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Report 100896

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Samples:

Seven rock samples, as detailed below, were submitted by Robert T. Boyd of Endurance Gold Corporation, with a request for petrographic study.

N.	*ID1*	*ID2*	*Section Type*	*Lithology*
1	G	7	polished thin section	Quartz-niccolite granofels
2	R	4	polished thin section	Sericite-albite altered fenite
3	GD	4	polished thin section	Quartz-albite-hematite-monazite-xenotime cataclasite
4	GD	7	polished thin section	Fenite
5	GD	65	polished thin section	Nepheline syenite
6	GD	72	polished thin section	Cataclasite
7	GD	73	polished thin section	Cataclasite

Summary:

Sample **5** is a nepheline syenite, composed of nepheline, K-feldspar and plagioclase. It is characterized by the alkaline composition of its mafic minerals, namely aegirine and possibly magnesioriebeckite.

Sample **4** is a fenite as defined by Zharikov et al. (2007), it is a fine-grained porphyritic rock composed of albite, K-feldspar and arfvedsonite (an alkaline amphibole). An alteration event caused the substitution of the euhedral crystals by albite, magnetite and hematite.

Sample **2** is a sericite-albite altered fenite. The original amphibole of the fenite was completely substituted by hematite, albite and magnetite. A subsequent alteration with albite and sericite overprinted the sample.

Sample **1** is the product of quartz-niccolite alteration. The sample is crosscut by quartz and bismuth veins. Due to the presence of quartz the alteration observed in sample 1 could be interpreted as an outermost alteration zone surrounding the fenite zone.

Sample **3** displays the most intense alteration and a consequently higher amount of hematite, monazite and xenotime. Polygonal quartz is fractured and infilled by albite, hematite, and minor monazite and xenotime. Monazite and xenotime generally host REE elements and further, more specific analyses (i.e. Scanning electron microscopy or ion microprobe - SIMS) are recommended in order to determine the content of REE within these accessory minerals.

Sample **6** and **7** share a brittle deformation event but had different protoliths. In the case of sample 6 cataclasis deformed a sandstone with calcite, minor quartz and sulphide infill. Sample 7 likely had a feldspathic protolith. In sample 7 abundant biotite (low in titanium) and a radioactive mineral (zircon?) were crystallized after the brittle deformation event, possibly together with sulphides of which only rare, relict pyrite is observed. Oxidation of the sulphides produced hematite, goethite and a diffuse limonitic stain dispersed along the fractures and along the compositional layering.

Individual descriptions, a glossary of microstructural terms and a set of photomicrographs are attached.

References

Zharikov, V.A., Pertsev, N.N., Rusinov, V.L., Callegari, E., and Fettes, D.J., 2007, 9. Metasomatism and metasomatic rocks., Recommendations by the IUGS Subcommission on the Systematics of Metamorphic Rocks: Web version 01.02.07.

Respectfully submitted

Fabrizio Colombo, Ph.D., P.Geo.

Sample: G7

Quartz-niccolite-fluorite granofels

The sample can be divided into two domains:

Domain a) is characterized by an inequigranular replacement structure of quartz, niccolite, bismuth, and cryptocrystalline aggregates, crosscut by a subparallel set of veinlets partially infilled by fluorite. Rare amoeboid domains of white mica and cryptocrystalline white mica+chlorite are also observed.

Domain b) consists of inequigranular quartz and minor fluorite which mostly occurs as a late infill of cavities within veinlets or fractures.

mineral	***modal %***			***main size range (mm)***
a) quartz-niccolite-fluorite granofels	**76**			
quartz	35	-	40	0.02-0.5
cryptocrystalline material	22	-	25	<0.001
niccolite	12	-	15	up to 1
bismuth	3	-	5	up to 0.1
b) quartz-fluorite vein	**24**			
quartz	20			0.001-0.1
bismuth	3			up to 1.5
calcite	tr			

a) quartz-niccolite-bismuth granofels

Quartz is inequigranular, with a grain size ranging from ~0.02 to 0.5 mm. The grain shape is generally amoeboid to polygonal. Coarser grain size and polygonal grain shape tend to be observed only within irregular cavity infill domains up to 1 cm in size. Quartz crystallization is associated with irregular domains of late-phase products including niccolite.

Niccolite is anhedral, fractured, partially resorbed and has a maximum grain-size of 1 mm. It precipitated around previously formed quartz crystals in the rock, together with quartz in the core of the infilled cavities and within the veinlets and fractures which crosscut the sample. Niccolite is rimmed by cryptocrystalline aggregates irresolvable by the microscope and the cryptocrystalline material is later crosscut by veinlets partially infilled by bismuth.

b) quartz-fluorite vein

Domain b mostly consists of inequigranular quartz and minor amounts of fluorite.

Quartz occurs as very fine-grained (0.001-0.002) aggregates in which the crystals are amoeboid to polygonal. These domains are often rimmed by coarser (0.1 mm) infill quartz with a higher percentage of polygonal grains than within the fine aggregates. Occasionally the euhedral crystals project into unfilled portions of the originally fluid-filled “open space”. Fractures containing limonitic material and bismuth crosscut both the aggregates and rims.

The boundary between the granofels (domain a) and vein (domain b) is marked by an irregular domain exceeding 1mm in size in which bismuth is markedly more abundant and infills cavities in the otherwise quartz-dominated aggregate.

Sample: R4

Sericite-albite altered fenite

The microstructure is characterized by acicular porphyroblasts, completely replaced by plagioclase, white mica and hematite, that are immersed in a fine-grained matrix of plagioclase and K-feldspar. The sample is overprinted by sericite which replaces K-feldspar and possibly albite within the groundmass and partially replaces the pseudomorphs after possibly aegirine. The alteration halos show irregular shape and are recognizable on the offcut by the grey-brown colour in contrast with the yellowish (after staining) groundmass still containing K-feldspar.

mineral	***modal %***	***main size range (mm)***
albite	35 - 40	up to 0.1
K-feldspar	20 - 25	up to 0.1
(aegirine): sericite, albite, hematite	20 - 25	up to 5
sericite	15 - 20	<0.002
hematite	4 - 6	up to 0.2
magnetite	1	0.02
apatite	tr	

Albite and **K-feldspar** constitute an inequigranular, xenoblastic and fine-grained (up to 0.1 mm) aggregate. In the portion of the rock overprinted by albite and sericite alteration, the groundmass is partially replaced by amoeboid aggregates of cryptogranular sericite and rare idioblastic prisms of albite (up to 0.2 mm). Albite prisms are particularly abundant within and in proximity to the pseudomorphs of amphibole. Within the matrix, albite mantles the pre-existing albite crystals as a reaction rim at the contact with the cryptocrystalline sericite aggregate.

The pseudomorphs of possibly aegirine are made up of a fine-grained and xenoblastic aggregate of sericite, albite and hematite. The acicular pseudomorphs may reach 5 mm in length and up to 0.3 mm in width. Within the alteration halo the pseudomorphs are replaced by cryptocrystalline sericite and euhedral albite, which locally forms aggregates of randomly oriented prisms up to 0.3 mm.

Hematite is the coarsest mineral within the pseudomorphs and occasionally reaches 0.2 mm in size. Hematite is generally absent outside of the pseudomorphs, however, in one domain characterized by a high density of pseudomorphs, hematite is also dispersed in the matrix of the rock. Hematite mantles and replaces fine-grained (up to 0.2 mm) **magnetite**.

Apatite is dispersed within the matrix of the rock as very fine-grained acicular prisms.

Sample: GD4

Quartz-albite-hematite-monazite-xenotime cataclasite

The microstructure of this sample is characterized by coarse-grained amoeboid to polygonal quartz and interstitial K-feldspar. Quartz is locally fragmented at the edge of both the quartz-rich domains and the domain made up of tabular plagioclase, hematite, very fine-grained quartz, xenotime, monazite and rare rutile.

mineral	*modal %*	*main size range (mm)*
quartz	40 - 45	up to 5
plagioclase (albite)	30 - 35	up to 1.2
hematite	15 - 20	up to 0.1
K-feldspar	7 - 10	up to 1.5
monazite	1 - 2	0.3-0.5
xenotime	1 - 2	up to 1
magnetite	1	up to 1
rutile	tr	0.05

Quartz is coarse-grained (up to 5 mm) and constitutes quartz-rich domains as amoeboid to polygonal aggregates. Most of the quartz boundaries are fractured and overgrown by tabular albite. Quartz is locally associated with interstitial **K-feldspar** (microcline with “tartan” twinning).

Albite occurs as tabular, fine-grained, euhedral prisms with a high aspect ratio (3:1 or higher) and a grain size reaching 1-1.2 mm. Most of the albite is partially replaced by fine-grained (~0.1 mm) hematite, however clear tabular albite crystals are also observed and are interpreted to belong to a second crystallization phase of albite following the crystallization of hematite.

Hematite crystallization preferentially occurs as partial replacement of tabular albite. Crystals are commonly anhedral and in rare instances exceed 1 mm in size. It forms interstitial domains within the the larger albite-rich domain.

Xenotime is anhedral, encloses euhedral albite and euhedral magnetite and its grain size reaches 1 mm.

Monazite is generally anhedral and occurs within the hematite-albite-rich domains or as anhedral crystals within the quartz-rich domains.

Sample: GD7

Fenite

This sample displays a porphyritic microstructure with fine-grained skeletal porphyroclasts of arfvedsonite in a matrix consisting of albite and minor K-feldspar. Euhedral pseudomorphs, possibly after amphibole, are substituted by albite, magnetite and hematite. Skeletal epidote and fluorite are minor constituents and are dispersed within the groundmass. Halos of coarser-grained albite and sericite locally alter the rock and replace arfvedsonite.

mineral	***modal %***			***main size range (mm)***
abite	50	-	55	up to 0.3
K-feldspar	30	-	35	up to 0.3
arfvedsonite	8	-	12	up to 2.5
magnetite	3	-	4	up to 0.2
sericite	2	-	4	0.02
magnetite	1	-	2	0.1
epidote?	0.5	-	1	<0.5
fluorite	tr			<0.5

Albite, along with minor **K-feldspar**, constitutes the groundmass. Albite and K-feldspar form a fine-grained inequigranular and interlobate aggregate with grain-size generally up to 0.3 mm. Albite occasionally forms larger anhedral crystals containing abundant K-feldspar inclusions and occasionally forms graphic intergrowths with K-feldspar. The coarser albite mantles skeletal amphibole crystals.

Arfvedsonite porphyrocrysts are skeletal, with grain-size ranging from 0.2 to 2.5 mm, and display a strong pleochroism (X=dark blue-green, Y=grey-blue, Z=dark green to greyish green) and a c-X angle of 10°. The skeletal crystals display interlobate margins with albite and albite inclusions.

Hematite is found within the euhedral pesudomporphs, possibly after pyroxene, as anhedral and fine-grained (up to 0.2 mm) crystals associated with albite. In some instances hematite mantles **magnetite** and shows crystallographically oriented replacement within magnetite. Hematite and magnetite mantle arfvedsonite and, in association with albite, define irregular domains, up to 2 mm in size, within the groundmass.

Anhedral **epidote** and fluorite grains are generally smaller than 0.5 mm, are rare and occur dispersed within the groundmass. Sericite and albite may locally alter the rock. Arfvedsonite, in proximity to these haloes, is replaced by very fine-grained sericite and minor hematite.

Sample: GD65

Nephelin syenite

The syenite's microstructure is dominated by the presence of euhedral phenocrysts of nepheline and K-feldspar, and finer-grained glomeroporphyritic euhedral aegirine.

mineral	***modal %***			***main size range (mm)***
nepheline	35	-	40	up to 5 mm
K-feldspar	25	-	30	up to 5 mm
albite	12	-	15	up to 1
aegirine	8	-	10	up to 1.5
magnesioriebeckite	5		8	up to 02.5
fluorite?	3	-	5	Up to 0.6
white mica	3	-	4	up to 0.5
(biotite?): aegirine, hematite	2	-	3	up to 0.7
hematite	2		3	up to 0.05
(ilmenite): hematite	1	-	2	up to 0.05
sphene	tr			Up to 0.6

Nepheline is the most abundant mineral in this sample. Its grain shape is anhedral, some of its crystals may exceed 5 mm in size and it is moderately to strongly altered by a very fine-grained dispersion of sericite. In most of the crystals only patches of relict nepheline are left intact by the alteration.

K-feldspar is anhedral, its grain-size varies from 1 to more than 5 mm in size, it contains abundant exsolution lamellae of albite and the smaller crystals tend to assume a tabular shape. Subhedral to euhedral crystals of plagioclase (albite) form at the boundary between nepheline and K-feldspar.

Aegirine is subhedral to euhedral and it forms acicular to prismatic crystals up to 2 mm in length with a generally high aspect ratio (3:1 or higher). It nucleates preferentially in proximity to pseudomorphs, possibly after **biotite**, of which rare skeletal relicts are observed. The pseudomorphous domains are made up of white mica, albite, relict oxidized biotite, and aegirine. Aegirine crystals are generally not enclosed by nepheline and K-feldspar. Only in a few instances does the euhedral termination of the amphibole pierce into nepheline crystals.

Magnesioriebeckite is skeletal and forms coarse-grained (up to 2.5 mm) crystals with abundant inclusions of hematite, replacing ilmenite or magnetite. Most of the time hematite completely replaces the amphibole and the aegirine preferentially nucleates in proximity to these pseudomorphs.

Different interstitial domains are formed by several minerals including **fluorite**, nepheline, and aegirine+biotite+oxides+hematite.
Structural relicts of **biotite** are mostly replaced by aegirine and hematite. Biotite flakes are recognized by very fine-grained epitaxial replacements by hematite, mostly after Ilmenite.

Sample: GD72

Cataclasite

Sample GD72 displays a brecciated microstructure with angular fragments of layered mudstone immersed in an inequigranular matrix of calcite, minor hematite and quartz.

mineral	*modal %*		*main size range (mm)*
sandstone	**43**		
irresolvable very fine-grained material		35 - 38	<0.001
quartz		4 - 5	up to 0.06
calcite (and minor dolomite?)		1 - 2	<0.02
matrix	**55**		
calcite (and minor dolomite?)		52 - 54	~0.25
hematite		1 - 2	~0.25
veins	**2**		
calcite (and minor dolomite?)		1	up to 0.1
hematite		1	0.1-0.3
quartz		tr	0.02
pyrite		tr	up to 0.2
micas		tr	up to 0.3

Lithic fragments of mudstone display sharp, angular shapes and dimensions ranging in size from 0.1 mm up to more than 10 mm. The fine-grained layers contain grains of less than 0.001 mm in size that are irresolvable by the microscope. They do, however contain some quartz as the fragments scratch glass. Coarser layers contain rare quartz fragments up to 0.06 mm in size.

The fragments are fractured and generally infilled by calcite, occasionally displaying well terminated crystals projecting toward the median zone of the fractures. In a few instances fractures are 0.1-0.15 mm wide and are infilled by very fine-grained (0.02 mm) quartz, blocky hematite, skeletal relicts of pyrite (up to 0.2 mm), altered micaceous minerals and irresolvable fan-like aggregates. The lithic fragments display a planar grain-size layering.

The matrix of the sample mostly consists of inequigranular calcite (and minor dolomite?) with a grain-size of up to 0.25 mm. The carbonate grains are generally amoeboid, however, in few instances at the fringes of the rotated lithic fragments, they display rhombohedral shapes and grains up to 0.4 mm in size. Polygonal calcite grains up to 0.2 mm are observed within 0.3-0.4 mm wide veinlets crosscutting the matrix.

Sample: GD73

Cataclasite

This sample displays a layered microstructure consisting of layers with different relative contents of quartz, plagioclase, clay, biotite, goethite and limonite, the latter of which is replacing pyrite. The grain-size differences were possibly produced by cataclasis and the differential staining is caused by differing relative amounts of goethite and limonite. Biotite is randomly oriented.

mineral	***modal %***			***main size range (mm)***
quartz	35		40	0.04-0.2
clay	25		30	<0.001
low-Ti biotite	15	-	20	0.4-2
plagioclase	10	-	15	0.1-0.2
hematite-goethite	7		10	up to 1
white mica	2	-	3	0.02-0.04
zircon?	2	-	3	up to 1
pyrite	tr			up to 0.04

Most of the sample is composed of layers with a fine-grained (0.2 mm) to very fine-grained (0.04 mm) matrix consisting of amoeboid to polygonal **quartz** and minor **plagioclase**. This layering and the matrix grain-size are interpreted as having been generated during a cataclastic event, and were later overprinted by biotite crystallization and, possibly, recrystallization of the matrix.

Clays are locally abundant in some very fine-grained layers where the presence of **kaolinite** is suspected. Within these layers the quartz clasts (up to 0.2 mm in size) are immersed in a very fine-grained matrix irresolvable by the microscope but with a slightly higher refractive index than quartz and a low birefringence.

Coarse-grained (up to 2 mm), skeletal and randomly oriented **biotite** defines 1.5-2 mm thick layers. Biotite includes abundant prismatic to acicular crystals up to 1mm in length, with a high aspect ratio (5:1 or higher) and that are surrounded by metamict halos. These crystals may be zircon, or another mineral containing radioactive elements. Biotite includes amoeboid (up to 0.5 mm) aggregates composed of very fine-grained white mica and possibly chlorite. Biotite crystals display, in a few instances, deformation bands. As shown by the lack of brown among the pleochroism colours biotite is Ti-poor.

Hematite, goethite and **limonitic material** tend to be more abundant along the biotite-rich layers where they substitute sulphides. A few skeletal grains of pyrite, with grain-size not exceeding 0.04 mm, are found as relicts within the sulphide pseudomorphs. Limonite precipitation followed fractures and intergranular permeability within the fine-grained and very fine-grained quartzofeldspathic matrix.

Glossary of microstructural terms

Aspect ratio: Ratio of length to width of crystals and grains.

Cataclastic microstructure: Microstructure of rocks (cataclasites) formed by brittle deformation, involving fracturing of grains and relative movement of fragments.

Epitaxial: Adjective of epitaxis (q.v.).

Epitaxis (epitaxy): Nucleation and growth of a mineral in another with a systematic relationship between the two crystal structures.

Fenite: Fenites are high temperature metasomatic rocks composed mainly of K-Na-feldspars (perthiteor antiperthite), albite, nepheline, alkaline pyroxenes (aegirine, aegirine-diopside, aegirineaugite), alkaline amphiboles (arfvedsonite, riebeckite, hastingsite, richterite); subordinate minerals include biotite-phlogopite micas, magnetite and ilmenite and the most common accessories are titanite and apatite. In some cases fenites contain calcite. Fenites are related to alkaline-ultramafic magmatic complexes and may replace a wide range of rocks including ultramafic rocks and carbonatites formed in the early magmatic stages, as well as acid host rocks such as granite-gneisses and more rarely sandstones. The fenitisation process occurs in exocontact aureoles of nepheline syenites. Fenites are formed mainly or completely during the magmatic stage by silica-undersaturated alkaline magmatic fluids. The width of fenitisation aureoles may reach several kilometres.

Glomeroporphyritic: Aggregate of phenocrysts, formed by either heterogeneous nucleation or synneusis (q.v.).

Graphic intergrowth: Intergrowth of two minerals, each in optical continuity, resembling some forms of ancient writing; most commonly intergrowths of quartz and alkali feldspar.

Interlobate: Describes the shape of grain aggregates, with irregular, lobate grain boundaries.

Interstitial: Describes the microstructure formed by the crystallization of fine-grained minerals within angular cavities or interspace fillings between coarser minerals.

Matrix: Aggregate that is distinctly finer-grained than the porphyroblasts in a metamorphic rock.

Metamict: A mineral affected by metamictization (q.v.).

Metamictization is a natural process resulting in the gradual and ultimately complete destruction of a mineral's crystal structure, leaving the mineral amorphous. Affected material is therefore described as metamict. Certain minerals occasionally contain interstitial impurities of radioactive compounds and it is the alpha radiation emitted from these compounds that is responsible for degrading a mineral's crystal structure through internal bombardment. Effects of metamictization are extensive: other than negating any birefringence previously present, the process also lowers a mineral's refractive index, hardness, and specific gravity. The mineral's colour is also affected: metamict specimens are usually green or brown.

Pleochroism: Pleochroism is the change in colour evident as the mineral is rotated under plane-polarized light. The primary cause of pleochroism in minerals is due to adsorption of particular wavelengths of light. This selective adsorption of certain wavelengths of light causes the transmitted light to appear coloured. This colour is a function of the thickness and the particular chemical and crystallographic nature of the mineral.

Porphyroblast: Large crystal, relative to the grain size of the matrix (q.v.), that has grown under metamorphic conditions in a metamorphic rock.

Porphyroclast: Large crystal, relative to the grainsize of the matrix, being a relic of a formerly large grain, such as a phenocryst (of magmatic origin) or a porphyroblast (q.v.).

Pseudomorph: A mineral or aggregate of minerals replacing an older mineral grain or crystal, preserving the original size and shape of the replaced mineral.

Synneusis: The drifting together and mutual attachment of crystals suspended in a magma.

References

The microstructural definitions are mostly taken from:

Passchier C.W. And Trouw R.A.J., 1998, Microtectonics, Springer, 289 pp.
Vernon R.H., 2004, A practical guide to rock microstructure. Cambridge University Press, 594 pp.

The definition of fenite is quoted from:

Zharikov, V.A., Pertsev, N.N., Rusinov, V.L., Callegari, E., and Fettes, D.J., 2007, 9. Metasomatism and metasomatic rocks., Recommendations by the IUGS Subcommission on the Systematics of Metamorphic Rocks: Web version 01.02.07.

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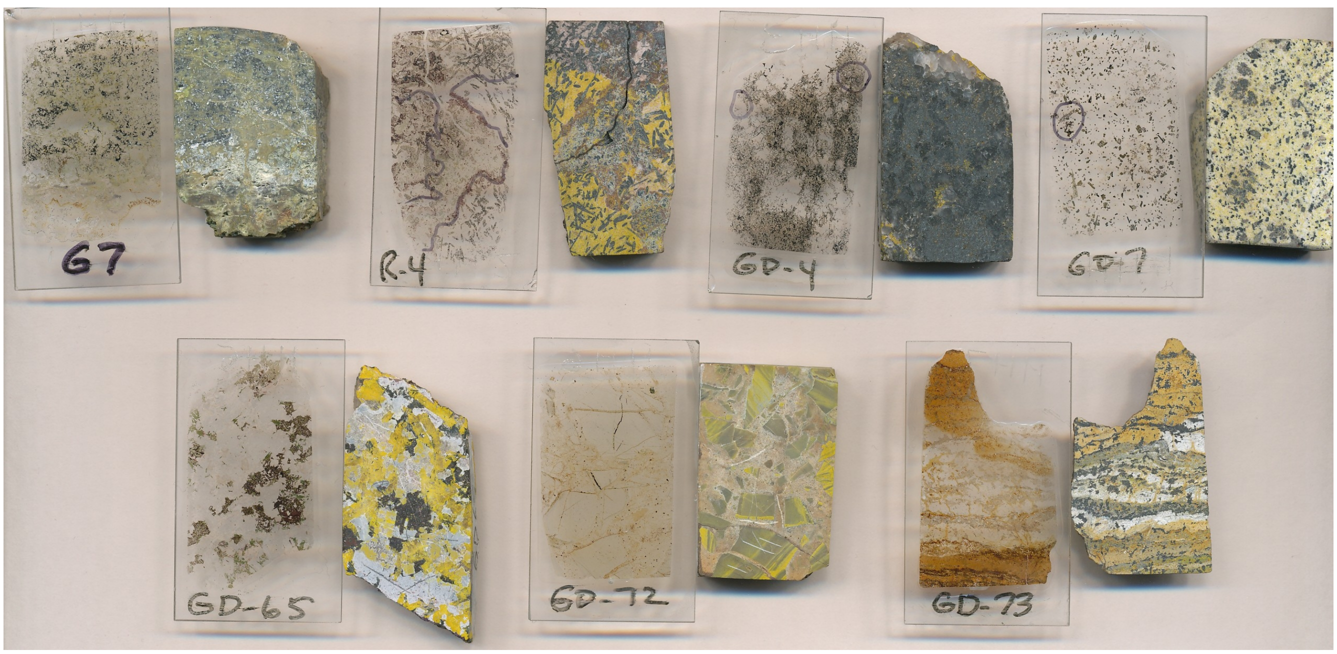
Figure 2a	R	4	Sericite-albite altered fenite
Figure 3	GD	4	Quartz-albite-hematite-monazite-xenotime cataclasite
Figure 4	GD	7	Fenite
Figure 5	GD	65	Nepheline syenite
Figure 6	GD	72	Cataclasite
Figure 7	GD	73	Cataclasite



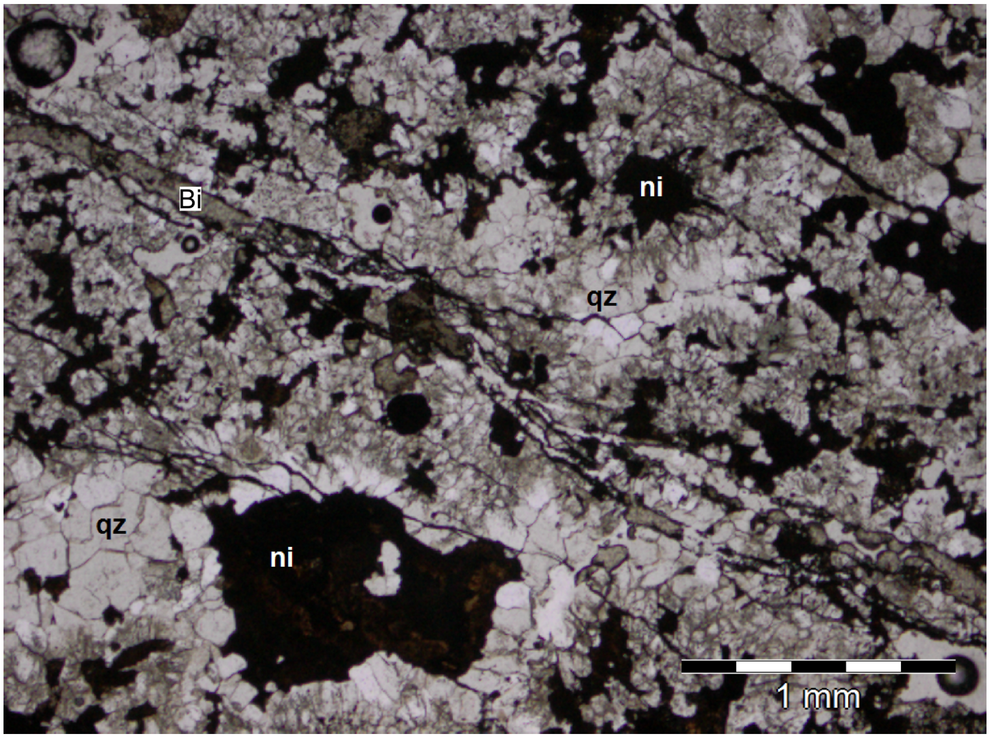


Figure 1: Quartz-niccolite granofels - Photomicrograph showing quartz (qz) and niccolite (ni) aggregate crosscut by bismuth (bi) and quartz veinlets. Plane-polarized transmitted light.

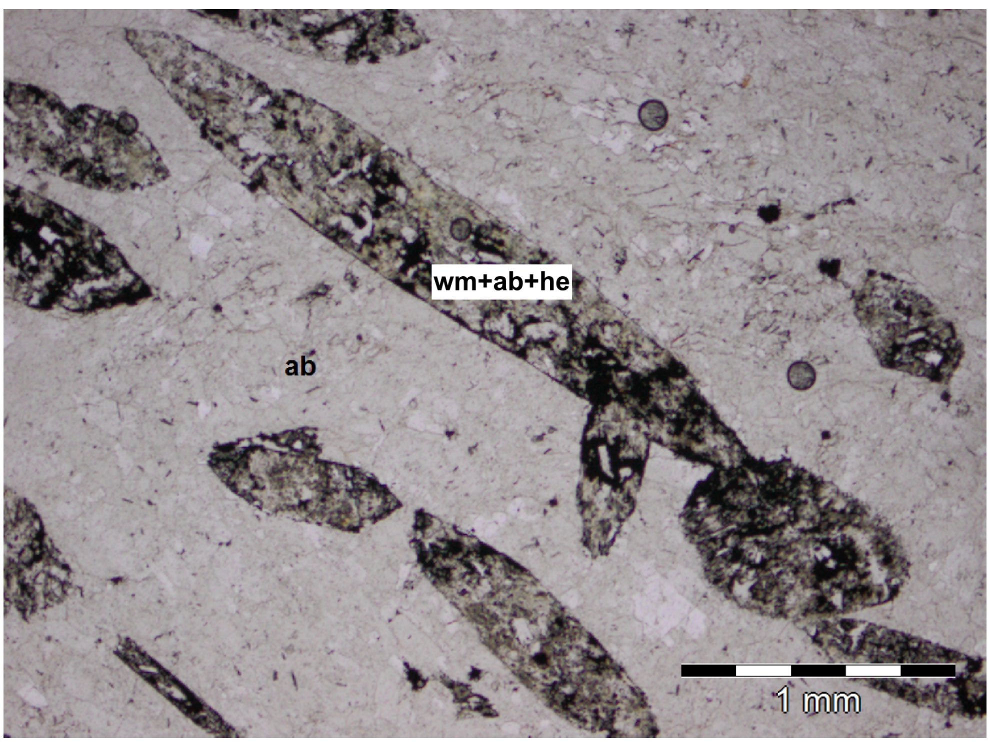


Figure 2: Sericite-albite altered fenite - Photomicrograph showing acicular porphyroblasts, possibly of aegirine completely replaced by white mica, albite and hematite (wm+ab+he). The pseudomorphosed porphyroblasts are immersed in a fine-grained matrix of albite (ab) and K-feldspar. Plane-polarized transmitted light.

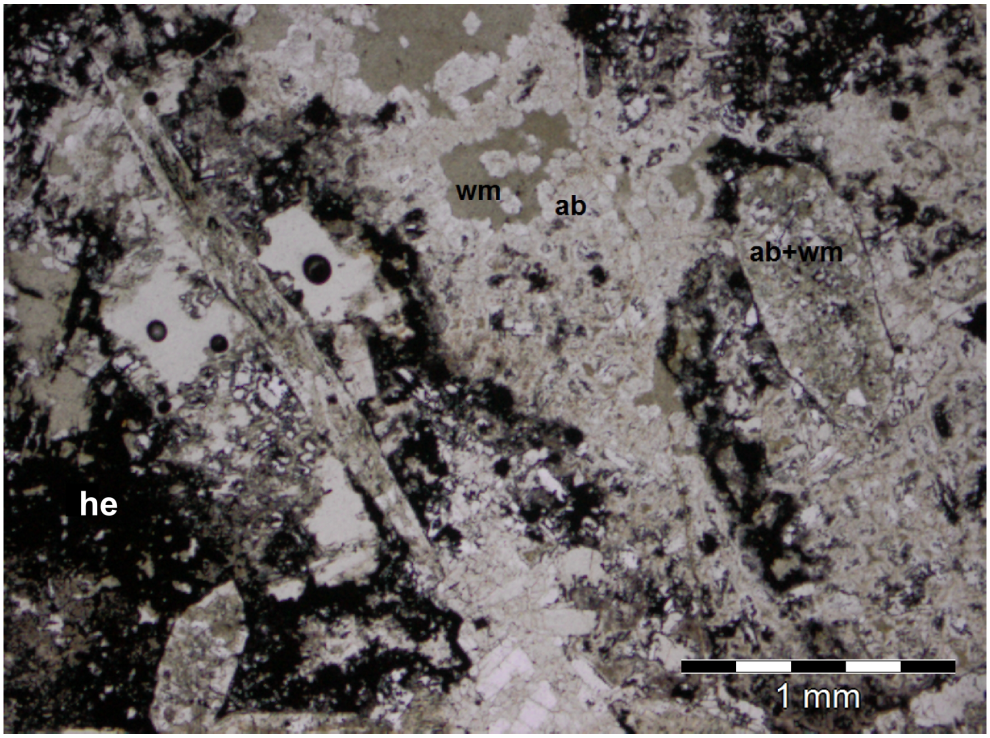


Figure 2a: Sericite-albite altered fenite - Photomicrograph detailing a more altered domain of sample R4. The acicular porphyroblasts, possibly of aegirine are replaced by white mica and albite and are immersed in a fine-grained matrix of albite (ab) and sericite (wm), hematite (he) is locally abundant. Plane-polarized transmitted light.

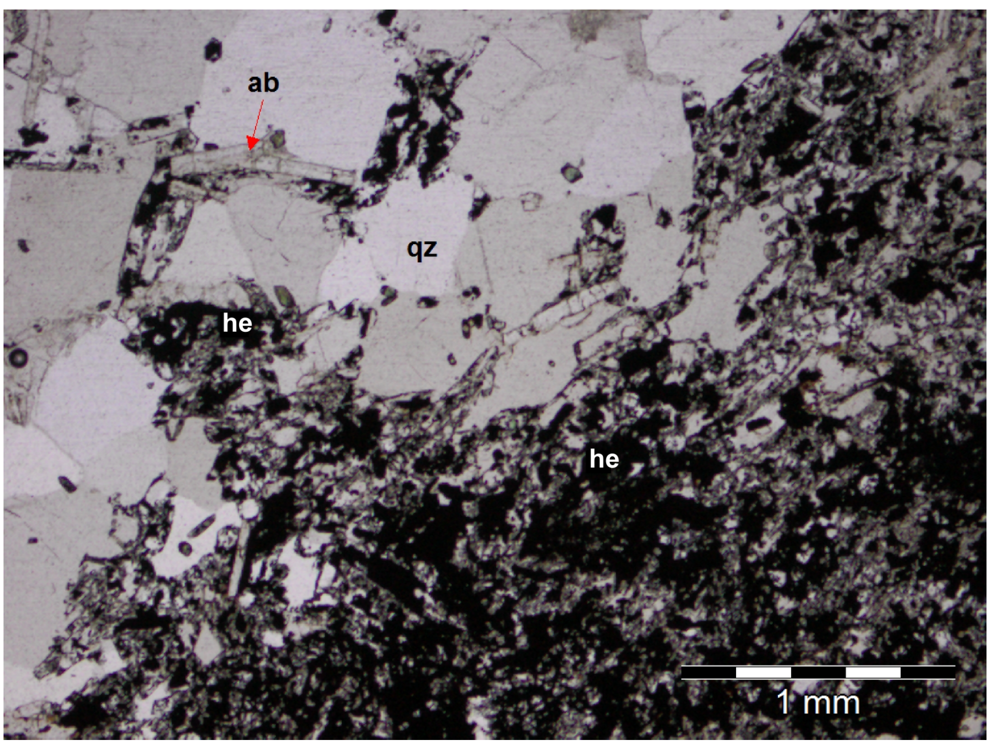


Figure 3: Quartz-albite-niccolite-monazite-xenotime cataclasite - Photomicrograph showing the cataclastic edge of a quartz domain (qz) infilled by hematite (he) and albite (ab). Plane-polarized transmitted light.

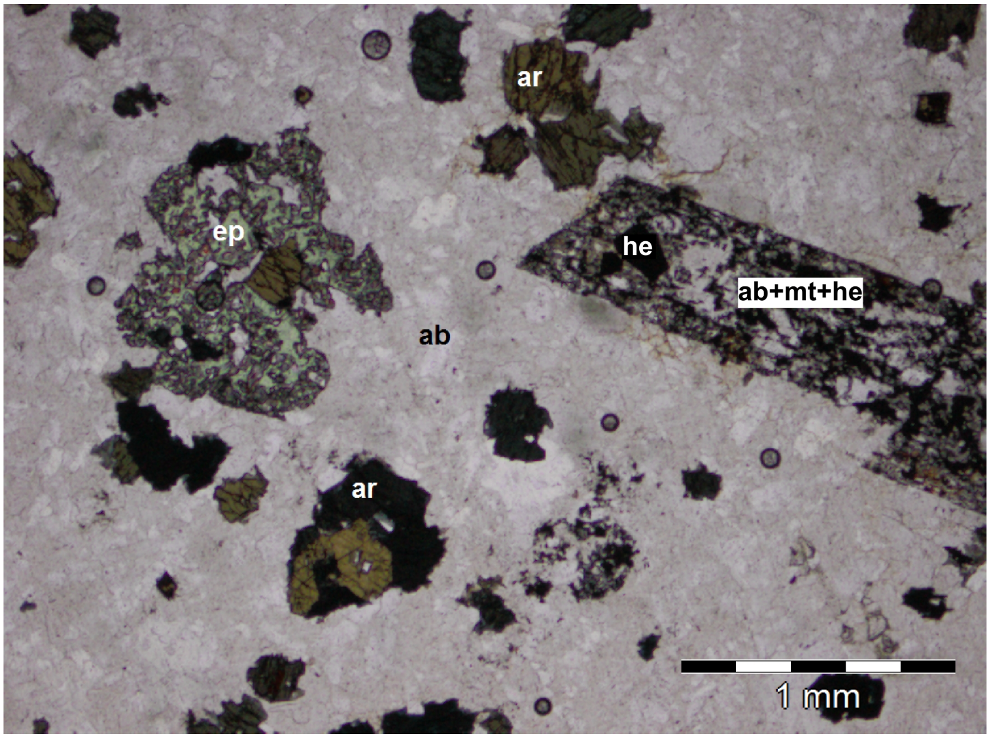


Figure 4: Fenite - Photomicrograph with porphyroblasts of arfvedsonite (ar), epidote (ep) and euhedral structural relicts, possibly after amphibole, constituted by albite+magnetite and hematite (ab+mt+he). The matrix is mostly composed of albite (ab). Plane-polarized transmitted light.

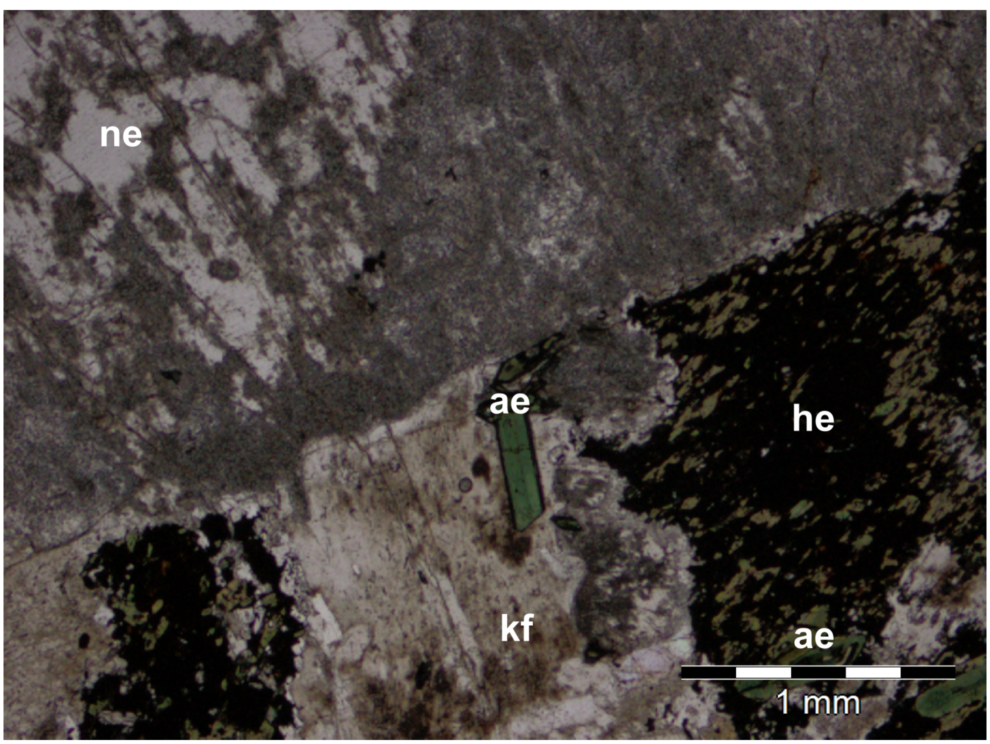


Figure 5: Nepheline syenite - Photomicrograph showing partially altered nepheline (ne), K-feldspar (kf) and euhedral crystals of aegirine (ae). Aegirine is locally intergrown with hematite (he). Plane-polarized transmitted light.

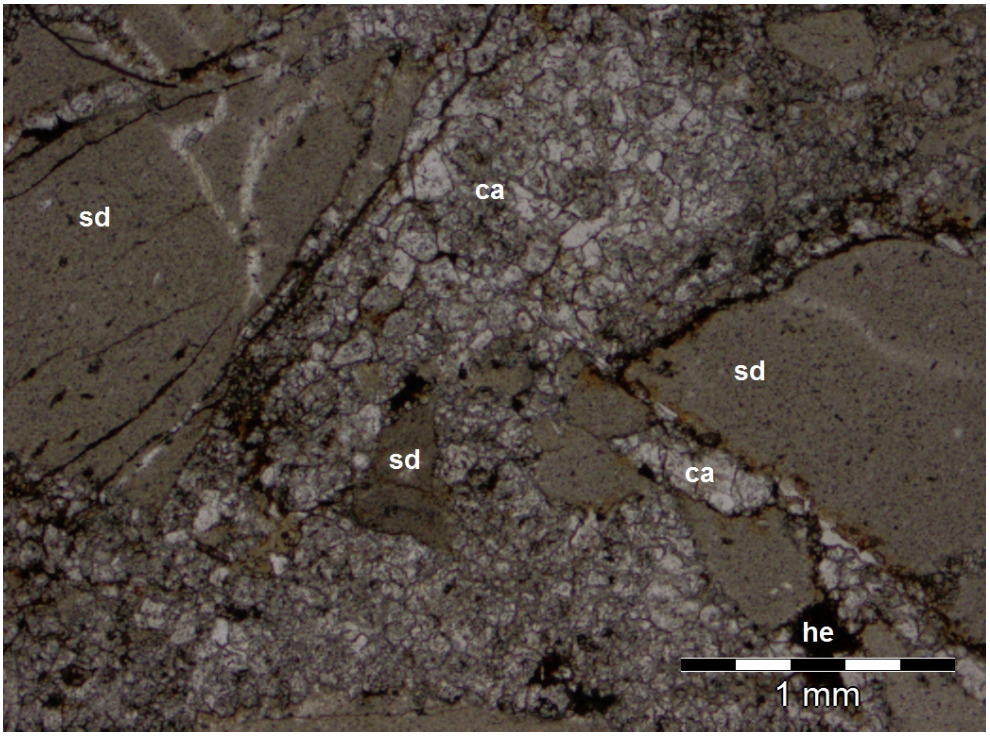


Figure 6: Cataclasite - Photomicrograph showing a cataclastic microstructure with fragments of sandstone (sd) immersed in a matrix of calcite (ca), limonite and hematite (he). Plane-polarized transmitted light.

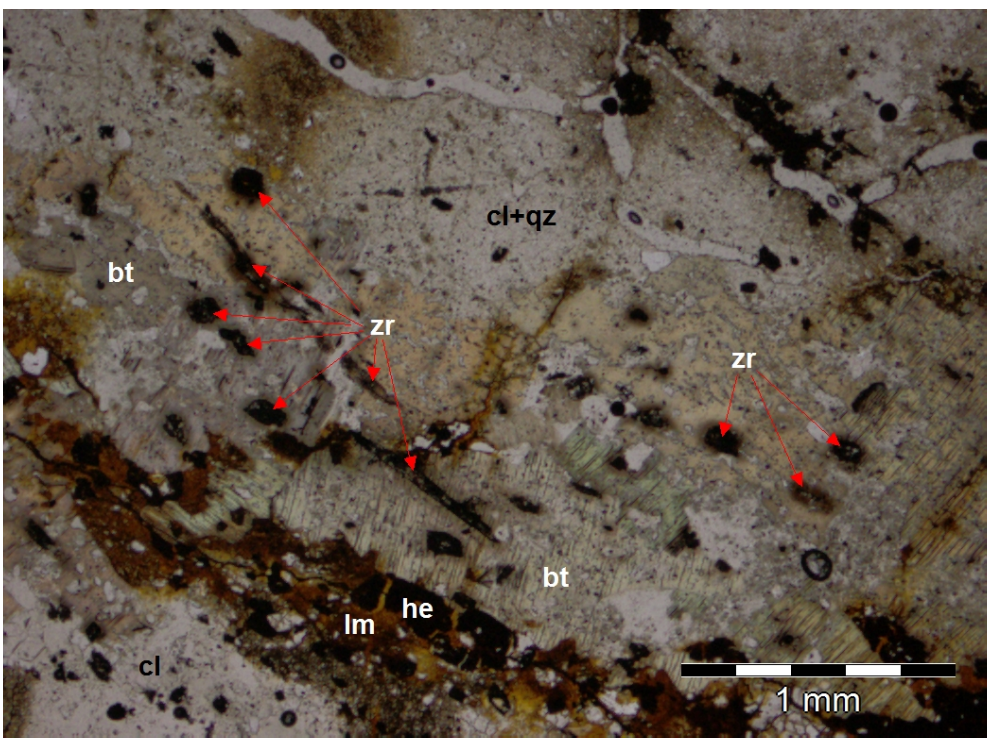


Figure 7: Cataclasite - Photomicrograph showing a layer made up of Ti-poor biotite (bt) with abundant zircon(?) (zr). The biotite-rich domain lays between a fine-grained clay+quartz domain (cl+qz), at the top of the photomicrograph and a hematite (he) +limonite (lm) domain. A clay-rich domain (cl) at the lower left of the photomicrograph. Plane-polarized transmitted light.