Leinis (Leanish), Barra

[NL 706 998]–[NL 699 988]

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Introduction

The Leinis GCR site (formerly termed 'Leanish'), situated on the east coast of Barra, constitutes one of the classic sections in Lewisian geology. Here the degree of Laxfordian reworking is lower than anywhere else in the Outer Hebrides, with very little evidence for any significant deformation after the Scourian events. Consequently, it is possible to examine the host Scourian felsic and mafic gneisses and the various suites of late-Scourian intrusions that are common in this part of Barra. Although intruded subsequently by members of later igneous suites, the field relationships of these Scourian rocks have remained essentially unaltered for over 2000 million years, that is since the Palaeoproterozoic. This effective window into the early geological history is crucial to our understanding of Hebridean geology. Although similar features are present on the small adjacent islands, this unique area provides the most coherent, comprehensive and accessible section, making the site of prime importance.

The Lewisian gneisses of Barra are roughly bisected by one of the major thrusts of the Outer Hebrides Fault Zone (OHFZ). The thrust forms a notable feature on the northern islands of Gighay and Hellisay and can be traced west and then south through the centre of Barra. It forms a prominent ESE-dipping scarp feature running obliquely down across the face of Sheabhal (Heaval) above Castlebay. The rocks exposed on the east coast of Barra thus lie above the thrust plane. The OHFZ normally forms a wide complex area of mixed faulted rocks (see 'Introduction', this chapter), but on Barra the thrust zone is manifest as a relatively narrow feature marked mainly by pseudotachylite breccia (see Cnoc an Thithich GCR site report, this chapter). As a result its hangingwall is virtually unaffected by the thrust-related deformation.

Francis (1973) divided this eastern hanging-wall block into three zones striking approximately NNW The eastern zone is characterized by the virtual absence of Laxfordian strain and contains pyroxene-bearing granulite-facies felsic and mafic gneisses, with the Scourian metamorphic assemblages dating from Archaean times. The central zone is one of strong Laxfordian reworking and amphibolite-facies metamorphism, and the most westerly zone consists of metadiorite and coarse-grained augened granitic gneiss and felsic gneiss. The Leinis GCR site transects the western part of the essentially undeformed eastern zone. Here, a variety of Archaean-age late-Scourian intrusive igneous rocks that post-date the main Scourian metamorphism, and representatives of the Palaeoproterozoic 'Younger Basic' dyke suite are readily identifiable. Excellent field exposures allow these late-Scourian intrusive rocks to be assessed both in terms of their relative ages and their relationships to the deformational phases. From youngest to oldest the late-Scourian elements comprise:

- Quartz-feldspar pegmatites and rare pegmatitic granites
- Monzonites, granites
- Microdiorites, monzodiorites.

A relatively weak deformational phase occurred following the intrusion of the microdiorites and prior to intrusion of the 'Younger Basic' dykes. This is believed to be equivalent to the Inverian event in the Lewisian gneisses of the mainland.

Jehu and Craig (1923) provided the first comprehensive description of the geology of Barra. Hopgood (1964, 1971) later described the polyphasal nature of the deformation and recognized several of the early intrusive suites. Francis (1969, 1973) noted that the area is marked by low Laxfordian strain and postulated that the 'Younger Basic' Suite had been intruded into hot gneisses at mid-crustal levels. Fettes *et al.* (1992) re-defined the nature of the intrusive suites and suggested a correlation of the late-Scourian deformation with the Inverian of the mainland (see (Table 2.1) in the 'Introduction', this chapter).

Description

The GCR site comprises a coastal section on the east side of Barra, from the Leinis peninsula northwards to Sloc nan Each, a distance of *c.* 1.5 km. The exposure is virtually continuous and is formed by low (2–4m-high) cliffs and clean, craggy, wave-cut platforms, which extend seawards for several tens of metres at low tide. The section is partly tidal; Orosay is a tidal island. The section is backed by low rather rocky hills. The geological elements of the site are shown in (Figure 2.25).

In the southern part of the site, on the Leinis peninsula the country rocks are amphibolite-facies hornblende-bearing felsic and subsidiary mafic gneisses, which give way northwards to massive, brownish-weathering, granulite-facies, pyroxene-bearing gneisses. Mafic bodies are present in parts, now represented by amphibolite, normally cross-cut by abundant quartz-feldspar and feldspathic veins. These are members of the 'Older Basic' Suite. A prominent net-veined and coarsely recrystallized hornblendite body occurs around [NL 7023 9902], from which Francis *et al.* (1971) recorded the mineral assemblage hornblende-pyroxene-biotite-plagioclase. The 'Older Basic' bodies, the ultramafic hornblendite, and adjacent gneisses, are all probably Scourian elements of Archaean age (see 'Interpretation').

In thin section the granulite-facies mafic rocks are composed of an equigranular assemblage of clinopyroxene, (± orthopyroxene), hornblende, plagioclase and quartz. Accessory magnetite and ilmenite are abundant and biotite is locally present. Hornblende may be a primary metamorphic phase locally, but normally it has formed by replacement of pyroxene. The felsic gneisses contain the assemblage quartz, plagioclase, biotite, (± hornblende), locally with orthopyroxene. Orthopyroxene, where present, is a pinkish hypersthene, commonly with retrograded margins. Both granulite- and amphibolite-facies assemblages are attributed to the main Scourian gneiss-forming events at *c.* 2850–2730 Ma.

The microdiorite sheets and dykes are uniform grey, medium-grained rocks, which form discrete, parallel-sided bodies that normally range from a few centimetres to 1 m in width (rarely up to 2 m). They occur throughout the section and cross-cut the gneissose foliation. In the larger dykes hornblende crystals have commonly aggregated to form mafic schlieren (streaks and elongate clots). Some schlieren show tight minor folding (Figure 2.26), whereas others are aligned parallel to the deformational fabric. The mineralogies and equigranular textures exhibited by the microdiorites are essentially metamorphic. In thin section the dykes are dominated by euhedral to anhedral plagioclase feldspar, with subordinate hornblende and biotite, and minor amounts of quartz and potash feldspar, and abundant accessory apatite. In parts the mafic minerals define a planar fabric. Francis (1973) distinguished two end members of this suite:

- a mafic variety with an abundance of pyroxene, hornblende and biotite; some of the pyroxenes enclosed in the hornblende may be relict igneous grains.
- a leucocratic variety dominated by plagioclase with subordinate potash-feldspar, quartz and biotite.

Monzonite and monzogranite intrusions are particularly numerous immediately to the north of the Leinis peninsula in the southern part of Earsairidh, opposite Osasaigh (Figure 2.25). They are pinkish equigranular rocks with a weak planar fabric, and consist of potash feldspar, plagioclase, quartz, biotite and hornblende. The granites cross-cut members of the microdiorite suite, but are themselves cut by late-Scourian pegmatitic granite veins, which occur throughout the section (Francis *et al.,* 1971). The pegmatite veins generally trend between west and north-west and are steeply dipping to sub-vertical. They range from a few centimetres to 5 m in width and have been traced for up to 80 m. Typically, they have white, quartz-rich cores and red feldspar-rich margins.

The mafic dykes of the Palaeoproterozoic 'Younger Basic' Suite are very prominent in the Leinis section. They show virtually no internal fabrics or deformational effects and clearly postdate the late-Scourian monzonite, granite and pegmatitic intrusive rocks. The mafic dykes trend between north and north-west and range from a few centimetres wide up to *c.* 20 m. They can be traced laterally for up to 800 m. Their near-parallel-sided form and blocky igneous appearance belies their Palaeoproterozoic age. In hand specimen they are mid- to dark-grey, medium-grained, granular metadolerites. In thin section they exhibit twopyroxene-hornblende-plagioclase assemblages, typical of granulite-facies rocks; small garnets are also present locally. In some cases aggregates of the mafic and felsic minerals appear to mimic an original ophitic texture, but the mineral compositions and equigranular textures are wholly metamorphic.

The age relationships between the various suites are well displayed throughout the section. On the Leinis peninsula, 'Younger Basic' dykes cross-cut quartz-feldspar pegmatite and rare pegmatitic granite veins, which in turn cut microdiorite dykes. All the intrusions cross-cut the Scourian gneissose foliation. For example, at [NL 7026 9864], a *c.* 1 m-wide mafic dyke cuts a *c.* 30 cm-wide late-Scourian quartz-feldspar pegmatite vein, with both demonstrably crosscutting a *c.* 15 cm-thick microdiorite dyke (Figure 2.27); Fettes *et al.,* 1992, plate 7). At [NL 7033 9869], a thick (8–12 m) mafic dyke cross-cuts a large (*c.* 3.5 m) quartz-cored pegmatitic granite vein. The mafic dyke is, in turn, cut by Laxfordian pegmatitic granite veins and by a Palaeogene dolerite dyke a short distance to the north-west at [NL 7030 9878]. Nearby (at [NL 7033 9876]), a *c.* 1 m-wide microdiorite is cut by a 30 cm-wide offshoot from the large mafic dyke mentioned above. The microdiorite contains well-defined mafic schlieren, which are locally folded, but which generally define a fabric lying at an angle to the margin of the dyke (Figure 2.26).

At the south end of Earsairidh (at [NL 7043 9938]) a *c.* 4 m-wide microdiorite dyke with mafic lenses is cut by a coarsely foliated granite, both of which are cross-cut by a pegmatitic granite vein of either late-Scourian or Laxfordian age. Nearby, a pink, coarse-grained monzogranite encloses fragments of microdiorite. To the north of this locality there are several microdiorite sheets with included mafic schlieren both folded into tight minor folds and defining the internal fabric. Coarse-grained granite veins traverse the microdiorite sheets, and thin quartz-feldspar pegmatite veins crosscut the biotite and hornblende fabric. North of these localities, towards Sloc nan Each, is a 2–4m-high cliff which is effectively formed by a large (*c.* 8 m) mafic dyke. A *c.* 10 cm-wide offshoot of this dyke cuts across a pink granite at [NL 7056 9959].

Palaeogene dolerite dykes occur throughout the section but are more abundant in the northern part. These later dykes commonly branch, cross-cut one another, and exhibit chilled margins and vesicle-defined flow fabrics.

Interpretation

The late-Scourian intrusive suites described above do occur elsewhere in the Outer Hebrides, although outwith eastern Barra the effects of Laxfordian structural and metamorphic reworking make their recognition difficult, and their original extent is effectively unknown. Microdiorite sheets and dykes have been recorded from the southern islands of Flodday and Mingulay and farther north from South Uist (Fettes *et al.,* 1992). Foliated and augened granite bodies occur extensively in North Uist, generally as kilometre-scale ovoid masses and here, at least, the late-Scourian granite suite is demonstrably of regional extent.

As mentioned above, Francis (1973) divided the area above the thrust in Barra into three NW-trending zones. The north-eastern zone is characterized by very low Laxfordian reworking, with discrete cross-cutting 'Younger Basic' dykes and evidence of several suites of late-Scourian intrusive rocks, as seen at the Leinis GCR site. In contrast, the middle zone shows a high degree of Laxfordian reworking, with the 'Younger Basic' dykes strongly deformed, migmatized and amphibolitized. This Laxfordian deformation masks any evidence of the late-Scourian intrusive suites, which, if present, have become indistinguishable from the earlier Scourian (Archaean) gneiss protoliths. The transition between the two zones is narrow, occurring over about 150 m on the south side of Bagh Bhreibhig (Brevig Bay), some 600 m south-west of the Leinis peninsula. The south-western zone is marked by moderate degrees of Laxfordian reworking with the 'Younger Basic' dykes locally folded and broken, but also, in places, displaying discordant contacts and relict granulite-facies mineralogies. No specific evidence of the late-Scourian intrusive suites has been found in that zone, although the gneisses in that area are dominantly of dioritic composition with subordinate bands of felsic gneiss. Hence, the south-western zone may represent a large late-Scourian diorite body modified during the subsequent Laxfordian deformational and metamorphic events.

Francis (1973) also recognized a zone below the thrust that shows evidence of very low Laxfordian strain, with pyroxene-bearing felsic gneisses and discordant late-Scourian intrusions similar to those at Leinis. This area, termed the 'Oitir Mhòr Zone', comprises the south-eastern part of the island of Fuday and the islands of Gighay, Hellisay and Fuiay. Francis determined that the Oitir Mhòr Zone lies in the core of a regional antiform, the Scurrival Antiform, a steep NW-plunging Laxfordian F3 fold whose axial plane trends north-west and dips steeply to the north-east. Its axial trace runs through Scurrival Point at the northern end of Barra. He also identified a complementary pinched-in synform lying about 1 km to the south-west. Francis (1973) correlated this synform with the Laxfordian strongly reworked 'middle zone'

above the thrust and correlated the Oitir Mhòr Zone with the Leinis-Earsairidh area, the fold pattern being effectively foreshortened by the thrust. These relationships are consistent with the overall structural pattern of the Uists and Barra, which is dominated by similarly orientated, regional-scale, cuspate antiforms and pinched in synclines (see North Uist Coast and Gearraidh Siar and Baile a' Mhanaich GCR site reports, this chapter). However, there is no evidence of such Laxfordian folding in the gneisses above the thrust plane in eastern Barra.

Coward *et al.* (1970) noted that this Laxfordian folding is accompanied by high strain and pervasive recrystallization in the tight synformal zones, but that earlier folds, fabrics and textures are preserved in the lower-strain broader antiformal zones. They suggested that the cuspate fold pattern resulted from the deformation of a boundary running along the length of the islands that separates more-competent rocks to the east from those to the west. Francis (1973) utilized this idea to suggest that in Barra there is a boundary between competent 'eastern' gneisses and less-competent 'western' gneisses. He suggested that this boundary might have some fundamental significance, and may possibly consititute an early infrastructure-suprastructure contact of some form. However, this view was largely discredited by Moorbath *et al.* (1975), who showed from Rb-Sr and Pb-Pb isotopic systematics that the great bulk of the quartzofeldspathic gneisses was derived from igneous protoliths generated shortly (100–200 million years) before the peak of Scourian metamorphism. They further argued that Scourian granulite-facies metamorphism was probably restricted to the south and east parts of the Uists and Barra. Hence, any differences in gneiss competency at the end of the Scourian reflected variations in the original igneous protoliths and the extent of Scourian granulite-facies metamorphism (see also Fettes *et al.,* 1992). Once formed, granulite-facies rocks are relatively anhydrous and tend to resist reworking. In contrast, zones of highly migmatized gneiss, once established, will tend to focus future strain and fluids. It is probable that in the Leinis GCR site area there was a coincidence of relatively dense protolith, which had had its competency further increased by granulite-facies metamorphism. This circumstance resulted in an exceptionally low level of Laxfordian reworking and the near-perfect preservation of the late-Scourian intrusive relationships.

Francis (1973) noted that the metamorphic orthopyroxene in the gneisses of the Leinis GCR site area is partially retrograded, whereas that found in the 'Younger Basic' Suite mafic dykes is pristine. He also noted that the intrusive granitoid bodies and the microdiorite dykes do not show evidence of granulite-facies metamorphism. To explain these observations he proposed that the granulite-facies metamorphism in the gneisses occurred during the main Scourian events, followed by partial retrogression under amphibolite-facies conditions in late-Scourian time. The intrusion of the microdiorites and granitoid rocks took place under these latter conditions.

The deformational episode that affects the microdiorites and monzogranites is not particularly intense in the Leinis GCR site area. However, in the Oitir Mhòr Zone, and particularly on the island of Fuday, it is significantly stronger. On Fuday the microdiorite dykes are tightly folded, yet are transected by undeformed 'Younger Basic' dykes (Fettes *et al.,* 1992, plates 8 and 9). This deformational episode is constrained to a period of *c.* 180–600 million years as it post-dates the late-Scourian pegmatites (*c.* 2600 Ma), and pre-dates the Palaeoproterozoic 'Younger Basic' Suite (*c.* 2420–2000 Ma). Fettes *et al.* (1992) correlated this deformation event with the similar-age Inverian episode of the mainland Lewisian. Elsewhere in the Outer Hebrides the degree of Laxfordian overprinting is normally too high to distinguish this episode and determine any regional pattern in its effects.

Intrusion of the 'Younger Basic' dykes also took place under amphibolite-facies conditions, probably at mid-crustal levels, although geothermal gradients at the time are unknown. However, the relatively anhydrous nature of the dykes resulted in their recrystallization with granulite-facies mineralogies (see Fettes *et al.,* 1992, for discussion).

The ages of the various intrusive lithologies as determined from field relationships at Leinis are pinned by the ages of the Archaean protoliths, the Scourian metamorphism (*c.* 2850–2700 Ma), the late-Scourian pegmatitic granites (*c.* 2600 Ma), the 'Younger Basic' mafic dykes (*c.*2420–2000 Ma), and the Laxfordian granitic pegmatites (*c.* 1680 Ma) (see (Table 2.1)). Francis *et al.* (1971) obtained isotopic ages for the Archaean hornblendite and the two sets of pegmatites present on the Leinis peninsula. These ages were obtained using the K-Ar and Rb-Sr isotopic systems, which tend to record the time of closure or subsequent disturbance of the particular isotopic system (i.e. normally uplift or cooling), rather than the intrusive or metamorphic event itself However, the low degree of Laxfordian reworking in the Leinis area has minimized such disturbance, and the ages obtained remain consistent with the generally accepted geological history and more-recent U-Pb zircon and Sm-Nd ages from the Lewisian Complex. Hence, although most of the ages will be younger

than the age of intrusion the overall inferences are still thought to be valid.

Francis *et al.* (1971) obtained a K-Ar hornblende age of 2583 ± 34 Ma from the net-veined hornblendite pod on the eastern side of the Leinis peninsula confirming its Archaean age. They also obtained a five-point Rb-Sr isochron giving an age of 2610 ± 50 Ma from whole-rock samples of three discordant pegmatites that are cross-cut by 'Younger Basic' dykes at the southern end of the Leinis peninsula. A K-Ar biotite age of 1679 ± 25 Ma was obtained from a nearby, large, E-W-trending, discordant, pink-orange pegmatitic granite vein, dating these later pegmatitic veins as Laxfordian (Francis *et al.,* 1971). This last age is in good agreement with U-Pb zircon ages from the Laxfordian pegmatitic granites of South Harris (Mason and Brewer, 2005) and the Uig Hills-Harris Granite Vein-Complex (Friend and Kinny, 2001).

Conclusions

The well-exposed coastal section at the Leinis GCR site provides a unique insight into the earlier parts of the geological history of the Outer Hebrides. In particular, it provides a virtually undisturbed snapshot of the pattern of structures and rock types that existed at the end of the Archaean, following Scourian gneiss formation around 2900–2700 Ma and intrusion of numerous types of dioritic and granitoid rocks during the late-Scourian. It also contains excellent examples of the Palaeoproterozoic metadolerite dykes of the 'Younger Basic' Suite, intruded between 2420 Ma and 2000 Ma, and of Laxfordian pegmatitic granites. The reason that all these features are so well preserved is that the deformation and recrystallization associated with subsequent Laxfordian events, which took place between *c.* 1800 Ma and 1550 Ma, are virtually absent in this area. Although other areas of low Laxfordian reworking occur in the Hebrides, none show the scale and range of elements seen here.

The greater part of the Leinis GCR site is composed of Scourian felsic gneisses with subsidiary mafic sheets, lenses and pods, and rare ultramafic pods. The protoliths of these rocks were mainly granodioritic, tonalitic and doleritic sheets and dykes that were emplaced during the Archaean at around 2900–2730 Ma.

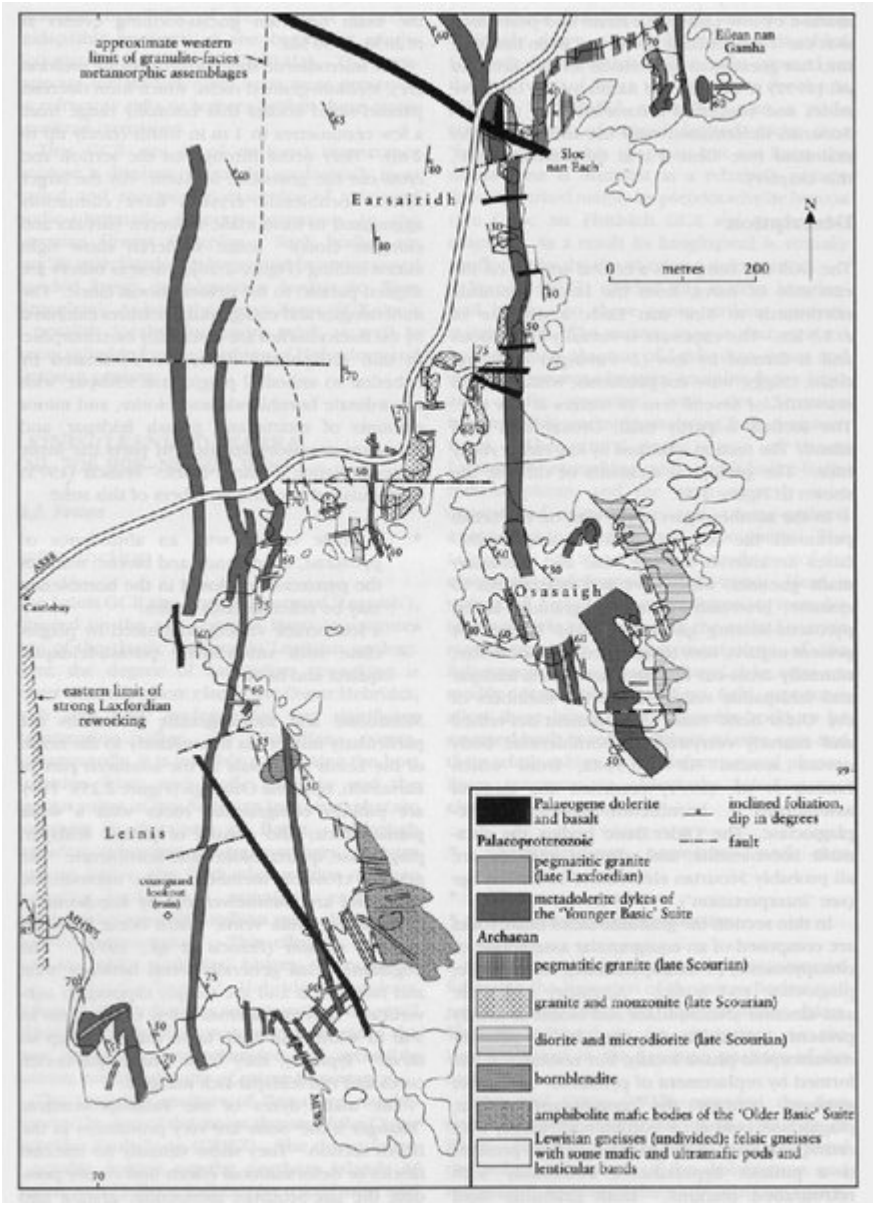
The presence of orthopyroxene in the gneisses implies that metamorphic conditions accompanying gneiss formation attained granulite facies, reflecting their formation at deep levels in the crust under extreme pressures and temperatures. These early-Scourian gneisses are cut by a sequence of late-Scourian intrusive rocks, which post-date the granulite-facies metamorphism and were intruded under middle amphibolite-facies conditions at mid-crustal levels. These 'later' dykes are markedly discordant to the earlier elements of the Lewisian gneisses and can be grouped into four suites: microdiorite dykes (oldest), granite and monzonite bodies, quartz-feldspar pegmatite veins, and the meta-dolerite dykes of the Palaeoproterozoic 'Younger Basic' Suite (youngest). A deformational episode post-dates the intrusion of the late-Scourian microdiorite–granite–monzonite suite, but pre-dates intrusion of the metadolerite dykes. It is equated with the Inverian event found in the mainland Lewisian rocks.

The exceptionally low degree of Laxfordian reworking in the Leinis GCR site results from the combination of its structural position in a possible Laxfordian antiformal hinge zone, and the relatively anhydrous and resistant nature of the gneisses. This latter property resulted from two factors, namely, a relatively competent early-Scourian igneous protolith, and the subsequent Scourian metamorphism at granulite facies. These unusual circumstances have given rise to a geological section that is of crucial importance in Hebridean geology. The site is of international importance in terms of understanding the early crustal history of the North Atlantic region and establishing correlations between Scotland and Greenland.

References

Eon/Era	Age (Ma)	Orogeny/Event	Igneous intrusions and sedimentary depositional events	Tectonic activity
MESOZOIC	200			
	300		Camptonite and monchiquite dykes Quartz-dolerite dykes	Formation of the Minch Fault marginal to Mesozoic basin
	400		Appinitic diorite	Extensional faulting follows thrusting to the WNW in OHFZ
PALAEOZOIC		Caledonian		
	500			
	1000			Uplift and ductile movement along Langavat Belt. Possible early thrusting on OHFZ
MESO-PROTEROZOIC	1100	Grenvillian		
	1400		Microdiorite dykes (rare)	
MESO-PROTEROZOIC	1500			Uplift
		Late-Laxfordian	Pegmatitic granites	Laxfordian $D4_L$ deformation
	1600			
	1700		Granite sheets and dykes, mainly in Uig Hills–Harris Granite Vein-Complex	Laxfordian $D3_L$ deformation and metamorphism.
		Main Laxfordian		
	1800		S. Harris Igneous Complex (SHIC)	Laxfordian $D2_L$ deformation and amphibolite-facies metamorphism. (Subduction, deformation and metamorphism of SHIC)
PALAEO-PROTEROZOIC	1900		Deposition of Leverburgh and Langavat belt sediments	
	2000			
	2100			
	2200			
	2300			
			'Younger Basic' Suite	Laxfordian $D1_L$ deformation
	2400		(= Scourie Dyke Suite)	
				Scourian $D4_S$ deformation
	2500		Quartz-feldspar pegmatite	Scourian $D3_S$ deformation
		Late-Scourian	Granite and monzonite	
	2600		Diorite and microdiorite	
	2700			Formation of Scourian gneisses and generation of main $D2_S$ fabrics and structures. Granulite- and amphibolite-facies metamorphism. Earlier $D1_S$ fabrics and structures.
		Main Scourian	Formation of main granodioritic and tonalitic gneiss protoliths	
ARCHAEAN	2800			
	2900		Deposition of sedimentary rocks and intrusion of 'Older Basic' Suite. Earliest granodioritic and tonalitic intrusions	
	3000			
	3100			

(Table 2.1) Chronology of the Lewisian Gneiss Complex in the Outer Hebrides.



(Figure 2.25) Simplified geological map of Leinis (Leanish), Barra. After Francis (1973).

(Figure 2.26) Mafic concentrates defining a folded fabric in a late-Scourian microdiorite dyke, Leinis peninsula [NF 7032 9876]. The hammer head is 14 cm long. (Photo: British Geological Survey, No. P008327, reproduced with the permission of the Director, British Geological Survey, © NERC.)

(Figure 2.27) Photograph of undeformed 'Younger Basic' dyke cutting a late-Scourian pegmatite, which itself cuts a late-Scourian microdiorite dyke, Leinis peninsula [NL 7026 9836]. The hammer is 28 cm long. (Photo: British Geological Survey, No. P219737, reproduced with the permission of the Director, British Geological Survey, © NERC.)