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REPORT 2007RR01

MINERAL WEATHERING IN RED DOG SOILS

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MINERAL WEATHERING IN RED DOG SOILS

SUMMARY

Mineral weathering in soils collected in the vicinity of Red Dog Operations in 2005 was studied. Analytical techniques were used to identify lead and zinc-containing minerals. Mineral weathering was determined using microscopic techniques.

Lead and zinc were detected in surface and sub-surface samples close to the mine and mill. The zinc was concentrated in the fine fraction in this sample. The lead and zinc distribution followed that of the mass fraction in samples some distance from the mine and mill. The main forms of lead and zinc identified in the soils were galena and sphalerite. The presence of anglesite and plumbojarosite indicated galena weathering had occurred. Evidence for sphalerite weathering was less clear as most weathering products are expected to be soluble. Detailed SEM analysis identified mineralized rims on galena. Lead chloride, lead sulfate, hematite and iron hydroxide were identified in the rimming around galena particles. Hematite rimming on a sphalerite particle also indicated weathering was occurring. Analysis of these samples was complicated by the low concentration of the mineral particles in the samples obtained some distance away from the mine and mill.

Mineral oxidation is likely to occur around the mine and mill. Naturally occurring mitigation mechanisms, such as sequestration by soils or natural buffering, were not investigated in this study. The impact of metals leaching on the tundra ecology should be investigated in the future.

BACKGROUND

The Red Dog mine is located in the DeLong Mountains in the Western Brooks Range. The Red Dog mine has been in operation since late 1989. The zinc and lead containing ore is upgraded to produce lead and zinc concentrates. On-going work at the mine site has resulted in significant decreases in the release of zinc and lead-containing particulates to the environment.

Teck Cominco Alaska Red Dog mine conducted soil and vegetation investigations in 2003 and 2004 to evaluate the extent of the lead and zinc deposition. Emission inventories and air dispersion models were developed and are being used to understand historic and existing fugitive particulate deposition. The data collected is intended to provide the State and Teck Cominco with information pertaining to the relative contributions of different sources of fugitive particulates.

Attention has been focused previously on quantifying fugitive particulates and evaluating sources. The potential of the particulates to affect local vegetation has not been studied in detail, but is planned in 2006. High lead to zinc ratios were observed in soils sampled around the Red Dog mill, crushing and tailings areas. The higher lead to zinc ratios in the soil samples compared to the ore suggests selective sphalerite oxidation is occurring, possibly through a galvanic mechanism. One result of the mineral oxidation is release of metal ions to and a change in soil pH in the surrounding environment. The presence of weathering in mineral particles is the focus of the present investigation. The potential for leaching is explored in a subsequent report [Jensen et al., 2006].

OBJECTIVES

The proposed study is designed to answer the following questions:

- What form is the lead and zinc in the tundra surrounding Red Dog Mine and Mill Operations?
- Is there any evidence for weathering in the mineral grains?

DETAILS

Sampling

Soils were collected from two locations. Soil samples were collected from areas of the tundra around the mine and mill where phytotoxic effects were observed in the vegetation (Triangle sample). Another set of soil samples was collected in the same manner from the tundra at a distance of 3.5 km from the mine and mill where no phytotoxic effects were observed in the vegetation (TT3). A sample was also collected from outside the gyratory crusher building located adjacent to the mine and mill. This sample represents the freshest particulates that could be deposited onto the tundra and could be used as a reference sample. Sample locations are given in Figure 1.

The samples were collected at two depths:

- A "surface" sample representing the top 1 inch of soil was collected. The "surface" samples contain potentially 90% vegetation/detritus and 10% inorganics.
- A second sub-surface sample was collected one foot below the surface. The sub-surface sample represents the naturally mineralized soil; approximately 90% clay and other inorganics. The sub-surface was referred to as "mineralized" by mine operations.

The Triangle, TT3 and gyrocrusher dust were sampled on August 21, August 23 and August 26 2005, respectively. Samples arrived sealed in a cooler at the Applied Technology and Research Group on October 12, 2005. These samples were used for SEM analysis, some preliminary leaching work and humidity cell testing.

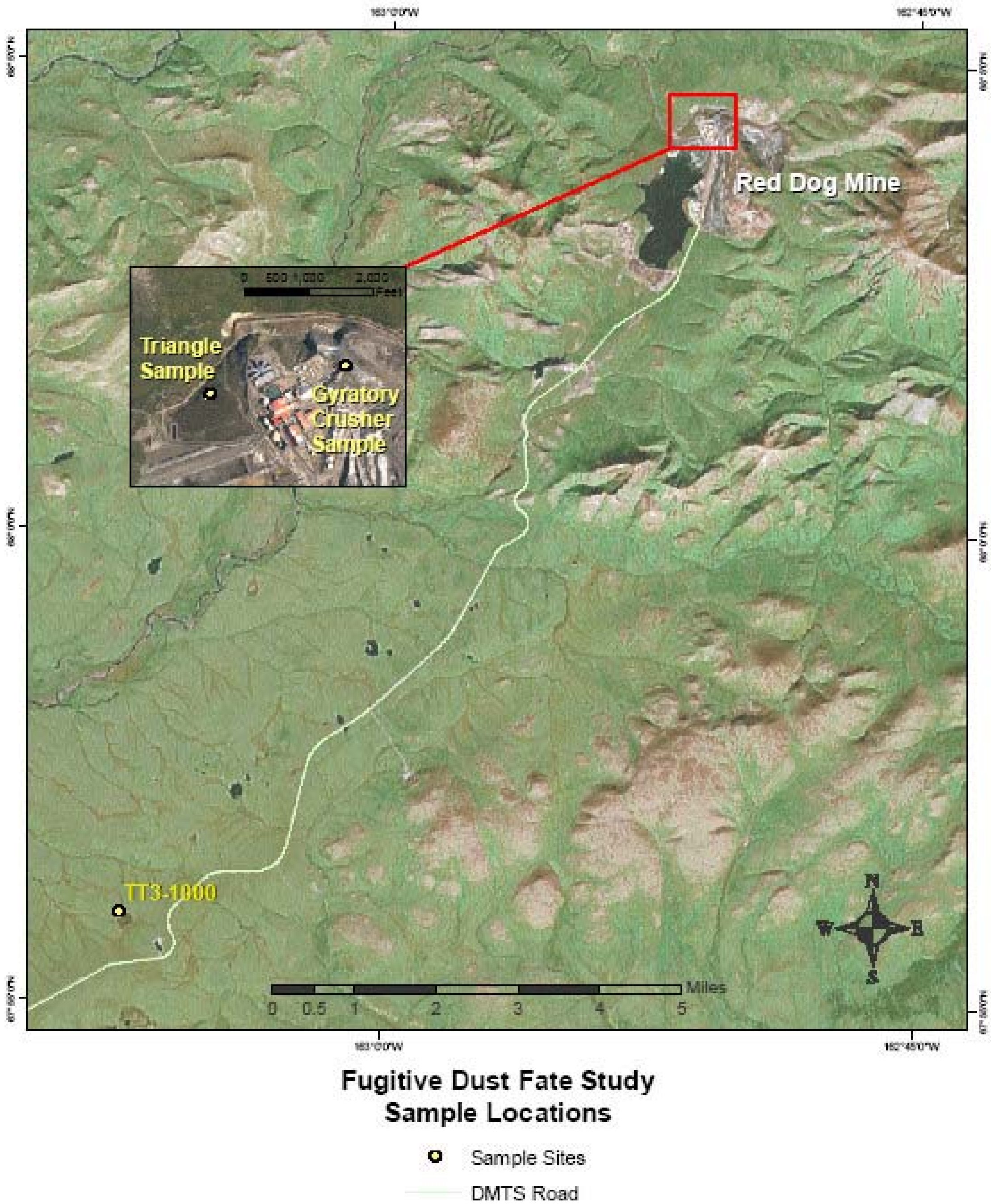

Figure 1. Sampling locations used in the study.

Methodology

Tundra soils were collected from the site and separated into fine and coarse size fractions by screening at 75 µm. The mineral grains present in the different fractions were then identified using scanning electron microscopy (SEM). Mineral phases were then separated from the organic components by centrifuging the samples in water. Quantitative mineral identification used a mineral liberation analyzer (MLA). The work was mainly done at Teck Cominco's Applied Research and Technology (ART) group in Trail, British Columbia, an independent facility to Red Dog Operations. Microscopic work using the MLA and initial SEM studies were also done at ART. Subsequent SEM analyses were done at the University of British Columbia. A schematic of the testing is given in Figure 2.

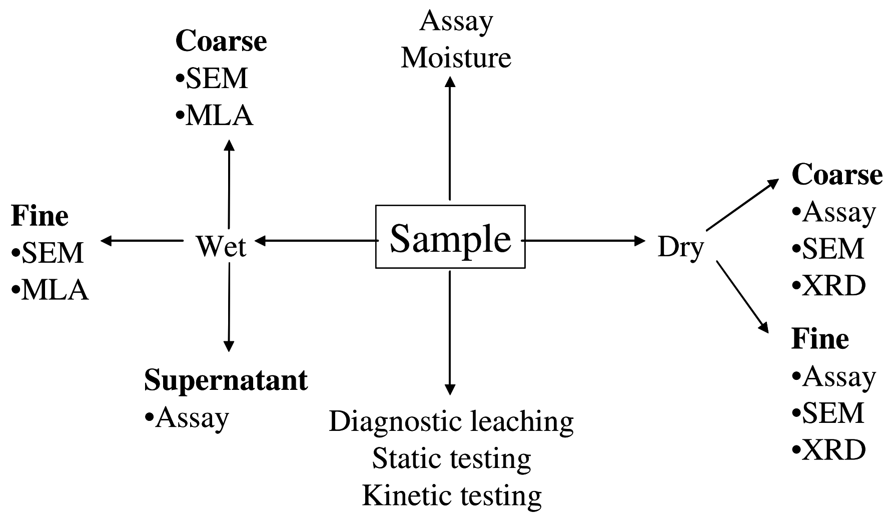

Figure 2. Schematic of soil weathering investigation.

Results

Sample characterization

Optical images of the Triangle and TT3 samples are given in Figures 3 and 4, respectively. The presence of organic matter samples such as the TT3 surface is very evident. The organic nature of the sample complicated sample preparation of the coarse fraction for assaying.

Figure 3. Optical images of Triangle samples (surface left, sub-surface right)

Figure 4. Images of TT3 minerals (surface left, sub-surface right)

Assay and sizing information is given in Table 1. Assay information from the head sample and fine sample (< 75 µm) was used to generate data for the coarse (>75 µm) sample. The coarse sample was not assayed due to difficulties in processing the sample. The lead and zinc concentrations of the TT3 surface sample was below the detection limit (<0.01%) due to difficulties in obtaining a sufficient mass of sample from the high-organic containing soils.

The mass distribution between coarse and fine fraction was split approximately 60% coarse and 40% fine in the Triangle samples. Lead and zinc were concentrated in the fine fraction in the Triangle surface samples. Similar results were also seen in the gyratory crusher sample.

The distribution of lead and zinc in the sub-surface samples between coarse and fine fractions was similar to the mass component in these fractions. The iron distribution was similar to the mass distribution for all samples. These results indicate that these elements were evenly distributed within the sample.

The lead to zinc ratios in the Triangle and TT3 samples are higher than that of the crusher dust. This result may indicate weathering processes are occurring that alter the ratio of lead to zinc.

Table 1. Size assay data and distribution for Red Dog soil samples.

Column	Mass (%)	Assays (%)			Distribution (%)		
		Iron	Lead	Zinc	Iron	Lead	Zinc
Crusher							
Fine	67	7.0	5.2	21.9	60	74	73
Coarse	33	9.4	3.7	16.4	40	26	27
Total	100	7.8	4.7	20.1	100	100	100
Triangle	**Surface**						
Fine	37	4.0	2.2	1.2	35	43	76
Coarse	63	4.3	1.7	0.2	65	57	24
Total	100	4.2	1.9	0.6	100	100	100
Triangle	**Sub-surface**						
Fine	32	4.1	0.11	0.09	30	39	36
Coarse	68	4.5	0.08	0.08	70	61	64
Total	100	4.4	0.09	0.08	100	100	100
TT3	**Surface**						
Fine	2	-	-	-	-	-	-
Coarse	98	-	-	-	-	-	-
Total	100	0.17	<0.01	<0.01	-	-	-
TT3	**Sub-surface**						
Fine	16	2.0	0.004	0.002	16	10	15
Coarse	84	2.0	0.006	0.002	84	90	85
Total	100	2.0	0.006	0.002	100	100	100

SEM particle analysis

SEM is used for mineral identification and semi-quantification. The magnification is up to 10,000 times. Visual inspection of the minerals was attempted to identify mineral grains that would allow the degree of weathering to be determined. Similar analyses have been done in the past using these techniques [USGS, 1999]. Micrographs not presented in the report are collated in the appendix.

Energy dispersive analysis (EDA) can be used to identify and semi-quantify elements present. The detection limit of EDA is approximately 0.5%. The Triangle and TT3 samples were mounted as received into the SEM to preserve the sample characteristics. These micrographs are given in Figures 3 and 4. The SEM micrograph of a TT3 surface weathered lead-containing grain is given in Figure 5.

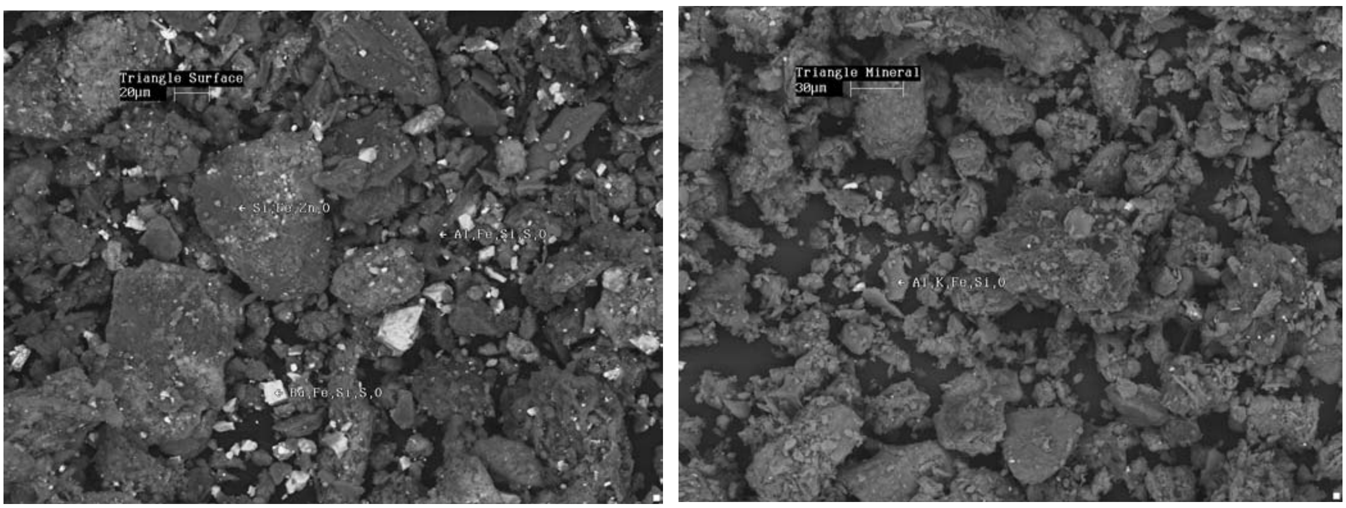

Figure 3. SEM images for the Triangle Minerals (surface left, sub-surface right)

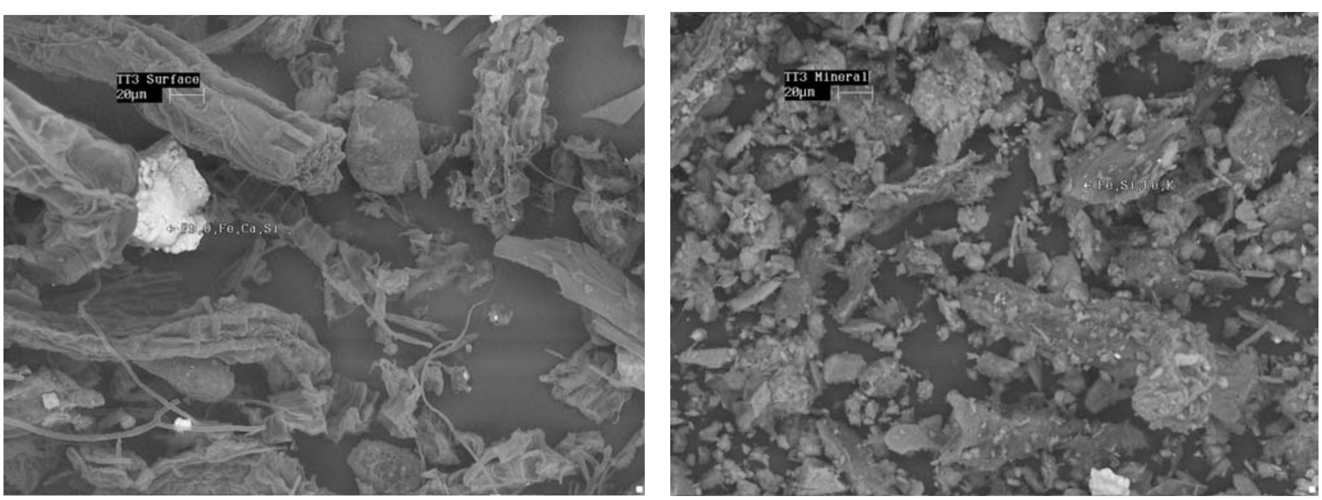

Figure 4. SEM images for the TT3 Minerals (surface left, sub-surface right)

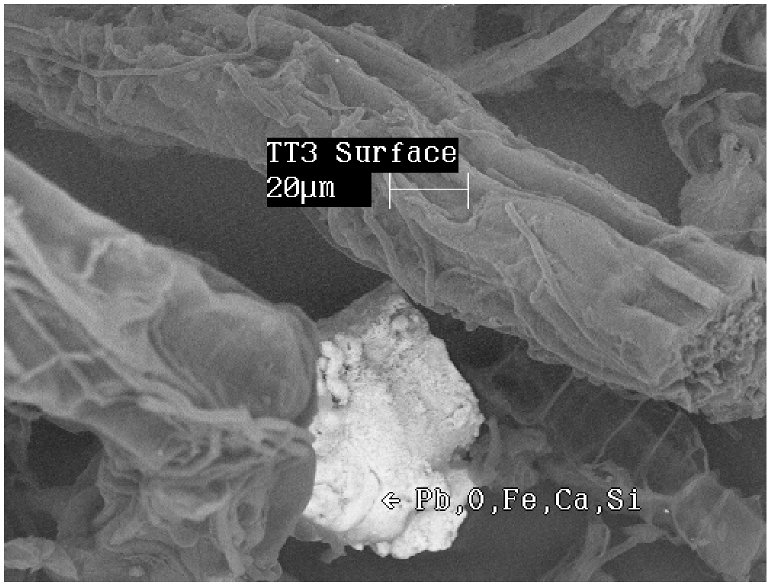

Figure 5. SEM detailed image for the TT3 surface indicating a lead-containing grain.

The lead-containing mineral grain identified in the TT3 surface sample (Figure 5) suggested some weathering had occurred. The grain does not exhibit pristine cleavage planes observed in the crusher dust sample. Zinc-containing mineral grains were not identified in this work.

SEM weathering analysis

SEM is also useful in the identification of weathering products. A second Triangle sample was obtained in 2006 [Jensen et al, 2006] for further testing. The Triangle samples were obtained and washed in water to release the mineral particles. These mineral particles were collected and smear mounted by Bob More at Global Discovery Laboratories in Vancouver. The SEM investigation used an instrument located at UBC. Additional micrographs are presented in the Appendix.

A lead-containing mineral grain is given in Figure 6 for a Triangle surface sample. The presence of riming on the galena grain is evident. The rim material contains lead chloride, lead sulfate, hematite and iron hydroxide. The grain shows fine-grained intergrowth of the lead sulfate, hematite and iron hydroxide.

Other evidence of weathering in other mineral grains from a Triangle surface sample is given in Figure 7. Unweathered barite was observed in the sample. Weathered galena was observed with the presence of lead sulfate and hematite. Secondary lead sulfate and hematite rims and impregnations were also observed in quartz as indicated in Figure 7.

Some fresh sphalerite was observed in the Triangle surface samples. The presence of secondary mineralization on sphalerite as a result of weathering is more difficult to determine as many weathering products are soluble. Some sphalerite grains were observed with a hematite rim, indicating some weathering of the sphalerite grains had occurred.

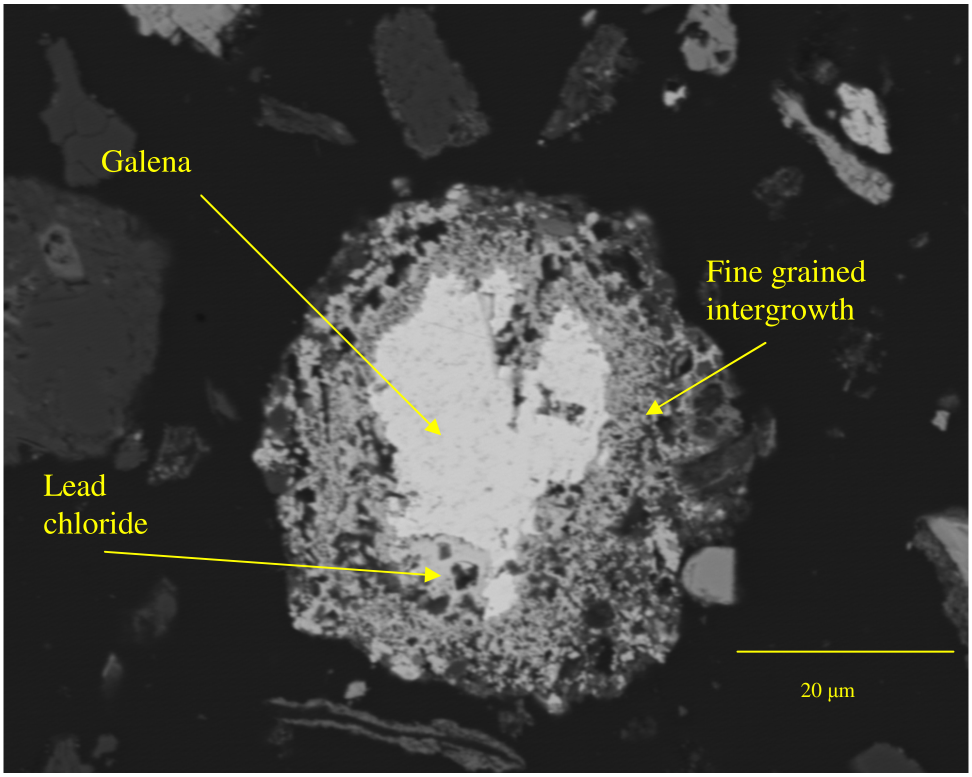

Figure 6.Weathered galena grain from a Triangle surface sample.

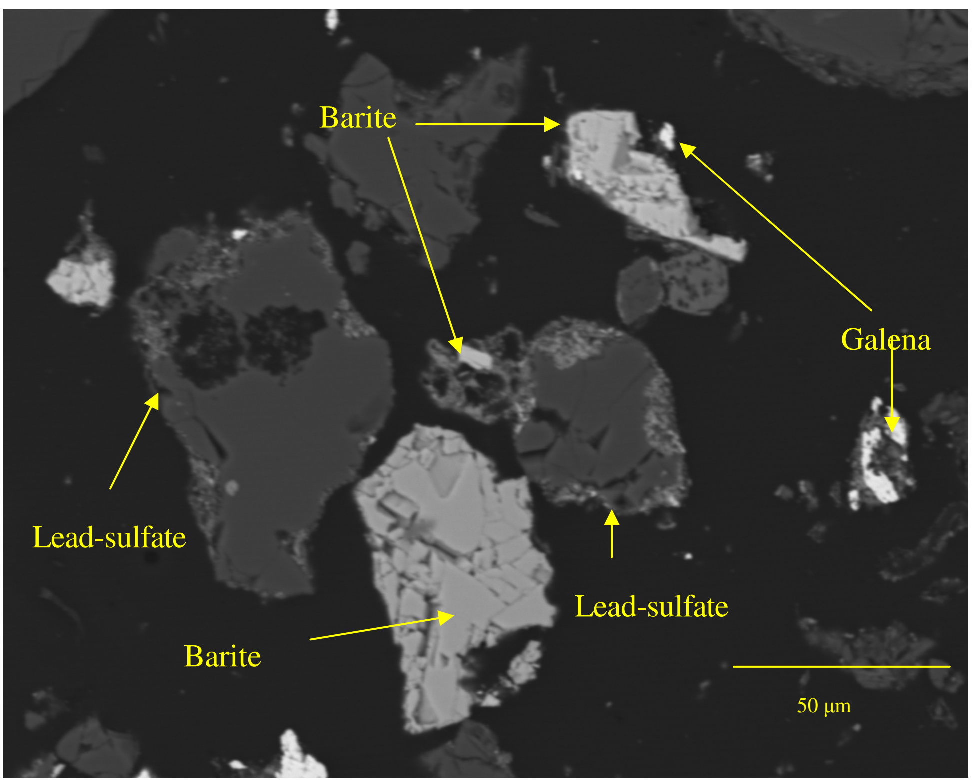

Figure 7.Weathered particles from a Triangle surface sample.

Unweathered galena particles were observed in the Triangle sub-surface sample. Unweathered barite was also observed in the Triangle sub-surface sample. Sphalerite was not observed in the SEM investigation. The absence of mineral weathering in the Triangle sub-surface sample is significant, suggesting further oxidation of the mineral grains does not occur once the mineral particles migrate to the sub-surface.

MLA analysis

The MLA system combines an SEM, energy dispersive spectral (EDS) X-ray analysis and a backscatter electron (BSE) detector with image analysis. The MLA is capable of automatically discriminating between mineral/phases based on the mean atomic number (BSE brightness), elemental composition (X-ray analysis) and a suite of reference samples. The MLA is capable of generating quantitative mineral identification.

The mineral concentration in the soil samples was low. Samples were pretreated with water before analysis and then centrifuged to isolate a fraction richer in the denser mineral components. Samples for the MLA are mounted into epoxy and presented as thin sections in the instrument. Carbon cannot be identified as it cannot be differentiated from the epoxy in the mount.

Mineral grains identified in the Triangle surface samples by the MLA are given in Figure 8. Selected mineral grains containing anglesite were associated with galena and plumbojarosite in some cases. Mineral grains containing sphalerite are mainly associated with other sphalerite forms. Locked particles such as galena-sphalerite composites were not identified. The sphalerite-containing mineral grains show complicated voids, suggesting some weathering processes could have been present.

The MLA analysis of the samples is given in Table 3. The percentages were determined as concentrations of all the minerals identified in the sample.

Table 3. Mineralization identified using MLA.

Mineral	**Mineral assay (%)**			
	Triangle surface	Triangle sub-surface	TT3 surface	TT3 sub-surface
Quartz	40.1	40.1	48.3	64.8
Albite	30.6	44.9	34.1	26.3
Barite	11.3	0.3	2.3	0.01
Chlorite	7.9	10.3	4.8	5.3
Plagioclase	1.1	2.0	2.4	2.0
Galena	1.8	-	-	-
Plumbojarosite	3.8	0.15	0.2	-
Anglesite	0.09	-	-	-
Sphalerite	2.1	0.03	1.9	-

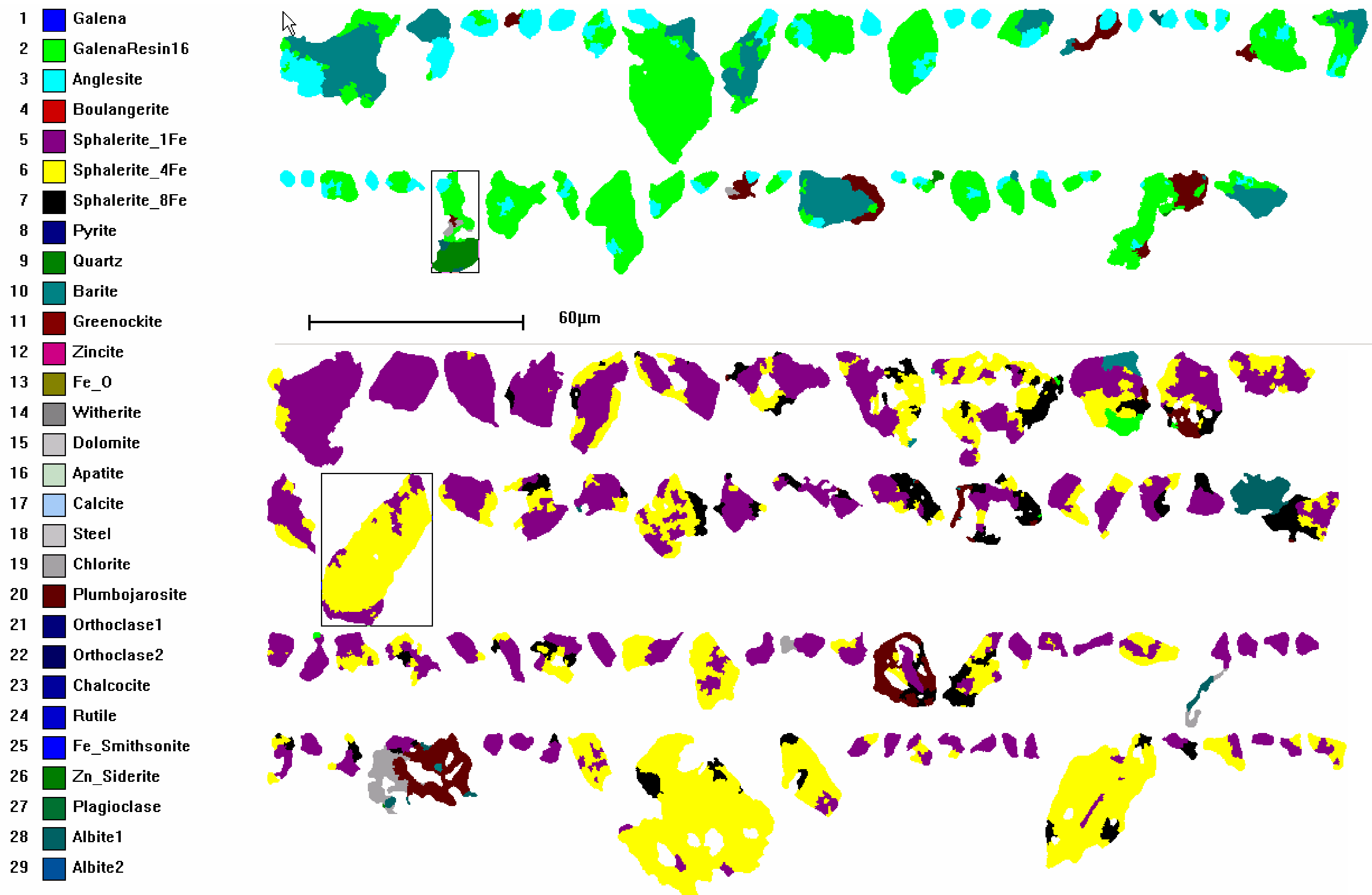

Figure 8. MLA images of minerals obtained from the TT3 surface sample

The major minerals identified in the samples were quartz, albite, barite and chlorite. Mineralization associated with zinc and lead was more difficult to determine. Galena was only identified in the Triangle surface, where the lead concentration was higher. Sphalerite mineralization was observed at low concentrations in the Triangle surface and TT3 surface samples. From these results the minerals associated with lead and zinc are mainly galena and sphalerite, respectively. Anglesite and plumbojarosite were also identified as weathered lead-containing minerals.

Galena was identified in the Triangle surface sample. The galena was mainly free (76%). The galena was also associated with barite ($BaSO_4$, 8.3%) and anglesite (3.1%). Barite is a minor constituent of Red Dog ore. The presence of lead and anglesite in association suggests weathering of the mineral grains is taking place. Sphalerite, where detected, was liberated in all samples.

CONCLUSIONS

The following conclusions can be drawn:

- Assay data indicate the lead concentrations in the Triangle regions close to the mine and mill are 1.9% and 0.09% for a surface and sub-surface sample, respectively. There is a possibility that galena in the sub-surface sample was contamination from the surface layer that occurred during sampling. The concentrations of surface and sub-surface zinc are 0.6% and 0.08%, respectively. The zinc is concentrated in the fine fraction in this sample. The lead concentration is lower at the TT3 sample (0.006%) and was not detected in the sub-surface sample.
- The main forms of lead and zinc identified in the soil samples by the MLA study were galena and sphalerite. Other minerals containing lead were anglesite and plumbojarosite, evidence of mineral weathering. The anglesite was largely associated with galena. Evidence for weathering products for sphalerite was not as clear, as oxidation products are likely to be water soluble.
- SEM investigations show evidence of galena weathering in the Triangle samples. Rimming of galena with layers of lead chloride, lead sulfate, hematite and iron hydroxide show some oxidative process occurring. Secondary lead sulfate and hematite rims were also identified on quartz grains. Some sphalerite grains were observed with a hematite rim, also indicating weathering.

RECOMMENDATIONS

The following recommendations are offered:

1. The results indicate weathering occurred by physical examination of mineral particles. The potential environmental impact of mineral weathering has not been determined. Leaching experiments will provide some insight into the potential effects of mineral weathering. Kinetic testing is also required to determine the potential effect of weathering on the tundra surrounding Red Dog mine and mill operations.

2. The environmental impact of this weathering has not been determined. A testing programme is required to determine the effects of the metal ion leaching on the environment surrounding Red Dog Operations. This process is already underway.

ACKNOWLEDGEMENTS

I wish to sincerely thank SJensen and SWalden for their many useful suggestions, extensive follow up work and review of this project. DBigras, RBlaskovich, HSittig, MWestphal and NMcKay were instrumental in collating and interpreting the SEM and MLA data at ART. A special thanks to MWestphal for additional SEM work at UBC to identify weathering products. Thanks also to JHarlamovs and DAshman for many helpful comments as well as for the Red Dog personnel for their support and in providing insights into the work. Finally thanks to CPicone for final report collation and issuing.

SIGNED:	**ENDORSED:**
______________________	______________________
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REFERENCES

Jensen, S. E., Brienne, S, H., 2007. Mineral Weathering in Red Dog Soils, Research Report 2007RR06, February 9.

USGS, 2003. The Natural Dispersal of Metals to the Environment in the Wulik River-Ikalukrok Creek Area, Western Brooks Range, Alaska, Fact Sheet 107-03, October.

APPENDIX

Red Dog SEM soil samples

Sample number XG0020061121 1353

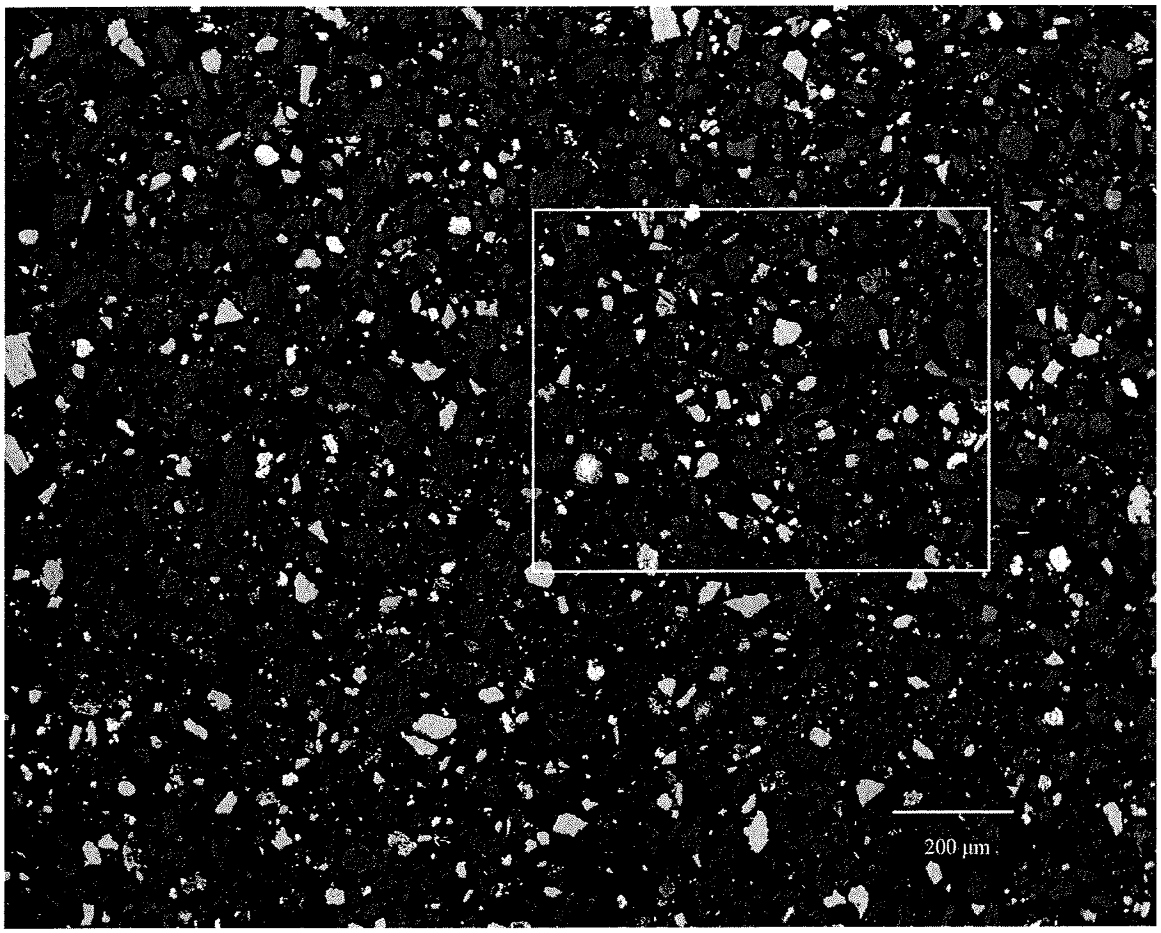

Figure 1 Overview – The bright grains are galena, the medium bright grains are sphalerite, barite, or pyrite, and the dark grains are quartz, feldspar, an amphibole (Fe-Mg silicate). The box indicates the area of Figure 2.

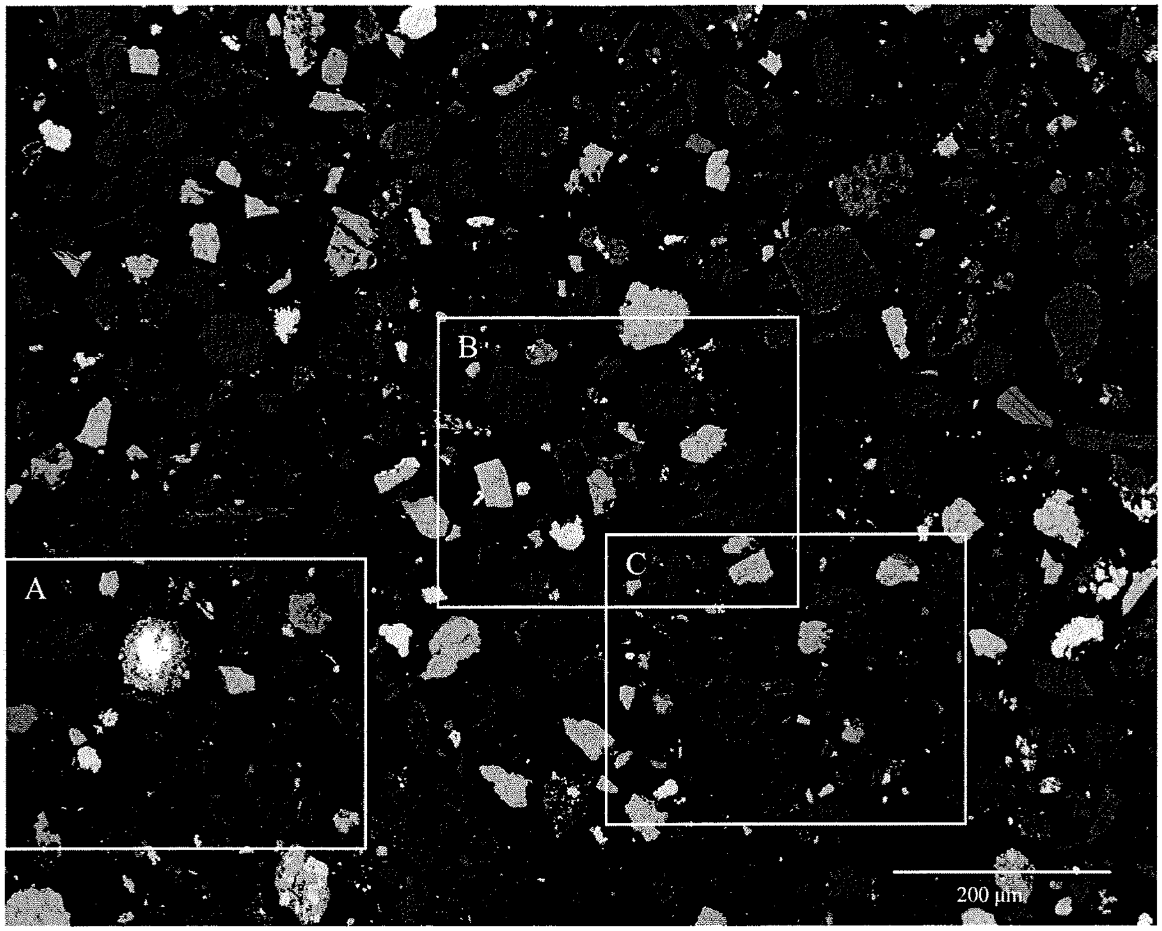

Figure 2 Further zoom in areas: A = Figure 3, B = Figure 5, C = Figure 7

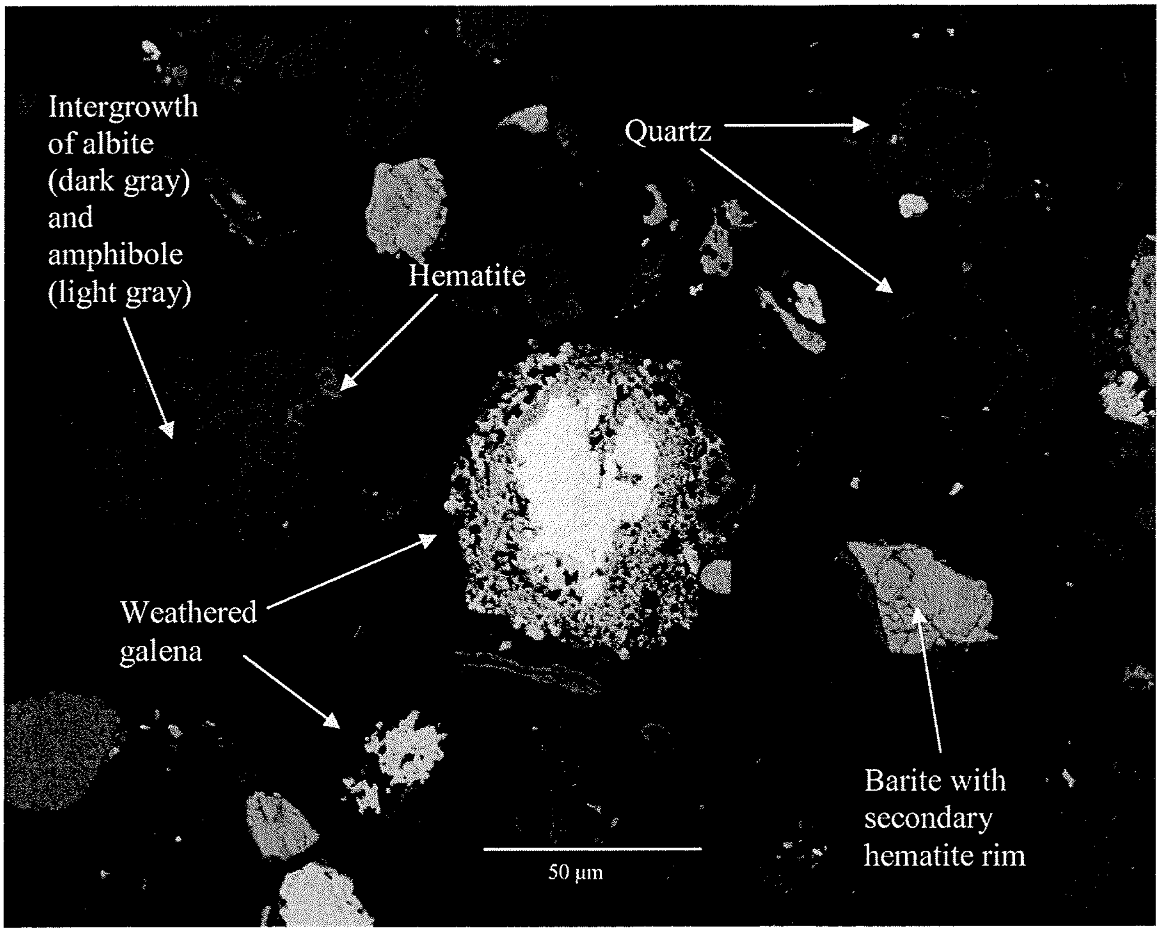

Figure 3 Grain of weathered galena (the lower one turned into lead-sulphate and dark iron-hydroxide, the large grain see figure 4) and a grain of barite with a secondary formed rim of hematite. The quartz shows some secondary lead- and iron- sulphates (lighter rims) (see also figure 6).

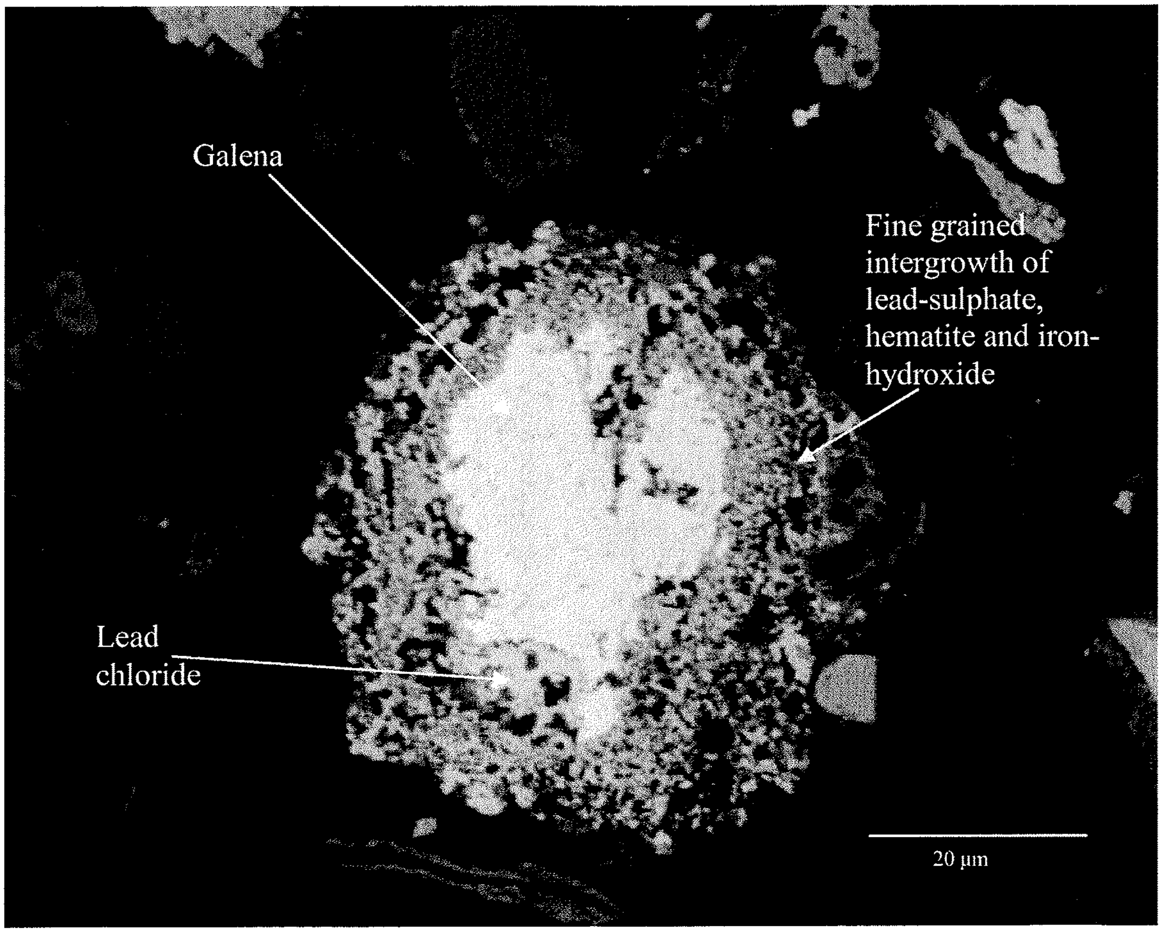

Figure 4 Weathered galena grain. The rim consists of lead chloride, lead sulphate, hematite, and iron hydroxide (decreasing brightness).

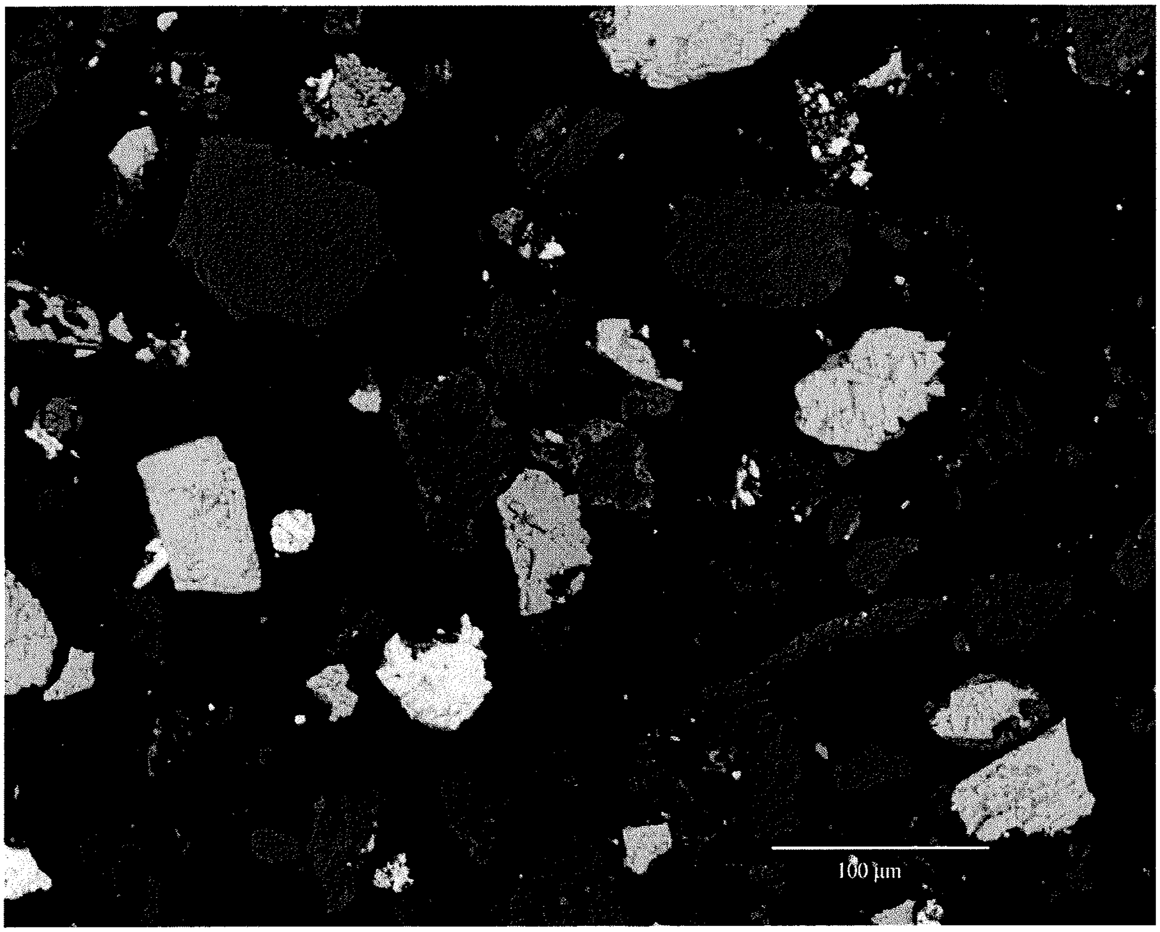

Figure 5 Area B

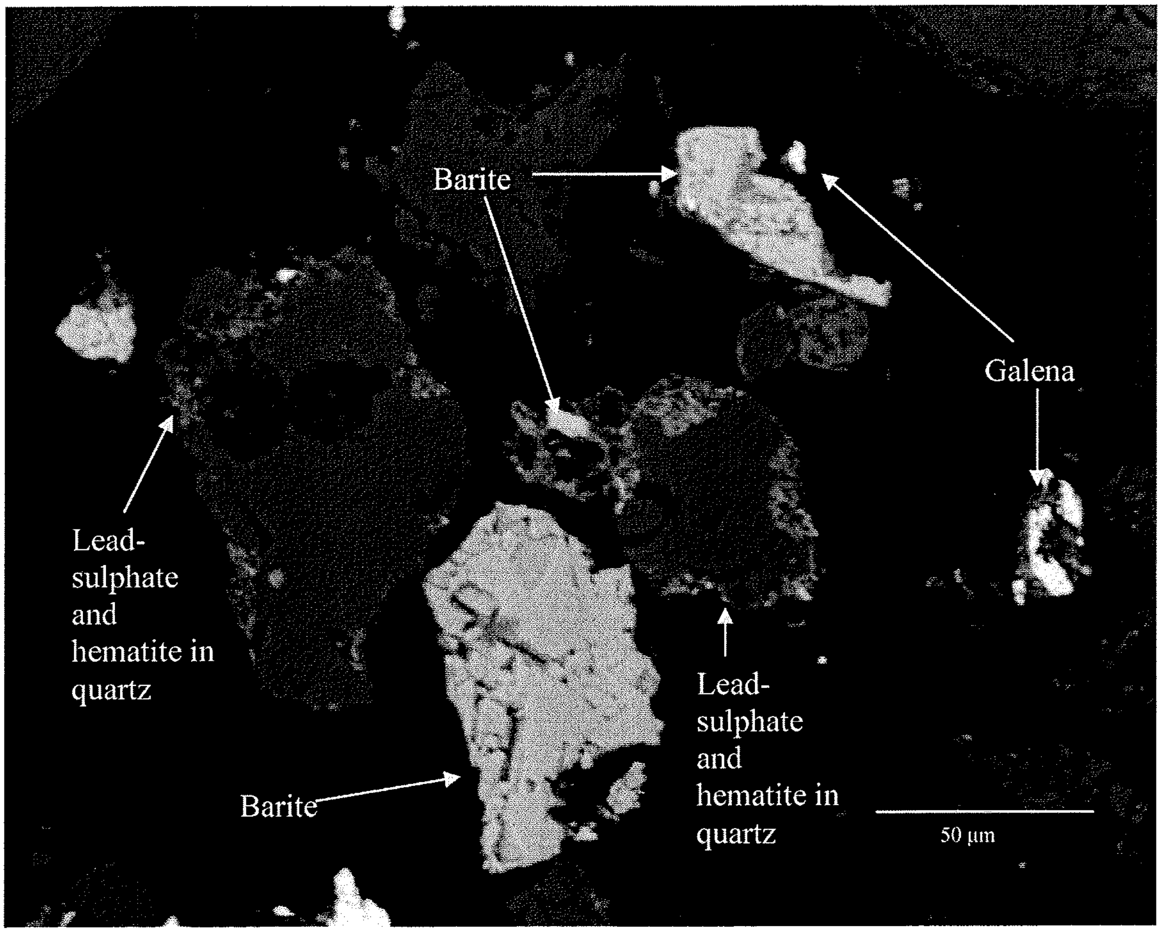

Figure 6 Unweathered barite, weathered galena with lead sulphate and hematite, and secondary lead-sulphate and hematite rims and impregnations.

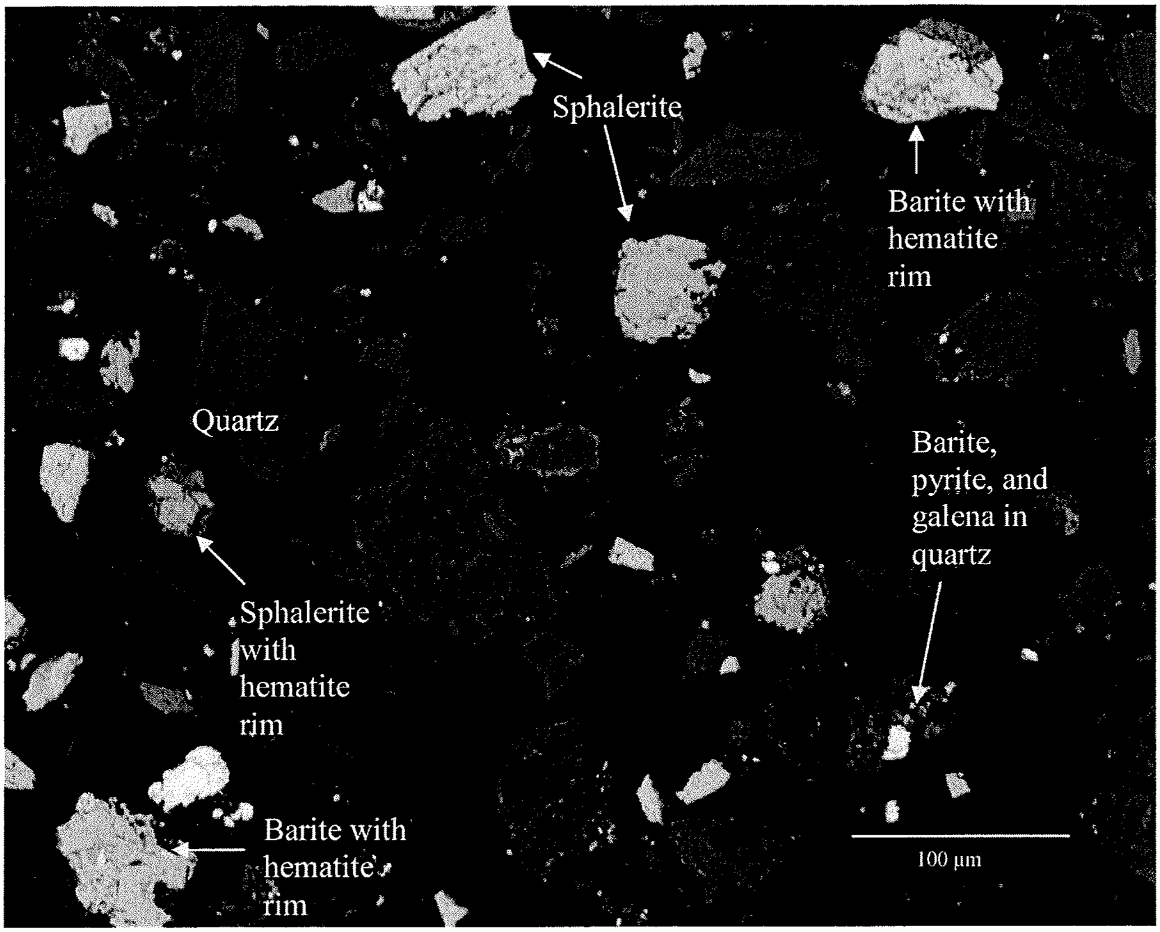

Figure 7 Fresh sphalerite and sphalerite with hematite rim, and barite and rimmed barite. The rimmed feldspar in the centre is shown in figure 8.

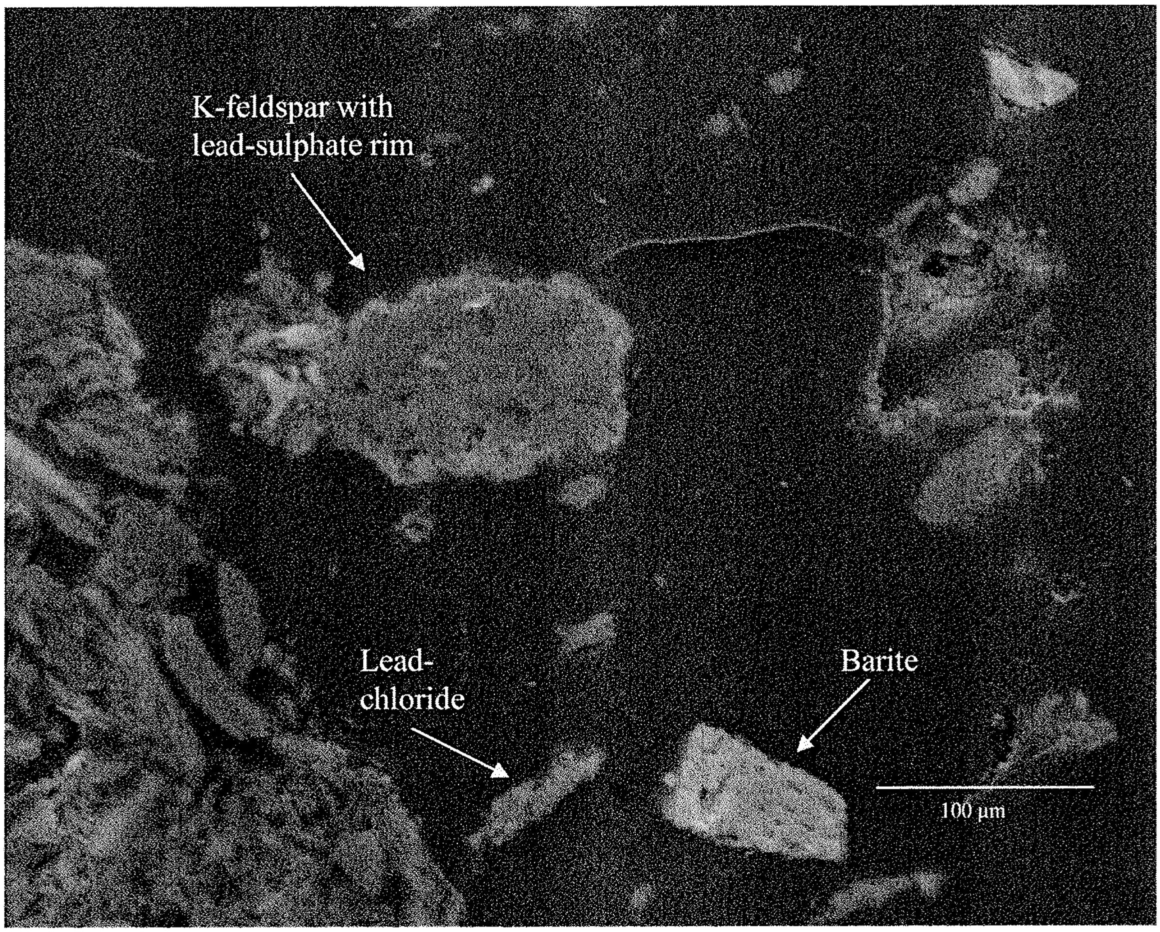

Figure 8 Lead-chloride, fresh barite, and a K-spar (potassium feldspar) rimmed and impregnated with lead-sulphate.

Sample number XG0020061121 1354

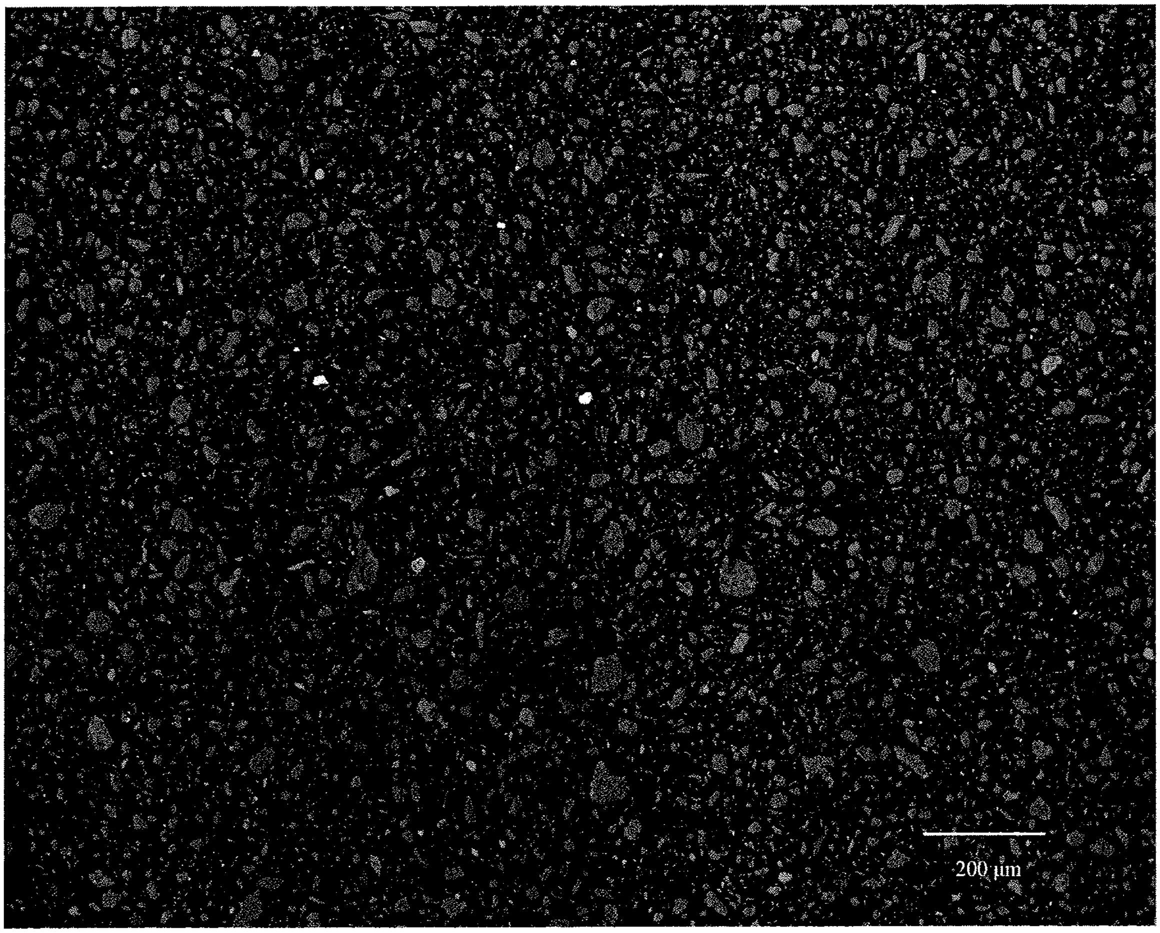

Figure 1 Overview – bright minerals are unweathered barite and galena – gray minerals are quarts, K-spar (potassium feldspar) and intergrown albite (sodium feldspar) and Na-amphibole (Fe-Mg silicate)

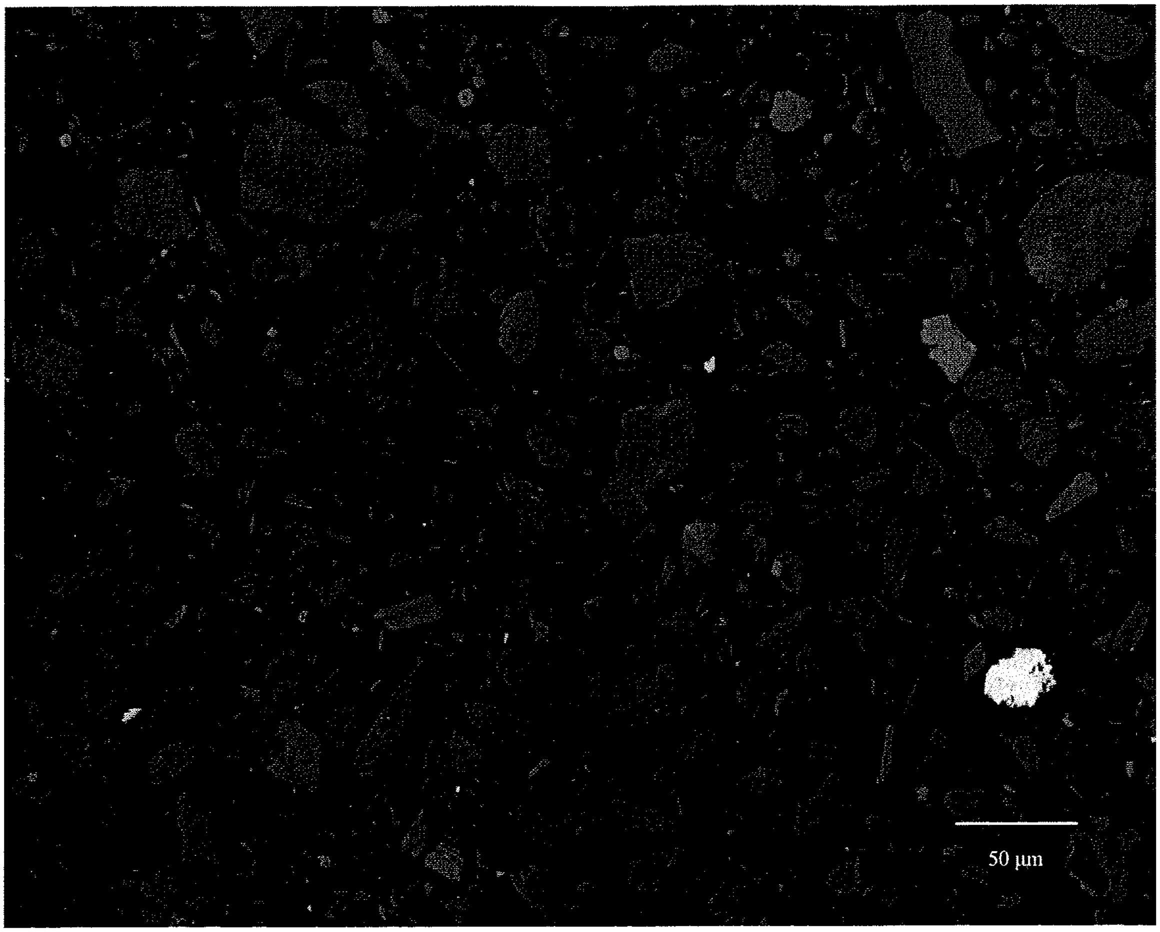

Figure 2 Unweathered galena (lower right corner) and two small barite grains (middle and lower right corner)

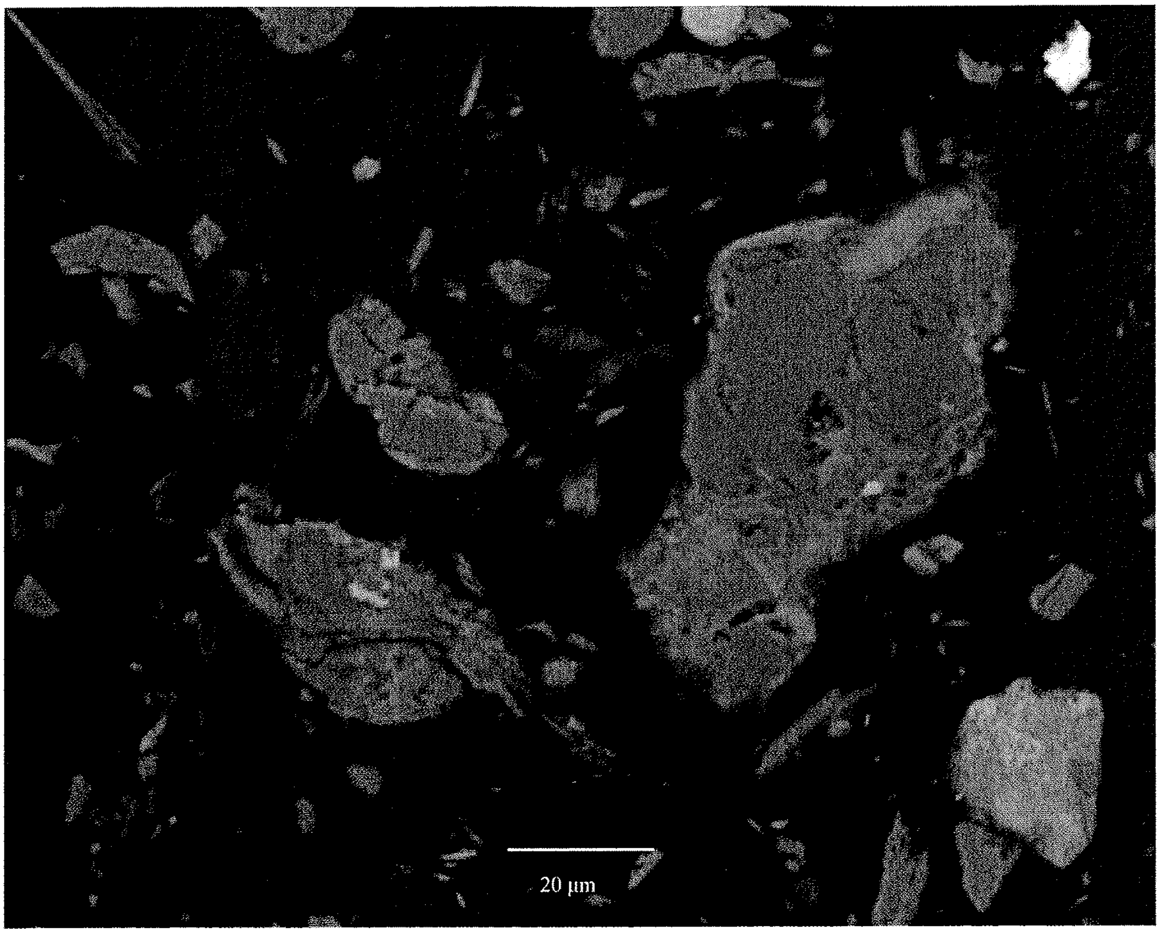

Figure 3 Unweathered barite (upper right) and intergrown albite (sodium feldspar) and Na-amphibole (Fe-Mg silicate) in the centre

Head Samples

Sample Type	Sample Date	Lot/Time	Descriptor	Type	Mass (g)	(%)	Assay Cd [%]	Cu [%]	Fe [%]	Pb [%]	S [%]	Zn [%]	Distribution Cd [%]	Cu [%]	Fe [%]	Pb [%]	S [%]	Zn [%]
TE99	20051121	5376	Gyro Crusher	<200 mesh	67.09	67.09	0.19	0.04	7	5.2	19.5	21.9	70.8	67.1	60.2	74.2	71.5	73.1
			Gyro Crusher	>200 mesh	32.91	32.91	0.16	0.04	9.43	3.68	15.85	16.43	29.2	32.9	39.8	25.8	28.5	26.9
TE99	20051121	5371	Gyro Crusher	Head	100	100	0.18	0.04	7.8	4.7	18.3	20.1	100.0	100.0	100.0	100.0	100.0	100.0
TE99	20051121	5377	Triangle Surface	<200 mesh	36.86	36.86	< 0.01	0.01	4	2.2	3.1	1.2			35.1	42.7	57.1	76.3
			Triangle Surface	>200 mesh	63.14	63.14			4.32	1.72	1.36	0.22			64.9	57.3	42.9	23.7
TE99	20051121	5372	Triangle Surface	Head	100	100	< 0.01	< 0.01	4.2	1.9	2	0.58			100.0	100.0	100.0	100.0
TE99	20051121	5378	Triangle Mineral	<200 mesh	31.75	31.75	< 0.01	< 0.01	4.1	0.11	0.16	0.09			29.6	38.8	42.3	35.7
			Triangle Mineral	>200 mesh	68.25	68.25			4.54	0.08	0.10	0.08			70.4	61.2	57.7	64.3
TE99	20051121	5373	Triangle Mineral	Head	100	100	< 0.01	< 0.01	4.4	0.09	0.12	0.08			100.0	100.0	100.0	100.0
TE99	20060511	376	TT3 Mineral	<200 mesh	15.59	15.59	0.00001	0.009	2.0	0.004	0.08	0.002	3.9	28.1	15.6	10.4	13.9	15.6
			TT3 Mineral	>200 mesh	84.41	84.41	0.00005	0.0043	2.00	0.0064	0.092	0.00200	96.1	71.9	84.4	89.6	86.1	84.4
TE99	20060511	375	TT3 Mineral	Head	100	100	0.00004	0.005	2.0	0.006	0.09	0.002	100.0	100.0	100.0	100.0	100.0	100.0
Insufficient sample for analysis			TT3 Surface	<200 mesh	0.58	2.32									0.0		0.0	
			TT3 Surface	>200 mesh	24.42	97.68									100.0		100.0	
TE99	20051121	5375	TT3 Surface	Head	25	100	< 0.01	< 0.01	0.17	< 0.01	0.08	< 0.01			100.0		100.0	

Total Weights(g)

	Triangle surface	Triangle Mineral	TT3 Surface	TT3 Mineral
	1658	1913	663	1377

Screening (200 mesh)

	Triangle surface	Triangle Mineral	TT3 Surface	TT3 Mineral	Gyro Dust
weight taken(g)	100	100	25	100	100
weight recovered(g) <200 mesh	36.86	31.75	0.58	15.59	67.09

MLA Results on minerals

Sample	Triangle Surface			Triangle Mineral			TT3 Surface			TT3 Mineral		
	Mineral	Distribution		Mineral	Distribution		Mineral	Distribution		Mineral	Distribution	
1	Quartz	40.05		Quartz	40.96		Quartz	48.28		Quartz	64.82	
2	Albite 1	22.23	30.64	Albite 1	33.82	44.94	Albite 1	20.45	34.12	Albite 1	18.23	26.3
3	Barite	11.31		Albite 2	11.12		Albite 2	13.67		Albite 2	8.07	
4	Albite 2	8.41		Chlorite	10.25		Chlorite	4.76		Chlorite	5.26	
5	Chlorite	7.85		Plagioclase	2.02		Plagioclase	2.39		Plagioclase	1.97	
6	Plumbojarosite	3.82		Orthoclase 2	0.49		Barite	2.34		Orthoclase 2	0.98	
7	GalenaResin16	1.81		Rutile	0.38		Fe_Smithsonite	1.53		Rutile	0.35	
8	Sphalerite 4Fe	1.07	2.06	Barite	0.32		Dolomite	1.43		Fe_O	0.25	
9	Plagioclase	1.05		Fe_O	0.27		Pyrite	1.08		Fe_Smithsonite	0.05	
10	Fe_O	0.76		Apatite	0.17		Sphalerite 8Fe	0.89	1.87	Dolomite	0.01	
11	Sphalerite 1Fe	0.54		Plumbojarosite	0.15		Fe_O	0.76		Witherite	0.01	
12	Sphalerite 8Fe	0.45		Witherite	0.02		Sphalerite 1Fe	0.53		Barite	0.01	
13	Apatite	0.16		Sphalerite 1Fe	0.01	0.03	Sphalerite 4Fe	0.45		Sphalerite 1Fe	0	
14	Orthoclase2	0.15		Sphalerite 4Fe	0.01		Rutile	0.41		Chalcocite	0	
15	Rutile	0.12		Sphalerite 8Fe	0.01		Orthoclase 2	0.39		Sphalerite 8Fe	0	
16	Pyrite	0.11		Zn Siderite	0.01		Witherite	0.21		Calcite	0	
17	Anglesite	0.09		Orthoclase 1	0		Plumbojarosite	0.2				
18	Fe_Smithsonite	0.02		Fe_Smithsonite	0		Zn Siderite	0.14				
19	Witherite	0.01					Apatite	0.08				
20	Chalcocite	0										
21	Steel	0										
22	Othoclase 1	0										
23												
24		100.01			100.01			99.99			100.01	
25												
26												
27												

Mineral		Galena	GalenaResin16	Anglesite	Boulangerite	Sphalerite_1 Fe	Sphalerite_4 Fe	Sphalerite_8 Fe	Pyrite	Quartz	Barite	Greenockite	Zincite	Fe_O
		0	0	0	0	0	0	0	0	0	0	0	0	0
Galena	0		0	0	0	0	0	0	0	0	0	0	0	0
GalenaResin16	0	0		3.14	0	0.03	0.46	0.54	0.02	1.90	8.30	0	0	0.04
Anglesite	0	0	44.32		0	0	0	0	0	1.10	4.46	0	0	0
Boulangerite	0	0	0	0		0	0	0	0	0	0	0	0	0
Sphalerite_1 Fe	0	0	0.11	0	0		32.70	6.56	0	0	0.40	0	0	0
Sphalerite_4 Fe	0	0	0.90	0	0	18.36		16.04	0	0.76	0.41	0	0	0
Sphalerite_8 Fe	0	0	1.67	0	0	5.82	25.36		0	1.18	0.77	0	0	0
Pyrite	0	0	0.42	0	0	0	0	0		0.98	2.25	0	0	0
Quartz	0	0	0.17	0.01	0	0	0.03	0.03	0.00		0.54	0	0	0.07
Barite	0	0	2.12	0.08	0	0.03	0.05	0.06	0.03	1.55		0	0	0.11
Greenockite	0	0	0	0	0	0	0	0	0	0	0		0	0
Zincite	0	0	0	0	0	0	0	0	0	0	0	0		0
Fe_O	0	0	0.10	0	0	0	0	0	0	1.85	1.06	0	0	
Witherite	0	0	0	0	0	0	0	0	0	0	21.12	0	0	0
Dolomite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0	0	0.26	0	0	0	0.96	0	0	11.37	3.23	0	0	0
Calcite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	0	0	0	0	0	0	0	0	0	0	0	0	0	25.72
Chlorite	0	0	0.28	0.00	0	0.01	0.05	0.04	0	3.28	1.48	0	0	1.52
Plumbojarosite	0	0	1.76	0.07	0	0.09	0.21	0.42	0.23	2.72	4.04	0	0	1.49
Orthoclase1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoclase2	0	0	0.11	0.16	0	0	0	0	0	2.46	0.15	0	0	0
Chalcocite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rutile	0	0	0	0	0	0	0	0	0	7.29	1.26	0	0	0
Fe_Smithsonite	0	0	0	0	0	0	0	0	0	0	0.54	0	0	17.30
Zn_Siderite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagioclase	0	0	0.13	0	0	0	0	0	0	1.91	0.76	0	0	0.04
Albite1	0	0	0.24	0.00	0	0.00	0.03	0.03	0.03	5.59	0.79	0	0	0.09
Albite2	0	0	0.14	0	0	0	0.00	0.02	0	2.34	0.60	0	0	0.14

Min Assn-Triangle Surface

Witherite	Dolomite	Apatite	Calcite	Steel	Chlorite	Plumbojarosite	Orthoclase1	Orthoclase2	Chalcocite	Rutile	Fe_Smithsonite	Zn_Siderite	Plagioclase	Albite1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0.02	0	0	1.69	4.46	0	0.01	0	0	0	0	0.12	2.59
0	0	0	0	0	0.18	2.66	0	0.24	0	0	0	0	0	0.60
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0.25	0.75	0	0	0	0	0	0	0	0.08
0	0	0.11	0	0	0.59	1.05	0	0	0	0	0	0	0	0.66
0	0	0	0	0	0.78	3.29	0	0	0	0	0	0	0	1.08
0	0	0	0	0	0	11.01	0	0	0	0	0	0	0	6.46
0	0	0.06	0	0	1.74	0.61	0	0.02	0	0.04	0	0	0.16	5.33
0.06	0	0.05	0	0	2.26	2.62	0	0.00	0	0.02	0.00	0	0.18	2.18
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0.04	22.21	9.19	0	0	0	0	0.83	0	0.09	2.43
	0	0	0	0	1.87	0	0	0	0	3.46	0	0	0	5.00
0		0	0	0	0	0	0	0	0	0	0	0	0	0
0	0		0	0	0.73	0.15	0	0.90	0	0	0	0	11.70	2.93
0	0	0		0	0	0	0	0	0	0	0	0	0	0
0	0	0	0		0	0	0	0	0	0	0	0	0	0
0.00	0	0.01	0	0		4.29	0.00	0.18	0	0	0.04	0	1.41	15.71
0	0	0.00	0	0	10.11		0	0.04	0	0.01	0.00	0	0.18	3.60
0	0	0	0	0	9.21	0		0	0	0	0	0	0	35.10
0	0	0.49	0	0	9.89	0.87	0		0	0	0	0	7.87	12.87
0	0	0	0	0	0	0	0	0		0	0	0	0	0
0.54	0	0	0	0	0	0.53	0	0	0		0	0	0.42	4.24
0	0	0	0	0	11.64	0.61	0	0	0	0		0	0	1.35
0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0.73	0	0	8.92	0.49	0	0.91	0	0.03	0	0		18.94
0.00	0	0.02	0	0	8.74	0.85	0.00	0.13	0	0.03	0.00	0	1.66	
0	0	0.03	0	0	7.81	0.44	0	0.08	0	0.07	0.01	0	2.21	18.32

Albite2	Free Surface
0	0
0	0
0.62	76.05
0	46.43
0	0
0	59.15
0.03	61.09
0.30	59.74
0	78.87
0.94	90.23
0.70	87.89
0	0
0	0
1.56	60.65
0	68.54
0	0
2.08	65.68
0	0
0	74.28
5.94	65.75
0.79	74.22
0	55.69
3.21	61.91
0	100.00
4.95	80.78
3.03	65.53
0	0
10.68	56.47
7.75	74.01
	67.79

Mineral		Galena	GalenaResin16	Anglesite	Boulangerite	Sphalerite_1 Fe	Sphalerite_4 Fe	Sphalerite_8 Fe	Pyrite	Quartz	Barite	Greenockite	Zincite	Fe_O
		0	0	0	0	0	0	0	0	0	0	0	0	0
Galena	0		0	0	0	0	0	0	0	0	0	0	0	0
GalenaResin16	0	0		0	0	0	0	0	0	0	0	0	0	0
Anglesite	0	0	0		0	0	0	0	0	0	0	0	0	0
Boulangerite	0	0	0	0		0	0	0	0	0	0	0	0	0
Sphalerite_1 Fe	0	0	0	0	0		17.96	0	0	0	0	0	0	0
Sphalerite_4 Fe	0	0	0	0	0	22.06		6.55	0	0	0	0	0	0
Sphalerite_8 Fe	0	0	0	0	0	0	8.25		0	0	0	0	0	0
Pyrite	0	0	0	0	0	0	0	0		0	0	0	0	0
Quartz	0	0	0	0	0	0	0	0	0		0.02	0	0	0.01
Barite	0	0	0	0	0	0	0	0	0	0.99		0	0	0
Greenockite	0	0	0	0	0	0	0	0	0	0	0		0	0
Zincite	0	0	0	0	0	0	0	0	0	0	0	0		0
Fe_O	0	0	0	0	0	0	0	0	0	0.54	0	0	0	
Witherite	0	0	0	0	0	0	0	0	0	0.95	0	0	0	0
Dolomite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0	0	4.36	0.24	0	0	0
Calcite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorite	0	0	0	0	0	0	0.00	0	0	1.98	0.07	0	0	0.59
Plumbojarosite	0	0	0	0	0	0	0.13	0	0	1.60	2.40	0	0	1.38
Orthoclase1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoclase2	0	0	0	0	0	0	0	0	0	0.65	0	0	0	0
Chalcocite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rutile	0	0	0	0	0	0	0	0	0	4.62	0.08	0	0	0
Fe_Smithsonite	0	0	0	0	0	0	0	0	0	0	0	0	0	67.91
Zn_Siderite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagioclase	0	0	0	0	0	0	0	0	0	0.56	0.04	0	0	0.01
Albite1	0	0	0	0	0	0	0	0.00	0	4.12	0.04	0	0	0.05
Albite2	0	0	0	0	0	0	0	0	0	1.51	0.00	0	0	0.01

Min Assn-Triangle Mineral

Witherite	Dolomite	Apatite	Calcite	Steel	Chlorite	Plumbojarosite	Orthoclase1	Orthoclase2	Chalcocite	Rutile	Fe_Smithsonite	Zn_Siderite	Plagioclase	Albite1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1.62	1.74	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	5.30
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.00	0	0.02	0	0	0.89	0.01	0	0.01	0	0.06	0	0	0.07	4.54
0	0	0.08	0	0	2.03	0.91	0	0	0	0.07	0	0	0.33	3.11
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	21.30	0.64	0	0	0	0	0.44	0	0.11	4.81
	0	0	0	0	3.02	0	0	0	0	5.56	0	0	0	3.52
0		0	0	0	0	0	0	0	0	0	0	0	0	0
0	0		0	0	0.46	0	0	4.27	0	0	0	0	5.82	1.39
0	0	0		0	0	0	0	0	0	0	0	0	0	0
0	0	0	0		0	0	0	0	0	0	0	0	0	0
0.01	0	0.01	0	0		0.08	0.00	0.16	0	0.05	0.00	0	1.74	14.04
0	0	0	0	0	6.51		0	0	0	0	0	0	0.37	2.42
0	0	0	0	0	15.11	0		23.35	0	0	0	0	10.61	12.20
0	0	1.29	0	0	4.49	0	0.16		0	0	0	0	3.92	6.30
0	0	0	0	0	0	0	0	0		0	0	0	0	0
0.60	0	0	0	0	1.47	0	0	0	0		0	0	0.16	3.90
0	0	0	0	0	23.67	0	0	0	0	0		0	0	0
0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0.22	0	0	5.99	0.02	0.01	0.49	0	0.02	0	0		21.86
0.00	0	0.01	0	0	5.70	0.01	0.00	0.09	0	0.05	0	0	2.57	
0.00	0	0.05	0	0	4.82	0	0	0.04	0	0.01	0	0	3.17	13.70

Albite2	Free Surface
0	0
0	0
0	0
0	0
0	0
0	82.04
0	68.03
0	86.45
0	0
0.67	93.70
0.11	92.37
0	0
0	0
0.30	71.85
0.90	86.04
0	0
4.15	79.31
0	0
0	0
4.75	76.53
0	85.20
0	38.73
1.17	82.01
0	0
0.39	88.78
0	8.42
0	100.00
10.77	60.02
5.48	81.86
	76.68

Mineral		Galena	GalenaResin16	Anglesite	Boulangerite	Sphalerite_1 Fe	Sphalerite_4 Fe	Sphalerite_8 Fe	Pyrite	Quartz	Barite	Greenockite	Zincite	Fe_O
		0	0	0	0	0	0	0	0	0	0	0	0	0
Galena	0		0	0	0	0	0	0	0	0	0	0	0	0
GalenaResin16	0	0		0	0	0	0	0	0	0	0	0	0	0
Anglesite	0	0	0		0	0	0	0	0	0	0	0	0	0
Boulangerite	0	0	0	0		0	0	0	0	0	0	0	0	0
Sphalerite_1 Fe	0	0	0	0	0		0	0	0	0	0	0	0	0
Sphalerite_4 Fe	0	0	0	0	0	0		35.77	0	0	0	0	0	0
Sphalerite_8 Fe	0	0	0	0	0	0	26.90		0	0	0	0	0	0
Pyrite	0	0	0	0	0	0	0	0		0	0	0	0	0
Quartz	0	0	0	0	0	0	0	0	0		0	0	0	0
Barite	0	0	0	0	0	0	0	0	0	0		0	0	0
Greenockite	0	0	0	0	0	0	0	0	0	0	0		0	0
Zincite	0	0	0	0	0	0	0	0	0	0	0	0		0
Fe_O	0	0	0	0	0	0	0	0	0	0	0	0	0	
Witherite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dolomite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorite	0	0	0	0	0	0	0	0	0	0	0	0	0	0.75
Plumbojarosite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoclase1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoclase2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chalcocite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rutile	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fe_Smithsonite	0	0	0	0	0	0	0	0	0	0	0	0	0	8.92
Zn_Siderite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagioclase	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Albite1	0	0	0	0	0	0	0	0	0	6.73	0	0	0	0
Albite2	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Min Assn-TT3 Surface

Witherite	Dolomite	Apatite	Calcite	Steel	Chlorite	Plumbojaro site	Orthoclase1	Orthoclase2	Chalcocite	Rutile	Fe_Smithso nite	Zn_Siderite	Plagioclase	Albite1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	3.98
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	3.67	0	0	0	0	0	10.67	0	0	0
	0	0	0	0	0	0	0	0	0	28.42	0	0	0	0
0		0	0	0	0	0	0	0	0	0	0	0	8.11	0
0	0		0	0	0	0	0	0	0	0	0	0	0	0
0	0	0		0	0	0	0	0	0	0	0	0	0	0
0	0	0	0		0	0	0	0	0	0	0	0	0	0
0	0	0	0	0		0	0	0.87	0	0	0	0	0	3.54
0	0	0	0	0	0		0	0	0	0	0	0	0	0
0	0	0	0	0	0	0		0	0	0	0	0	0	0
0	0	0	0	0	7.49	0	0		0	0	0	0	38.90	0
0	0	0	0	0	0	0	0	0		0	0	0	0	0
20.17	0	0	0	0	0	0	0	0	0		0	0	0	0
0	0	0	0	0	0	0	0	0	0	0		0	0	0
0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	3.86	0	0	0	0	0	0	6.80	0	0	0	0		9.37
0	0	0	0	0	1.04	0	0	0	0	0	0	0	1.82	
0	0	0	0	0	0	0	0	0	0	0	0	0	4.74	16.07

Albite2	Free Surface
0	0
0	0
0	0
0	0
0	0
0	100.00
0	64.23
0	73.10
0	100.00
0	96.02
0	100.00
0	0
0	0
0	85.66
0	71.58
0	91.89
0	100.00
0	0
0	0
0	94.84
0	100.00
0	0
0	53.61
0	0
0	79.83
0	91.08
0	100.00
11.80	68.16
7.78	82.64
	79.19

Mineral		Galena	GalenaResin16	Anglesite	Boulangerite	Sphalerite_1 Fe	Sphalerite_4 Fe	Sphalerite_8 Fe	Pyrite	Quartz	Barite	Greenockite	Zincite	Fe_O
		0	0	0	0	0	0	0	0	0	0	0	0	0
Galena	0		0	0	0	0	0	0	0	0	0	0	0	0
GalenaResin16	0	0		0	0	0	0	0	0	0	0	0	0	0
Anglesite	0	0	0		0	0	0	0	0	0	0	0	0	0
Boulangerite	0	0	0	0		0	0	0	0	0	0	0	0	0
Sphalerite_1 Fe	0	0	0	0	0		0	0	0	0	0	0	0	0
Sphalerite_4 Fe	0	0	0	0	0	0		0	0	0	0	0	0	0
Sphalerite_8 Fe	0	0	0	0	0	0	0		0	0	0	0	0	0
Pyrite	0	0	0	0	0	0	0	0		0	0	0	0	0
Quartz	0	0	0	0	0	0	0	0	0		0	0	0	0.00
Barite	0	0	0	0	0	0	0	0	0	0		0	0	0
Greenockite	0	0	0	0	0	0	0	0	0	0	0		0	0
Zincite	0	0	0	0	0	0	0	0	0	0	0	0		0
Fe_O	0	0	0	0	0	0	0	0	0	0.14	0	0	0	
Witherite	0	0	0	0	0	0	0	0	0	3.47	0	0	0	0
Dolomite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Apatite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Calcite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Steel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chlorite	0	0	0	0	0	0	0	0	0	1.92	0	0	0	0.23
Plumbojarosite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoclase1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orthoclase2	0	0	0	0	0	0	0	0	0	0.51	0	0	0	0
Chalcocite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Rutile	0	0	0	0	0	0	0	0	0	1.43	0	0	0	0
Fe_Smithsonite	0	0	0	0	0	0	0	0	0	0	0	0	0	13.80
Zn_Siderite	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Plagioclase	0	0	0	0	0	0	0	0	0	0.43	0	0	0	0
Albite1	0	0	0	0	0	0	0	0	0	3.11	0	0	0	0.01
Albite2	0	0	0	0	0	0	0	0	0	0.72	0	0	0	0

Min Assn-TT3 Mineral

Witherite	Dolomite	Apatite	Calcite	Steel	Chlorite	Plumbojaro site	Orthoclase1	Orthoclase2	Chalcocite	Rutile	Fe_Smithso nite	Zn_Siderite	Plagioclase	Albite1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.00	0	0	0	0	0.30	0	0	0.01	0	0.01	0	0	0.03	1.36
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	5.33	0	0	0	0	0	2.92	0	0	0.71
	0	0	0	0	0	0	0	0	0	15.74	0	0	0	1.25
0		0	0	0	0	0	0	0	0	0	0	0	0	0
0	0		0	0	0	0	0	0	0	0	0	0	0	0
0	0	0		0	0	0	0	0	0	0	0	0	0	0
0	0	0	0		0	0	0	0	0	0	0	0	0	0
0	0	0	0	0		0	0	0.26	0	0.06	0.01	0	1.10	4.89
0	0	0	0	0	0		0	0	0	0	0	0	0	0
0	0	0	0	0	0	0		0	0	0	0	0	0	0
0	0	0	0	0	1.90	0	0		0	0	0	0	2.28	1.13
0	0	0	0	0	0	0	0	0		0	0	0	0	0
1.08	0	0	0	0	1.14	0	0	0	0		0	0	0	0.56
0	0	0	0	0	1.04	0	0	0	0	0		0	0	0
0	0	0	0	0	0	0	0	0	0	0	0		0	0
0	0	0	0	0	2.50	0	0	0.71	0	0	0	0		10.81
0.00	0	0	0	0	1.74	0	0	0.06	0	0.01	0	0	1.69	
0	0	0	0	0	0.88	0	0	0.02	0	0.01	0	0	1.20	3.51

Albite2	Free Surface
0	0
0	0
0	0
0	0
0	0
0	100.00
0	0
0	100.00
0	0
0.17	98.11
0	100.00
0	0
0	0
0	90.90
0	79.53
0	100.00
0	0
0	100.00
0	0
1.31	90.21
0	0
0	0
0.18	94.00
0	100.00
0.19	95.59
0	85.16
0	0
4.07	81.48
1.87	91.50
	93.67