Disposal Overpack and Waste Package Options - LANL

Petrographic descriptions of FEBEX Section 49 - Dismantlement Phase operation

M4 Letter Report

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Spent Fuel & Waste Disposition Science and Technology

Introduction and objective

The Grimsel Test Site (GTS) is located in the Swiss Alps near the Grimsel Pass (Bern Canton, Switzerland) The site was established in 1984 as a center for underground Research and Development (R&D) supporting the geological disposal of radioactive waste (Grimsel, 2017). The Full Scale High-Level Waste Engineered Barrier System Experiment (FEBEX) is a 1:1 scale demonstration project for the emplacement of spent nuclear fuel (SNF). Two heaters replicating SNF canisters (4.5 meters long, 12 ton each) were emplaced and surrounded by blocks of compacted bentonite clay. The FEBEX experiment was designed to determine the performance of the Engineered Barrier System (EBS) under realistic conditions and demonstrate the feasibility of EBS construction. The FEBEX project was initiated in 1996 with the construction of the tunnel. The FEBEX tunnel proper is located in Grimsel granodiorite at a depth of 450 meters below the surface. By 1996, construction was complete, sensors were installed, and experimental drift was sealed. In February 1997, heaters were switched on and data acquisition began. The heaters were kept at a constant temperature to facilitate a temperature of 180 ^{o}C at the surface of the canister (FEBEX, 2014).

In 2002, heating of the first canister was stopped and that portion (including the canister) of the experiment was excavated. After removal, a dummy canister (no heating capability) was emplaced, EBS blocked were reinserted, and a concrete plug was constructed. The second portion of the experiment ran until 2015, when full excavation of FEBEX was initiated (Figure 1). The samples of concern (Table 1) for this study were taken from a radial pattern in Section 49 (Figure 2).

The objective was to perform a petrographic study of select samples that include Grimsel granodiorite wall rock (3 samples), and nine samples of from the bentonite blocks. The EBS samples were chosen to study the transition from heated canister to the outer edge of the clay blocks near the tunnel wall rock. By recording textures and potential mineral transitions along that transect, one may be able to gather insights into thermal gradients, water saturation, and kinetic effects.

Petrographic observations and preliminary interpretations

Of the twelve samples prepared for petrographic examination from FEBEX section 49 (Table 1), nine were examined in detail. The remaining three thin sections were not examined due to dehydration effects resulting in delamination. Full petrographic descriptions are presented in Appendix I. Samples of bentonite were chosen to linearly represent the NNE quadrant (from heater to tunnel wall) of section 49.

All bentonite samples were taken from the compressed bentonite blocks with Sample BM-C-49-1 (Figures 3 & 4) and Sample BM-C-49-2 representing the innermost (closest to heater) ring of blocks. The middle ring was represented by Sample B-C-49-10 (Figures 5 & 6). The final sample photographed, Sample B-C-49-9 (Figures 7 & 8), along with samples B-C-49-7 and B-C-49-11, represent the outer bentonite block, which is adjacent to the Grimsel granodiorite wall rock.

Three of the Grimsel granodiorite samples (Samples BG-C-49-1, BG-C-49-2, BG-C-49-3) were chosen to be examined from the opposing quadrant.

The bentonite block samples have the following common features. All samples are a mix of compressed clay "chips" which are angular to rounded and range in size from 0.5 to 5.0 mm in longest dimension, and interstitial clay "powder". Texturally the clay chips show grain alignment and deformational fabric. The grain alignment does not cross chip boundaries and is therefore not likely due to the compression during manufacturing, but rather post emplacement processes. Relict phenocrysts from the precursor ash fall are low in volume at approximately 3 volume percent. Of this, plagioclase and K-feldspar dominate, with minor quartz and rare clinopyroxene. The feldspars are heavily altered. Generally the clay chips have altered (to varying degrees) from montmorillonite to smectite or sericite. The identification of sericite is borne out by the elongate nature of the crystals and high birefringence. Confirmation would be by XRD or TEM characterization.

Certain mineralogic and textural features change with distance from the heated canister. Sericite grains are coarsest, longest (up to 2.0 mm) and highest volume in the innermost block samples (BM-C-49-1 and BM-C-49-2). This secondary phase after smectite get shorter, finer, and less in volume as one moves further away from the heater. The sericite grains in the intermediate block samples typically are a maximum of 1 mm in length, and approximately 50% of the smectite clay has transitioned to sericite. In the distal zone of clay blocks, the alteration from smectite to sericite is even lower (25-35 volume percent) and the grains smaller (maximum of 0.5 mm). However sericite is present in all clay samples.The grain alignment in the brown clay chips also exhibit a trend of less alignment and deformation along the transect from inner ring to distal ring. This is borne out in Figures 4, 6, and 8, respectively.

The granodiorite samples all have similar mineralogy and textures. Major mineral phases are K-feldspar, plagioclase, and quartz. Minor phases are muscovite and biotite. Trace phases are allanite, zircon and apatite. Various mineral phases (quartz, biotite) exhibit morphologies which indicate tectonic stresses. There have been chemical alterations also, as evidenced by varying degrees of seritization of feldspars. All three samples display properties that indicate the rock is slightly metamorphosed. In hand sample there is a definite lineation of the mafic mineral phases, along with quartz stringers. In thin section, biotite exhibits shearing along cleavage planes (Figure 11), and quartz displays undulatory extinction (Figure 12), both of which indicate tectonic stresses. There have been chemical alterations also, as evidenced by varying degrees of seritization of feldspars (Figures 9 and 10).

Summary

Petrographic examination confirms that the Grimsel granodiorite is both chemically altered and tectonically stressed. This confirms that the formation has been metamorphosed. The same transmitted light optical examination of the bentonite block material indicated that there is replacement of smectite by sericite. We recognize that close to the heater, there appears to be a greater abundance of sericite, and that this trends downward as samples approach the outer wall contact. This may indicate that the earliest heat pulse and dehydration may be causal in this phyllosilicate phase change. Although temp gradient has lessened with the duration of the FEBEX experiment, there is still a water saturation gradient still in effect. A higher water saturation content at the distal bentonite block would potentially inhibit the phase transition to sericite (which has a lower structural water content). Confirmation of this potential mineralogy transition observed with QXRD information, temperature probe data, and water saturation mapping in section 49 would be critical to understanding Engineered Barrier System performance.

REFERENCES

FEBEX (2014). FEBEX-DP Kick-off Meeting. Co-conveners: Gaus, I., Kober, F., Lanyon, G.W. NAGRA, Thun, Switzerland, June 10, 2014, 66 pp.

Grimsel (2017). FEBEX-DP Full-scale Engineered Barrier Experiment – Dismantling Project http://www.grimsel.com/gts-phase-vi/febex-dp/febex-dp-introduction

Table 1. Samples from section 49 obtained from FEBEX project.

Samples highlighted in green were examined for this report.

FEBEX	Caporuscio
Box 1	BG-C-43-1
	BG-C-43-2
	BG-C-43-3
	BG-C-49-1 Granite
	BG-C-49-2 Granite
	BG-C-49-3 Granite
	B-C-49-7
	B-C-49-8
	B-C-49-9
	B-C-49-10
	B-C-49-11
	B-C-49-12
Box 2	BG-C-53-1-Granite
	BG-C-53-2-Granite
	BG-C-53-3-Granite
	B-C-53-7
	B-C-53-8
	B-C-53-9
	B-C-53-10
	B-C-53-11
	B-C-53-12
	BG-C-58-1 Granite
	BG-C-58-2 Granite
	BG-C-58-3 Granite
Box 3	B-C-58-67
	B-C-58-68
	B-C-58-69
	B-C-58-70

	B-C-58-71
	B-C-58-72
	B-C-58-73
	B-C-58-74
	B-C-58-75
	B-C-58-76
	B-C-58-77
	B-C-58-78
	BM-C-49-3
Block	BM-C-43-1
	BM-C-43-2
	BM-C-43-3
Liner	BM-C-43-1
	BM-C-43-2
	BM-C-43-3
Block	BG-C-43-1
	BG-C-43-2
	BG-C-43-3
Cores	B-C-43-37
	B-C-43-38
	B-C-43-39
	B-C-43-40
	B-C-43-41
	B-C-43-42
Block	BG-C-49-1
	BG-C-49-2
Block	BG-C-49-3
Block	BM-C-49-1
	BM-C-49-2
	BM-C-49-3
Liner	BM-C-49-1
	BM-C-49-2
	BM-C-49-3
Block	BM-C-53-1
	BM-C-53-2
	BM-C-53-3
Block	BG-C-53-1
	BG-C-53-2
	BG-C-53-3
Block	BG-C-58-1
	BG-C-58-2

	BG-C-58-3
Unlisted	BM-D-49-1
	BM-D-49-2
	BM-D-49-3

FIGURES

Figure 1. Exposure face of FEBEX experiment during dismantling of experiment. Note steel liner near center and Grimsel granodiorite at outer edge of drift.

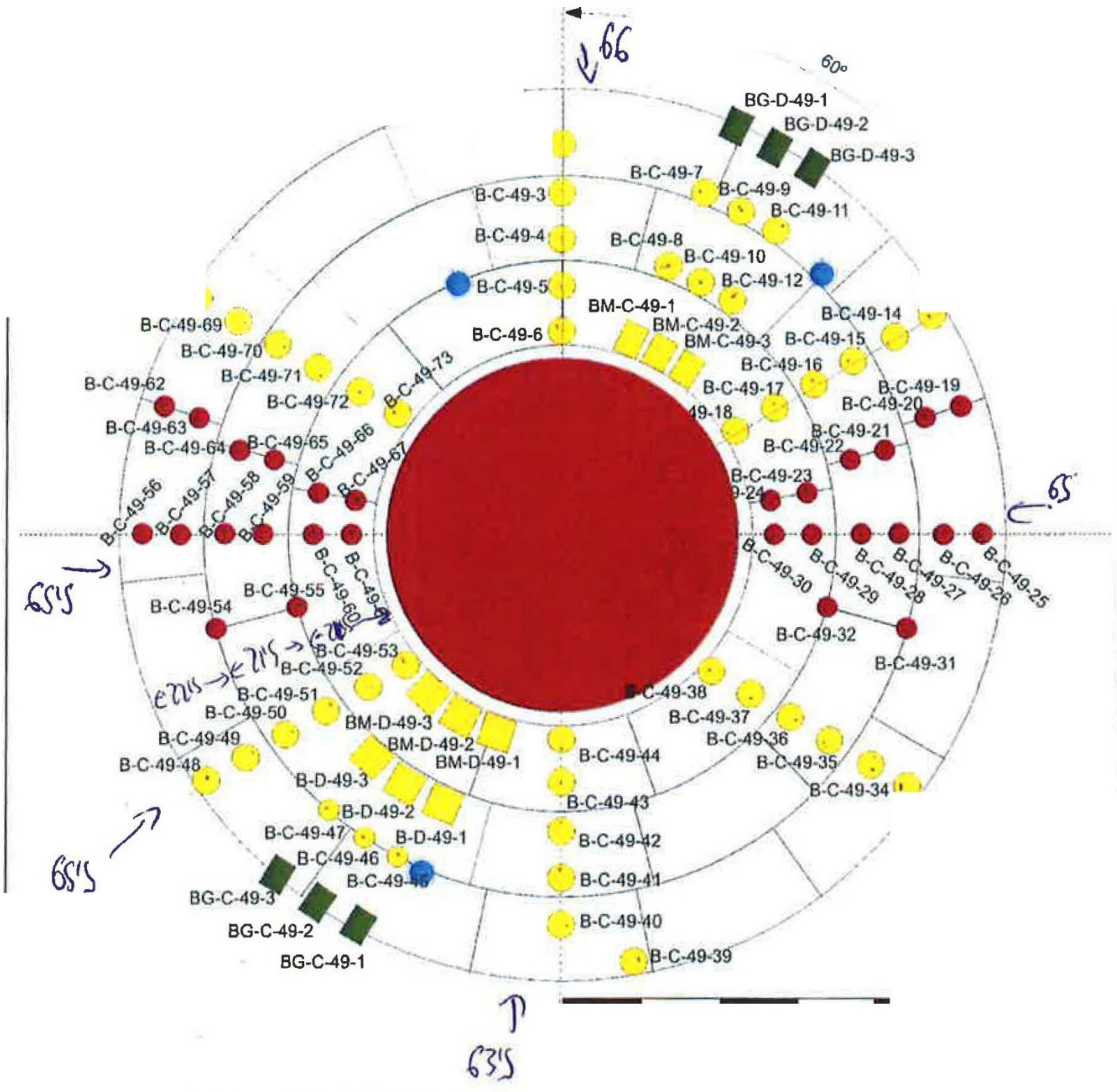

Figure 2. Sampling locations of section 49. Green symbols indicate granodiorite samples, while yellow symbols are bentonite locations.

BENTONITE BLOCK PHOTOMICROGRAPHS

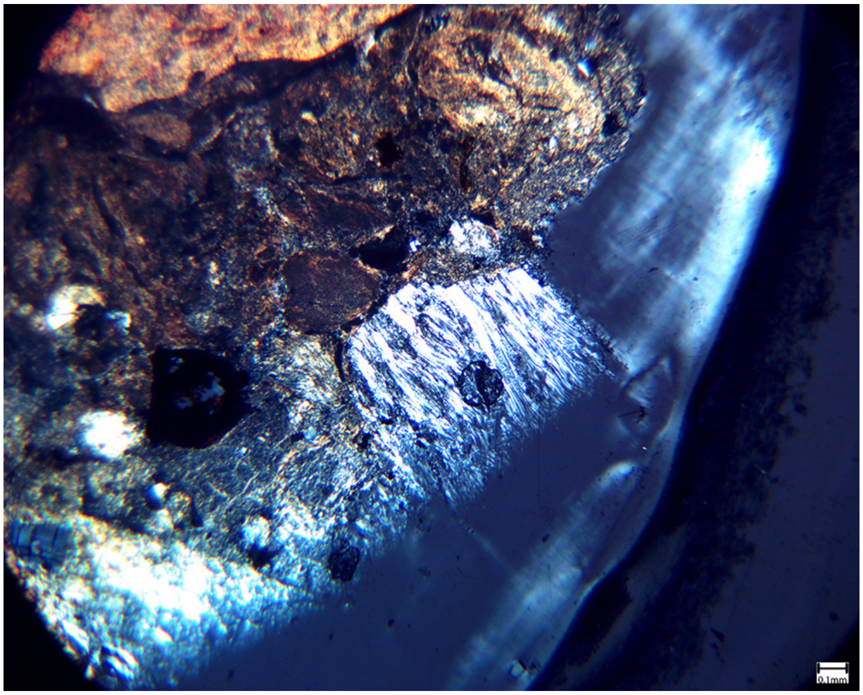

Figure 3. Sample BM-C-49-1 (inner most bentonite block) **–** Sericite needles. This and all remaining images are in cross nicols.

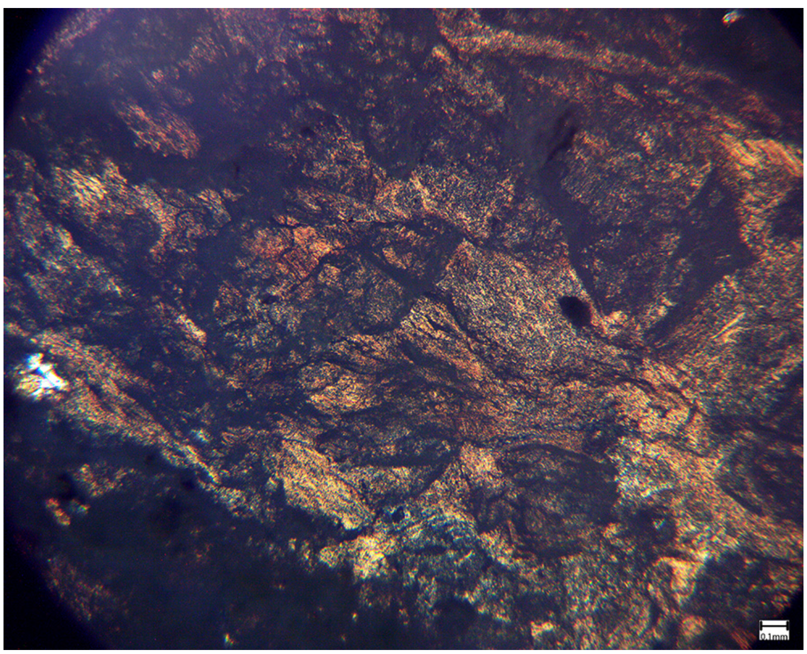

Figure 4. Sample BM-C-49-1 – (inner most bentonite block) Smectite rich clay chip

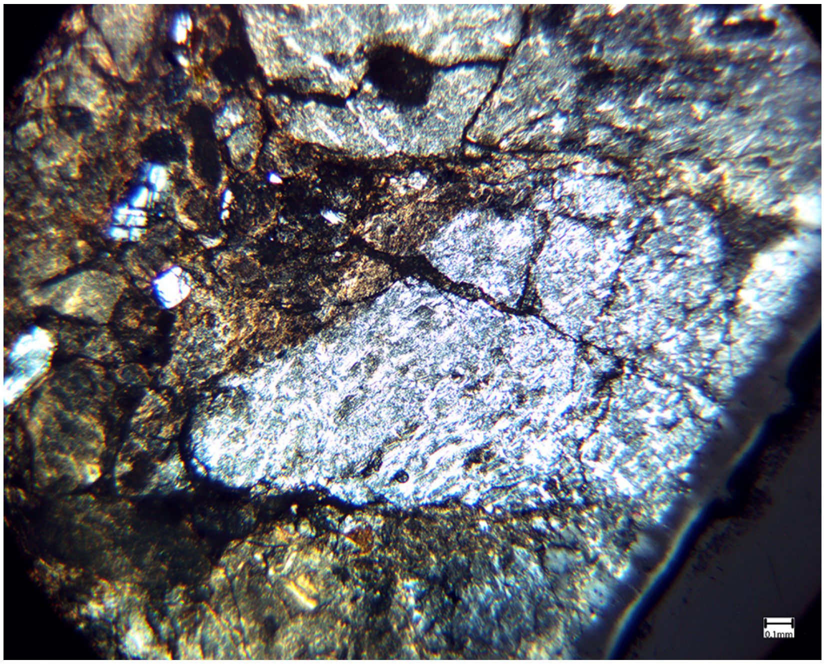

Figure 5. Sample B-C-49-10 – (middle bentonite block ring) Sericite-rich clay chip.

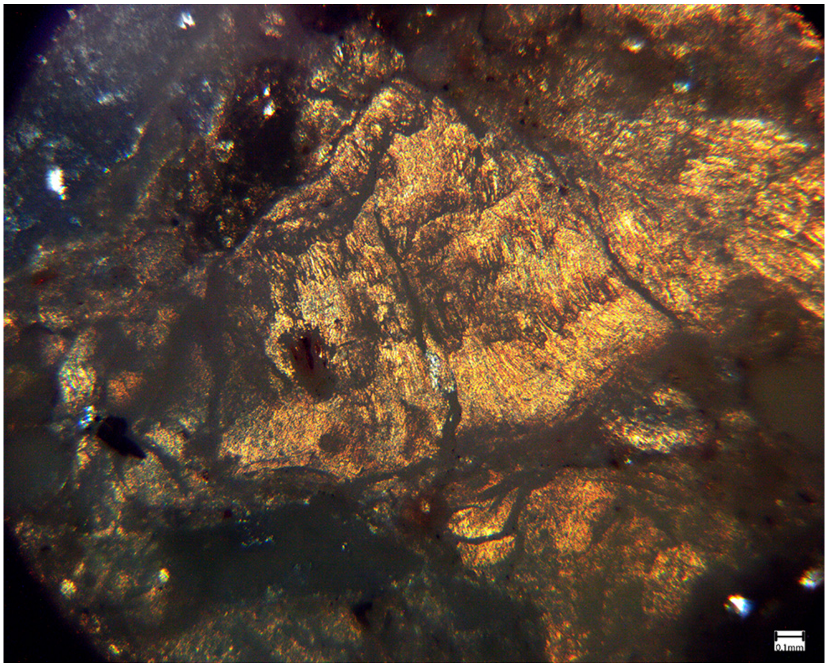

Figure 6. Sample B-C-49-10 – (middle bentonite block ring) smectite rich clay chip

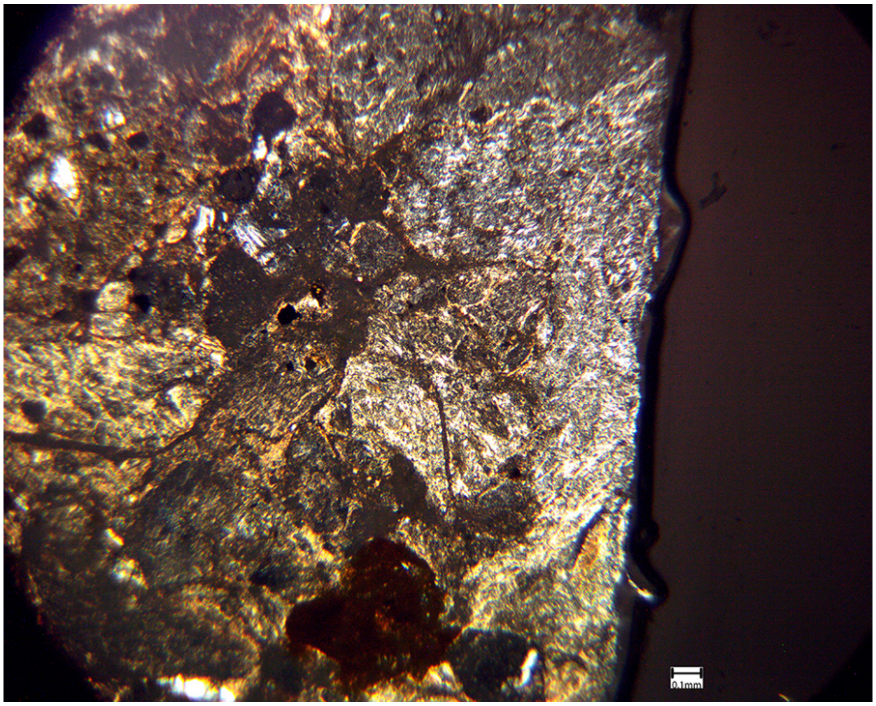

Figure 7. Sample B-C-49-9 – (outer bentonite block ring) Sericite replacing smectite on right hand side chip.

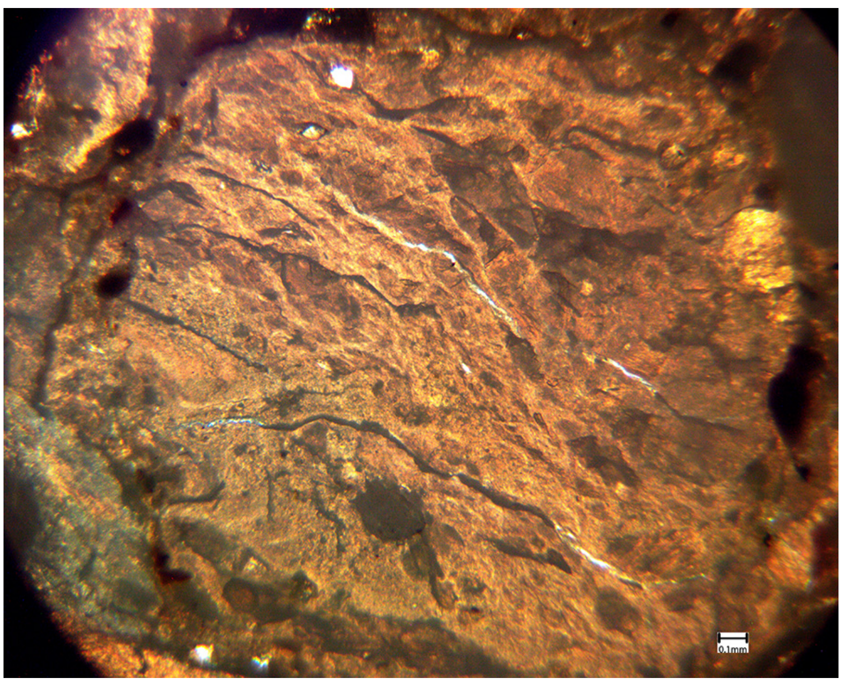

Figure 8. Sample B-C-49-9 – (outer bentonite block ring) clay chip

GRIMSEL GRANODIORITE PHOTOMICROGRAPHS

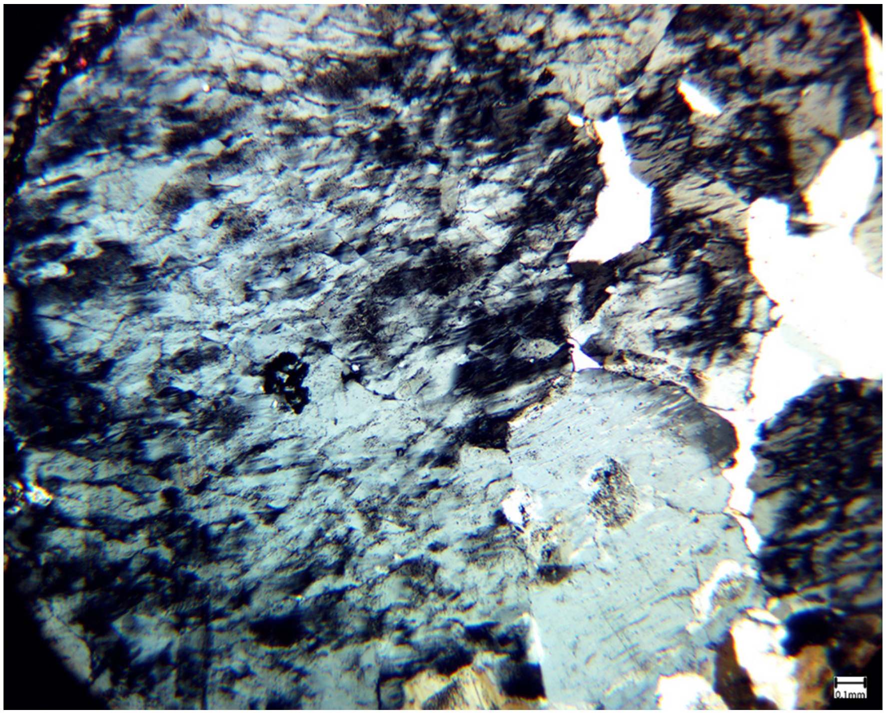

Figure 9. Sample BG-C-49-3. K- feldspar with minor sericite alteration.

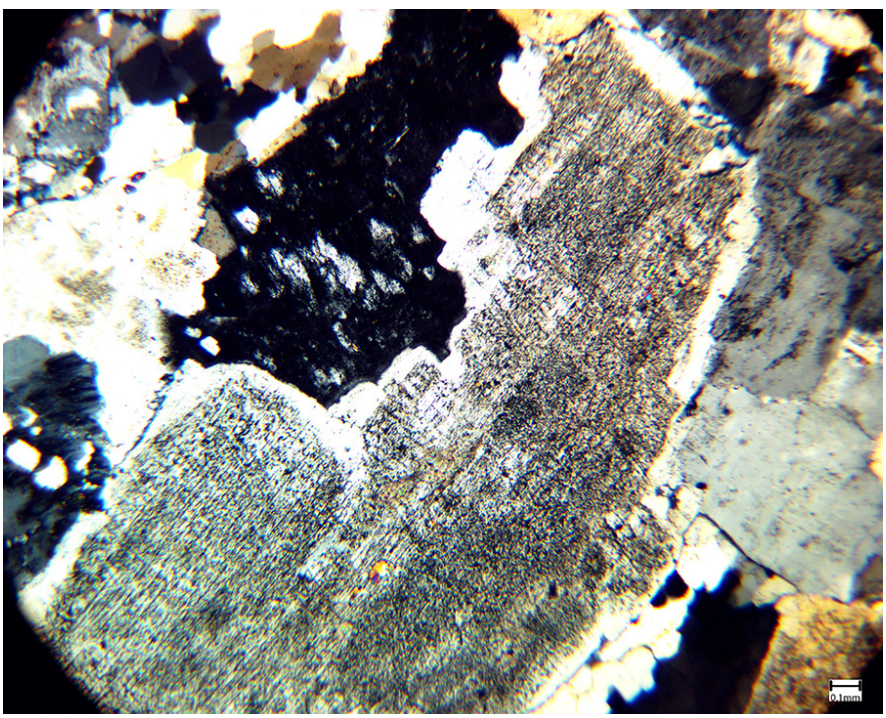

Figure 10. Sample BG-C-49-3. Plagioclase feldspar with major sericite alteration.

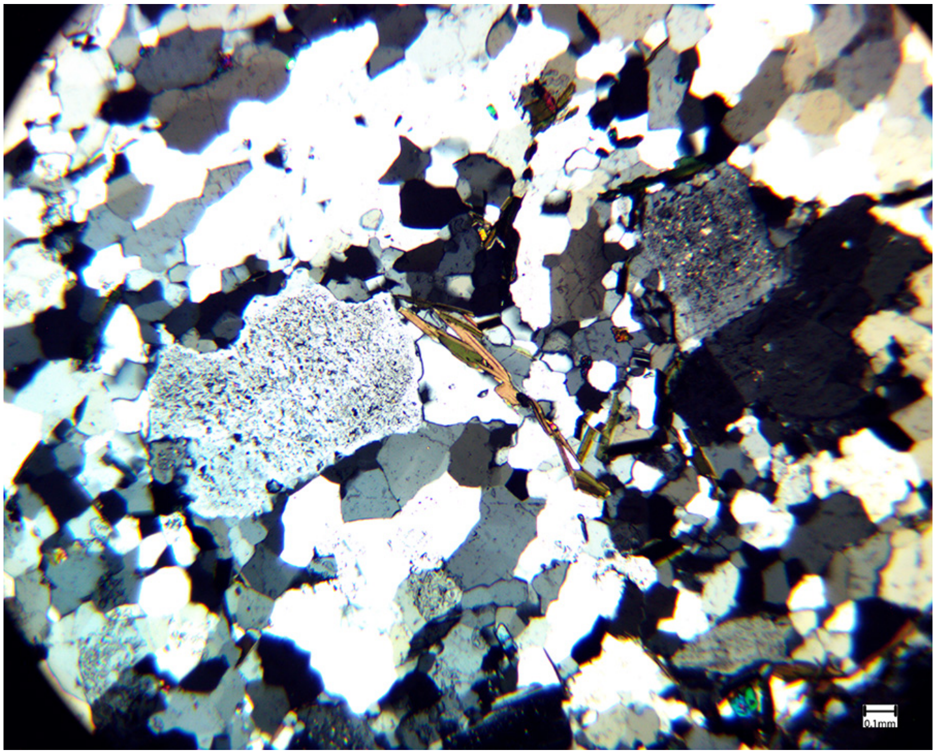

Figure 11. Sample BG-C-49-2. Biotite grain (peach colored) delaminated by tectonic stresses.

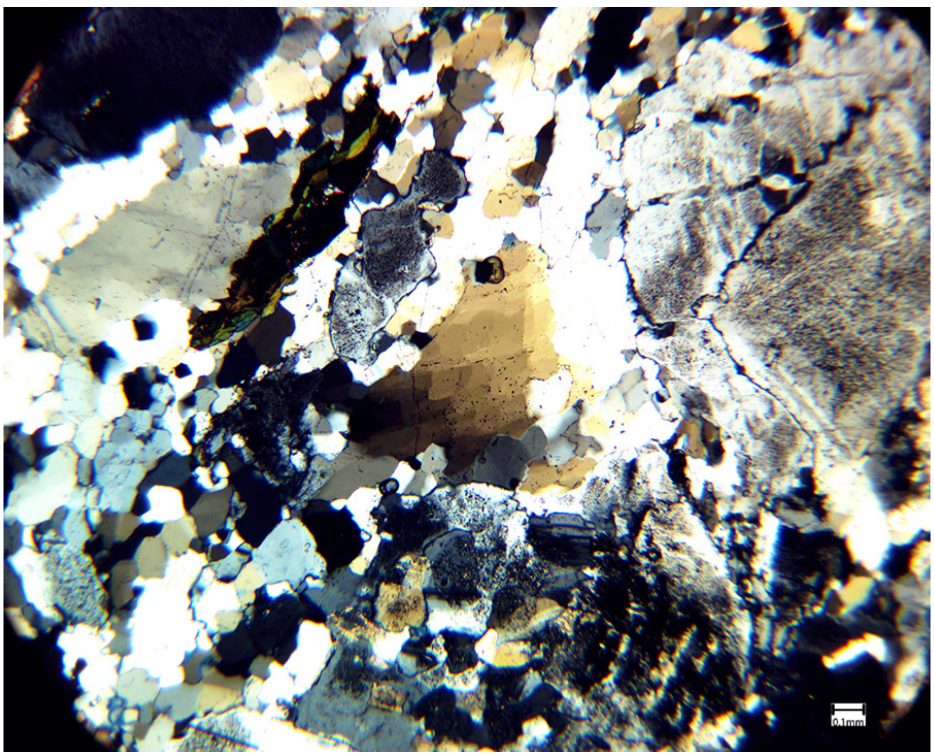

Figure 12. Sample BG-C-49-1. Quartz grains (center – brown/tan and upper left - grays) exhibit undulatory extinction. This is indicative of tectonic stresses.

Appendix I

Petrographic descriptions of select samples from Section 49 of the FEBEX dismantling project

Inner most bentonite block (closest to heater)

Sample BM-C-49-1 - Figures 3&4-: This clay block is a mixture of clay "powder" and chips (0.5 – 5.0 mm on edge) with relict phenocrysts (heavily altered feldspars [plagioclase and K-feldspar], minor quartz and rare clinopyroxene). Chips predominate over powder.

Clay chips are angular to rounded. Texturally the chips show grain alignment and deformational fabric. Precursor clay shows almost complete alteration to sericite (?). Individual sericite grains are up to 2.0 mm in length.

Clay powder (actually interstitial material around chips) is very dark brown in color and therefore difficult to determine whether material is smectite or sericite.

Sample BM-C-49-2: This clay block is a mixture of clay "powder" and chips (0.5 – 5.0 mm on edge) with relict phenocrysts (heavily altered feldspars [plagioclase and K-feldspar], minor quartz and rare clinopyroxene).

Clay chips are angular to rounded. Texturally the chips show grain alignment and deformational fabric. Precursor clay shows alteration to sericite (?). Individual sericite grains are up to 2.0 mm in length.

Clay powder (actually interstitial material around chips) is very dark brown in color and therefore difficult to determine whether material is smectite or sericite.

Intermediate zone bentonite block (medial to heater)

Sample B-C-49-10 – Figures 5&6-: This clay block is a mixture of clay "powder" and chips (0.5 – 5.0 mm on edge) with relict phenocrysts (heavily altered feldspars [plagioclase and K-feldspar], minor quartz and rare clinopyroxene). Chips are approximately equivalent in volume to powder in this sample.

Clay chips are angular to rounded. Texturally the chips show grain alignment and slight deformational fabric. Precursor clay shows approximately 50% alteration to sericite (?). Individual sericite grains are up to 1.0 mm in length.

Clay powder (actually interstitial material around chips) is very dark brown in color and therefore difficult to determine whether material is smectite or sericite.

Distal zone bentonite block (furthest from heater)

Sample B-C-49-7: This clay block is a mixture of clay "powder" and chips (0.5 – 5.0 mm on edge) with relict phenocrysts (heavily altered feldspars [plagioclase and K-feldspar], minor quartz and rare clinopyroxene). In this sample chips dominate in volume to powder.

Clay chips are rounded. Texturally the chips show less grain alignment (approximately 25-30%) and deformation is present but rare. Precursor clay exhibits less pronounced alteration to sericite (?) with high proportion of smectite still present. Largest individual sericite grains commonly measure only 0.5 mm in length.

Clay powder (actually interstitial material around chips) is very dark brown in color and therefore difficult to determine whether material is smectite or sericite.

Sample B-C-49-9 – Figures 7&8-: This clay block is a mixture of clay "powder" and chips (0.5 – 5.0 mm on edge) with relict phenocrysts (heavily altered feldspars [plagioclase and K-feldspar], minor quartz and rare clinopyroxene). In this sample chips dominate in volume to powder.

Clay chips are rounded. Texturally the chips show less grain alignment (approximately 25-30%) and deformation is present but rare. Precursor clay exhibits less pronounced alteration to sericite (?) with high proportion of smectite still present. Largest individual sericite grains commonly measure only 0.5 mm in length.

Clay powder (actually interstitial material around chips) is very dark brown in color and therefore difficult to determine whether material is smectite or sericite.

EXCEPTION – In this sample there is one large glass lapilli fragment with very little alteration present

Sample B-C-49-11: This clay block is a mixture of clay "powder" and chips (0.5 – 5.0 mm on edge) with relict phenocrysts (heavily altered feldspars [plagioclase and K-feldspar], minor quartz and rare clinopyroxene). In this sample chips dominate in volume to powder.

Clay chips are rounded. Texturally the chips show less grain alignment (approximately 25-30%) and deformation is marginally higher than the previous two samples. Precursor clay exhibits slightly more alteration to sericite (?) than previous two samples (35-40 volume %), however with high proportion of smectite still present. Largest individual sericite grains commonly measure only 0.5 mm in length.

Clay powder (actually interstitial material around chips) is very dark brown in color and therefore difficult to determine whether material is smectite or sericite.

Grimsel Granodiorite (wall rock of adit)

Samples BG-C-49-1, BG-C-49-2, BG-C-49-3: All three samples display properties that indicate the rock is slightly metamorphosed. In hand sample there is a definite lineation of the mafic mineral phases, along with quartz stringers. In thin section, biotite exhibits shearing along cleavage planes (Figure 11), and quartz displays undulatory extinction (Figure 12), both of which indicate tectonic stresses. There have been chemical alterations also, as evidenced by varying degrees of seritization of feldspars (Figures 9 and 10).

Sample BG-C-49-1: Major mineral phases are K-feldspar, plagioclase, and quartz. Minor phases are muscovite and biotite. Trace phases are allanite, zircon and apatite.

Various mineral phases (quartz, biotite) exhibit morphologies which indicate tectonic stresses. There have been chemical alterations also, as evidenced by varying degrees of seritization of feldspars.

Sample BG-C-49-2: Major mineral phases are K-feldspar, plagioclase, and quartz. Minor phases are muscovite and biotite. Trace phases are allanite, zircon and apatite.

Various mineral phases (quartz, biotite) exhibit morphologies which indicate tectonic stresses. There have been chemical alterations also, as evidenced by varying degrees of seritization of feldspars.

Sample BG-C-49-3: Major mineral phases are K-feldspar, plagioclase, and quartz. Minor phases are muscovite and biotite. Trace phases are allanite, zircon and apatite.

Various mineral phases (quartz, biotite) exhibit morphologies which indicate tectonic stresses. There have been chemical alterations also, as evidenced by varying degrees of seritization of feldspars.