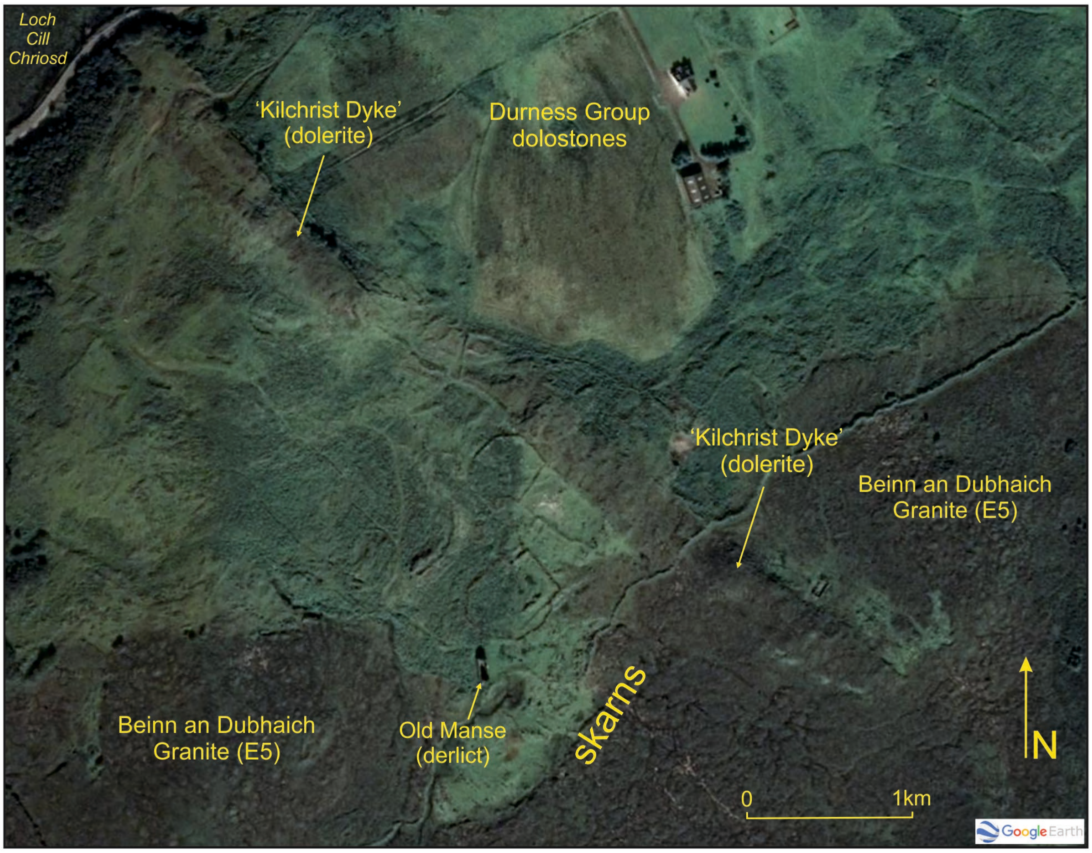


Figure 6-99 – Schematic geological map illustrating the nature of the granite-marble contact at the Old Manse at Kilchrist, at the eastern end of the Beinn an Dubhaich Intrusion, and a Google Earth© image of the same area.

In a detailed investigation of these skarns, (Tilley, 1951) describes over ten discrete outcrops from around the Beinn an Dubhaich Intrusion. In a traverse towards the granite, chert-bearing dolostones that have (simply) been metamorphosed (forsterite-bearing) typically give way to zones rich in forsterite and diopside (1–2cm), and then pass into a hedenbergite-plagioclase-wollastonite rock of metasomatic origin.

(Tilley, 1951) recognises two main groups of skarns, characterised by their different mineral assemblages: Group 1, at the granite-country-rock contact and not containing any fluorine- or boron-bearing minerals; and, Group 2, on the country-rock side of Group 1 assemblages and containing fluorine- and boron-bearing minerals, together with magnetite and monticellite. Group 1 skarns can be independent of Group 2 skarns, but this is not common. Group 1 assemblages include: grossular garnet + wollastonite and hedenbergite + plagioclase (see above). The commonest Group 2 assemblage consists of magnetite + forsterite + chondrodite + clinohumite + diopside + grossular garnet + clinochlore. The boron- and fluorine-bearing minerals within the Group 2 skarns include: fluoborite, szaibelyite, datolite, ludwigite, and harkerite (boron-bearing); and, chondrodite, clinohumite, cuspidine and fluoborite (fluorine-bearing). The source of the boron and fluorine is considered to have been the crystallising granitic magma. The commonest (and most obvious) skarns involve magnetite, examples being the deposits south of the Old Manse at Kilchrist, and at Kilbride, south of Ashbank.

Studies of the granite-dolostone contact by ground magnetometry identified over 25 'anomalies', suggesting that several magnetite-bearing skarns may be present at no great depth below the present-day level of erosion (Whetton & Myers, 1949).

In the Beinn an Dubhaich area, dolerite dykes intruded into the country-rock dolostones are cut by the younger granite (Figure 6-100). These dykes have been subjected to Ca-metasomatism during the alteration of the dolostones (see above). This metasomatism is readily noted within the dykes south of the old manse at Kilchrist, where primary pyroxene has been replaced by a secondary brown amphibole.

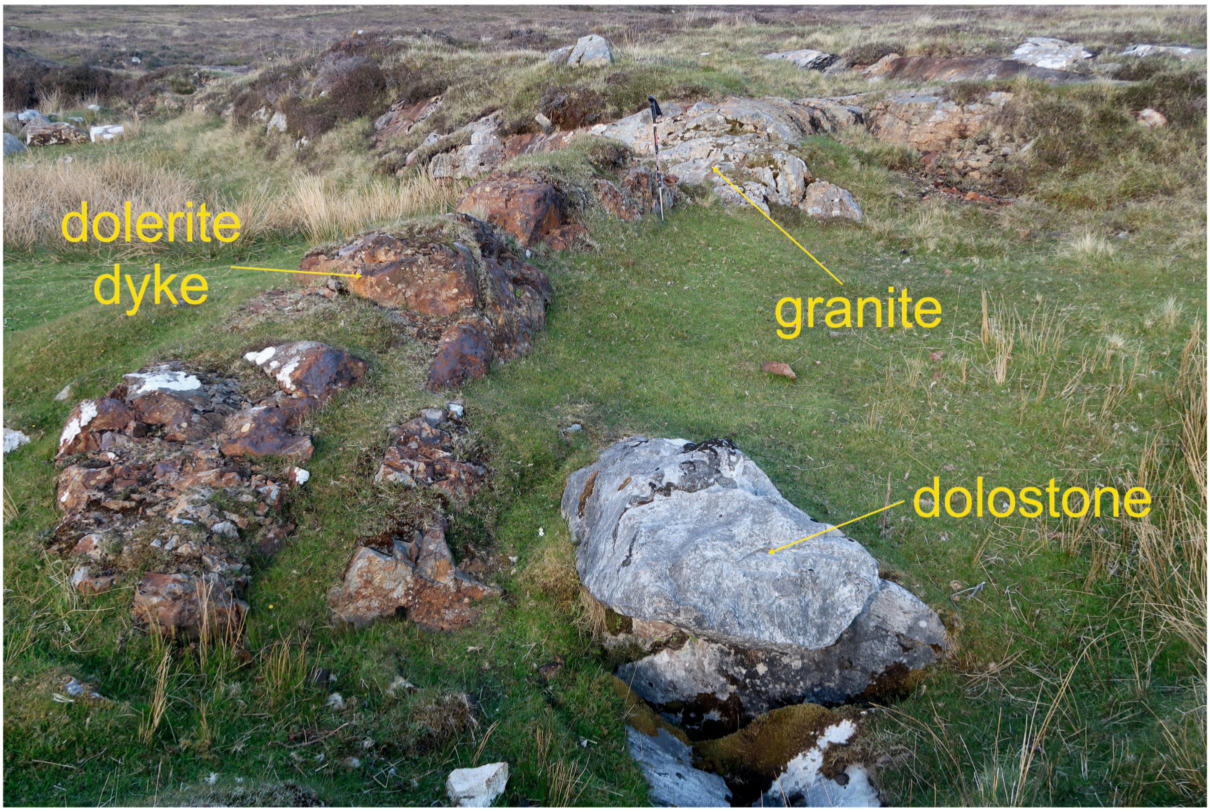


Figure 6-100 – Altered Paleocene dolerite dyke within Cambro-Ordovician Durness Group dolostones close to the margin of the Beinn an Dubhaich Granite. Intrusion of the granite post-dates dyke emplacement. Pole *c.* 1m long at margin of granite. View towards the SE.

Mineral assemblages of metasomatic origin are also found within the marginal facies of the granite. In addition to the alkali-rich pyroxenes, described above, (Tilley, 1951) records pods and veins of clinopyroxene (diopside to hedenbergite), plagioclase (oligoclase to andesine), fluorite, grossular and andradite garnet, idocrase, epidote and allanite from within the granite south of the Old Manse at Kilchrist.

The only other metamorphic or metasomatic effects attributable to the granites of the ERHIC are found within the Middle Jurassic Bearreraig Sandstone Formation (4.C) south of Dunan, between Glas-Bheinn Bheag and the Allt Strollamus. The boundary between the granite and the country-rock strata was originally described by (Day, 1931), who concludes that metasomatic processes were involved during the formation of the associated hornfelses, and that the contact is intrusive. (Black, 1955), however, concluded that it is a fault. Furthermore, Black suggests that the contact-rocks are not true hornfelses that developed in response to high heat flow from the granite, but are cataclastic in origin (essentially a fault breccia), with net additions of Fe, Mg, Ti and H_2O considered to have been deposited from volatiles streaming along the granite - country-rock boundary.

(Smith, 1960) re-investigated these contact rocks and defined six zones of increasing metamorphic grade, ranging from strata with very slight amounts of recrystallisation, through to hornfelses nearest to the granite, containing feldspar porphyroblasts (Figure 6-101). (Smith, 1960) concluded that during the development of these rocks there was a net removal of K, Na, Mg, Fe and H_2O from the granite, as it crystallised, into the country-rocks.

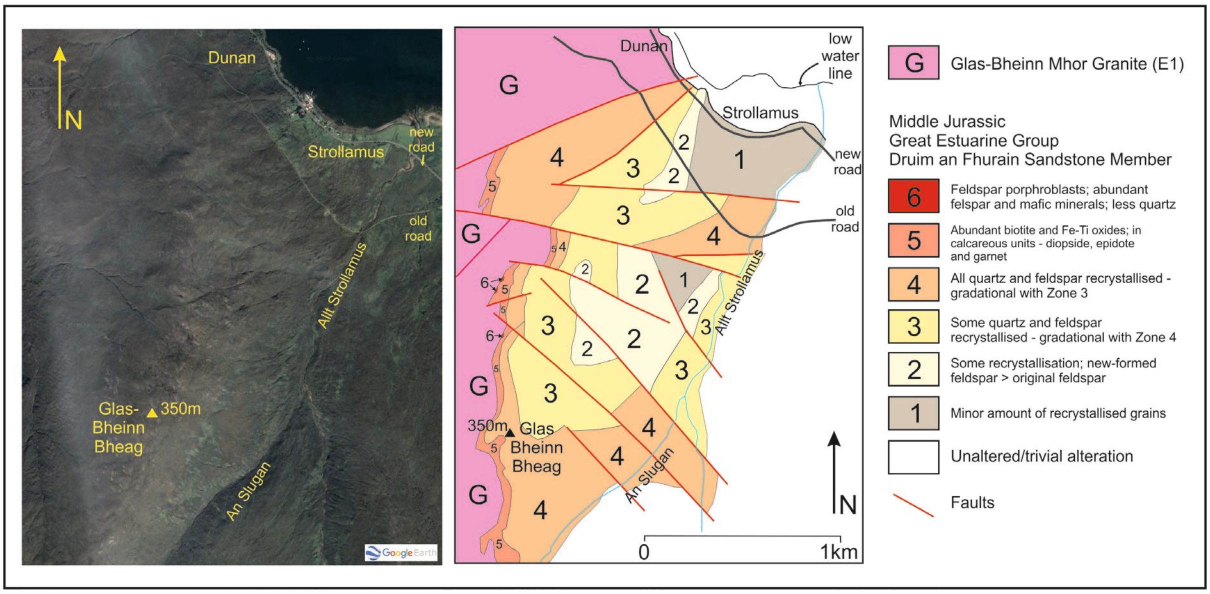


Figure 6-101 – Geological sketch map illustrating the nature and distribution of the contact metamorphic zones within Middle Jurassic Bearreraig Sandstone Formation strata east of Glas-Bheinn Bheag, adjacent to the ERHIC Beinn na Cró Granite [NG 5820 2560], and Google Earth© image of the same area. (after Smith 1960).

Chapter 7 The Skye Regional Dyke Swarm and Other Dykes

The Skye Regional Dyke Swarm represents the plumbing system that delivered mantle-derived magmas to the Paleocene land surface to form the thick and laterally extensive plateau lava sequences. The extensional stress field was oriented SW-NE, resulting in the eruption fissures, hence the dyke swarm, being oriented NW-SE. The swarm has its maximum dilation in the vicinity of the Cuillin Intrusive Centre, indicating that the siting of the intrusive centre was linked to the Paleocene stress field.

7.A Introduction

Numerous types of minor intrusion of Paleocene age are associated with the Skye Lava Field (SLF) (Chapter 5) and the Cuillin Intrusive Centre (CIC) (Chapter 6). They are extremely variable, both in form, for example, dykes, sills, cone-sheets and plugs, and in composition, from peridotite and troctolite through to rhyolite. The time-relationships of these minor intrusions are, in some instances, obscure, principally because of a lack of clear field evidence. Nevertheless, a wealth of information on the field relationships and compositional characteristics of these intrusions has been presented by several researchers, notably (Harker, 1904) and (Anderson & Dunham, 1966). In this chapter the focus is on dykes, in particular the Skye Regional (or Main) Dyke Swarm, but also various other dykes, some of which are spatially and genetically related to the CIC. Cone-sheets are dealt with in Chapter 6 (6.B.10) and the sills of north Skye, members of the Little Minch Sill Complex, are detailed in Chapter 8.

7.B The Skye Regional Dyke Swarm and Associated Sub-swarms

The regional dyke swarm associated with the CIC has a general NW-SE trend and invades an area of at least 4000km^2 (Speight, et al., 1982) (Figure 7-1). The majority of these dykes are less than 2m wide and are either of alkali olivine basalt/dolerite or tholeiitic basalt/dolerite composition, together with their associated differentiates, although other less-common types occur (see below). The thickest dykes occur closest to the CIC. In spatial and temporal association are sub-swarms, which have a completely different trend (NE-SW). Two have been identified: the Scalpay Sub-swarm and the Glenbrittle Sub-swarm (Speight, et al., 1982). As these are co-linear, it is possible that they are part of one larger unit/swarm. Field evidence suggests that the sub-swarm(s) and the main swarm were penecontemporaneous, although (Speight, et al., 1982) note that dykes of the regional swarm are typically younger.

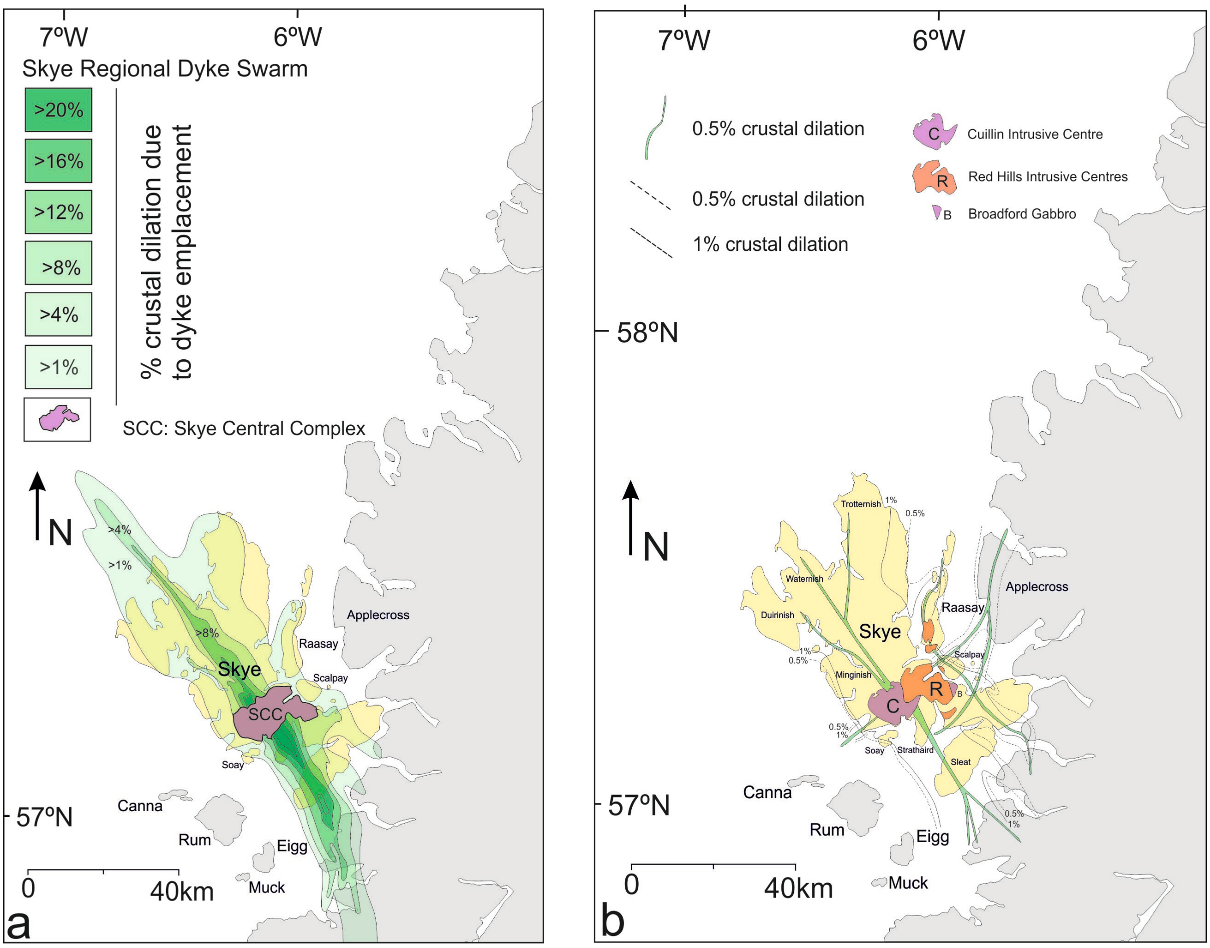


Figure 7-1 – The Skye Regional Dyke Swarm and sub-swarms (after Speight *et al.* 1982).

Both (Speight, et al., 1982) and (Wilson, et al., 1982) consider that the main swarm and sub-swarms were intruded over a relatively short period of time and acted as fissure feeders to the Skye Lava Field (Chapter 5). Most of the dykes are vertical, or near vertical, and show little sign of tectonic disturbance. In general, the dykes are discordant to the main units which they cut, although, locally, adopt trends which are controlled by their host-rocks (for example, where bedding or foliation planes have enabled easier passage of magma). Typically, the dykes either stand proud or inweather relative to the rocks which they have intruded (Figure 7-2), giving rise to a very irregular topography where they occur in large numbers, most obviously where they intrude the CIC (Figure 7-3).

Close to the CIC, the average crustal dilation (or extension) caused by the main NW-SE -trending swarm is of the order of 15%, decreasing to the NW and SE, along strike. The amount of crustal dilation decreases markedly perpendicular to the strike of the swarm, typically over a distance of 10–15km. Some of the widest dykes cut the CIC and the adjacent country-rocks (Figure 7-4). Cross-cutting relationships are common where crustal dilation is greatest, especially where the country-rocks are relatively homogeneous, as for example within the coarse-grained basic and ultrabasic rocks of the CIC (Figure 7-5).

Figure 7-2 – Members of the Skye Regional Dyke Swarm intruded into Pabay Shale Formation strata on the north side of Loch Eishort. View towards the NW from Ord.

Figure 7-3 – Inweathered (forming gullies) and outweathered (forming ridges) members of the Skye Regional Dyke Swarm intruded into bytownite-gabbros on Blà-bheinn (left) and Clach Glas (right). The large scree chute indicates an extension of the Coire Uaigneich Granite, which crops out on the lower ground. View is towards the west from Torrin.

Figure 7-4 – A wide gabbro dyke of the Skye Regional Dyke Swarm intruded into strata of the Torridonian Supergroup Sgùrr na Stri Member on the west side of Camas Fhionnairigh [NG 5085 1823]. View towards the NW from the west side of Camasunary Bay.

Figure 7-5 – Cross-cutting dykes intruded into bytownite-gabbros in Camasunary Bay, demonstrating their relative ages. Note development of thin fine-grained ('chilled') margins with orthogonal fractures *c.* [NG 5108 1962]. Pole *c.* 1m long.

Multiple dykes also occur and are commonest close to the CIC. (Speight, et al., 1982) record that up to 60% of the NW-SE -trending dykes exposed along Strathaird, SE of the CIC, are of this type (Figure

7-6). The commonness of this feature may be attributed to the ease with which a second or subsequent magma pulse used the pre-existing weaknesses developed by the initial intrusion.

Figure 7-6 – Several dykes of the Skye Regional Dyke Swarm intruded into Middle Jurassic Great Estuarine Group strata in a relatively narrow zone on the west side of Strathaird [NG 5165 1468]. View towards the north.

Radial and tangential sets of dykes, in close proximity to the CIC, have been reported by (Harker, 1904). However, their validity as a distinct group (and not as components of the Scalpay and Glenbrittle sub-swarms) is in doubt (Speight, et al., 1982), as Harker's detailed mapping did not extend any significant distance from the intrusive centre.

The origin of the main NW-SE -trending swarm is related to a distinct axis of crustal dilation that developed during the Paleocene. This axis has much in common with those of the Rum, Ardnamurchan, Mull, Arran and St. Kilda intrusive centres. Injection of magma was most likely in a vertical direction from an elongate, NW-SE -trending chamber at depth (20–50km, (Speight, et al., 1982)), as there is little evidence of lateral migration of magma within the swarm close to the central complex. Tensile stresses would have been oriented perpendicular to the planar structure of the swarm, whilst compressive stresses developed parallel to the dominant 'grain', both vertically and horizontally.

In a detailed study of the geometries of well-exposed clusters of narrow (up to 12 cm across) basaltic dykes in Coire Làgan (Figure 7-7), at Uamh Tharsgabhaig (Tarscavaig) on the west coast of the Sleat Peninsula, and on the south shore of Loch Brittle, (Platten, 2000) presents evidence for multiple dilation events that affected single dyke fissures, i.e, single magma-filled voids (Figure 7-8; Figure 7-9). Examples are described of narrow dykes that cut and chill against each other and against a spatially and temporally associated larger dyke and its country-rock. In each instance, the narrow dykes can be traced into the larger dyke for only a short distance, where they terminate. In some cases, at these terminations, the central parts of both dykes merge and the chilled margin is absent. (Platten, 2000) concludes that after the initial dilation of a fracture and the introduction of magma, there are subsequent increments of dilation, sufficiently spaced in time for preceding injected batches of magma to have solidified (crystallised). Distant from the dyke terminations, the dyke fissure was maintained as an open, magma-filled void due to continued flow of magma during further increments of fracture dilation. From these observations, it is concluded that magma-filled dyke fissures varied in width during their development, possibly controlled by magma input pressure.

Figure 7-7 – Field images of dykes from Coire Làgan exposures, SW of the lochan [NG 4442 2089], intruded into Outer Bytownite Troctolites (B): (a) apparent basalt dyke terminations, pole *c.* 1m long; (b) dolerite dyke offset, coin *c.* 24mm across.

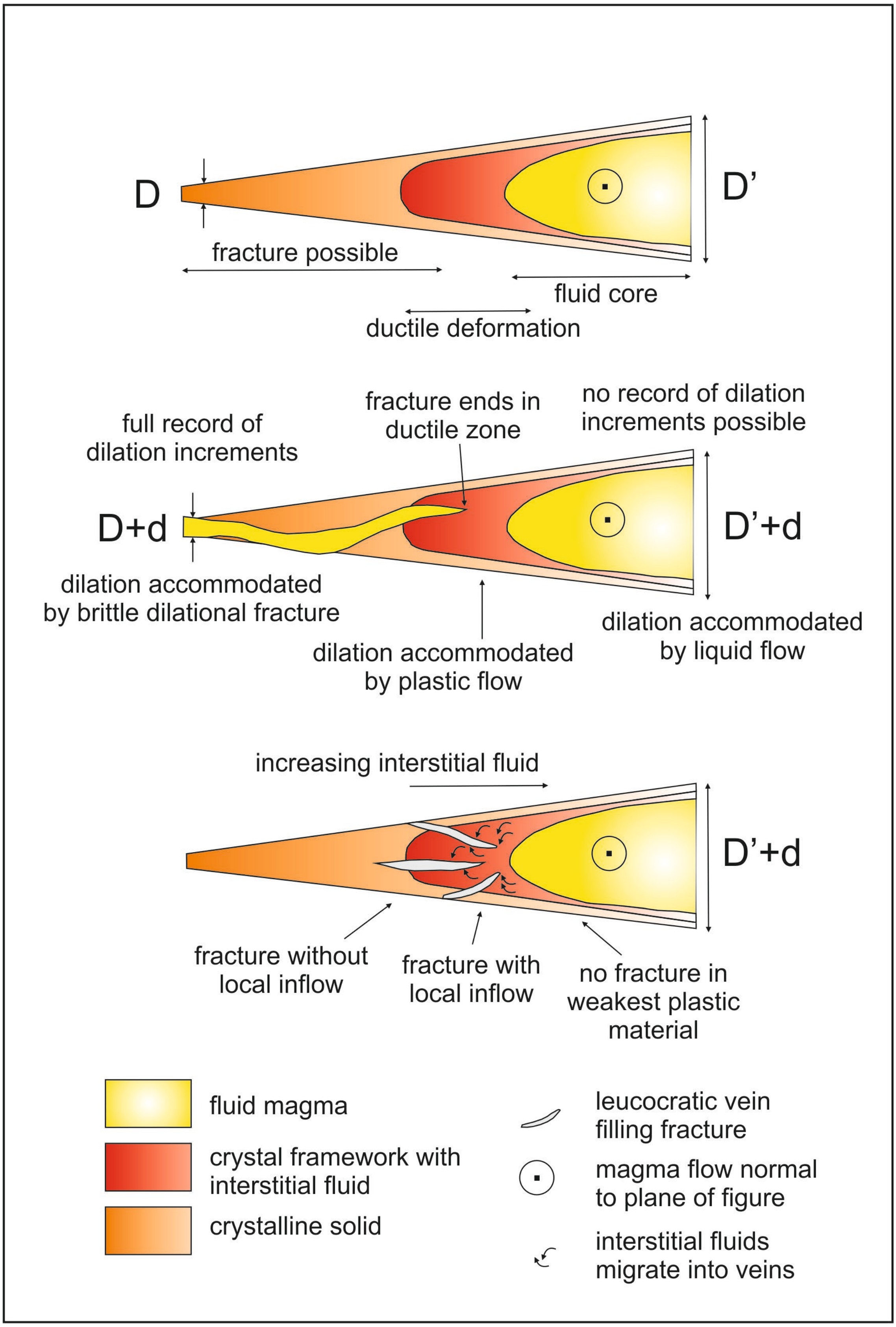


Figure 7-8 – The effects of incremental dilation during dyke emplacement (after Platten 2000).

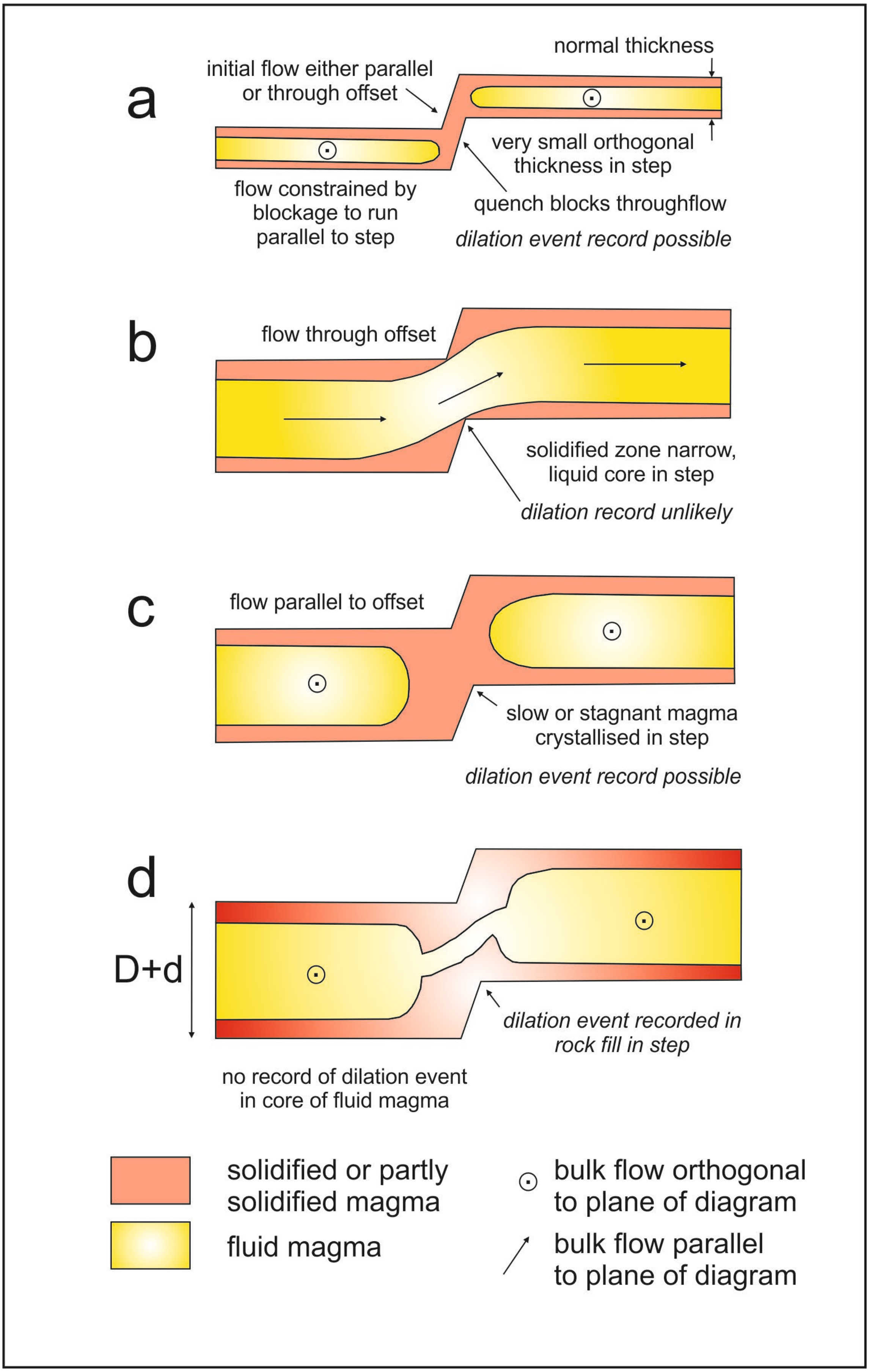


Figure 7-9 – Dyke emplacement processes (after Platten 2000).

Cooling joints are relatively common within many of the dykes, typically developed orthogonal to the vertical margins, through which heat is lost (Figure 7-10).

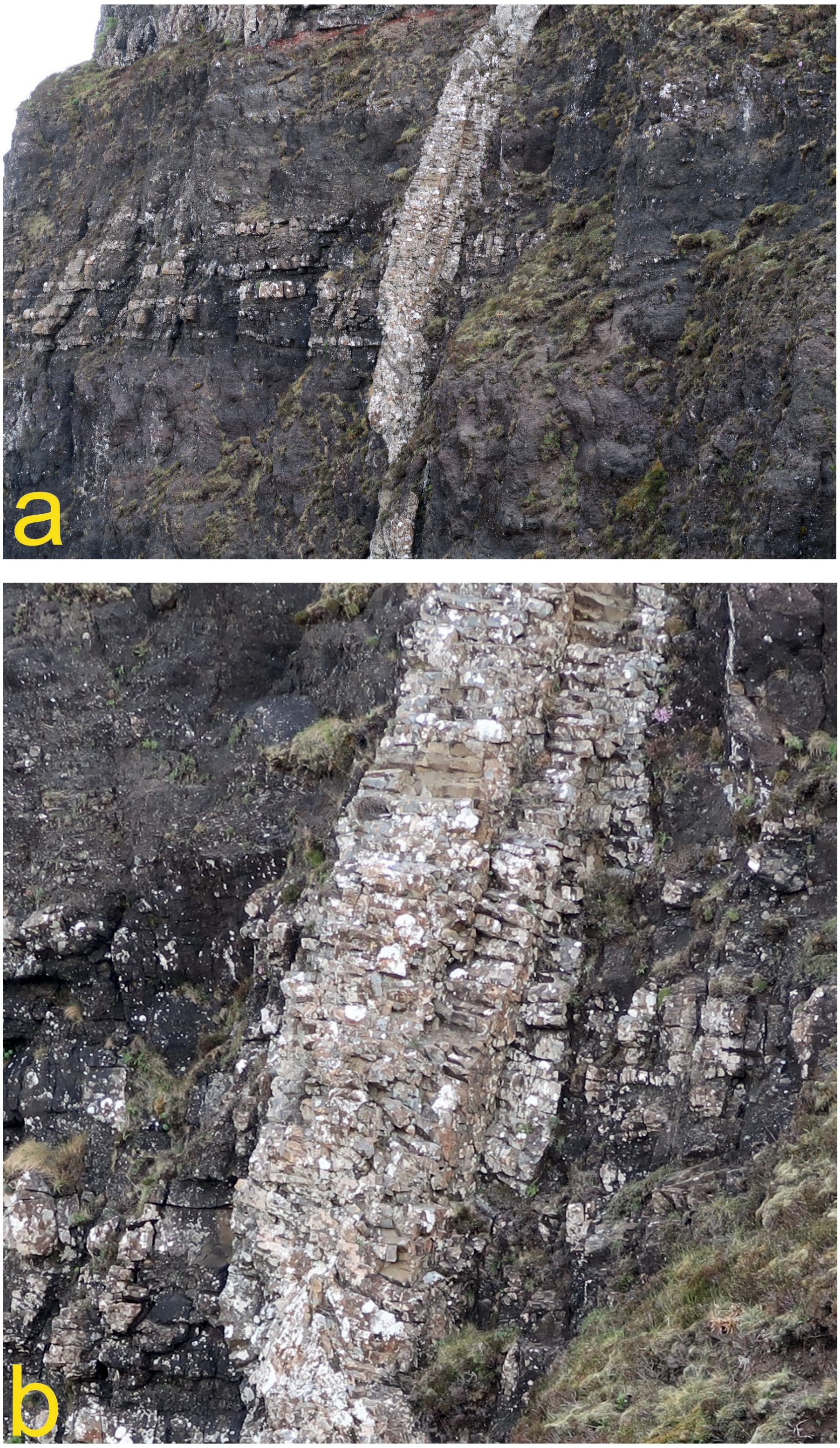


Figure 7-10 – (a) Columnar joint development orthogonal to vertical dyke margins. The country-rocks are basaltic lavas of the Beinn Edra Formation (see Fig. 5.27) on the east-facing escarpment at Sròn Vourlinn on Trotternish at *c.* [NG 4500 7150]; (b) detail of (a).

7.B.1 Compositions of the Basic Dykes of the Regional Swarm

The compositional affinities of basic members of the regional dyke swarm have been determined by (Mattey, et al., 1977) and (Bell, 1984b). Those studied by (Mattey, et al., 1977) are from four traverses across the general trend of the regional swarm: along the SE coast of Harris, Outer Hebrides; on Waternish; on the Sleat Peninsula; and, along the north coast of Loch nan Uamh, near Arisaig on the Scottish Mainland. The dykes studied by (Bell, 1984b) are from the Eastern Red Hills district on Skye. Generally, the dykes are porphyritic, with randomly distributed phenocrysts within the central portions, flanked by relatively aphyric marginal facies.

(Mattey, et al., 1977) distinguish three groups of basic dykes, each compositionally distinctive and attributable to a different parental magma. They are: (1) the tholeiitic basalt Preshal More type; (2) the mildly alkaline Fairy Bridge type; and, (3) dykes with compositions similar to the volumetrically-dominant mildly alkaline Skye Main Lava Series (SMLS) of the Skye Lava Field (Chapter 5).

Approximately 70% of the dykes investigated by (Mattey, et al., 1977) are members of Group (1) and appear to have their greatest concentration in the area nearest to the CIC, where crustal dilation was greatest (Figure 7-11). The sole lava with a near-identical composition is the intra-canyon lava of the Talisker Group, remnants of which form the two inselbergs, Preshal More and Preshal Beg on Minginish (5.D). The remainder of the dykes are either of SMLS affinity or are of the Fairy Bridge type, both types represented by lavas within the Skye Lava Field, although the former is considerably more abundant. The systematic spatial distribution of the groups led (Mattey, et al., 1977) to suggest that the swarm, itself, should be regarded as being of a compound nature.

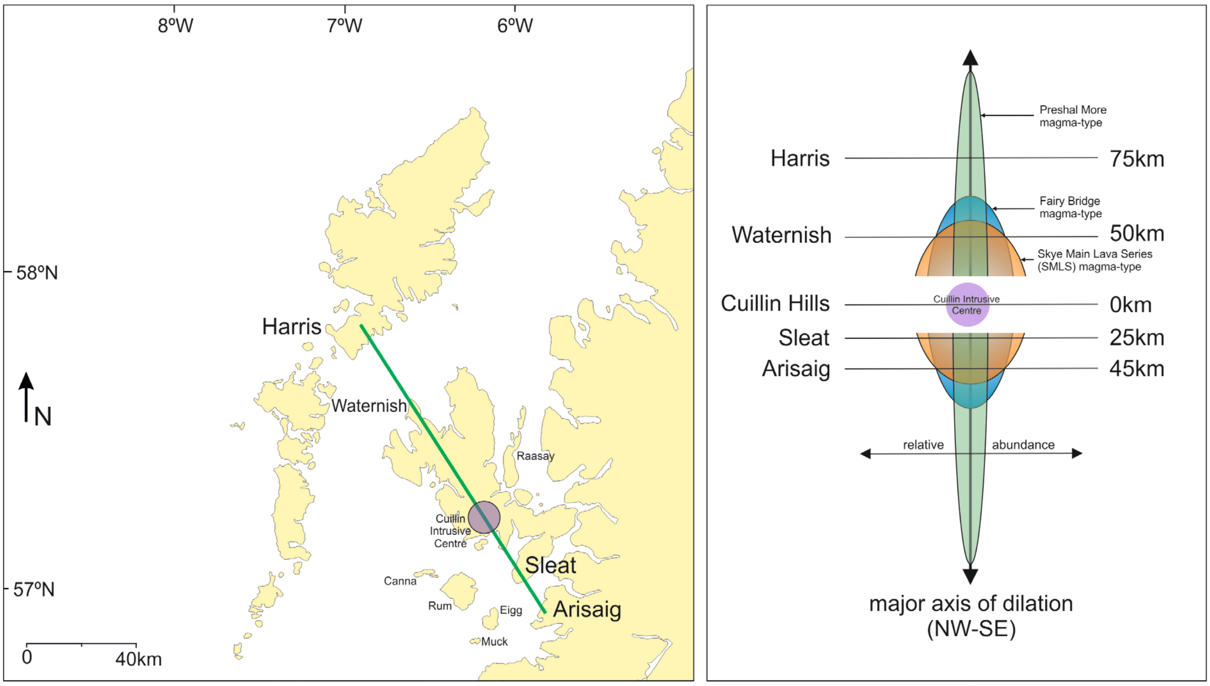


Figure 7-11 – Map showing locations of dyke traverse and relative abundance data of the three magma types (after Mattey *et al.* 1977).

Although not common, dykes of all three groups intrude the granites of the Western and Eastern Red Hills intrusive centres ((Mattey, et al., 1977); (Bell, 1984b)). Significantly, intruding the granites and therefore relatively late in the overall intrusive sequence, is a fourth group of dykes, the so-called Beinn Dearg Type (Harker, 1904). The Beinn Dearg dykes are characterised by high alkali-element contents. They are particularly well represented on both of the red hills that are called Beinn Dearg Mhòr, one in the Western Red Hills (Beinn Dearg Mhòr; the *type-locality*) and one in the

Eastern Red Hills (Beinn Dearg Mhòr). They are readily identified by their brown coloration on weathered surfaces (Figure 7-12).

Figure 7-12 – A wide dolerite dyke intruded into the Beinn na Caillich Granite of the ERHIC, on the east side of Beinn na Caillich. View towards the west from the Broadford-Torrin road, north of Suardal.

7.C The Ultrabasic (Picritic) Dykes (and Sills) of Central Skye

Although basic dykes are by far the most common type, other distinct compositional groups are recognised and are described in this and subsequent sections.

The ultrabasic dykes that intrude the Cuillin Intrusive Centre (CIC) (6.B), the lavas of Strathaird (5.D), and the pre-Paleocene country-rocks of the surrounding area, including the island of Soay, were originally described by (Harker, 1904). Subsequently, (Bowen, 1924) concluded that many of the marginal off-shoots of these intrusions were doleritic (but see below), with olivine typically concentrated in the central portions. Further studies by (Drever & Johnson, 1958), (Wyllie & Drever, 1963), Gibb ((Gibb, 1966); (Gibb, 1967); (Gibb, 1968); (Gibb, 1969); (Gibb, 1971)) and (Gibb & Henderson, 1971) have provided much additional data. Some of the descriptions below are taken from the more recent publications.

(Gibb, 1968) defines two distinct groups of ultrabasic intrusions: (1) the Coire Làgan Type, typically the smaller intrusions and devoid of any xenoliths (Figure 7-13); and, (2) the Ben Cleat Type, typically the larger intrusions and containing cognate xenoliths (Figure 7-14; Figure 7-15). The first group is described by (Drever & Johnson, 1958), whereas the publications of Gibb (see above) consider in detail the Ben Cleat Type. Unlike the ultrabasic sills of north Skye (see Chapter 8), none of these intrusions show alkaline affinities.

Figure 7-13 – Field image of a Coire Làgan Type ultrabasic dyke, intruded into Outer Bytownite Troctolites (B), SW of the lochan in Coire Làgan [NG 4439 2086]. Pole *c.* 1m long.

Figure 7-14 – Xenolithic ultrabasic dyke, An Leac, on the north side of Soay Sound [NG 4405 1699]. Pole *c.* 1m long.

Figure 7-15 – Detail of xenolithic ultrabasic dyke, An Leac, on the north side of Soay Sound [NG 4405 1699], with sub-angular fragments of banded troctolite in a picrite matrix. Coin *c.* 24mm across.

The Coire Làgan dykes, together with some associated sills, are typically less than 3m wide/thick and generally have fine-grained, picritic (ultrabasic) marginal facies. Examples include: near Leac nam Faoileann on Soay; Camas nan Gall on Soay; 2km east of Kinloch, in central Sleat; in the Allt an t-Sìthein, north of Loch Sligachan; and, in Coire Làgan, itself, in the Cuillin Hills (NW of the main track).

Crystals of olivine dominate the matrix of these intrusions. They are unzoned and have a relatively constant high Mg content of Fo_{89} (Drever & Johnson, 1958). In general, crystal size increases from the dyke margins towards the centre. The groundmass comprises clinopyroxene and plagioclase in an ophitic to sub-ophitic, or doleritic, textural arrangement and is commonly associated with a second generation of much smaller olivine crystals. The proportion of groundmass plagioclase to clinopyroxene (augite) is relatively constant, although the absolute amounts of these two minerals is dependent upon the olivine content of the intrusion under consideration.

(Drever & Johnson, 1958) suggest that the Coire Làgan intrusions were initially derived by the selective fusion of pre-existing ultrabasic rocks, to form a magma with a silica content less than that of basalt (i.e. somewhere between basic and ultrabasic in composition), which then fractionated forsteritic olivine. The composition of the magma is most likely represented by the fine-grained, marginal facies of some of these intrusions (see above) and, if so, appears to be 'transitional' (with respect to the Critical Plane of Silica Undersaturation of (Yoder & Tilley, 1962)). Flow differentiation processes, whereby early formed crystals of olivine become more concentrated in the central axes of intrusions, may also have contributed to the mineral distribution patterns. Unlayered, non-xenolithic, ultrabasic dykes and sills occur south of Beinn an Dubhaich, in the district of Strath. Field and mineralogical evidence suggest that these rocks may have affinities with the Coire Làgan Type of intrusions.

Considerable heat accompanied the intrusion of this group of dykes and associated sills. Torridonian sedimentary rocks (3.C), typically feldspathic sandstones, at the margin of the sill at Loch Doir' a' Chreamha, in SW Soay, were, locally, up to 92% melted, precipitating tridymite, cordierite, hypersthene and magnetite upon cooling ((Wyllie, 1959); (Wyllie, 1961)). The remainder of the liquid was quenched to a glass.

The Ben Cleat Type of picrites occurs only as dykes and typically contain cognate xenoliths (autoliths), of ultrabasic material. (Gibb, 1968) reports details on over 30 dykes on Strathaird and throughout the Cuillin Hills and concludes that the mineralogy and whole-rock compositions of the non-xenolithic component of these dykes are very similar to that reported from the Coire Làgan Type (see above). Olivine (Fo_{88}, (Gibb, 1968)) is the dominant mineral, together with lesser amounts of clinopyroxene, calcic plagioclase ($An_{52–85}$) and chrome-spinel. In general, olivine is a phenocryst phase and most of the dykes are distinctly porphyritic, although (Gibb, 1968) reports that non-porphyritic variants also exist. The olivine tends to be enriched in the central portions of the dykes (see below).

The most accessible dykes of this type crop out on Strathaird, due east and due west of the summit of Ben Cleat, and on the SW side of the valley between Ben Cleat and Ben Meabost. Others crop out south of Sgùrr nan Gobhar and along the main Cuillin Ridge (Gibb 1968). The Cuillin dykes show a radial distribution pattern about the Layered Peridotites (6.B.4). There is a positive correlation between dyke width and absolute olivine content; local changes in width do not greatly affect this relationship.

The xenoliths that are dispersed throughout these dykes range from 1–60cm across, vary in shape from sub-equant to elongate, and may be angular to rounded (Gibb, 1968). Contacts between xenoliths and dyke-rock are sharp. The same minerals that dominate the dyke-rocks are present within the xenoliths, namely: olivine, clinopyroxene, plagioclase, chrome-spinel, and magnetite. The relative proportions of each of these minerals within an individual xenolith are quite variable. Most of the xenoliths from a dyke studied by (Gibb, 1969), east of the summit of Ben Cleat on Strathaird, are of feldspathic peridotite, with lesser amounts of the variants dunite, peridotite, troctolite and picrite also present. There is little evidence of axial concentration of the xenoliths. (Gibb, 1969) concludes that the xenoliths were most likely derived by the disaggregation of some already-crystallised ultrabasic mass at depth and, therefore, are cognate.

Subsequently, (Gibb, 1976) suggested that the dyke materials were introduced as a magmatic suspension consisting of olivine phenocrysts and ultrabasic xenoliths in a magma somewhat more basic than basalt; olivine distribution patterns developed as a result of crystal-liquid fractionation by flow differentiation.

7.D The Ultrabasic (Troctolitic) Dykes of North Skye

The troctolite (formerly referred to as allivalite) and anorthite-bearing gabbro dykes of north Skye have been described by (Anderson & Dunham, 1966) and (Donaldson, 1977). The majority of these intrusions crop out in the area north of Bracadale, between the village and Beinn a' Chlèirich.

(Donaldson, 1977) identifies numerous intrusions within this area, together with similar small outcrops to the south of Bracadale and north of Loch Ravag (Figure 7-16; Figure 7-17). Dykes of similar composition also crop out in south Skye at Am Màm, east of Camasunary Bay.

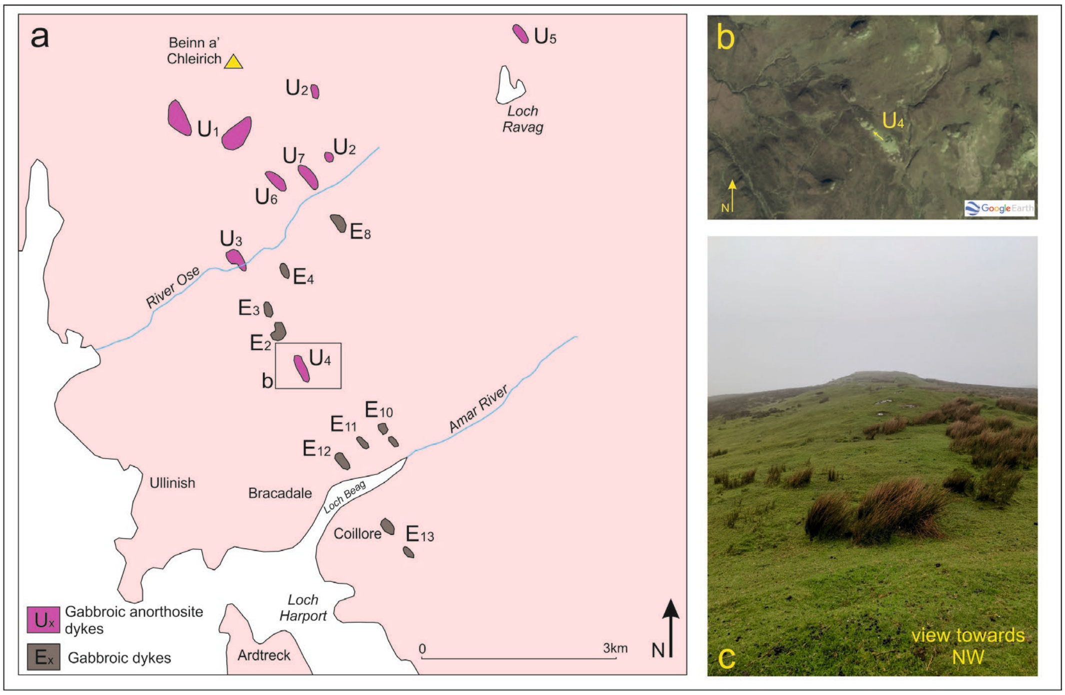


Figure 7-16 – (a) Simplified location map for the ultrabasic (troctolitic) dykes of Bracadale (after Donaldson 1977); (b) Google Earth© image of outcrop area of dyke U_4 (see (a)); (c) field view of surface expression of dyke U_4.

Figure 7-17 – (a) Field image of troctolite (anorthite-bearing gabbro) dyke U_4, SE of Beinn nan Braclaich; and, (b) detail of troctolite dyke U_4 on a weathered surface, coin *c.* 24mm across.

Most of the intrusions are elongate and have near-vertical margins, indicating their dyke-like form. They have widths of up to 80m and form elongate, rounded hummocks that trend NW-SE and can be traced for distances of up to 500m. They cut the lavas of the Bracadale Group (5.D) and are commonly cut by basaltic and doleritic dykes of the regional swarm (see 7.B, above).

These dykes are composed of a central, coarse-grained facies consisting of anorthite-bytownite and olivine megacrysts, set in a groundmass of troctolite composition. Marginal facies may be regarded as feldspar-phyric basalts containing sparse megacrysts of plagioclase ($An_{87–93}$, 20 vol. %) and olivine ($Fo_{78–87}$, 1–10 vol. %) set in a fine-grained groundmass (Donaldson, 1977). This marginal rock grades over a few tens of centimetres into a central, coarse-grained facies that contains the same megacrysts with the same compositions. Within each dyke, the proportion of megacrysts increases towards the centre, although maxima are not found at the centre, but on either side of it. According to the studies of (Gibb, 1968), this type of crystal distribution pattern may also be attributed to flow differentiation processes.

(Donaldson, 1977) reports xenoliths of the following rock-types from these dykes: olivine-anorthite rock; augite-anorthite rock; and, fluxion-banded troctolite. Also present are xenocrysts (2–2.5cm) of plagioclase (An_{92}), olivine ($Fo_{82–84}$) and augite.

The two intrusions on either side of the Brois(g)illmore Burn in Bracadale show clearly many of the features present in these dykes. Likewise, the intrusions at Creag Dhubh and NW of Dùn Garsin, both NE of the village of Bracadale, are instructive, and have easier access. By subtracting modal percentages of plagioclase and olivine present within marginal facies of these dykes, (Donaldson, 1977) calculated that the groundmass composition is hypersthene-normative., i.e. of tholeiitic affinity.

The initial development of these dykes involved the intrusion of the marginal facies material, essentially a megacryst-poor, tholeiitic basalt magma, which then crystallised inwards to a coarser-grained rock. Subsequently, a crystal-rich magma (of similar composition) was intruded and underwent flow differentiation within the dyke conduit. These dykes, therefore, consist of megacryst-depleted, fine-grained, marginal facies and a megacryst-rich central zone. Detailed mineralogical studies indicate that the megacrysts and the groundmass mineral assemblages of individual dykes are not cognate (Donaldson, 1977).

(Donaldson, 1977) also concludes that the Ca-rich tholeiitic basaltic magmas (or 'high-lime liquids' of (Drever & Johnston, 1966)) that were involved in the formation of the mineral assemblages of these dykes may have been similar to those involved in the formation of the Unlayered Bytownite Troctolite ('White Allivalite') of the Border Group of the Cuillin Intrusive Centre (see Section 6.B.2) and the crystallisation of the Ca-rich, Ti- and P-poor Preshal More lava of the Talisker Group on Minginish (5.D).

7.E The Layered Ultrabasic (Picrite) Dyke of Stac Suisnish, Strath

A 30-40m wide vertical picrite dyke, composed of layers or bands with olivine-rich basal parts and plagioclase-rich upper parts, is intruded into gently dipping (towards the west) Lower Jurassic Pabay Shale Formation strata on the east side of Loch Slapin, at Stac Suisnish (Parslow, 1976) (Figure 7-18). The layers within the dyke are also inclined towards the west, at *c.* 20°. What sets out this intrusion as being unusual is that it is a relatively narrow dyke, yet it shows internal mineralogical variation in the form of graded layers, formed by some sort of crystal-liquid fractionation mechanism, typical of considerably larger intrusions (Figure 7-19; Figure 7-20). It is also relatively easily accessed by comparison with the layered ultrabasic and basic rocks of the Cuillin Intrusive Centre (6.B).

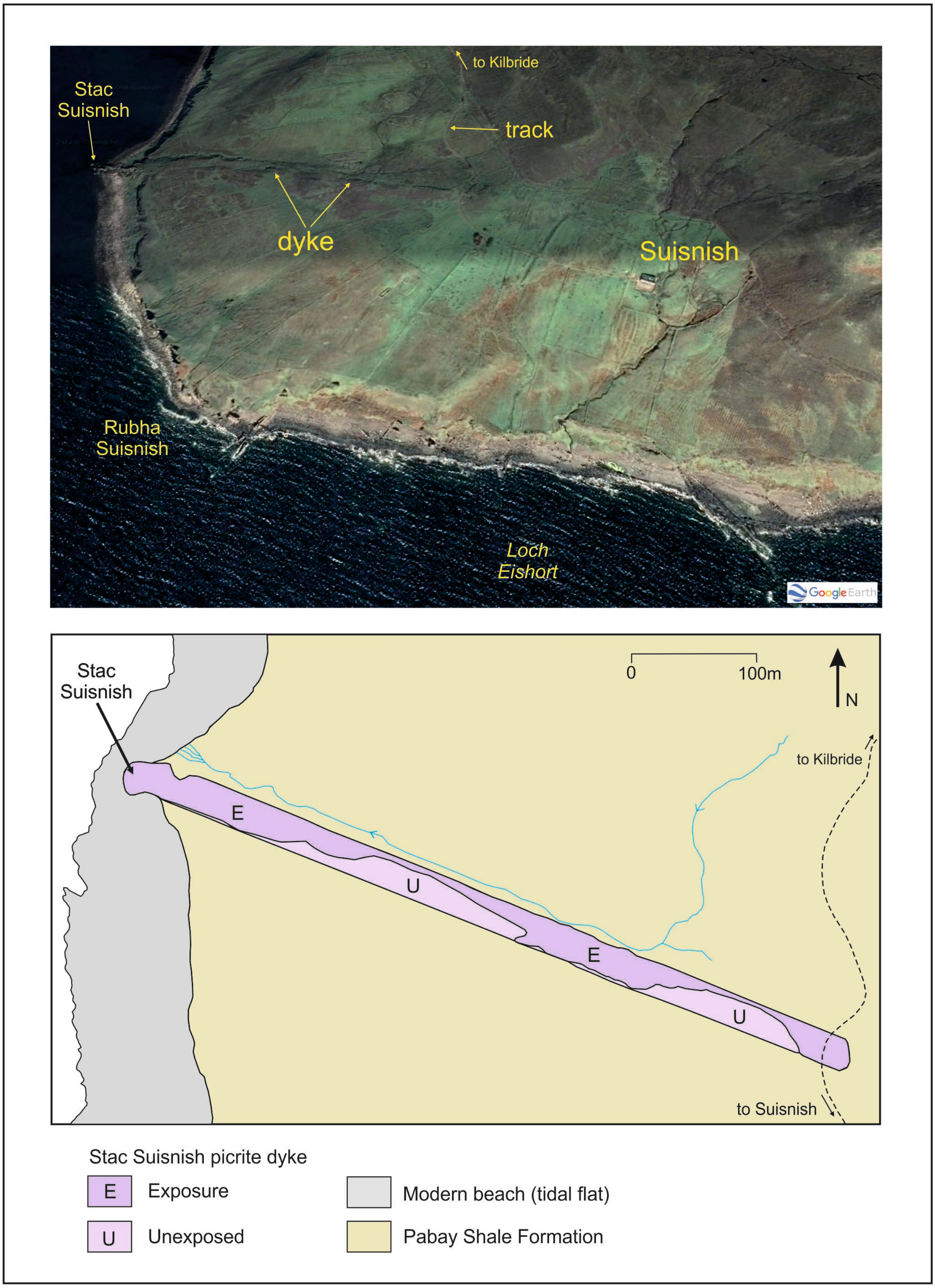


Figure 7-18 – Schematic map of the Stac Suisnish Dyke on the east side of Loch Slapin [NG 5878 1625] (after Parslow 1976) and Google Earth© image of the same area.

Figure 7-19 – Field view of the south side of the Stac Suisnish layered picrite dyke, with conspicuous plagioclase-rich layers dipping towards the west [NG 5852 1628]. Pole *c.* 1m long.

Figure 7-20 – Detail of the Stac Suisnish layered picrite dyke, with conspicuous plagioclase-rich layers and, in the lower layer, autoliths (cognate xenoliths) dominated by plagioclase (anorthosite) [NG 5852 1628]. Hand lens *c.* 3cm long.

The dyke is superbly exposed in the sea cliff and on the stack (Stac Suisnish) and can be traced inland, forming an obvious ridge-like feature for *c.* 550m to the track that parallels the coastline

(Figure 7-18). (Parslow, 1976) concludes that thermally metamorphosed siltstones occur above the dyke along this ridge, implying that, at the present level of erosion, the top, or roof, of the dyke was no great distance above the cliff exposures. Minor faults displace segments of the dyke.

The dominant minerals, typically unaltered, are subhedral olivine (Fo_{83}, 0.5-1.7mm, 50 vol. %), subhedral plagioclase (An_{80-90}, 0.2-0.9mm, 35 vol. %) and anhedral clinopyroxene (augite, 0.5-0.7mm, 15 vol. %), the last two in an ophitic textural arrangement. Also present are accessory chrome-spinel and magnetite, together with sub-spherical structures, possibly ocelli linked to some form of liquid immiscibility segregation, or vapour phase separation (Parslow, 1976).

Twenty distinct layers are present, with thicknesses in the range 15-120cm. A typical mineralogically-graded layer has an olivine-rich base and a plagioclase-rich top. There is no microscopic lamination due to plagioclase alignment. Boundaries between layers are typically sharp. The plagioclase-rich tops to layers are commonly brecciated or contain autoliths (cognate xenoliths) of plagioclase-rich material (Figure 7-20). Such autoliths are less common in the olivine-rich basal parts of layers. Uncommon clots of olivine-rich material occur in the basal parts of layers.

A sample from the poorly exposed chilled margin of the dyke, which has an estimated width/thickness of *c.* 30cm, is typically phaneritic, with phenocrysts of plagioclase, but not of olivine, which may be attributed to some form of flow differentiation process during dyke emplacement. The country-rock siltstones are significantly metamorphosed only up to 10cm from the contact, although minor thermally induced changes are recognised up to 65m from the contact (Parslow, 1976), both suggesting overall, slow cooling of the picritic parental magma.

(Parslow, 1976) concludes that a combination of flow differentiation during the initial emplacement of magma into the fissure/conduit, followed by gravitationally-assisted crystal accumulation in a dynamic flow regime, best explains the mineralogical features of the Stac Suisnish Dyke.

A banded dyke (the so-called Mystery Dyke; (Drever, 1969), located near Kilmuir on the west side of Trotternish is spatially associated with the Little Minch Sill Complex of North Skye and is more appropriately included with the account of these picritic and doleritic sills (Chapter 8).

7.F The Trachyte Dykes

Two distinct groups of trachyte dykes are associated with the Skye Central Complex: (1) the Drynoch Group, at the head of Loch Harport (Figure 7-21); and, (2) the Broadford and Sleat Group, on the Sleat Peninsula and in the eastern part of the district of Strath (Figure 7-22). (Harker, 1904).

Dykes from both groups are readily identified by their dull grey coloration and platy fracture, together with their generally non-porphyritic texture.

Figure 7-21 – Field image of a trachyte dyke, north of Drynoch at the head of Loch Harport [NG 4111 3202]. Pole *c.* 1m long (on contact with country-rock Paleocene lavas). View towards the north.

Figure 7-22 – Field view of a trachyte dyke, SW of Coire-chat-achan, Strath.

Members of the Drynoch Group are exposed in the Allt Coir' a' Ghobhainn and the Allt na Guile, both north of the head of Loch Harport. Typically, these dykes are less than 5m wide and are oriented parallel to the NW-SE -trending regional dyke swarm (7.B). They are dominated by oligoclase and alkali feldspar (0.1–0.2mm), in a well-developed trachytic texture, together with accessory augite, Fe-Ti oxides and biotite.

The dykes of the Broadford and Sleat Group are also oriented parallel to the regional dyke swarm and show similar petrographic features, but additionally exhibit a marginal, spherulitic facies which has an alignment fabric, or 'rodded' structure (Harker, 1904). This lineation dips at an average angle of 45° and has been interpreted as the direction of magma migration through the fissure during magma emplacement. The individual spherules are 5–10mm in diameter and are composed of radiating aggregates of oligoclase and alkali feldspar. Within these marginal facies, as well as in the central portions of certain dykes, there are amygdales of various zeolites. Examples of trachyte dykes which show these features include: a dyke near the footpath which crosses the Broadford River, east of Coire-chat-achan; and, dykes in the Allt Rèidhe Ghlais, at the head of Loch Eishort, *c.* 1km west of the road. Another member of this group, but which does not show the spherulitic structure, is located *c.* 800m NNE of the summit of Bheinn Shuardail in the district of Strath. It is a sparsely porphyritic rock, buff-coloured, and shows a crude trachytic texture.

In the case of the Broadford and Sleat Group, there is no obvious connection between these dykes and any extrusive trachytes. However, the trachytes of the Drynoch Group are in close spatial association with trachytic lavas of the Bracadale Group (5.D) and are interpreted as the feeders to these extrusive units.

7.G The Augite-andesite Dykes

Dykes of augite-andesite composition crop out in the district of Strath and on the Sleat Peninsula (Harker, 1904). These rocks may be distinguished from more basic and silicic types by their distinctive mineralogy, consisting of phenocrysts of labradorite and augite set in a groundmass of variable composition ranging between a relatively silicic glass and its fine-grained devitrification products. As a typical example, (Harker, 1904) describes a dyke on Glas Eilean, opposite Lower Harrapool in Broadford Bay, which is readily identified in the field because of its dull grey and somewhat 'rotted' appearance. It is dominated by phenocrysts of labradorite in a groundmass consisting of feldspar, augite and glass; the latter two now completely altered. An example of a more glassy type crops out on the north side of Loch Eishort, west of the abandoned settlement of Boreraig. This dyke consists of phenocrysts of labradorite (5–6mm) and augite (1–3mm), set in a black, glassy groundmass containing small crystals of plagioclase and altered augite.

With decreasing amounts of plagioclase and augite, and an increase in silica content in the glassy groundmass, there appears to be a transition between the augite-andesite dykes and the vitrophyre ('pitchstone') dykes described in Section 7.H, below.

7.H The Vitrophyre ('Pitchstone') Dykes

In comparison to other igneous centres within the province, Skye contains very few vitrophyres (pitchstones of older literature), either intrusive or extrusive. This rock-type forms thin dykes that crop out along a narrow corridor of ground running from Glamaig in the NW, to the Allt Duisdale, near Isle Ornsay (Eilean Iarmain), in the SE. (Harker, 1904) identifies two spherulitic vitrophyre dykes on the western slopes of Glamaig. The most prominent one is located at *c.* 400m OD and trends NW-SE, parallel to the regional dyke swarm (see Section 7.B). This multiple dyke is *c.* 60cm wide and is readily identified as a dark green, glassy rock.

Other dykes in this group crop out on: the eastern slopes of Glas-Bheinn Mhòr; at Coire-chat-achan on the eastern slopes of Beinn na Caillich; and, in the Allt Duisdale, west of Isle Ornsay.

(Harker, 1904) also identifies a group of dykes that he regarded as altered vitrophyres. They are most abundant east of Beinn na Caillich and are referred to, informally, as the Coire-chat-achan Type (Figure 7-23; Figure 7-24) These dykes are readily identified by their dull grey-brown coloration and contain spherules along marginal facies, giving rise to a 'rodded' structure. In thin-section the bulk of these dykes consist of pale yellow, altered glass, with scattered microphenocrysts of sanidine and augite.

Figure 7-23 – Field image of a vitrophyre dyke, SE of Coire-chat-achan, Strath. View towards the SE. Pole *c.* 1m long.

Figure 7-24 – Detail of inclined 'rodded structure' on margin of vitrophyre dyke, SE of Coire-chat-achan, Strath. Coin *c.* 24mm across.

The main difference between the Coire-chat-achan vitrophyre dykes and the others noted above may be one of age, as the former most likely pre-date the granites, and therefore have been subjected to the intense hydrothermal alteration associated with these large intrusions (6.H).

7.I Deformed Paleocene Dykes and Sills

Deformed basic and silicic igneous sheets within Cambro-Ordovician Durness Group dolostones (3.E) around the margins of the Beinn an Dubhaich (Granite) Intrusion (6.G.5) have been described by Nicholson ((Nicholson, 1970); (Nicholson, 1985)) and (Longman & Coward, 1979) (Figure 7-25; Figure 7-26).

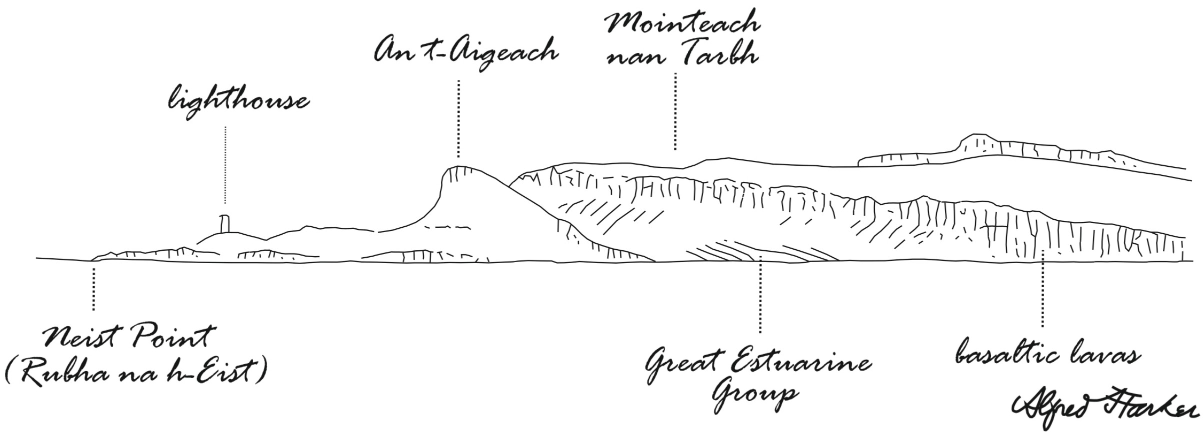
These minor intrusions are boudinaged and folded and this deformation has been attributed to radial compressive forces emanating from the western part of the granite intrusion, presumably during its emplacement. Boudin necks within these dykes (for example, at Camas Malag) show evidence of chilling, suggesting that the deformation took place before the intrusions had completely crystallised. Other examples may be examined at Dùn Beag, on the east side of Loch Slapin, and around the Old Manse at Kilchrist.

Figure 7-25 – Field image of deformed Paleocene dykes, emplaced into Cambro-Ordovician Durness Group dolostones in Torrin Quarry [NG 5840 2018].

Figure 7-26 – Field image of deformed Paleocene dyke with altered margin, emplaced into Cambro-Ordovician Durness Group dolostones, Leac nan Craobh, SW of Torrin. Pole *c.* 1m long.

Chapter 8 The Little Minch Sill Complex and Other Sills

The dramatic coastlines of Trotternish and Duirinish in north Skye are due to the emplacement of the Paleocene Little Minch Sill Complex into Middle and Upper Jurassic strata. These sills rarely penetrate the overlying Paleocene lavas and generally follow the shallow synclinal structure of the sedimentary host rocks. Columnar joints are common and are typified by the justifiably famous Kilt Rock, south of Staffin.



8.A Introduction

The Jurassic sedimentary rocks that crop out on the three peninsulas of north Skye, Trotternish, Waternish and Duirinish, and on Raasay, are intruded by sills belonging to a large complex that extends to the NW onto the Shiant Islands (Na h-Eileanan Mòra) in the Little Minch, from which it gets its name, the Little Minch Sill Complex ((Anderson & Dunham, 1966); (Gibb & Gibson, 1989)) (Figure 8-1). The extent of the complex, as much as 4,000km^2, is illustrated in Figure 8-2, which is based on offshore geophysical data (Chesher, et al., 1983). At different localities, total sill thicknesses are relatively constant at *c.* 250m, with individual sills typically in the range 10-130m, commonly achieving thicknesses in excess of 90m, for example, at Meall Tuath, north of Duntulm. Many intrusions are multiple, with (internal) sill-sill contacts. The dominant lithologies are picrite, picrodolerite, olivine dolerite and crinanite (8.C).

Figure 8-1 – The Shiant Islands (Na h-Eileanan Mòra), dominated by remnants of the Little Minch Sill Complex intruded into Upper Jurassic strata. The 'paired' island on the left is Eilean an Taighe, with Garbh Eilean beyond, and the island on the right is Eilean Mhuire. View is towards the NW from Meall Tuath, north of Duntulm, Trotternish.

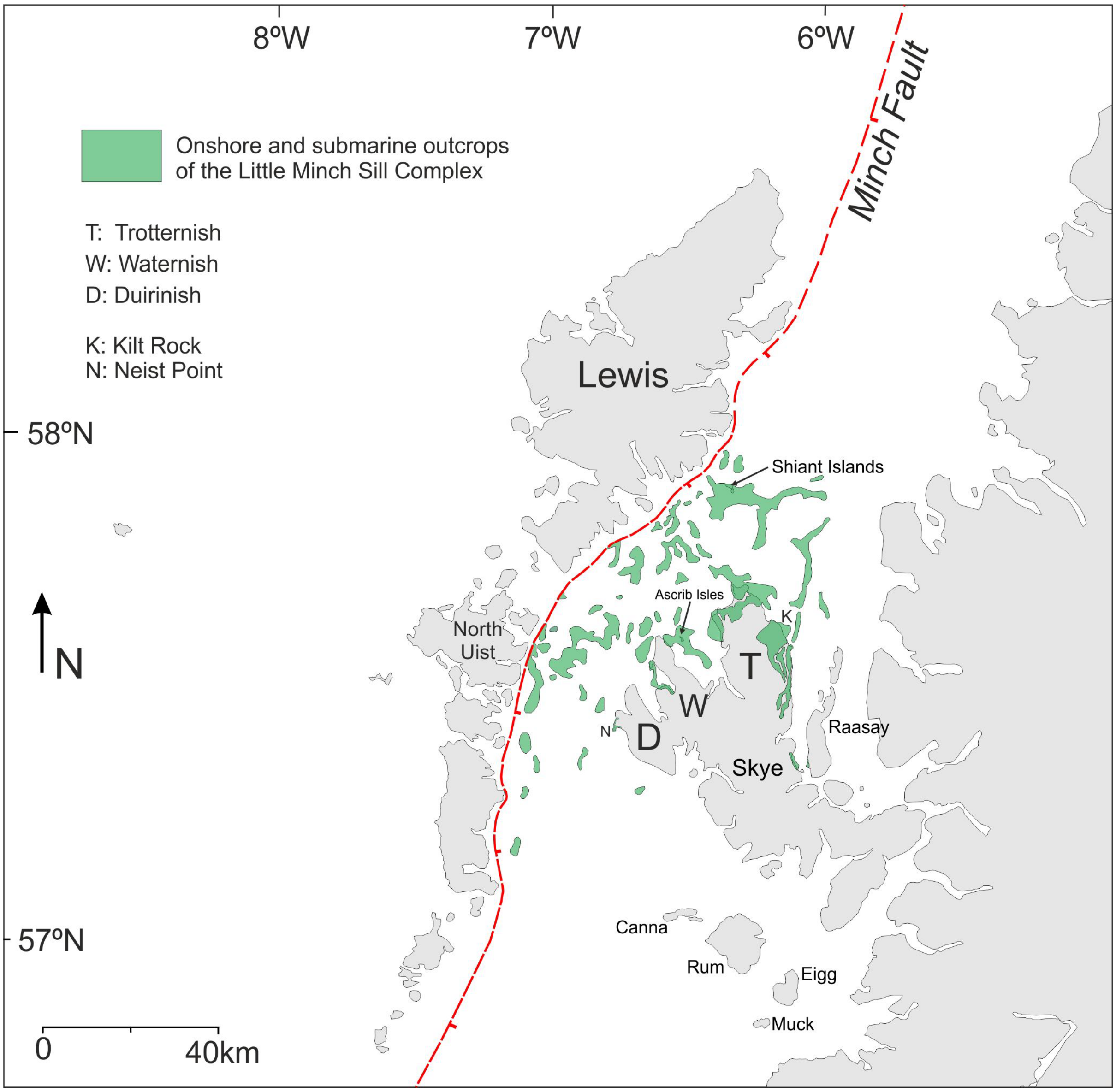


Figure 8-2 – The onshore and submarine outcrops of the Little Minch Sill Complex (after Gibb & Gibson 1989).

Faulting and tilting affect the outcrop pattern of the complex, although it is likely that it was originally relatively flat-lying to gently synclinal. Apparent sill transgressions are common, for example along the east coast of Trotternish from the Kilt Rock at Loch Mealt, south to Rubha nam Brathairean ('Brother's Point') (8.B). The Trotternish sills typically dip towards the west and transgress up-sequence from south (within the Middle Jurassic Bearreraig Sandstone Formation) to north (within the Upper Jurassic Staffin Shale Formation) (4.C). Only rarely do parts of the sill complex invade the overlying lavas, for example, at Oisgill Bay, on the west coast of Duirinish (Figure 8-3) and on Raasay, north of Dùn Caan. Due to the present-day level of erosion, upper contacts of the sills are rare. Access to some of the best sections through the sills on Trotternish is, at best, difficult, and in places not possible, restricting observations to be from adjacent cliff tops or from a boat (Schofield, et al., 2016).

Figure 8-3 – Multiple olivine dolerite sill intruded into basaltic lavas forming the cliff of Biod Bàn at the southern end of Oisgill Bay, on the west coast of Duirinish. View towards the north.

Prismatic and columnar joints are common and give rise to spectacular scarp slopes on the east side of Trotternish, the most famous example being the Kilt Rock, with columns in excess of 30m in length (Figure 8-4). Another excellent example is the thick sill that forms the headland at Bornesketaig in the NW part of the Trotternish (Figure 8-5). Generally, these cooling-induced joints are oriented perpendicular to the relatively flat-lying Jurassic bedding surfaces and, therefore, are inclined at a high angle. Locally, the joints have more complex forms, for example fan-like arrays, where the bedding of the host rocks is more irregular, or the sill is transgressive. A spectacular example occurs at Lùb a' Sgiathain ('Bay of the Wing'), east of Rubha Hunish, at the northern end of Trotternish (Figure 8-6).

Figure 8-4 – The Kilt Rock on the east coast of Trotternish at Eillishadder, composed of an upper columnar-jointed crinanite sill, a horizontally-bedded sequence of Valtos Sandstone Formation strata, and a lower columnar-jointed crinanite sill. Cliff is *c.* 90m high. View towards the north from the Kilt Rock Viewpoint (Aite-faire Creag an Fhèilidh).

Figure 8-5 – Columnar-jointed picrite sill forming the coastline north of Bornesketaig on the NW coast of Trotternish. View is east towards Gairbh-sgeir at the southern end of Lùb an Sgòir. Cliff is *c.* 40m high.

Figure 8-6 – Complex columnar joints within the olivine dolerite sill at Lùb a' Sgiathain ('Bay of the Wing'). View towards the east from Meall Tuath at the northern end of Trotternish. Cliff is *c.* 80m high.

Field relationships of the Little Minch Sill Complex on Skye have been investigated by (Anderson & Dunham, 1966), Simkin ((Simkin, 1965); (Simkin, 1967)) and (Schofield, et al., 2016) (8.B), whereas mineralogical and petrological aspects of the sills are described by (Walker, 1932), (Anderson & Dunham, 1966), (Gibson, 1990) and (Gibson & Jones, 1991) (8.C).

8.B Field Relationships of the Little Minch Sill Complex

(Anderson & Dunham, 1966)and (Schofield, et al., 2016) provide details of the field relationships of the north Skye sills, and the latter an interpretation of emplacement mechanisms.

On a gross scale, the sills are tabular, concordant with the host Jurassic strata, but with apparent local transgressions. (Schofield, et al., 2016) develop a model of emplacement that comprises key stages, involving vertical inflation of the host rocks as magma propagates through it. Segments of the sill complex merge with increased magma flux, producing so-called bridges and broken bridges (Figure 8-7). Based upon evidence at Rubha nam Brathairean on the east coast of Trotternish, where inclined rafts of Middle Jurassic Lealt Shale Formation strata separate picrodolerite sills at different stratigraphic levels (Figure 8-8), it is concluded that a bridge has formed in response to magma emplacement. The long axis of the bridge structure (NW-SE) is orthogonal to the inferred axis of magma emplacement (NE-SW).

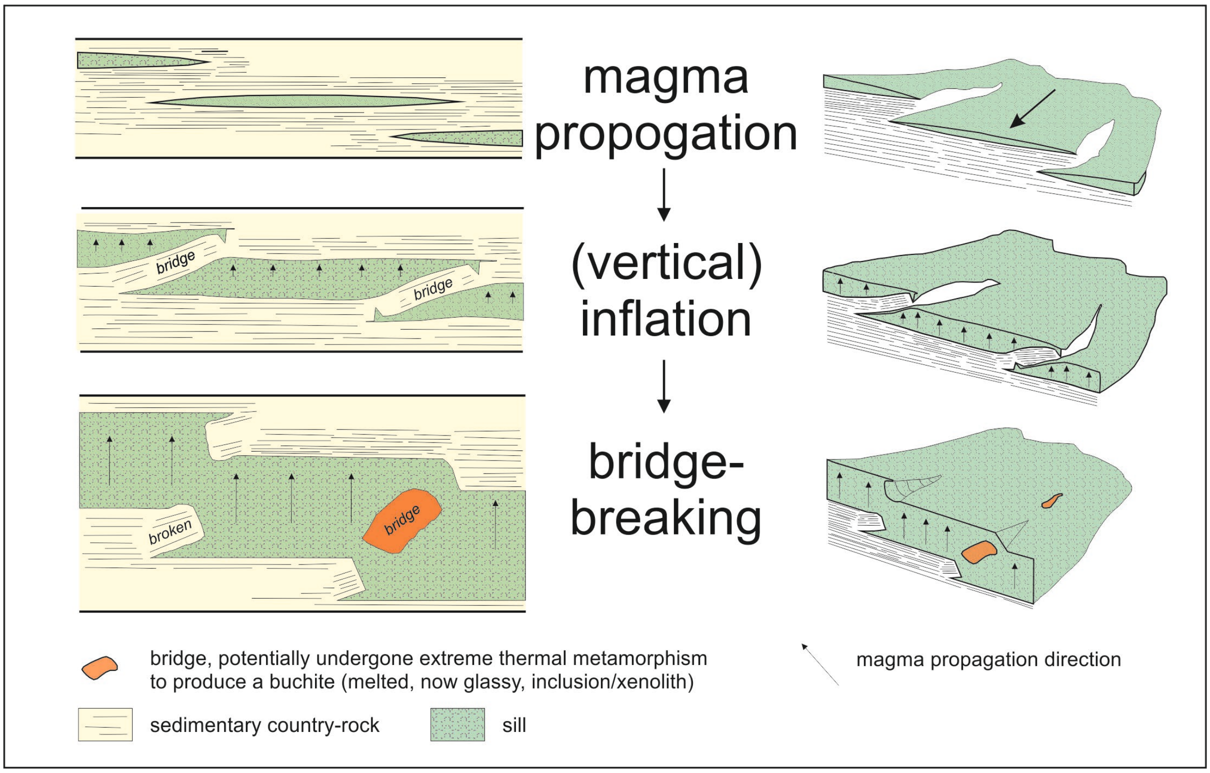


Figure 8-7 – The development of bridge and broken bridge structures in sills (after Schofield *et al.* 2016).

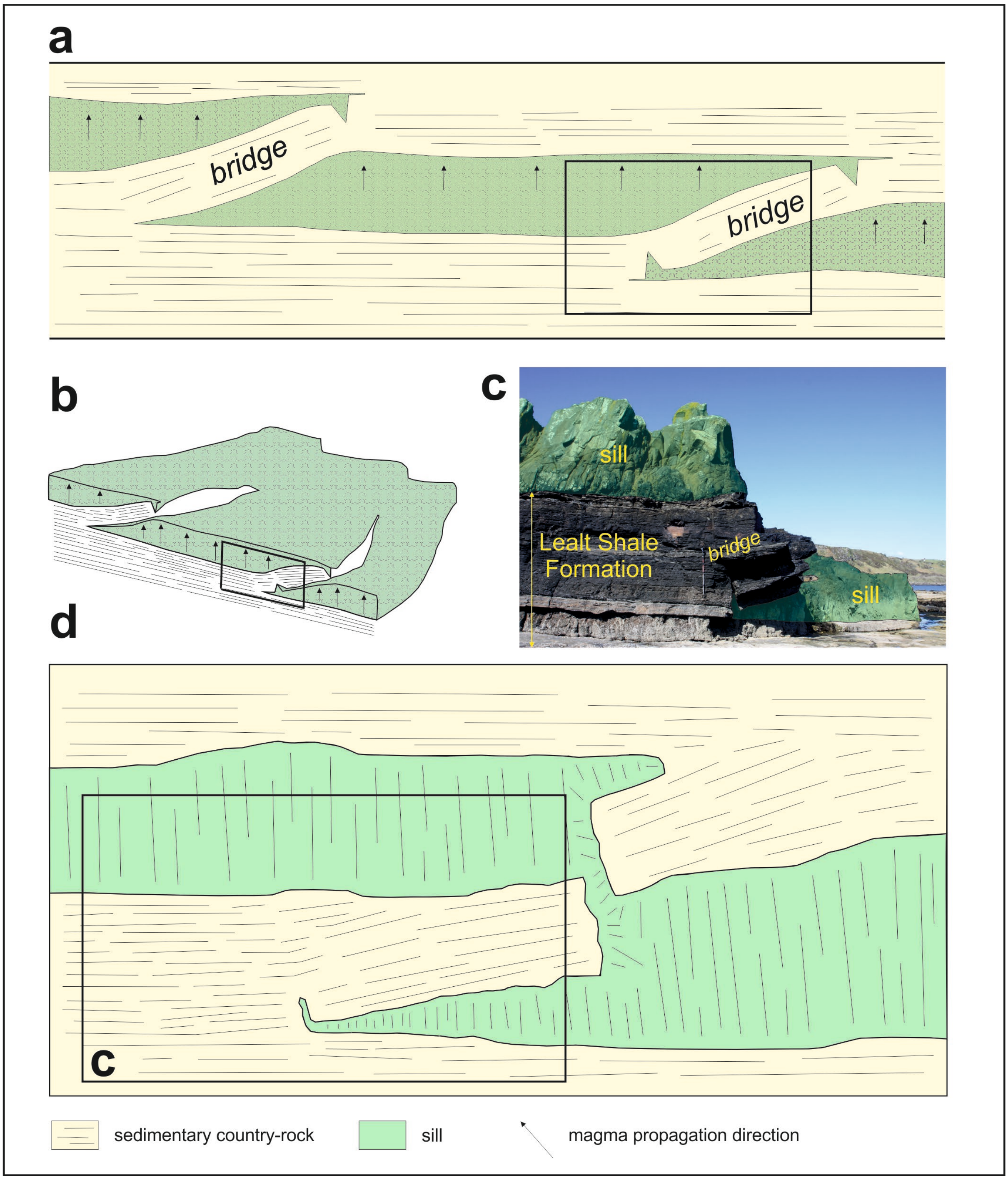


Figure 8-8 – (a) & (b) Schematic diagrams illustrating mechanism of magma propagation and sill development (after Schofield *et al.* 2016); and, (c) & (d) example of a tensile cross fracture within Middle Jurassic Lealt Shale Formation strata intruded by an apophysis of an olivine dolerite sill during propagation/inflation process, Sgeir Gharbh [NG 5228 6284], pole *c.* 1m long.

Further north, between the Kilt Rock at Loch Mealt and Dùn Dearg, Middle Jurassic Valtos Sandstone Formation strata (4.C) act as a host to sills. Here, the sills, some tens of metres thick, are generally concordant to bedding. (Schofield, et al., 2016) identify various step-like features, bridges, broken bridges and rafts of country-rock strata that segment and complicate the sill outcrop pattern (Figure 8-9). They argue that this N-S coastal section is orthogonal to the axis of magma emplacement (E-W). In this section, multiple sills are common, with clear-cut internal contacts, indicative of multiple magma emplacement events, albeit not necessarily separated by substantial time intervals. (Schofield, et al., 2016) conclude that the sill complex at this locality developed by pulsed injection of laterally-restricted sheets of magma parallel to the stratification of the host-rocks at different stratigraphic levels, which subsequently merged, or almost merged (Figure 8-7).

Figure 8-9 – Oblique view of the east coast of Trotternish, north towards the Kilt Rock from Rubha nam Brathairean, illustrating the complex geometry of the sill complex. At the Kilt Rock (Figure 8.4) two intrusions of the complex are separated by an interval of horizontally bedded Valtos Sandstone Formation strata, whereas south (left) of the waterfall at the Kilt Rock Viewpoint (Aite-faire Creag an Fhèilidh) the cliff is composed of a single intrusion, which is the upper of the two intrusions at the Kilt Rock section.

At Staffin Harbour, sills occur at two stratigraphic levels within Middle Jurassic Great Estuarine Group strata, a lower unit within the Duntulm Formation and an upper unit within the Kilmaluag Formation (4.C) (Figure 8-10). Here, the upper surface of the Staffin Slipway sill is exposed and preserves flow indicators in the form of ropey structures and stretched and aligned vesicles (Figure 8-11). (Schofield, et al., 2016) interpret the gross morphology of the upper sill, which forms highs along the cliff line, as evidence for a large-scale finger-like geometry (Figure 8-7).

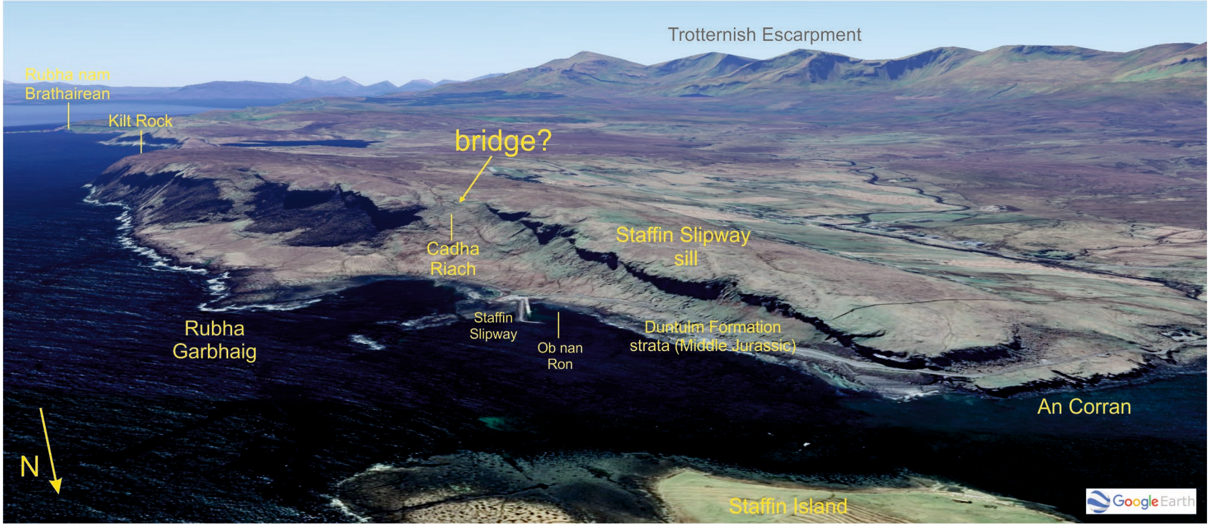


Figure 8-10 – Oblique Google Earth© image of the coastline between An Corran and the Staffin slipway at Ob nan Ron. The inland cliff is composed of a crinanite sill intruded into Middle Jurassic Duntulm Formation strata (exposed on the shore). View towards the south.

Figure 8-11 – Field image of the prismatic-jointed Staffin Slipway sill, viewed from the slipway towards the west. Height of cliff *c.* 70m.

At Neist Point (Rubha na h-Eist) on the west coast of Duirinish, a thick olivine dolerite sill forms the prominent cliffs upon which the Stevenson-designed lighthouse is located (Figure 8-12). South of the Point, in Moonen Bay, Middle Jurassic Lealt Shale Formation strata, inclined at *c.* 40°, form a large bridge, up to 40m across, separating two leaves of the sill complex (Figure 8-7). The bridge structure is further affected by irregular dyke-like masses of olivine dolerite. (Schofield, et al., 2016) interpret these dyke-like intrusions as evidence of magma invading fractures as the country-rock strata was inflated during sill emplacement, bridge development, and subsequent deformation of the bridge.

Figure 8-12 – (a) The Neist Point Sill viewed towards the SSW from the coastal cliffs. The prow of An t-Aigeach ('The Stallion') has a height of *c.* 90m above sea level. The top of the olivine dolerite sill is locally preserved, seen at the far left of the cliff line, where (inaccessible!) hornfelsed, flat-lying Middle Jurassic Lealt Shale Formation strata are preserved. The sill has a complex, irregular set of prismatic joints; and, (b) detail of Lealt Shale Formation strata above sill. The lighthouse at Neist Point (Rubhan a h-Eist), Skye's most westerly coastline, was designed by David Alan Stevenson and first lit in November 1909.

Figure 8-13 – Irregular top of the olivine dolerite sill forming Sgeir nan Sìdhean, east of Neist Point in Moonen Bay, Duirinish. The sill is intruded into horizontally bedded Middle Jurassic Lealt Shale Formation and overlying Valtos Sandstone Formation strata. View towards the SE.

On the west coast of Raasay, between Oskaig Point and Eilean Àird nan Gobhar, a multi-leaved sill with units composed of all of the main compositional types (8.C) is exposed (Figure 8-14); inland exposure is poor and the eastern margin of the outcrop is interpreted as a fault against Middle Jurassic Bearreraig Sandstone Formation strata (4.C) and the Raasay Granite Sill (8.E) (BGS, 2006a).

In common with exposures of picrite sills on Skye, for example at Duntulm, the Oskaig Sill is, locally, significantly weathered and susceptible to erosion, producing olivine-rich sediment, locally pebbly ((Walker, 1932); (Davidson, 1933)). Spheroidal (or onion-skin/doleritic) weathering of these more olivine-rich sills is also relatively common (Figure 8-15). Where less weathered, it is evident that the Oskaig Sill has a layered character, similar to some of the sills on Skye.

Figure 8-14 – The Oskaig Sill on the west coast of Raasay, forming the promontory of Oskaig Point, is a multiple intrusion with leaves of the main compositions (picrite, picrodolerite, olivine dolerite and crinanite), with well-developed, near-vertical prismatic joints. View towards the west, with the east coast of north Skye in the distance. Sheep for scale.

Figure 8-15 – Spheroidal (or onion-skin/doleritic) weathering of the picrite sill at Rubha nam Brathairean *c.* [NG 5267 6263] on the east side of the peninsula.

South and north of the highest point on Raasay, Dùn Caan, flat-lying sheets of dolerite and crinanite (8.C) are interpreted as sills ((Walker, 1932); (BGS, 2006a)) (Figure 8-16). The sill south of Dùn Caan is intruded along the unconformity between Middle Jurassic Lealt Shale Formation strata (4.C) and the Upper Cretaceous Morvern Greensand Formation (4.D), whereas those to the north are interpreted to been intruded into an outlier of the Skye Lava Field (5.D).

Figure 8-16 – View towards the south from the summit of Dùn Caan on Raasay, with the elongate Loch na Mna on the west (right) side of the image. The rugged crags immediately below, with the associated boulder scree, is the outcrop of a flat-lying multiple olivine dolerite sill intruded into poorly exposed Middle Jurassic Lealt Shale Formation strata.

Based upon these various lines of evidence, and by comparison with sill complexes, worldwide, (Schofield, et al., 2016) argue that growth of the Little Minch Sill Complex involved the emplacement of laterally-restricted concordant sheets of magma, which, in some instances, ultimately connected across so-called bridges, leading to broken bridges (Figure 8-7) and segments of the sills that are generally interpreted as locations where sills have migrated up- or down-sequence.

Various other minor geographically-isolated sills, typically composed of dolerite, occur in the district of Strath, intruded into pre-Paleocene strata. For example, on Strathaird, south of Elgol, a sill forms a prominent topographic feature, where it is intruded along the contact between Middle Jurassic Garantiana Clay/Shale Formation and Cullaidh Shale Formation strata (Figure 8-17)

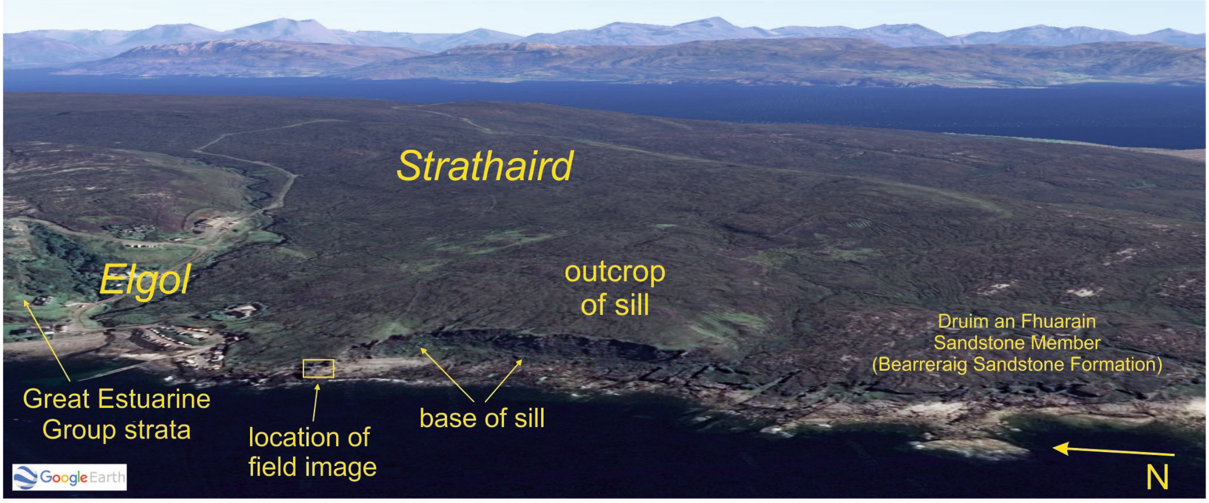


Figure 8-17 – Oblique Google Earth© image of the Elgol sill and field image of the base of the sill where in contact with the Garantiana Shale Member of the Bearreraig Sandstone Formation [NG 5154 1347]. Pole *c.* 1m long.

Internal chills between distinct units are common (Gibson & Jones, 1991), involving both compositionally similar and compositionally contrasting units. In some instances, units are separated by relatively continuous layers, or rafts, of Jurassic sedimentary rock (but see below) which, in extreme cases have been thermally metamorphosed to the extent that they started to melt, or fuse, and, upon cooling, form sheets or discrete masses of glassy material, now partially devitrified, referred to as buchites (Figure 8-18; Figure 8-19). Where these conditions of extreme temperature led to pyrometamorphism and, given an appropriately aluminous country-rock composition, minerals such as mullite, cordierite, sapphire and various Al-spinels formed.

Figure 8-18 – (a) A buchite formed by the pyrometamorphism of Middle Jurassic Duntulm Formation strata within the picrite sill north of Cairidh Ghlumaig, SW of Duntulm on Trotternish, at *c.* [NG 4099 7408], pole *c.* 1m long; and, (b) detail of the contact between the picrite sill (orange) and a buchite (pale grey), note vesiculation of the sill (right-hand side), pole *c.* 1m long.

Figure 8-19 – Buchite formed by the pyrometamorphism of folded Middle Jurassic Valtos Sandstone Formation strata (?), SE Hunish, below the Meall Tuath cliff, Trotternish, at *c.* [NG 4113 7637]. Coin *c.* 24mm across.

Stratification, or layering, or banding, is a conspicuous feature of some sills, forming relatively laterally extensive layers, for example the picrite sill below the ruins of Duntulm Castle, the sill at Rubha nam Brathairean, and the sill at Meall Tuath (Figure 8-20; Figure 8-21; Figure 8-22). Stratification commonly occurs right up to the margins of these sills and is typically enhanced by differential weathering. The mineralogical basis of the stratification is the relative proportions of mafic (olivine and clinopyroxene) and felsic (plagioclase) minerals, with the former tending to be more susceptible to weathering. Typically, each layer grades between a basal mafic mineral-rich part and an overlying felsic mineral-rich part. The textural relationships of the minerals also change within these graded layers, with the clinopyroxene involved in an ophitic relationship with plagioclase in the mafic-rich portions, through large ophitic plates mid-layer, to discrete granules in the felsic-rich portions (Gibson & Jones, 1991). Fine-scale stratification has also developed in sills adjacent to rafts of sedimentary rock and buchites, for example, within the Duntulm Castle sill.

Figure 8-20 – The layered picrite sill below the ruins of Duntulm Castle on the coast in NW Trotternish [NG 4087 7440]. Height of cliff is *c.* 20m. The layered character of the sill is due to the relative amounts of the main minerals, with dark layers dominated by olivine and pyroxene, grading into paler layers with a higher percentage of plagioclase. The castle has a long history, from the time of the Norse, through the Middle Ages when occupied by the McLeods then the MacDonalds, although the present building may date only from the 1800s.

Figure 8-21 – Detail of the layered character of the picrite sill below the ruins of Duntulm Castle (see Figure 8.20).

Figure 8-22 – Detail of the layered character of the picrite sill below the ruins of Duntulm Castle (see Figure 8.21), with a lower pale (relatively plagioclase-rich) layer overlain (with a sharp boundary/interface) with the base of a darker more olivine- and pyroxene-rich layer. Note insipient (hydrothermal) alteration along steeply inclined cooling joints. Hammer *c.* 30cm long.

A banded dyke (the so-called Mystery Dyke, possibly based upon it being a 'unique' example), with many features in common with the sills, has been briefly described from Dun Borneskitaig, near Kilmuir on the west coast of Trotternish by (Drever, 1969) (Figure 8-23; Figure 8-24). It has a N-S trend, is *c.* 1.5m wide (thick), and can be traced along trend for *c.* 60m. Parallel to the dyke margins are alternating bands dominated by (dendritic-textured) olivine and augite. A zeolite-rich central portion of olivine dolerite is particularly obvious (Figure 8-24). Its location, within the outcrop area of the Little Minch Sill complex, suggests a genetic relationship, involving some form of flow differentiation mechanism of formation.

Figure 8-23 – The N-S -trending banded/layered 'Mystery Dyke' identified by Drever (1969) on the shore west of Dun Borneskitaig, NW Trotternish [NG 3712 7160], comprising alternating bands of dendritic olivine and augite. Pole *c.* 1m long.

Figure 8-24 – Detail of the N-S -trending banded/layered 'Mystery Dyke' identified by Drever (1969) on the shore west of Dun Borneskitaig, NW Trotternish [NG 3712 7160], comprising the central zeolitised olivine dolerite portion. Ruler 30cm long.

8.C The Magmatic Evolution of the Little Minch Sill Complex

(Walker, 1932), (Anderson & Dunham, 1966) and (Gibson & Jones, 1991) identify five distinct rock compositions of sills (or leaves, or units) within the sill complex: (1) olivine dolerite (for example, the sill at the Loch Mealt waterfall, the so-called Kilt Rock); (2) marginal tachylitic and crystalline basaltic variants (the upper contact of the lower sill at Rubha Hunish); (3) picrite (40-60% olivine) and picrodolerite (10-20% olivine) (Ru Bornesketaig, Kilmuir); (4) crinanite (analcime-bearing alkali basalt/dolerite) and teschenite (alkaline basalt/dolerite with less than 5% olivine) variants (the lower sill at Rubha Hunish and the sill at Tulm Bay, north of Duntulm); and, (5) pegmatites, dominated by clinopyroxene and plagioclase, within the dolerites (for example, the Kilt Rock Sill) and within many of the picrite and picrodolerite sills. All five rock-type groups contain varying amounts of: forsteritic olivine (*c.* Fo_{80}), diopsidic augite, calcic plagioclase (*c.* An_{60-30}), chrome-spinel, Fe-Ti oxides and zeolites (analcime and thomsonite). Where augite and plagioclase dominate the rock-types are (1) and (2), grading into (3) with higher olivine content, and (4), where zeolites become significant. The development of (5) appears to have been more specific, being dependent upon the build-up of volatiles during late-stage crystallisation processes.

Figure 8-25 illustrates the distribution and contact relationships of picrite, picrodolerite and crinanite units throughout Trotternish. Over much of the peninsula, a picrite unit is prominent, up to 50m thick, and commonly in contact with an overlying picrodolerite unit, giving rise to so-called multiple sills. Typically, in such multiple sills, the structurally lower unit is of picrite, with picrodolerite or other more evolved lithologies (e.g. crinanite) forming the structurally higher (i.e. overlying) unit. Upper picrite units are absent, most likely due to erosion.

(Walker, 1932) suggested that variations in composition throughout the sill complex could be attributed to *in situ* crystal-liquid fractionation by gravitational settling of early precipitated crystals. However, (Anderson & Dunham, 1966) concluded that there is little good mineralogical evidence for this model, although they do propose that the variations in mineralogy between individual sills throughout the district may be the result of such processes having operated in a magma chamber (but with no direct evidence of its existence) at depth.

In a subsequent re-investigation of these associations, (Simkin, 1967) proposed that some form of flow differentiation process has taken place. As magma was injected along flat-lying fissures, phenocrysts would move towards the centre of the conduit and there would be rapid chilling of magma at the fissure margins, resulting in the tachylitic and basaltic marginal facies of some sills. The porphyritic magma within the central portion of the conduit, when spreading out laterally, would be influenced by gravity and hence facilitate the formation of olivine cumulates (i.e. the picrites and picrodolerites).

(Gibson & Jones, 1991) concluded that the textural characteristics of the graded layers indicate that much, if not all, of the crystallisation was *in situ*, with no field-scale or microscopic textural evidence for crystal-settling processes. Cryptic mineral variation has not been recognised. Most of the recognised mineral textures, such as elongate plagioclase crystals and swallow-tail terminations of clinopyroxene crystals, indicate rapid cooling and crystal growth. As relatively rapid cooling of individual units occurred, the large thermal contrast between each unit and its country-rocks (either Jurassic strata or already-crystallised sills) would have significantly influenced the order of formation and the textural characteristics of the crystallising minerals. As certain minerals crystallised, for example olivine and clinopyroxene, the magma would be depleted in the components needed for their formation, ultimately (but) temporarily halting their precipitation and causing plagioclase to crystallise. This cycle of selective crystallisation would repeat, resulting in the many mineralogically-graded layers preserved in certain sills.

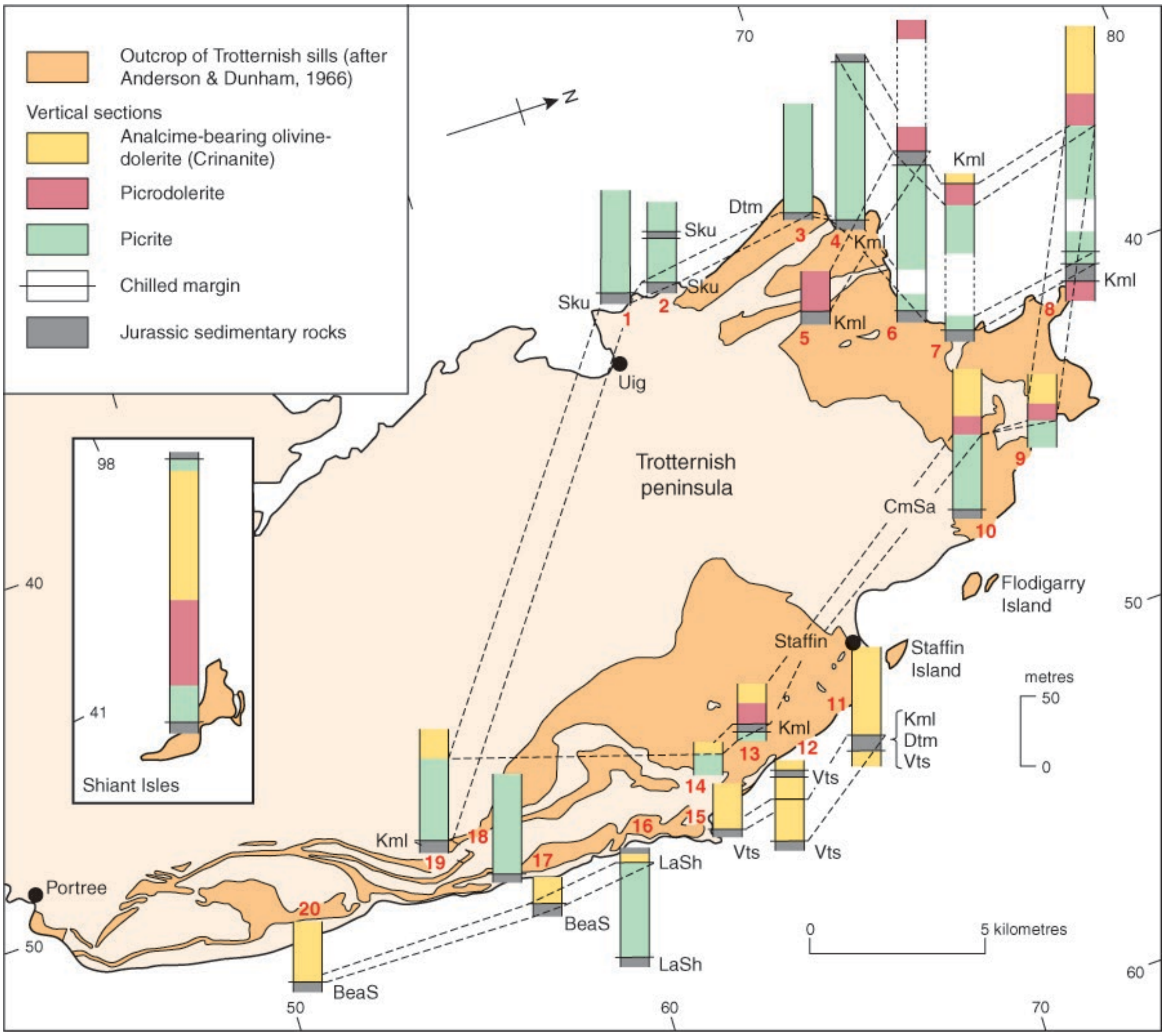


Figure 8-25 – Igneous stratigraphy of the Little Minch Sill Complex at selected localities on Trotternish and the Shiant Isles. Country-rock Jurassic strata (undifferentiated) are also indicated. Based on Gibson & Jones (1991) and Emeleus & Bell (2005). Key to localities: 1: Skudiburgh; 2: Kilbride Point; 3: Sgeir Lang; 4: Bornesketaig; 5: Heribusta; 6: Osmigarry; 7: Creagan Iar; 8: Meall Tuath; 9: Balmaqueen; 10: Flodigarry; 11: Staffin; 12: Loch Mealt; 13: Dùn Raisaburgh; 14: Culnaknock; 15: Dùn Connavern; 16: Inver Tote; 17: Leac Tressirnish; 18: Rigg; 19: Tottrome; 20: Bearreraig Bay. Jurassic sedimentary rocks: BeaS: Bearreraig Sandstone Formation; LaSh: Lealt Shale Formation; Vts: Valtos Sandstone Formation; Dtm: Duntulm Formation; Kml: Kilmaluag Formation; Sku: Skudiburgh Formation; CmSa: Carn Mor Sandstone Formation.

Pegmatites and localised veins are interpreted as the products of relatively late-stage interstitial melts that have amalgamated by some form of filter-press mechanism involving (gravity-driven) compaction, as they are expelled from the dominant, already-crystallised crystal framework of the cooling sills (Figure 8-26; Figure 8-27). Low-temperature late-stage minerals, such as zeolites, formed in response to elevated H_2O contents.

Figure 8-26 – Near-horizontal gabbro pegmatite layers in the picrite sill north of where the Lealt River enters the sea at Inver Tote on the east coast of Trotternish [NG 5203 6060]. The main minerals within the pegmatite are clinopyroxene and plagioclase. Pole *c.* 1m long.

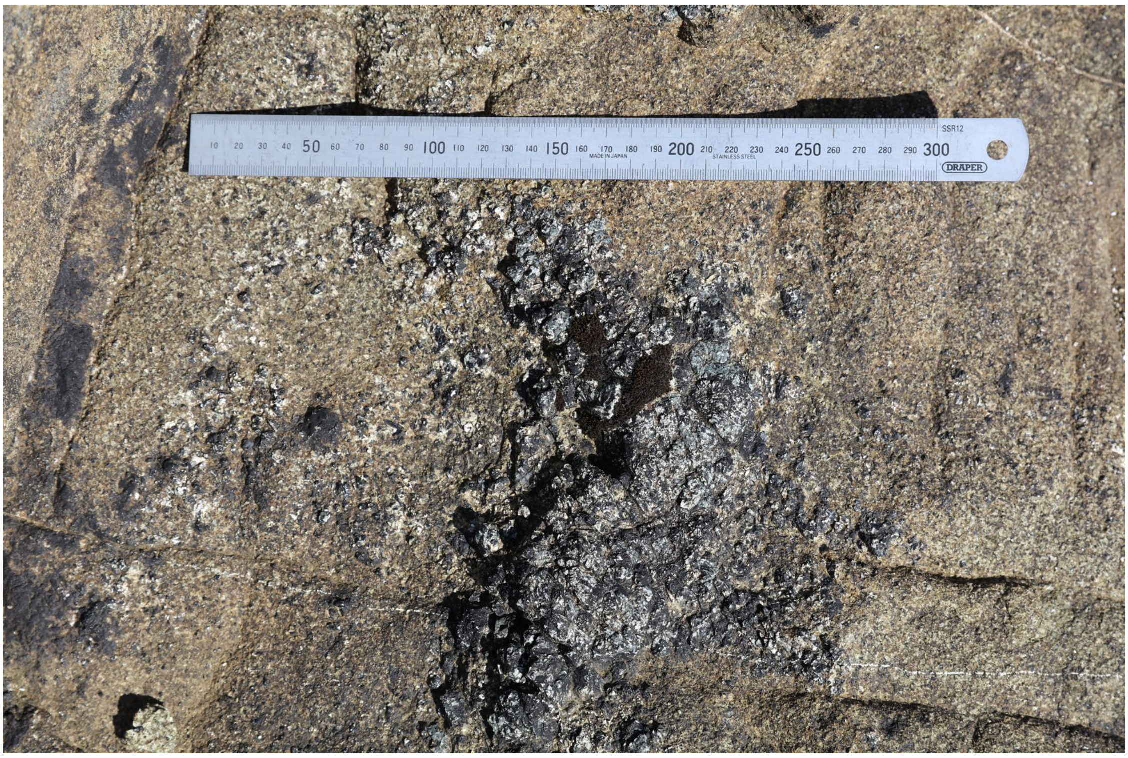


Figure 8-27 – An irregular patch of gabbro pegmatite within the Oskaig Sill on the west coast of Raasay, forming the promontory of Oskaig Point. Ruler 30cm long.

(Gibson & Jones, 1991) have outlined the geochemical evolution of the sills. They identify that the parental magma was an alkali olivine basalt with *c.* 10% MgO. Fractional crystallisation of such a magma in upper crustal magma chambers, together with various differentiation processes during sill emplacement and crystallisation (see above), enabled the various mineralogical and textural variants (picrite, picrodolerite etc.) to form. The similarity of olivine compositions in different lithologies, for example the picrites and the crinanites, suggests that they have a common source and have not necessarily crystallised as part of the intrusion in which they occur.

Emplacement of the sills appears to have been a complex, discontinuous process((Gibson & Jones, 1991); (Holness, et al., 2017)). As magma was withdrawn from a deeper-level, compositionally-zoned, storage and processing chamber, the rate of discharge may have been critical, with high discharge rates favouring olivine-rich magmas, i.e. with accumulative olivine. The field evidence suggests that such olivine-rich magma was withdrawn first from the chamber (or chambers) and emplaced as early picrite and picrodolerite sills. A reduction in the (magma) withdrawal rate would enable the ascent of the olivine-poor magmas that crystallised to form the olivine dolerite, crinanite and teschenite sills. Essentially, the picrites may represent magmas that have accumulated olivine, and the crinanites and teschenites represent magmas that have lost, or fractionated, olivine. The role of crystal setting is less clear and will be influenced by many factors, including: the percentage of phenocrysts in the magma, the rate of magma emplacement, the geometry (including thickness) of the sill; and, the rate of heat loss and crystallisation history of the magma.

(Gibson, 1990) provides further details of the geochemical evolution of the Little Minch Sill Complex. Similarities between the identified alkali olivine basalt parental magma (see above) and the parental magma(s) of the Skye Main Lava Series are noted (Chapter 5). The most compositionally-evolved sills, the crinanites and teschenites, are the most (crustal) contaminated, as indicated by their disturbed radiogenic isotope signatures, involving the assimilation of amphibolite facies basement gneiss of the Lewisian Gneiss Complex (3.B) during fractional crystallisation of the parental magma, so-called assimilation-during-fractional-crystallisation (or AFC).

8.D The Gars-bheinn Ultrabasic Sill

The Gars-bheinn Ultrabasic Sill crops out on the southern side of Gars-bheinn, at *c.* 300m OD in the southern part of the Cuillin Hills and has been described in detail by (Weedon, 1960) and (Bevan & Hutchison, 1984) (Figure 8-28). It extends for *c.* 300m from east-to-west and is composed of feldspathic peridotite, with the upper 15m of this 80m-thick intrusion comprising alternating layers or bands of plagioclase-rich pegmatitic material (Figure 8-29; Figure 8-30). The sill is intruded into Paleocene lavas (5.D) and a possible feeder dyke cuts the underlying Torridonian strata (3.C). The base of the sill is not exposed, although the lower portion appears to be connected to the inferred feeder dyke. Marginal chill facies are present but are not obvious in the field.

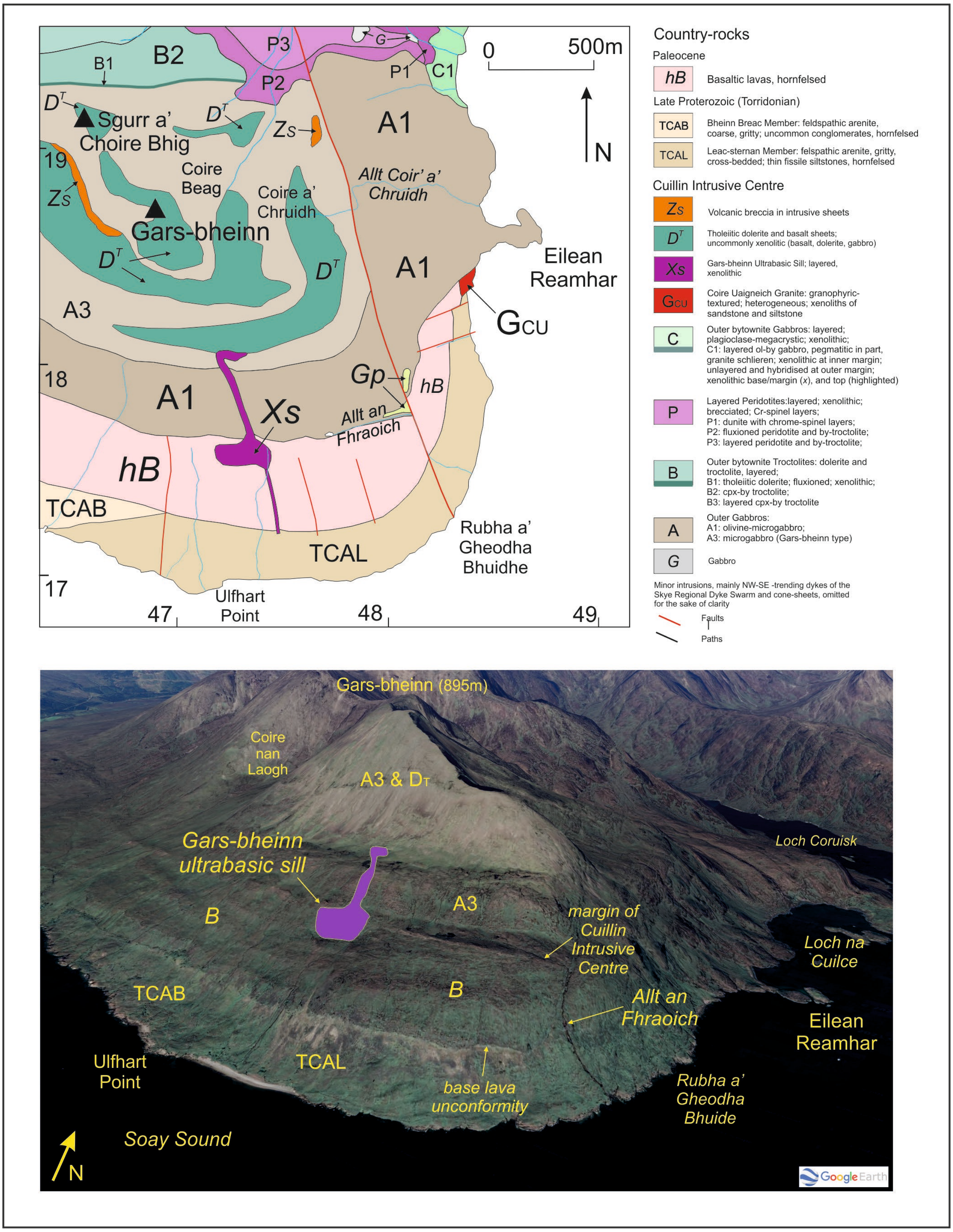


Figure 8-28 – Oblique Google Earth© image and simplified geological map illustrating the location of the Gars-bheinn Ultrabasic Sill on the south side of the mountain of that name.

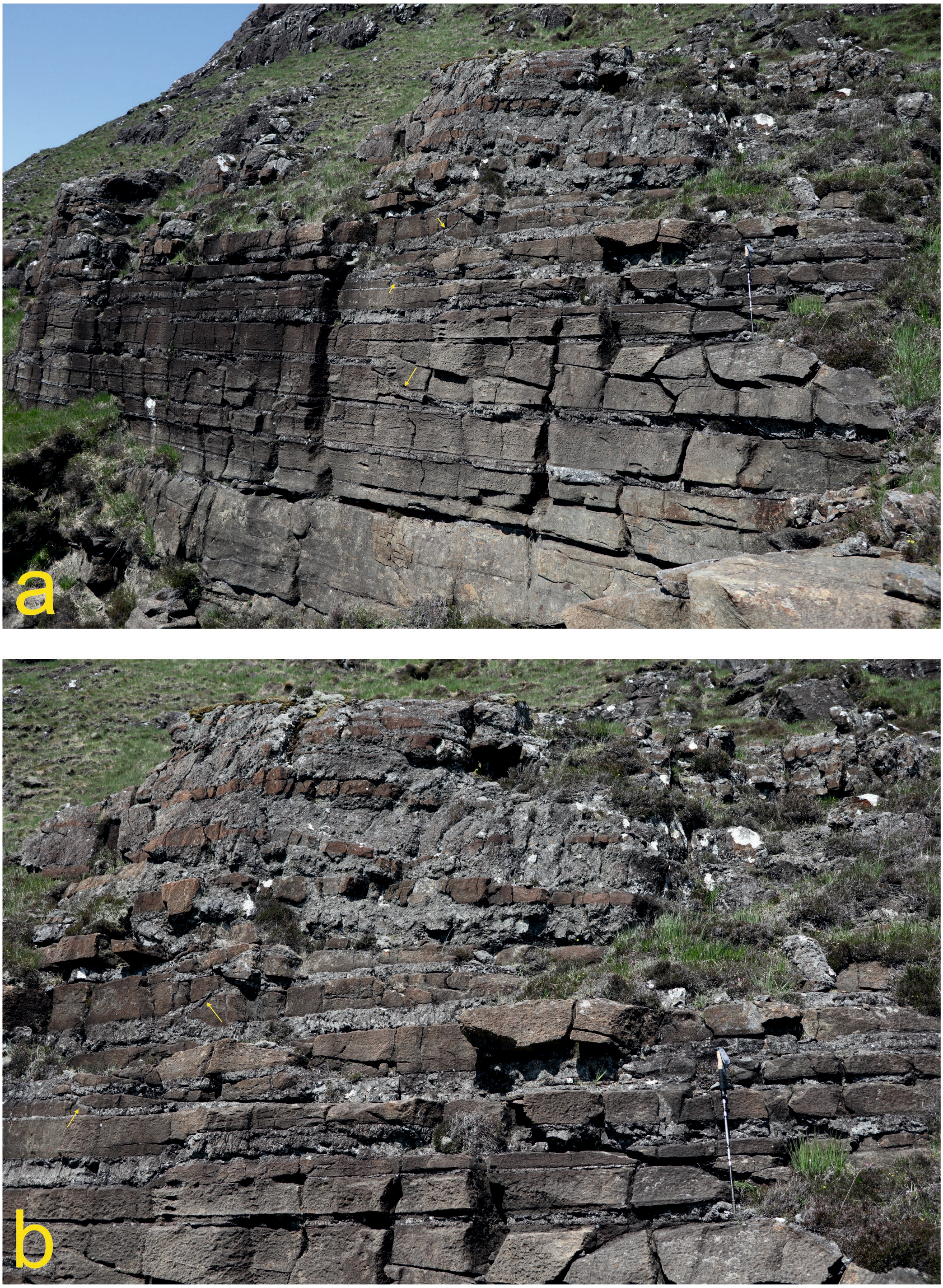


Figure 8-29 – Field images of the upper part of the Gars-bheinn Ultrabasic Sill, with pale, pegmatoid, plagioclase-rich layers within dark (orange) feldspathic peridotite ('host'). Arrows indicate locations where pegmatoid layers appear to be transgressive with respect to the near-horizontal stratification of the dark feldspathic peridotite. Pole *c.* 1m long.

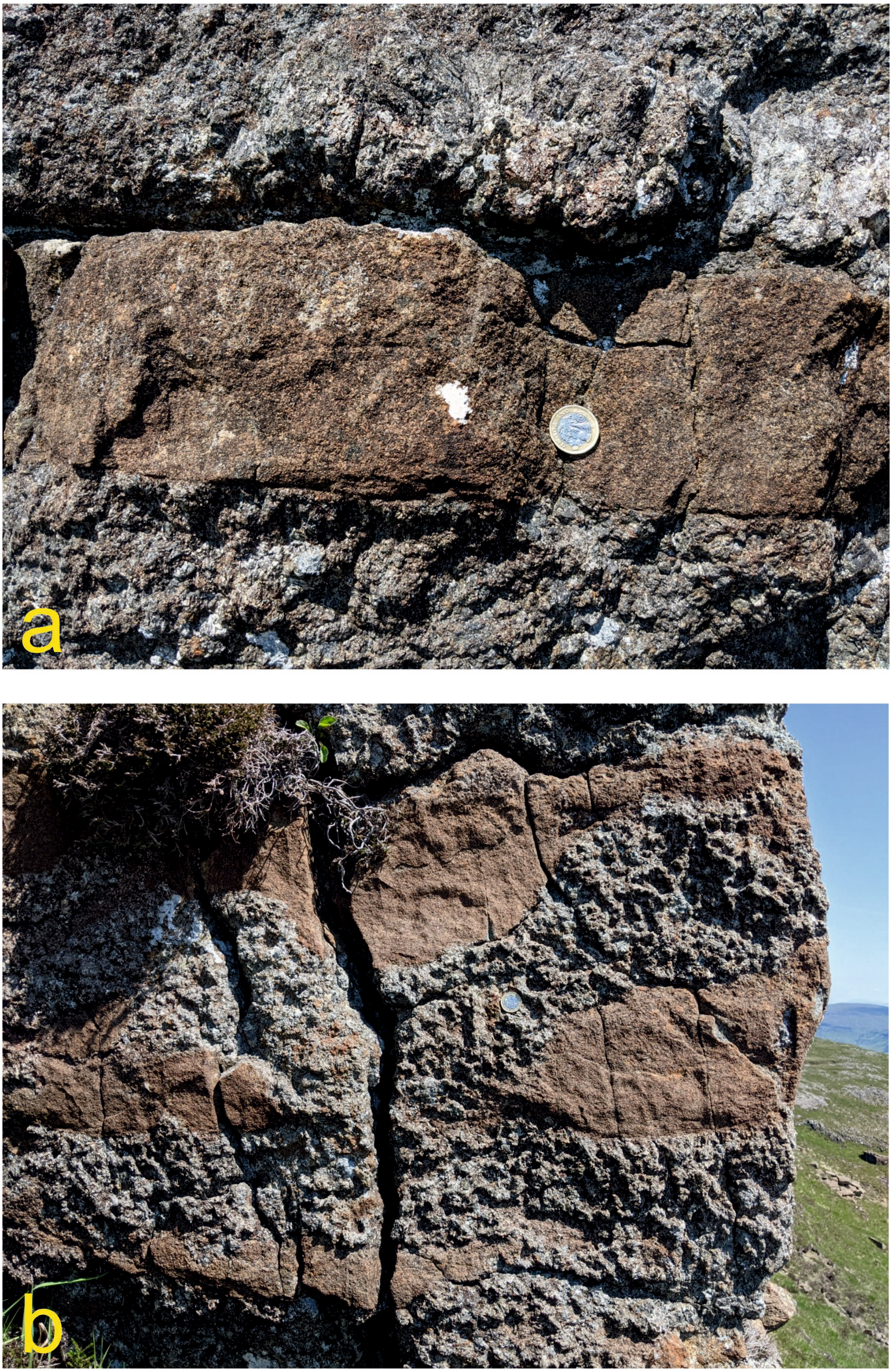


Figure 8-30 – Field images of the Gars-bheinn Ultrabasic Sill, with pale, pegmatoid, plagioclase-rich layers within disrupted/segmented layers of dark (orange) feldspathic peridotite. Coin *c.* 24mm across.

The plagioclase-rich layers in the upper part of the sill commonly show a pegmatoid texture, with individual crystals extending across the complete thickness of individual layers (1–2cm). Clinopyroxene is interstitial to the plagioclase. Plagioclase crystals in these layers have compositions similar to those in the non-layered main (lower part) of the intrusion. Individual layers are thicker, up-sequence. The olivine-rich layers contain interstitial plagioclase and an Fe-rich clinopyroxene.

Compositional data from the chilled marginal facies of the dyke located below the sill indicate a parental picritic magma (Weedon, 1960), with affinities to some of the ultrabasic dykes (7.C) associated with the Cuillin Intrusive Centre (6.B). Within the upper part of the sill, some olivine-rich layers have mineralogical and petrological features in common with these ultrabasic dykes.

According to (Weedon, 1960), the formation of the sill, including the well-developed layers in the upper part and the presence of pegmatoid structures in the plagioclase-rich portions, was dominated by crystal-liquid fractionation processes involving crystal settling. The main portion of the sill, consisting of unlayered feldspathic peridotite, was formed by gravitational settling of olivine crystals and intercumulus growth of plagioclase and clinopyroxene. Any liquid not involved in this intercumulus growth process was removed, by diffusion, compaction or convective mechanisms, thus enriching the magma above the crystal-liquid interface in Ca, Al, K, Na and volatiles, capable of crystallising the pegmatoidal plagioclase-rich layers, referred to above. Further cumulus growth of olivine within unfractionated magma would give rise to the subsequent olivine-rich layer. This process was repeated several times. Increases in the thicknesses of individual plagioclase-rich layers, ‘up sequence’, may be attributed to an overall build-up of volatiles within the residual magma. The model of (Weedon, 1960), therefore, is temperature-independent and strongly controlled by local variations in magma composition.

On the basis of a detailed re-investigation of the field relationships and mineralogy of the sill, (Bevan & Hutchison, 1984) describe cross-cutting and near-vertical attitudes to the pegmatitic material and conclude that these coarse-grained, plagioclase-rich layers were introduced in the form of high-temperature fluid 'sills' that were injected into already-consolidated peridotite. These sills appear to be related to the magma which crystallised to form the outer (bytownite-)gabbroic unit(s) of the Cuillin Intrusive Centre (6.B) and are not co-genetic with the peridotite portions of the sill. Similar pegmatitic material occurs within nearby hornfelsed lavas (6.D).

8.E The Raasay Granite Sill

The Raasay Granite Sill crops out over a significant part of the southern half of Raasay (Figure 6-7) and is the only unequivocal significant concordant granitic intrusion in the Skye-Raasay area. In key publications on the igneous geology of Raasay (for example, (Davidson, 1935)) it is referred to as a granophyre sill on the basis of the common development of its two key minerals, quartz and alkali feldspar, in a distinctive texture referred to as a granophyric intergrowth, or texture. Quartz and alkali feldspar are also present as phenocrysts, typically up to 5mm, and the main ferromagnesian mineral is the alkali-rich amphibole, riebeckite, blue when fresh, but typically weathered to a rusty brown on most surfaces. Close to non-faulted contacts, the granite tends to be relatively fine-grained, essentially a very pale microgranite or felsite (Figure 8-32). Some of the uncommon apophyses of the granite have a spherultic texture, indicating rapid cooling of the granitic magma. Near Loch Storab, relatively close to the centre of the northern outcrop (see below), auto-intrusive veins of the microgranite/felsite, up to *c.* 30cm across, contain needles of riebeckite. In the same area, the granite is a host to veins contains cavities (druses) with faceted crystals of quartz, alkali feldspar and riebeckite (Davidson, 1935), implying relatively low-pressure crystallisation at a shallow depth below the contemporaneous land surface.

Figure 8-31 – Field view of the Rassay Granite Sill from Maol na Gainmhich on Skye. The pale sill forms the obvious crags above the coast and is underlain by dark Lower Jurassic Pabay Shale Formation strata. View towards the north.

Figure 8-32 – The near-horizontal, fine-grained, lower contact of the southern outcrop of the pale-weathering Raasay Granite Sill, intruded into dark Lower Jurassic Pabay Shale Formation strata (now hornfelsed), on the landward side of the road at Suisnish Point, at *c.* [NG 5534 3469]. Pole *c.* 1m long.

Two main outcrops are recognised, together with several small, isolated masses (due to present-day erosion). The smaller southernmost outcrop is located in the area between Inverarish and Suisnish and has the more complex contacts, in place relatively concordant with its country-rocks, predominantly Triassic and Lower Jurassic Ardnish Formation and Pabay Shale Formation strata (4.B; 4.C) (Figure 8-32), whereas its contacts with Torridonian strata (3.C) are interpreted as faults (BGS, 2006a).

The northern outcrop in intruded at the stratigraphic level between the Middle Jurassic Bearreraig Sandstone Formation and the Great Estuarine Group (4.C). Along its eastern margin, this outcrop of the granite has a faulted contact, predominantly against basaltic lavas (5.D), with an escarpment trending NNW-SSE and giving rise to the elongate Loch na Meilich (Figure 8-33) and Loch na Mna.

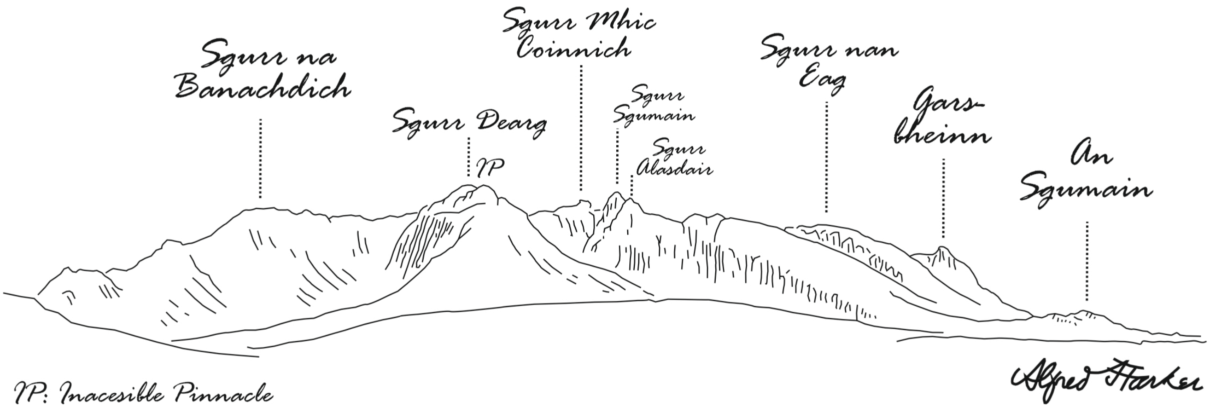
Figure 8-33 – Escarpment of the Raasay Granite Sill (on left), in faulted contact with more easily-eroded Middle Jurassic Bearreraig Sandstone Formation strata (on right). The elongate Loch na Meilich is located on the Jurassic rocks. View from south of the path at Bealach Ruadh, at *c.* [NG 5760 3928], towards the north.

Much of both outcrops of the sill are relatively well exposed, although where poorly exposed the sparse vegetation that grows on the granite enables it to be defined relatively easily (Figure 8-34).

Figure 8-34 – Typical level of exposure of the Raasay Granite Sill. View from near the path at Bealach Ruadh at *c.* [NG 5760 3928] towards the NW. In the distance, across the Sound of Raasay, is Ben Tianavaig (south of Portree Bay), comprising landslipped Paleocene lavas overlying Lower and Middle Jurassic strata.

Chapter 9 Late Palaeogene and Neogene

Following the Paleocene magmatic events, much of NW Scotland underwent significant weathering and erosion during the Eocene, Oligocene, Miocene and Pliocene epochs (55-2.5 Ma). As the volcanic edifices, now represented by the exhumed intrusive centres, and the lava field were downwasted, significant material was shed into adjacent basins.



An absolute age, or date, for the cessation of magmatic activity on Skye is yet to be agreed ((Emeleus & Bell, 2005)). A radiometric age as young as 55.7 Ma has been determined for a late-stage vitrophyre ('pitchstone') dyke that cuts the Beinn na Caillich Granite, in the Eastern Red Hills Intrusive Centre (Chapter 6) and an age of 55.89 ± 0.15 Ma for the nearby Beinn an Dubhaich Granite appears to confirm the interpreted late-stage chronology of these intrusive units (Emeleus & Bell, 2005).

Application of low-temperature thermochronology techniques provides some constraints on the cooling history of the igneous units (Dobson, et al., 1990), whereby their cooling history, together with the timing of any uplift and erosion events, can be estimated. Specifically, (U-Th)/He data from zircon crystals and apatite fission-track data from many of the intrusive units, which constrain when these rocks cooled to a temperature below *c.* 110°C, yield near-identical ages to the crystallisation ages. Consequently, we may deduce that the Paleocene intrusions cooled very rapidly, most likely involving contemporaneous uplift and erosion, although any estimate as to how close to the Earth's surface these rocks were when they locked in their low-temperature cooling age will depend upon, amongst other factors, the geothermal gradient at the time.

Indirect corroborative evidence for the rapid erosion of the volcanic edifices of the province is outlined in 5.D, whereby the Minginish Conglomerate Formation within the Skye lava sequence contains exotic and distinctive clasts of various extrusive and intrusive lithologies derived by the unroofing of the Rum Volcano to the south (Figure 5-35; Figure 5-38; Figure 5-39) (Williamson & Bell, 1994). At a later stage in the development of the lava field, a significant erosional topography developed, with steep-sided river valleys that were subsequently infilled by a lava derived from the relatively late-stage Cuillin Volcano (Figure 5-50), now represented by the unroofed Cuillin Intrusive Centre (Bell & Williamson, 2013) (6.B).

However, apatite fission track data for certain small-volume intrusions, for example the various units of the Marscoite Suite of the Western Red Hills Intrusive Centre (6.F.6), give a mid-Eocene cooling age, *c.* 45-47 Ma (Dobson, et al., 1990), suggesting continued high, but sub-magmatic, temperatures, or a discrete pulse of heat at this time. This age, of interest, correlates well with a relatively well-determined $^{40}Ar/^{39}Ar$ plateau (crystallisation) age of *c.* 45 Ma for the late-stage xenolithic Loch Roag dyke (Faithfull, et al., 2012), a monchquite (an alkali-rich basic igneous rock with phenocrysts of clinopyroxene and biotite), interpreted to be the product of small degrees of mantle melting, which intrudes the basement Lewisian Gneiss Complex on the Isle of Lewis, to the NW, and which is on-trend with other intrusions of the Skye Regional Dyke Swarm (7.B). Thereafter, the constructional geological record on Skye goes quiet as ocean floor spreading gets underway in the NE Atlantic Ocean and the continental lithospheric plate that includes Greenland drifts north-westwards.

Following on from the Paleocene magmatic events, a protracted period of intense weathering and erosion occurs, starting in early Eocene times (*c.* 56 Ma), coincident with the short-lived Paleocene-Eocene Thermal Maximum (PETM) (Kennett & Stott, 1991), when the global average temperature was more than 8°C warmer than today, through the Eocene (*c.* 56-34 Ma) and Oligocene (*c.* 34-23 Ma) epochs, into the Neogene Period, which consists of the Miocene (*c.* 23-5.3 Ma) and Pliocene (*c.* 5.3-2.6 Ma) epochs (Figure 9-1). Preserved examples of Eocene to Pliocene weathering profiles include: deeply-inweathered dolerite dykes; the ferrodiorite unit of the Marscoite Suite of the Western Red Hills Intrusive Centre (6.F.6) (Figure 9-2) and, deeply-weathered gabbro in Coire na Banachdich in the Cuillin Hills. It is possible that the large landslipped masses at The Storr and The Quiraing in north Skye (10.G) started to develop during this period.

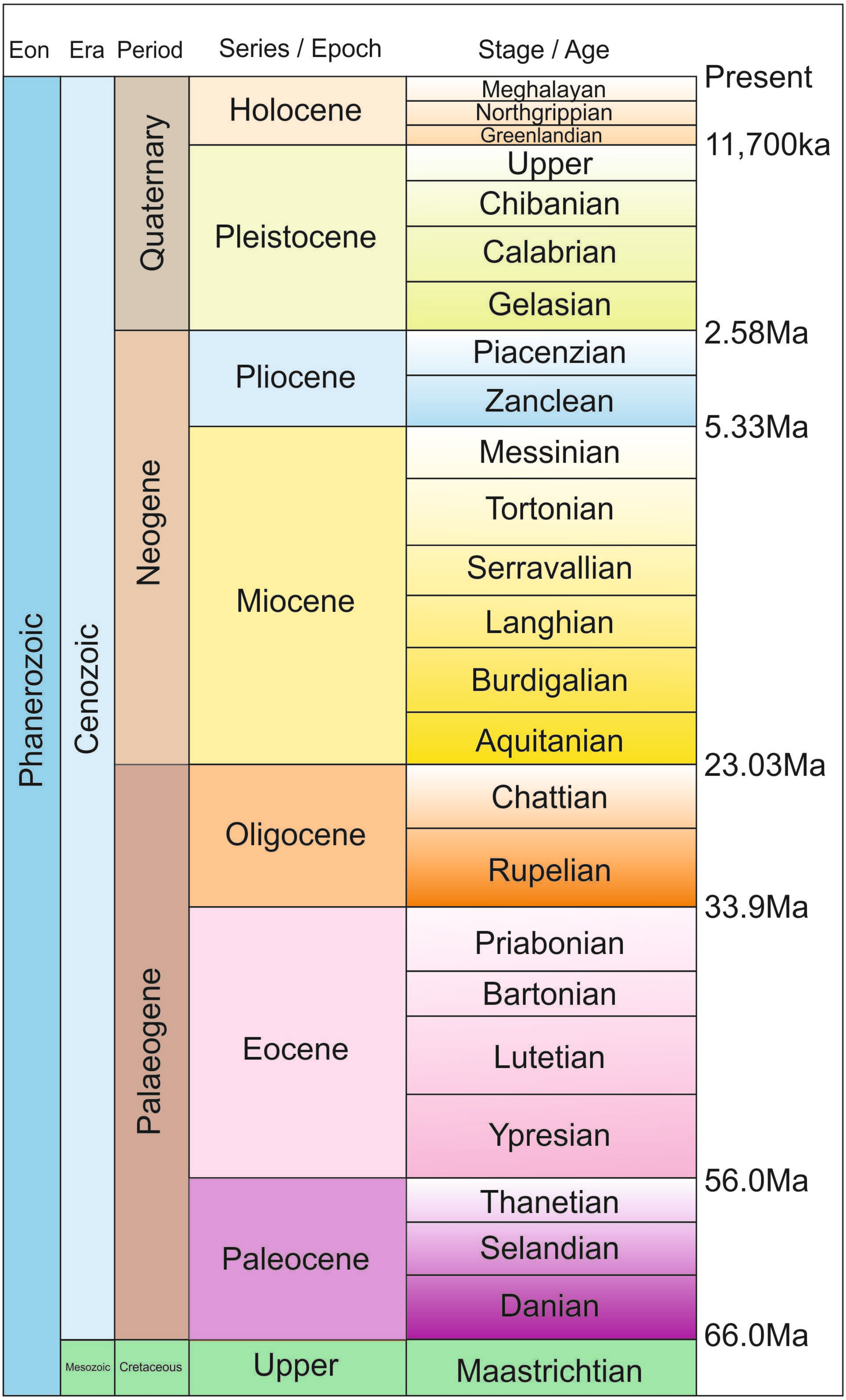


Figure 9-1 – Cenozoic chronostratigraphy.

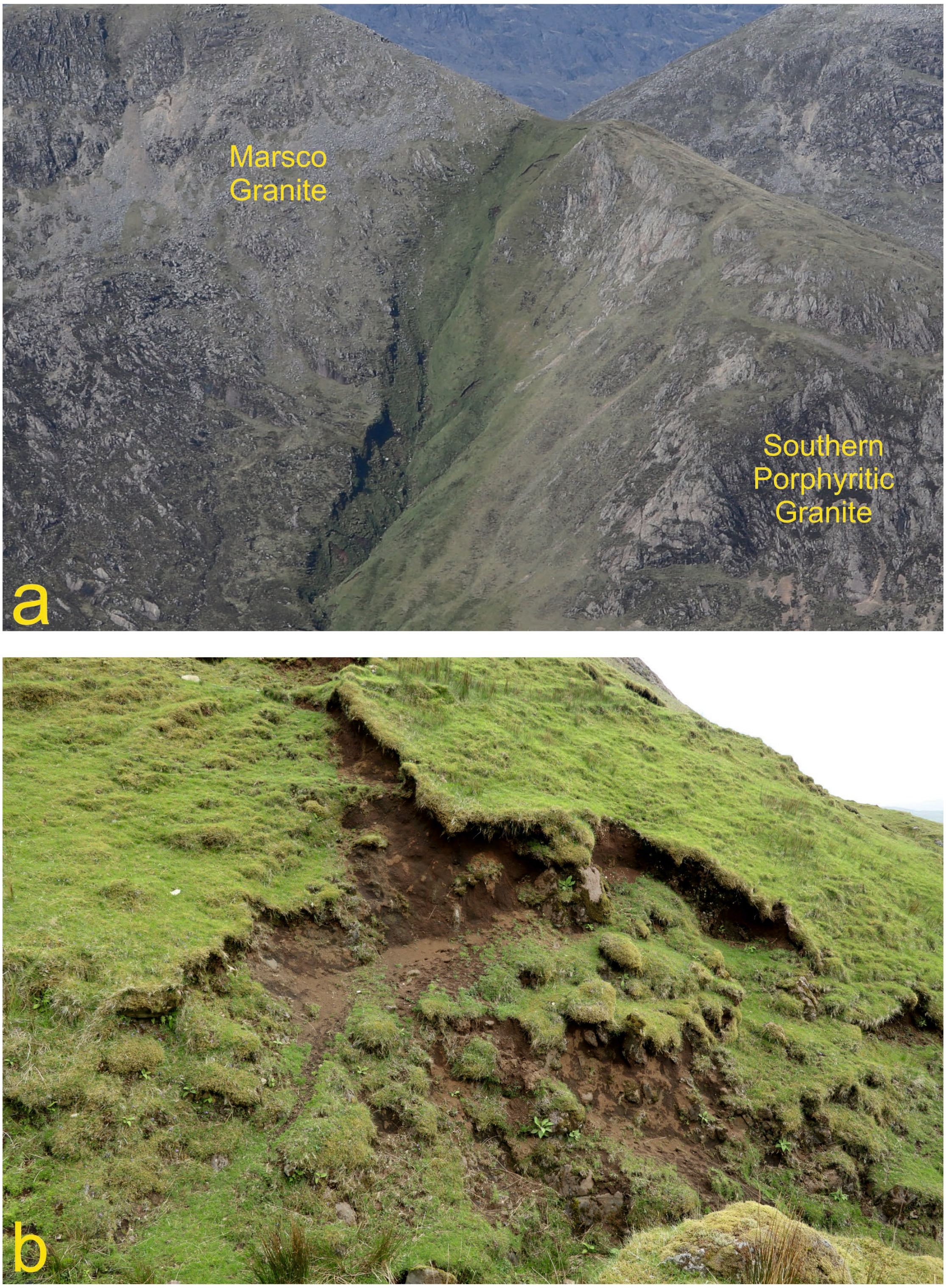
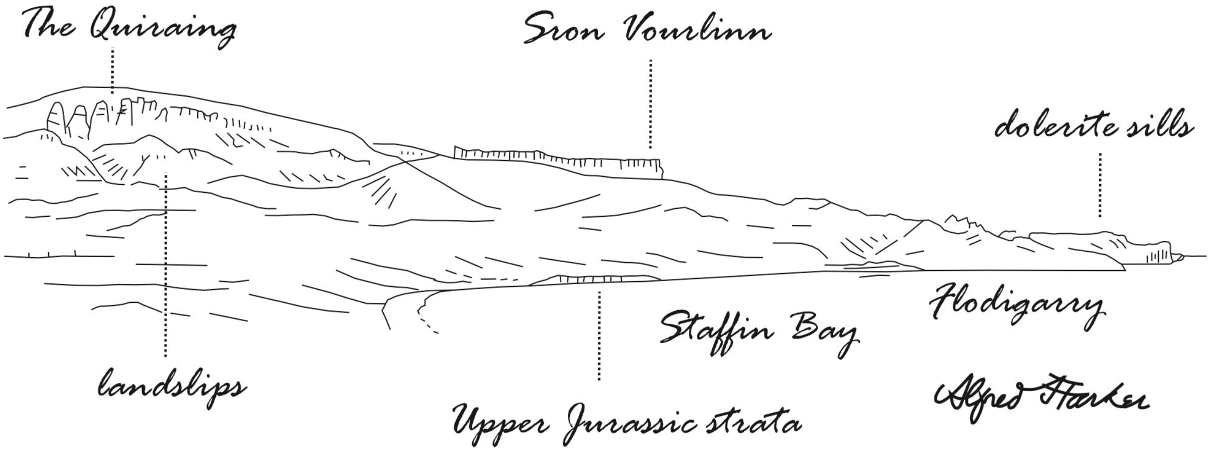


Figure 9-2 – (a) Outcrop of the Marscoite Suite of the Western Red Hills Intrusive Centre, forming a prominent verdant gully on the east side of Druim Eadar Dà Choire; and, (b) detail of the deeply weathered ferrodiorite unit of the Marscoite Suite within the gully.

Cooling intensified at around 2.6 Ma and culminated with the onset of the so-called Ice Age (Ballantyne & Lowe, 2016), which marks the beginning of the present period, the Quaternary, comprising the Pleistocene (2.6 Ma – 11,700 yr BP) and Holocene (11,700 yr BP to today) epochs. These glacial and associated inter-glacial processes and events are considered in detail in Chapter 10.

Chapter 10 The Quaternary Period

At the beginning of the Quaternary Period (c. 2.5 Ma), and throughout the Pleistocene Epoch, the climate deteriorated significantly, heralding repeated glaciations interspersed by warmer intervals when glaciers retreated. The final glacial event ended at c. 11,700 yr BP and the climate throughout the succeeding Holocene Epoch has been one of mild and generally wet conditions influenced by proximity to the North Atlantic Ocean.



10.A Introduction

The Quaternary Period is formally subdivided into the Pleistocene (2.6 Ma – 11.7 ka (or 11,700 yr BP) (BP, before present)) and the Holocene (11.7 ka to the present-day) epochs. Repeated (periods of) glaciation, referred to as stades, and intervening ('complementary') interstades of milder climatic conditions throughout the Pleistocene Epoch played a significant role in sculpting the landscape of Scotland, including the western seaboard, to its present-day appearance. However, as with any protracted period of glaciation, details of early events are commonly and relatively easily overprinted and obscured by younger events (Ballantyne & Lowe, 2016).

Consequently, we have a relatively good understanding of the advance and retreat of the last major ice sheet, which developed during a time interval referred to as the Last (or Late) Glacial Maximum (LGM), or Dimlington Stadial, and later (younger), but smaller, glacial readvancements (Loch Lomond Stadial or Younger Drias) (Figure 10-1). This last major ice sheet reached west to the Atlantic shelf edge, *c.* 150km west of Skye, during which the whole of Skye and Raasay were covered by glacier ice.

The LGM, from *c.* 31 ka to *c.* 14.7 ka, was the last time within the more protracted Last Glacial Period (LGP), also referred to as the Devensian Stage, *c.* 116 ka – *c.* 11.7 ka, that ice-sheets covered much of North America and Northern Europe, causing profound changes to Earth's climate, including a large drop in sea-level, drought, and desertification. The LGP in the British Isles occurred after the Eemian Interstadial (*c.* 130 ka to *c.* 115 ka). During the LGP there was several episodes or periods of glacial advance and glacial retreat.

Following the LGM, there was a period of climate amelioration, referred to as the Late Glacial (or Windermere) Interstadial (*c.* 14.7 ka – *c.* 12.9 ka) succeeded by the Loch Lomond (or Younger Drias) Stadial (*c.* 12.9 ka – *c.* 11.7 ka) (Figure 10-1).

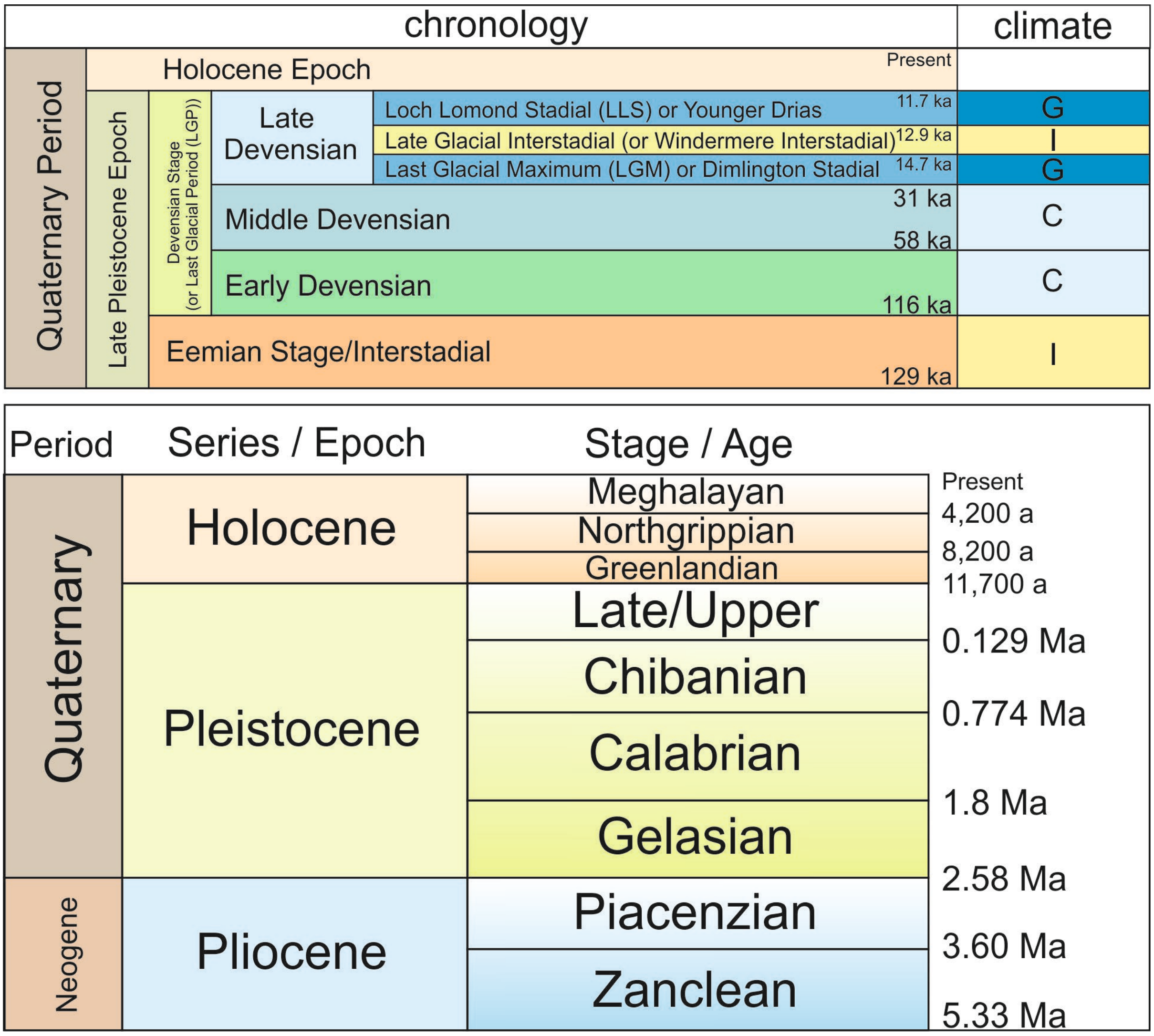


Figure 10-1 – Subdivisions of the Quaternary Period. Climate conditions: G, glacial; I, interglacial; C, cold conditions, with possible glacial and interglacial periods.

In particular, the last of the ice-sheet glaciations, the Late Glacial Maximum during the Late Devensian (Figure 10-1), involved a discrete ice field or dome that deflected westward-migrating ice from the Scottish Mainland and fed ice into the so-called Minch Ice Stream (Ballantyne & Lowe, 2016). During the last gasp of the ice-dominated Pleistocene World, Skye appears to have maintained a stranded, independent ice field that underwent one or more readvances. During the so-called Loch Lomond (or Younger Drias) Stadial, from 12.9 to 11.7 ka, a glacier developed on the Cuillin Hills, together with many small corrie glaciers, ultimately leading to the deposition of substantial and well-preserved moraines.

During the original geological survey of Skye, Alfred Harker produced an interpretation that has largely stood the test of time, in which he recognised glacial events that can be attributed to mainland-derived ice, as well as a more localised younger glacial event that developed on Skye (Harker, 1901) (Figure 10-2).

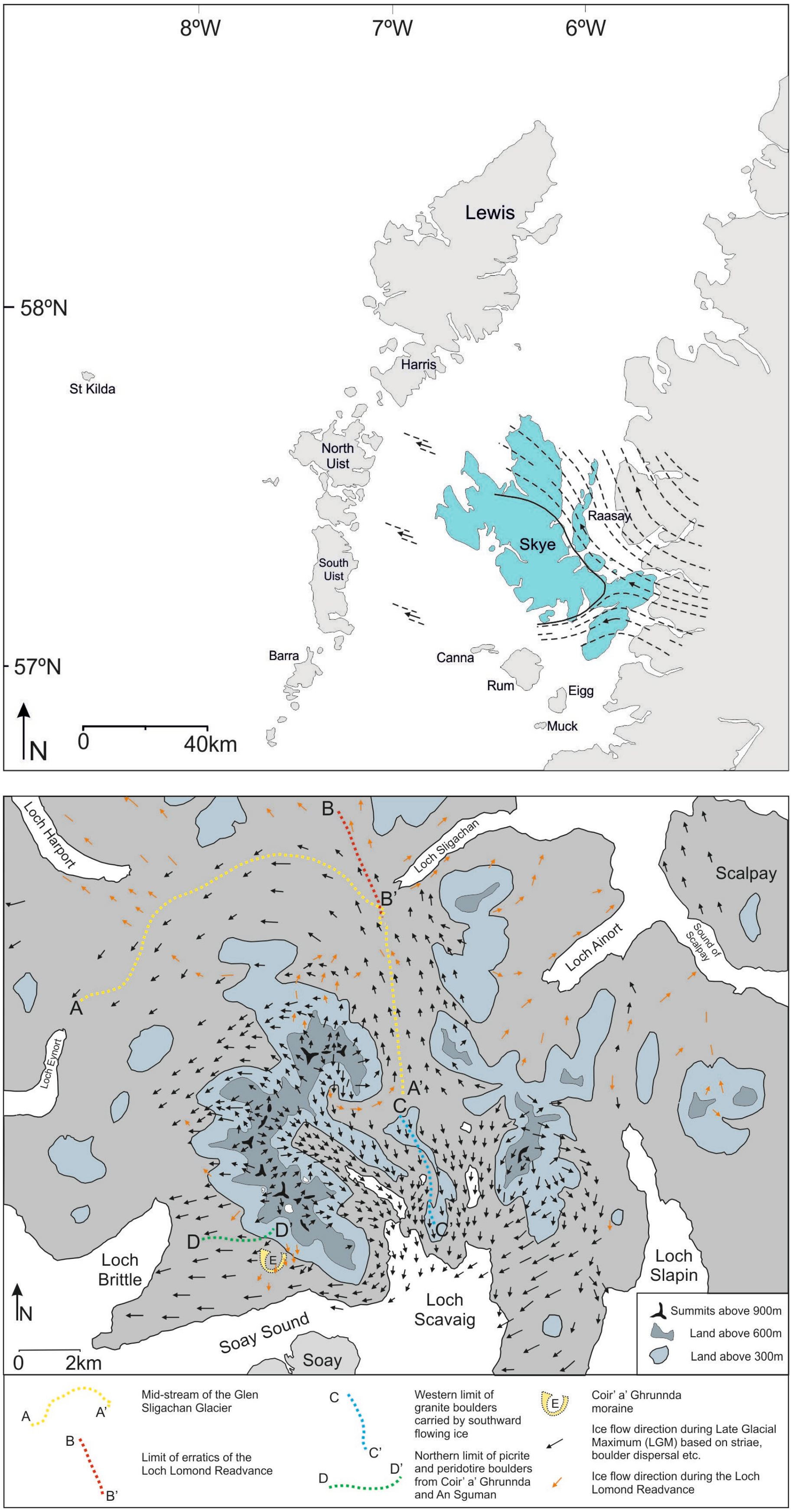


Figure 10-2 – (a) Harker's (1901) sketch map illustrating his interpretation of how the Mainland-derived ('foreign') ice flow was deflected by the Skye-centric ('native') ice field; and, (b) Harker's (1901) sketch map illustrating the central part of Skye and its glacially-related features.

Skye displays many exceptional glacigenic landforms (corries, arêtes, horns (or pyramidal peaks), roche moutonnées, rock steps (or corrie lips), striae/striations etc.) (Figure 10-3; Figure 10-4; Figure 10-5; Figure 10-6; Figure 10-7; Figure 10-8; Figure 10-9) and various deposits (referred to, for example, as boulder clay/diamictite, moraines, tills, erratics etc.) (Figure 10-10; Figure 10-11; Figure 10-12; Figure 10-13), together with various forms of evidence that enable rates and volumes of glacial erosion to be determined (Ballantyne & Lowe, 2016) (Figure 10-14; Figure 10-15). Eustatic changes, global effects due to a change in the volume of water in the oceans or the shape of ocean basins, and isostatic changes, due to crustal/tectonic processes, in (relative) sea-level, produced various raised shorelines.

Figure 10-3 – Corries separating the Eastern Red Hills summits of Beinn na Caillich, Beinn Dearg Mhòr and Beinn Dearg Bheag, with an arête (ridge) between Beinn Dearg Mhòr and Creagan Dubh. Oblique Google Earth© Image. View towards the east.

Figure 10-4 – Coire nan Laogh on the NE side of Marsco. View towards the SW.

Figure 10-5 – Coire Riabhach, north of Sgùrr nan Gillean. View towards the SW.

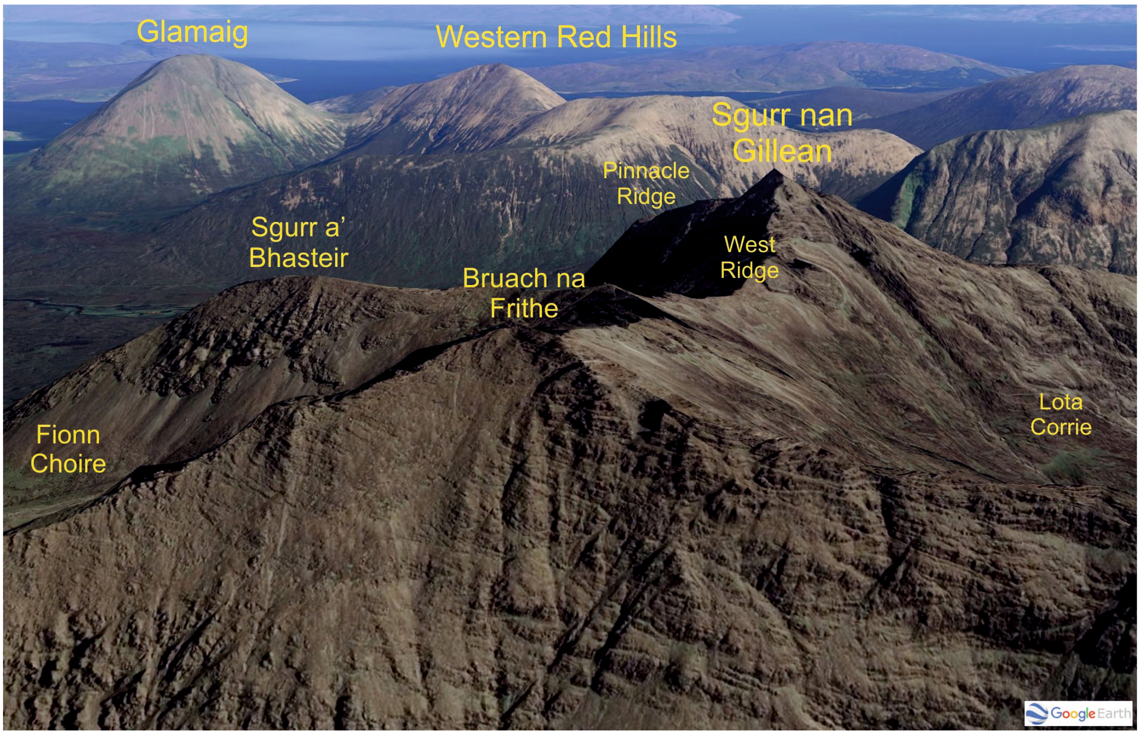


Figure 10-6 – Oblique Google Earth© image illustrating arêtes and horns (pyramidal peaks) in the northern Cuillin Hills: Bruach na Frithe (nearest) and Sgùrr nan Gillian (farthest). Radiating from Sgùrr nan Gillian are the Pinnacle Ridge, the West Ridge and the SE Ridge, all arêtes. In the distance are the granite-dominated summits of the Western Red Hills, including Glamaig. View towards the NE.

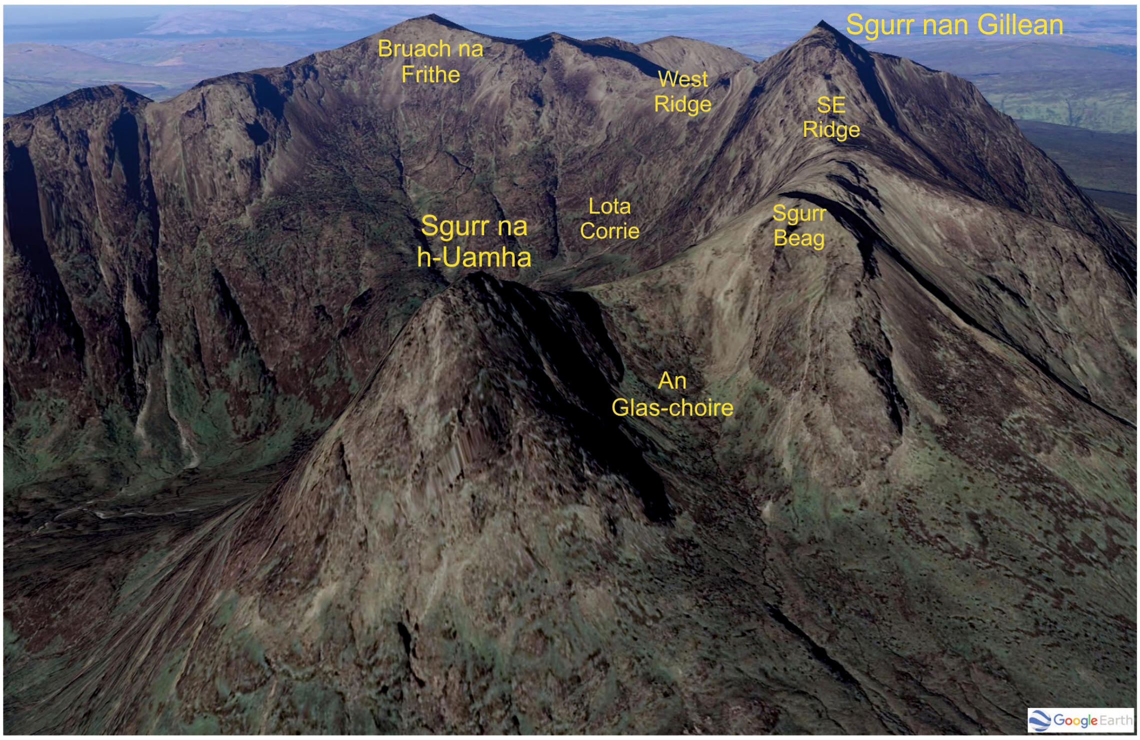


Figure 10-7 – Oblique Google Earth© image illustrating arêtes and horns (pyramidal peaks) in the northern Cuillin Hills: the horn of Sgùrr na h-Uamha (nearest), and the horns of Sgùrr Beag and Sgùrr nan Gillean connected by the arête known as the SE Ridge. Left of centre in the distance is Bruach na Frithe. View towards the east.

Figure 10-8 – The Scavaig River, possibly the shortest river in Scotland, connecting the corrie-occupying freshwater Loch Coruisk (right) and the sea loch of Loch Scavaig (left). The ridge between the two lochs is a rock step or corrie lip. View towards the west.

Figure 10-9 – The spine (arête) on the southern side of Blà-bheinn (Blaven). On the east (right-hand-) side of the arête, in the valley (corrie) of the Allt nan Leac, is a sub-glacially-formed hummocky moraine.

Figure 10-10 – A terminal moraine defined by large boulders at the mouth of Coir' a' Ghrunnda in the SW Cuillin Hills. The floor of the corrie (near ground) consists of glacially-moulded bedrock, the so-called 'boiler plates' of Coir' a' Ghrunnda. View towards the SW, with Soay (near left) and Rum (far centre).

Figure 10-11 – Glacial erratics at Am Màm east of Loch Scavaig near to the Kilmarie-Camasunary footpath. View towards the south.

Figure 10-12 – Glacial erratics sitting on striated, glacially-moulded bedrock close to the SE end of Loch Coruisk. View towards the NW.

Figure 10-13 – Raised beach at the northern end of Àird Ghiuthais in SW Raasay. View towards the south.

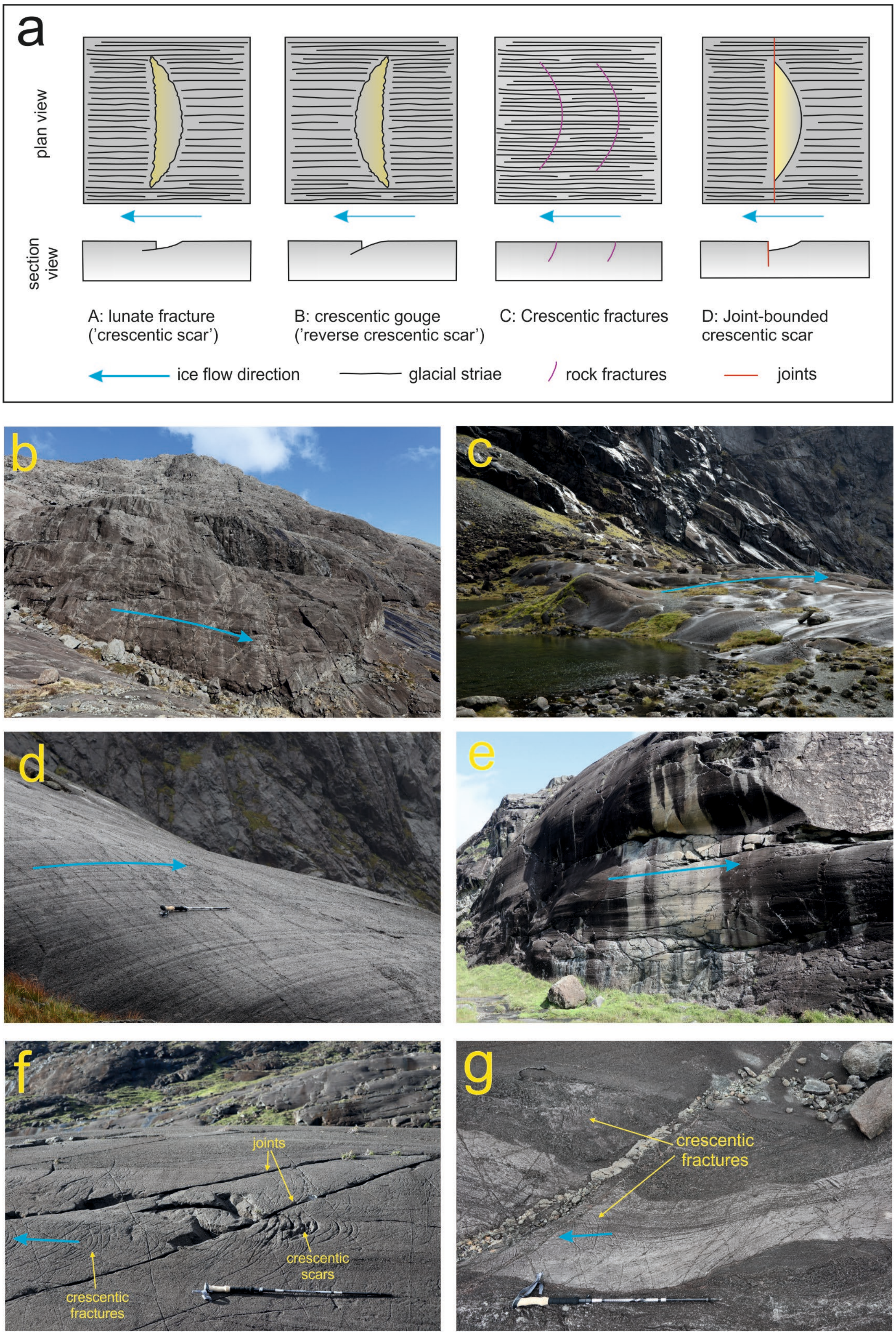


Figure 10-14 – (a) Schematic of glacial striae, lunate fractures, crescentic gouges, crescentic fractures and crescentic scars; (b) near-vertical, glacially-excavated rockface on the SE side of Coir' a' Ghrunnda, giving way upwards through a trimline (vertical extent of last ice), above which the rock surface is mantled by loose blocks forming by freeze-thaw weathering; (c) ice-sculpted rock step or corrie lip in Coire àà; (d) glacial striae on a gabbro surface at the upper Coire Làgan rock step (or lip), pole *c.* 1m long; (e) glacial striae on a vertical surface of gabbro due east of the Coruisk Memorial Hut, west of the Scavaig River; (f) crescentic scars and fractures ('chattermarks') on gabbro surface, SW side of Loch Coruisk, pole *c.* 1m long; and, (g) crescentic fractures on gabbro surface, SW side of Loch Coruisk, pole *c.* 1m long.

Periglacial phenomena, features formed peripheral to glaciated areas, take the form of blockfields (*in situ* boulder-rich debris mantling the land surface), trimlines (junctions between upper frost-weathered/shattered rock and lower ice-moulded rock), and solifluction features (downslope transported sheets and lobes of debris) (Figure 10-15; Figure 10-16).

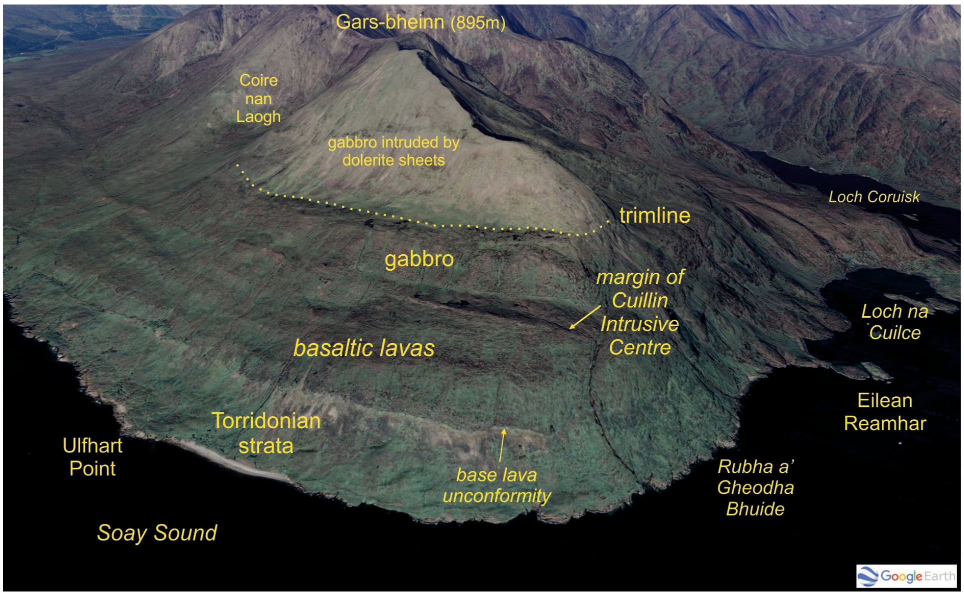


Figure 10-15 – Oblique Google Earth© Image illustrating a trimline in the southern Cuillin Hills on the southern slopes of Gars-bheinn. The contrasting lithologies above (microgabbro and dolerite) and below (gabbro, basalt and sandstone) may, in part be responsible for the contrasting weathering and erosion characteristics, with abundant loose blocks and scree above the trimline. View towards the NW.

Figure 10-16 – The trimline (base of obvious scree) on the north side of Ben Aslak, North Sleat. View towards the south from Sgùrr na Coinnich.

So-called paraglacial effects or landforms, due to the retreat of glacier ice, contributed to landslide development, various types of rockfalls, and the accumulation of talus/scree deposits, some of which are now vegetated (Figure 10-17; Figure 10-18; Figure 10-19).

Figure 10-17 – Landslipped block on the Trotternish Escarpment between Sgùrr a' Mhadaidh Ruaidh and Creag a' Lain. Note moraines at base of escarpment. View towards the SSW from Marishader.

Figure 10-18 – Screes ('stone chutes') on the east side of the Blà-bheinn (Blaven) (left-hand-side) – Clach Glas (right-hand-side) ridge. The location of these screes is typically where 'country-rock' gabbro (and similar coarse-grained rocks) is cut by minor intrusions such as dykes and cone-sheets. In this case, it is offshoots of the Coire Uaigneich Granite that produce the scree. View towards the west from Torrin.

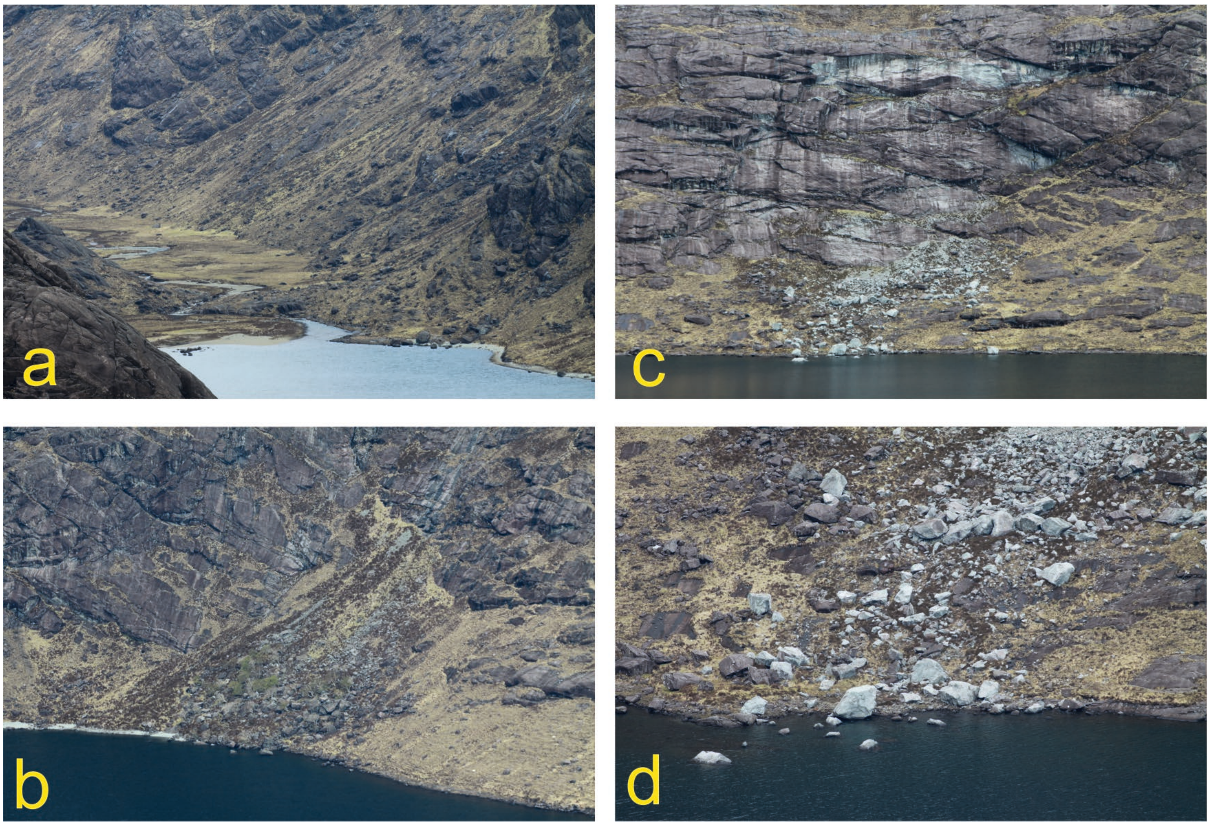


Figure 10-19 – (a & b) Partially vegetated old scree deposits on the north side of Loch Coruisk at its NW end. Such scree accumulations are relatively common where minor intrusions invade 'country-rock' gabbro (and similar coarse-grained rocks) on glacially-produced (now steep) faces; and, (c & d) on the NE side of Loch Coruisk (at its southern end) are more recent screes, one of which formed in the early 1980s.

During the Holocene Epoch, after Skye and Raasay were free of ice, periglacial activity was strongly influenced by high precipitation and strong winds, much like the present-day, and comprises frost-sorted patterned ground (interbedded coarse and fine sediment), non-sorted patterned ground (earth hummocks and relief stripes), and wind-patterned ground.

Diatomite deposits accumulated in some of the freshwater lochs, in particular in the landslipped area below the main escarpment of Trotternish, after the final deglaciation (Figure 10-20). These deposits are typically covered by peat, up to a few metres thick, indicating that it is either not accumulating at present, or is overwhelmed by the ongoing formation of peat (Figure 10-21). River alluvium and blown sand deposits are also currently forming throughout both islands.

Figure 10-20 – Hummocky ground at the base (east of) the Trotternish Escarpment, south of where the Staffin-Uig road cuts across/through the escarpment. The prominent isolated hill is Cleat and the lochs are Loch Leum na Luirginn (nearest) and Loch Cleat (farthest). Such lochs are common along the base of the escarpment and have formed due to the impervious nature of the detritus that has formed by the landslip events and the presence of moraines. Note old peat cuts on the west (right) side of Loch Leum na Luirginn. View towards the SSE from the Staffin-Uig road.

Figure 10-21 – Exposed banks of peat between the Lealt River and the dismantled railway that accessed Loch Cuithir (for diatomite) below the Trotternish Escarpment WSW of Lealt. Pole *c.* 1m long.

10.B Research on Skye's Glacial and Post-glacial History

Research into and the acceptance of the evidence that the present-day landscape of Skye (and Raasay) is strongly influenced by past glacial and related processes can be traced back to the work of

James David Forbes, dating from 1836 through until published in 1845 (Forbes, 1845). (Cunningham, 1990) has produced a detailed biography on Forbes, focussing on his studies on Scottish glaciers. Forbes embraced the theory of the Swiss-American biologist and geologist, Louis Agassiz, that Earth had, in comparatively recent times, gone through Ice Ages and that abundant evidence is available for interpretation, in both the landscape and in surface deposits on Skye and Raasay.

Evidence that convinced Forbes, based upon time spent in the area around Loch Coruisk, includes glacial striae, ice-moulded bed rock (Figure 10-12; Figure 10-22; Figure 10-23), roches moutonnées and trimlines, together with various types of moraine. Other observations were made in Coire Riabhach, NE of Sgùrr nan Gillean, in Coire na Creiche facing into Glen Brittle and, most compelling of all, in Coir' a' Ghrunnda, where the so-called boiler plates of ice-moulded bed rock that form the stepped floor of the corrie give way, where it opens out into the open country to the SW, a spectacular end moraine (Figure 10-10; Figure 10-24). In Coire Làgan, spectacular stone chutes indicate the action of freeze-thaw processes (Figure 10-25).

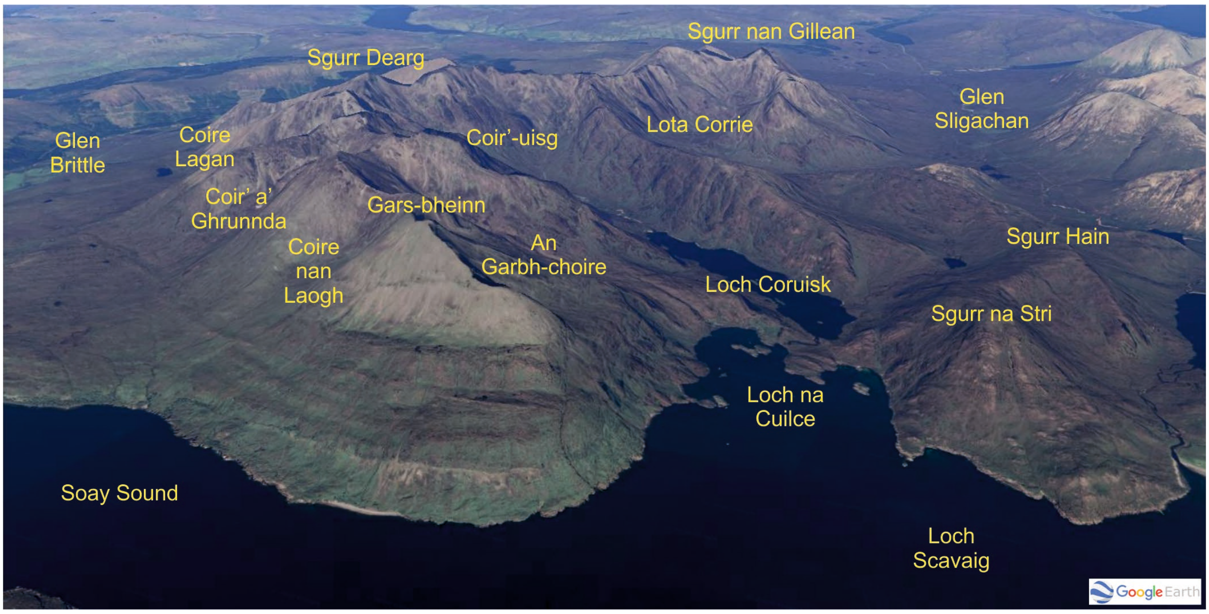


Figure 10-22 – Classic glaciated terrain of the Cuillin Hills, with corries, (arêtes) and horns (pyramidal peaks). Oblique Google Earth© Image. View towards the north.

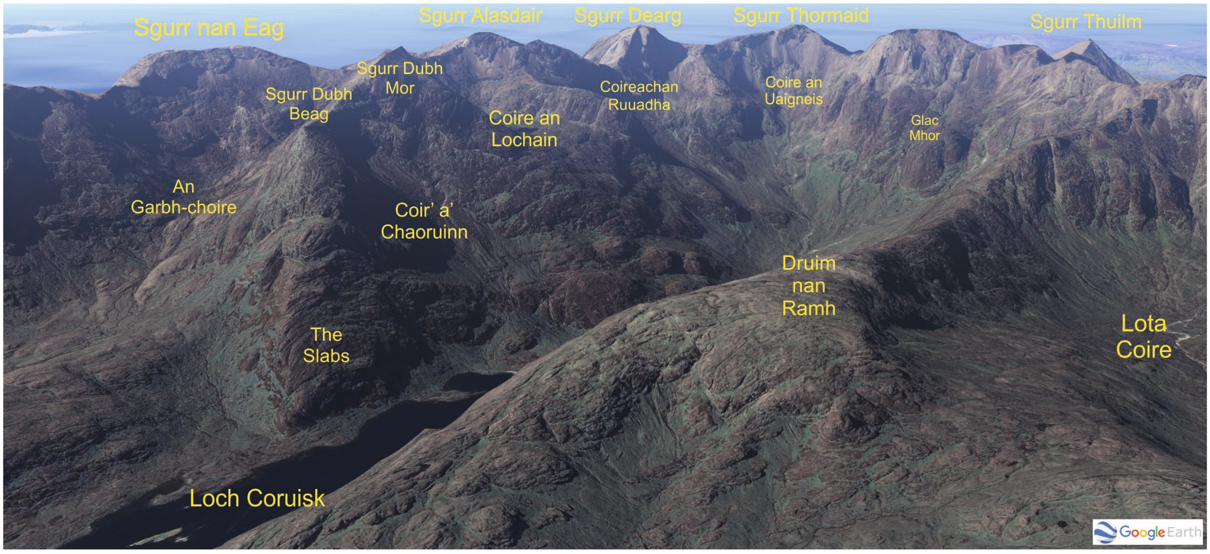


Figure 10-23 – Classic glaciated terrain of the Cuillin Hills, with corries, arêtes and horns (pyramidal peaks). Oblique Google Earth© Image. View towards the SW.

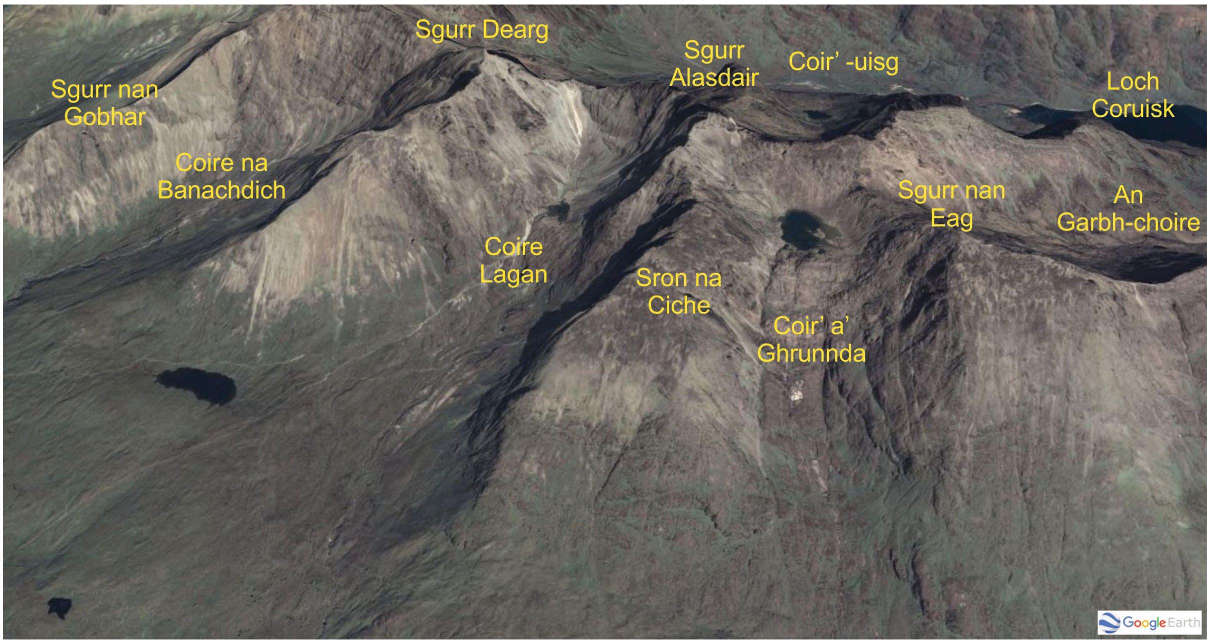


Figure 10-24 – Classic glaciated terrain of the Cuillin Hills, with corries, arêtes, horns (pyramidal peaks) and tarns (in Coire Làgan and Coir' a' Ghrunnda). Note scree at the head of Coire Làgan, one of the dramatic 'stone chutes' that have formed due to efficient freeze-thaw action on minor intrusions within the Cuillin Intrusive Centre. Oblique Google Earth© Image. View towards the north.

Figure 10-25 – The Great Stone Chute in Coire Làgan between Sgùrr Alasdair (right-hand-side) and Sgùrr Thearlaich (left-hand-side). This huge scree is due to efficient freeze-thaw action on minor intrusions within the Cuillin Intrusive Centre. View towards ENE.

Subsequent studies by A. Geikie (Geikie, 1863) and Bonney (Bonney, 1871) added detail, outlining evidence for glacially sculpted corries and various types of moraines. J. Geikie (Geikie, 1893) recognised evidence for a locally-developed, or -nourished, ice cap on the Cuillin Hills, together with a separate stream of ice that flowed westwards from the Scottish Mainland. Alfred Harker, based upon his detailed fieldwork in central Skye for the British Geological Survey in the late 1890s, confirmed and added detail to J. Geikie's interpretation ((Harker, 1899); (Harker, 1901)).

Subsequent studies, mainly in the 1950s, 1960s and 1970s, produced a plethora of observations, but little in the way of consensus of interpretation. Periglacial features and paraglacial effects, including the development of the spectacular landslips in northern Skye were investigated and are summarised by (Ballantyne & Lowe, 2016). From the 1980s, onwards, detailed studies of the geomorphology of Skye and the palaeo-ecology of its Pleistocene and Holocene deposits, have yielded a much more coherent understanding of the most recent glacial events, along with a limited, but useful, glimpse of older glacial events (Ballantyne & Lowe, 2016).

10.C Glacial Landforms and Deposits

Traditionally, the glacial history of an area, now free of ice, is interpreted through its glacial landforms and deposits formed during the glacial period. However, a third approach is available that allows landscape evolution, erosion rates and exhumation events to be deciphered using isotopic analysis of rocks presently preserved on Earth's surface. Skye displays a wide range of these landforms and deposits and has acted as a test bed for these low-temperature isotopic analytical techniques (Benn, et al., 2016).

The outer, convex side of the summit ridge of the Cuillin Hills displays textbook examples of corries. Other large-scale glacial landforms include arêtes that separate corries, truncated spurs, rock basins and trimlines, together with smaller features such as whaleback ridges, ice-moulded rock and roches moutonnées. The through valleys of Camasunary-Srath na Crèitheach-Glen Sligachan and Srath Mòr are two examples of deep, glacially-formed troughs (Figure 10-26). On the Sleat Peninsula, so-called *cnoc and lochan* topography, with low rounded hills and small shallow lochs, for example east of the quartzite ridge of Sgiath-bheinn an Uird, formed where ice sheets flowed over difficult-to-erode rocks (Figure 10-27; Figure 10-28).

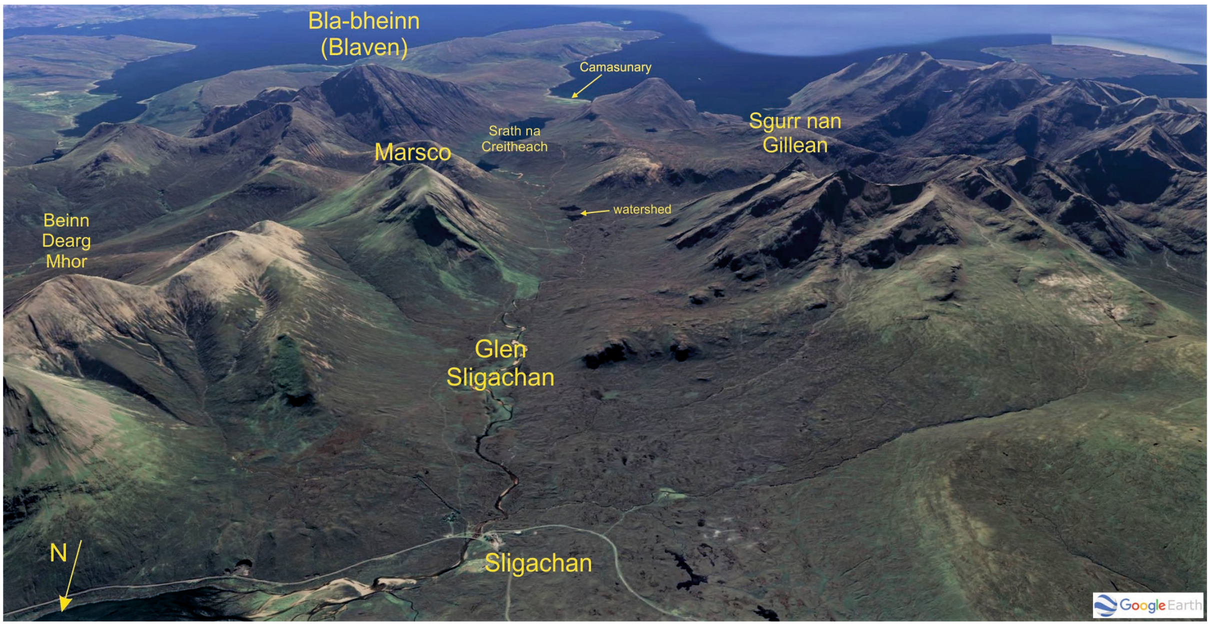


Figure 10-26 – The classic U-shaped valley of Glen Sligachan. This glen continues south into Srath na Crèitheach and on to the south coast at Camasunary Bay. To the east (left-hand-side) are the Western Red Hills and to the west (right-hand-side) are the Cuillin Hills, each with distinctive corries, arêtes and horns (pyramidal peaks). Oblique Google Earth© image. View towards the south.

Figure 10-27 – ***Cnoc and lochan*** **topography, with low rounded hills and small shallow lochs on the Sleat Peninsula, formed where ice sheets flowed over difficult-to-erode rocks. The white exposures on the ridge of Sgiath-bheinn an Uird are composed of Cambrian sandstone (quartzite). Oblique Google Earth© image. View towards the east.**

Figure 10-28 – ***Cnoc and lochan*** **topography, with low rounded hills and small shallow lochs on the Sleat Peninsula, formed where ice sheets flowed over difficult-to-erode rocks. The white exposures on the ridge of Sgiath-bheinn an Uird are composed of Cambrian sandstone (quartzite). View towards the SE, across Loch Eishort, from Suisnish.**

Glacial deposits are dominated by various types of moraine, essentially accumulations of unconsolidated glacial debris. End moraines define the limits of some of the Loch Lomond Stadial (LLS) corrie glaciers (10.E), for example to the SW of Coir' a' Ghrunnda, where it opens out onto open moorland (Figure 10-10; Figure 10-24). These deposits comprise multiple arcuate belts that formed along an ice margin. The material is transported both subglacially and as part of the supra-glacial load. The material is generally unweathered and well preserved, with typically poor sorting involving a sandy matrix containing large clasts of corrie-derived lithologies.

Hummocky moraine is a somewhat enigmatic material that is associated with the larger LLS glaciers on Skye (10.E), deposited within their limits and giving rise to distinctive ridges and chains of mounds (Figure 10-29). Good examples occur in the district of Strath (Figure 10-30; Figure 10-31), in Gleann Torr-mhichaig in the Western Red Hills, in Coire na Creiche west of Bruach na Frithe, and in Glen Arroch in the Kyleakin Hills. An example of a medial moraine occurs south of Blà-bheinn (Blaven), whereby two glaciers have converged, one flowing south down Srath na Crèitheach, the other sourced from the head of the Abhainn nan Leac valley, on the other side of the Blà-bheinn ridge (Figure 10-29).

Figure 10-29 – Detail of the sub-glacially-formed hummocky moraine on the SE side of Blà-bheinn (Blaven) in the valley of the Allt nan Leac. View towards the NE.

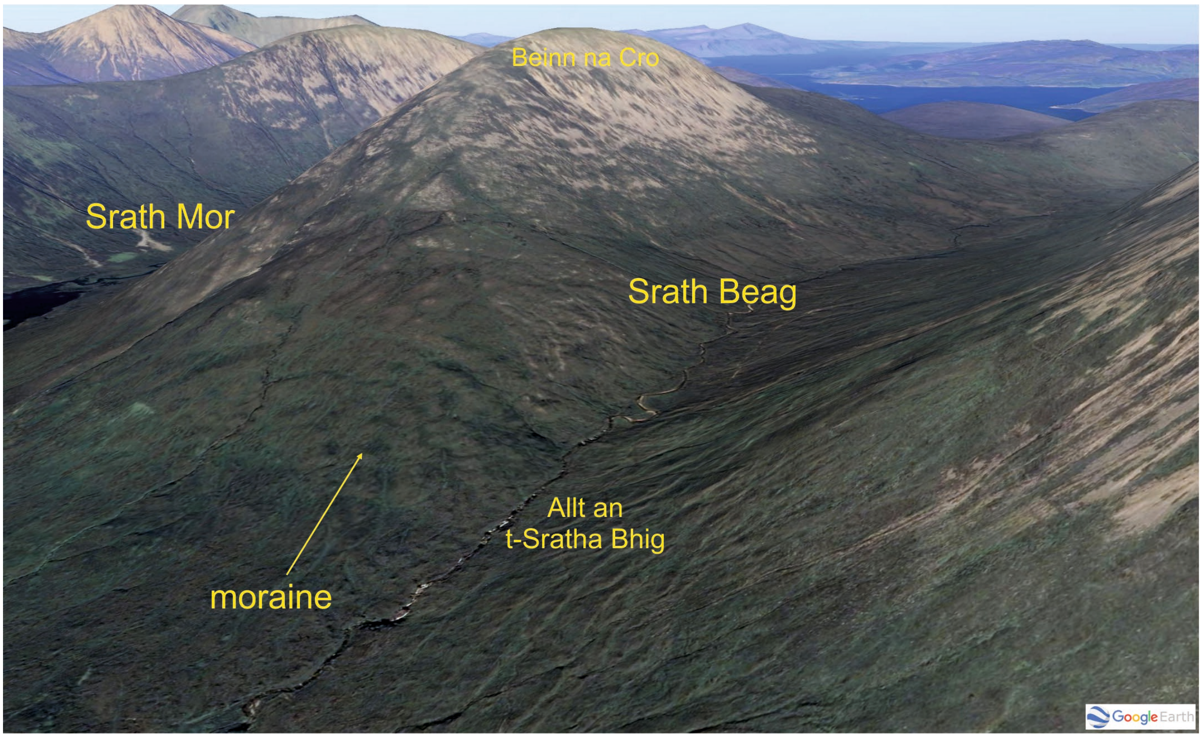


Figure 10-30 – Sub-glacially-formed hummocky moraine in the valley of the Allt an t-Sratha Bhig. Oblique Google Earth© image. View is NW towards Beinn na Crò.

Figure 10-31 – Detail of the sub-glacially-formed hummocky moraine in the valley of the Allt an t-Sratha Bhig. View WNW towards Belig.

Hummocky moraine commonly takes the form of large-scale ridges of hummocks on opposing valley sides. Where they converge, down-valley, they develop an overall chevron-like geometry/pattern

(Benn, et al., 2016). In some instances, these moraines can have transverse, longitudinal and non-aligned components. The material is typically heterogeneous, poorly sorted, uncommonly stratified and locally preserves evidence of deformation in the form of folds and sheared material. These features are interpreted as evidence of incremental formation/deposition at an ice margin during periods of stand-still and during minor readvances. The clasts and matrix materials can be generated by the action of the glacier responsible for their deposition, or they can have been generated at an earlier stage, essentially reworked from older deposits.

Subglacial tills are a common product of the LLS corrie glaciers (10.E) and comprise discontinuous fissile (i.e. with a strong fabric) sheet-like deposits characterised by sub-angular to sub-rounded clasts with striated surfaces due to transport over abrading surfaces, and are deposited in a subglacial environment (Benn, et al., 2016).

10.D The Last Ice Sheet

As we go backwards in time from the development of the last ice sheet on Skye, our understanding diminishes as the preserved evidence becomes more limited and less easy to decipher. Glacial events most likely go back to *c.* 2.6 Ma, but essentially are overprinted by more recent events. During the so-called Last (or Late) Glacial Maximum (LGM) or Dimlington Stadial (*c.* 31-14.7 ka), all of Skye and Raasay was completely covered by glacier ice. The timing for the initiation of this cold period is uncertain, but most likely is more recent than *c.* 32 ka, based upon a radiocarbon age determined for organic material on the Isle of Lewis (and other sites in Scotland) below tills, which indicates ice-free conditions at that time (Ballantyne & Lowe, 2016). Whether the ice cover was locally nourished/produced, or was fed westwards from the Scottish Mainland, is less easily determined.

Since that time, through until 11.7 ka, the climate varied, leading to retreat and advance of the ice cover, with the final warming event starting at *c.* 14.7 ka, with the onset of the so-called Lateglacial (or Windermere) Interstadial. A minor return to colder conditions and a limited glaciation took place during the Loch Lomond Stadial (LLS) or Younger Dryas, from 12.9 ka through to 11.7 ka. Then the ice was gone.

During the LGM, a substantial, discrete icefield developed over the central mountainous part of Skye. Isolated corrie glaciers developed elsewhere on the island. At this time, the Mainland icefield was no closer than the upper reaches of Loch Alsh and the mouth of Loch Hourn, some 30km to the east (Ballantyne, et al., 2016). As the isolated icefield or ice cap that developed in Central Skye expanded during the temporarily colder Loch Lomond Stadial (LLS), it migrated outwards in all directions. To the SE of Central Skye, in Glen Ord on the Sleat Peninsula, (Peach, et al., 1910) recognise glacial erratics that have been derived from both the NW and from the east, and which have been interpreted as evidence for the expansion of a locally-developed icefield in Central Skye that ultimately was overwhelmed by westward-flowing ice from the Scottish Mainland.

Complete cover of the land surface of SE Skye by a Mainland-derived ice sheet during the LGM is inferred from westward- to north-westward -oriented glacial striae and ice-moulded bed rock in the Kyleakin Hills. Glacial erratics on the highest point of the Kyleakin Hills, around Sgùrr na Coinnich, can be matched to Mainland lithologies, as can material on the lower ground of the Sleat Peninsula and the shores of Loch Eishort (Ballantyne, et al., 2016).

In Central Skye, glacial striae, ice-moulded bed rock and glacial erratics all indicate that this mountainous area developed its own, isolated ice cap, or dome, which diverted the westward-flowing Mainland ice, to the north over Raasay and northern Skye, and to the south over the Sleat Peninsula (Figure 10-2). (Harker, 1901) estimated that these two deflected ice streams diverged in the vicinity of Broadford. He recognises that Mainland-derived erratics are restricted to the coastline of Central Skye above a surface referred to as the Marine Limit (ML), the highest recognised former sea-level after the disappearance of the ice. (Harker, 1901) concludes that these erratics were deposited from floating ice, rather than glaciers. To the NE of the Cuillin Hills and the Red Hills, mainland-derived erratics occur on the islands of Raasay and Scalpay at all elevations, whereas to the south, on Soay, the erratics can be attributed to the Mainland and the Sleat Peninsula.

The extent of the ice cover on the highest summits of the Cuillin Hills is uncertain. Exposure ages determined by (Fabel, et al., 2012) using ^{10}Be data, indicate complete cover of even the highest summits. However, the lack of ice-moulded bedrock at high elevations and the shapes of some of the highest pinnacle summits suggest that they survived above the surface of the Last Ice Sheet as nunataks (Ballantyne, et al., 2016) (Figure 10-32). As the Mainland ice sheet retreated, it is possible that the Central Skye icefield expanded to the north, south and east (Harker, 1901).

Figure 10-32 – Sgùrr nan Gillean and the Pinnacle Ridge in the northern part of the Cuillin Hills, which formed a nunatak during the late-stage glaciation of the Loch Lomond Readvance (Stadial) event. View towards the SW from south Raasay.

In north Skye, good evidence of the glaciation is only seen on Trotternish. Here, ice-moulded blocks of landslipped material, roches moutonnées and streamlined drift all indicate ice flow towards the north (Ballantyne, 1990). Less well understood is the up-slope limit of the ice on the escarpment.

The identification of a trimline defined by the upper vertical extent of ice-moulded bedrock suggests a significant limitation of the ice sheet, not beyond the Minch, which can be countered by robust data from the offshore area that implies that the ice sheet reached the shelf edge, some 150km to the west (Ballantyne, et al., 2016).

Glacial readvances prior to *c.* 14.7 ka, during the Dimlington Stadial, can be inferred from data onshore in Strath Suardal and in Glen Drynoch. Offshore, south of the Cuillin Hills in Loch Scavaig, bathymetry data indicate an approximately E-W-trending moraine, interpreted as the limit of a glacier coming from the Coruisk Basin (Ballantyne, et al., 2016). The moraine comes onshore on Soay, where it forms a *c.* 5m high ridge, *c.* 250m in length ((Clough & Harker, 1904); (Ballantyne, et al., 2016)) containing large boulders of gabbro. The timing of this glacial readvance is inferred from the observation that on the south side of Gars-bheinn, north of Soay, glacial striae indicate ice flow from east to west during the LGM, and that the moraine indicates the extent to which ice readvanced after the Mainland ice retreated.

In summary, after the retreat of the Mainland Ice of the LGM, glaciers developed on the mountainous area of Central Skye and readvanced onto the surrounding low ground. The extent of these glaciers was greater than that determined for the subsequent (younger) Loch Lomond Stadial glacier(s).

10.E The Loch Lomond Readvance

The Loch Lomond Readvance (LLR), is a relatively late expansion of glacier ice during the Loch Lomond Stadial (LLS) during the Younger Drias (chronozone), approximately between 12.9 ka and 11.7 ka (Ballantyne, et al., 2016). The climate deteriorated after the Lateglacial (or Widermere) Interstadial (14.7-12.9 ka), with cooler summers and considerably cooler winters, possibly due to a weakening or collapse of the North Atlantic thermohaline circulation. Ice build-up at the beginning of the LLS and its demise at the beginning of the Holocene were most likely protracted events, not synchronous throughout Scotland. Being the last significant glacial event, evidence is good, and it has been studied in considerable detail (Ballantyne, et al., 2016). The relatively obvious features, first alluded to by (Forbes, 1845), (Bonney, 1871), (Harker, 1901) and (Peach, et al., 1910), can be attributed to this late glacial event, including corries disposed around the main ridge of the Cuillin Hills, corrie and end moraines, and hummocky moraines (see above).

The extent of the ice cover during the LLS has been the subject of much debate (Ballantyne, et al., 2016), leading to (Ballantyne, 1989) producing a reconstruction illustrating the likely distribution of glaciers (Figure 10-33). This construction is based on data on glacial striae, ice-moulded bedrock, roches moutonnées, fluted moraines, lateral moraines and glacial erratics. These glaciers appear to have terminated at or close to the present-day coastline.

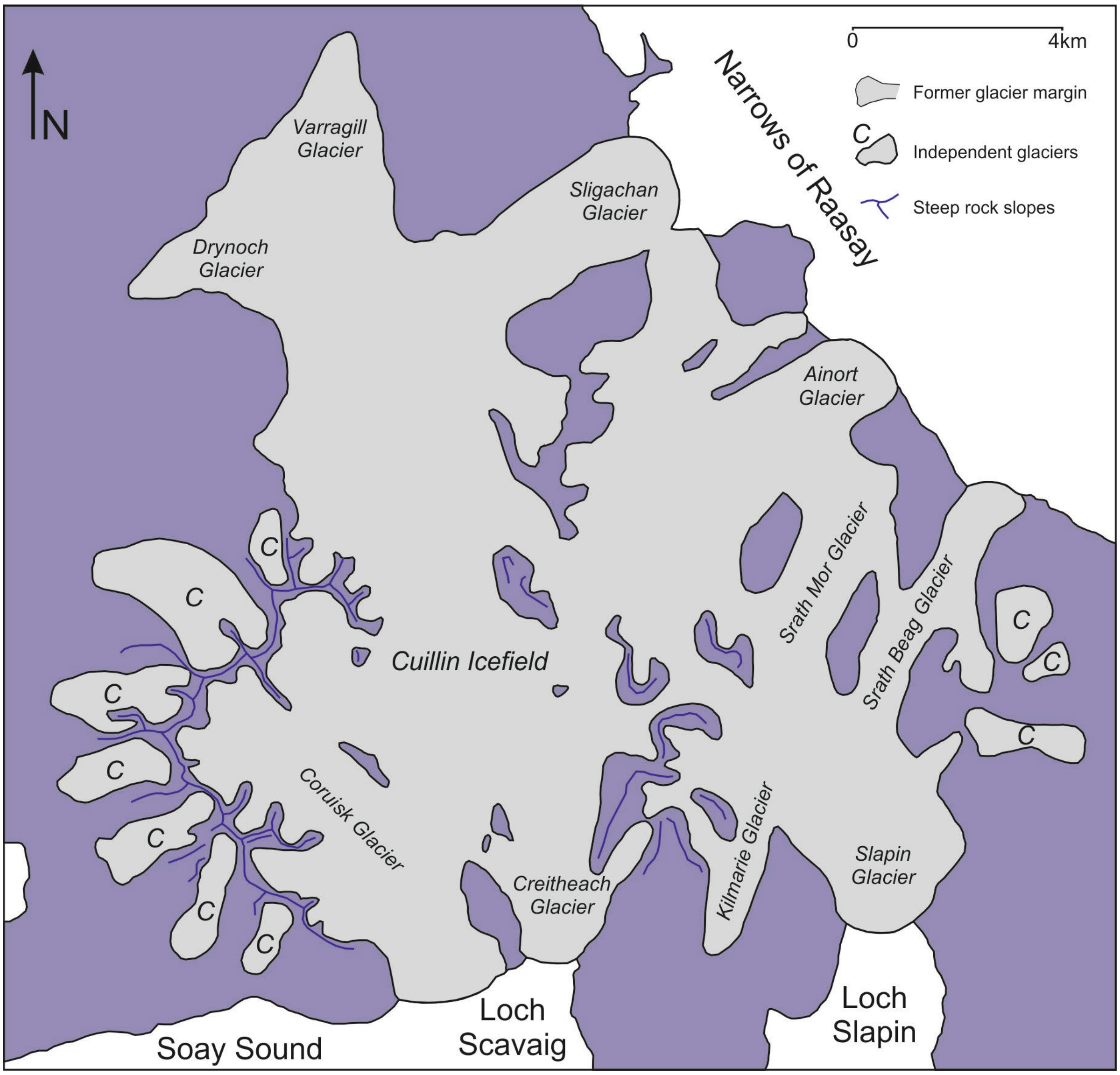


Figure 10-33 – Reconstruction of the Cuillin Icefield during the Loch Lomond Readvance in central Skye (after Ballantyne 1989).

Similar corrie glaciers developed in the Eastern Red Hills in the district of Strath, with associated lateral and end moraines (Ballantyne, 1989) (Figure 10-3; Figure 10-34), and in the Kyleakin Hills, where ice flowed from Bealach Udal, west into Glen Arroch, east into Kylerhea Glen, and south into Coire nan Cuilean (Benn, 1992). The Coire Fearchair boulder moraines in the Eastern Red Hills comprise at least five nested ridges that record the phased retreat of the small glacier that formed and occupied the corrie (Figure 10-34). The ridges formed during periods of stand-still, or retreat. The moraines achieve their greatest height, *c.* 20m, and lateral continuity on the SE side of the corrie mouth. Minor cross-cutting of the moraine ridges suggest that they are a composite of more than one event. The uneven spacings between the ridges along their lengths suggest localised disparate amounts of glacier retreat. The maximum amount of retreat recorded is *c.* 300m. The boulders are exclusively of granite, up to 2m across. The large size of these boulders suggests that material was derived from a failure scarp at the back of the corrie; the timing of such a failure is unclear.

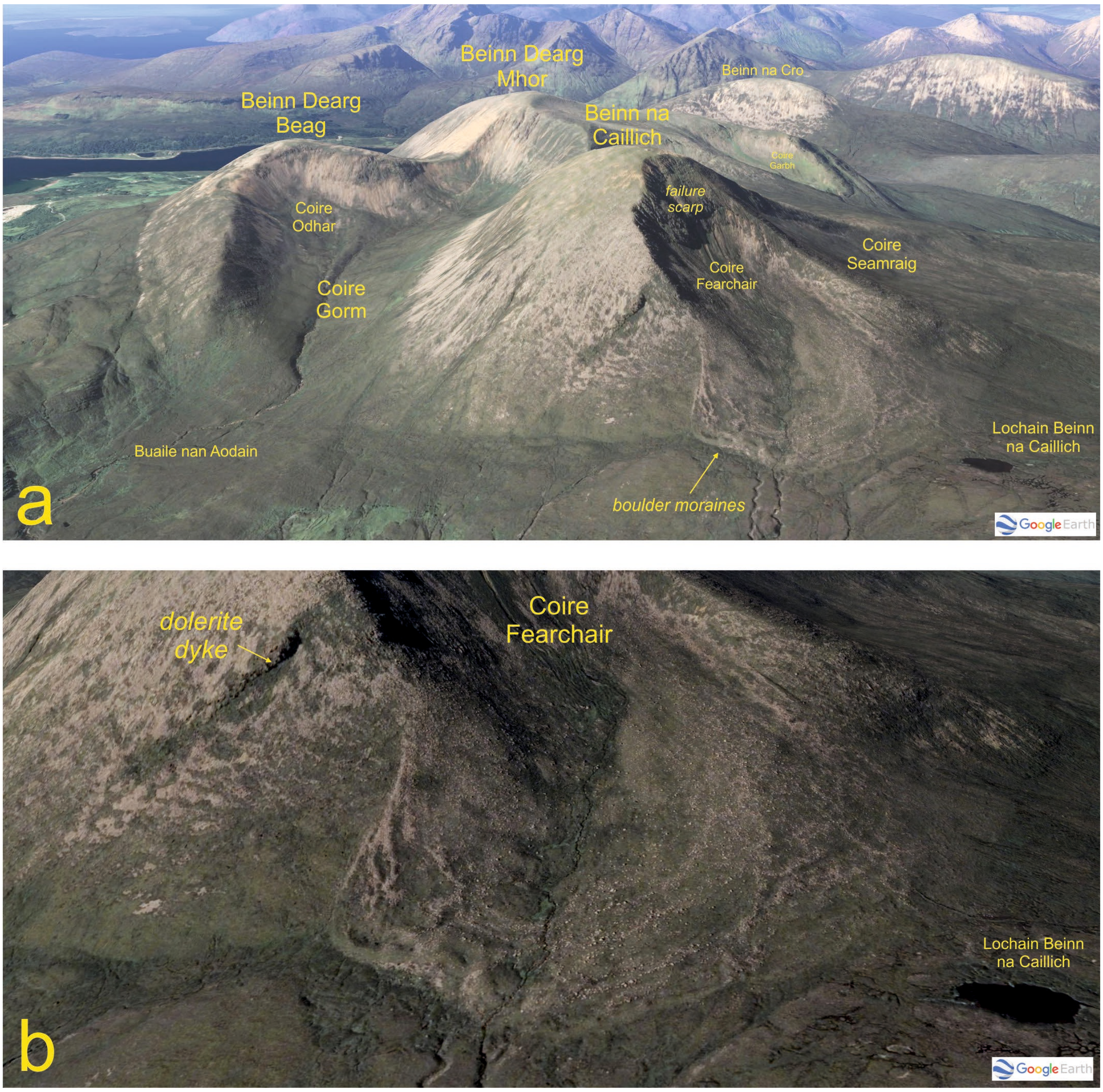


Figure 10-34 – (a) and (b) The Coire Fearchair boulder moraines, NE of Beinn na Caillich in the Eastern Red Hills. Oblique Google Earth© images. View towards the SW.

The extent of the ice cover is open to debate, with an ice-free summit interpretation proposed by (Benn, 1992), in contrast to a thin covering of non-erosive ice (Rea & Evans, 2003). On Trotternish, only two sites have been identified for LLR glaciers, Coire Cuithir where there is an extensive lateral moraine, and Coire Scamadale where a moraine ridge is preserved (Ballantyne, 1990). Other sites have been proposed, but lack well-preserved, convincing evidence.

The timing of the LLR event has been deduced from various strands of evidence ((Walker, et al., 1988); (Ballantyne, et al., 2016)). First, periglacial features (10.A; 10.F) are absent inside the defined limit of the LLR, interpreted as evidence that the readvance occurred towards the end of glacial conditions on Skye. Second, high-level (> 15m above OD) Late Glacial shorelines are restricted to the area outside the limit of the LLR, interpreted as evidence that the LLR took place when sea-level was relatively low, with Late-glacial shorelines formed during or after ice-sheet retreat, being destroyed by the readvance. Third, pollen analysis and radiocarbon dating of cores inside and outside the defined limit of the readvance provide contrasting datasets: outside the limits, all cores have a basal layer rich in organic material that can be related to the Late Glacial Interstadial (14.7-12.9 ka), such that they had no ice-cover during the LLS; inside the limits, all cores only have Holocene organic-rich muds and peat, due to the former presence of the LLS ice.

10.F Periglacial and Paraglacial Features

Periglacial features form during periods when the climate is cold, but non-glacial, and can be attributed to freeze-thaw action of the ground, together with aeolian (wind) action. The present-day climate of the high tops of Skye, the Cuillin Hills and the Red Hills, is sufficiently cold to enable periglacial processes, albeit less developed, to continue.

Blockfields, consisting of relatively continuous covers of *in situ* boulder-rich regolith, on the high ground of the Red Hills and the Trotternish Escarpment, are the oldest periglacial features on Skye (Ballantyne, 2016). The steepness of the Cuillin Ridge and associated spurs preclude their development and preservation. The Kyleakin Hills were totally glaciated, with erosional features, even on the summits.

Physical weathering, involving frost wedging and granular disaggregation of joint-bounded blocks during cold periods, is the main agent of blockfield development (Ballantyne, 2016). Typical profiles, from the surface, downwards, comprise regolith of angular clasts in a sandy matrix with some clay (from chemical weathering), below which are discrete angular boulders, giving way, downwards, to jointed bedrock. Typically, the accumulations are up to 1m thick.

On high ground, for example on the Trotternish Escarpment, the bedrock is either shattered or processed into blockfields; at lower elevations the bedrock is ice-moulded (i.e. glacially-abraded). Where these two complimentary sets of characteristics meet is referred to as a trimline. On Trotternish, the elevation of the trimline decreases, northwards (Ballantyne, 2016). Trimlines have also been identified in the Cuillin Hills and in the Red Hills.

The age of trimline development has been variously interpreted. Originally, attributed to the Last Glacial Maximum, between 31 ka and 14.7 ka, this interpretation fits neither with the interpretation that the last ice sheet extended to the Atlantic shelf edge, nor with cosmogenic exposure ages of *c.* 16-15 ka for glacial erratic boulders on blockfields in NW Scotland (Fabel, et al., 2012), which indicate that such blockfields pre-date the last ice sheet and (mainly) survived below cold-based ice frozen to the bedrock. Hence, the age of these trimlines is considerably older, most likely pre-Late Devensian, i.e. older than 31 ka, possibly as old as the Late Pleistocene Epoch (i.e. 135 ka) (Ballantyne, 2016).

The trimlines in the Cuillin Hills are attributed to the Loch Lomond Stadial glaciers ((Forbes, 1845); (Harker, 1901)). Trimlines are much less common in the Red Hills, but occur on Beinn na Crò (*c.* 300m OD) and on Beinn Dearg Mhòr (*c.* 350-400m OD) (Figure 10-35). In areas affected by the LLS glaciers, subsequent (i.e. Holocene) periglacial activity is limited to widening of joints in the bedrock and rounding-off of surfaces by granular disaggregation. In the Red Hills, boulders within the blockfields are, similarly, rounded on their top surfaces, but angular below (Ballantyne, 2016).

Figure 10-35 – Trimline *c.* midway up the east side of Beinn Dearg Mhòr in the Western Red Hills. View towards the west from Gleann Torra-mhichaig.

Remnants of solifluction, in the form of degraded partial coverings of slopes with tabular bodies of debris are relatively common, for example in the Red Hills, in the Kyleakin Hills, and along the Trotternish Escarpment. These deposits are attributed to gelifluction, whereby downslope movement of waterlogged soils occurs due to seasonal freeze-thaw action (Ballantyne, 2016).

Periglacial activity in the (post Loch Lomond Stadial) Holocene Epoch continues due to the cold seasonal temperatures enjoyed by Scotland. Impressively high levels of precipitation and strong winds contribute significantly to these processes. Patterned ground occurs in three forms: a small-scale, frost-sorted type with coarse and fine sediment at the Earth's surface; a non-sorted type with small-scale surface relief; and, a wind-patterned type (Ballantyne, 2016).

Small-scale patterned ground, in the form of nets and stripes, 30-60cm wide and with depths up to 20cm, occurs on unvegetated ground and is attributed to recent shallow frost action. Formation is due to the growth of needle ice spicules in the shallow subsurface, below surface clasts, thereby lifting them above the level of the ground surface, leading to the formation of alternating highs and lows, or hummocks and depressions (Ballantyne, 2016). During periods of thaw, clasts move into the depressions, which after many cycles of freeze and thaw, leads to the formation of the patterned ground. On sloped ground, whereby clast movement is enhanced, sorted stripes may form. Patterned ground is common on erosional (deflation) scars on the Trotternish Escarpment, and also occurs in the Cuillin Hills. They are rare in the Red Hills and absent in the Kyleakin Hills. Non-sorted patterned ground, in the form of relief stripes that occur oblique to gentle slopes, occurs near to the summit of The Storr, downslope from so-called earth hummocks, or thúfur, most likely formed from the action of frost heave (Ballantyne, 2016).

The third type, wind-patterned ground, takes the form of isolated and linear areas of vegetation on otherwise vegetation-free deflation surfaces, for example in the Red Hills. This partial removal of the vegetation cover has been attributed to climatic stress during the so-called Little Ice Age of the 16-19th centuries or may be the result of more recent overgrazing by sheep (Ballantyne, 2016).

Examples of Holocene solifluction are common along the Trotternish Escarpment. Here, lobes of mobilised soil occur above organic soil layers, the latter sitting on top of thick accumulations of regolith that blanket parts of The Storr above *c.* 580m OD. Rates of movement are of the order of 1cm per year. Associated with this solifluction are small, stepped, turf-banked terraces (Ballantyne 2016), which additionally involve wind erosion. These, similarly, occur on the Trotternish Escarpment and in the Red Hills.

Wind-eroded (deflation) surfaces and associated aeolian deposits occur on the Trotternish Escarpment in the vicinity of The Storr and are up to *c.* 3m thick, vegetated, and largely uneroded. These aeolian deposits are composed of lava-derived sand grade material, together with a small gravel component. Sections through the sequence, devoid of significant depositional breaks, suggest near-continuous sediment accumulation (Ballantyne, 2016). Similar deposits occur in the Red Hills but are considerably thinner and less extensive. Using a technique referred to as optically-stimulated luminescence (OSL) dating, whereby the time that quartz grains were last exposed to light, an age for the Red Hills deposits may be established. (Morocco, et al., 2007) determined ages for an unweathered sand unit overlying an older weathered sand unit: the upper unit has a calculated age (as of 2004 AD, when the ages were determined) of 358 ± 79 years, whereas the lower unit has an age of 1674 ± 240 years. The age of the younger unit suggests recent deposition of reworked sand, consistent with regional erosion of aeolian sand from upland plateaux after AD 1550-1700, when Scotland endured a sustained period of poor weather, referred to as the *Little Ice Age* ((Morocco, et al., 2007); (Ballantyne, 2016)), but also possibly due to overgrazing by the introduction of sheep.

Paraglacial features, directly conditioned by preceding glaciation and deglaciation events, indicate how Earth's surface adjusts to newly occurring post-glacial conditions. On Skye and Raasay, this is typified by significant rock-slope failures, as exemplified along the Trotternish Escarpment, but also occurring elsewhere in northern Skye and on Strathaird (10.G). Also present are significant talus (scree) accumulations in the mountainous part of central Skye, some of which are vegetated but deeply incised by steep-sided gullies (Ballantyne, 2016) (Figure 10-36).

Figure 10-36 – Vegetated talus (scree) on the east side of Glamaig in the Western Red Hills. View towards the west from Gleann Torra-mhichaig.

Spectacular talus slopes, partially mantling the sea-cliffs of Skye, occur on Trotternish (Figure 10-37), and form significant accumulations within the corries of the Cuillin Hills and the Red Hills. Those in the corries of the Cuillin Hills are evidently post-glacial, for example in Coire Làgan, forming over the last *c.* 10 ka. Beyond the limits of the LLS glaciers, such talus deposits have a longer and more complex evolution, developing after the retreat of the ice sheet(s) associated with the Last Ice Sheet (10.D) at *c.* 17-14.7 ka. Examples occur along the east-facing slopes of the Trotternish Escarpment and along the east-facing slopes of Ben Meabost and An Carnach on Strathaird. Where incised by gullies, the complex evolution of these accumulations can be determined in detail.

Figure 10-37 – Coastal talus accumulation below the east-facing cliffs north of Portree. View towards the NW from west coast of Raasay.

The unstable nature of these deposits is such that they are commonly modified by surface processes, for example, reworking into debris flow deposits, associated with periods of significant rain and snow melt. Such deposits are typified by a wedge-shaped gully cut into the crest of the slope and a flow track flanked by parallel levées of debris, terminating down-slope by a boulder-rich apron (Figure 10-36) (Ballantyne, 2016). Examples occur both in the Red Hills and along the Trotternish Escarpment. The process of talus reworking by debris flow continues today.

10.G Landslides and Associated Rock Failures

Landslides, or rock failures, form some of the most spectacular scenery of north Skye along the inland, east-facing Trotternish Escarpment. Similar features occur along the east side of Raasay. Coastal landslides occur on Trotternish, Waternish (e.g. Scòre Horan) and Duirinish, one of the most spectacular being on the east side of Ben Tianavaig, south of Portree. Another coastal landslip occurs on the west coast of Strathaird at Càrn Mor on the west side of Ben Cleat. Inland, in central Skye, there is a landslip on the NW side of Glas-Bheinn Mhór, and there are two landslips in the Kyleakin Hills, on Beinn na Caillich and on Beinn Bhuidhe. Other than the last three listed, all have several geological aspects in common.

All of the main landslips on Skye comprise thick sequences of Paleocene lavas unconformably overlying mechanically weak Jurassic strata (4.C), typically, but not exclusively, shales and siltstones. Failure occurs at the interface between the two contrasting lithologies, with the dense volcanic rocks undergoing significant, complex, multiple lateral displacements. The Jurassic sequence is intruded by thick picrite and dolerite sills of the Little Minch Sill Complex (8.B), which, locally, may have contributed to some of the landslip events. Timing of the landslips is also complex, with glacially modified landslipped material indicating that some failures pre-date at least the last glaciation event(s). Initiation of the landslips is more difficult to determine. Evidence of both post- and pre-glaciation landslipping negates a simple glaciation-deglaciation mechanism, although the retreat of glaciers, which took place on Trotternish at *c.* 14.7 ka (10.D), will have led to crustal rebound, stress release and fracture propagation, all potentially contributing factors. Many of the landslips, however, show no evidence of glacial modification, suggesting failure took place since the end of the Loch Lomond Stadial (10.E). An exposure age determined using cosmogenic isotope data indicates an age of *c.* 6.1 ± 0.5 ka for The Storr landslip (Ballantyne, et al., 2014). Movement continues to the present day, as evidenced by the near-continuous repairs that have to be made to the public road at Flodigarry, near the northern end of the Trotternish Escarpment, below the Quiraing-Sròn Vourlinn Landslip, and by the continuing claiming of coastal fences by the sea. The landslips of the Trotternish Escarpment are readily viewed from the main public road running north from Portree, through Staffin, to Flodigarry. However, a more detailed understanding of their complex nature is gained by accessing them via well-worn walking tracks.

The Trotternish Escarpment forms a N-S -trending *c.* 25km long inland spine, from north of Portree to Flodigarry.(Figure 10-38). Landslipped material is concentrated in two sectors along the escarpment: between The Quiraing and Sròn Vourlinn (including features such as The Table, The Needle and The Prison), running down to the coast at Flodigarry (Figure 10-39; Figure 10-40; Figure 10-41; Figure 10-42; Figure 10-43; Figure 10-44; Figure 10-45; Figure 10-46; Figure 10-47; Figure 10-48) and, in the vicinity of The Storr (including the well-known rock pillar of The Old Man of Storr) (Figure 10-49; Figure 10-50; Figure 10-51; Figure 10-52; Figure 10-53; Figure 10-54). Elsewhere along the escarpment there is little evidence of significant landslipping, although there are relict talus deposits. (Ballantyne, 2016) identifies two zones of landslipped material: an inner zone, closest to the escarpment, composed of detached pillars, ridges and spines; and, an outer zone, composed of more rounded masses of rock. Much of the latter material appears to have landslipped by a rotational mechanism prior to (at least) the last glaciation events, indicated by its N-trending, ice-moulded characteristics.

Within this outer zone are many small lochs and till-filled hollows (Ballantyne, 2016). Diatomite (diatoms: a hard-shelled algae, composed of opaline silica) accumulations occur within some of these small lochs, at Digg, Sartle and Kilmuir, with the more extensive being at Loch Cuithir, below Flasvein, on the inland lava escarpment. These deposits accumulated on glacial moraines during the Holocene Epoch, during a period of relative higher temperatures; however, the presence of overlying peat, which has accumulated during subsequent less mild and wetter conditions, suggests that diatomite is no longer accumulating.

Material closest to the escarpment, some barely detached, has more angular characteristics and has not undergone significant rotation, although toppling and tilting of some pillars has taken place. Minor movements still occur.

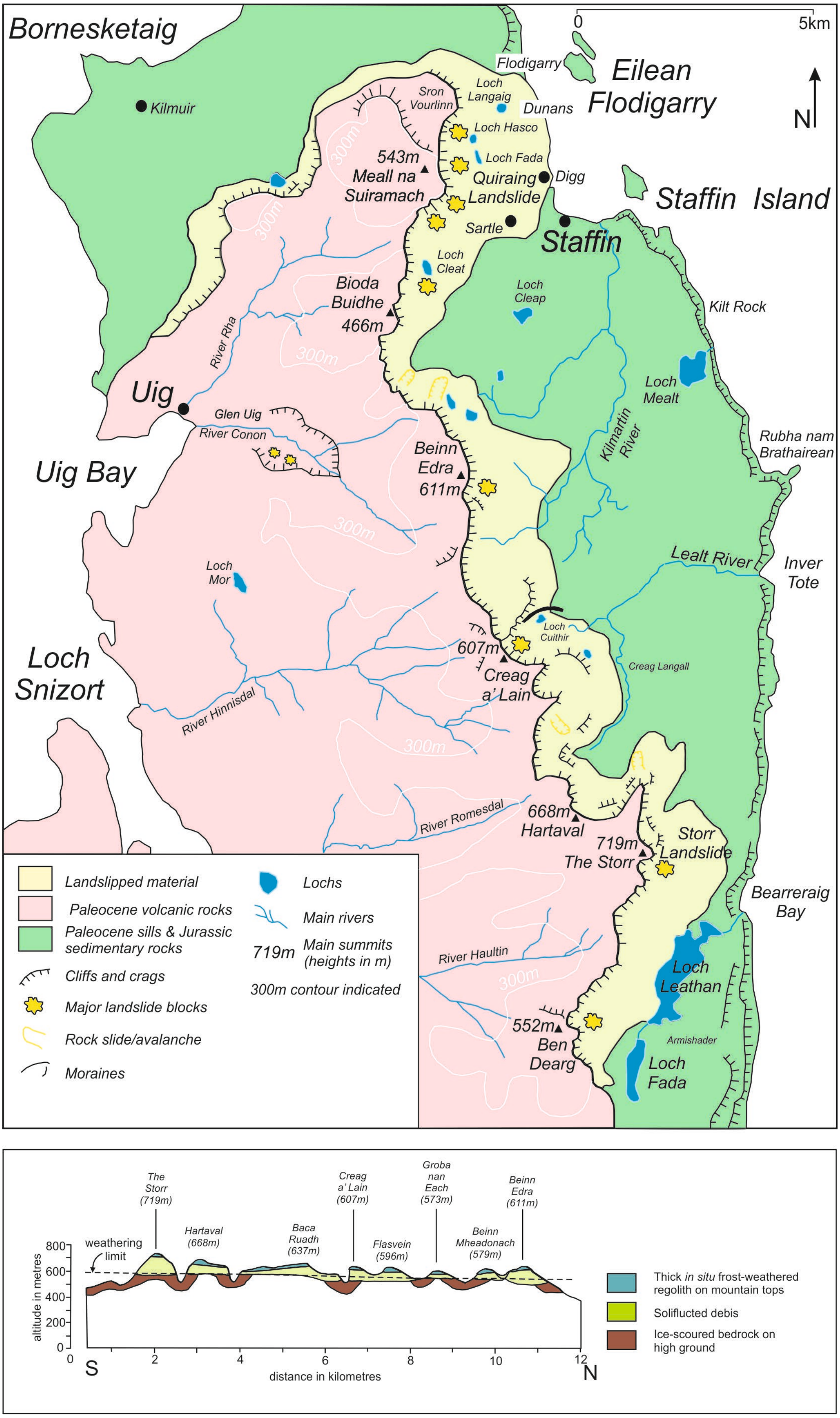


Figure 10-38 – The Trotternish Escarpment of northern Skye (after (Ballantyne, 2016)).

Figure 10-39 – Information board at the beginning of the Quiraing path at Flodigarry.

Figure 10-40 – The Needle, a spire of landslipped lavas, at the Quiraing on the Trotternish Escarpment. View towards the NW.

Figure 10-41 – The Table, a remarkably flat-surfaced block of lavas at the Quiraing on the Trotternish Escarpment. Sheep at the far end for scale. View towards the south.

Figure 10-42 – View from the Trotternish Escarpment from north of the Quiraing, NE towards Flodigarry, with Loch Hasco (nearest) and Loch Langaig (farthest). These lochs are common along the base of the escarpment and have formed due to the impervious nature of the detritus that has formed by the landslip events and the presence of moraines.

Figure 10-43 – View from the Trotternish Escarpment from between Fir Bhreugach and Sròn Vourlinn, NE towards Flodigarry, with Loch Droighinn (to the left) and Loch Langaig (to the right). These lochs are common along the base of the escarpment and have formed due to the impervious nature of the detritus that has formed by the landslip events and the presence of moraines. The island is Eilean Flodigarry.

Figure 10-44 – View from the Trotternish Escarpment, from Sròn Vourlinn, towards the south. The small loch in the distance is Loch Fada. These lochs are common along the base of the escarpment and have formed due to the impervious nature of the detritus that has formed by the landslip events and the presence of moraines.

Figure 10-45 – Landslipped material east of the Trotternish Escarpment at Flodigarry. There is no simple geological logic to the topography, as it comprises rotated and toppled blocks of lava in a totally random manner. Note road sign warning.

Figure 10-46 – Road sign warning at Flodigarry.

Figure 10-47 – Road damage at Flodigarry. Repairs are made on an almost annual basis due to ongoing minor movements within the landslipped material as it migrates eastwards towards the coast.

Figure 10-48 – Landslipped material on the coast at Dunans, south of Flodigarry. The material comprises rotated and toppled fragments of lava is a totally random manner. Note abandoned building and disrupted line of fence.

The commonly quoted interpretation of landslip development on the Trotternish Escarpment is by rotational failure, whereby large coherent masses of lava have detached from the escarpment, and is illustrated in Figure 10-49 (Anderson & Dunham, 1966). In this model, one of the sills intruded into the Jurassic strata plays a key role in The Storr landslip. However, more recent investigations have identified flaws in this simple model, including the not-recognised low dips of the more distal landslipped blocks in the (Anderson & Dunham, 1966) model, and the fact that some landslipped masses closest to the escarpment have been tilted in the opposite direction, i.e. towards the west. More likely mechanisms identified by various workers ((Martin, 2011); (Murphy, 2011); (Fenton, et al., 2015)) include translational sliding of blocks, toppling of blocks, and minor rotation of blocks, less extreme than that proposed by (Anderson & Dunham, 1966). Some of the surfaces involved in block rotation may have soled out in a geometry similar to listric faults. In places, simple collapse of the lava cliff appears to be the dominant failure mechanism, with secondary reworking via debris flow processes, possibly still ongoing.

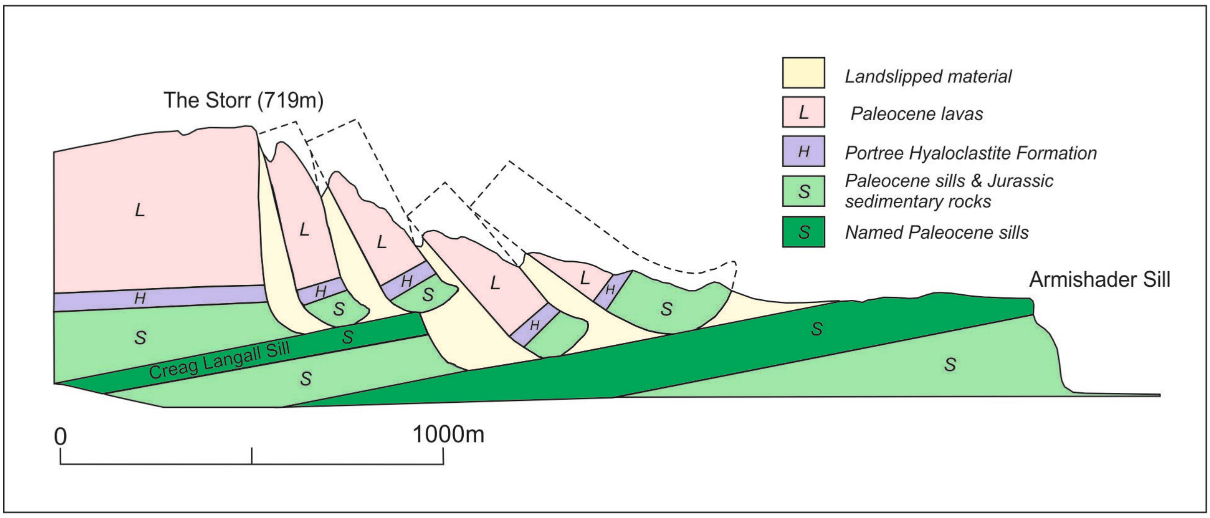


Figure 10-49 – The simplistic and largely incorrect Anderson & Dunham model to explain the Storr Landslip (after Anderson & Dunham 1966).

Figure 10-50 – The Storr section of the Trotternish Escarpment landslip, with the prominent rock pillars of The Old Man of Storr (the largest, most obvious spire) and, beyond, The Needle (the small spire immediately to the left). View towards the north from Loch Fada. Vehicles on road for scale.

Figure 10-51 – The Storr section of the Trotternish Escarpment landslip, with the prominent rock pillars (right-of-centre) of The Old Man of Storr (the largest, most obvious spire) and, to its right, The Needle, both below the skyline. The highest point on the escarpment is The Storr. View towards the NW from the Storr Lochs Dam, where the Bearreraig River exits Loch Leathan.

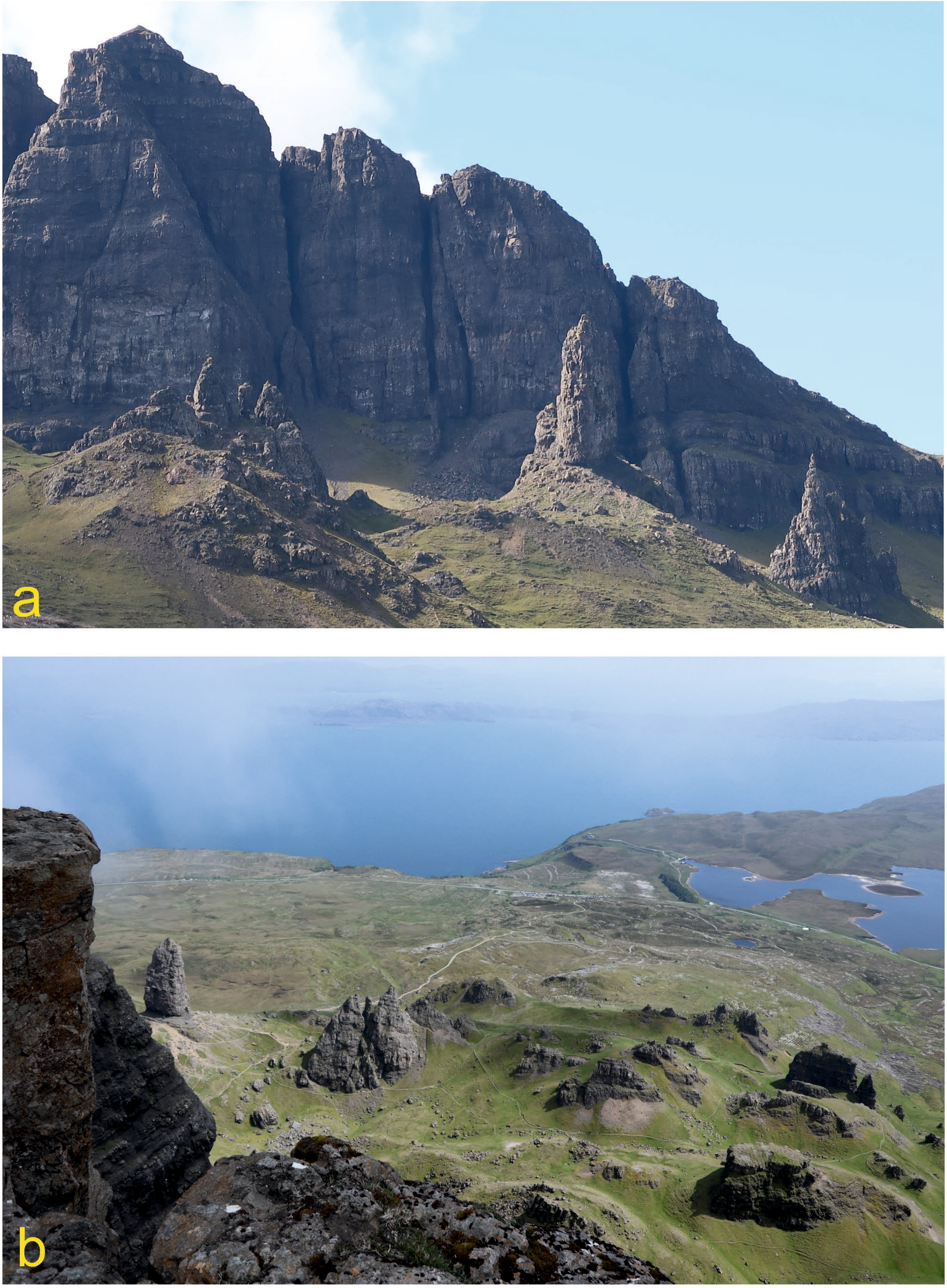


Figure 10-52 – Views up (a) and down (b) of the Storr section of the Trotternish Escarpment landslip, with the prominent rock pillar of The Old Man of Storr (the largest, most obvious spire) and, in (a) to its right, The Needle. The highest point on the escarpment is The Storr. View in (a) towards the NW, and in (b) towards the east.

Figure 10-53 – The Storr section of the Trotternish Escarpment landslip, with the prominent rock pillars of The Old Man of Storr (the largest, most obvious spire) and, in line and nearer, The Needle. The highest point on the escarpment is The Storr. View is towards the south, towards the Storr lochs.

Figure 10-54 – Detail of The Storr section of the Trotternish Escarpment landslip, with the prominent rock pillars of The Old Man of Storr (the largest, most obvious spire) and, in line and nearer, The Needle. View is towards the south, towards the Storr lochs.

Eighteen coastal landslips are recognised in cliff-fringed north Skye (Ballantyne, 2016). The most impressive occurs on the east side of Ben Tianavaig, south of Portree (Figure 10-55; Figure 10-56;

Figure 10-57) where multiple slip surfaces have caused the complex collapse of a sequence involving Jurassic strata (4.C) floored by a sill of the Little Minch Sill Complex (8.B) overlain by Paleocene lavas of the Ben Edra Group (5.D). This landslip may still be active.

Figure 10-55 – The Ben Tianavaig landslip, south of Portree, viewed towards NNW from Suisnish at the southern end of Raasay.

Figure 10-56 – The Ben Tianavaig landslip, south of Portree, viewed towards NNW from Suisnish at the southern end of Raasay.

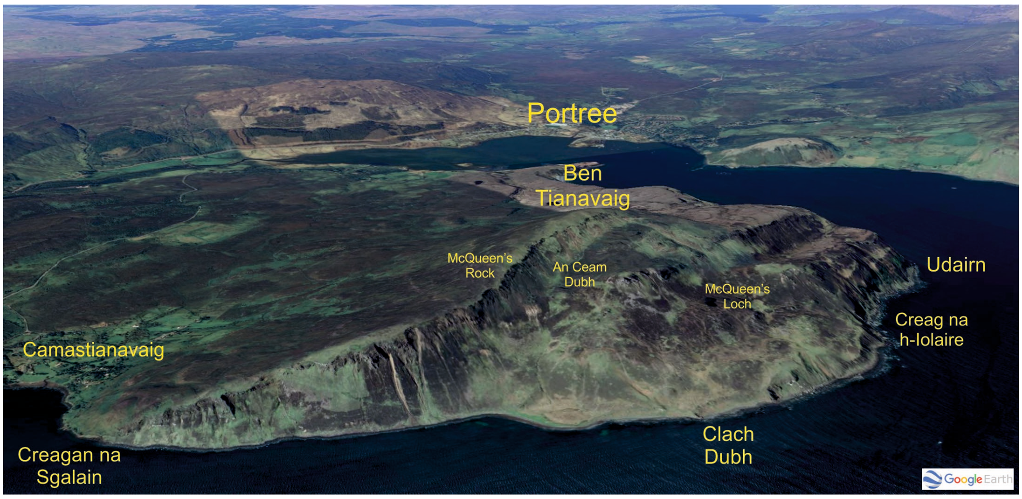


Figure 10-57 – The Ben Tianavaig landslip, south of Portree. View towards the NW. Oblique Google Earth© image.

Elsewhere along the coast of north Skye, the landslipped sequence involves only Jurassic strata intruded by sills, where the lava sequence has been removed by erosion, for example, at Valtos and at Rubha Garbhaig, east of Staffin. In these examples, active coastal erosion has contributed to the failure, with associated block rotation and rockfall mechanisms. The large landslip at Waterstein Head on Duirinish is similarly lava-free (Figure 10-58). Other coastal landslips of note in north Skye occur at Loch Bay on the west side of Waternish and at Scòre Horan on the east side of Waternish. The ages of these landslips are not easily determined, with pre-last-glacial and post-glacial types likely. Certainly, some of the landslipping events are of Holocene age and, indeed, are continuing as coastal erosion acts as a catalyst.

Figure 10-58 – The Waterstein Head landslip, viewed towards the east from Neist Point (Rubha na h-Eist). The Neist Sill forms the obvious jointed exposure in the middle distance; the inclined lavas in the distance belong to the Ramasaig Group. The landslip disrupts the lavas and gives rise to the brown and white detritus on the coastline below the lavas.

The landslips of central Skye have not been studied in as much detail as those on Trotternish. The two recognised examples in the Kyleakin Hills, on Beinn na Caillich and on Beinn Bhuidhe, involve steeply inclined Torridonian strata (4.B), where slip of a few metres has been along bedding planes ((Peach, et al., 1910); (Ballantyne, 2016)). Both landslips have not been modified by glaciation, implying their post-glacial age.

The Glas-Bheinn Mhór landslip, on the NE side of that hill, SSW of Strollamus, has a *c.* 500m long arcuate backscarp, below which is a complex apron-like mass of poorly-exposed granite boulders. Failure may be attributed to slope-parallel joints within the granite (Benn, 1990). A post Loch Lomond Stadial age is indicated as the slide partially occupies an area formerly occupied by the Srath Mòr Glacier.

The landslides on Rassay are, in some ways, similar to those on Skye, although the involvement through the effects of loading of Paleocene lavas (5.D) and sills (8.B) must be negligible. (Lee, 1920) provides a brief account of the landslipped areas on the east side of the island, which predominantly involve and modify the outcrops of Jurassic strata (4.C). (Lee, 1920) recognised the significance of a curved fault that has caused the (coherent) downthrow of a large (kilometre-scale) block of Lower and Middle Jurassic strata at Beinn na Leac (Figure 10-59; Figure 10-60).

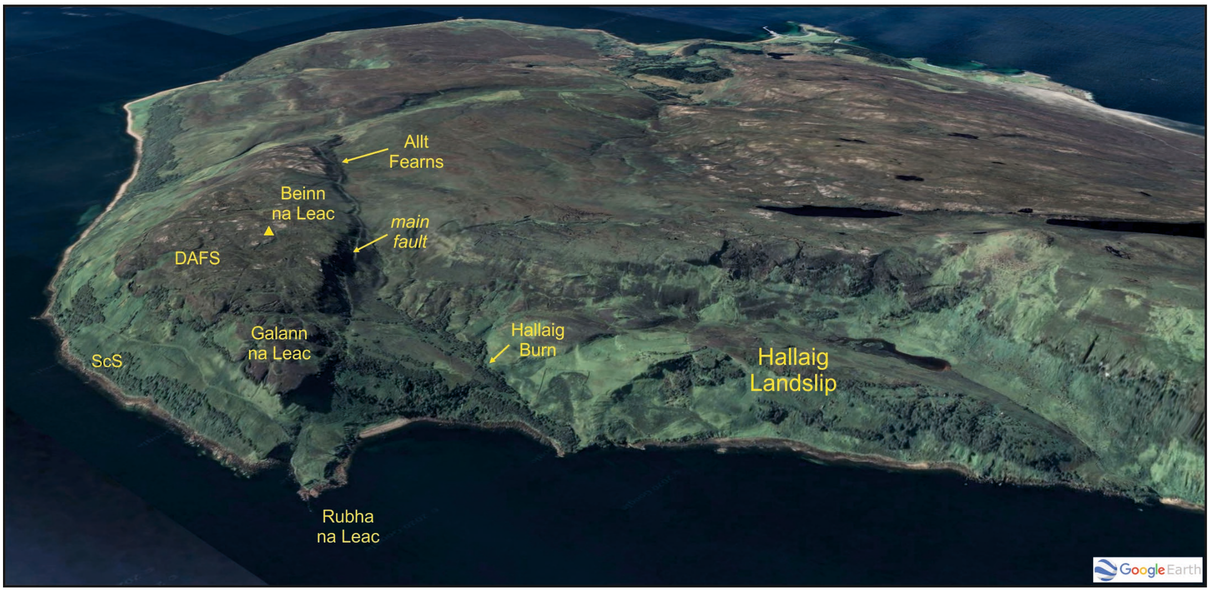


Figure 10-59 – The Beinn na Leac and Hallaig landslips in SE Raasay. Oblique Google Earth© image. ScS: Scalpay Sandstone Formation; DAFS: Druim an Fhuarain Sandstone Member.

(Morton, 2014) has contributed minor modifications to the stratigraphy of the down-dropped block, which is volumetrically dominated by the Scalpay Sandstone Formation and the Druim an Fhuarain Sandstone Member of the Bearreraig Sandstone Formation (BGS, 2006a). The fault also affects Triassic Stornoway Formation strata (4.B) and possibly Torridonian (Supergroup) strata (3.C).

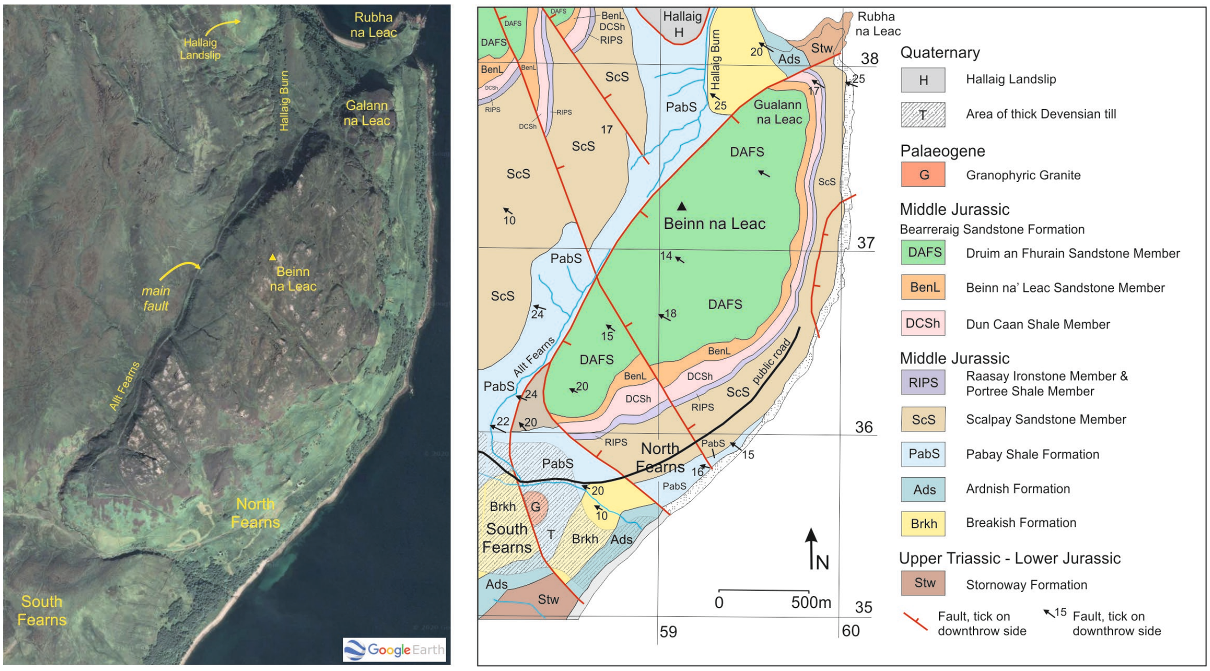


Figure 10-60 – The Beinn na Leac Landslip in SE Raasay (based on BGS (2006a) and Morton (2014)). This is the Hallaig Landslip of Smith *et al.* (2009).

The arcuate Benn na Leac Fault is the product of Quaternary (age) overdeepening of trenches in the sea east of Raasay (Morton, 2014). These glacially-induced modifications of the landscape caused instability of the Mesozoic (and to a limited extent Paleocene) sequences on the east side of Raasay, most notably in the SE part of the island at Beinn na Leac. Landslips elsewhere, for example at Hallaig and west of Druim an Aonaich, are considerably shallower and are not on the same scale. Within the Beinn na Leac Landslip, at North Fearns, there is a discrete mass of landslipped material (BGS, 2006a).

Multiple movements of the fault are recognised: in the South Fearns area, Devensian fluvio-glacial sediments are not faulted and blanket the fault trace. This has been attributed to thick Devensian tills that, in essence, acted as a buttress and prevented movement in post-Devensian times. Further to the NE, these tills are not present and post-Devensian displacement(s) have occurred (Morton, 2014).

(Smith, et al., 2009) refer to this fault as the Hallaig Fault and describe its surface expression, comprising significant trenches in the landscape (Figure 10-61). They attribute movement to have taken place during the Late Devensian, after the decay of the last ice sheet, when periglacial (cold climate) processes occurred (10.F), with the accumulation of large aprons of talus/scree below the cliffs. Unloading of the ice resulted in crustal rebound, possibly leading to fault (re)activation. Displacement during the Holocene is not recognised, including any present-day movement (Smith, et al., 2009).

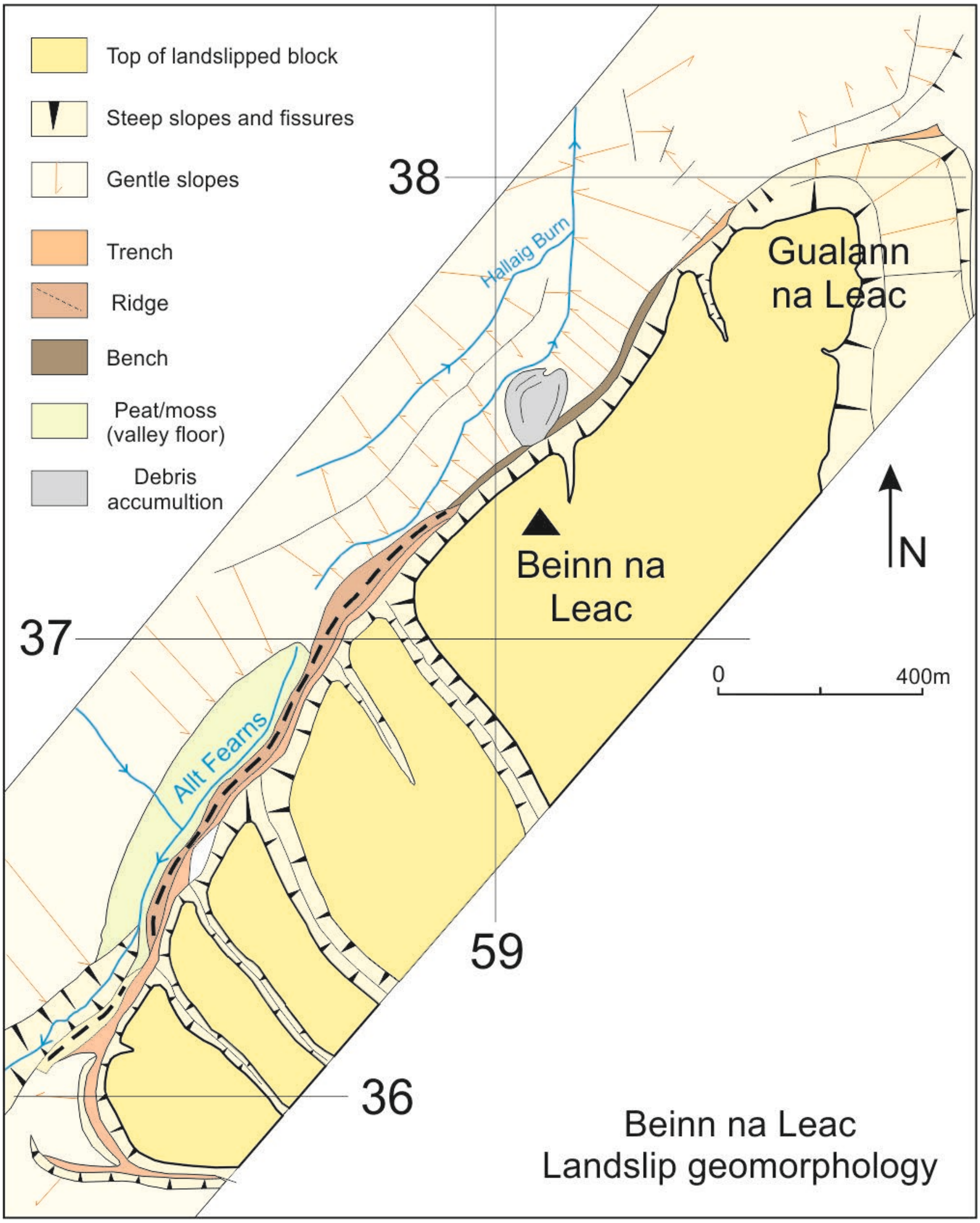


Figure 10-61 – Details of geomorphological features associated with the Beinn na Leac Landslip (after Smith et al. 2009, who refer to it as the Hallaig Landslip).

The landslip further north at Hallaig-Creag nan Cadhaig has not been studied in as much detail (Figure 10-62; Figure 10-63). It is dominated by Lower Jurassic strata, mainly Pabay Shale Formation and Scalpay Sandstone Formation strata (BGS, 2006a), with over-steepened strata due to block rotation, and the formation of significant trenches defining fault traces, large enough to swallow a sheep.

Figure 10-62 – The Hallaig Landslip, with multiple internal bench-like scars, and (in the distance) the northern part of the Beinn na Leac Landslip in SE Raasay. View towards the SE from the summit of Dùn Caan.

Figure 10-63 – The Hallaig Landslip in SE Raasay. View towards the SE from Brochel on the east coast of the island.

Where the Middle Jurassic Druim an Fhuarain Sandstone Member of the Bearreraig Sandstone Formation (4.C) forms large east-facing inland cliffs at Druim an Aonaich, it is evident that there are areas of instability, with the potential for significant blocks to detach from the crags and either rotate or tumble eastwards towards the coastline (Figure 10-64).

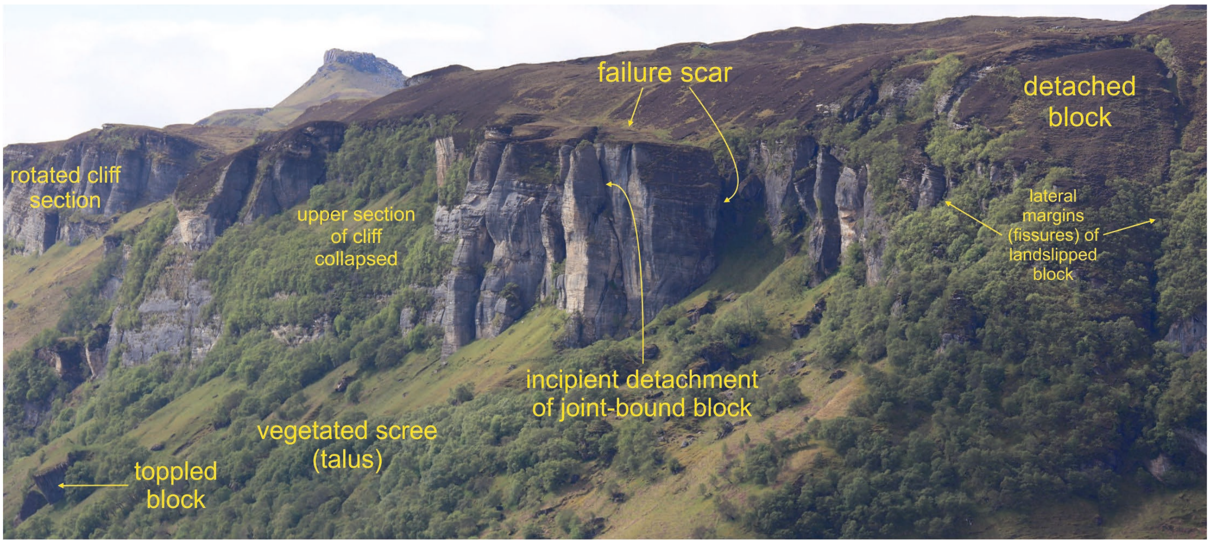


Figure 10-64 – Insipient failures within the Druim an Fhuarain Sandstone Member between Creag na Bruaich and Druim an Aonaich on the east coast of Raasay. View towards the south from Brochel.

10.H Raised Shorelines

Skye and Raasay have spectacular coastlines, with cliffs, inland-penetrating sea lochs (fjords) and sandy bays, all of which offer superb views of the inland parts of the islands (Figure 10-65; Figure 10-66; Figure 10-67; Figure 10-68; Figure 10-69). Where not fringed by cliffs, there are textbook examples of raised shorelines that have formed in response to glacio-isostatic uplift (rebound due to the retreat of the ice) and eustatic sea-level changes, although details of their origin and timing of development are not always clear. These raised shorelines can be subdivided into four types: high rock platforms; low rock platforms; raised shorelines attributed to ice-sheet deglaciation; and, Holocene raised shorelines. (Selby & Smith, 2016) provide a useful survey and summary.

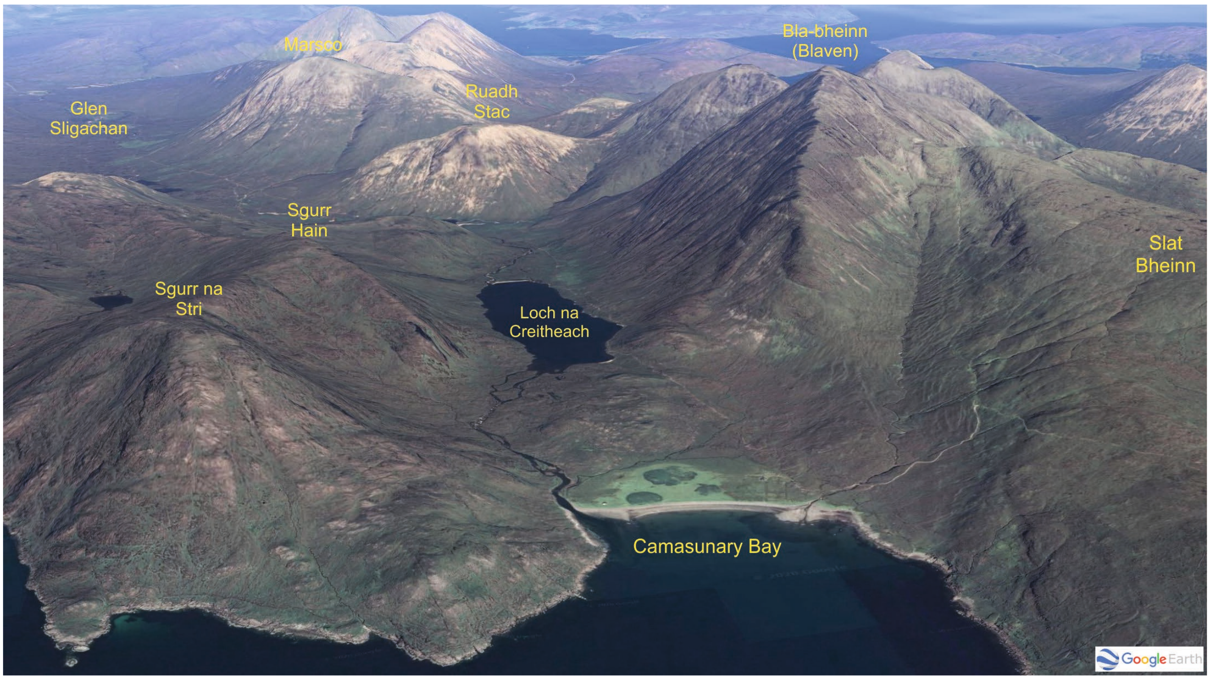


Figure 10-65 – The glacial U-shaped valley of Glen Sligachan – Srath na Crèitheach, with a raised beach at its southern end in Camasunary Bay, viewed looking towards the north. Oblique Google Earth© image.

Figure 10-66 – Camasunary Bay at the head of Loch Scavaig with its prominent raised beach. View towards the west from the Kilmarie-Camasunary track.

Figure 10-67 – Camas Malag on the east coast of Loch Slapin with its prominent raised beach. View towards the east from Kepoch on Strathaird.

Figure 10-68 – The raised beach at Camas Malag on the east coast of Loch Slapin. View towards the west, with the Blà-bheinn (Blaven) - Clach Glas - Garbh-bheinn ridge in the distance.

Figure 10-69 – The raised beach at Rubha an Torra Mhòir on the north side of the entrance to Loch Sligachan. View towards the north from the entrance to Loch Sligachan.

High rock platforms typically occur at heights of 17-30m above present-day sea-level on Skye and are well developed along the east coast of Trotternish, for example at Rubha Garbhaig, with a width of *c.* 150m (Figure 10-70) and at Rubha Hunish (Figure 10-71). Some of these platforms cut through till deposits, for example at Staffin. Covers of shingle are relatively common, for example, at Holm, south of Bearreraig Bay. Formation of these platforms is ascribed to relatively Lateglacial coastal activity, i.e. during the Late Glacial Interstadial between 14.7 ka and 12.9 ka ((Richards, 1969); (Richards, 1971)). High rock platforms are uncommon in west Skye and absent in south and east Skye.

Figure 10-70 – The high rock platform (17-30m) at Rubha Garbhaig, south of Staffin Bay on the east coast of Trotternish. View towards the SE.

Figure 10-71 – The high rock platform (17-30m) on the peninsula of Rubha Hunish at the northern end of Trotternish. View towards the north from the Meall Tuath cliffs.

Low rock platforms occur at or close to (2-7m OD) present-day sea-level and are relatively common around Skye. Partial coverings of cemented beach gravel have been recorded from parts of the east coast of Trotternish, between Portree and Staffin. In south Skye, on the Sleat Peninsula and on Strathaird, low rock platforms are well-developed, with associated raised sea caves and stacks, for example at Glasnakille on the east coast of Strathaird. Interpretation of their formation and timing of formation is based upon correlative evidence from elsewhere along the western seaboard of Scotland, where the so-called Main Rock Platform, understood to have formed by rapid intertidal erosion due to periglacial conditions during the Loch Lomond Stadial (LLS) (10.E). This interpretation is backed up by the observation that low rock platforms do not occur around lochs Sligachan, Ainort and Slapin, which were ice-filled during the LLS.

Terraces of gravel and cobbles covering raised shorelines attributed to ice-sheet deglaciation, up to 30m above present-day sea-level, are relatively common around Skye and Raasay. ((Clough & Harker, 1904); (Peach, et al., 1910); (Richards, 1971); (Walker, et al., 1988)). Good examples occur along the coast between Kyleakin and Broadford and continue to be used as a source of aggregate (Figure 10-72).

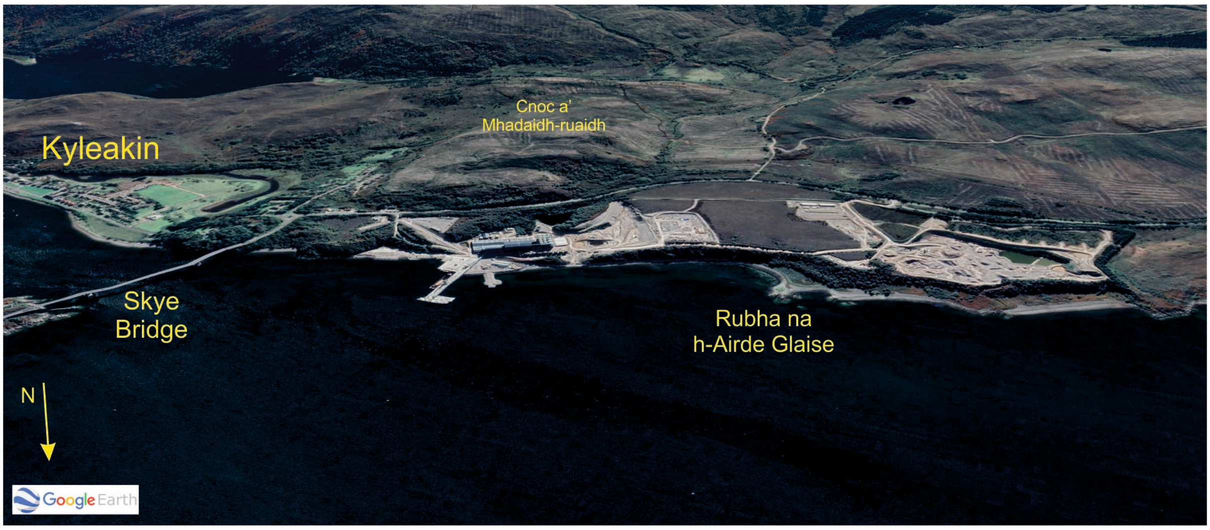


Figure 10-72 – Oblique Google Earth© image of the coastal area west of Kyleakin, comprising raised shoreline accumulations of sand and gravel. View towards the south.

The highest of these deposits is interpreted as having formed when the marine limit was at its maximum, during the Lateglacial Interstadial (14.7-12.9 ka), prior to the Loch Lomond Stade (10.A; 10.E). The height relative to present-day sea-level is not constant across Skye, with a value of *c.* 30m in the area around Kyleakin, reducing to *c.* 15m near Loch Harport, on the north side of Minginish, with a gradient of *c.* 0.4m.km^{-1} (Walker, et al., 1988), attributable to differential isostatic uplift. The high values in east Skye, around Kyleakin, and south onto the Sleat Peninsula, indicate that *relative* sea-level remained high in this area until the Mainland ice (10.D) had retreated eastwards from Skye. Localised anomalies are present, for example, at the mouth of Loch Brittle, west of the Cuillin Hills, where the raised shoreline deposits at Culnamean indicate significant uplift in the time interval between the initial deglaciation and the subsequent local development of ice before the Lateglacial Interstade at *c.* 14.7 ka (Walker, et al., 1988).

Of note, raised shorelines and associated deposits above *c.* 15m are not present within the determined limit of the Loch Lomond Stadial (10.E). This height limit can be attributed to the fact that by the time of the Loch Lomond Stadial maximum, relative sea-level was below the level of the highest Holocene raised shoreline due to rapid isostatic uplift during the Late Glacial Interstadial.

Examples of this contrast between inside and outside the limit of the Loch Lomond Readvance include the absence of raised shorelines and associated deposits around Loch Ainort and around the inner parts of lochs Scavaig and Slapin, and that within the limit of the readvance, at Sconser and Sligachan, the raised shoreline is at *c.* 7m OD, whereas at The Braes and where Loch Scavaig opens out into the Narrows of Raasay, *c.* 1km outside the readvance limit, the raised shoreline is at *c.* 30m OD.

Holocene raised shorelines are well-developed around Skye and Raasay and are typically at *c.* 10m OD (the so-called 25 Foot Raised Beaches identified on older maps of the Geological Survey of Great Britain). Coast geometry controls their form, variously taking the form of raised ridges of shingle (e.g. Staffin Bay) and raised tombolos (e.g. Àird Mhòr on the west coast of Waternish and An Àird on the Narrows of Raasay). An example of a present-day tombolo is at Lampay, NW of Dunvegan (Figure 10-73).

Inside the limit of the Loch Lomond Readvance, such raised shorelines are commonly on moraines, for example at the head of Loch Slapin and at Luib on the south side of Loch Ainort. Both glacio-isostatic uplift (rebound due to retreat of the ice) and eustatic (worldwide) sea-level changes have contributed to their development, greatest in east and SE Skye, least in north and west Skye and Raasay.

Figure 10-73 – Tombolo between the (tidal) island of Lampay and the west coast of Skye on the eastern shore of Loch Dunvegan. To the north (right-hand-side) are the coral sands of Claigan. View towards the west, with Dunvegan Head in the distance.

Throughout the Holocene Epoch, various small marine-marginal areas, so-called isolation basins and back-barrier areas, on Skye were temporarily inundated by the sea (Figure 10-74; Figure 10-75; Figure 10-76). Ages for these events, attributable to relative changes in sea-level as a consequence of glacial-isostatic adjustment and eustatic processes, have been determined from lithostratigraphic analysis combined with analyses of pollen and diatoms of shallow cores through the sedimentary sequences within these areas. These data provide an indication of the environments of deposition (marine or non-marine), the ages at which the environment of deposition changed (from radiocarbon dating techniques), and the duration of each event ((Selby & Smith, 2016) and references therein).

Figure 10-74 – Isolation basin – back barrier at Kilvaxer (Cille a' Bhacstair) on the west coast of Trotternish that has been subjected to Holocene flooding events. View towards the NE.

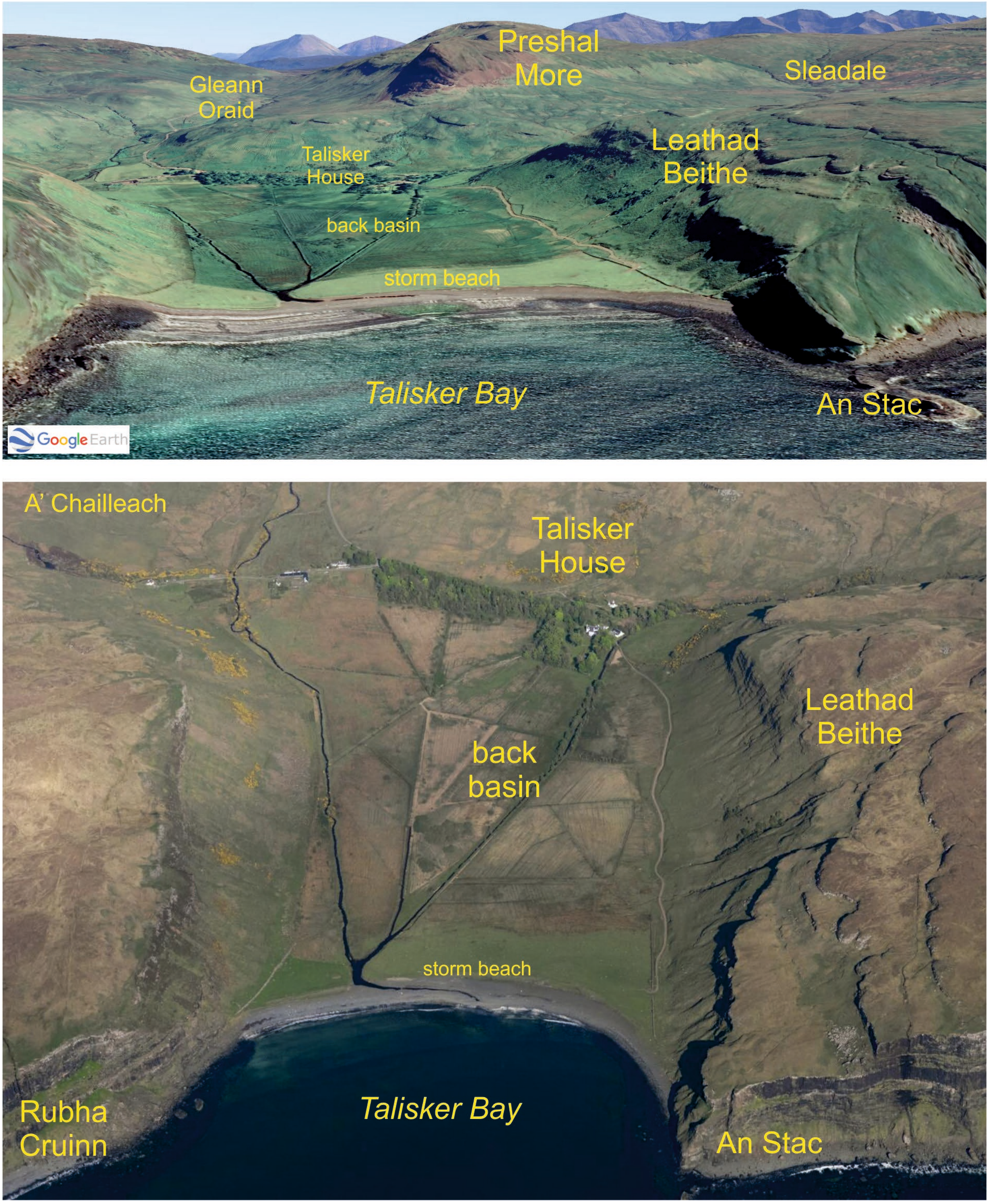


Figure 10-75 – Talisker Bay on the west side of Minginish, with its present-day beach and associated storm beach, behind which is a basin that is subjected to occasional inundation of the sea during exceptional tides and storm conditions. It has been recorded that that the sea has reached Talisker House, which is located *c.* 1km inland, but at an altitude of less than 10m OD. View towards the east with the valley of Gleann Oraid and the lava inselberg of Preshal More (320m OD). Oblique Google Earth© image.

Figure 10-76 – Talisker House at the back of Talisker Bay, viewed from the summit of Preshal More. It has been reported that the sea reached this far inland (*c.* 1km) during exceptional tides and storm conditions.

Six sites on Skye have been examined, from Point of Sleat in the SE, to Ardmore Bay on Waternish in the NW. The combined dataset indicates that the environment in these marine-marginal areas was not synchronously marine or non-marine, varying across the island. For example, at Point of Sleat, closest to the Mainland, where glacio-isostatic adjustment was greatest, the environment was marine sometime during the Late Glacial Interstadial, possibly becoming non-marine during the Loch Lomond Stadial, returning to marine or estuarine conditions at the start of the Holocene Epoch. During the Holocene, the environment of deposition, marine versus non-marine, varied in a complex manner. At the start of the Holocene, a marine incursion had most likely occurred. Similar oscillations between marine and non-marine conditions in these marine-marginal areas occurred at sites further to the NW, although not necessarily synchronous with the Point of Sleat events.

The timing(s) of marine inundations, some relatively short-lived, have been potentially correlated with major inputs of water into the (global) marine environment, such as the massive discharge of water from (the glacial) Lake Agassiz-Ojibway in North America between 8490 and 8420 a BP (years before present) that may correlate with a marine incursion (inundation) recorded at Talisker Bay ((Barber, et al., 1999); (Ellison, et al., 2006)). Similarly, the marine Storegga Slide tsunami, originating off the Norway coast and dated at 8110 ± 100 a BP may have caused short-lived incursions of marine water into some of the Skye marine-marginal areas (Smith, et al., 2013).

10.I Lateglacial and Early Holocene Environmental Changes

Pollen-stratigraphic analysis of material from Skye and Raasay provides a record of the environment during the Late Glacial Interstadial (14.7-12.9 ka), the Loch Lomond Stadial (LLS) (12.9-11.7 ka) and the Early Holocene Epoch (starting at 11.7 ka). Interpretation of these local events can be assessed with reference to data from elsewhere in the North Atlantic area, which provides context in terms of climate change. Insect assemblages, including chironomids, and Iceland-derived tephra accumulations (10.J), also aid in developing a chronological account of the environment during this time interval. (Lowe & Walker, 2016) provide a useful summary, from which the following has been taken.

Climatic conditions clearly influenced the extent of plant and animal colonisation. As the climate warmed during the Early Holocene, colonisation progressively took place. Elsewhere in the Hebrides and on the Scottish Mainland, a consistent sequence of deposits recorded three events: a non-organic sediment layer (oldest) formed during withdrawal of Dimlington Stadial ice (10.A); an organic unit (muds or gyttja) formed during the Late Glacial Interstadial; and, a non-organic sediment layer (youngest) formed during the Loch Lomond Stadial. The type and number of taxa that are recorded in these sediments are a clear indication of the climate, with a reduced number of taxa and a cold-tolerant range of taxa during the colder periods. Material from four locations (Druim Loch, south of Portree, Elgol on Strathaird, Slochd Dubh on the SE side of Loch Brittle, and Loch Ashik, east of Broadford) confirm this tripartite subdivision, although pollen data record a significant revertence, or backward step, in the plant succession (or colonisation) within the uppermost of the three units. Sediments from lochs inside the ice-limit of the Loch Lomond Readvance do not record the tripartite sequence, with only sediments of Early Holocene, or younger, preserved.

The Loch Ashik site preserves the most complete record of the vegetational succession, as well as the most complete insect (chironomid) dataset. Tephra accumulations within the Loch Ashik sequence further augment the dataset and are detailed in Section 10.J. Radiocarbon ages for these deposits remain problematic (Lowe & Walker, 2016).

The Lateglacial Interstadial units at the base of the sequence record the colonisation by pioneer plants such as *Rumex* (docks and sorrels) and *Salix* (willow), followed by *Juniperus* (juniper), which is characteristic of the warming that took place at the beginning of the interstadial. Towards the end of the milder climate of the interstadial, *Empetrum* (crowberry, a dwarf heath evergreen) and *Erica* (heath or heather), along with *Betula* (birch), were dominant, with increased *Rumex* and *Lycopodium* (clubmoss), *Salix* and reduced *Juniperus* and *Empetrum.* This change in pollen assemblage is marked by a reduction in organic carbon. Overall, this change marks a temporary deterioration in the climate.

Continuing into the Loch Lomond Stadial, birch is essentially absent and so-called disturbed-ground taxa, such as *Artemisia* (daisy family) and *Lycopodium* (club moss, ground pines, creeping cedars) are relatively common. Reworking of older material is also evident, which may explain anomalous radiocarbon ages (Lowe & Walker, 2016).

The Early Holocene part of the sequence indicates a warmer climate, with the taxon, *Myriophyllum* (freshwater aquatic plants). Also present are open-ground taxa, indicative of a surrounding grassland dominated by herbaceous plants. Subsequently, *Juniperus* (juniper), *Betula* (birch) and *Corylus* (hazel) become more common. Data collected from several sites provide a relatively consistent story concerning the plant succession (Lowe & Walker, 2016), from open-habitat communities to woodland and scrub dominated by birch and hazel.

An additional dataset for the Loch Ashik sequence comprises details of chironomid (non-biting midges) assemblages, which enable an estimation of Summer temperatures throughout the Late Glacial-Early Holocene interval. The core from which the insect head capsules were recovered can be correlated with other cores taken from Loch Ashik (see above and Section 10.J). Certain taxa are indicative of so-called ultra-cold conditions, whereby the mean temperature is < 5°C, whereas others are indicative of July temperatures in the range *c.* 15-20°C (Lowe & Walker, 2016). Thus, these data can be used as a palaeo-climate proxy. Cool-temperate conditions (mean July temperature of *c.* 11-13°C) are indicated for most of the Lateglacial Interstade, with a significantly cooler period at *c.* 14 ka. A drop in temperature, gradually at first, then more rapidly, between *c.* 13.1 ka and 11.4 ka, matches well with the Loch Lomond Stadial (10.A). The thawing conditions at the end of the Loch Lomond Stadial are identified within the sequence, with a mean temperature above 11°C in the Early Holocene. There is a good correlation between the chironomid-based palaeo-climate data and degraded/deteriorated pollen: during cold time intervals, significant amounts of pollen are degraded.

10.J Iceland-derived Tephra Deposits

Skye preserves within Late Glacial to Early Holocene (terrestrial) loch sediment sequences, such as at Loch Ashik, east of Broadford, minor amounts of tephra (ash) from Icelandic volcanoes such as Katla, Grimsvötn and Askja (Lowe, et al., 2016). Within cores recovered from these sediment sequences, small quantities of dispersed, but stratigraphically distinguishable, microscopic fragments of ash, referred to as crypto-tephra (typically < 100µm across), have been recovered, chemically analysed (major-, trace- and isotope data), and correlated with major volcanic events identified in Iceland. Integration with other lithostratigraphic and climate-stratigraphic datasets (10.I) has been undertaken to strengthen and validate proposed chrono-stratigraphic correlations. A wide range of volcanological, weather-related, biological and sedimentation- and surface-reworking factors will have influenced the amount of tephra/ash that has accumulated and been preserved from any one eruption. Devitrification of some of the originally glassy fragments is common and significantly reduces its usefulness in any interpretation.

Crypto-tephra of basaltic and rhyolitic compositions has been recovered from sediment in Loch Ashik of Late Glacial age and can be correlated with material from other sites, for example, Vedde in Norway, which is the 'type-locality', together with elsewhere in Europe (as far south as Slovenia and Italy), with an age of *c.* 12 ka and attributed to the Katla volcano (Lowe, et al., 2016).

Pyne-O'Donnell ((Pyne-O'Donnell, 2007); (Pyne-O'Donnell, 2007)) identifies another discrete rhyolitic (crypto-) tephra deposit in the Late Glacial Interstadial sediments in Loch Ashik and Druim Loch, the latter referred to as the Penifiler Tephra, a location between Loch Portree and Camas Bàn, south of Portree.

The famous Saksunarvatn Ash, of basaltic composition and attributed to Grimsvötn Volcano, was named from Lake Saksunarvatn on the island of Streymoy in the Faroe Islands, where it was first recognised (Waagsten & Johansen, 1968). It has been identified in the Skye sequence and radiocarbon dated as being of Early Holocene age, *c.* 10,210 ± 35 a BP (Lowe, et al., 2016). Other ashes have been tentatively identified on Skye, giving a total of six within the Late Glacial Interstadial to Early Holocene interval.

10.K Holocene Colonisation

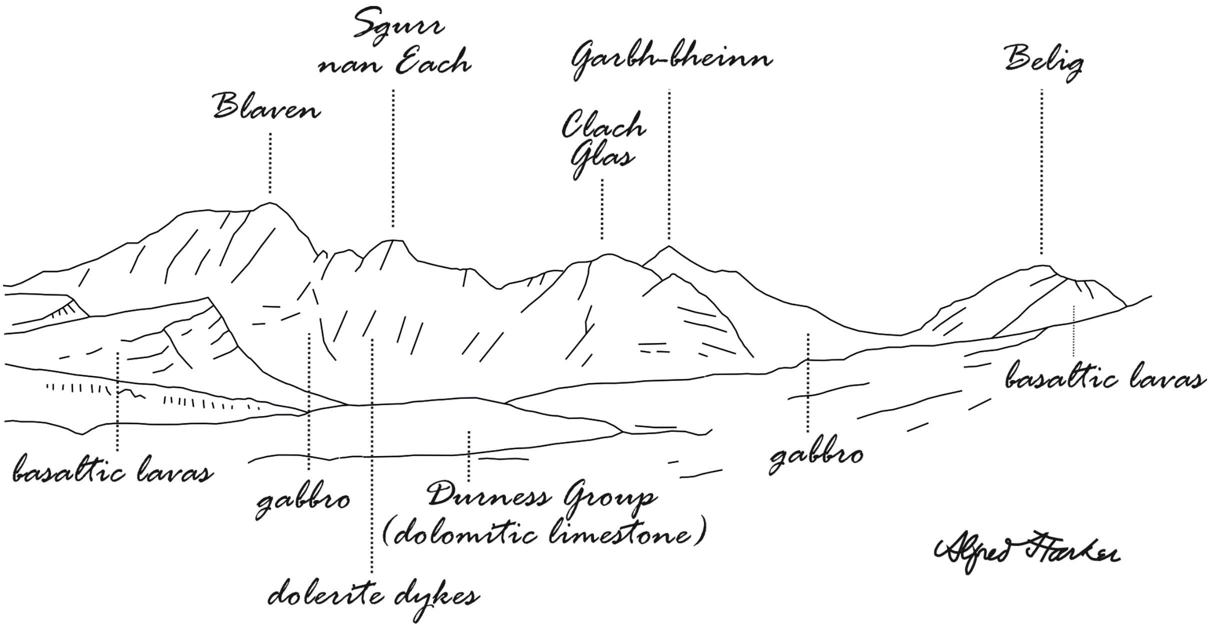
As Skye and Raasay emerged from the glacial environment at the beginning of the Holocene Epoch around 11,700 a BP, the climate ameliorated, sea-level started to rise (10.H) and plants and animals, not tolerant to cold conditions, started to colonise the islands (Birch, 2016). Thereafter, human beings began to colonise the islands, first as hunter-gatherers and fishermen, and subsequently as farmers where the land was of sufficient quality. Colonisation inevitably led to significant modification of the landscape (Figure 10-77), through removal of trees to provide fuel and to enable farming. One of the first sites to be colonised was on the SW coast of Raasay, at Clachan in Churchton Bay, where evidence for the presence of Mesolithic people at *c.* 7.1-7.6 ka BP, takes the form of fabricated lithics, such as blades and flakes. Other sites include: An Corran on the south side of Staffin Bay on Trotternish; Loch a' Sguirr (Loch an Sgurra) at the northern end of Raasay; and, Camas Daraich at the southern end of the Sleat Peninsula (Birch, 2016).

One cannot fail to notice some of the more obvious archaeological sites on Skye and Raasay when studying the islands' geological evolution. Although beyond the scope of this book, where appropriate in the accompanying geological excursions, brief outlines are given. (Birch, 2016) provides an excellent summary of the prehistoric archaeology of Skye and Raasay, together with details of some of the most important sites.

Figure 10-77 – Rapid erosion by apparently mindless tourists on the 'path' from the main road to the Old Man of Storr at the foot of the Trotternish Escarpment.

Chapter 11 Geological Resources

Geological materials of economic value on Skye and Raasay are limited, although past endeavours to exploit Cambro-Ordovician marble, Lower Jurassic ironstone and Quaternary deposits of diatomite provide engaging stories of ingenuity and fortitude. Today, the only materials actively exploited are Cambro-Ordovician marble, Proterozoic hard-rock, and Quaternary sand and gravel.



11.A Introduction

Financially viable geological resources on Skye and Raasay are limited and currently comprise: decorative marble and crushed rock products at Torrin; crushed hard-rock products at Sconser; and, sand and gravel extracted at Kyleakin.

Marble at Torrin, the result of contact metamorphism of Cambro-Ordovician Durness Group dolostones by the Paleocene Beinn an Dubhaich Granite of the Eastern Red Hills Intrusive Centre (6.G.5; 6.H), has been a source of decorative stone, slow release fertiliser and aggregate since 1951, when a small quarry, now abandoned, was developed at Cnoc Slapin. Production switched to the currently active quarry in Torrin in 1960. Older quarries at Kilchrist, now abandoned, exploited the same marble and date back to the early 20th Century.

Diatomite extraction at Loch Cuithir, Digg, Sartle and Kilmuir on Trotternish (10.G) was a relatively short-lived industry at the beginning of the 20th Century, although important at the time.

Similarly, extraction of material from the Lower Jurassic Raasay Ironstone Formation in south Raasay (4.C) provided an important source of iron ore during the First World War; production stopped soon after, the mine was put on care and maintenance, and ultimately closed and abandoned.

Crushed hard-rock aggregate is currently produced at Sconser from thermally-altered Proterozoic Applecross Formation (Torridonian) strata (3.C; 6.H) north of the Western Red Hills Intrusive Centre.

At Kyleakin, sand and gravel are extracted from Quaternary raised shoreline (coastal) deposits (10.H).

Summaries of these exploitations, past and present, are set out below.

11.B Strath Marble Quarries

Some of the earliest observations that marble was extracted from the thermally altered Cambro-Ordovician Durness Group dolostones in Strath were made by Martin Martin (*A Description of the Western Isles of Scotland,* 1716), Thomas Pennant (*A Tour in Scotland, and Voyage to the Hebrides,* 1772) and John Macculloch (*A Description of the Western Isles of Scotland, Including the Isle of Man,* 1819). (Macculloch, 1819) notes that material was exported from Skye as an ornamental stone, with its attractive patches of green coloration due to hydration of metamorphic olivine to serpentine.

In the first decade of the 20th Century, an extraction company was set up and started to work material that occurs adjacent to gabbro 2.5km NW of Broadford. A short tramway was built to enable material to be transported to the public road and onwards to a pier on the west side of Broadford Bay. (Peach, et al., 1910) record that in 1908 the only material exported from this venture was small chips of marble for the production of mosaic cubes and terrazzo mosaic. It was planned to develop slab and block production thereafter. There are no records as to how this developed but it is safe to say that it was not successful and the operation was terminated.

The same company set up trial quarries SE of Loch Cill Chriosd (Kilchrist), which were subsequently expanded and produced substantial blocks of ornamental stone for export (Figure 11-1; Figure 11-2; Figure 11-3; Figure 11-4; Figure 11-5). It is recorded that blocks and slabs of this marble were used in buildings such as Iona Abbey and Armadale Castle, the latter on the Sleat Peninsula, SE Skye.

The enterprise started in 1907 with an on-site processing plant close to Loch Cill Chriosd for cutting and polishing material. Subsequently, production extended to crushed stone (aggregate) that was then transported 3 miles (5km) to the pier at Broadford on a narrow gauge (914mm or 3 feet) railway. Horses initial provided the pulling power, but were replaced briefly by steam power. The locomotive used, *Skylark,* was built in 1892 by the Hunslet Engine Company of Leeds. The operation closed in 1912. The infrastructure of the operation (houses, a shop and a club) were demolished, the railway line was lifted and the train disposed of. The locations of the upper and lower railway lines are still visible, the upper marked by the so-called Marble Line Path (part of the path between Broadford to Boreraig). Still preserved on-site items of interest include remnants of some buildings, including a crushing plant, the railway loading platform, and the base of a wagon turntable. The railhead at Broadford was located close to the outflow of the Broadford River.

Figure 11-1 – Typical marble from one of the abandoned quarries at Kilchrist. The green coloration is metamorphic olivine replaced by secondary serpentine. Coin *c.* 24mm across.

Figure 11-2 – Information board with details of the early 20th Century marble quarries at Kilchrist.

Figure 11-3 – Workers at the Kilchrist marble quarries.

Figure 11-4 – The steam locomotive *Skylark,* used to haul material from the Kilchrist quarries to the pier at Broadford.

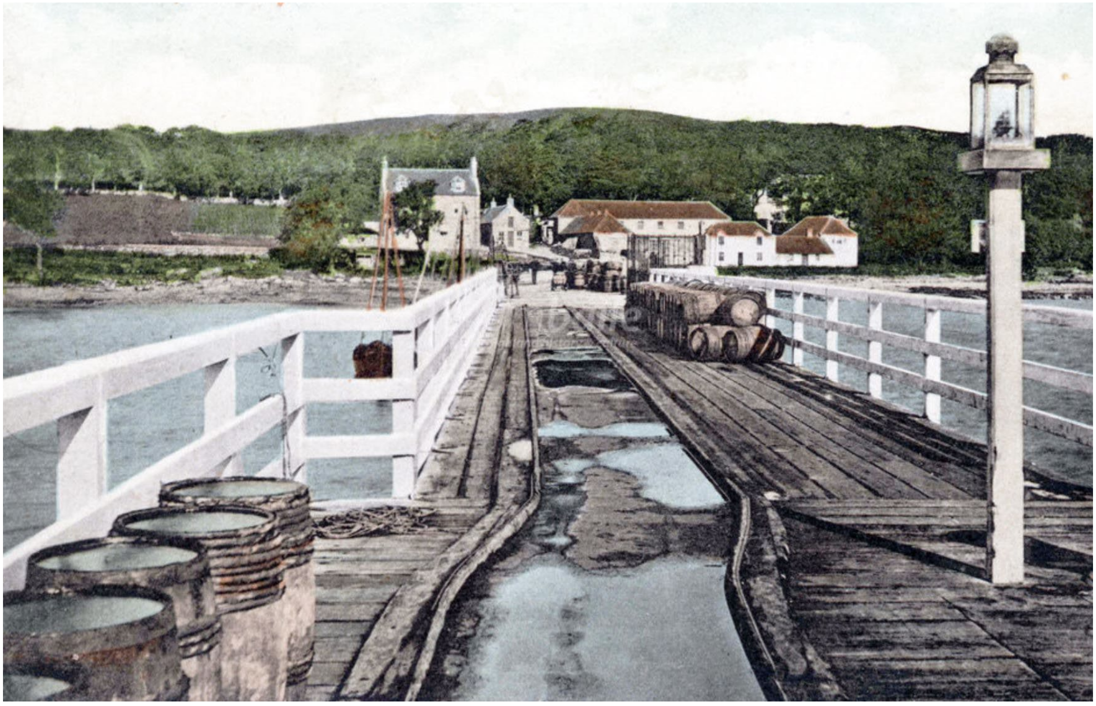


Figure 11-5 – The old pier at Broadford.

Interest in the marble as a slow release fertiliser and aggregate was rekindled after the Second World War and, in 1951, a small quarry, now abandoned, was developed at Cnoc Slapin (Figure 11-6**;** Figure 11-7). Production switched to the active quarry in Torrin in 1960 (Figure 11-8**;** Figure 11-9). Currently, the range of products comprises slow-release fertiliser, concrete products, decorative stone and pebble dash coatings for buildings.

Figure 11-6 – The abandoned marble quarry at Cnoc Slapin, close to the head of Loch Slapin. View towards the NE from the east side of Strathaird.

Figure 11-7 – Detail of the abandoned quarry at Cnoc Slapin, with a segmented Paleocene dolerite dyke within Cambro-Ordovician Durness Group dolostones. Fence post for scale.

Figure 11-8 – The active marble quarry at Torrin. View towards the NW from the Kilbride-Camas Malag road.

Figure 11-9 – Detail of the active quarry at Torrin, with irregular-shaped Paleocene dolerite dykes within Cambro-Ordovician Durness Group dolostones.

11.C Diatomite Extraction on Trotternish

Diatomite was discovered at a number of locations on Trotternish in north Skye in 1886 and exploited by the Skye Diatomite Company from 1899.

Diatomite (diatomaceous earth, or *kieselguhr*) is the remains of diatoms, single-celled aquatic algae made of opaline silica that can accumulate in fresh-water loch (lake) sediments. If no other material is deposited, very pure layers can form. It is green when wet and white when dry and processed. Diatomite is capable of absorbing up to three times its weight of water. Consequently, after processing, it has a wide variety of commercial applications: a stabiliser for explosives; filters; very mild abrasives; insecticides; thermal barriers; and various agricultural products.

Discoveries were made at at Digg, Sartle and Kilmuir (10.G), with the most extensive being at Loch Cuithir, below Flasvein on the inland lava escarpment (Figure 11-10; Figure 11-11; Figure 11-12; Figure 11-13; Figure 11-14). The deposits accumulated on Quaternary glacial moraines during the Holocene Epoch, a period of relatively higher temperatures; however, the presence of overlying peat, which has formed during subsequent less mild and wetter conditions, suggests that diatomite is no longer accumulating.

All that is left of this industry that employed up to fifty people at Loch Cuithir are remnants of the narrow gauge (2 foot; 61cm) tramway that ran parallel to the Lealt River, and derelict buildings at Loch Cuithir and at Inver Tote on the coastline. The diatomite was processed at Inver Tote and shipped out. Peat was cut during the winter months to facilitate the kiln drying process.

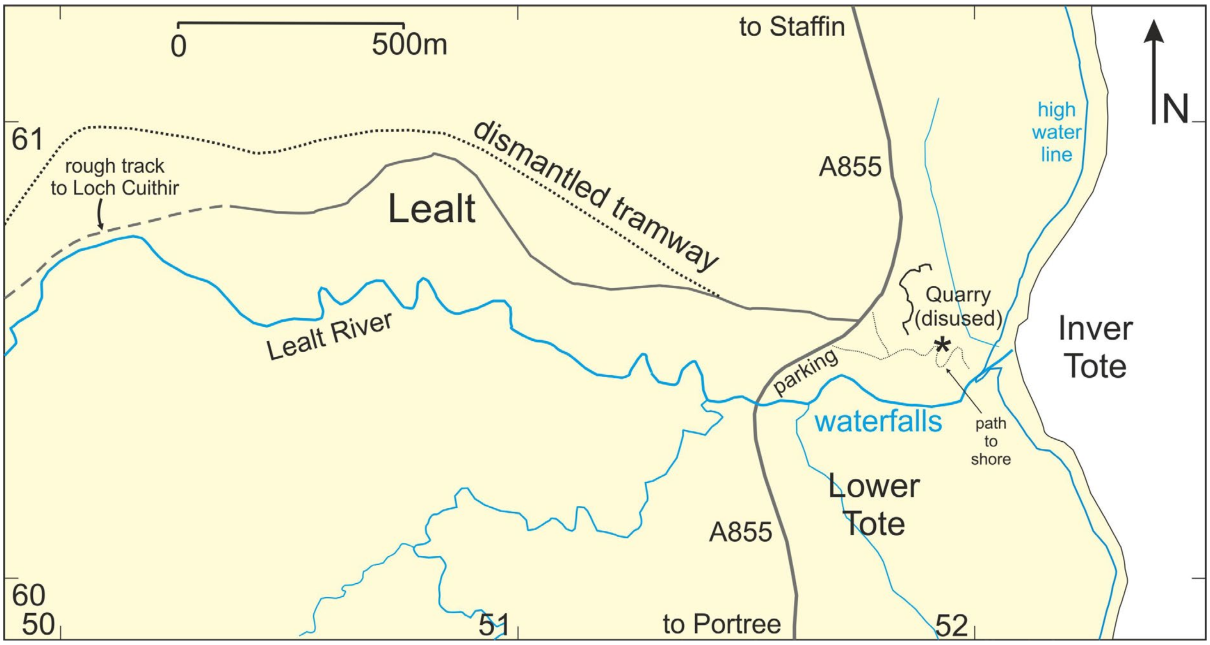
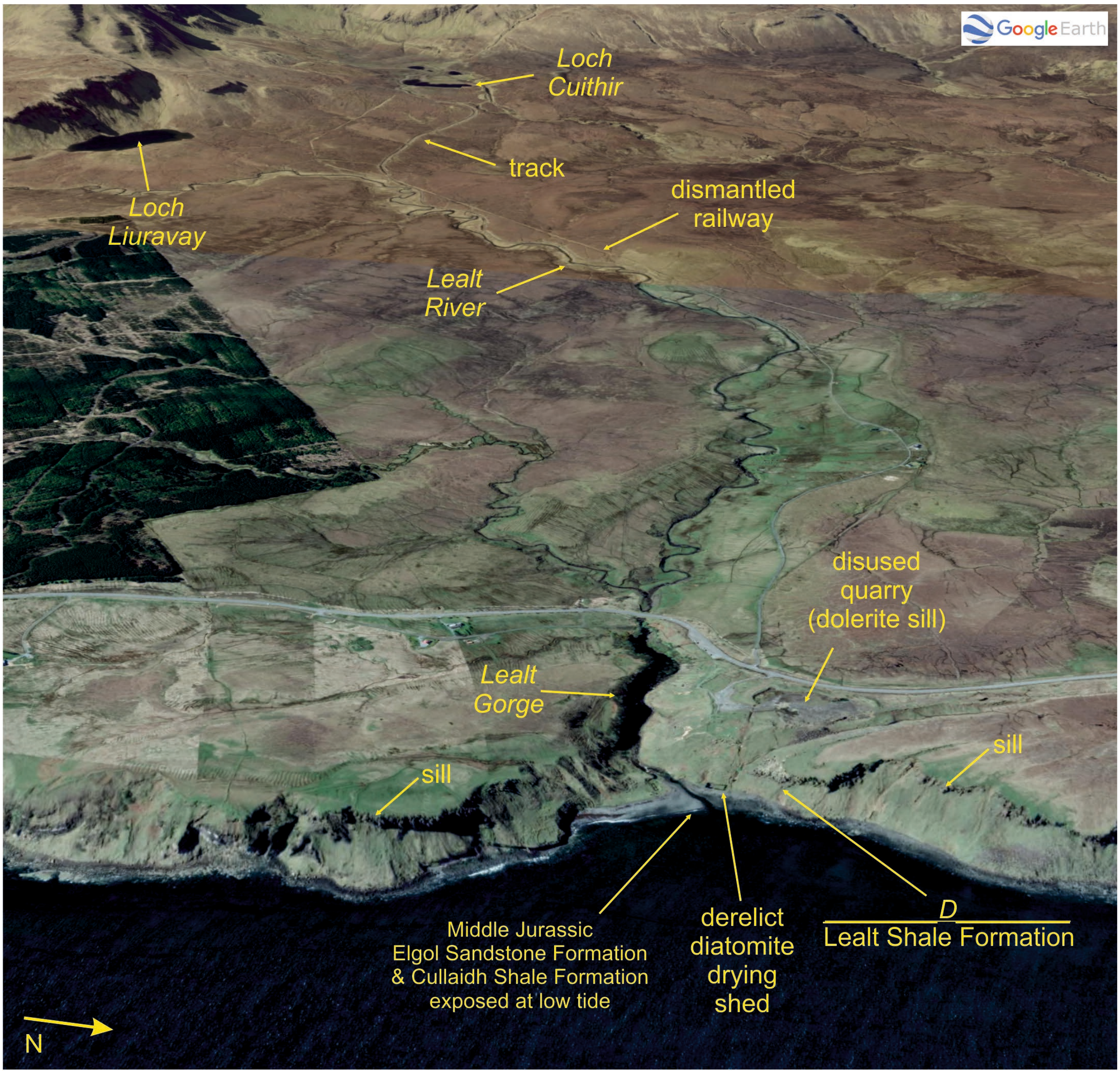


Figure 11-10 – Location map for Loch Cuithir - Lealt - Inver Tote area.



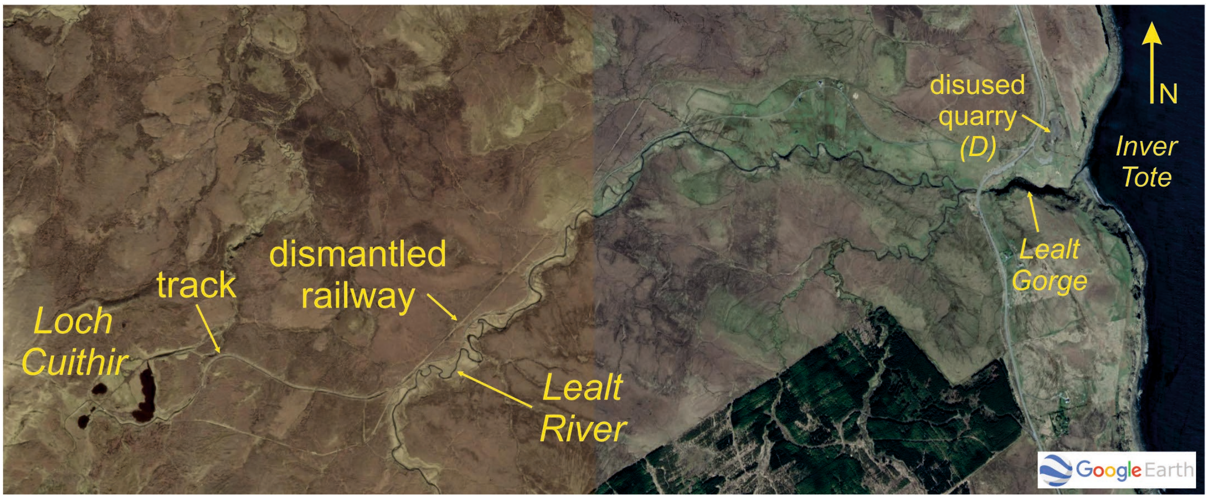


Figure 11-11 – Annotated Google Earth® images of the Loch Cuithir – Inver Tote area.

Figure 11-12 – Loch Cuithir, view towards the west.

Figure 11-13 – Remains of extraction plant at Loch Cuithir.

Figure 11-14 – Trace of tramway between Loch Cuithir and Inver Tote. View towards the west.

Locally known as *caile* (Gaelic, chalk), the diatomite was dried on wire nets at Loch Cuithir and then transported to Inver Tote, initially on horseback, but subsequently via a gravity-driven tramway, first by manpower and later using a stream locomotive. At Inver Tote, the diatomite was kiln dried, ground and calcined (heat treated, to remove carbonate and any organic material) (Figure 11-15; Figure 11-16). It is estimated that *c.* 2000 tons of diatomite were extracted.

Figure 11-15 – Information board on the Loch Cuithir diatomite exploitation at the Lealt River coastal viewpoint.

Figure 11-16 – Remains of the kiln at Inver Tote.

The diatomite from the Loch Cuithir deposit is very pure, with little or no interlayered silt or mud, and contains over 96% silica (SiO_2). The absorptive value of the material is over 3.56 (a good diatomite would have an absorptive value in excess of 4.0).

An article in *The Scotsman* newspaper, published in 1887, describes the construction of the extraction and processing infrastructure. It also describes how the loch was drained via the formation of a 300m long cutting, 4m wide and 4m deep.

The diatomite formed a layer just 0.5m below the surface, extending to a depth of *c.* 8m, and was cut using a peat spade into blocks and hand-barrowed to the drying sheds.

One account of the activity was recorded by Dr J. A. MacCulloch, Rector of Saint Columba's in Portree. His report was compiled from observations made on one of the boats that collected the diatomite:

'A drying and grinding factory has been erected at the water's edge; great sheds stand on the upper slopes at a precarious angle; while a miniature railway, a continuation of one which runs inland to the diatomite beds, connects the edge of the cliff with the landing-stage and factory far below. When we arrived the work-people were all at the loch and there was scarce a sign of life round this lonely day. But presently a long train of men and women began to zigzag down the path on the face of the slope and transformed this solitude into humming activity. They must get the cargo embarked while the tide served. Each one carried a bag of diatomite from the grinding-house to the boat slip, till the coble was piled up with sacks. Then it made a slow journey to the steamer, where the sacks were transferred to the hold. Meanwhile a second coble was a-filling, and so all day long, for there were hundreds and hundreds of sacks to be removed, the work went steadily on.'

An article in *Scotsman* newspaper describes how the diatomite was processed (Figure 11-17).

THE LOCH QUIRE DIATOMITE WORKS.—These works on the Kilmuir estate, Skye, continue to make satisfactory progress. The Company was formed about a year ago, and active operations were begun in February last. Since then a force of men varying from fifteen to fifty has been steadily employed. The loch, the bed of which is quite level and covered with marshy reeds, has been successfully drained by the formation of a cutting 300 yards long, 12 feet wide at the top, and from 12 to 18 feet deep. Two smaller cuttings have been carried partly round the loch, and a pretty large drain reaches through the centre. The bed of the loch is now fairly dry. The cost of drainage has been about £200. A supply of peat has been cut for kiln-drying during the winter season. Twelve wooden drying sheds have also been erected, and others are in course of erection. The sheds are 25 feet long by 3 feet 6 inches broad, open at the sides, with five drying pans in each, one above the other. Two semi-circular iron stores, 25 feet long by 18 feet broad, with a radius from side to side of 28 feet, are likewise nearly finished. Two similar stores, 50 feet long by 18 feet broad, are being put up at the seaside. The stores are constructed of galvanised corrugated iron. The diatomite, which lies about 18 inches below the surface and extends downwards to a depth of 25 feet, is cut with an ordinary peat spade, in blocks about 10 inches long by 3 broad. It is taken on hand-barrows to the drying sheds, where it is left till dry. It is then put into the stores. When cut it has a greenish appearance and is pretty heavy. After being dried, the colour changes to white, and the weight is very much decreased. During the bright sunshine of last week the drying sheds, with their shelves all filled with blocks of pure white diatomite, and situated amidst the wide moors, formed an exceedingly pretty spectacle. Until such time as a permanent road from the seaside to the works is constructed the diatomite will be conveyed on horseback to the shipping place, at a cost of about 15s. per ton. A visit to the works now in progress readily convinces one of the almost inexhaustible supply of pure diatomite embedded there, and of the great importance of the new industry to this portion of Skye. It is reported that similar works will ere long be started at Loch Callumkill, on the farm of Monkstadts. The deposit at Loch Callumkill is very accessible, but not quite so pure as that at Loch Quire.

Figure 11-17 – Details of how diatomite from the Loch Cuithir deposit was processed (from the Scotsman (23rd June 1887)).

Production was significant during the First World War and intermittent thereafter. Production finally ceased in 1960. A feasibility studied at the end of the 1960s concluded that a restart to extraction was uneconomic. A useful summary was published in the *Stornoway Gazette* (5th March 2008):

In the Trotternish area of Skye, taking the Staffin road out of Portree, travellers will pass the Storr Rock, and then after continuing a further five miles or so, arrive at a lay-by near a gorge with a sign pointing off to the left, indicating the small community of Lealt. There is a lot more to this area than first meets the eye, and it's all down to a substance called Diatomite and even a brush with German espionage. Known to the locals as 'Caile' (Gaelic for chalk), Diatomite is a clay-like floury grey substance, found in certain freshwater lochs and suppling many minerals used in the production of numerous products, ranging from beverages, sugars and cosmetics to chemicals, industrial oils and paint. Trotternish was home to two mining areas – one in Digg, Staffin, and the other at Loch Cuithir in Lealt. Although little is known of the Digg mine, where production ended sometime after the First World War, it is the history of the Loch Cuithir mine which is of interest. Work began at Cuithir in 1899 and finally ceased over six decades later in 1960. Over the years, the mine saw periods of inactivity, but when up and running operations made use of the large industrial works at the area – a large factory building, a railway with embankment cuttings, and a rolling stock traversing three miles of landscape, including an aerial ropeway. The light railway was used to transport the Loch Cuithir Diatomite to the shores at Invertote for a final drying and grinding, and a large building containing a furnace, grinding machine and storage space was constructed there for this purpose. Such modernised business works were quite remarkable for this part of the world at the time. In those days there was no road between Staffin and Portree, so a puffer boat would anchor in the bay at Lealt, and local skiffs were used to transport the finished Diatomite from shore to boat, ready for shipping to the mainland. There were around 40 to 50 people steadily employed at Lealt, yet on days that the boat came in this total rose to as many as 80 workers. Perhaps one of the most intriguing aspects of the mine's history comes from the ownership of the drying factory at Invertote by Germans. Although closed during the period of the Great War, surprisingly the now enemy foreign residents were allowed to stay on. Shortly afterwards a rumour began to circulate that the area was haunted and that the ghost of a recent tragic death at the Lealt Falls had appeared at the factory. As the local story goes, (the rumour was actually started by the Germans) with the intent of keeping locals away. It turned out that the resident Germans were spies and that, almost unbelievable to the community, the area was being used as a German base with submarines surfacing in the sea bay! Moving on, the year 1950 saw the next development in the mining of Diatomite from Loch Cuithir. As the loch was one and a half miles up the moor, through peat bogs and rivers, the Department of Agriculture and Fisheries for Scotland (DAFS) decided that a road should be built, with the intention of extracting the Diatomite by digger, and then taking it to the Lealt road end above Invertote. The road took around a year and a half to build, during which the mine was put out of operation. Yet, when production started again, the new method of extraction did not reach the high standard of quality which was achieved when extracted manually by spades. The mechanical extraction resulted in the diatomite being less pure, and full of unwanted dirt. Drying the substance is, in fact, the problem of the process, for it is obvious that in a damp climate like Skye, the diatomite does not lose its moisture quickly. The problems which began after the construction of the 1950s road were further highlighted and compounded six years later. A new factory was built at Uig (the site where the Cal Mac offices are now situated), far from the mining site at Loch Cuithir, and it may be said that this move was the ruining of the entire diatomite industry upon Skye. As diatomite was no longer dried at

Inver Tote it now had to be transported by road, wet, for the much-needed drying process to Uig, 23 miles away. A vehicle may have left Loch Cuithir carrying five tonnes of Diatomite, yet only producing one tonne of the finished product after drying had taken place – a finished product which was also not as pure as it ought to be for the specialised work it had to do in various products. A lot of money was wasted on travelling, and within the factory itself, inefficiency was also present, with machinery often breaking down due to the damp state of the diatomite. Outside the factory, the scenic communities of Trotternish also began to suffer. When the factory was working, it poured out a fine white dust which covered every house in the area. Grass became chalky in colour and after dry spells in the weather, the road-sides from Staffin to Uig would turn white with diatomite – Uig was constantly under a cloud of dust. With complaints of insubstantial profits and bad management, the factory was finally closed to production for the last time in 1960. Yet, although the diatomite mining industry on Skye came to an abrupt ending, it was still regarded by many locals as a blessing at the time. Following from World War One, the industrial works provided employment for many returning men who could not find work elsewhere in the island. And at peak production, around 1955/56, 50 to 60 men were paid good wages to work at the factory.

Evidence of the former diatomite extraction process occur in a variety of forms: the derelict buildings at Loch Cuithir and Inver Tote, sections of rails from the tramway between Loch Cuithir and Inver Tote, and rusted remnants of wagons used to transport the diatomite (Figure 11-18). Rare photographs of the workers remind us of the importance of diatomite mining to the local population (Figure 11-19).

Figure 11-18 – The rusted remnants of a diatomite wagon on the shore at Digg, north of Staffin Bay.

Figure 11-19 – Diatomite workers at Digg in 1918.

11.D Rassay Ironstone Mine

The abandoned ironstone mine on Raasay was active during the First World War and provides an engaging story of the development of an economic resource on a relatively remote Scottish island. The iron ore was extracted from both surface outcrop and underground, processed and shipped to the Scottish Mainland to help fulfil demands caused by the war and the lack of material from abroad (Figure 11-20; Figure 11-21).

Figure 11-20 – The Mine #1 entrance at the time of the mining operation.

Figure 11-21 – The Mine #1 entrance after closure.

The publication *The Raasay Iron Mine (where enemies became friends)* by Laurence & Pamela Draper (1990) is an excellent account of the development of the opencast and mining operations and much of the summary, below, is attributed to this publication. The black & white photographs are from the British Geological Survey archive (codes P000038, 39, 41, 43, 44, 47 & 48).

It is useful to understand the formation of the ironstone (Figure 11-22; Figure 11-23; Figure 11-24; Figure 11-25; Figure 11-26; Figure 11-27; Figure 11-28; Figure 11-29; Figure 11-30). The Raasay Ironstone Formation is a chamositic ooidal ironstone that ranges from massive, through to thinly bedded, locally cross-bedded. It overlies a sequence of dark grey to black, organic-rich, micaceous mudstones (the Portree Shale Formation) with sparse benthic fossils (4.C). Combined, these two units are typically 5-6m thick. They are of Lower Jurassic age (Toarcian; 174-183 Ma) and overlie shallow marine siltstones and sandstones of the Scalpay Sandstone Formation. The overlying Bearreraig Sandstone Formation marks a return to significant coarse clastic sediment input to the basin and was deposited in a shallow marine environment.

Deposition of the Portree Shale Formation and the Raasay Ironstone Formation occurred throughout the Hebrides Basin, although are best developed (or at least recognised) on Raasay and north Skye. Ironstones of similar age occur elsewhere, for example the Cleveland Basin of NE England. Formation of the Raasay Ironstone Formation is considered to have taken place during one of the two main Phanerozoic ironstone-forming periods in shallow marine subtidal to intertidal waters during a period of sea-level change and negligible clastic sediment input. Ammonites and belemnites are relatively common and confirm a marine environment of deposition. Weathering was important at this time, facilitated by the Toarcian warm humid climate, producing iron-rich waters delivered into the basin. The dominance of chamosite (an Fe-rich chlorite) ooids in a calcium carbonate matrix, together with cross-stratification, indicate the important role of intertidal currents during their formation. Other indicators of a shallow water depositional environment include the (uncommon) presence of crinoids and stromatolites.

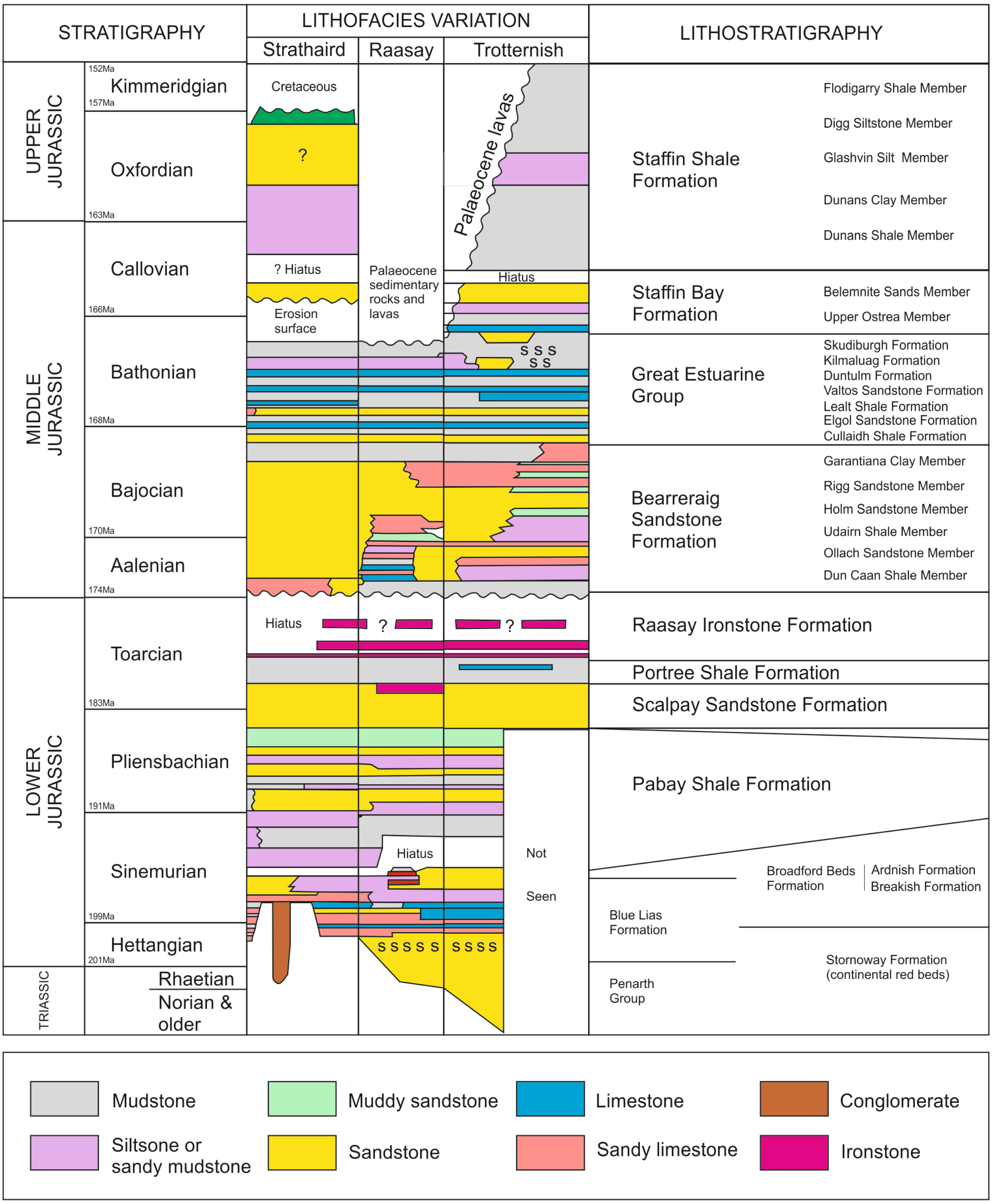


Figure 11-22 – Stratigraphy of the Jurassic within the Hebrides Basin.

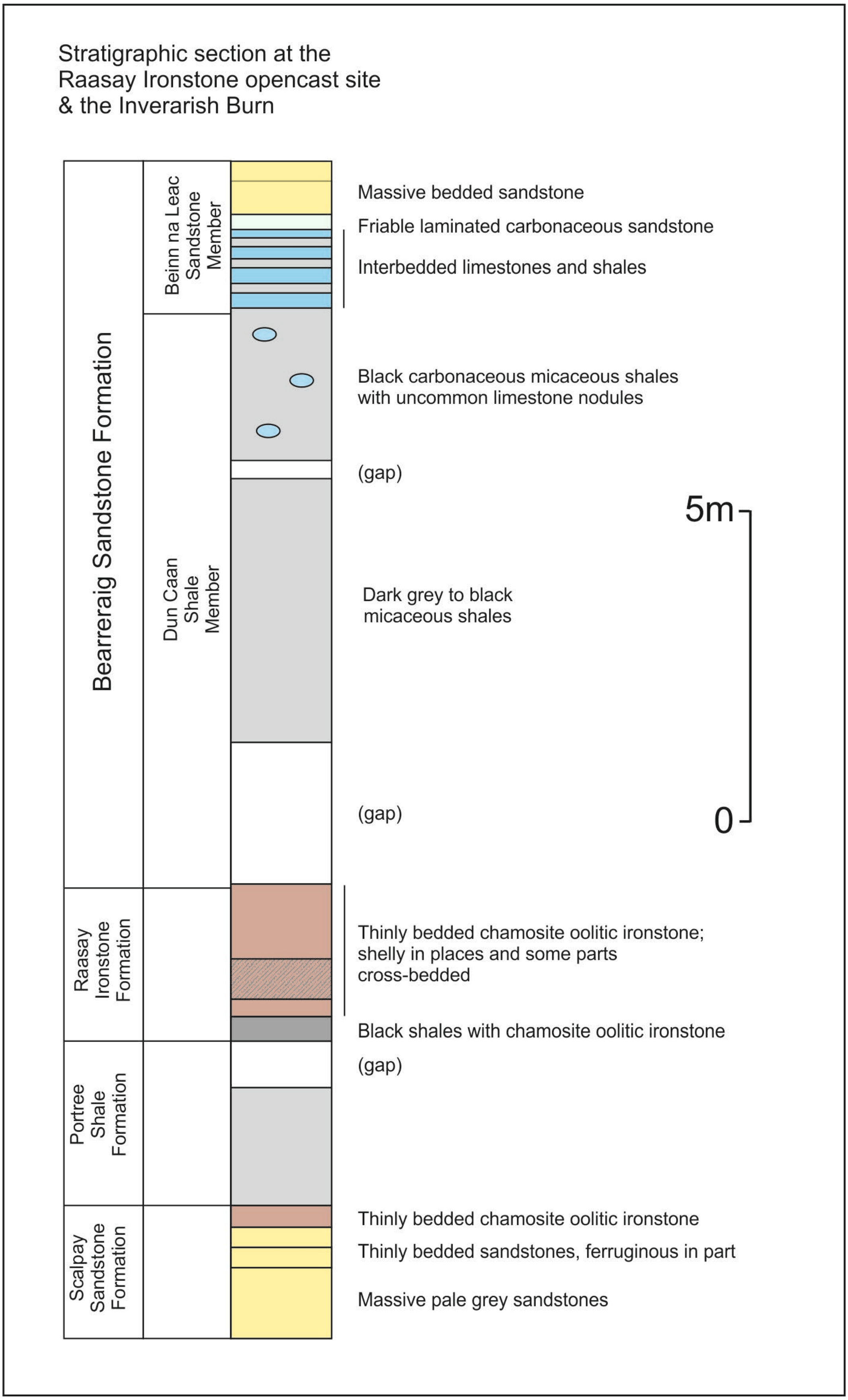


Figure 11-23 – Details of the stratigraphy of the Raasay Ironstone Formation, together with underlying and overlying strata.

Figure 11-24 – Photomicrograph of the Raasay Ironstone Formation chamositic ooidal ironstone with echinoderm fragments in a carbonate matrix/cement. Image *c.* 5mm across. View under plane polarised light.

11.D.1 Discovery of the Raasay Ironstone Formation

The Raasay Ironstone Formation was discovered with sleuth-like tenacity by Horace B. Woodward of the British Geological Survey in 1893. References to earlier observations are difficult to substantiate. Exposures are rare and it was where the outcrop crosses the Inverarish Burn that the discovery was made. Prior to the development of the mine, the distribution of the ironstone was determined by exploratory (manually drilled) boreholes. A typical and workable thickness of *c.* 2m was recorded and an estimated 10 million tons of extractable material determined.

Exploitation of the ironstone was restricted to Raasay, where it has an outcrop and an extensive subcrop, albeit of variable thickness (or is not present). It is typically very poorly exposed, and has no commercial value (in the context of the early 20th Century) except in the area NE of Inverarish (the sole village on Raasay). The lack of good exposure is in part due to the ironstone's relatively rapid decomposition when directly exposed to the atmosphere. When fresh it is dark green, but upon exposure, or near (< 5m) to the Earth's surface, the carbonate within it is leached out and oxidation occurs, producing a dull rusty brown material. Typical fresh (green) ironstone has an iron content of 20-30%, whereas weathered/altered (brown) material is somewhat enriched. The presence of calcium carbonate within the ironstone is advantageous with respect to its processing.

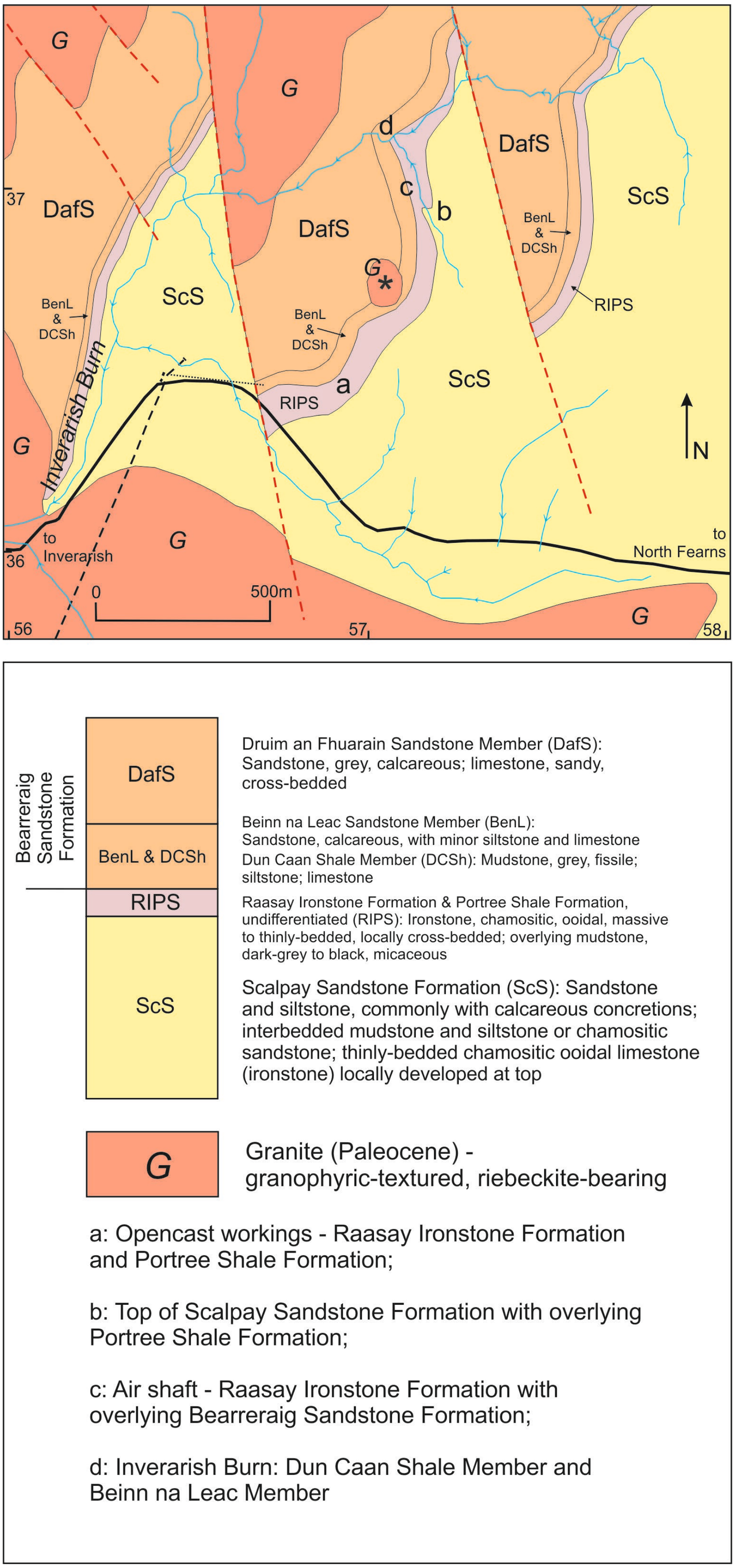


Figure 11-25 – Simplified geological map and stratigraphic details of the opencast area and mine in the vicinity of the Inverarish Burn.

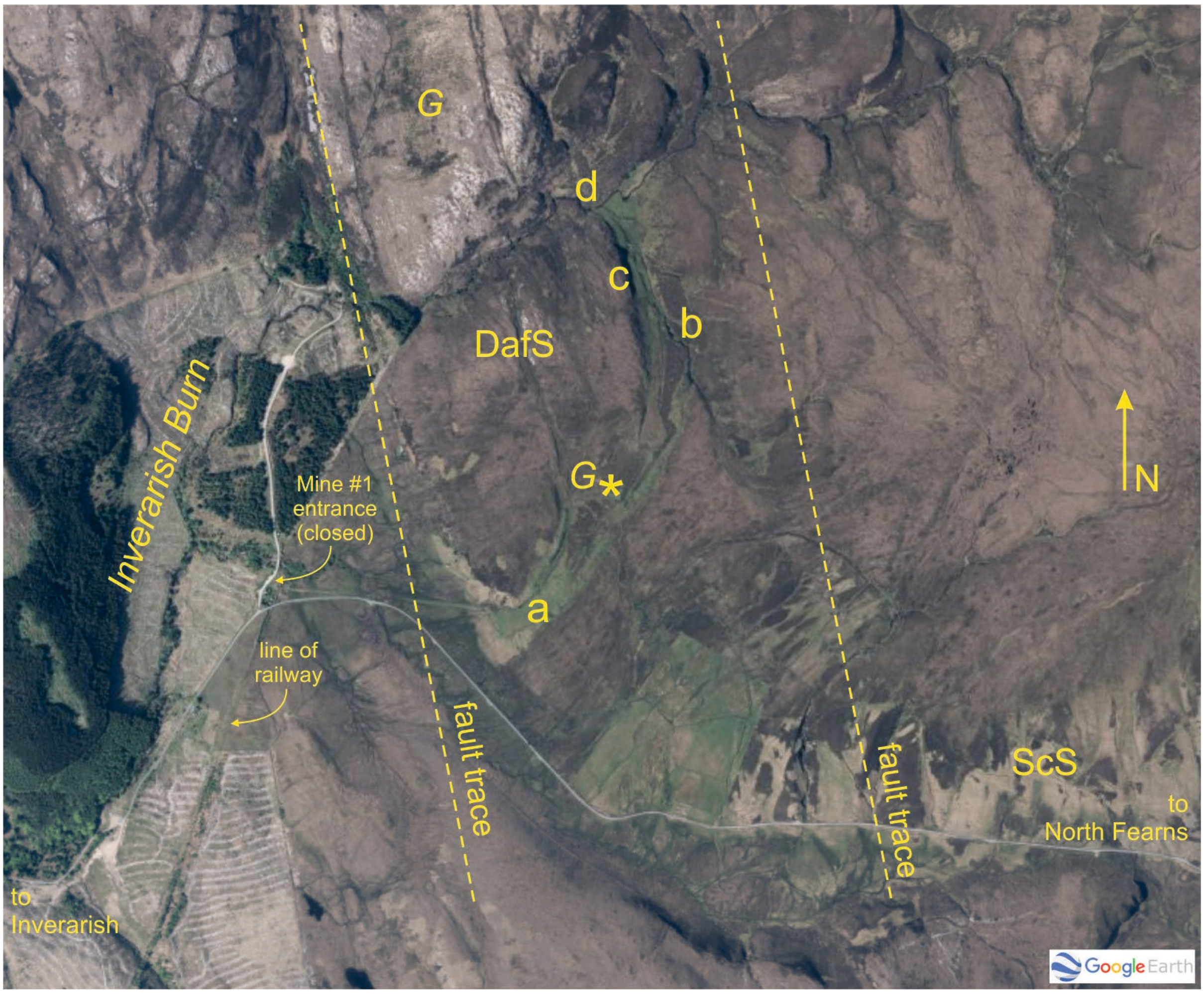


Figure 11-26 – Annotated Google Earth® image of the opencast area (a, b, c & d) and Mine #1 entrance in the vicinity of the Inverarish Burn.

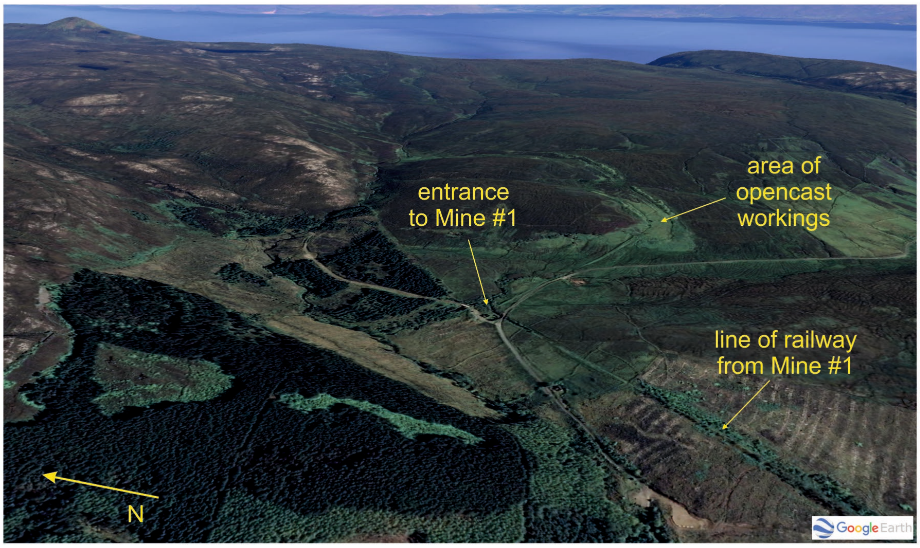


Figure 11-27 – Annotated vertical and oblique Google Earth® images of the area involved in the exploitation of the Raasay Ironstone Formation, including the opencast area and Mine #1 in the vicinity of the Inverarish Burn.

Figure 11-28 – Opencast area, east of entrance to Mine #1. Above the outcrop of inclined Raasay Ironstone Formation strata are (overburden) spoil heaps. View towards the north.

Figure 11-29 – Exposure of Raasay Ironstone Formation strata at the opencast area. Pole *c.* 1m long.

Figure 11-30 – Detail of Raasay Ironstone Formation strata at the opencast area. The pale green 'cores' are fresh material, surrounded by a boxwork of rusty-brown weathered (oxidised) material. Ruler 30cm long.

11.D.2 Development of the Opencast Site and Mine(s)

Initial serious interest to exploit the Raasay ironstone can be traced back to 1910, when William Baird & Company Ltd of Glasgow, with interests in iron and coal, approached the then proprietor of Raasay, Wallace Thorneycoft, a mining engineer and coal mine owner with an interest in geology, to determine the extent of the reserves and subsequently sell (them) the estate (in 1911). Documentation of the development of the opencast and mining operations is good (see above) and of interest (Figure 11-31; Figure 11-32; Figure 11-33; Figure 11-34; Figure 11-35; Figure 11-36; Figure 11-37; Figure 11-38; Figure 11-39).

The initial stage of the mining activity was the extraction of ore from the surface outcrop. Two mine entrances were identified (Mine #1 & Mine #2) and infrastructure was gradually installed. For Mine #1, which ultimately was the sole underground entrance, a straight double-track narrow-gauge (2'3" or 0.7m) cable-haulage rail, *c.* 2.5km long, was built to the coast at the newly constructed pier (specifically for the mining activity) at East Suisnish, where the processing plant, including kilns, was also built). Prior to the completion of the railway, ore was transported by horse and cart to the old pier at Clachan.

Figure 11-31 – Trial adit into the Raasay Ironstone Formation located at the top of the incline in the area where opencast production occurred. Note rail head. Person for scale. [BGS P000039]

Figure 11-32 – Information boards close to the entrance to Mine #1 and derelict main hauler house.

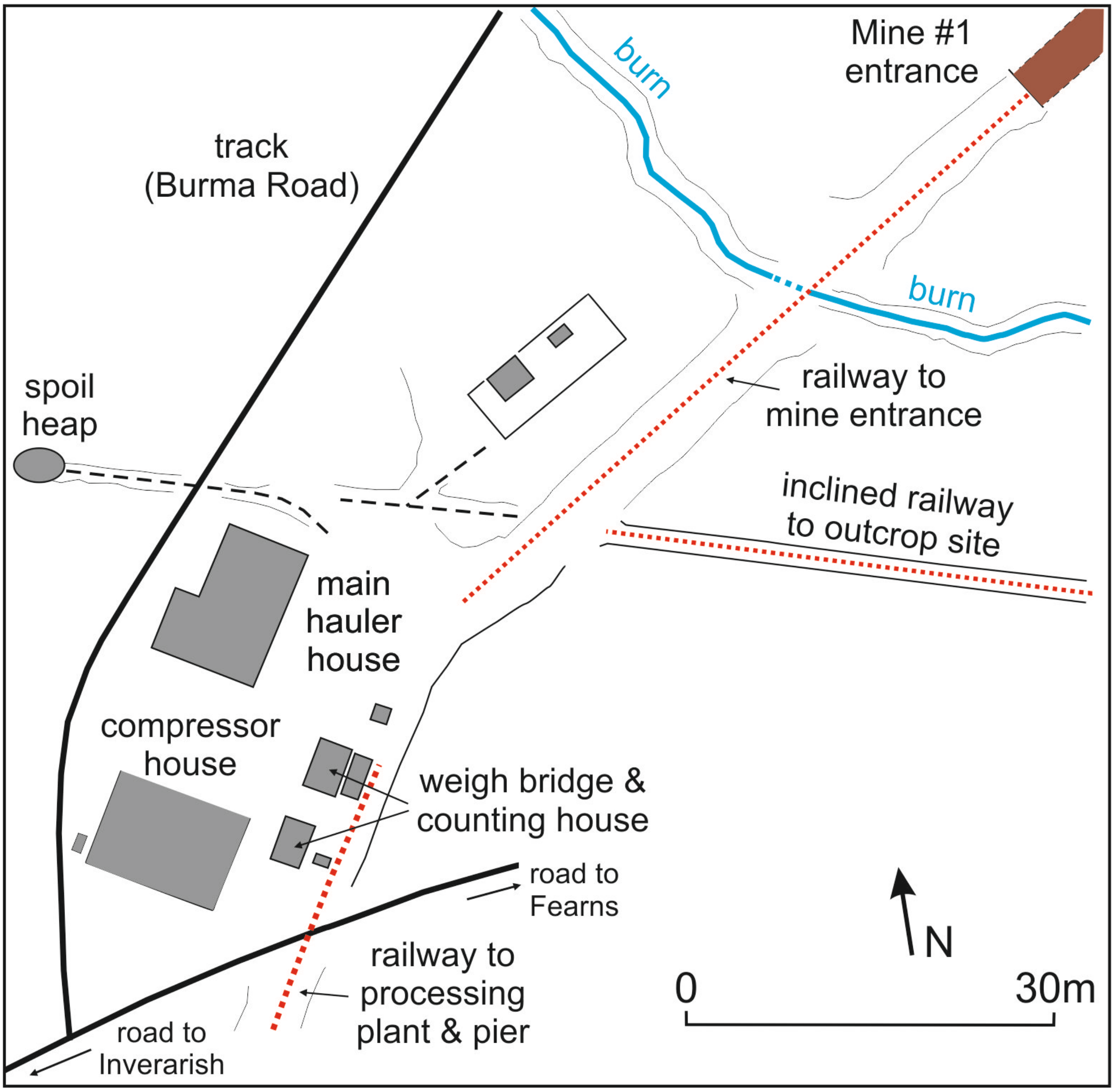


Figure 11-33 – Sketch plan of area around entrance to Mine #1.

Figure 11-34 – Derelict main compressor house, near to entrance to Mine #1.

Figure 11-35 – Information boards close to the entrance to Mine #2.

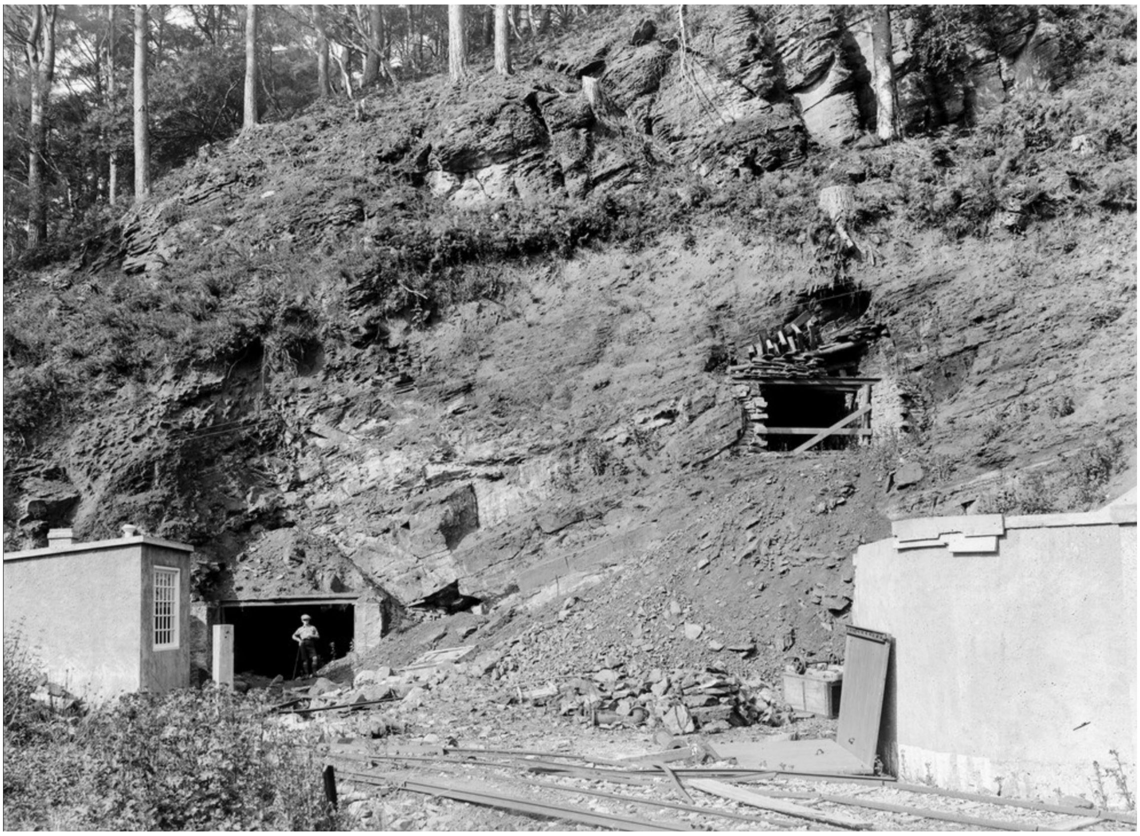


Figure 11-36 – Entrance to Mine #2. This mine was not productive due to unforeseen geological complexities, most likely faults. The site was later used as a sawmill, for the production of pit props, rail sleepers and power poles. [BGS P000041]

Figure 11-37 – Derelict building close to the entrance to Mine #2.

Figure 11-38 – A Bucyrus Steam Dragline ('Steam Navvy') near to the entrance to Mine #1, used to remove superficial material from the area developed for opencast extraction. [BGS P000047]

Figure 11-39 – Detail of Bucyrus Steam Dragline ('Steam Navvy') near to the entrance to Mine #1, used to remove superficial material from the area developed for opencast extraction. Note armed guard, suggesting that at least some of the workers perched on the dragline are German prisoners-of-war. [BGS P000048]

The processing plant at East Suisnish was constructed by Robert McAlpine & Sons and comprised a crusher (where coal was added), kilns to calcine (roast, to create a concentrate) the ironstone, and a large hopper to store processed material prior to shipping. Not all the ore was processed on the island, with some shipped directly after passing through the crusher (Figure 11-40; Figure 11-41; Figure 11-42; Figure 11-43; Figure 11-44; Figure 11-45).

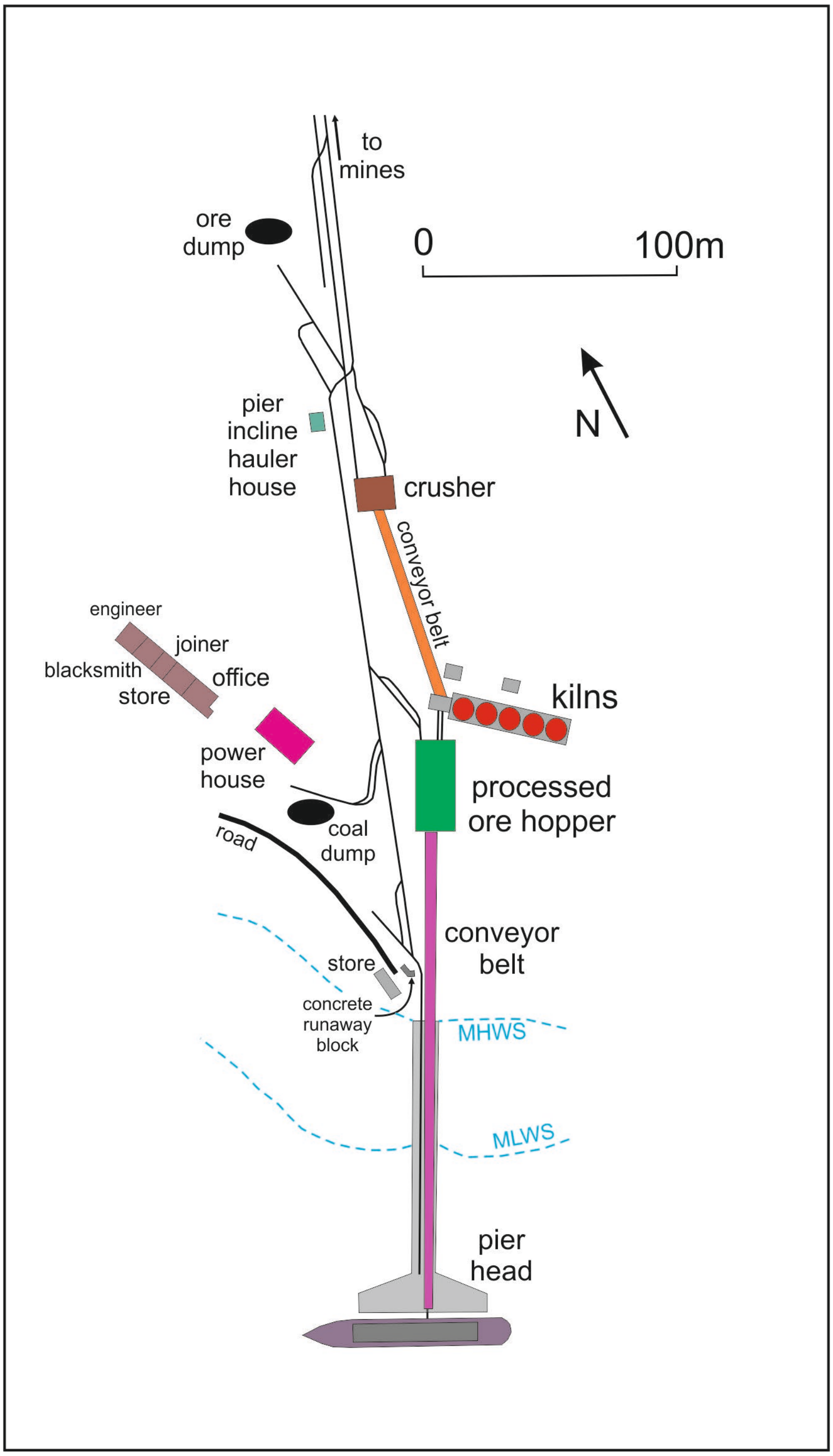


Figure 11-40 – Layout of the processing plant.

Other onsite facilities included an office for administration staff and workshops for joiners, blacksmiths and engineers. Dynamite and detonators were stored in a remote stone building surrounded by a blast bank. There was a lightening conductor on the roof.

Figure 11-41 – Processing plant at East Suisnish, viewed towards the east. At the top of the short rail incline is the pier hauler incline house, to the right of which is the crusher (arched roof) and conveyor to the top of the kilns. Coal was taken to the crusher via the short rail incline, where it was mixed with the unprocessed ore and thence to the kilns. The white building, to right, comprises offices, stores and workshops for joiners, blacksmiths and engineers. [BGS P000044]

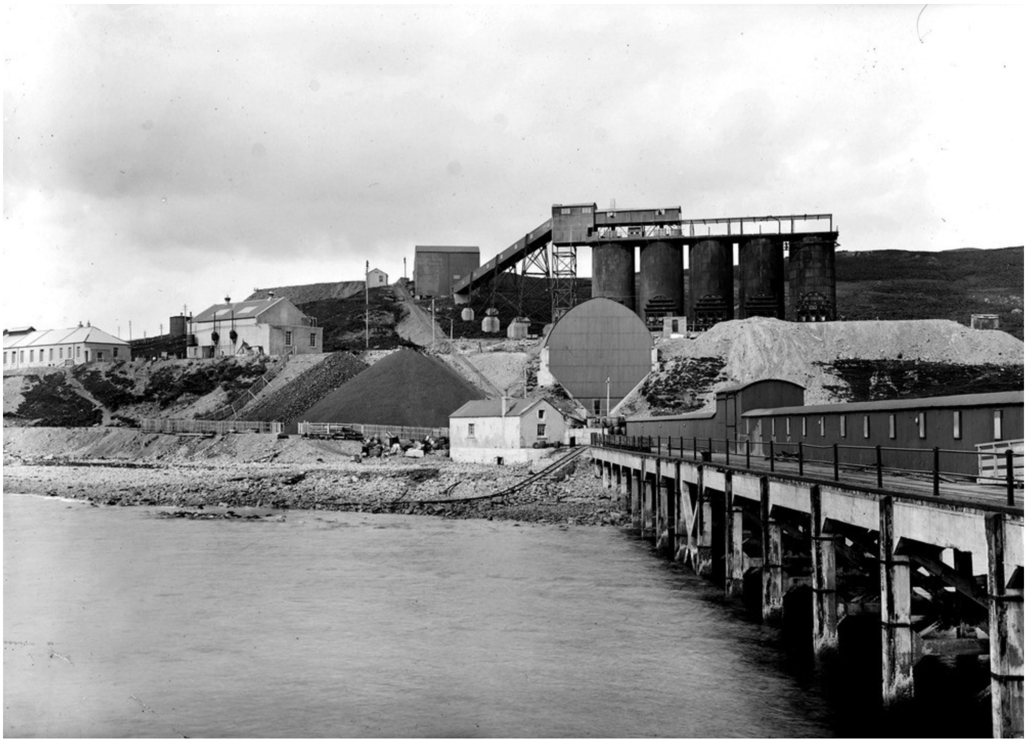


Figure 11-42 – Pier and processing plant at East Suisnish, including five cylindrical calcining kilns, store (to left of pier), coal dump and storage hopper (with arch roof). At the top of the short rail incline is the Pier Hauler Incline House, to the right of which is the crusher with a conveyor to the top of the kilns. Coal was taken to the crusher via the short rail incline, where it was mixed with the unprocessed ore and thence to the kilns. [BGS P000043]

Figure 11-43 – Remnants of main cable railway above the main processing plant at East Suisnish and the ore shipping pier, beyond. View south towards Skye.

Figure 11-44 – Derelict base to the kilns, uphill from the ore hopper, East Suisnish. View south towards Skye.

Figure 11-45 – Ore hopper within the processing plant, East Suisnish. View towards the NE.

Opencast mining commenced in August 1916, involving the stripping of overburden from the area to the east of the entrance to Mine #1 by a Bucyrus Steam Dragline (‘Steam Navvy’), with the ironstone then extracted using two Bucyrus Rev Shovels. Material was conveyed via a two-stage cable-haulage rail to the processing plant at East Suisnish, first on a single-track from the opencast area to near to the entrance of Mine #1 and then via its double-track cable-haulage rail, downhill to the processing plant.

The underground mining operation also commenced in the Summer of 1916. The electrically driven cable-haulage system from near to the entrance to Mine #1 was the main transport mechanism, involving wagons (‘hutches’) that were attachable to the haulage cable, allowing them to be safely transported downhill full of ore, and back to the mine entrance to collect further material.

The track from the failed Mine #2 joined the main (Mine #1) track via a single-track at a junction downhill from the entrance to Mine #1, where ore would be transferred to the ‘main’ line. However, due to geological complexities not identified prior to the initiation of Mine #2 it was not able to provide a significant amount of ore and was abandoned.

The drop in height of the main haulage track is *c.* 120m over the *c.* 2.5km from the mine to the processing plant. Where it approached the processing plant, it was diverted around a large concrete block, installed to stop any runaway wagons. A variety of embankments and cuttings were constructed to produce the constant gradient of the ‘main’ line from the Mine #1/#2 junction. Two viaducts were also necessary; one over a gully close to the entrance to Mine #1 and a second where the spur line to Mine #2 crossed the Inverarish Burn and the road out to Fearns.

Mining involved the traditional room and pillar (or bord and pillar) technique. First, two adits (tunnels; one for extraction, the other for ventilation and access for the miners) were driven (excavated), *c.* 14m apart from the Mine #1 entrance, NE for *c.* 300m to the main extraction area. From here, a quasi (N-S & E-W) grid system of 'rooms' was excavated (i.e. the ore that was removed, leaving the pillars to support the roof). Ore was not extracted fully to the top of the Raasay Ironstone Formation stratum; the locally developed overlying Dùn Caan Shale Member was unstable and capable of collapsing, so a *c.* 0.3m thickness of ironstone was left *in situ,* enabling a thickness of *c.* 2m to be removed. The overall gradient of the floor of the mine (adits and extraction 'rooms') was *c.* 1 in 100 towards the SW, which aided water drainage from the mine and removal of the ore in wagons to the mine entrance.

Extraction involved drilling and blasting, followed by removal on an evolving underground rail system to the mine entrance. The workers operated a three-shift system: drilling from late afternoon until late evening; blasting during the night; and extraction of the ore during the day. British miners worked the drilling and blasting shifts, with German prisoners-of war (see below) working the daytime extraction shift. Lighting was primitive, using small oil lamps, attached to the miners' helmets.

A weigh bridge at the top of the main line recorded the amount of ore extracted. An estimated 12,000 tons of ore were extracted from the opencast site, compared to *c.* 150,000 tons from the underground operation.

Houses for the workers were constructed in Inverarish, comprising four terraces, each of sixteen houses. In addition, Churchton House and Suisnish House were built at this time, also for employees of William Baird & Company Ltd.

Extraction of ore was delayed for a variety of reasons, the main one being the start of World War 1 and its significant impact on the availability of suitable workers. However, the difficulties of obtaining suitable iron ore from outside the UK at this time caused the Government to investigate and back the extraction of Raasay ironstone to help with the war effort. After much discussion it was agreed that William Baird & Company Ltd should manage the operation on behalf of the Government and that German prisoners-of-war would be made available to partially man the operation.

Necessary security was be put in place by the British Army for the duration of the mining. Funding was provided for any outstanding construction and infrastructure costs, including repairs to and depreciation of the plant. Prisoners-of-war started to arrive in mid-1916 and rose to *c.* 250, with a further *c.* 60 Britons involved, some from Raasay, others from elsewhere in the United Kingdom. Most of the Germans were selected based on appropriate mining and other skills and were housed in the suitably fortified Inverarish terraced houses. Worker unrest in early 1917 occurred due to significant wage disparities between the Raasay workers and those from elsewhere, and also grievances due to the presence of the German prisoners-of-war workers. These issues were resolved early in 1918 by an increase in pay, although friction continued, and various minor disputes erupted from time-to-time.

11.D.3 End of the Mining Activity

A significant fall in demand for iron occurred after the end of World War 1 and the UK Government moved to shut down the Raasay production in early 1919. Repatriation of the prisoners-of-war was completed by early 1920. Meanwhile, twelve of the Germans died during the 1918-19 Spanish flu pandemic. A further two of the prisoners-of-war had died because of accidents whilst involved in the mining operations.

William Baird & Company Ltd sold the estate in 1921-22 to the Scottish Board of Agriculture. Thereafter, the natives of Raasay were able to access land suitable for crofting. Soon after, a small amount of mine infrastructure material was removed from the island. However, the main plant was kept on a care-and-maintenance basis, with the thought that production may again be required. This did not happen and by 1941 it was determined that, because of the availability of cheaper ore from elsewhere, the mine and all its plant be abandoned. Salvageable material, for example the kilns, was removed and transported off the island to be used elsewhere. The present-day state of the buildings and other infrastructure is the result of removal of materials useful elsewhere on the island and natural degradation over the decades.

11.E Sconser Quarry

The quarry at Sconser has produced hard rock aggregate from thermally altered Proerozoic Applecross Formation (Torridonian) strata north of the Western Red Hills Intrusive Centre (3.C; 6.F) since at least the early 1940s (Figure 11-46; Figure 11-47).

Figure 11-46 – The Sconser rock aggregate quarry at Achadh Mòr on the old coastal road between Sconser and Loch Ainort.

Figure 11-47 – Detail of the plant used in the Sconser rock aggregate quarry at Achadh Mòr on the old coastal road between Sconser and Loch Ainort. View SW towards Glamaig.

11.F Kyleakin Quarry

The Kyleakin Quarry produces sand and gravel from Quaternary raised shoreline (coastal) deposits (10.H) that formed when the marine limit was at its maximum (*c.* 30m higher than present day sea level), during the Late Glacial Interstadial (14.7-12.9 ka), prior to the Loch Lomond Stadial (10.H). The main products are general purpose aggregate, decorative aggregate and mixed concrete products (Figure 11-48; Figure 11-49). Production started in the last century and the quarry was the main source of aggregate for concrete used in the construction of the Skye Bridge (1992-95).

Figure 11-48 – The Kyleakin sand and gravel quarry, west of Kyleakin. View towards the west.

Figure 11-49 – The Kyleakin sand and gravel quarry, west of Kyleakin. View towards the east.

11.G Other Quarries

During the construction of the network of tracks, and later roads, on Skye and Raasay, numerous quarries were opened to supply local needs. These quarries are still obvious but long since abandoned. One worthy of note is located east of Ord, at Coille a' Chuaraidh, where Cambro-Ordovician sandstone ('quartzite') (3.E) was quarried and the aggregate was transported downhill to a slipway at Ord using a hand-worked narrow gauge rail system (Figure 11-50). Remnants of the infrastructure are still to be found in the immediate area, including where pieces of rail are used as fence posts. Production started in 1945 and ended in 1960.

Figure 11-50 – The roadside quarry east of Ord. The Cambo-Ordovician sandstone ('quartzite') that was extracted was primarily used for local needs.

Appendix A Some Definitions

A.1 Igneous

ACID/ACIDIC. See *SILICIC.*

ADAMELLITE. Coarse-grained, *SILICIC.* An intrusive rock dominated by quartz and feldspar. Alkali feldspar and plagioclase occur in approximately equal amounts. Accessory mica, amphibole, pyroxene and Fe-Ti oxides.

ADCUMULATE. *CUMULUS* crystals that have continued to grow and are unzoned. Contains lower-than-normal amounts of *INTERCUMULUS* material.

AGGLOMERATE. Redundant term previously used to describe a coarse-grained (> 64mm) *PYROCLASTIC* rock, with rounded to sub-angular fragments set in a fine-grained matrix of the same material. See *BRECCIA.*

ALKALINE. Rich in alkali-elements (Na and K) and/or alkali-rich minerals.

ALKALI OLIVINE BASALT. Fine-grained, *BASIC*. A critically silica-undersaturated basalt, containing *normative* nepheline.

ALKALI OLIVINE DOLERITE. Medium-grained, *BASIC.* A critically silica-undersaturated dolerite, containing *NORMATIVE* nepheline.

ALLIVALITE. Redundant term. See *TROCTOLITE.*

ANDESINITE. Coarse-grained, *BASIC.* A rock composed predominantly of calcic plagioclase (andesine).

ASH. Fine-grained (<2mm) *PYROCLASTIC* material *(TEPHRA).* When consolidated, referred to as a *TUFF.*

AUGITE-ANDESITE. Fine-grained, *INTERMEDIATE.* Phenocrysts of plagioclase (labradorite) and augite set in a glassy groundmass.

BASALT. Fine-grained, *BASIC.* Contains plagioclase (labradorite) and clinopyroxene, with or without olivine, orthopyroxene, nepheline, and quartz. Varieties: *ALKALI OLIVINE BASALT* and *THOLEIITIC BASALT.*

BASIC. Igneous rocks with 45–52 wt.% SiO_2 and dominated by dark-coloured (mafic) minerals (plus plagioclase). See: *GABBRO, DOLERITE, BASALT.*

BEINN DEARG TYPE DYKES. Dykes of *ALKALI OLIVINE BASALT/DOLERITE* composition.

BENMOREITE. Fine-grained, *INTERMEDIATE.* Silica-saturated to -undersaturated, between *MUGEARITE* and *TRACHYTE* in the *ALKALI OLIVINE BASALT* fractionation series.

BRECCIA. A coarse-grained (>64mm) rock (sedimentary or volcanic) containing angular fragments in a fine-grained matrix.

CRINANITE. Medium-grained, *ALKALINE BASIC.* An olivine-bearing *TESCHENITE.*

CRINANITIC. Pertaining to a *CRINANITE.*

CUMULATE. A coarse-grained (usually *BASIC* or *ULTRABASIC*) accumulative rock consisting of touching crystals formed by some type of fractionation process (for example, crystal settling or *in situ* congelation crystallisation).

CUMULUS. Pertaining to a *CUMULATE.*

DIORITE. Coarse-grained, *INTERMEDIATE*. An intrusive rock dominated by amphibole and sodic plagioclase. Pyroxene and/or quartz may also be present.

DIORITIC GLAMAIGITE. A locally-used, homogeneous form of *GLAMAIGITE*. A coarse-grained, mixed-magma rock of *INTERMEDIATE* composition.

DOLERITE. Medium-grained, *BASIC.* Contains calcic plagioclase (labradorite) and clinopyroxene, typically in an ophitic intergrowth, with or without olivine, orthopyroxene, nepheline, and quartz.

DUNITE. Coarse-grained, *ULTRABASIC*. A variety of *PERIDOTITE* composed almost entirely of olivine. Accessory chromite.

EUCRITE. Redundant term used to describe coarse-grained, *BASIC-ULTRABASIC igneous rocks*. A variety of *GABBRO* containing calcic plagioclase ($An_{70–90}$) and clinopyroxene, with or without olivine. See *GABBRO.*

FELDSPATHIC PERIDOTITE. Coarse-grained, *ULTRABASIC*. A variety of *PERIDOTITE* rich in calcic plagioclase (20–30%).

FELSITE. Fine-grained, *SILICIC*. A pale-coloured rock dominated by quartz and alkali feldspar, with or without phenocrysts of these minerals. Possibly originally a glassy rock.

FERRODIORITE. Coarse-grained, *INTERMEDIATE-BASIC.* A *DIORITE* with modal plagioclase ($An_{30–50}$) and Fe-rich ferromagnesian minerals.

GABBRO. Coarse-grained, *BASIC.* Contains calcic plagioclase (labradorite) and clinopyroxene, with or without olivine, orthopyroxene, nepheline, and quartz. Where plagioclase is calcium-rich, referred to as a BYTOWNITE *GABBRO.*

GLAMAIGITE. A locally-used, coarse- to medium-grained, mixed-magma rock consisting of dark patches of *MARSCOITE* (itself a mixed-magma rock) set in a lighter groundmass of similar composition.

GRANITE. Coarse-grained, *SILICIC*. An intrusive rock dominated by quartz and feldspar. More than two-thirds of the feldspar is alkali feldspar. Accessory mica, amphibole, pyroxene, olivine, and Fe-Ti oxides.

GRANOPHYRE. Coarse-grained, *SILICIC*. A variety of *GRANITE* in which the quartz and alkali feldspar have crystallised in an irregular, commonly microscopic, intergrowth.

HAWAIITE. Fine-grained, *INTERMEDITE-BASIC.* Silica-undersaturated, between *ALKALI OLIVINE BASALT* and MUGEARITE in the *ALKALI OLIVINE BASALT* fractionation series.

HETERADCUMULATE. A *CUMULATE* where the *INTERCUMULUS* (interstitial) crystals are of the same composition as, but are distinct from, the cumulus crystals. See *ADCUMULATE.*

HYALOCLASTITE. A glassy volcanic deposit, consisting of shattered fragments of rapidly-chilled intrusive or extrusive material, formed by interaction with water, ice, or water-saturated sediments. Typically of *BASIC* composition, mainly *BASALT* and *DOLERITE*.

IGNIMBRITE. A fine-grained *PYROCLASTIC* rock formed by the consolidation (and in some instances welding) of *SILICIC* particles (*ASH* or *LAPILLI*).

INTERCUMULUS. The spaces between *CUMULUS* crystals.

INTERMEDIATE. Igneous rocks with 52–65 wt.% SiO_2, between *SILICIC* and *BASIC*. e.g. *DIORITE*.

LAMPROPHYRE. Medium-grained, *ALKALINE SILICIC-INTERMEDIATE-BASIC.* Dark-coloured rocks containing phenocrysts of mafic minerals (typically biotite, hornblende and pyroxene) set in a fine-grained groundmass of the same minerals, plus feldspars and/or feldspathoids.

LAPILLI/LAPILUS. Medium-sized *PYROCLASTIC* material (2–64mm) fragments *(TEPHRA)*. When consolidated, referred to as a *LAPILLI-TUFF.*

LAPILLI-TUFF. A *PYROCLASTIC* rock consisting of *LAPILLI*-sized (2–64mm) fragments *(TEPHRA).*

MARSCOITE. A locally-used, medium-grained, mixed-magma rock of *INTERMEDIATE* composition containing xenocrysts of andesine, alkali feldspar and quartz, set in a groundmass dominated by the same minerals.

MESOCUMULATE. A *CUMULATE* containing a small amount of *INTERCUMULUS* material. Between an *ADCUMULATE* and an *ORTHOCUMULATE.*

MINETTE. Medium-grained, *ALKALINE SILICIC*. A *LAMPROPHYRE* containing biotite phenocrysts in a groundmass of alkali feldspar and biotite.

MUGEARITE. Fine-grained, *INTERMEDIATE.* Between *HAWAIITE* and *BENMOREITE* in the *ALKALI OLIVINE BASALT* fractionation series.

NORMATIVE. Pertaining to a mineral which, according to a set of predetermined rules applied to the major-element chemistry of the rock, should be present. In practice, this is not always the case.

ORTHOCUMULATE. A *CUMULATE* plus the crystallisation products of the *INTERCUMULUS* liquid.

PEGMATITE. A very coarse-grained (> 3cm) rock with interlocking crystals. The minerals involved are often late-stage, hydrous phases.

PERIDOTITE. Coarse-grained, *ULTRABASIC.* A rock rich in olivine, with or without other mafic minerals (pyroxenes, amphiboles, micas) and almost devoid of plagioclase. A *PERIDOTITE* composed only of olivine (with accessory chromite) is a *DUNITE.*

PICRITE. Medium- to coarse-grained, *ULTRABASIC*. A rock rich in olivine (plus minor pyroxene, amphiblole and mica), plus 5–10% plagioclase. Where little or no plagioclase is present, the name *PERIDOTITE* is used.

PICRODOLERITE. Medium-grained, *BASIC-ULTRABASIC*. Intermediate between *PICRITE* and *DOLERITE.*

PITCHSTONE. Redundant term for a glassy, *SILICIC-INTERMEDIATE* rock. A volcanic rock with a dull, waxy (pitch-like) lustre. Contains crystallites (crystals not large enough to show polarization colours) typically of feldspar, set in an often-devitrified groundmass.

PORPHYRY. A porphyritic rock with obvious phenocrysts.

PYROCLASTIC ROCK. A fragmental volcanic rock. e.g. *TUFF, LAPILLI-TUFF, BRECCIA.*

RHYOLITE. Glassy to fine-grained, *SILICIC.* A flow-banded, typically porphyritic (with phenocrysts of quartz and/or alkali feldspar) lava.

SILICIC. Igneous (and metamorphic) rocks with more than 65 wt.% SiO_2 and dominated by light-coloured minerals. e.g. *granite*, *granophyre*, *felsite*.

TACHYLITE. Glassy, *BASIC.*

TACHYLITIC. Pertaining to a *TACHYLITE.*

TEPHRA. Fragmental material that form a *PYROCLASTIC* rock. See *ASH, LAPILLI.*

TESCHENITE. Medium-grained, *ALKALINE BASIC.* An analcime-bearing *DOLERITE.*

TESCHENITIC. Pertaining to a *TESCHENITE.*

THOLEIITE. Fine-grained, *BASIC.* A silica-saturated *BASALT,* containing Ca-poor pyroxene, Ca-rich pyroxene and calcic plagioclase. Characterised by *NORMATIVE* hypersthene.

THOLEIITIC BASALT. See *THOLEIITE.*

TRACHYTE. Fine-grained, *ALKALINE SILICIC.* An alkali feldspar -dominated rock, with lesser amounts of sodic plagioclase, plus pyroxene, amphibole and biotite mica. The alkali feldspar crystals typically have a sub-parallel alignment.

TRANSITIONAL BASALT. A *BASALT* with a composition close to the so-called Critical Plane of Silica Undersaturation. Essentially, transitional between *ALKALI OLIVINE BASALT* and *THOLEIITE.*

TROCTOLITE. Coarse-grained, *BASIC.* A variety of *GABBRO* containing calcic plagioclase (labradorite) and olivine, with little or no pyroxene.

TUFF. A *pyroclastic* rock with fragments typically < 2mm.

ULTRABASIC. Igneous rocks with less than 45 wt.% SiO_2 and dominated by dark-coloured minerals. e.g. *PERIDOTITE, PICRITE.*

VOGESITE. Medium-grained, *ALKALINE SILICIC.* A *LAMPROPHYRE* containing hornblende phenocrysts in a groundmass of alkali feldspar and hornblende.

A.2 Metamorphic

AMPHIBOLITE. A contact- or regional-metamorphosed *BASIC* rock dominated by amphibole.

BUCHITE. A *HORNFELS* in which partial fusion has taken place. Formed by extreme thermal (pyro)metamorphism.

GNEISS. A banded, high-grade, regional metamorphic rock.

GRANULITE. A high-grade metamorphic rock consisting of interlocking crystals, all approximately the same size, and with little or no visible preferred orientation.

GRANULITIC. Pertaining to a *GRANULITE.*

HORNFELS. A fine-grained rock formed by contact metamorphism and lacking any obvious fabric (mineral alignment).

MARBLE. A contact- or regional-metamorphosed *CARBONATE*-rich rock.

METABASITE. A metamorphosed (recrystallised) *BASIC* rock.

MYLONITE. An intensely deformed rock, with a streaky or banded appearance, associated with thrusts.

MYLONITIC. Pertaining to *MYLONITE.*

PELITE. A metamorphosed *SILTSTONE* or *MUDSTONE.*

PELITIC. Pertaining to, or characteristic of, a *PELITE.*

PHYLLONITE. A banded rock, less deformed than a *MYLONITE,* associated with thrusts.

PHYLLONITIC. Pertaining to a *PHYLLONITE.*

PSAMMITE. A metamorphosed, impure *SANDSTONE.*

PSAMMITIC. Pertaining to, or characteristic of, a *PSAMMITE.*

PYROXENE HORNFELS. A high-grade contact metamorphic rock formed at low pressures in the inner parts of contact metamorphic aureoles.

QUARTZITE. A regional- or contact-metamorphosed pure *SANDSTONE* (cf. *PSAMMITE*).

SCHIST. A foliated (layered), crystalline, regional metamorphic rock, with a definite fabric and typically containing visible minerals such as mica.

SERPENTINITE. A rock composed of serpentine-group minerals, formed by the metamorphism of *ULTRABASIC* rocks.

SKARN. A rock formed by the metamorphism and metasomatism of *CARBONATE*-rich rocks.

A.3 Sedimentary

ALGAL STROMATOLITE LIMESTONE. A *LIMESTONE* consisting of structures formed by micro-organisms (algae) which, as they grow, trap, bind and/or cause precipitation of sediment.

ALLUVIUM. Material transported by a river.

ARENACEOUS. Pertaining to, or characteristic of, an *ARENITE.*

ARENITE. A relatively pure, cemented *SANDSTONE.*

ARGILLACEOUS. Pertaining to, or characteristic of, a rock dominated by clay-size particles. e.g. *SHALE, MUDSTONE.*

ARKOSE. A feldspar-rich (at least 25%) *SANDSTONE* or *GRIT.*

BRECCIA. A coarse-grained (> 64mm) rock (sedimentary or volcanic) containing angular fragments in a fine-grained matrix.

CALCAREOUS. Said of a rock which contains calcium carbonate.

CARBONATE. A sedimentary rock dominated by carbonate minerals. e.g. *LIMESTONE.*

CEMENTSTONE. A carbonate-cemented, silty/clay-rich rock.

CHAMOSITE OOLITE. A rock dominated by ooliths (small (0.5–1mm), round, accretionary bodies) of the chlorite-group mineral, chamosite. A variety of bedded iron ore.

CHERT. A hard, micro- or crypto-crystalline rock/material of quartz and/or amorphous silica (opal).

CLASTIC. Said of a rock composed of fragments of pre-existing rocks that have been subjected to weathering, erosion and transportation. See: *ARGILLACEOUS, ARENACEOUS* and *RUDACEOUS* rocks (*MUDSTONE, SHALE, SILTSTONE, SANDSTONE, ARENITE, GRIT, CONGLOMERATE, BRECCIA*).

CONGLOMERATE. A coarse-grained, *CLASTIC* rock containing rounded to sub-angular fragments > 4mm.

DIAGENESIS. The process(es) that describe(s) the physical and chemical changes as a sediment is transformed into a sedimentary rock (also referred to as lithification).

DIATOMITE. A deposit consisting of the remains of diatoms (single-celled organisms made of opaline silica).

DOGGER. An irregular concretion or nodule, of diagenetic origin, within a sedimentary rock.

DOLOSTONE. A *carbonate*-rich rock dominated by dolomite.

GRIT. A *CLASTIC* rock with angular fragments, 2–4mm.

LIGNITE. A low-grade, brownish-black coal, intermediate between *PEAT* and sub-bituminous coal.

LIMESTONE. A chemical/*CLASTIC* rock with more than 50% calcium carbonate.

MARL. A *CALCAREOUS MUDSTONE.*

MICRITIC LIMESTONE. A *LIMESTONE* with greater than 90% *CARBONATE* mud (lithified), with crystals < 30 microns in diameter.

MUDSTONE. A non-fissile (non-laminated), clastic rock dominated by approximately equal amounts of clay-size (< 0.002mm) and silt-size (0.002-0.0625mm) grains.

OOLITIC LIMESTONE. A *LIMESTONE* dominated by ooliths (small (0.5–1mm), round, accretionary bodies) of, commonly, calcite or dolomite.

PEAT. An unconsolidated deposit of semi-carbonised vegetable matter.

RUDACEOUS. Pertaining to, or characteristic of, a rock dominated by coarse-grained particles. e.g. *GRIT, CONGLOMERATE, BRECCIA.*

SANDSTONE. A medium-grained, *CLASTIC* rock composed of rounded to sub-angular fragments of sand-size (0.0625-2mm) grains.

SHALE. A fissile (laminated), *CLASTIC* sedimentary rock dominated by approximately equal amounts of clay and silt.

SILTSTONE. A clastic rock composed of fragments of silt-size (0.002.0625mm) grains, intermediate between *SHALE/MUDSTONE* and *SANDSTONE.*

Appendix B Place Names, Translations and Locations

Skye place names are derived from both Gaelic and Old Norse sources, together with English forms. Listed below are many of the place names used in the main text and the excursions. Where possible, the etymology of the place name is given. However, accuracy in all cases cannot be guaranteed.

For each place name, a link to the online UK Ordnance Survey map portal is provided. These maps can be accessed via the Survey's website (available as an app), which displays the location on maps at a range of scales, including the commonly used 1:25,000 scale, and on its aerial image database. Map and aerial image data can be downloaded, useful when live access is not possible due to lack of signal in parts of Skye and Raasay. Also given are grid references to the nearest 1 kilometre for users of traditional (paper) maps.

B.1 Gaelic Pronunciation

Gaelic spelling is more regular than English spelling, which means that it reflects more accurately the actual sounds of the language. It should be stressed, however, that the sound system of Gaelic is different from Standard English (Received Pronunciation), Scottish Standard English, Scots, or any of the Scottish or English dialects, except for the so-called West Highland accent, which has been heavily influenced by Gaelic. There are, however, more similarities with Scottish Standard English than with Standard English (Received Pronunciation), so most of the examples below are taken from Scottish Standard English. Modern Gaelic spelling recommendations are embodied in the Gaelic Orthographic Conventions that are available online on the SQA website.

Gaelic uses an alphabet of 18 letters, namely a, b, c, d, e, f, g, h, i, l, m, n, o, p, r, s, t, u. A major feature of the Gaelic spelling system is the concept of broad and slender vowels, which are also referred to as back and front vowels. The broad or back vowels are a, o, u, the slender or front vowels are e, i. The pronunciation of most consonants is different depending on whether they are beside a broad vowel or a slender vowel. For this reason a consonant or group of consonants in the middle of a word must have either a broad vowel on either side or a slender vowel on either side.

All vowels can be long or short, with length being indicated by a grave accent (`). Formerly acute accents (´) were used on e and o to indicate not only length (quantity) but also quality, with è pronounced like a long French è (as in Scottish English cortege), and é pronounced like a long French é (as in Scottish English bay); while ò was pronounced like Scottish English awe, and ó like Scottish English owe. However, the acute accent (´) has been abandoned in modern spelling recommendations so that the grave accent (`) now indicates length only.

These modern spelling recommendations also explain why forms formerly written with u in unstressed syllables such as calltuinn, camus, tarsuinn, are now written with a, calltainn, camas, tarsainn.

What follows is only a rough approximation of sounds. Remember that the English words given as equivalents are to be pronounced more like Scottish Standard English than Standard English (received pronunciation), unless otherwise stated.

B.1.A Vowels

Single vowels:

- a: like a in ’hat’, often like u in ’but’; before nn it is like ow in ’cow’
- à: like a in ’half’
- e: short closed e like a in ’rate’ and short open e like e in ’fetch’
- è: long closed e like ay in ’bay’ (formerly é) and long open e like e in ’cortege’ (formerly è)
- i: like ee as in ’keep’
- ì: like ee in ’keep’ but longer
- o: short closed o like oa in ’boat’, and short open o like o in ’lot’
- ò: long closed o like ’owe’ (formerly ó), and long open o like ’awe’ (formerly ò)
- u: like oo in ’book’
- ù: like oo in ’book’, but longer

B.1.B Vowel Groups

Most groups of two or three vowels are pronounced much as would be expected, that is as separate sounds rapidly following one another. However, often one of the vowels is there simply to indicate whether a consonant is broad or slender, for example, in fearann the a following the e indicates that the r is broad, so that ea is pronounced simply as e (as in ’get’). However, note the following:

- ao: a long sound with no equivalent in English. Try saying Gaelic ù (like oo in ’book’, but longer) without rounding your lips
- eu: like ia in ’Maria’ or like ay in ’bay’

B.1.C Consonants

This is not a complete or exact description of how each consonant or group of consonants are pronounced. However, those that are most unfamiliar to someone used to the English spelling system are given below, with their approximate English value:

- bh: like v at the beginning of words, otherwise like w, or silent (that is not heard at all); for example dubh is pronounced approximately as ’doo’
- c: like c in ’cat’ or c in ’cue’; when it occurs between two vowels or as the last letter of a word it is preceded by the sound ch in ’loch’
- ch: like ch in ’loch’
- cn: like cr
- d slender (that is in contact with one of the slender vowels e, i): like j in ’jam’
- dh broad (that is in contact with one of the broad vowels a, o, u): the same sound as Gaelic broad gh, almost like French r in ’rire’. When it is not at the beginning of a word it is often pronounced only very lightly or not at all

- dh slender (that is in contact with one of the slender vowels e, i): the same sound as Gaelic slender gh, like y in ’yet’. When it is not at the beginning of a word it is often pronounced only very lightly or not at all
- fh: silent, that is not pronounced at all
- gh broad (that is in contact with one of the broad vowels a, o, u): the same sound as Gaelic broad dh, almost like French r in ’rire’. When it is not at the beginning of a word it is often pronounced only very lightly or not at all
- gh slender (that is in contact with one of the slender vowels e, i): the same sound as Gaelic slender dh, like y in ’yet’. When it is not at the beginning of a word it is often pronounced only very lightly or not at all
- l broad (that is in contact with one of the broad vowels a, o, u): like a hollow or dark l, as in ’full’, with the blade (as opposed to the tip) of the tongue touching the teeth
- l slender (that is in contact with one of the slender vowels e, i): like lli in ’million’ when it is at the beginning of a word; otherwise like ll in ’silly’
- mh: like v at the beginning of words, otherwise like w, or silent (that is not heard at all). It also makes the vowel before it sound very nasal.
- ph: like f
- r slender (that is in contact with one of the slender vowels e, i): can be pronounced like r in Scottish English ’tree’, but in several dialects it is pronounced like th in ’the’
- rd and rt: in many Gaelic dialects this is pronounced with a light sh as in ’she’ between the two consonants
- s slender (that is in contact with one of the slender vowels e, i): like sh in ’she’
- t slender (that is in contact with one of the slender vowels e, i): like ch in ’church’
- th: like h in ’he’ at the beginning of words, otherwise silent

B.2 Some Grammar

The following is not a full description of Gaelic grammar. However, in order to use the Elements Index it is important to know a little about these things. A full description can be found in any book for Gaelic learners, sources for which are given in the further information section.

Certain regular changes take place in Gaelic in nouns, adjectives and the definite article, depending on such grammatical features as gender (masculine or feminine), number (singular or plural), and case (nominative, genitive, dative). All Gaelic nouns are either masculine or feminine, and it will become clear that it is important to know what gender a noun belongs to. Some nouns, however, are used in masculine and feminine forms depending on local usage. They are marked nmf in the glossary. The genitive case indicates possession, as indicated in English by ’of the’.

B.2.A Definite Article

'The' is the only form of the definite article in English. However, as with most other European languages, Gaelic has several forms, depending on number, gender and case, as well as on the initial letter or letters of the following noun.

B.2.A.1 Singular

- a’: for example, before a feminine noun in the nominative case beginning with b(h), c(h), g(h), m(h), p(h), as in A’ Bheinn [NM 84 03], A’ Chruach [NM 90 21], A’ Phàirc Loisgte [NN 48 56]; or before a masculine noun in the genitive case beginning with b(h), c(h), g(h), m(h), p(h), as in Sròn a’ Bhàird [NR[76[62], ’nose of the poet’, containing the genitive of am bàrd ’the poet’, Allt a’ Choire Dhuibh [NN 25 64], ’burn of the black corrie’, containing the genitive of an coire dubh ’the black corrie’. This form of the definite article always causes lenition (see below).
- am: before a masculine noun in the nominative case beginning with b, f, m, p, as in Am Fasgadh [NN 01 69], Am Meall [NR 76 65].
- an: for example, before a masculine noun in the nominative case beginning with any consonant except b, f, m, p, as in An Cnap [NS 01 46], or before a feminine noun in the nominative case beginning with a vowel or f(h), as in An Àird [NG 53 35], An Fhang [NR 65 52].
- an t-: for example, before a masculine noun in the nominative beginning with a vowel, as in An t-Inbhir [NN 40 48]; before a masculine noun in the genitive beginning with s + vowel, l, n, or r, as in Cnoc an t-Sagairt [NR 83 68], ’hill of the priest’, containing the genitive of an sagart ’the priest’, Meall an t-Sluic [NN 5 152], containing the genitive of an sloc ’the hollow’; or before a feminine noun in the nominative beginning with s + vowel, l, n, or r, as in An t-Sàil Bheag [NG 87 61], An t-Sròn [NL 93 42]. Note that in all cases following an t- the initial s is silent, that is it is not pronounced.
- na: before a feminine noun in the genitive beginning with a consonant, as in Loch na Bèiste [NR 76 54], Port na Cille [NR 64 44].
- na h-: before a feminine noun in the genitive beginning with a vowel, as in Gob na h-Àirde Mòire [NB 01 17], containing the genitive of An Àird Mhòr ’the big headland’.

The forms of the definite article with singular nouns can be summarised in this table:

Singular		Initial letter of following noun					
		b, m, p	c, g	d, l, n, r, t	f	s	vowel
Masculine	nom	am	an	an	am	an	an t-
	gen	a’	a’	an	an	an t-	an
Feminine	nom	a’	a’	an	an	an	an
	gen	na	na	na	na	t- na	na h-

B.2.A.2 Plural

- na: before masculine and feminine nouns in the nominative beginning with a consonant, as in Na Cnuic Liatha NC1810, plural of an cnoc liath ’the grey hill’ (cnoc is masculine), Na Croitean [NM 37 21], plural of a’ chroit ’the croft’ (croit is feminine).

- na h-: before masculine and feminine nouns in the nominative beginning with a vowel, as in Na h-Easan [NC 43 00], plural of an t-eas ’the waterfall’ (eas is masculine) or Na h-Ìnnsean [NC 25 22], plural of an innis (innis is feminine).
- nam: before masculine and feminine nouns in the genitive beginning with b, f, m, p, as in Toll nam Broc [NR 80 82], Creag nam Fitheach [NR 78 76].
- nan: before masculine and feminine nouns in the genitive beginning with any letter except b, f, m, p, as in Druim nan Toll [NN 70 94].

The forms of the definite article with plural nouns can be summarised in this table:

Plural		Initial letter of following noun		
		b, f, m, p	other consonants	vowel
Masculine or Feminine	nom	na	na	na
	gen	nam	nan	h- nan

B.2.B Lenition

Gaelic is a Celtic language and, as in other Celtic languages such as Irish and Welsh, the consonants at the beginning of words can change according to gender, number and case. In Gaelic this is called lenition, meaning literally ’softening’, and it is usually signalled by putting the letter h after the lenited or softened consonant.

The initial consonants that are affected by lenition by the addition of an h are b, c, d, f, g, m, p, s, t. The consonants l, n, r can also be affected by lenition, but this is not expressed in the spelling.

These are some of the main circumstances in which lenition occurs:

- in a feminine singular noun following the definite article, as in A’ Bheinn [NM 84 03], An Fhang [NR 65 52]
- in an adjective following a feminine singular noun, as in Creag Bhreac [NM 84 00] or Beinn Mhòr [NH[99 28]
- in the genitive of a masculine singular noun following the definite article a’, as in Eilean a’ Bhuic [NB 54 52] (genitive of boc)
- in the adjective qualifying a masculine genitive singular noun, as in Rubha a’ Phuirt Mhòir [NR 24 57] (genitive of port mòr)
- in the genitive singular of masculine personal names, as in Geodha Chaluim MhicMhuirich [NA 07 01] (’the ravine of Calum MacVurich or Malcolm Currie’) or Sgùrr Thormaid [NG 44 22] (’Tormad’s or Norman’s peak’)
- in a noun following an adjective, regardless of the noun’s gender, as in Glas-Choire [NS 15 98]

Further information is available on the Ordnance Survey website.

Two useful sources of translations of Gaelic and Norse place-names on Skye and Raasay are:

- *Place-names of Skye and adjacent islands* by Alexander Robert Forbes (Alexander Gardner, Paisley, 1923);
- *Reading the Gaelic Landscape (Leughadh Aghaidh na Tìre)* by John Murray (Whittles Publishing, Dunbeath, Caithness, 2019).

B.3 Referenced Place Names

A

Abhainn, Abhuinn - river

Abhainn an t-Sratha Mhòir: The river of the great/big strath (valley) [NG 55 23]
Abhainn Camas Fhionnairigh: River of the bay of the fair (white) shieling (bothie) [NG 50 19]
Abhainn nan Leac: River of the flat (or stepping) stones [NG 52 19]
Abhainn Torra-mhichaig: The river of the hill of Michaig [NG 53 30]

Achadh Mòr: The big field [NG 54 31]
A' Chailleach: The old wife or woman [NG 32 31]
Achnacloich: The field of stone, or stone field [NG 59 08]
Àird: The heights, point or promontory [NG 59 00]

Àird Ghiuthais: Uncertain [NG 54 36]
Àird Ghunail: Gunhilda's height [NG 70 11]

Allt – burn, stream

Allt a' Bhealaich Bhric: The burn of the speckled or russet pass [NG 54 30]
Allt a' Chaoich: The mad burn [NG 47 19]
Allt a' Choire Riabhaich: The burn of the grey, dull, drab or striped corrie [NG 49 20]
Allt an Fhraoich: The heather burn [NG 47 17]
Allt a' Ghairuillt: Uncertain [NG 59 17]
Allt a' Mheadhoin: The middle burn [NG 54 25]
Allt an t-Sithein: The burn of the fairy hill [NG 49 31]
Allt an t-Sratha Bhig: The little burn of the valley [NG 57 22]
Allt Apoldoire: The river of the bay, or water copse (small group of trees) [NG 60 26]
Allt Beag: The little burn [NG 48 19]
Allt Cnoc nan Uan: The burn of the round hill of the lamb [NG 60 20]
Allt Coir' a' Chruidh: The burn of the horse-shoe corrie [NG 47 18]
Allt Coir' a' Ghobhainn: The burn of the blacksmith's corrie [NG 41 33]
Allt Coire Forsaidh: The burn of the waterfall corrie [NG 60 20]
Allt Coire Làgan: The burn of the little hollow corrie [NG 43 20]
Allt Coire na Banachdich: The burn of the corrie of the smallpox [NG 41 21]
Allt Coire na Ciche: The burn of the corrie of the breast [NG 52 26]
Allt Coire nam Bruadaran: The burn of the corrie of dreams or visions [NG 52 25]
Allt Coire na Seilg: The burn of the hunting corrie [NG 53 24]
Allt Daraich: The burn of the oak [NG 49 29]
Allt Duisdale: The burn of the misty valley [NG 68 12]
Allt Eoghainn: Ewan's Burn [NG 59 26]
Allt Fearna: The burn of the alder tree [NG 61 25]
Allt Fearns: The burn of the alder tree [NG 58 36]

Allt Fiaclan Dearg: The burn of the red teeth [49 25]
Allt Geodh a’ Ghamhna: The ravine of the stirk [NG 37 19]
Allt Mam a' Phobuill: The burn of the people's mound [NG 51 25]
Allt Mhic Mhoirein: Uncertain [NG 53 27]
Allt Mòr: The big burn [NG 36 21]
Allt Mòr Doire Mhic-uin: The big burn of the grove [NG 52 29]
Allt na Guile: The wailing burn [NG 42 32]
Allt na Meacnaish: Meacnaish’s burn [NG 43 17]
Allt na Measarroch: The frugal burn [NG 50 26]
Allt nam Fraoch-choire: The burn of the heathery corrie [NG 50 23]
Allt nan Leac: The burn of the flat (or stepping) stones [NG 59 18]
Allt nan Suidheachan: The burn of the seats (or shelving rocks) [NG 59 20]
Allt na Teangaidh: The burn of the tongue [NG 59 24]
Allt Poll a' Bhainne: The burn of the white pool [NG 59 17]
Allt Port na Cullaidh: The burn of the harbour of the seal [NG 52 13]
Allt Rèidhe Ghlais: The burn of the green plain [NG 70 19]
Allt Slapin: The burn of the muddy loch [NG 58 21]
Allt Stapaig: Possibly the burn of oatmeal [NG 60 27]
Allt Strollamus: The burn of Struli’s moss, or moss of the bull [NG 59 26]
Allt Teanga Bradan: The burn of the salmon tongue [NG 51 22]
Amar River: The river of the rocky channel [NG 36 38]
Am Bile: The edge or lip [NG 50 44]
Am Fraoch-choire: The heathery corrie [NG 51 23]
Am Fuar-choire: The cold corrie [NG 50 27]
Am Màm: The round hill [NG 52 18]
An Àird: The promontory or heights [NG 53 35]
An Càrnach: The stony place or knoll [NG 55 19]
An Càrn Liath: the grey cairn or knoll [NG 49 55]
An Cuileagorran: The point [NG 48 68]
An Coileach: The peak, crest or cock [NG 52 30]
An Cròcan: Uncertain [NG 38 19]
An Cruachan: The little stack (of peat) [NG 38 22]
An Dorus: The door [NG 44 23]
An Garbh-choire: The rough corrie [NG 46 20]
An Leac: The flat or stepping-stones [NG 43 16] Skye
An Leac: The flat or stepping-stones [NG 59 37] (Raasay)
An Leth-allt: The half-hillock burn[NG 57 44]
An Sgùman: The stack [NG 43 18]
An Sithean: The fairy knoll [NG 62 22]
An Slugan: The gorge(s) of the river [NG 58 24]
An Teanga: The tongue (of land) [NG 58 25]
An Stac: The precipitous hill [NG 54 21] Strath
An Stac: The rock [NG 31 29] Talisker
An t-Aigeach: The stallion’s head [NG 12 47]
An t-Sron: The nose [NG 51 20]

Ard - height, promontory

Ard an Torrain: The promontory of the mound or tumuli [NG 58 49]

Àrd Ghunel: Gunhilda's promontory or height [NG 70 11]

Ard nan Gamhain: The promontory of the stirk [NG 31 36]

Ardnish: The promontory [NG 67 24]

Àrd Thurinish: Uncertain [NM 59 99]

Ardtreck: Uncertain [NG 33 35]

Ardtreck Point: Uncertain [NG 33 36]

Ardvasar: The deadly or fatal height [NG 63 03]

Ardmore Bay: The bay of the point or end of the big promontory [NG 22 60]

Ardmore Point: The point or end of the big promontory [NG 21 59]

Armadale: Possibly the dale where the forces gathered [NG 63 03]

Arnaval: The eagle mount or fell [NG 34 31]

Arnish: The height or extremity of the promontory [NG 59 48]

Ascrib Islands: Possibly ridge with a hump (in profile) [NG 29 64]

Ashbank: The hillside of the ash trees [NG 59 20]

B

Baca Ruadh: The red ridge [NG 47 57]

Balachuirn: Cairn settlement [NG 55 40]

Balmaqueen: MacCuien's Settlement [NG 44 74]

Balmeanach: Mid-township [NG 46 68]

Balmeananch: Mid-township [NG 56 40]

Bealach -pass

Bealach a' Chuirn: Cairn's pass [NG 48 54]

Bealach a' Garbh-choire: The pass of the rough corrie [45 20]

Bealach a' Mhàim: The pass of the round hill [NG 44 26]

Bealach Cumhang: The narrow pass [NG 50 45]

Bealach Hartaval: The pass of Hartival (Harta Fell) [NG 47 55]

Bealach na Sgàirde: The pass of the scree [NG 51 29]

Bealach Ruadh: The red pass [NG 57 39]

Bealach Udal: The gloomy pass [NG 75 20]

Beal (Bile) Chapel: The chapel of/at the edge [NG 49 44]

Beal Point: The promontory of the pasturage [NG 51 45]

Bearreraig Bay: Uncertain [NG 51 53]

Bearreraig River: Uncertain [NG 51 52]

Beinn, Bheinn – peak or summit

Beinn a' Bhràghad: The peak of the upland country [NG 42 25]

Beinn a' Chapuill: The peak of the horse (or mare) [NG 57 43]

Beinn a' Chlèirich: The peak of the cleric [NG 33 45]

Beinn an Dubhaich: The peak of darkness [NG 59 19]

Beinn an Eòin: Ewan's Peak [NG 38 20]

Beinn Bhreac: Speckled peak [NG 46 15] Soay

Beinn Bhreac: Speckled peak [NG 34 26] Minginish

Beinn Bhuidhe: The yellow peak [NG 61 17]
Beinn Dearg Bheag: The little red peak [NG 59 21]
Beinn Dearg Mheadhonach: The middle red peak [NG 51 27]
Beinn Dearg Mhòr: The big red peak [NG 52 28] Western Red Hills
Beinn Dearg Mhòr: The big red peak [NG 58 22] Eastern Red Hills
Beinn Edra: The in-between peak [NG 45 62]
Beinn Leacach: The stony peak [NG 52 17]
Beinn na Caillich: The peak of the old woman [NG 60 23] Strath
Beinn na Caillich: The peak of the old woman [NG 77 22] Sleat
Beinn na Càrn: The round rocky peak [NG 63 18]
Beinn na Crò: The peak of the sheep fold [NG 56 24]
Beinn na h-Iolaire: Eagle Peak [NG 59 50]
Beinn na Leac: The peak of the flat or stepping-stones [NG 59 37]
Beinn nan Dubh-lochan: The peak of the black lochan [NG 31 32]
Beinn na Seamraig: The peak of the clover [NG 72 17]
Beinn Staic: Stack peak [NG 39 23]
Beinn Totaig: Possibly the peak of the toft (area separated from the community) [NG 40 36]
Bheinn Shurdail: The grassy peak [NG 63 20]
Belig: Possibly hill of the bellowing (of stags) [NG 54 24]
Ben – mountain, hill
Ben Aslak: The hill of the goat [NG 75 19]
Ben Cleat: The hill of the sea cliff [NG 52 15]
Ben Connan: The lusty mountain [NG 19 40]
Ben Chracaig: Possibly the summit of the fissure, or the summit of Crow Bay [NG 49 43]
Ben Geary: The summit of the enclosure [NG 25 61]
Ben Idrigill: The summit of the ravine or narrow gully [NG 23 38]
Ben Lee: The smooth summit [NG 50 33]
Ben Meabost: The summit of the narrow homestead or dwelling [NG 53 15]
Ben Scudaig: Possibly the outlook summit [NG 35 40]
Ben Scaalan: The summit or place of the sheiling [NG 33 26]
Ben Tianavaig: The summit above the bay [NG 51 40]
Ben Volovaig: The summit of the steading for animals [NG 43 76]
Bidein an Fhithich: The peak of the raven [NG 51 14]
Bidein Druim nan Ramh: The peak of the ridge or back of the oar [NG 45 23]
Biod Mòr: The big peak [NG 37 27]
Biod Ruadh: The red peak [NG 31 28]
Blà-bheinn (Blaven): The sunny or warm mountain [NG 52 21]
Boreraig: Castle Bay [NG 61 16]
Bornesketaig: The low cape [NG 37 70]
Bracadale: The spotted valley [NG 34 38]
Brae: The brae or hillside [NG 56 41]
Braes: The braes or slopes [NG 51 36]
Brandarsaig: Brander's Bay [NG 25 39]
Breakish: The place of the speckled people (smallpox) or speckled stones [NG 68 23]
Broadford: The place of the broad crossing (An t-Àth Leathann) [NG 64 23]

Broadford Bay: The bay of the broad crossing [NG 65 23]
Broadford River: The river of the broad crossing [NG 62 22]
Brochel: The rock fort [NG 58 46]
Brogaig: Castle or burgh bay [NG 47 68]
Broisgill More: The rough river course [NG 34 41]
Bruach – bank, brim, rim
    Bruach na Frithe: The peak of the steep slope [NG 46 25]
    Bruach nam Bò: The bank of the cattle [NG 52 26]
Buaile – cattle fold
    Buaile an Fharaidh: The fold of the height or cattle sheiling [NG 33 30]
    Buaile nan Aodan: The hillside of the cattle gathering [NG 61 22]
    Buaile Dubh: The black cattle fold [NG 41 19]
Budhmor: Uncertain [NG 48 44]
Bualintur: The tower fold [NG 40 20]

C

Cadha Carnach: The stony place of the pass [NG 58 39]
Cairidh Ghlumaig: Fish-weir pool [NG 40 73]
Caisteal a' Garbh-choire: The castle of the rough corrie [NG 45 20]
Calligarry: Kali's enclosure [NG 62 03]
Calum's Road: [NG 58 47]
Camas - bay, channel
    Camas Bàn: The fair bay [NG 49 42]
    Camascross: The bay of the cross [NG 69 11]
    Camas Daraich: Oak tree or wood bay [NG 56 00]
    Camas Fhionnairigh (Camasunary Bay): The bay of the white shieling (bothie) [NG 51 18]
    Camas Malag: Malag Bay [NG 58 19]
    Camas Mòr: The big bay [NG 37 70]
    Camas nan Gall: The stranger's bay [NG 45 14]
    Camas nan Sìdhean: The fairy bay [NG 14 47]
    Camasunary: The bay of the white (or fair) shieling (bothie) [NG 51 18]
    Camasunary Cottage: The cottage of the white (or fair) shieling [NG 51 18]
    Camustianavaig: The bay of the summer sheiling [NG 50 39]
Caolas Scalpay: The narrows of Scalpay [NG 59 27]
Caol Fladda: The kyle (water straight) of Fladda(y) [NG 59 50]
Capistal: Uncertain, possibly proper name [NG 60 01]
Caradal: Uncertain, possibly proper name [NG 56 04]
Carbost: The mossy place [NG 38 31]
Càrn Dearg: The red, rocky hill or cairn [NG 59 16]
Càrn Mòr: The large rocky place or cairn [NG 39 17]
Càrn Mòr: The large rocky hill or cairn [NG 40 73] Trotternish
Càrn Mòr: The large rocky hill or cairn [NG 52 15] Strathaird
Càrn Sgrabach: Uncertain [NG 57 39]
Ceann a' Chreagain: The craggy headland [NG 54 31]

Ceann na Beinne: The head of the summit [NG 42 17]
Cìche na Beinne Deirge: The pinnacle of the red mountain [NG 51 26]
Cioch Buttress: The nipple-like buttress [NG 44 20]
Clach na Craoibhe Chaoruinn: The stones of the rowan (mountain ash) trees [NG 49 27]
Cladach a' Ghlinne: The beach or shore of the glen (valley) [NG 52 16]
Clett: (An) isolated rock [NG 22 58]
Cnoc – knoll, hillock

- Cnoc an t-Sìthein: The fairy knoll [NG 49 31]
- Cnoc Breac: The speckled knoll [NG 52 14]
- Cnoc Càrnach: The small knoll [NG 65 19]
- Cnoc Dubh Heilla: The dark knoll [NG 35 34]
- Cnoc Glas Heilla: The grey/green knoll [NG 34 34]
- Cnoc Mhèirlich: Uncertain [NG 44 68]
- Cnoc na Fuarachad: The cold knoll [NG 62 13]
- Cnoc nam Fitheach: The knoll or crag of the raven [NG 59 21]
- Cnoc Roll: The marching knoll [NG 41 73]
- Cnoc Scarall: The knoll of the fissure [NG 39 28]
- Cnoc Slapin: The knoll of Slapin [NG 57 21]

Coille - wood

- Coille a' Chuaraidh: The wood of Chuaraidh [NG 62 12]
- Coille Gaireallach: The wood of Gaireallach [NG 60 19]

Coille an Leatraich: Uncertain [NG 55 42]
Coire, Coir' - corrie

- Coire a' Bhàsteir: The corrie of the executioner [NG 46 25]
- Coire a' Càise: The cheese (-shaped) corrie [NG 54 22]
- Coireachan Ruadha: The red corrie(s) [NG 44 21]
- Coire a' Chruidh: The corrie of the cattle [NG 47 18]
- Coire a' Ghreadaidh: The corrie of the thrashings [NG 43 23]
- Coir' a' Ghrunnda: The corrie of the ground or rock [NG 44 19]
- Coire an Lochain: The corrie of the small loch [NG 45 20]
- Coire Beag: The small corrie [NG 46 18]
- Coire-chat-achan: The corrie of the place of cats [NG 62 22]
- Coire Choinnich: Kenneth's corrie [NG 54 25]
- Coire Dubh: The black corrie [NG 52 22]
- Coire Dubh Measarroch: The black frugal corrie [NG 50 26]
- Coire Faoin: The empty or lonely corrie [NG 49 53]
- Coire Forsaidh: Waterfall corrie [NG 60 21]
- Coire Gorm: The blue/azure corrie [NG 59 22]
- Coire Làgan: The little hollow corrie [NG 43 20]
- Coire Laogh: The corrie of the calves or deer fawns [NG 58 23]
- Coire Mhic Eachainn: MacEachan's Corrie [NG 44 71]
- Coire na Banachdich: The corrie of the smallpox (pock-marked rocks) [NG 42 21]
- Coire na Creiche: The corrie of devastation [NG 43 25]
- Coire nam Bruadaran: The corrie of dreams or visions [NG 52 25]
- Coire nan Laogh: The corrie of the calves or deer fawns [NG 51 25]

Coire na Seilg: The hunting corrie [NG 53 24]
Coire na Sgàirde: The corrie of scree [NG 50 29]
Coire Riabhach: The grey corrie [NG 48 21] Central Cuillin Hills
Coire Riabhach: The grey corrie [NG 47 26] NE Cuillin Hills
Coire Rèidh: The smooth or level corrie [NG 59 23]
Coire Scamadal: The corrie of the short valley [NG 49 55]
Coire Seamraig: The clover corrie [NG 59 24]
Coire Uaigneich: The corrie of solitude [NG 53 21]
Coir'-uisg: The water corrie [NG 46 22]

Coral Beaches: The coral beaches [NG 22 54]
Corry: The corrie [NG 64 24]
Coruisk River: The river of the water corrie [NG 46 21]
Craig Ulatota: Uncertain [NG 50 47]
Creag, Creagan - crag, rock, precipice

Creag a' Chapaill:The crag of the chapel [NG 40 16]
Creag a' Lain: The crag of the enclosed ground [NG 46 58]
Creag an Daraich: The oak rock or crag [NG 60 15]
Creag an Eòin: Ewan's crag [NG 59 50]
Creag a' Sgùrr: The crag of the peak [NG60 51]
Creag Bhàn: The white crag [NG 59 47]
Creag Dhubh: The black crag [NG 36 39]
Creagan Dubh: The black crags [NG 58 24]
Creagan Fitheach: The crags of the raven [NG 60 21]
Creagan Iar: The crags of the west [NG 40 73]
Creag Loisgte: The burnt crags [NG 44 69]
Creag Mhòr: The big crag [NG 40 17] SE of Cuillin Hills
Creag Mhòr: The big crag [NG 36 38] Bracadale
Creag Mhòr: The big crag [NG 50 44] North of Portree
Creag na Bruaich: The bank or border crag [NG 58 43]
Creag na Laire: The crag of the mare [NG 39 21]
Creag nan Cadhaig: Possibly the crag of the pass [NG 59 38]
Creag Strollamus: The crag of Stroli's moss [NG 60 26]

Cuillin Hills: Origin uncertain [NG 45 22]
Cuithir: Uncertain [NG 48 58]
Culnacnoc: Back of the crag [NG 51 62]
Culnamean: Back of the mountains [NG 41 20]

D

Digg: The ditch [NG 46 69]
Doire - grove

Doire na h-Achlais: The grove of the hollow or armpit [NG 58 04] Sleat

Druim – ridge

Druim an Aonaich: The ridge of the hill or hill-slope [NG 58 42]
Druim an Fhuarain: The ridge of the well or spring [NG 56 19]

Druim Eadar Da Choire: The ridge between the two corries [NG 52 24]
Druim Hain: The ridge of the hinds [NG 49 22]
Druim na Criche: The boundary ridge [NG 43 37]
Druim nan Cleochd: The ridge or high pass of the mist [NG 53 29]
Druim nan Ramh: The ridge of the oar [NG 46 22]
Druim na Ruaige: The ridge of the pursuit or chase [NG 50 27]

Drinan: Not known [NG 54 15]
Dirivallan: Not known [NG 33 33]
Drumfearn: Alder ridge [NG 67 15]
Drynoch: Place of the thorns [NG 41 31]
Duirinish: Norse: the deer promontory [NG 20 45]
Dun, Dunan – mound, heap, hillock

Dunan: The hill or mound [NG 58 27]
Dùnan Ruadh: The red hill [NG 78 19]
Dunans: The place of the mounds [NG 46 70]
Dùnan Thearna Sgùrr: The mound at the tail of the hill [NG 36 20]
Dùn Ard an t-Sabhail: The hill of the promontory or barn/granary [NG 31 33]
Dun Beag: The little mound [NG 57 19]
Dun Bornaskitaig: The mound of the low cape [NG 37 71]
Dùn Caan: The white fort or hill [NG 57 39]
Dùn Garsin: [NG 35 38]
Dun Liath: The grey mound [NG 54 14]
Dùn Vàllerain: [NG 46 69]

Duntulm: The fort of Tulm Island [NG 41 74]
Duntulm Castle: The castle of Duntulm [NG 40 74]
Dunvegan: Various: the fort of the few / Vikings / saplings [NG 25 48]
Dunvegan Head: The promontory of Dunvegan [NG 17 56]

E

Eaglais Briege: Uncertain [NG 58 43]
Eas - waterfall

Eas a' Bhradain: The waterfall of the salmon [NG 53 26]
Eas a' Chait: The waterfall of the cat [NG 53 24]
Eas Mòr: The great waterfall [NG 41 21]

East Buttress of Sròn na Cìche: The east face of Sròn na Ciche [NG 44 20]
Eastern Red hills (district): The red hills in the east (SW of Broadford) [NG 59 23]
Eilean - island

Eilean Àird nan Gobhar: The promontory of goat island [NG 54 36]
Eilean an Inbhire: The island at the confluence [NG 54 42]
Eilean Chaluim Chille: The island of Calum's church [NG 37 68]
Eilean Dubh: Black Island [NG 61 14]
Eilean Fladday: Flat Island [NG 58 50]
Eilean Flodigarry: The floating island enclosure [NG 47 71]
Eilean Gaineamhach an Arda: Uncertain [NG 62 14]

Eilean Heast: The horse (colt)-shaped island [NG 64 15]
Eilean na h-Àirde: The island of (with) the promontory [NG 52 11]
Eilean Reamhar: The broad or fat island [NG 48 18]
Eilean Tigh: House Island [NG 60 53]

Elgol: [NG 52 14]
Elishadder: The seat of the cave [NG 50 65]
Erisco: Eric's settlement [NG 41 75]
Eynort: Island sea-firth [NG 38 26]
Eyre Burn: The burn of the gravelly beach [NG 57 34]
Eyre Point: The point of the gravelly beach [NG 58 34]

F

Fairy Bridge: The bridge of the fairies[NG 27 51]
Faoilean: Exposed place by the shore[NG 56 20]
Fiaclan Dearg: The red tooth [NG 50 25]
Fionna-choire: The white or fair corrie [NG 53 21]
Fionn Choire: The white or fair corrie [NG 45 25]
Fir Bhreugach: The false man [NG 44 70]
Fiskavaig: Fish Bay [NG 32 34]
Fiurnean: Place of alders [NG 51 49]
Flasvein: Uncertain [NG 46 59]
Flodigarry: The floating enclosure [NG 46 71]

G

Garbh-bheinn: The rough mountain [NG 53 23]
Gars-bheinn: The echoing mountain [NG 46 18]
Gairbh-sgeir: Rough skerry or reef [NG 38 72]
Geodha Daraich: The inlet of the oak tree [NG 37 19]
Geodha na h-Airigh Mòire: The inlet of the big sheiling [NG 37 18]
Geodha nan Daoine: The inlet of the men [NG 24 36]
Gillean Burn: The burn of the hollows [NG 59 08]
Glac Mhòr: The big hollow [NG 45 23]
Glac Ghealaridh: Uncertain [NG 25 37]
Glame: The noise of a burn, or where the land has been eroded [NG 55 43]
Glamaig: The mountain gorge, on account of it verdant top fed by a spring [NG 51 30]
Glas – grey, green

Glas-Bheinn Bheag: The little grey/green mountain [NG 58 25]
Glas-Bheinn Mhòr: The big grey/green mountain [NG 55 25]
Glas Eilean: The grey/green island [NG 65 23]

Glasphein: The grey/green penny-land (an area of land) [NG 46 68]
Glasnakille: The grey/green meadow of the church [NG 53 12]
Gleann, Glen – valley

Gleann Meadal: The narrow glen [NG 66 10]

Gleann Meadhonach: The middle glen [NG 59 05]
Gleann Oraid: The glen of speech [NG 33 30]
Gleann Thorabhaig: Uncertain [NG 67 09]
Gleann Torra-mhichaig: The glen of the hills [NG 53 30]
Glen Arroch: Glen of the spectre, or short glen [NG 73 21]
Glen Boreraig: The glen of castle bay [NG 59 17]
Glen Brittle (Gleann Bhreatail): Uncertain [NG 41 24]
Glenbrittle House: The house of Glen Brittle [NG 41 21]
Glen Caladale: The cold glen [NG 34 25]
Glendale: The glen or the valley (dale) [NG 17 49]
Glen Drynoch: The thorny glen [NG 42 30]
Glenmore: The big glen [NG 43 40]
Glen Osdale: The glen of the east hill [NG 23 43]
Glen Scaladal: The glen of the sheiling [NG 52 16]
Glen Scamadal: The short glen [NG 42 70]
Glen Sligachan: The glen of the shelly place [NG 49 27]
Glen Uig: The glen of the bay [NG 41 63]
Glen Varragill: The glen of the weir [NG 47 35]

Great Stone Chute: The steep narrow scree channel on the NW side of Sgùrr Alasdair [NG 44 20]
Gualann na Leac: The stony shoulder, slope or hillside [NG 59 37]

H

Hallaig: The place of the burn [NG 59 38]
Harlosh: The place of the buck (male goat) [NG 28 41]
Harlosh Island: Goat Island [NG 28 39]
Harker's Gully: Gully on NW side of Marsco, named for geologist, Alfred Harker [NG 50 25]
Harrapool: Possibly the Lord's dwelling place [NG 65 22]
Harta Corrie: The corrie of the hart or the stony corrie [NG 47 23]
Healabhal Bheag (Lesser Macleod's Table or Macleod's Table South): As named [NG 22 42]
Healabhal Mhòr (Greater Macleod's Table or Macleod's Table North): As named [NG 21 44]
Heaste: The place of the horse (facing Eilean Heaste, the horse-shaped island) [NG 64 17]
Herishader: Lord's seat or place [NG 51 62]
Hoe Rape: Hoe Cape, the high sea cliff [NG 15 43]
Holm: The alluvial land [NG 52 51]
Holm Island: The island offshore of Holm [NG 52 51]
Holoman Bay: Bay of the little knoll or hillock [NG 54 39]
Holoman Island: The island in Holoman Bay [NG 54 40]
Huisgill: The valley or ravine of the house [NG 32 31]
Hunish: Hun's or the (northern) place [NG 41 76]

I

Idrigill: The ravine or narrow gully [NG 25 37]
Idrigill Point: The promontory of the ravine or narrow gully [NG 25 36]

Inghir a’ Ghàrraidh: Inghir’s Garden [NG 24 36]
Inverarish: The mouth of the burn or river [NG 55 35]
Inverarish Burn: [NG 56 36]
Inver Tote: The confluence of the River (Tote) [NG 52 60]
Ìosaigh: Uncertain [NG 21 57]
Isle Ornsay: Ebb tide island [NG 69 12]

K

Kilbride: St Bride's Church [NG 59 20]
Kilbride House: The house of Kilbride [NG 58 20]
Kilchrist: Christ's Church [NG 61 20]
Kilchrist Manse: The (old, abandoned) manse of Kilchrist [NG 61 20]
Kildorais: St Truos’ Church or cell [NG 46 71]
Kilmaluag: St Molag's Church [NG 42 73]
Kilmaluag Bay: The bay of St Molag's Church [NG 44 75]
Kilmarie: Mary’s Church [NG 55 17]
Kilmartin River: The river of Martin's Church [NG 48 66]
Kilmuir: The church of the sea [NG 38 70]
Kilvaxter: The church of the baker [NG 38 69]
Kilt Rock: Where the columnar rocks bare a resemblance to the pleats of a kilt [NG 50 66]
Kinloch: The head of the loch [NG 70 15]
Kirkibost: Church place at the home-farm or settlement [NG 54 17]
Knock: The round hill or knoll [NG 67 08]
Knock Bay: The bay of the round hill or knoll [NG 67 08]
Kyle - Strait
  Kyleakin: Acunn or Haco's Strait [NG 75 26]
  Kylerhea: The King's Strait [NG 78 20]
  Kylerhea River: The river of the King's Strait [NG 77 20]

L

Lampay: Uncertain [NG 21 55]
Leac nam Faoileann: The seagull’s flagstone or perch [NG 42 14]
Lealt: Half (height) stream, or burn [NG 50 60]
Lealt River: The river of Lealt [NG 49 60]
Leathad – brae, slope
  Leathad Beithe: The brae of the birches [NG 31 29]
  Leathad Chrithinn: The brae of the aspen tree [NG 55 29]
  Leachd Thuilm: Thuilm’s brae [NG 42 24]
  Leathad Dubh: The black brae [NG 51 30]
Leir Mhaodail: Muddy place [NG 57 99]
Loch - lake
  Loch a’ Chad-charnaich: Loch of the stony pass [NG 58 39]
  Loch a' Choire Riabhaich: The loch of the grey corrie [NG 49 21]

Loch a' Ghlinne: Loch of the glen [NG 59 05]
Lochain Beinn na Caillich: The loch of the mountain of the old woman [NG 61 24]
Loch Ainort: [NG 55 28]
Loch Alsh: [NG 80 26]
Loch an Athain: The loch of the little ford [NG 51 22]
Loch an Fhir-bhallaich: Loch of the spotted rock(s) or person [NG 42 20]
Loch an Ime: Butter loch [NG 67 10]
Loch an Leòid: Broad loch [NG 59 16]
Loch an Uachdair: Summit or upper loch [NG 58 47]
Loch an Sgurra: The loch of the cragù[NG 60 52]
Lochan nan Dunan: The loch of the mounds [NG 46 70]
Loch Arnish: Possibly the Eagle loch [NG 58 48]
Loch Ashik: Uncertain [NG 69 23]
Loch Aruisg: Loch of the demon or evil spirit [NG 57 00]
Loch Baravaig: The loch at the summit of the bay[NG 68 09]
Loch Bay: The bay of the loch [NG 26 55]
Loch Beag: The little loch [NG 34 37]
Loch Beg: The little loch [NG 58 47]
Loch Bracadale: The loch of the spotted valley [NG 29 38]
Loch Brittle: Uncertain [NG 40 19]
Loch Buidhe: The yellow loch [NG 63 19]
Loch Chaluim Chille: The loch of Malcolm's Church [NG 37 68]
Loch Cill Chriosd: The loch of Christ's Church [NG 60 20]
Loch Cill Chriosd Churchyard: The churchyard of the loch of Christ's Church [NG 61 20]
Loch Cleat: The loch of the hill of the sea cliff [NG 41 74]
Loch Coir' a' Ghrunnda: The loch of the bottom corrie [NG 45 20]
Loch Coruisk: The loch of the water corrie [NG 48 20]
Loch Cuil na Creige: The loch in the back of the crags [NG 60 25]
Loch Cuithir: Uncertain [NG 47 59]
Loch Doir' a' Chreamha: The loch of the wild garlic grove [NG 43 13]
Loch Droighinn: Bramble thorn loch [NG 45 71]
Loch Dunvegan: Various: the loch of the fort of the few / Vikings / saplings [NG 21 52]
Loch Eishort: Ice loch [NG 62 15]
Loch Eynort: Island sea-firth [NG 36 24]
Loch Fada: The long loch [NG 45 69] North Skye
Loch Fada: The long loch [NG 60 16] Strath
Loch Harport: The loch of the buck (goat, hare, rabbit) [NG 36 34]
Loch Hasco: The loch of the high place [NG 45 70]
Loch Lamascaig: Uncertain [NG 58 03]
Loch Langaig: Loch-bay loch [NG 46 70]
Loch Leathan: The broad loch [NG 50 51]
Loch Lonachan: The small marshy loch [NG 62 19]
Loch Meall Daimh: The hill of the stag [NG 57 40]
Loch Mealt: The loch of the unlucky river [NG 50 64]
Loch na Bèiste: The loch of the cattle [NG 75 25]

Loch na Bronn: Uncertain [NG 57 46]
Loch na Crèitheach: The loch of the brushwood or aspen trees [NG 51 20]
Loch na Cuilce: The reedy loch [NG 48 19] (Skye)
Loch na Cuilce: The reedy loch [NG 57 47] (Raasay)
Loch na Dal: The loch of the field [NG 70 14]
Loch na h-Àirde: The high loch [NG 39 16]
Loch na Meilich: The loch of the weed [NG 57 39]
Loch na Mna: The loch of a man dressed as a woman (from a traditional tale) [NG 57 38]
Loch nan Dùbhrachan: Black or dark braes' loch [NG 67 10]
Loch nan Leachd: The loch of the flat stones [NG 49 19]
Loch nan Learg: The loch of the black-throated diver, or cormorant [NG 59 19]
Loch na Sguabaidh: The loch of the cleansing [NG 55 23]
Loch Portree: The loch of the King's Harbour [NG 48 42]
Loch Ravag: The noisy or splashing loch [NG 37 44]
Loch Scavaig: The gloomy or dark loch [NG 50 16]
Loch Sheanta: The holy loch [NG 47 69]
Loch Slapin: The muddy loch [NG 57 17]
Loch Sligachan: Loch of the shells [NG 51 32]
Loch Sneosdal: The snow loch or fiord [NG 41 69]
Loch Snizort: The snow loch or fiord [NG 33 60]
Loch Snizort Beag: The little snow loch [NG 39 54]
Loch Storab: Storab's loch [NG 56 38]
Loch Vallerain: Uncertain [NG 46 69]

Lòn Bàn: The white or fair meadow [NG 43 18]
Lon Druiseach: The dewy meadow [NG 49 47]
Lonfearn: Alder meadow [NG 51 62]
Longay: Long Island [NG 65 31]
Lota Corrie: The marshy corrie [NG 47 24]
Lower Tote: Uncertain [NG 51 60]
Lub – bay, bend in shoreline

Lùb a' Sgiathain: The bay of the wing [NG 41 76]
Lùb an Sgòir: The rocky bay [NG 39 73]

Luib: The bend [NG 56 27]

Luib na Moil: The bend or bay of the shingly beach [NG 56 30]

Lusa: The flowery place [NG 69 24]
Lyndale Point: The point of the dale (valley) of flax [NG 36 57]

M

Màm a' Phobuill: The people's mound [NG 51 25]
Maol – (bare) summit

Maol Bàn: The fare bare summit [NG 56 29]
Maol na Gainmhich: The summit of the sandy shore [NG 56 31]

Manish Island: Mani's Island [NG 56 48]
Manish Point: Mani's Promontory [NG 56 48]

Marishader: Summer pasture of the horses [NG 49 63]
Marsco: Sea-gull rock, or steep rock [NG 50 25]
Meall – shapeless hill
- Meall a' Mhaoil: The shapeless bare hill [NG 55 30]
- Meallan Dearg: The small round red hill [NG 48 22]
- Meall Buidhe: The yellow hill [NG 55 30]
- Meall Coire Forsaidh:The hill of the waterfall corrie [NG 60 21]
- Meall Dà-Bheinn: The hill of the summit [NG 62 11]
- Meall Dearg: The red hill [NG 49 23] Skye
- Meall Dearg: The red hill [NG 59 49] Raasay
- Meall na Cuilce: The reedy hill [NG 48 19]
- Meall na Suiramach: Uncertain [NG 44 69]
- Meall Odhar: Dun hill [NG 46 26]
- Meall Port Mhealaraigh: The hill of the Mealary harbour [NG 74 16]
- Meall Tuath: Possibly the northern hill [NG 41 76]

McFarlane's Rock: McFarlane's Rock [NG 30 31]
Macleod's Maidens: Macleod's Maidens (sea stacks) [NG 24 36]
Merkadale: Merk valley [NG 39 31]
Milovaig: The place of the bent grass [NG 15 49]
Mine #1 (Raasay): [NG 56 36]
Mine #2 (Raasay): [NG 55 36]
Mingay: Great Island [NG 22 57]
Minginish: Possibly the Great Promontory - Norse [NG 35 30]
Mointeach nan Tarbh: Mossy place of the bull [NG 13 48]
Moll: The shingly or pebbly beach [NG 56 30]
Moll River: The river of the shingly or pebbly beach [NG 55 30]
Moonen Bay: The bay of the trickling waterfall [NG 14 46]
Mugeary: Dark or gloomy field [NG 44 38]

N

Na Huranan: Uncertain [NG 34 31]
Narrows of Raasay: The straight or channel between Raasay and Skye [NG 54 35]
Nead na h-Iolaire: The nest of the eagles [NG 48 27]
Needle Rock: The Needle Rock [NG 50 54]
Neist: Uncertain [NG 12 47]
North Dunans: The northern part of the place of the mounds [NG 46 71]
North Fearns: The northern place of the alder tree [NG 59 35]
North Screapadal: The northern part of the rough dale (valley) [NG 57 44]

O

Ob - bay
- Ob Breakish (Bhreacais): The bay of the place of the speckled people (smallpox) [NG 68 24]
- Ob Lusa: The bay of the flowery place [NG 70 24]

Oisgill Bay: The bay of the river outlet [NG 13 49]
Old Man of Storr: The rock pillar of the Storr [NG 50 53]
Ord: The place of the round hill, or point or corner [NG 61 13]
  Ord Bay: The bay of the place of the round hill [NG 61 13]
  Ord River: The river of the place of the round hill [NG 62 12]
Orbost: Orr or Orris' settlement [NG 25 43]
Oronsay: Tidal Island [NG 31 35]
Osdale: East dale (valley) [NG 32 41]
Oskaig: The outlet of the river [NG 54 38]
Oskaig Point: The promontory of the outlet of the river [NG 54 38]

P

Peingown: The smith's (penny) -land [NG 40 71]
Penifiler: Uncertain [NG 48 41]
Point of Sleat: The end or promontory of Sleat (mountain slopes or sloping moorland) [NM 56 99]
Poldorais: St Turos' Pool [NG 47 71]
Port - harbour, bay
  Port a' Bhata: The harbour of the boats [NG 50 44]
  Port a' Chuil: The harbour in the recess [NG 59 00]
  Port Duntulm: The harbour of the fort of Tulm Island [NG 41 74]
  Port Earlish: The earl's harbour [NG 52 62]
  Port Gobhlaig: The forked or double harbour [NG 43 75]
  Port Lag a' Bhleodhainn: Uncertain [NG 41 76]
  Port na Cullaidh: The harbour of the seal [NG 51 13]
  Portnalong: The ship's harbour [NG 34 34]
  Portree: The King's Harbour [NG 48 43]
Preshal Beag: Small hill [NG 32 27]
Preshal Mhor: Great hill [NG 33 29]

Q

(The) Quiraing: The round fold or pen [NG 45 69]

R

Raasay House: The house of roe island [NG 54 36]
Ramasaig: Raven's Bay [NG 16 44]
Ramasaig Bay: Raven's Bay [NG 15 43]
Ramasaig Cliff: The cliff of Raven's Bay [NG 15 44]
Red Hills: The granite hills of central Skye, red due to oxidation of (magmatic) minerals [NG 55 25]
Rigg: The ridge [NG 51 56]
River Chracaig: Possibly the river of the little fissure [NG 48 44]
River Sligachan: The river of the shelly place [NG 48 29]
River Snizort: The river of the snow loch or fiord [NG 42 48]

River Talisker: The river of the house of the rock [NG 40 22]
Robostan: Rob’s Place [NG 54 17]
Roineval: The raven’s hill [NG 41 35]
Rona: Rock-surfaced or rocky island [NG 61 55]
Ros a' Mheallain: The small elongate hill [NG 37 40]
Ruadh Stac: Red stack or the red hill [NG 51 23]
Rubha, Rubh' - point, promontory

- Rubha a’ Gheodha Bhuidhe: The promontory of the yellow cove [NG 48 17]
- Rubh’ an Uillt Dharaich: Oak tree (burn) promontory NG 55 32]
- Rubha an Dùnain: The point of the small hill [NG 38 16]
- Rubh' an Eireannaich: Possibly the promontory of the goat or Irishman's Point [NG 64 24]
- Rubha an Inbhire: The promontory of the confluence [NG 54 41]
- Rubha an Tòrra Mhoir: Tormore Point [NG 53 32]
- Rubha Ardnish: The point of the promontory [NG 68 24]
- Rubh' Achadh a' Chuirn: Cairn field promontory [NG 66 23]
- Rubha Bàn: The fair (pale) promontory [NG 13 50] Duirinish
- Rubha Bàn: The fair (pale) promontory [NG 50 17] Cuillin Hills
- Rubha Buidhe: The yellow promontory [NG 49 18] Cuillin Hills
- Rubha Buidhe: The yellow promontory [NG 79 25] Sleat
- Rubha Crion: The little or short promontory [NG 59 48]
- Rubha Cruinn: The round promontory [NG 30 30]
- Rubha Dubh Àird: The point of the black promontory [NG 62 14]
- Rubha Garbhaig: The promontory of the flounder [NG 49 68]
- Rubha Hunish: Hun’s or the (northern) promontory [NG 40 77]
- Rubha na Cloiche: The promontory of the green stone [NG 56 33]
- Rubha na h-Àirde Glaise: The grey or green promontory [NG 51 45]
- Rubha na h-Àirighe Bàine: The white or pale promontory [NG 51 17]
- Rubha na Leac: The promontory of the flag-stones [NG 60 38]
- Rubha na Maighdeanan: Uncertain [NG 24 36]
- Rubha nam Brathairean: Brothers’ (monks’) promontory [NG 52 62]
- Rubha na Sgianadin: The pointed promontory [NG 62 26]
- Rubha Port Sgàile: The promontory of the shallow port or bay [NG 48 19]
- Rubha Suisnish: Possibly the seething or roaring promontory [NG 58 15]
- Rubha Voreven: Possibly promontory of the hill [NG 40 75]

Ru Bornesketaig: The point of the low cape [NG 37 71]
Ru Meanish: Possibly Narrow point [NG 40 74]

S

Sartle: The muddy valley [NG 46 67]
Scaladal Burn: The burn of the sheiling valley [NG 52 16]
Scalpay: Cave Island [NG 60 30]
Sconser: Uncertain [NG 52 32]
Score Horan: The wolf’s peak [NG 28 59]
Sgeir - skerry, sea-rock, reef

Sgeir Gharbh: The rough skerry [NG 52 62]
Sgeir Gormul: The green/blue (azure) skerry [NG 63 15]
Sgeir Mhòr: The big skerry [NG 39 15]
Sgeir Mhòr: The big skerry [NG 49 43]
Sgiath-bheinn an Uird: The wing of the hammer [NG 64 13]
Sgiath-bheinn Chrosabhaig: The wing of the Cross [NG 62 11]
Sgiath-bheinn Tògabhaig: The wing of the bay [NG 61 11]
Sgùrr - peak, rock summit
Sgùrr a' Bhasteir: The peak of the executioner [NG 46 25]
Sgùrr a' Choire Bhig: The peak of the little corrie [NG 46 19]
Sgùrr a' Ghreadaidh: The peak of torment or of the thrashings (strong winds) [NG 44 23]
Sgùrr Alasdair: Alexander's Peak [NG 44 20]
Sgùrr a' Mhadaidh: The peak of the foxes [NG 44 23]
Sgùrr a' Mhadaidh Ruaidh: The peak of the red foxes [NG 47 58]
Sgùrr a' Mhalaidh: Possibly peak of the prince [NG 46 56]
Sgùrr an Duine: The peak of the man [NG 35 21]
Sgùrr an Fheòir: The green peak [NG 31 30]
Sgùrr Dearg: The red peak [NG 44 21]
Sgùrr Dearg Stone Chute: The stone chute of the red peak [NG 44 21]
Sgùrr Dubh Mòr: The black peak [NG 45 20]
Sgùrr Dubh an Da Bheinn: The black peak of the double mountain [NG 45 20]
Sgùrr Dubh Beag: The small black peak [NG 46 20]
Sgùrr Hain: Uncertain [NG 50 20]
Sgùrr Mhairi: Marie's (Mary's) Peak [NG 30 51]
Sgùrr Mhic Choinnich: MacKenzie's Peak [NG 44 21]
Sgùrr Mòr: The great peak [NG 30 31]
Sgùrr na Banachdich: The smallpox/milkmaid's peak (pitted nature of rocks) [NG 44 22]
Sgùrr na Coinnich: The mossy peak [NG 76 22]
Sgùrr na h-Uamha: The peak of the caves [NG 47 24]
Sgùrr nam Boc: The peak of the bucks (male goats) [NG 36 21]
Sgùrr nan Cearcall: The peak of the circle or hoops [NG 41 16]
Sgùrr nan Eag: The notched peak [NG 45 19]
Sgùrr nan Each: The peak of the horses [NG 53 22]
Sgùrr nan Gillean: The peak of the young men [NG 47 25]
Sgùrr nan Gobhar: The peak of the goats [NG 42 22]
Sgùrr na Stri: The peak of the fight [NG 50 19]
Sgùrr Sgumain: The stack peak [NG 44 20]
Sgùrr Thearrlaich: Charles' Peak [NG 45 20]
Sgùrr Thormaid: Norman's Peak [NG 44 22]
Sgùrr Thuilm: Tulin's Peak (43 24]
Sìthean - fairy
Sìthean a' Choire Odhair: The dun or dusky-grey fairy corrie [NG 77 23]
Sìthean Beag: The little hill (fairy knoll) [NG 58 08]
Sìthean a' Bhealaich Chumhaing: The hillock of the fairy pass [NG 50 46]
Sìthean Mòr: The big fairy hillock [NG 59 47] Raasay

Sìthean Mòr: The big fairy hillock [NG 59 07] Skye
Skridan: The rocky hillside or scree [NG 34 25]
Skudiburgh: Uncertain [NG 37 64]
Skulamus: Uncertain [NG 66 22]
Slat Bheinn: The mountain of the twig or rod [NG 53 19]
Sleadale: Uncertain [NG 32 28]
Sleat (Peninsula): The mountain slopes or sloping moorland [NG 64 10]
Sligachan: The shelly place [NG 48 29]
Slochd Dubh: The black hollow or pit [NG 40 16]
Soay: Sow or pig island [NG 44 14]
Soay Sound: The water straight(s) or narrows of sow or pig island [NG 43 15]
Sound of Sleat: The water straight(s) of the mountain slopes or sloping moorland [NG 67 04]
South Fearns: The southern place of the alder tree [NG 58 35]
South Screapadal: The southern part of the rough dale (valley) [NG 58 44]
Spar Cave: The calcite or carbonate cave [NG 53 12]
Srath, Strath - valley
Srath Beag: The little valley [NG 57 23]
Srath Mòr: The big valley [NG 56 24]
Srath na Crèitheach: The valley of the brushwood or aspen trees [NG 51 22]
Sròn - nose or spur
Sròn a' Bhealain: The nose of the pass [NG 50 28]
Sròn Àrd a' Mhullaich: The nose of the promontory [NG 54 27]
Sròn na Cìche: The spur of the breast or nipple [NG 44 19]
Sròn Vourlinn: The mill point promontory [NG 45 71]
Stac a' Mheadais: The rock pillar of Mheadais [NG 33 25]
Stack of Skudiburgh: The rock pillar of Skudiburgh [NG 37 64]
Stachd: The stack [NG 42 16]
Stac Suisnish: The sea stack of Suisnish [NG 58 16]
Staffin: The place of the upright pillars [NG 47 67]
Staffin Bay: The bay of the place of the upright pillars [NG 48 69]
Stockval: The ridge or crags of the lumpy rocks [NG 34 29]
(The) Storr: The steep high cliff or pinnacle [NG 49 54]
Storr Lochs: The lochs of the steep high cliff or pinnacle [NG 50 50]
Storr Lochs Dam: The dam of the steep high cliff or pinnacle [NG 51 52]
Strath - valley
Strath: Broad valley with river – a district between Broadford and Torran [NG 60 20]
Strathaird: The promontory or heights of Strath [NG 54 17]
Strath Suardal: The grassy valley (sward or green turf) [NG 61 21]
Strollamus: Stroli's moss [NG 59 26]
Struan: The streamlet [34 38]
Suisnish: Possibly the seething or roaring point [NG 59 16]
Suisnish Hill: Possibly the hill of the seething or roaring point [NG 56 34]
Suisnish Point: Possibly the seething or roaring promontory [NG 55 34]

T

Tairbeart: The isthmus [NG 59 47]
Talisker: The house of the rock [NG 32 30]
Talisker Bay: The bay of the house of the rock [NG 31 30]
Tarskavaig: Whale Bay [NG 58 09]
Tarner Island: The island at the foot of the hills [NG 29 38]
Teangue: Th narrow strip of land [NG 66 09]
The Aird: The headland [NG 43 76]
The Inaccessible Pinnacle: The rock pinnacle that is inaccessible [NG 44 21]
The Hoe: The high sea cliff [NG 16 41]
(The) Kilt Rock: Where the columnar rocks bare a resemblance to the pleats of a kilt [NG 50 66]
The Prison: The prison [NG 45 68]
The Needle: The needle [NG 45 69]
(The) Quiraing: The round fold or pen [NG 45 69]
The Shelter Stone: A stone offering shelter in Harker's Gully on the NW side of Marsco [NG 50 25]
The Slabs: The Slabs [NG 47 20]
(The) Storr: The steep high cliff or pinnacle [NG 49 54]
The Storr Lochs: The lochs of the steep high cliff or pinnacle [NG 50 50]
The Table: The Table [NG 45 69]
Tokavaig: The swelling or boisterous bay, or south bay [NG 60 11]
Tormichaig: The hill of Michaig [NG 53 31]
Torran: The heaps or mounds [NG 59 49]
Torrin: The hillock (little hill) [NG 58 20]
Toravaig: Hill Bay [NG 49 44]
Tottrome: The toft (homestead) of the stream [NG 50 54]
Trotternish: Possibly Trond's Headland or enchanted promontory – Norse [NG 45 65]
Truagh Mheall: The worthless hill [NG 38 21]
Trumpan: The one-sided hill [NG 22 61]
Tulm Bay: The bay of the stack or cliff [NG 41 75]
Tulm Island: The stack or cliff island [NG 40 74]
Tungadal River: The river of the tongue valley [NG 41 39]
Tusdale: Uncertain [NG 35 25]

U

Udairn: The hideous, awful or inhospitable caves [NG 51 42]
Uig: The bay [NG 39 63]
Uig Bay: The bay [NG 38 62]
Ulfhart Point: The wolf heights or crags [NG 47 16]
Ullinish: Uncertain [NG 32 37]
Ullinish Point: Uncertain [NG 31 36]
Umachan: Uncertain [NG 60 49]
Upper Tote: Uncertain [NG 51 59]

V

Valtos: Fold (wall) ridge [NG 51 63]
Varragill River: The river of the weir valley [NG 47 38]
Vriskaig Point: The promontory of the bay of the (mythical) monster [NG 48 42]

W

Waterloo: Named after veteran soldiers of the battle of Waterloo (1815) [NG 66 23]
Waternish: The water promontory - Norse [NG 28 57]
Waternish Point: The point or end of the water promontory [NG 23 67]
Waterstein Head: The promontory of the water stone (or stone in the water) [NG 14 47]
Wiay: The island [NG 29 36]

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