Research Essay

St Andrews Laidlaw Scholars Programme

Lola Sophia Mors, Supervisor: Dr. Sebastian Fischer

From Zircons to Shear Zones: Linking Iona's Gneisses to Britain's Old Crust

An Independent Research Project

Department of Earth Sciences

August 31, 2022

Word count: 2654

Contents

1 Introduction & Definitions

Iona is an island off Mull on the Scottish West coast, famous for its abbey, its diverse wild life, and its unique geology. Figure 1 shows a geological map of Iona, separated in the Lewisian Gneiss complex (that this investigation will focus on) and the younger sedimentary and igneous rock units. **Lewisian Gneiss** is an ancient metamorphic rock [1]. **Metamorphic rocks** are created when preexisting rocks are subject to high pressure and temperature ("are cooked").

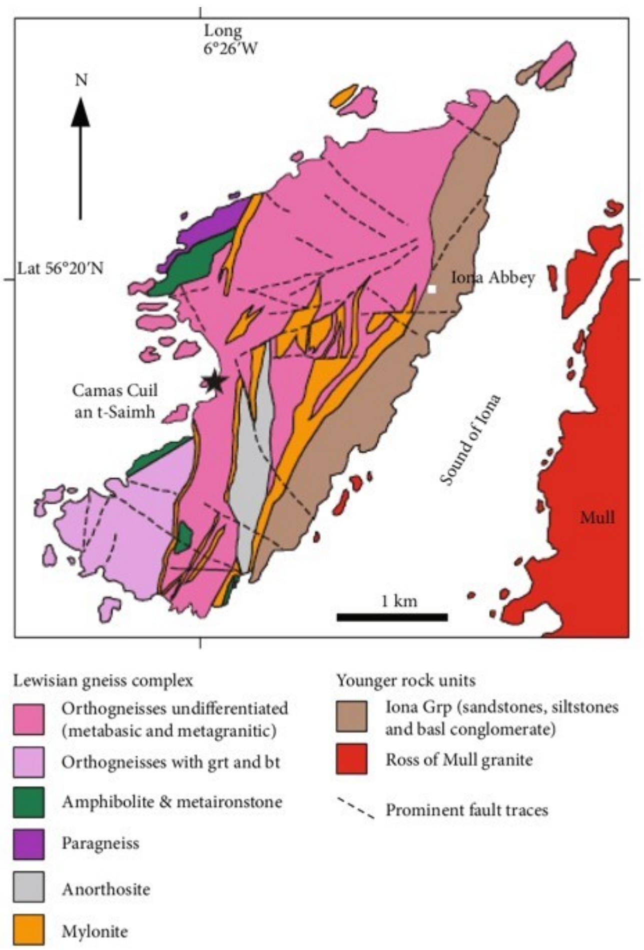


Figure 1: Map of Iona, Showing the Boundary between Orthogneiss with garnit and biotite (light pink) and Undifferenciated Orthogneiss (dark pink). [2]

The Lewisian Gneiss on Iona has only been connected to the Lewisian Gneiss in the Scottish NW Highlands by visual comparison of the composition and metamorphic features. The project's aim is to relate the **Lewisian Gneiss on Iona**, an island on the West coast of Scotland, to the wider Lewisian Gneiss

Complex in the NW Scottish Highlands by visual comparison of shear zones that might be geologically related and by obtaining a first age constraint for Lewisian Gneiss from Iona. A **shear zone** is a zone where blocks of rocks on both sides moved relative to each other, thereby causing deformation. The findings could shed light on lower crustal processes three billion years ago [3].

To relate the Iona gneiss to the wider Lewisian Gneiss Complex in the NW Scottish Highlands, this project investigates a **possible equivalent of the Laxford Shear Zone** on Iona. The proposed shear zone is on South Iona, along the boundary between orthogneiss with garnit and biotite (light pink in Figure 1) and undifferenciated Orthogneiss (dark pink in Figure 1) [2]. On the mainland, the Laxford shear zone separates a northern block dominated by K-Feldspar-bearing lithologies (the proposed Rhiconich terrane, appearing pink) from the so called central block that is conspicuously K-Feldspar-absent (the proposed Assynt terrane, appearing white) [4]. An equivalent shear zone may exist on Iona.

The three parts of the project's first summer of the project are fieldwork to collect gneiss samples, an optical comparison of the Laxford Shear Zone and the possible equivalent on Iona, and the separation of the mineral zircon for forthcoming research on an age constraint for Iona gneiss.

2 Literature review

2.1 Lewisian Gneiss

Lewisian gneiss is interpreted as fragments of Archean crust [5]. One model is that oceanic crust melted and then cooled at depth. As the magma cooled, it formed granodiorite [6]. Granodiorite is an igneous rock — formed from cooling magma — that is coarse grained and felsic to intermediate in composition, as opposed to mafic, meaning rich in magnesium and iron. Over time, metamorphic events altered the granodiorite by exposing it to high temperatures and pressures and thereby transformed the granodiorite to gneiss [5]. The Lewisian Gneiss Complex in the NW Highlands has been divided into three terranes. The Northern and a Southern terranes show granulite facies, meaning they experienced higher maximum temperatures and pressures, whereas the Central region shows amphibolite facies, meaning it experienced relatively maximum lower temperatures and pressures [7]. The different models that explain how the different terranes were created and if the regions are truly geologically distinct are significant for the research on Archean rocks all over the world [7].

2.2 A Short Geological History of Iona

The oldest rocks found on Iona are Lewisian gneisses [8]. The protoliths (meaning the initial rocks that were than later metamorphosed, or "cooked") were mostly igneous (formed directly from cooling lava or magma) [9]. Much rarer on Iona are gneisses with sedimentary protoliths [9]. A sedimentary rock is formed by the accumulation of little pieces of pre-existing rocks and/or organisms, later subjected to moderate pressure.

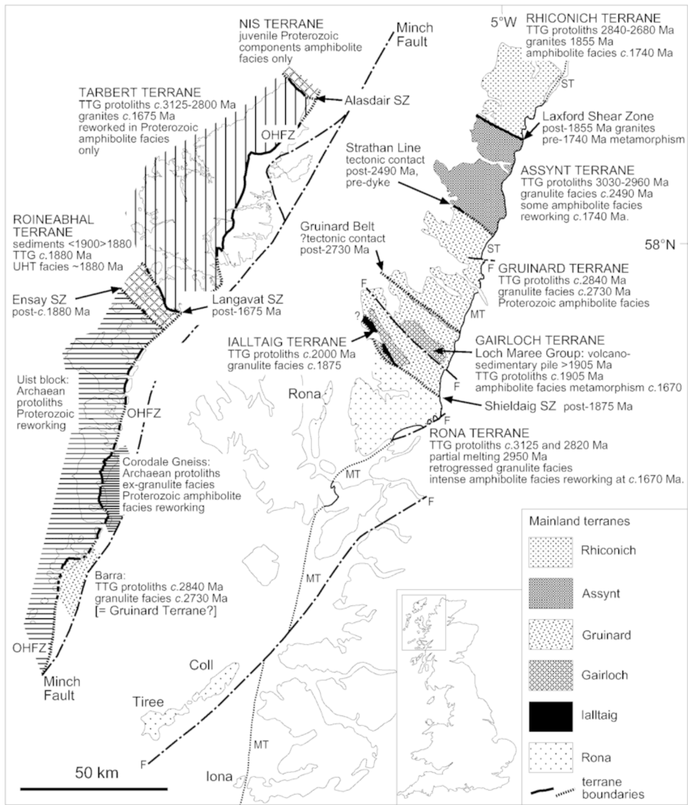


Figure 2: Sketch of the Proposed Terrane-model for the Lewisian Gneiss Complex in the NW Highlands. Note the Assynt Terrane in the North, divided by the Laxford Shear Zone from the Rhiconich Terrane [10].

If the optical attribution of the Lewisian gneiss on Iona to the Lewisian gneiss on the Scottish mainland, especially to the Assynt terrane (Central region), holds true, the age constraint based on Uranium-Lead Decay for the Assynt terrane could serve as a guidance for the Lewisian gneiss on Iona [8] (Figure 2). The protoliths of the Assynt terrane are dated at 2958 $\pm$ 7 million years ago and the high-grade metamorphism (characterised by high temperatures and relatively high pressures) occured around 2482 $\pm$ 6 million years ago [11]. The high-grade metamorphic events transformed the protoliths into orthogneisses (for igneous protoliths) and paragneisses (for sedimentary protoliths). The high-grade metamorphic events occured deep in Earth's crust and could correspond to the amphibolite facies Badcallian event in the Assynt terrane [11]. Tectonic uplift and erosion (possibly more then 10 kilometres) brought the gneisses to the surface [12]. Once at the surface, more sedimentary rocks (termed the "Iona group") deposited and were deformed by low-grade metamorphism (at lower temperatures and/or pressures) [1]. The deposition and deformation of the Iona group occured between circa 1490 million years ago and circa 422 million years ago [1].

At circa 422 million years ago, micrograntes started to intrude. Granites are felsic coarse grained igneous rocks, formed by slow cooling of magma, normally at greater depth. Felsic refers to having a relatively high content of elements that form the minerals feldspar and quartz, namely silicon, oxygen, aluminium, sodium, and potassium. In the Permean (between 298.9 and 251.9 million years ago), igneous lamprophyres intruded [13]. After subsequent erosion [12], the youngest geological unit — the Machair (a type of shell-sand) — was deposited after the last ice age [14].

2.3 Lack of Published Ages for Lewisian Gneiss on Iona

There is no published age constraint for Lewisian Gneiss on Iona. The only unpublished data comes from the Abstracts of the 49th Annual Irish Geological Research Meeting University College Cork, stating the ages of Lewisian gneiss on Iona as 2701 ± 6 million years for intermediate orthogneisses (orthogneisses are gneisses with igneous rocks as protoliths) (Daly et al. 2006) and 2721 ± 21 million years (Daly et al. 2006) for acidic orthogneisses [1]. The whole-rock model ages based on Sm-Nd isotopic ratios are 2839 Ma and 2737 Ma, respectively (Daly et al. 2006). These ages are interpreted to represent the formation of continental crust in the Neoarchaean. There is a published age for marble on Iona of 1418 ± 56 Ma, likely representing disturbances during younger Caledonian events [15]. The Lewisian Gneiss Complex is geologically very complex due to the metamorphic history outlined above. Therefore, more reliable data on age constraints using U-Pb for Lewisian gneiss are needed to obtain a more coherent picture of crustal processes in the Archean.

2.4 The Laxford Shear Zone and a Proposed Shear Zone on Iona

The Laxford Shear Zone (Figure 1) in the NW Highlands divides the proposed Rhiconich terrane in the North (K-Feldspar-rich) from the proposed Assynt terrane in the South (K-Feldspar-depleted) [7]. The change in element composition of the mineral indicates a different age of the rock units. This is an important indication for a possible equivalent of the Laxford Shear Zone on South Iona.

3 Hypothesis

Across fault zones, the distinct blocks of rocks often differ in mineral composition. Furthermore, the rocks typically "dip" (are inclined) at a steeper angle closer to the fault. At the Laxford Shear Zone, the two blocks of rocks differ as the Northern block is characterised by K-Feldspar rich gneiss (pink) and the Southern block is characterised by K-Feldspar poor gneiss (white) [4]. If the boundary on South Iona is equivalent to the Laxford Shear Zone, a similar distinction between pink gneiss in the NE of Iona and white gneiss in the SW of Iona would be observable. Furthermore, a steeper dip is expected for rocks closer to the centre of the shear zone compared to rocks in the surrounding area.

This essay's focus is on the work completed this summer. Since the U-Pb dating of the zircons itself is not possible until the microprobe is operating in winter 2022/23, the hypothesis for the age of Lewisian Gneiss on Iona is not included here.

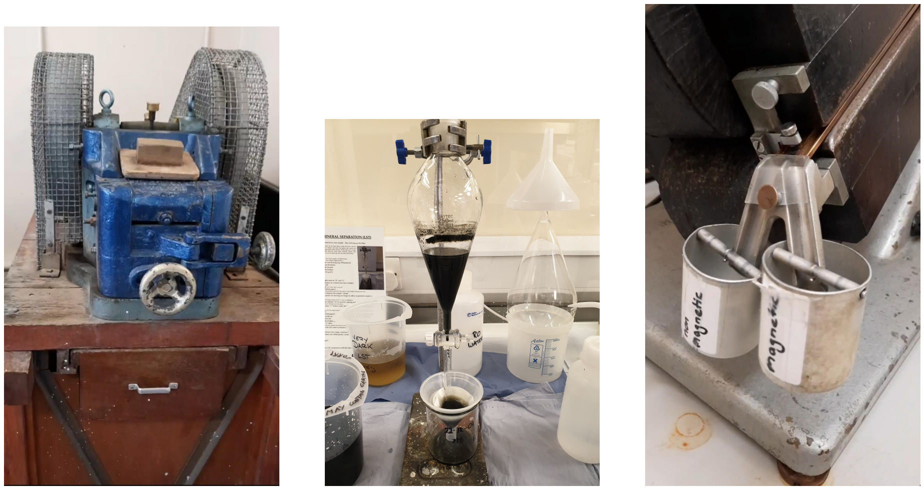
4 Methodology

The research this summer was divided in three major parts: collection of samples, field observations comparing potential shear zones, and the separation of zircons from the sample for dating. The dating itself is scheduled for winter 2022/23.

A targeted field trip to the Scottish NW Highlands and to Iona allowed for the collection of mafic (rich in magnesium and iron), felsic, and intermediate samples. Specifically, samples of K-Feldspar-rich (pink) Lewisian gneiss and K-Feldspar-poor (white) Lewisian gneiss were collected at both sides of the Laxfordian shear zone and on both sides of the hypothesised shear zone on Iona (Figure 1).

Examining the outcrops of Lewisian Gneiss at the Laxfordian sheen zone (NW Highlands) and on South Iona allowed for familiarising oneself with the different mineral composition and metamorphic features present. These visits in the field allowed for detailed notes on metamorphic features and approximations of trends in dips (how steeply the rocks are inclined).

Subsequent work in the St Andrews laboratories of the Department of Earth science was essential for isolating possible zircons by density and magnetic separation. The samples of K-Feldspar-rich (pink) Lewisian gneiss and K-Feldspar-poor (white) Lewisian gneiss from Iona were broken using a jaw crusher (Figure 3 b). In a professional electrical sieve, the grains were separated according to size. The grains of $< 350\ \mu m$ were separated according to density as zircons have a higher density as most of the other minerals present in the bed rock. For this purpose, heavy liquid in a separating funnel was used (Figure 3 b). The grains with density $> 2.8\ gcm^{-3}$ were further separated by magnetic properties, keeping all grains that displayed non-magnetic properties (Figure 3 c) as zircons are non-magnetic. These grains were subsequently examined under the microscope to identify individual zircons using shine, colour, and shape as indicators.



(a) Jaw crusher Used to Break Gneiss Samples.

(b) Separation funnel (photo: Zoe Lynn).

(c) Magnetic separator "Frantz".

Figure 3: Overview over the different steps of laboratory work performed.

5 Results

The results only relate to the hypothesis regarding the possible shear zone on Iona, equivalent to the Laxford Shear Zone on the mainland, and do not include an age constraint for the Lewisian gneiss on Iona as further ion mass spectrometry (SIMS) analyses can only be performed in winter 2022/23 as the facility is not functioning yet.

5.1 Observations

Figure 4: Shear Zone on South Iona with Approximated Dips (Picture: Dr. Sebastian Fischer, Editing: Lola Sophia Mors)

The field observations focused on the apparent dip of the gneiss in relation to the distance from the middle of the shear zone and on the change in mineral composition, with a special focus on K-Feldspar.

Figure 3 shows the that the dip of Lewisian Gneiss on Southern Iona steepens by multiple tens of degrees compared to the baseline state (Figure 4). The steepening is consistent along the fault. This steepening in apparent dip is similar to the change in dipping angle observed near the Laxford Shear Zone in the NW Highlands. In the NW Highlands, the observed dipping angle near the Laxford Bridge was approximately over 60 degrees compared to around 40 degrees between Rhiconich and Sarsgrum and values around 20 degrees further North (these are all approximations).

Figure 5: Overview of Lewisian Gneiss on South Iona with a few hundreds on meters distance to the proposed centre of the shear zone.

Figure 6 shows the location of the proposed fault between the K-Feldspar bearing (pink) gneiss in the NE of Iona and the K-Feldspar poor (white) gneiss in the SW of Iona. The observed change in mineralogy largely corresponds with the expected locality according to Figure 1 (between light pink and dark pink). The distinction between pink and white gneiss is not as clear cut in the field as in theory (the white gneiss still contains some K-Feldspar), however, the dominant colour change associated with distinct mineral content is visible.

5.2 Interpretations

Figure 6: Boundary Between White and Pink Gneiss on South Iona

The observed change in colour between pink K-Feldspar rich gneiss in the NE of Iona and white K-Feldspar poor gneiss in the SW of Iona provides evidence that the two block of rocks are distinct and were formed at different times. In a typical simple geological structure, the oldest rocks get deposited first and are at the bottom, then the second oldest rocks get deposited, and so on, up to the top layer of rock (the youngest one). In one layer, all rocks are expected to be of a similar age. In the case of Southern Iona, the difference in colour (and mineral composition) indicates that rocks of different ages are now side by side (in one "layer", so to speak). A possible explanation for this is a fault running through South Iona that moves blocks of rocks of different ages and with distinct geological histories next to each other.

Interpreting the change in dip values is only possibly if the estimated dips truly reflect the continual rock layers and not outliers like fallen boulders or cracks in the rock (instead of layering). Since the steepening in dip was continuous walking North and South along the proposed shear zone, it is expected to represent the bedrock layers. The steepening in the dip closer to the centre of the proposed shear zone supports that a fault was active in this area. However, the change in estimated dip values alone could also be evidence for a fold (a bend in the rock layers) instead of a fault (a break in the rock layers). Therefore, it is most meaningful when considered together with other lines of evidence such as mineral composition.

6 Limitations

A major limitation is the lack of quantitative data. Field observations are a fundamental base for further research in the laboratory. However, it would require quantitative data on the ages of the blocks of rock and of the fault itself to connect this fault to the Laxford Shear Zone.

7 Further research

The zircons separated from the samples this summer will be used determine ages for two types of Lewisian Gneisses on South Iona using the new geochronology facility of the Department of Earth Science at the University of St Andrews. As a next step, the zircon grains will be identified under the microscope based on the optical properties of sheen, colour, and shape (already started). The state-of-art facilities at St Andrews then allows to investigate the zonations in the extracted zircons and identify different growth domains. This is relevant as the growth domains can correspond to different metamorphic events (so they could be supporting evidence for the impact of, for example, the Badcallian event on Iona gneiss) when the necessary temperatures and pressures where achieved to crystallise new zircon. Very simplified, this could be thought of as tree rings: the zircon mineral grows outwards over time. Therefore, to create an accurate age-constraint, one must know which "mineral ring" one is dating (one can date multiple ones in the same mineral grain). Then, U-Pb dating can be performed using the new Ion Microprobe (which will start operating November 2022 earliest). The obtained age constraint will allow an insight into a possible link between the Laxford Shear Zone and the fault in Lewisian Gneiss on South Iona as well as Archean plate tectonics.

8 Conclusion

The field observations at the Laxford Shear Zone in the NW Highlands and on Iona support the hypothesis that an equivalent to the Laxford Shear Zone could be present on South Iona. The supporting evidence includes a change in colour caused by a different mineral composition of the Feldspars present in the rocks on opposite sides of the shear zones as well as a steeper dip of the Lewisian gneiss closer to the centre of the sheen zone compared to the surrounding bedrock. However, these changes in colour and dip could be caused by other geological phenomena or the shear zone on Iona could have an independent geological history from the Laxford Shear Zone. Further research including an age-constraint for the Iona gneiss could shed more light on the relationship between Lewisian gneiss in the NW Highlands and on Iona.

9 Acknowledgements

This project would not have been possible without my research supervisor Dr. Sebastian Fischer, the encouragement by the fellow Laidlaw scholar Zoe Lynn, and the help by the Earth Science Department, especially by Dr Catherine Rose and by Dr Will McCarthy. Special thanks go to Lord Laidlaw and to the Laidlaw Foundation for funding this project, and to Celina O'Connor, Hayley Mathews, and Catriona Wilson from the St Andrews Laidlaw team.

References

1. McAteer, C. A., Daly, J. S., Flowerdew, M. J., Whitehouse, M. J. & Monaghan, N. M. Sedimentary provenance, age and possible correlation of the Iona Group SW Scotland. *Scottish Journal of Geology* **50,** 143–158 (2014).
2. Dempster, T. J. *et al.* Deformation-induced and reaction-enhanced permeability in Metabasic Gneisses, Iona, Scotland: controls and scales of retrograde fluid movement. *Geofluids* **2021** (2021).
3. Miocevich, S. R., Copley, A. & Weller, O. M. Testing the importance of sagduction: insights from the Lewisian Gneiss Complex of northwest Scotland. *Precambrian Research* **379,** 106708 (2022).

4. Goodenough, K., Crowley, Q., Krabbendam, M. & Parry, S. New U-Pb age constraints for the Laxford Shear Zone, NW Scotland: Evidence for tectono-magmatic processes associated with the formation of a Paleoproterozoic supercontinent. *Precambrian Research* **233,** 1–19 (2013).

5. Fischer, S. *et al.* Using zircon in mafic migmatites to disentangle complex high-grade gneiss terrains–Terrane spotting in the Lewisian complex, NW Scotland. *Precambrian Research* **355,** 106074 (2021).

6. Wheeler, J., Park, R., Rollinson, H. & Beach, A. The Lewisian Complex: insights into deep crustal evolution. *Geological Society, London, Special Publications* **335,** 51–79 (2010).

7. Goodenough, K. *et al.* The Laxford shear zone: an end-Archaean terrane boundary? *Geological Society, London, Special Publications* **335,** 103–120 (2010).

8. Troll, V. R., Nicoll, G. R., Ellam, R. M., Emeleus, C. H. & Mattsson, T. Petrogenesis of the Loch Bà ring-dyke and Centre 3 granites, Isle of Mull, Scotland. *Contributions to Mineralogy and Petrology* **176,** 1–22 (2021).

9. Fraser, F. M. *The Lewisian and Torridonian geology of Iona* PhD thesis (University of St Andrews, 1977).

10. Kinny, P., Friend, C. & Love, G. Proposal for a terrane-based nomenclature for the Lewisian Gneiss Complex of NW Scotland. *Journal of the Geological Society* **162,** 175–186 (2005).

11. MacDonald, J. M. *et al.* Temperature–time evolution of the Assynt Terrane of the Lewisian Gneiss Complex of Northwest Scotland from zircon U-Pb dating and Ti thermometry. *Precambrian Research* **260,** 55–75 (2015).

12. Gordon, J. E. & Stone, P. in *Landscapes and Landforms of Scotland* 15–40 (Springer, 2021).

13. Beckinsale, R. & Obradovich, J. Potassium-Argon ages for minerals from the Ross of Mull, Argyllshire, Scotland. *Scottish Journal of Geology* **9,** 147–156 (1973).

14. Gillham, M. E. Coastal vegetation of Mull and Iona in relation to salinity and soil reaction. *The Journal of Ecology,* 757–778 (1957).

15. Whitehouse, M. & Russell, J. Isotope systematics of Precambrian marbles from the Lewisian complex of northwest Scotland: implications for Pb Pb dating of metamorphosed carbonates. *Chemical Geology* **136,** 295–307 (1997).