

Characterization of Mica in Granulite and Eclogite Facies Rocks on Bårdsholmen, Western Gneiss Region, Norway

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Introduction

Bårdsholmen, a small island located in the Western Gneiss Region of Norway, contains Proterozoic granulite facies rocks that were variably overprinted at eclogite ± amphibolite facies conditions during the Caledonian Orogeny. Previous studies have utilized multiminerall Rb-Sr geochronology by isotope dilution for both the granulite and eclogite facies assemblages to constrain the timing of each metamorphic episode. One of the conclusions of these isotopic studies was that biotite Rb-Sr dates are geologically meaningless as the mica is not in isotopic equilibrium with either metamorphic assemblage. Recent advances of Rb-Sr geochronology by Laser-Ablation, Inductively-Coupled-Plasma, Mass-Spectrometry (LA-ICP-MS) allows for *in situ* collection of isotope ratios among texturally and chemically distinct grains, which can be compared with other isotopic information (e.g., Ar-Ar dates) from the same mineral. Together, these data can reveal geologically meaningful information that can characterize mica in the granulite and eclogite facies rocks from Bårdsholmen.



Figure 1: Simplified map of the Western Gneiss Region. Research area, the island of Bårdsholmen, is denoted by the red star. Adapted from Beyer *et al.* (2006).

Methods

- Documenting mica textures using a petrographic microscope and backscatter electron images with the Scanning Electron Microscope (SEM)
- Electron Probe Microanalysis to determine the major element chemistry of micas
- *In situ* Rb-Sr mica geochronology by Laser-Ablation, Inductively-Coupled-Plasma, Mass-Spectrometry (LA-ICP-MS)

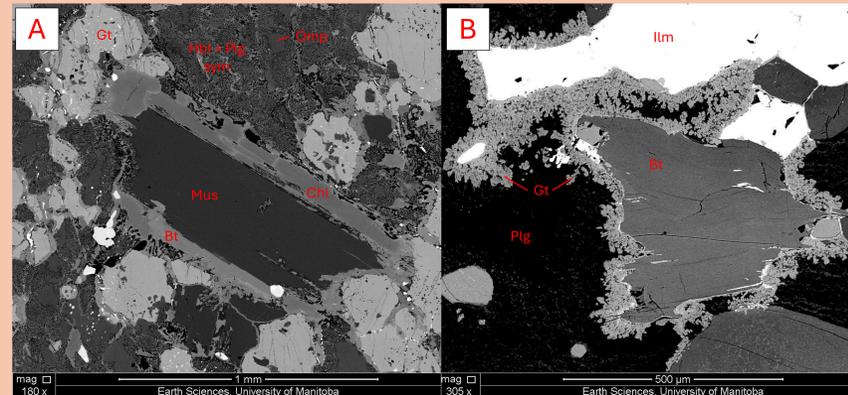


Figure 3: Backscatter electron photos. A - Phengite rimmed by biotite and chlorite, hornblende (amphibole) and plagioclase symplectites (Sample 2B1a). B - Biotite reacting with ilmenite to form garnet in a plagioclase matrix (Sample 2B2). Bt - biotite, Chl - chlorite, Gt - garnet, Hbl - hornblende, Ilm - ilmenite, Mus - muscovite, Omp - omphacite, Plg - plagioclase.

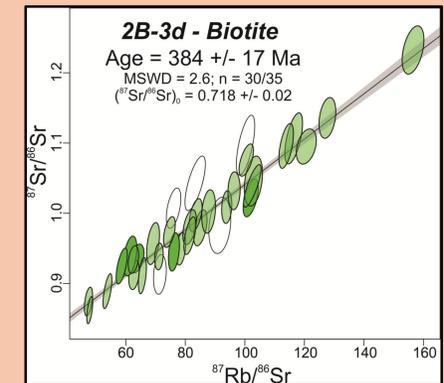


Figure 6: Isoplot of Rb-Sr ratio of biotite in sample 2B3d. Data collected using New Wave UP-213 Laser Ablation System partnered with Agilent 8900 Triple Quadrupole ICP-MS at the Department of Earth Sciences, at the University of Manitoba.

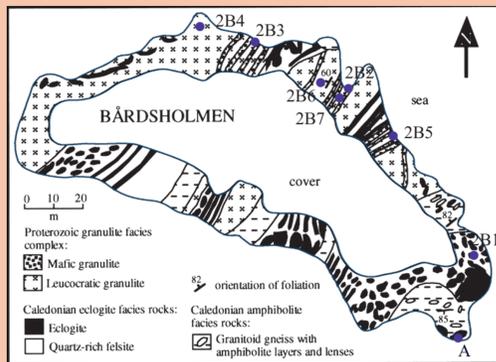


Figure 2: Lithology and structure map of Bårdsholmen, Western Norway. Sample locations are denoted by blue circles. Adapted from Engvik *et al.* (2000).

Regional Geology

Western Gneiss Region (WGR)

The Western Gneiss Region (WGR) in Norway encompasses >50,000 km² and stretches from Bergen to Trondheim (Möller *et al.*, 2024). The WGR developed through the collision of Laurentia and Baltica during closure of the Iapetus Ocean which resulted in the subsequent emplacement of allochthons onto of Baltica, eastward subduction of Baltica beneath Laurentia (430-400 Ma), followed by exhumation of the terrane (400-385 Ma; Engvik *et al.*, 2001; Hacker *et al.*, 2010). The Proterozoic basement is predominately made up of high-grade Precambrian intrusive rocks such as tonalitic and granodioritic gneisses (Hacker *et al.*, 2010; Möller *et al.*, 2024). Mafic bodies present throughout the Precambrian gneisses were variably transformed to eclogite facies during subduction (Hacker *et al.*, 2010; Möller *et al.*, 2024). The variable preservation of eclogites is due to the overprint of amphibolite facies connected to exhumation (Engvik *et al.*, 2000; Glodny *et al.*, 2008). Granulite facies was reached prior to the Caledonian Orogeny, during the Sveconorwegian Orogeny (1140-920 Ma; Slagstad *et al.*, 2020).

The Island of Bårdsholmen

The island of Bårdsholmen is located within the southern Dalsfjord area, approximately 100 km north of Bergen. The island is roughly 180 x 70 m with exposures along the shore (Engvik *et al.*, 2000). The dominant lithology is banded granulites with mafic and felsic (leucocratic; figure 2) components (Engvik *et al.*, 2001). To a lesser extent, Bårdsholmen has eclogite lenses, felsites and layered amphibolites (figure 2; Engvik *et al.*, 2000).

Previous Work

- **Granulite Facies Metamorphism**
 - Temperatures of **800-900 °C** (orthopyroxene-clinopyroxene) at assumed pressures of **4 kbar** (Glodny *et al.*, 2008)
 - Temperatures of **815-845 °C** (orthopyroxene-clinopyroxene; Engvik *et al.*, 2000)
 - **955 ± 3 Ma** (U-Pb; Glodny *et al.*, 2008)
 - Sveconorwegian tectonic event
- **Eclogite Facies Metamorphism**
 - Temperatures of **650-750 °C** (garnet-clinopyroxene; Glodny *et al.*, 2008) at pressures of **19-25 kbar** (garnet-phengite-clinopyroxene)
 - Temperatures of 455-510 °C (garnet-clinopyroxene; Engvik *et al.*, 2000) at pressures of **>12 kbar** (clinopyroxene; Glodny *et al.*, 2008)
 - **404 ± 2 Ma** (Rb-Sr multiminerall; Glodny *et al.*, 2008)
 - Caledonian tectonic event, burial to >120 km depth
- **Amphibolite Facies Metamorphism**
 - Temperatures of **460-465 °C** (amphibole-plagioclase; Engvik *et al.*, 2000)
 - **~395 Ma** (Ar-Ar; Glodny *et al.*, 2008)
 - Caledonian tectonic event, isothermal decompression

Textural Observations

Granulite Facies Mineral Assemblage

- Mafic Rocks: Pyroxene, biotite, plagioclase, ilmenite
- Felsic Rocks: Plagioclase, K-feldspar, quartz

Eclogite Facies Mineral Assemblage

- Garnet, omphacite, white mica, rutile ± biotite

Amphibolite Facies Mineral Assemblage

- Amphibole + plagioclase symplectites

Mica Chemistry

- The white mica in sample 2B1a (eclogite) is classified as phengite (figure 5).
- The biotite in samples 2B2, 2B3a and 2B5b (all mafic granulite) are classified as annite-rich biotite (figure 4).
- The biotite in sample 2B3d (eclogite) is Mg-rich and is classified as phlogopite (figure 4).

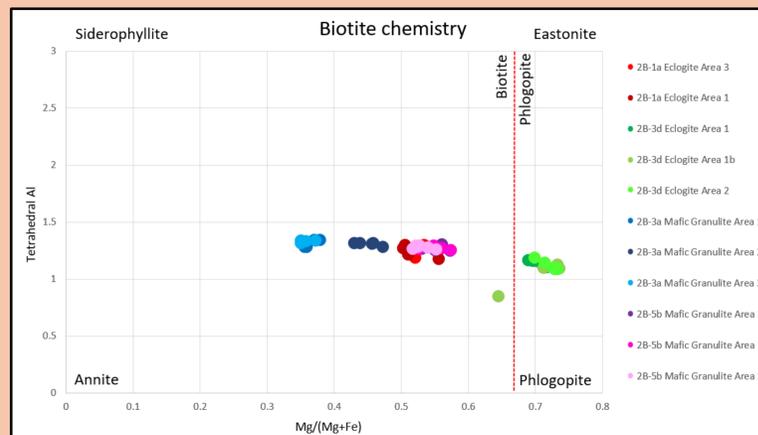


Figure 4: Biotite major element chemistry classified using Karimpour *et al.* (2010)'s chart based off magnesium number and the tetrahedral Al.

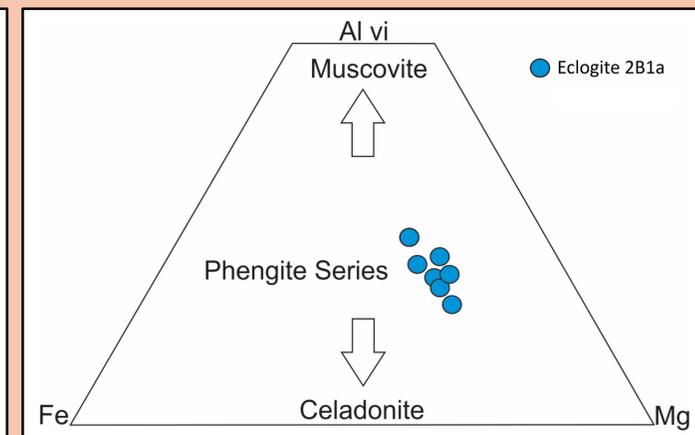


Figure 5: Sample 2B1a's white mica major element chemistry classified using Tappert *et al.* (2013)'s ternary diagram based off substitutions in the octahedral site.

Rb-Sr Geochronology

- 2B1a: 550 ± 189 Ma
 - Phengite part of eclogite (texturally), Rb-Sr age between granulite & eclogite
- 2B1b: 401 ± 48 Ma
 - Phengite part of granulite (texturally), Rb-Sr age aligns with eclogite
- 2B2: 885 ± 31 Ma
 - Biotite part of granulite (texturally), Rb-Sr age close to granulite
- 2B3d: 384 ± 17 Ma (figure 6)
 - Biotite part of eclogite (texturally), Rb-Sr age close to amphibolite
- 2B5b: 787 ± 67 Ma
 - Biotite part of granulite (texturally), Rb-Sr age between granulite & eclogite
- 2B6: 388 ± 6 Ma
 - Phengite part of granulite (texturally), Rb-Sr age close to amphibolite

Table 1: Rb-Sr ages compared to Ar-Ar ages of same minerals in samples. Ar-Ar data from Camacho (unpublished data). Ar-Ar data is referred to by their file name.

Sample	Mineral	Rb-Sr age (Ma)	MSWD	Ar-Ar age (Ma)	MSWD
2B1a	Phengite	550 ± 189	1.2		
	Muscovite 3 batch 2			915 ± 5	1.8
2B1b	Phengite	401 ± 48	1.4		
	Muscovite batch 1			636 ± 1	184.26
	Muscovite 1 batch 2			673 ± 6	3.87
2B2	Biotite	885 ± 31	24		
	Biotite 1 batch 2			1183 ± 4	8.5
	Biotite 2 batch 2			1199 ± 5	25.3
2B3d	Biotite	384 ± 17	2.6		
2B5b	Biotite	787 ± 67	32		
	Biotite 1 batch 1			956 ± 2	1.5
	Biotite 2 batch 2			913 ± 4	8.05
2B6	Phengite	388 ± 6	2.6		
	Muscovite 1 batch 2			401 ± 2	1.3
	Muscovite 2 batch 2			399 ± 2	1.16
	Muscovite 3 batch 2			402 ± 2	0.6

Discussion

- Ages of Rb-Sr are younger than the Ar-Ar ages and other geochronology methods. This could be due to:
 - Excess Ar through inclusions or fluids result in an older Ar-Ar age.
 - Isotopic equilibrium was not reached on Bårdsholmen
- Two stages of biotite crystallization
 - Granulite facies
 - Biotite textural timeline is within 50 Ma of Rb-Sr ages.
- Eclogite facies
 - Biotite textural timeline lines up within margin of error for Rb-Sr age. Increase in Mg, reflected in mineral chemistry

References

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