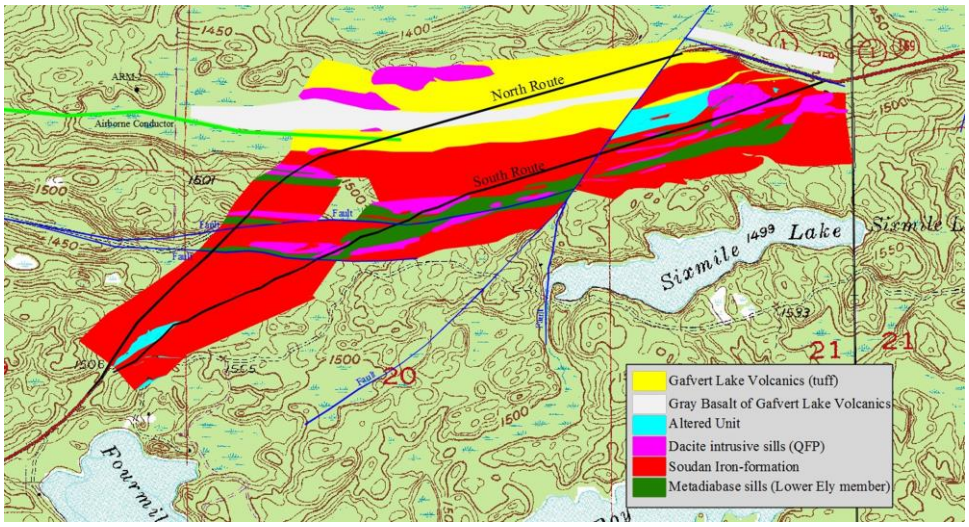
A SECOND ADDENDUM TO: GEOLOGY AND SULFIDE CONTENT OF ARCHEAN ROCKS ALONG TWO PROPOSED HIGHWAY 169 RELOCATIONS TO THE NORTH OF SIXMILE LAKE, ST. LOUIS COUNTY, NORTHEASTERN MINNESOTA



by
John J. Heine

August 2015
Technical Report
NRRI/TR-2015/12

Natural Resources Research Institute
University of Minnesota Duluth
5013 Miller Trunk Highway
Duluth MN 55811-1442

This publication is accessible from the home page of the Economic Geology Group of the Center for Applied Research and Technology Development at the Natural Resources Research Institute, University of Minnesota Duluth (http://www.nrri.umn.edu/egg) as a PDF file readable with Adobe Acrobat 9.0.

Date of release: August 2015

Cover Image Caption

Geologic map of the Sixmile Lake project area as determined by the distribution of lithologies present in groups of outcrops modified from Severson and Heine (2010).

Recommended Citation

Heine, J.J., 2015, A Second Addendum To: Geology and Sulfide Content of Archean Rocks Along Two Proposed Highway 169 Relocations to the North of Sixmile Lake, St. Louis County, Northeastern Minnesota: Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2015/12, 45 p.

Natural Resources Research Institute
University of Minnesota, Duluth
5013 Miller Trunk Highway
Duluth, MN 55811-1442
Telephone: 218-720-4272
Fax: 218-720-4329
e-mail: shauck@nrri.umn.edu

Web site: http://www.nrri.umn.edu/egg

ABSTRACT

This second addendum to GEOLOGY AND SULFIDE CONTENT OF ARCHEAN ROCKS ALONG TWO PROPOSED HIGHWAY 169 RELOCATIONS TO THE NORTH OF SIXMILE LAKE, ST. LOUIS COUNTY, NORTHEASTERN MINNESOTA (Severson and Heine, 2010) examines the bedrock outcrops in the western part of the area along the existing Highway 169 alignment. This area is the western part of the identified "Northern Alignment" alternative. Outcrops were examined to determine rock type, sulfide content, and structural features. Samples were collected of both representative rock types and any rock types with elevated sulfides present. Twenty-six samples were collected during this project, and an additional sixteen samples collected during the 2010 work were included from the area where the areas overlapped.

The current map area contains generally higher visual pyrite content and higher sulfur analyzed by Leco technique (AcmeLabs, Canada) than observed along the "Southern Alignment" in Severson and Heine (2010). This elevated sulfur content is due to a number of factors:

1. The presence of the upper black cherty Soudan Iron-Formation, which contains syngenetic disseminated and bedded pyrite (FeS_2);
2. The presence of faults in the central part of the area and increased localized shearing; and
3. The new rock units that include the Gray Basalt and Gafvert Lake Sequence, which both contain elevated sulfides.

Observed sulfide mineral contents and chemical concentrations are higher in the Northern Alignment than the Southern Alignment, suggesting that based on sulfide mineral contents and sulfur concentrations alone, the Southern Alignment would be the preferred alignment; however, consideration of other factors beyond the scope of this report are also required for determining the final location for the highway. Additionally, should this route be chosen, additional drilling would be needed to supplement the outcrop information in areas with less exposure.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

This addendum is a follow up to Severson and Heine (2010) and Severson and Heine (2012) reports on the geology of Sixmile Lake, to fill in the geology along the existing western portion of Minnesota Highway 169 in the area of interest. Geologic mapping to the north of Sixmile Lake was initiated at the request of the Minnesota Department of Transportation (Mn/DOT) in response to concerns brought forth by local property owners regarding relocating a portion of Minnesota Highway 169. This relocation, referred to as the "South Route" (Fig. 1), was planned to both straighten out the highway and to position the road on top of a large hill, rather than at the base of the hill (north-facing slope) where the road is currently situated, to allow for more sunlight conditions in the winter to melt road ice and snow.

Property owners in the Sixmile Lake area believe that the waters of Sixmile Lake would be adversely affected by weathering of sulfide-bearing rocks, and subsequent run-off from newly-constructed roadcuts along the proposed South Route. Because of this environmental concern, Mn/DOT contracted with the Natural Resources Research Institute (NRRI) to conduct geologic mapping in the vicinity of the proposed relocation, paying special attention to the type and amount of sulfide minerals in the rock and their mode of occurrence. Mapping also took place along an alternative "North Route" (also shown in Fig. 1). At the time of the initial mapping, the area along the current highway alignment in the west of the area was not included in the project scope. This report fills in information for that area.

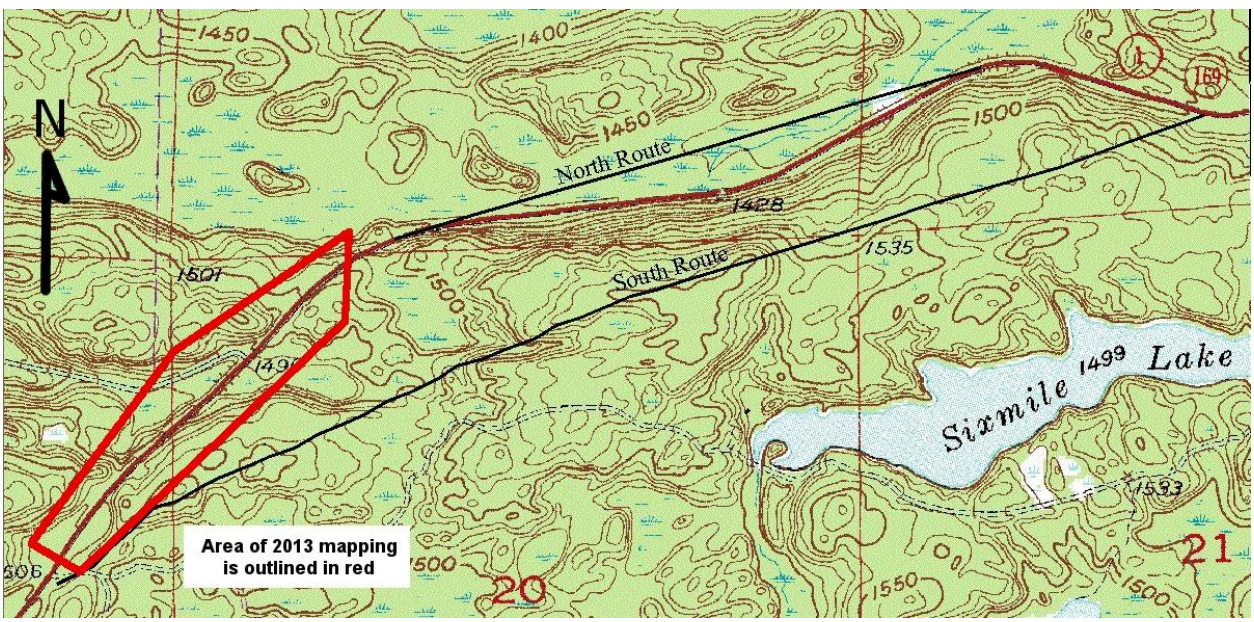


Figure 1. Mn/DOT-proposed relocation routes for Minnesota Highway 169 to the north and northwest of Sixmile Lake, St. Louis County, MN (T.62N., R.14W.).

The results of the NRRI geologic mapping in the Sixmile Lake area were presented in a report by Severson and Heine (2010). These same results were presented at several meetings attended by personnel from the NRRI, Mn/DOT, Minnesota Department of Natural Resources

(MDNR), and Minnesota Pollution Control Agency (MPCA). During these meetings, it was jointly decided that sulfur analyses should be performed on rock samples that were collected from areas where future rock cuts would be made along the "South Route" of the Minnesota Highway 169 relocation.

The Severson and Heine (2012) addendum report was completed to: 1) present the analytical results of their sampling campaign; 2) provide the appropriate GIS-related shape files that were omitted from the initial report by Severson and Heine (2012; and 3) describe the results of geologic mapping that took place in November, 2011 to the east of Sixmile Lake along other proposed Highway 169 relocations in the Armstrong Lake area.

GENERAL GEOLOGY

The bedrock geology in the Sixmile and Armstrong lakes area is part of the Neo-Archean (~2.7 Ga) Vermilion Greenstone Belt that includes rocks of the: Lower member of the Ely Greenstone Formation, Soudan Iron-formation member of the Ely Greenstone Formation, and the Gafvert Lake volcaniclastic sequence of the Lake Vermilion Formation. The regional distribution of these members is shown in Figure 2. The geologic units that occur at Sixmile Lake during mapping (Fig. 3) are briefly described in Severson and Heine (2010) and include:

1. *Soudan Iron-formation member (BIF)* – composed of thinly-laminated, magnetic chert (black to gray) with variable amounts of red jasper beds along with lesser amounts of the mafic flows, tuffs, and sediments. This package of rocks formed during a period of quiescence in volcanism at the end of the deposition of the Lower Ely Greenstone;
2. *Metadiabase sills (Metadiabase)* – these rocks are spatially correlative with the Lower Ely Greenstone and occur as intrusive sills in the Soudan Iron-formation. These sills generally extend for several hundred feet along bedding trends and are thought to have served as feeder dikes to the overlying mafic volcanic units exposed elsewhere in the Soudan Iron-formation (or even as feeders to the overlying Upper Ely Greenstone member);
3. *Dacite Porphyry* – occurs as sills and minor dikes in the Soudan Iron-formation and, to a lesser extent, all of the other rock types. These rocks are thought to be the feeders for the overlying Gafvert Lake volcaniclastic unit. For the most part, the dacite sills intrude all rock types; however, local dikes of metadiabase are seen to intrude the dacite;
4. *Gafvert Lake volcaniclastic unit* – present well to the north of Sixmile and Armstrong lakes. This unit has been informally designated a subunit of the Lake Vermilion Formation and is best exposed in an area peripheral to Gafvert Lake. These rocks represent a period of explosive volcanism. In the area of this investigation, the rocks consist of a series of felsic tuffs and block-and-ash flows; and
5. An informally-designated "*gray basalt unit*" – present near the basal portion of the Gafvert Lake volcaniclastic unit to the north of Sixmile Lake. To the east of the Sixmile Lake area, and on the geologic map of the Eagles Nest quadrangle (Jirsa et

al., 2001), this unit is designated as tholeiitic, pillowed to flow-layered, basaltic lava flows that are interbedded with the Soudan Iron-formation.

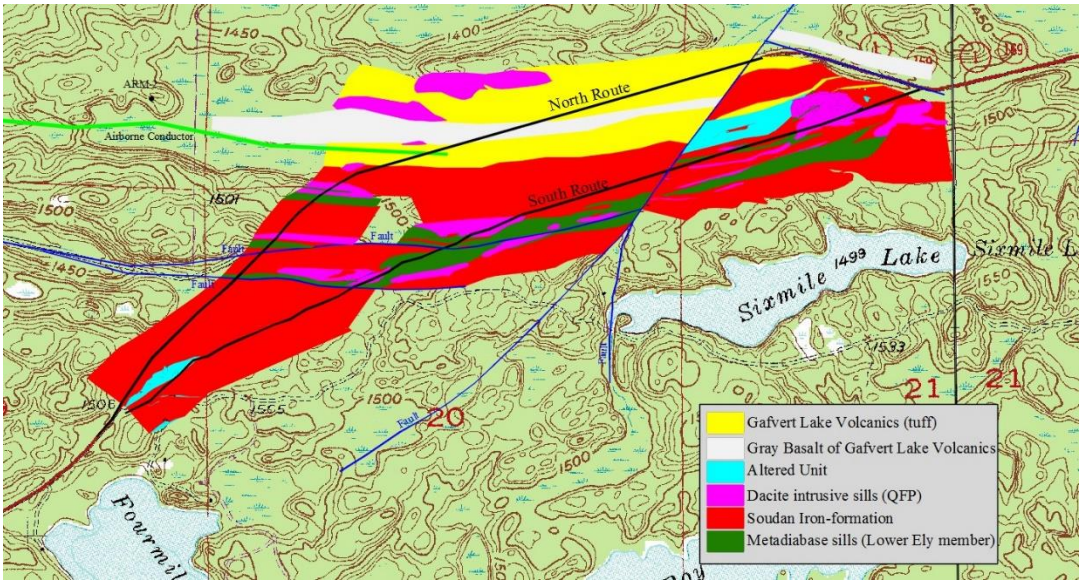


Figure 2. Geologic map of the Sixmile Lake project area as determined by the distribution of lithologies present in groups of outcrops modified from Severson and Heine (2010).

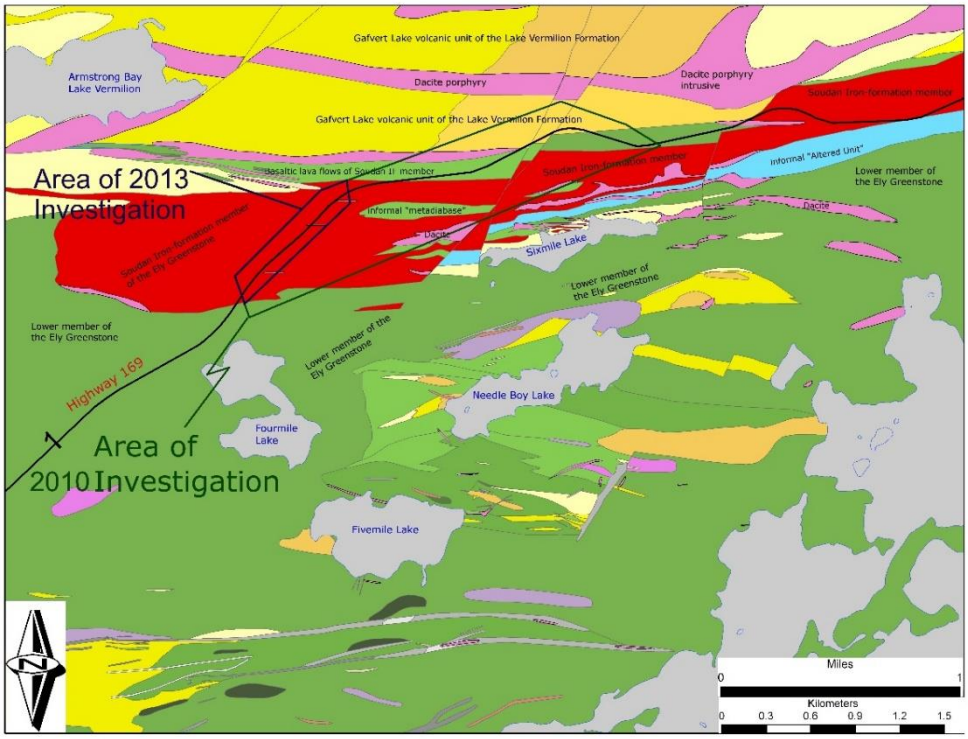


Figure 3. Regional geologic map of the western Vermilion District (modified from Peterson and Jirsa, 1999) showing the major geological formation names and outline of the area of the mapping and sampling investigation that took place in the Sixmile Lake area during 2010 and

SULFIDE CONTENT, MORPHOLOGIES, AND ROCK ASSOCIATIONS

The focus of this work is to evaluate the occurrence of sulfide minerals in outcrops present in the field area. Pyrite was the only sulfide mineral observed and occurs in a number of forms (Severson and Heine, 2012):

1. disseminated 1-5mm cubes that are present in both fresh rocks and weathered/"punky" iron-stained rocks; both types are most common in the iron-formation. The presence of iron-staining, sometimes indicative of the possible presence of pyrite, was always taken seriously, and stained zones were sampled for later geochemical analyses;
2. syngenetic massive pyrite beds up to several millimeters thick and occurring in several repetitive micro-beds over a collective thickness of up to one foot thick;
3. disseminations and coatings in crosscutting veins, veinlets, and joint planes that are commonly filled/coated with quartz and/or iron-carbonate;
4. discontinuous massive pyrite patches that consist of medium- to coarse-grained, 2-6mm cubic pyrite aggregates that are most often seen along joint planes or sheared zones in the metadiabase unit and along bedding-parallel bands or joints in the iron-formation; both are generally more common proximal to fault zones;
5. discontinuous massive sulfide patches that are fine-grained and up to several centimeters across and are associated with shear fabrics – this type is most often seen in reworked tuffs and sediments of the Gafvert Lake volcaniclastic unit; and
6. weathered-out pyrite cubes along bedding-parallel bands in the iron-formation; often more common near fault zones. It is difficult to visually estimate the amount of fresh pyrite present in this situation in that the rock breaks into many smaller pieces when hammered – each piece is similar to the large piece, and only trace amounts of fresh pyrite can be seen. In these types of cases, large samples of similar-looking material were sampled intact for geochemical analyses.

GEOCHEMICAL SAMPLING PROCEDURES

Twenty-six samples were collected in 2013 from both sulfide-bearing rock exposures and sulfide-poor exposures. An additional 16 samples were analyzed from the eastern part of the area, which was mapped previously (Severson and Heine, 2010). Samples were collected using the same procedures as Severson and Heine (2010, 2012):

1. random samples of generic rock type were collected from all rock types within a group of close-spaced exposures;
2. red-stained areas with sulfide potential, and/or areas of "punky" rock with weathered out pyrite pits, were sought out and sampled – in some cases, large samples of the "punky" material was collected in attempts to collect a specimen with preserved pyrite; and

3. whenever sulfide-bearing zones were found, either a series of chip samples across that portion of the exposure were collected or grab samples with the highest sulfide contents were sampled – a reasonable attempt to find the most sulfide-rich zones in a series of outcrops was made during sampling, but there may be localized exceptions, with even higher sulfide contents, that were not discovered during sampling.

Before the samples were sent to a commercial laboratory for geochemical analysis, they were prepared in the same manner as that described in Severson and Heine (2012):

1. All weathering rinds are removed with a rock saw. This procedure is commonly used in the preparation of samples that are run for whole rock analyses. The procedure is also effective in removing any gossanous coatings that by their very definition contain no sulfur. However, in some isolated instances sulfides are inadvertently removed in partly-coated gossanous samples, and the resultant sulfur analysis was lower than would be expected based on the amount of visually-estimated sulfides in the initial rock sample. This relationship is unavoidable and, at the same time, attests to the three-dimensional variability of sulfides in the samples;
2. The samples are then cut in half, with one half to be sent to the assay lab and the remaining half to be kept for future reference; the retained half has since been turned over to Mn/DOT. The student workers and staff performing this activity are made aware of the "nugget effect" and are told to always pick the "half sample" with the most sulfides for geochemistry that, conservatively, should provide a higher sulfur analysis. This "nugget effect" is related to the three-dimensional variability of sulfides in the rock;
3. The samples are weighed, and a minimum of 100 grams were sent to the lab whenever possible – in some cases, most of a small-volume sample was sent to the lab in order to meet this 100-gram minimum;
4. The lab was instructed to provide the results of their internal duplicate analyses (this is a standard lab practice, and nine duplicate analyses were provided by the lab);
5. A total of 42 samples were sent to Acme Lab in Vancouver, Canada in November, 2014. Results were received in November, 2014.

GEOCHEMISTRY RESULTS

Visual estimates of the amount of pyrite were made in the field for each sample location and for the outcrop as a whole. For this work, the term "anomalous sulfide" was dropped from use in respect to the previous work, because there is disagreement over what is considered anomalous. Table 1 and Appendix C contain a listing of visually estimated pyrite during field work and Leco analyzed percent S. Sulfur analysis was performed by AcmeLabs, Canada.

Table 1. Listing of visual estimates of pyrite during field works and Leco analyzed percent S for samples collected during field work in the area.

Sample Number	Lithology	Visual Estimate of Mineralization	S%
SL10-200a	Strongly sheared Dacite Porphyry	12-15% 2-7mm cubic pyrite	1.63
SL10-200b	Moderately sheared Dacite Porphyry	1-2% 1-2mm cubic pyrite, locally up to 5%	<0.02
SL10-201	Black Chert	0.5% 1-2mm cubic pyrite	<0.02
SL10-202	Black/gray chert with bedded pyrite	2-3% 2-5mm cubic pyrite	0.41
OC-085A	DACITE	rare	<0.02
OC-085B	DACITE	1% pyrite	0.76
OC-086A	GRAY BASALT	none	0.28
OC-086B	GRAY BASALT	rare	0.16
OC-086C	GRAY BASALT	none	0.14
OC-087	DACITE	none	<0.02
OC-088	GAFVERT Lake	trace	0.13
OC-301	BIF	rare	<0.02
OC-302	BIF	trace	0.16
OC-303	BIF	5% pyrite	0.33
OC-303DAC	DACITE	rare	0.03
OC-304	CHERT	3% pyrite	0.11
SL13 110	BIF	none	1.29
SL13 109C	Metadiabase	trace fine-grained pyrite	0.24
SL13 109B	Dacite	trace cubic pyrite	<0.02
SL13 109A	BIF	0.5% pyrite, disseminated and in veinlets	0.10
SL13 108F	Black cherty IF	1% disseminated 1-3mm pyrite	0.28
SL13 108E	Black cherty IF	0.25% cubic pyrite, 2-4mm, disseminated and in quartz-carbonate veins	0.02
SL13 108D	BIF	2% pyrite in tension gash filling	0.35
SL13 108C	Chilled Diabase contact	none	<0.02
SL13 108B	Metadiabase	none	<0.02
SL13 108A	Dacite	trace pyrite associated with iron carbonate veinlets	0.10
SL13 107B	Black Cherty IF with bedded disseminated pyrite	1% pyrite, bedded in IF and with quartz-carbonate veins	0.17
SL13 107A	Black Cherty IF with bedded disseminated py	0.5% bedded disseminated pyrite and associated with quartz veinlets	0.03

Sample Number	Lithology	Visual Estimate of Mineralization	S%
SL13 107	Black Cherty IF	trace 1-2mm cubic pyrite	0.26
SL13 106B	Black Cherty IF	trace 1-2mm cubic pyrite	0.08
SL13 106A	Pyritic black cherty IF	2% cubic to blocky disseminated pyrite	0.64
SL13 105B	Black Cherty IF	trace 1-2mm cubic pyrite	0.12
SL13 105A	Black Cherty IF	1-2% pyrite in quartz vein	0.18
SL13 1003	BIF	trace pyrite in quartz-carbonate veins	<0.02
SL13 1002C	Metadiabase	0.25% disseminated cubic 1-2mm pyrite	<0.02
SL13 1002B	BIF	none	0.08
SL13 1002A	BIF	0.10% pyrite	0.12
SL13 1001B	BIF	none	0.02
SL13 1001A	Metadiabase	trace disseminated pyrite	<0.02
SL13 1000B	BIF	none	<0.02
SL13 1000A	BIF	trace	<0.02
SL13 1(04)	Dacite	trace pyrite cubes associated with quartz-iron carbonate veins	0.29

Overall, the highest sulfur value reported was 1.63% S occurred in an outcrop of sheared Dacite Porphyry, and 13 samples were below the 0.02% detection limit. Fifteen of the 42 samples (36%) were above 0.15% S, and 21 samples (50%) were above 0.10% S. Compared to the sulfur data from Severson and Heine (2012), the current data set is generally higher in sulfur. There is a poor correlation between the visual estimates and the sulfur analyses in this study. Much of the pyrite in the black cherty iron-formation and the gray basalt was sub-millimeter in size and difficult to estimate. Fortunately, the upper black cherty member of the Soudan Iron-Formation and gray basalt are limited to the northern part of the area and do not occur in the area of the Southern Alignment.

Sulfur Contents by Rock Type

Dacite Porphyry

Nine samples were collected from the Dacite Porphyry and range from 3 samples below the 0.02% S detection limit to 1.63%. In this area, all of the Dacite Porphyry show some signs of alteration, either associated with local shearing or from near the contact with Soudan Iron-Formation. Compared with the majority of the samples from Severson and Heine (2012), the Dacite in this area has higher sulfur content.

Metadiabase

Five samples of the intrusive metadiabase were collected from the area; four were below detection limit and one contained 0.24% S. This distribution is similar to the metadiabase sulfur distribution from Severson and Heine (2012), suggesting that it only locally contains elevated sulfide.

Soudan Iron-Formation

Over half of the samples were collected from exposures of the Soudan Iron-Formation; 12 from the lower banded iron-formation and 12 from the upper black cherty iron-formation. The lower banded iron-formation is often jaspery and contains soft-sediment deformation, while the upper black cherty iron-formation is laminar bedded with black to dark gray chert intervals that increase in number and thickness upward through the sequence.

The lower banded (jaspery) iron-formation had four samples that contained less than the 0.02% S detection limit, two additional samples that were less than 0.10% S, five that ran between 0.12 and 0.35% S, and one sample that ran 1.29% S. Except the 1.29% sample, the elevated samples are in folded rocks, near intrusive contacts or in foliated and faulted rocks. The sample containing 1.29% sulfur had no visible sulfides in the field, but when cut, a fracture-filling sulfide skin was revealed. The sulfur distribution is similar to that outlined in Severson and Heine (2012) for the Soudan Iron-Formation, the samples which were from the lower banded iron-formation in the area south of this study.

The twelve samples from upper black cherty iron-formation contained one sample below the 0.02% S detection limit, two samples that were less than 0.10% S, seven that ran between 0.12 and 0.35% S, and two samples that were 0.41 and 0.64% S. The upper unit showed a more consistent elevated sulfur distribution. This consistency may be because much of the pyrite in these rocks was bedded and disseminated and appeared to be syngenetic, compared with the strong association of pyrite with later secondary features in the lower banded Soudan Iron-Formation.

Gray Basalt

This unit is a dark gray, massive flow that is above the Soudan Iron-Formation locally in the study area, and has been colloquially named the “Gray Basalt” (Jirsa et al., 2001). Three samples were collected in the current study area, which ranged from 0.14-0.28% S. Visually, very little sulfide was observed in the field. It may be that this unit also contains more abundant sub-millimeter grains of sulfide. These rocks may constitute a risk of higher sulfide concentrations should the new alignment encounter them.

Gafvert Lake Sequence

The Gafvert Lake Sequence is composed of felsic volcanic units that appear to unconformably overlie the Soudan Iron-Formation (Lodge et al., 2013). Only one sample of this unit was collected in the current area, and it contained 0.13% S. Other outcrops of this material have been mapped by Severson and Heine (2010) nearby that contain over 10% visible sulfide as clasts in a basal block and ash flow for this sequence. These rocks would constitute a risk of higher sulfide concentrations should the new alignment encounter them.

CONCLUSIONS

The sulfur analyses of the samples collected for the current area show a general increase in sulfur when compared with samples from Severson and Heine (2012). This sulfur increase is due to a number of factors:

1. The presence of the upper black cherty Soudan Iron-Formation that contains syngenetic disseminated and bedded pyrite;
2. The presence of faults in the central part of the area and increased localized shearing; and
3. The new rock units that include the Gray Basalt and Gafvert Lake Sequence, both of which contain elevated sulfides.

Observed sulfide mineral contents and chemical concentrations are higher in the Northern route than the Southern route, suggesting that based on sulfide mineral contents and sulfur concentrations alone, the Southern Alignment would be the preferred alignment; however, consideration of other factors beyond the scope of this report are also required for dermining the final location for the highway. Additionally, should this route be chosen, additional drilling would be needed to supplement the information obtained from outcrop in areas with less exposure.

REFERENCES

Jirsa, M.A., Boerboom, T.J., and Peterson, D.M., 2001, Bedrock geologic map of the Eagles Nest Quadrangle, St. Louis County, Minnesota: Minnesota Geological Survey Miscellaneous Map Series M-114, scale 1:24,000. http://conservancy.umn.edu/bitstream/57 174/2/m-114.pdf.

Lodge, R.W.,D., Gibson, H.L., Stott, G.M., Hudak, G.J., Jirsa, M.A., and Hamilton, M.A., 2013, New U-Pb geochronology from the Timiskaming-type assemblages in the Shebandowan and Vermilion greenstone belts, Wawa Subprovince, Superior Craton: Implications for the Neoarchean development of the southwestern Superior Province: Precambrian Research, v. 235, p. 264-277.

Peterson, D.M. and Jirsa, M.A., 1999, Bedrock geological map and mineral exploration data, western Vermilion District, St. Louis and Lake counties, northeastern Minnesota: St. Paul, Minnesota Geological Survey Miscellaneous Map Series M-98.

Severson, M.J., and Heine, J.J., 2010, Geology and sulfide content of Archean rocks along two proposed Highway 169 relocations to the north of Sixmile Lake: Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2010/43, 171 p.

Severson, M.J., and Heine, J.J., 2012, An addendum to: Geology and sulfide content of Archean rocks along two proposed Highway 169 relocations to the north of Sixmile Lake, St. Louis County, northeastern Minnesota, and Geologic investigations in the Armstrong Lake area: Natural Resources Research Institute, University of Minnesota Duluth, Technical Report NRRI/TR-2012/20, 83 p.

APPENDIX A:

VAN14003781 Certificate
and
MnDOT Sixmile Sample Data 2013 w sulfur.xls
https://drive.google.com/open?id=1wb-aWY-c2pgeYV64yW2Dx79uznIWUKFtg2Aq9UlpQ9I
(Also included on CD with paper copies of this report)

AcmeLabs™
A Bureau Veritas Group Company

www.acmelab.com

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver BC V6P 6E5 CANADA
PHONE (604) 253-3158

Client: **Natural Resources Research Institute**
University of Minnesota
5013 Miller Trunk Hwy.
Duluth MN 55811 USA

Submitted By: John Heine
Receiving Lab: Canada-Vancouver
Received: November 21, 2014
Report Date: November 28, 2014
Page: 1 of 3

CERTIFICATE OF ANALYSIS VAN14003781.1

CLIENT JOB INFORMATION

Project: MNDOT 169
Shipment ID: 804297917039
P.O. Number
Number of Samples: 42

SAMPLE DISPOSAL

RTRN-PLP Return
RTRN-RJT Return

Acme does not accept responsibility for samples left at the laboratory after 90 days without prior written instructions for sample storage or return.

SAMPLE PREPARATION AND ANALYTICAL PROCEDURES

Procedure Code	Number of Samples	Code Description	Test Wgt (g)	Report Status	Lab
PRP70-250	42	Crush, split and pulverize 250 g rock to 200 mesh			VAN
TC002	42	Total S Analysis by Leco	0.1	Completed	VAN
DRPLP	42	Warehouse handling / disposition of pulps			VAN
DRRJT	17	Warehouse handling / Disposition of reject			VAN

ADDITIONAL COMMENTS

Invoice To: Natural Resources Research Institute
University of Minnesota
5013 Miller Trunk Hwy.
Duluth MN 55811
USA

CC: Steven Hauck

BRITISH COLUMBIA CERTIFIED ASSAYER
Marcus Lau
MARCUS LAU
Geochemical Laboratory Manager

This report supersedes all previous preliminary and final reports with this file number dated prior to the date on this certificate. Signature indicates final approval; preliminary reports are unsigned and should be used for reference only.
All results are considered the confidential property of the client. Acme assumes the liabilities for actual cost of analysis only. Results apply to samples as submitted.
"*" asterisk indicates that an analytical result could not be provided due to unusually high levels of interference from other elements.

AcmeLabs™
A Bureau Veritas Group Company
www.acmelab.com
Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver BC V6P 6E5 CANADA
PHONE (604) 253-3158

Client: **Natural Resources Research Institute**
University of Minnesota
5013 Miller Trunk Hwy.
Duluth MN 55811 USA

Project: MNDOT 169
Report Date: November 28, 2014

CERTIFICATE OF ANALYSIS VAN14003781.1

	Method	WGHT	TC000
	Analyte	Wgt	TOT/S
	Unit	kg	%
	MDL	0.01	0.02
SL-202	Rock	0.22	0.41
SL-201	Rock	0.23	<0.02
SL-200B	Rock	0.11	<0.02
SL-200A	Rock	0.22	1.63
SL13 110	Rock	0.33	1.29
SL13 109C	Rock	0.25	0.24
SL13 109B	Rock	0.28	<0.02
SL13 109A	Rock	0.28	0.10
SL13 108F	Rock	0.21	0.28
SL13 108E	Rock	0.21	0.02
SL13 108D	Rock	0.33	0.35
SL13 108C	Rock	0.26	<0.02
SL13 108B	Rock	0.19	<0.02
SL13 108A	Rock	0.22	0.10
SL13 107B	Rock	0.38	0.17
SL13 107A	Rock	0.51	0.03
SL13 107	Rock	0.32	0.26
SL13 106B	Rock	0.23	0.08
SL13 106A	Rock	0.40	0.64
SL13 105B	Rock	0.34	0.12
SL13 105A	Rock	0.30	0.18
SL13 1003	Rock	0.19	<0.02
SL13 1002C	Rock	0.21	<0.02
SL13 1002B	Rock	0.40	0.08
SL13 1002A	Rock	0.14	0.12
SL13 1001B	Rock	0.25	0.02
SL13 1001A	Rock	0.20	<0.02
SL13 1000B	Rock	0.34	<0.02
SL13 1000A	Rock	0.17	<0.02
SL13 1	Rock	0.27	0.29

AcmeLabs™
A Bureau Veritas Group Company
www.acmelab.com
Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver BC V6P 6E5 CANADA
PHONE (604) 253-3158

Client: **Natural Resources Research Institute**
University of Minnesota
5013 Miller Trunk Hwy.
Duluth MN 55811 USA

Project: MNDOT 169
Report Date: November 28, 2014

CERTIFICATE OF ANALYSIS VAN14003781.1

		Method	WGHT	TC000
		Analyte	Wgt	TOT/S
		Unit	kg	%
		MDL	0.01	0.02
SL-10 OC-304	Rock		0.32	0.11
SL-10 OC-303 DAC	Rock		0.24	0.03
SL-10 OC-303	Rock		0.27	0.33
SL-10 OC-302	Rock		0.22	0.16
SL-10 OC-301	Rock		0.30	<0.02
SL-10 OC-088	Rock		0.17	0.13
SL-10 OC-087	Rock		0.14	<0.02
SL-10 OC-086C	Rock		0.13	0.14
SL-10 OC-086B	Rock		0.18	0.16
SL-10 OC-086A	Rock		0.16	0.28
SL-10 OC-085B	Rock		0.22	0.76
SL-10 OC-085A	Rock		0.23	<0.02

AcmeLabs™
A Bureau Veritas Group Company

www.acmelab.com

Bureau Veritas Commodities Canada Ltd.
9050 Shaughnessy St Vancouver BC V6P 6E5 CANADA
PHONE (604) 253-3158

Client: **Natural Resources Research Institute**
University of Minnesota
5013 Miller Trunk Hwy.
Duluth MN 55811 USA

Project: MNDOT 169
Report Date: November 28, 2014

QUALITY CONTROL REPORT VAN14003781.1

	Method	WGHT	TC000
	Analyte	Wgt	TOT/S
	Unit	kg	%
	MDL	0.01	0.02
Pulp Duplicates			
SL13 1001B	Rock	0.25	0.02
REP SL13 1001B	QC		<0.02
SL-10 OC-085A	Rock	0.23	<0.02
REP SL-10 OC-085A	QC		0.02
Reference Materials			
STD GS311-1	Standard		2.47
STD GS311-1	Standard		2.42
STD GS910-4	Standard		8.48
STD GS910-4	Standard		8.46
STD GS311-1 Expected			2.35
STD GS910-4 Expected			8.27
BLK	Blank		<0.02
BLK	Blank		<0.02
Prep Wash			
ROCK-VAN	Prep Blank		<0.02
ROCK-VAN	Prep Blank		<0.02

APPENDIX B:

MnDOT_Sixmile_Outcrop_Data_2013.xls
https://drive.google.com/open?id=1InePJj-Aub3XxeDnI0osI7R3ZlkEmlsJR3k5RSKvbKM
(Also included on CD with paper copies of this report)

APPENDIX C:

MnDOT_Sixmile_Sample_Data_2013.xls
https://drive.google.com/open?id=15YCvLILZbqOVbfApPH8yOV8gU8bTnxDCAavCU8Ffu4E
(Also included on CD with paper copies of this report)

APPENDIX D:

Field Data Sheets

By: JH 10/2/13

Field Photographs

REE project

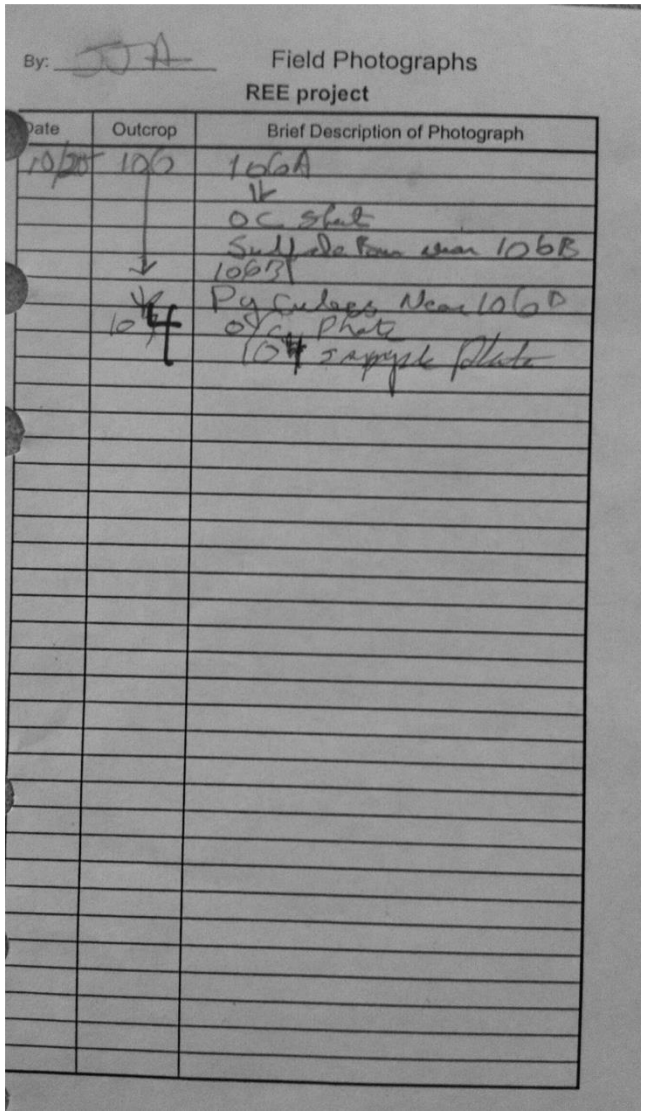
	Outcrop	Brief Description of Photograph
1	1000	BFF
2	1000	BFF Fold Axis
3	1000	BFF w/ Qtz veins in fold Axis
		Sample 1000A
5	↓	BFF Sample 1000B
6	100	Sample 1001A
		1001B
8	1002	Sulfide Burn on fold Hinge
		Same place after sampling
		Sample SL13 1002A
9	↓	Sample 1002B BFF
	↓	Sample 1002C Diabase

By: JSR

Field Photographs

REE project

Date	Outcrop	Brief Description of Photograph
10/8	105	105A Burn on IF
10/8	105	105B Black Cherty IF

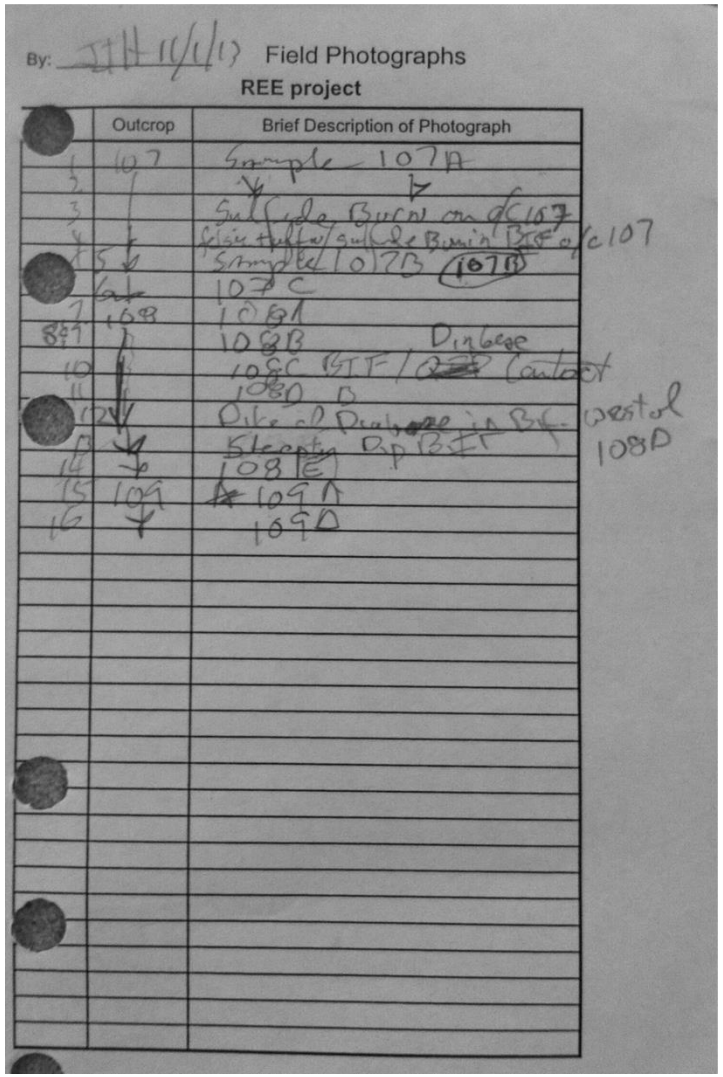


By: JJA

Field Photographs

REE project

Date	Outcrop	Brief Description of Photograph
10/20	106	106A
		↓
		OC shot
		Sulfide Bum near 106B
	↓	106B
	↓	Py Cubes Near 106D
	107	OC Photo
		107 sample photo

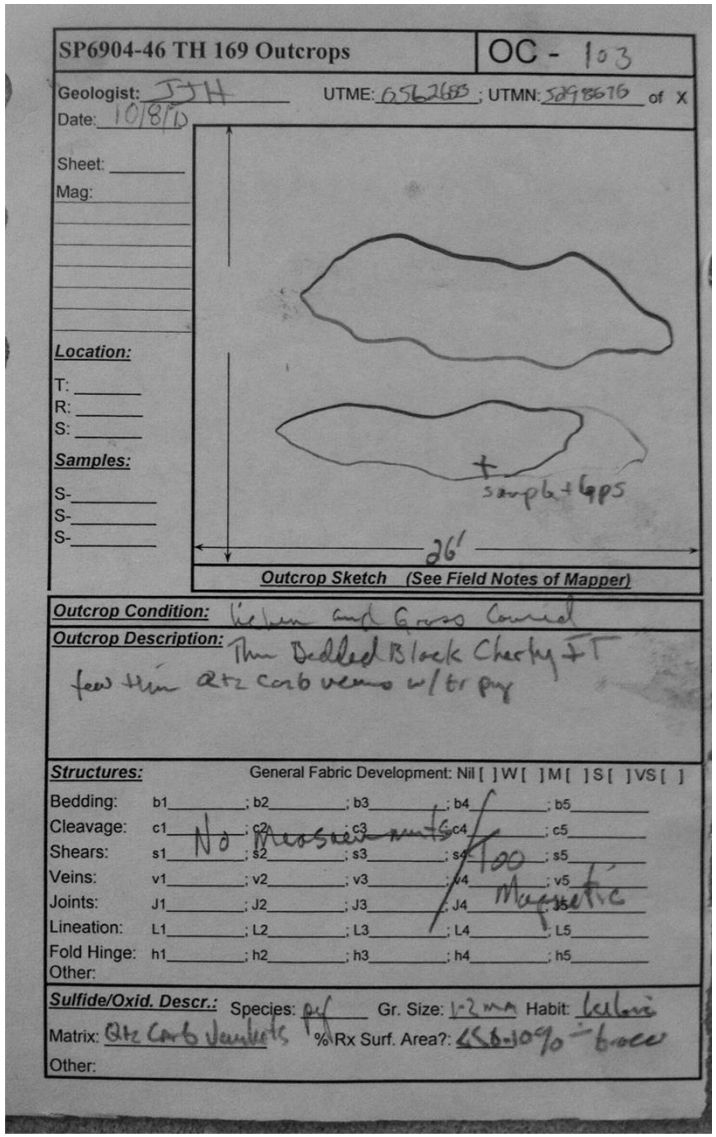


By: JJH 11/1/13

Field Photographs

REE project

	Outcrop	Brief Description of Photograph
1	107	Sample 107A
2	↓	↓
3		Sulfide Burn on OC 107
4		Fish tuffs w/ sulfide Burn in BG o/c 107
5	↓	Sample 107B (107B)
6		107C
7	108	108A
8	↓	108B
9		Dinbeze
10		108C BIF / Contact
11		108D B
12	↓	Dike of Dinbeze in BG - westof 108D
13	↓	Sleeping Bp BIF
14	↓	108E
15	109	109A
16	↓	109D



SP6904-46 TH 169 Outcrops | OC - 103

Geologist: JJH UTME: 0562683 ; UTMN: 5298676 of X

Date: 10/8/16

Sheet:

Mag:

Location:

T:

R:

S:

Samples:

S-

S-

S-

+ sample + gps

26'

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition: Weathered and Grass Covered

Outcrop Description: Thin Bedded Black Cherty FT few thin qtz carb veins w/ tr py

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 ; b2 ; b3 ; b4 ; b5

Cleavage: c1 ; c2 ; c3 ; c4 ; c5

Shears: s1 ; s2 ; s3 ; s4 ; s5

Veins: v1 ; v2 ; v3 ; v4 ; v5

Joints: J1 ; J2 ; J3 ; J4 ; J5

Lineation: L1 ; L2 ; L3 ; L4 ; L5

Fold Hinge: h1 ; h2 ; h3 ; h4 ; h5

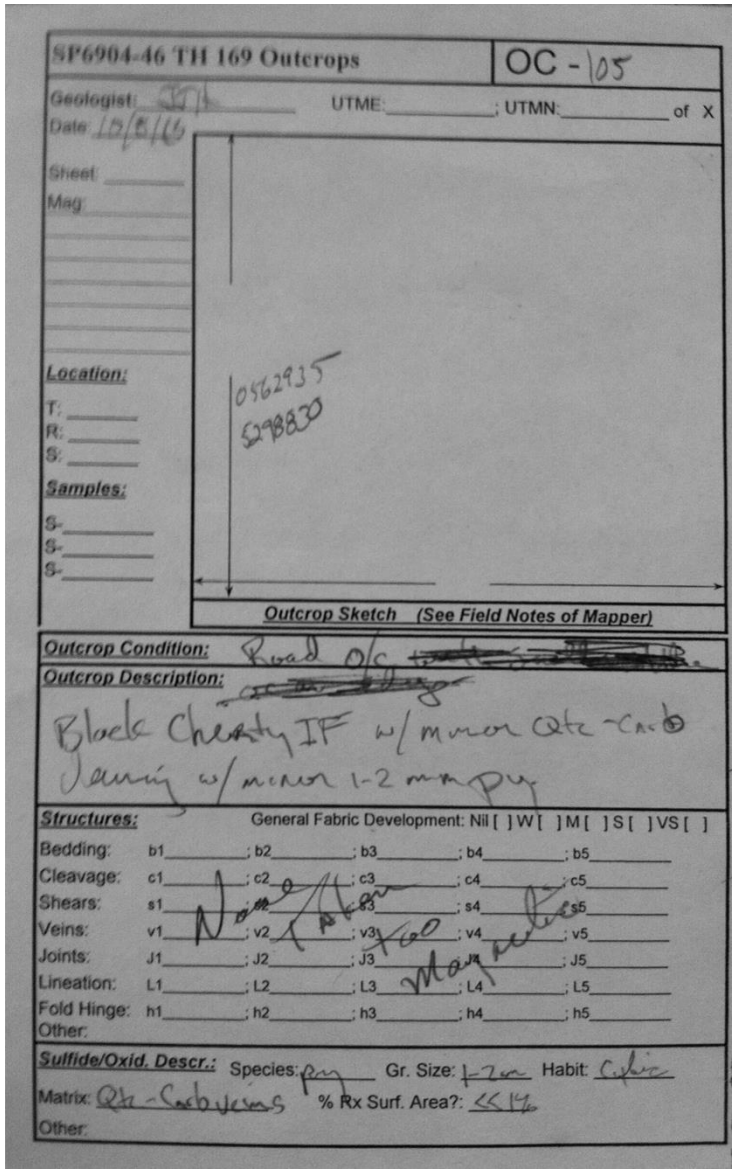
Other:

No Measurements / Too Magnetic

Sulfide/Oxid. Descr.: Species: py Gr. Size: 1-2 mm Habit: Euhedral

Matrix: Qtz Carb veinlets % Rx Surf. Area?: <<5-10% - trace

Other:



SP6904-46 TH 169 Outcrops | OC - 105

Geologist: JJH UTME: ; UTMN: of X

Date: 10/8/16

Sheet:

Mag:

Location:

T:

R:

S:

Samples:

S-

S-

S-

0562935

5298820

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition: Road O/C

Outcrop Description: Black Cherty IF w/ minor Qtz-Carb veining w/ minor 1-2 mm py

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 ; b2 ; b3 ; b4 ; b5

Cleavage: c1 ; c2 ; c3 ; c4 ; c5

Shears: s1 ; s2 ; s3 ; s4 ; s5

Veins: v1 ; v2 ; v3 ; v4 ; v5

Joints: J1 ; J2 ; J3 ; J4 ; J5

Lineation: L1 ; L2 ; L3 ; L4 ; L5

Fold Hinge: h1 ; h2 ; h3 ; h4 ; h5

Other:

No Measurements / Too Magnetic

Sulfide/Oxid. Descr.: Species: py Gr. Size: 1-2 mm Habit: Cubic

Matrix: Qtz-Carb veins % Rx Surf. Area?: << 1%

Other:

SP6904-46 TH 169 Outcrops | OC - 106

Geologist: JJH UTME: 563190 ; UTMN: 5299118 of X

Date: 10/25/13

Sheet:

Mag:

Location:

T:

R:

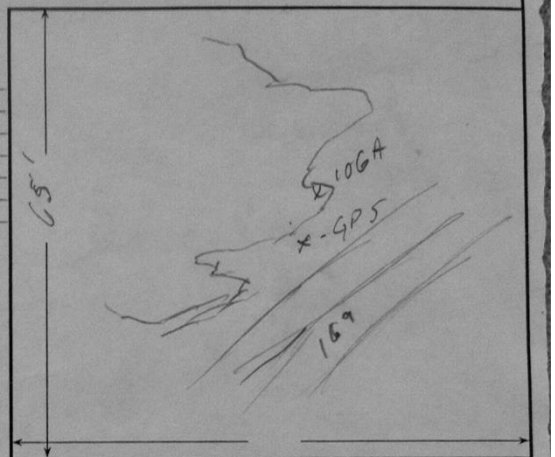
S:

Samples:

S-

S-

S-



Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition:

Outcrop Description: Black Cherty IF mod to Strong Mag - No Sum/No Struct Measurement Zones of 2-3% fine grained 1-2 mm diss Py

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding:	b1	b2	b3	b4	b5
Cleavage:	c1	c2	c3	c4	c5
Shears:	s1	s2	s3	s4	s5
Veins:	v1	v2	v3	v4	v5
Joints:	J1	J2	J3	J4	J5
Lineation:	L1	L2	L3	L4	L5
Fold Hinge:	h1	h2	h3	h4	h5

Other:

Sulfide/Oxid. Descr.: Species: py Gr. Size: 3-7 mm Habit: Cubic

Matrix: Qtz Vein % Rx Surf. Area?: 0.5%

Other:

Date: 10/2/13 **Sample #** SL13 - 1002A

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 0562659 R:

UTMN: 5298694 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Grab ( ) Outcrop : 1002

Chip ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Bif in fold hinge, thin bdd

Alteration: Carbonate is moderate

Mineralization: py in fold hinge qtz-Vein

Structure: folding

SL13 -

Date: 10/2/13 Sample # SL13 - 1002B

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 562655 R:

UTMN: 5298685 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop : 1002

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Thin to Reg Bdd BIF w/ minor jasper

Alteration: weak weathering

Mineralization: Nil

Structure: Soft sed folding

SL13 - 1002B

Date: 10/2/13 Sample # SL13 - 1002C

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 562649 R:

UTMN: 5298682 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop : 1002C

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Diabase - fine grained mafic intrusive

Alteration: silicified weakly

Mineralization: ~0.25 % diss cubic 1-2mm py

Structure: jointed

SL13 -

Date: 10/2/13 Sample # SL13 - 1603

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:
UTME: 0562683
UTMN: 5298876
ZONE: 15
DATUM: NAD 83
T:
R:
S:
QTR:
QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop : 1003
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Thin Bdd Black Cherty IF

Alteration: N.I

Mineralization: tr py in qtz carb veinlets

Structure: jnted

SL13 -

Date: 10/8/13 Sample # SL13 - 105A

Geologist: JDH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:
UTME: 0562901
UTMN: 5298817
ZONE: 15
DATUM: NAD 83
T:
R:
S:
QTR:
QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop : 105
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black Cherty IF w/ Qtz+Carb + Py Veins

Alteration: Weathered Veins/sulfide Rim

Mineralization: 1-2% py in Qtz Veins

Structure: —

SL13 -

Date: 10/8/13 Sample # SL13 - 105D

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 0562895 R:

UTMN: 5298804 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop: 105

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black Cherty IT
Mod magnetite Spidery Qtz-carb veins

Alteration: None

Mineralization: Tr 1-2mm Cubic Py

Structure: —

SL13 -

Date: 10/25/13 Sample # SL13 - 106A

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 563195 R:

UTMN: 5299111 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop: 106

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black pyritic cherty IT

Alteration: Veined qtz carb

Mineralization: 2% cubic to blebby disseminated Py (Primary) and minor qtz veins

Structure:

SL13 -

Date: 10/25/13 Sample # SL13 - 106

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: R:

UTMN: S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop: 106

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black cherty BIF

Alteration: Nil

Mineralization: tr 1-2 mm py assoc w/ Qtz - Fe Carb veining

Structure:

SL13 -

Date: 11/1/13 Sample # SL13 - 107

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 0562325 R:

UTMN: 5299180 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop: 107

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black Cherty IF w/ tr disseminated py

Alteration: Nil

Mineralization: tr diss bdd py

Structure:

SL13 -

Date: 11/1/13 Sample # SL13 - 107B

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: 3229

UTME: 0563228 T:

UTMN: 5299173 R:

ZONE: 15 S:

DATUM: NAD 83 QTR:

QUAD:

Sampling Information

(X) Grab ( ) Outcrop : 107B

( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black Cherty BIF w/ Bdd Diss py

Alteration: Nil

Mineralization: 1/2% Bdd diss py and some ~~[illegible]~~ w/ qtz veinlets 2'4 [illegible]

Structure:

SL13 -

Date: 11/1/13 Sample # SL13 - 107A

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 0563215 R:

UTMN: 5299173 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

(X) Grab ( ) Outcrop : 107

( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black Cherty BIF w/ Diss Bdd py

Alteration: Nil Surface weathering

Mineralization: 1% py 2-3 mm n cubes Bdd in IF and w/ qtz carbonate

Structure: Soft Seal (old mean bay

SL13 -

Date: 11/1/13 Sample # SL13 - 108A

logist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:

ME: 563406 T:

N: 5299268 R:

ZONE: 15 S:

DATUM: NAD 83 QTR:

QUAD:

Sampling Information

X Grab ( ) Outcrop :

( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Qtz Muscovite, Sericite ± P

Alteration: Chl + Epidote + Fe carb

Mineralization: tr py mass w/ Fe carb veinlets

Structure: S.H.

SL13 -

Date: 11/1/13 Sample # SL13 - 108B

logist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:

ME: 563379 T:

N: 5299263 R:

ZONE: 15 S:

DATUM: NAD 83 QTR:

QUAD:

Sampling Information

( ) Grab ( ) Outcrop :

( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Dacite - felsic porphyritic mafic intrusion

Alteration: Chl

Mineralization: N.I

Structure: S.H

SL13 -

Date: 11/1/13 Sample # SL13 - 108C

Geologist: JSX

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 563335 R:

UTMN: 5299229 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock ( ) Grab ( ) Outcrop : X08

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Chilled Diabase Dikeout w/ BIF

Alteration: Silicified

Mineralization: Nil

Structure:

SL13 -

Date: 11/1/13 Sample # SL13 - 108D

Geologist: JSX

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 563330 R:

UTMN: 5299216 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock ( ) Grab ( ) Outcrop : 108

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Bled IF near contact w/ Diabase - Some fault Breccia present

Alteration: Sil

Mineralization: By 2% Tensile Quartz filling

Structure: faulted

SL13 -

Date: 11/1/13 Sample # SL13 - 1085

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 563303 R:

UTMN: 5299203 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock ( ) Grab ( ) Outcrop :

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: BIF Black Cherty

Alteration: Fe Carb

Mineralization: tr - 1/4 py cubes 2-4 mm Assoc w/ qtz - carb veins and diss in BIF

Structure:

SL13 -

Date: 11/1/13 Sample # SL13 - 1088

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 563272 R:

UTMN: 5299176 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

(✓) Grab ( ) Outcrop : 100

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Black Cherty BIF w/ 1% 0.5-3 mm py

Alteration: N.I

Mineralization: 1% Diss 1-3 mm py

Structure: steeply Dipping

SL13 -

Date: 11/1/13 Sample # SL13 - 109 A

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:
UTME: 563229 R:
UTMN: 5299122 S:
ZONE: 15 QTR:
DATUM: NAD 83 QUAD:

Sampling Information

Rock ( ) Grab ( ) Outcrop : 109
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Weakly sheared Bif w/ disseminated py assoc w/ alt. Carb veins

Alteration: fe carb

Mineralization: 1/2% py diss and w/ veinlets

Structure: sheared slightly.

SL13 -

Date: 11/1/13 Sample # SL13 - 109B

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:
UTME: 563215 R:
UTMN: 5299108 S:
ZONE: 15 QTR:
DATUM: NAD 83 QUAD:

Sampling Information

Rock ( ) Grab ( ) Outcrop :
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

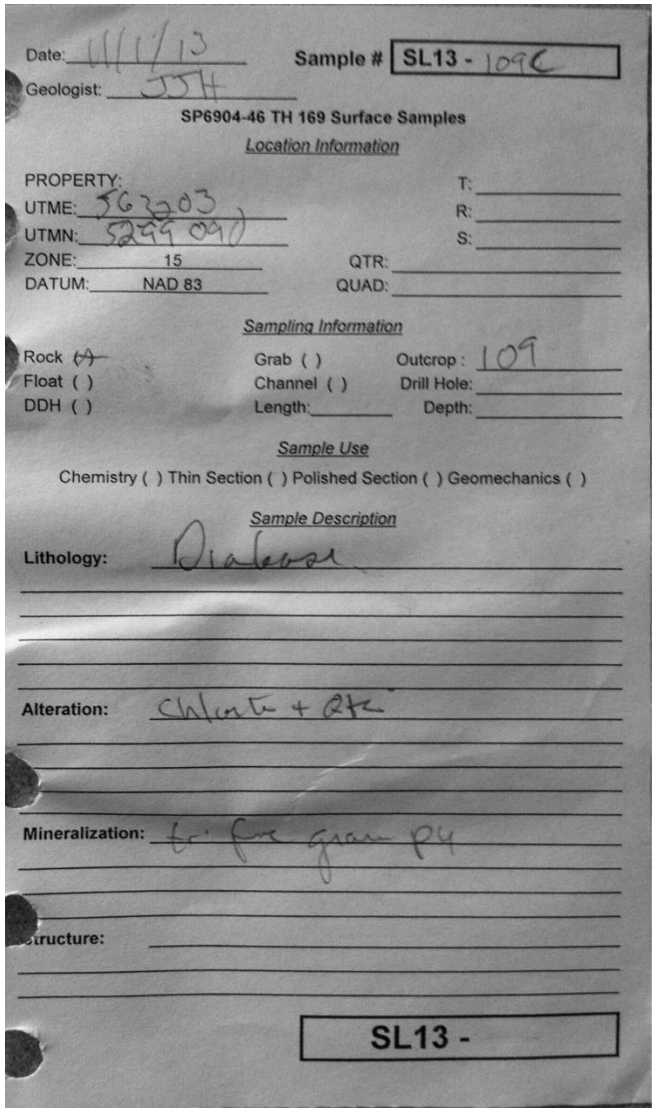
Lithology: ~~Sear~~ QFP

Alteration: Fe-carb / Epidote

Mineralization: Epidote py

Structure:

SL13 -



Date: 11/1/13 Sample # SL13 - 109C

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 563703 R:

UTMN: 5299090 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (✓) Grab ( ) Outcrop : 109

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

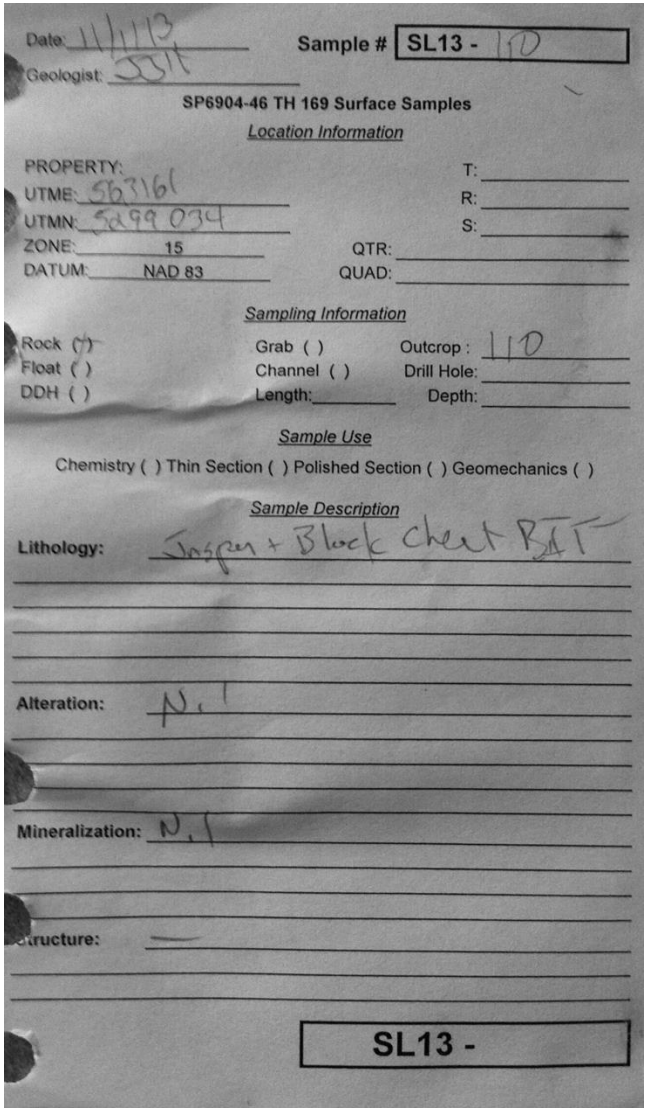
Lithology: Diabase

Alteration: Chlorite + Qtz

Mineralization: tr fine grain py

Structure:

SL13 -



Date: 11/1/13 Sample # SL13 - 110

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T:

UTME: 563161 R:

UTMN: 5299034 S:

ZONE: 15 QTR:

DATUM: NAD 83 QUAD:

Sampling Information

Rock (✓) Grab ( ) Outcrop : 110

Float ( ) Channel ( ) Drill Hole:

DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Jasper + Black Chert BIF

Alteration: N.I

Mineralization: N.I

Structure: —

SL13 -

Date: 10/25/13 Sample # SL13 - [redacted]

Geologist: JTH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:
UTME: 563209
UTMN: 5249134
ZONE: 15
DATUM: NAD 83

T:
R:
S:
QTR:
QUAD:

Sampling Information

Rock (X) Grab ( ) Outcrop : [redacted]
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Qtz Monzonite w/ 3-5mm qtz + feldspar phenos (7-10% of each

Alteration: Qtz Epidote + Fe Carb

Mineralization: tr py 1-2 mm cubes disseminated/qtz-FeCarb veins

Structure:

SL13 -

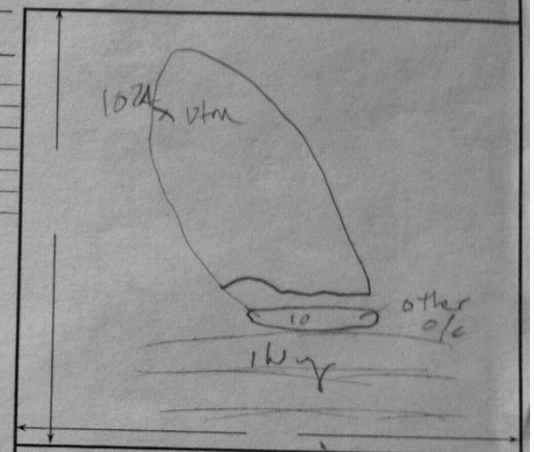
SP6904-46 TH 169 Outcrops OC - 107

Geologist: UTME: 0563215 UTMN: 5249173 of X

Date:

Sheet:

Mag:



Location:

T:
R:
S:

Samples:

S-
S-
S-

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition:

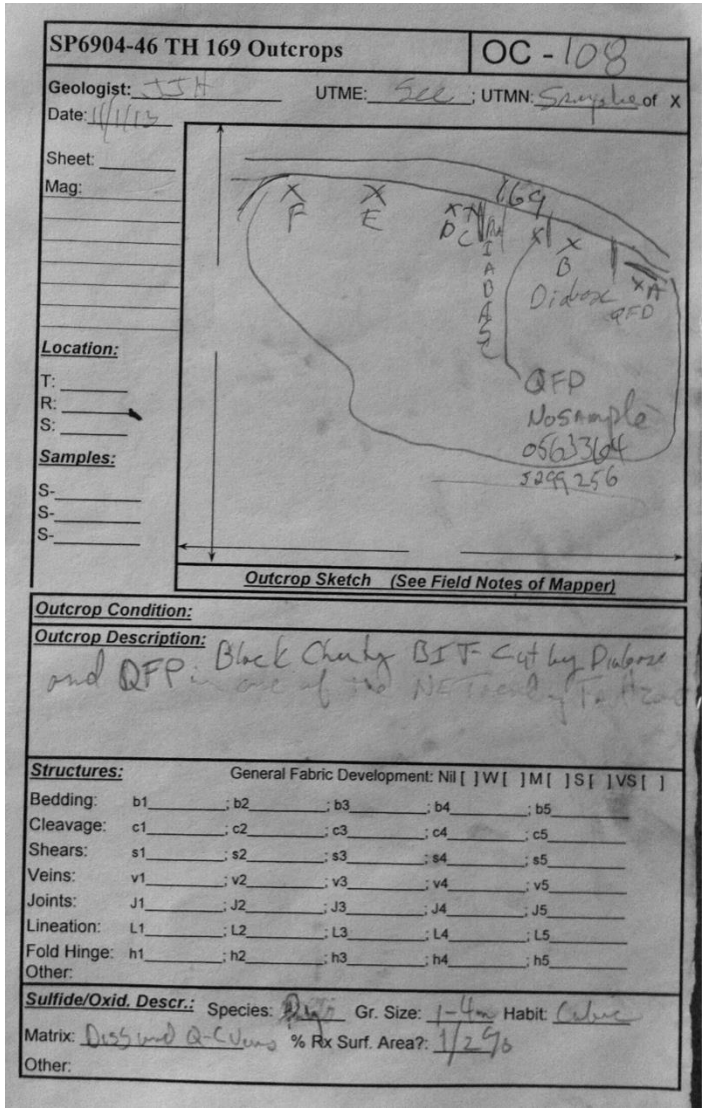
Outcrop Description: Black Cherty BIF w/ 1/4% py oss mostly diss bdd py 1-3 mm and minor py 2-4 mm w/ Qtz-carb veins

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 ; b2 ; b3 ; b4 ; b5
Cleavage: c1 ; c2 ; c3 ; c4 ; c5
Shears: s1 ; s2 ; s3 ; s4 ; s5
Veins: v1 ; v2 ; v3 ; v4 ; v5
Joints: J1 ; J2 ; J3 ; J4 ; J5
Lineation: L1 ; L2 ; L3 ; L4 ; L5
Fold Hinge: h1 ; h2 ; h3 ; h4 ; h5
Other:

None / None seen / None o/c

Sulfide/Oxid. Descr.: Species: py Gr. Size: 1-4 mm Habit: cubic
Matrix: diss and veinlets % Rx Surf. Area?: 1/4%
Other:



SP6904-46 TH 169 Outcrops | OC - 108

Geologist: JJH UTME: See ; UTMN: Sample of X

Date: 11/1/13

Sheet:

Mag:

Location:

T:

R:

S:

Samples:

S-

S-

S-

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition:

Outcrop Description: Black Cherty BIF Cut by Diabase and QFP in one of the NE trend of the Area

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1; b2; b3; b4; b5

Cleavage: c1; c2; c3; c4; c5

Shears: s1; s2; s3; s4; s5

Veins: v1; v2; v3; v4; v5

Joints: J1; J2; J3; J4; J5

Lineation: L1; L2; L3; L4; L5

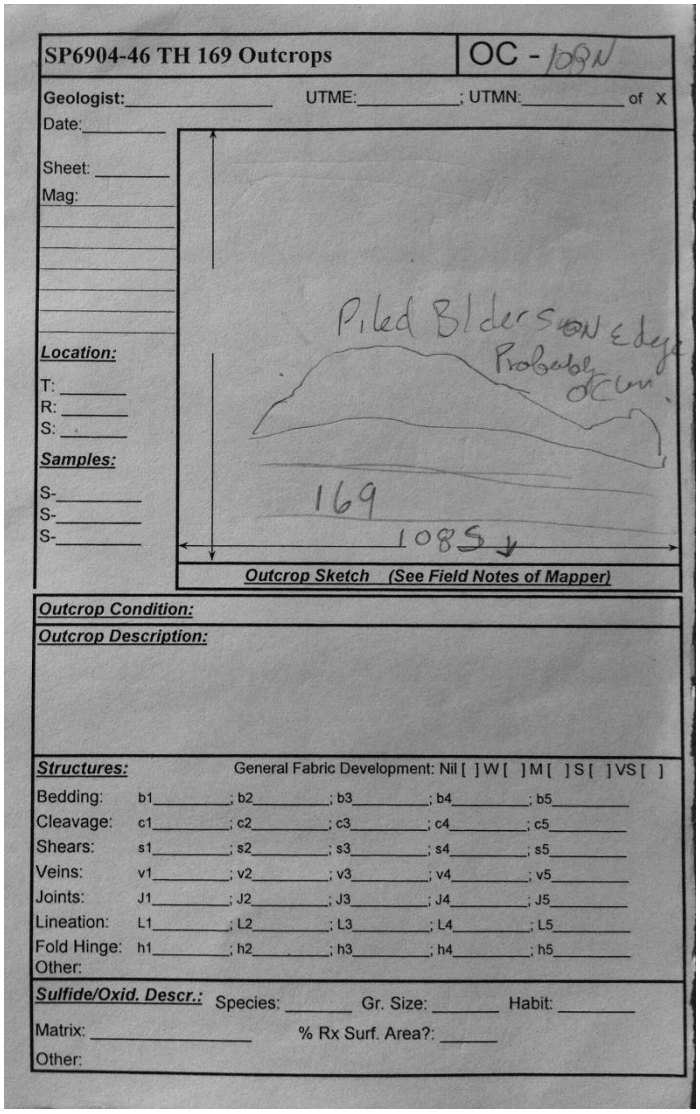
Fold Hinge: h1; h2; h3; h4; h5

Other:

Sulfide/Oxid. Descr.: Species: Py Gr. Size: 1-4mm Habit: Cubic

Matrix: Diss and Q-Veins % Rx Surf. Area?: 1/2%

Other:



SP6904-46 TH 169 Outcrops | OC - 109N

Geologist: UTME: ; UTMN: of X

Date:

Sheet:

Mag:

Location:

T:

R:

S:

Samples:

S-

S-

S-

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition:

Outcrop Description:

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1; b2; b3; b4; b5

Cleavage: c1; c2; c3; c4; c5

Shears: s1; s2; s3; s4; s5

Veins: v1; v2; v3; v4; v5

Joints: J1; J2; J3; J4; J5

Lineation: L1; L2; L3; L4; L5

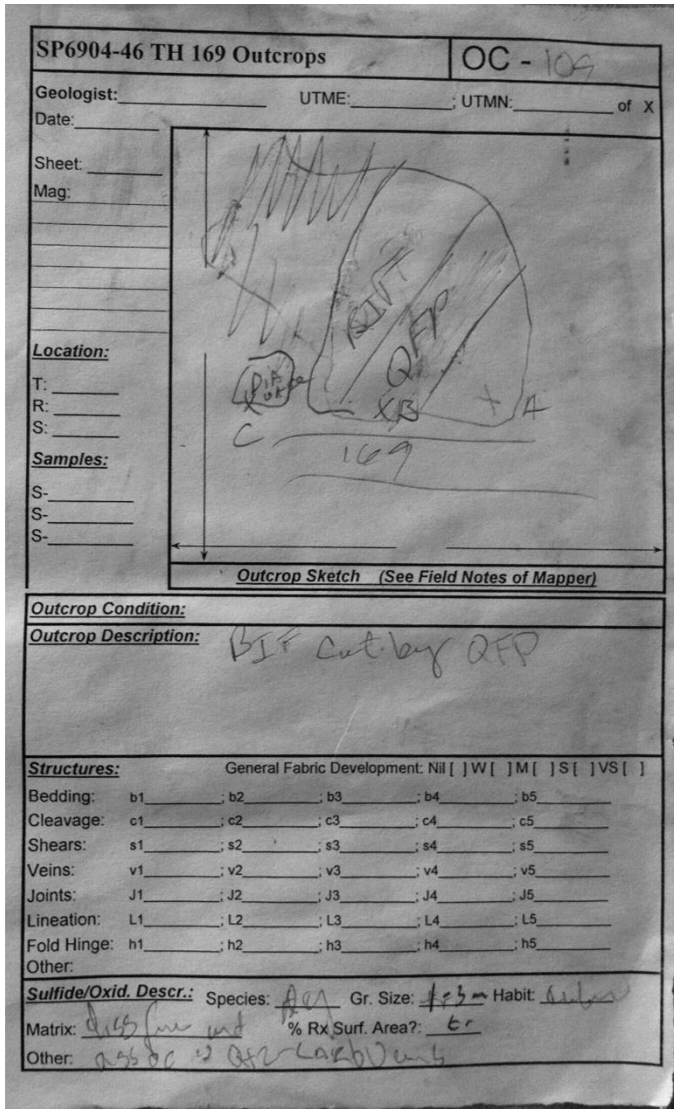
Fold Hinge: h1; h2; h3; h4; h5

Other:

Sulfide/Oxid. Descr.: Species: Gr. Size: Habit:

Matrix: % Rx Surf. Area?:

Other:



SP6904-46 TH 169 Outcrops | OC - 109

Geologist: _____ UTME: _____ ; UTMN: _____ of X

Date: _____

Sheet: _____

Mag: _____

Location:

T: _____

R: _____

S: _____

Samples:

S- _____

S- _____

S- _____

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition:

Outcrop Description: BIF cut by QFP

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 _____ ; b2 _____ ; b3 _____ ; b4 _____ ; b5 _____

Cleavage: c1 _____ ; c2 _____ ; c3 _____ ; c4 _____ ; c5 _____

Shears: s1 _____ ; s2 _____ ; s3 _____ ; s4 _____ ; s5 _____

Veins: v1 _____ ; v2 _____ ; v3 _____ ; v4 _____ ; v5 _____

Joints: J1 _____ ; J2 _____ ; J3 _____ ; J4 _____ ; J5 _____

Lineation: L1 _____ ; L2 _____ ; L3 _____ ; L4 _____ ; L5 _____

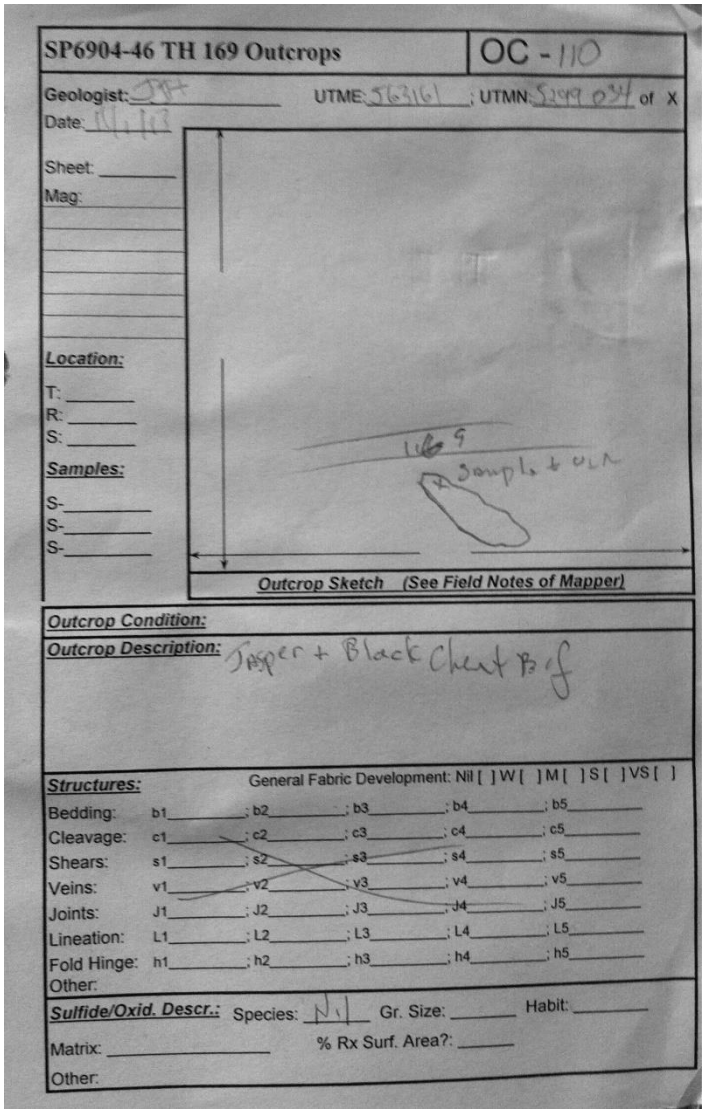
Fold Hinge: h1 _____ ; h2 _____ ; h3 _____ ; h4 _____ ; h5 _____

Other:

Sulfide/Oxid. Descr.: Species: Aps Gr. Size: fe3m Habit: Euhed

Matrix: Qtz fine ind % Rx Surf. Area?: tr

Other: assoc w QFP-carb veins



SP6904-46 TH 169 Outcrops | OC - 110

Geologist: JH UTME: 563161 ; UTMN: 5299034 of X

Date: 11/1/13

Sheet: _____

Mag: _____

Location:

T: _____

R: _____

S: _____

Samples:

S- _____

S- _____

S- _____

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition:

Outcrop Description: Jasper + Black Chert BIF

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 _____ ; b2 _____ ; b3 _____ ; b4 _____ ; b5 _____

Cleavage: c1 _____ ; c2 _____ ; c3 _____ ; c4 _____ ; c5 _____

Shears: s1 _____ ; s2 _____ ; s3 _____ ; s4 _____ ; s5 _____

Veins: v1 _____ ; v2 _____ ; v3 _____ ; v4 _____ ; v5 _____

Joints: J1 _____ ; J2 _____ ; J3 _____ ; J4 _____ ; J5 _____

Lineation: L1 _____ ; L2 _____ ; L3 _____ ; L4 _____ ; L5 _____

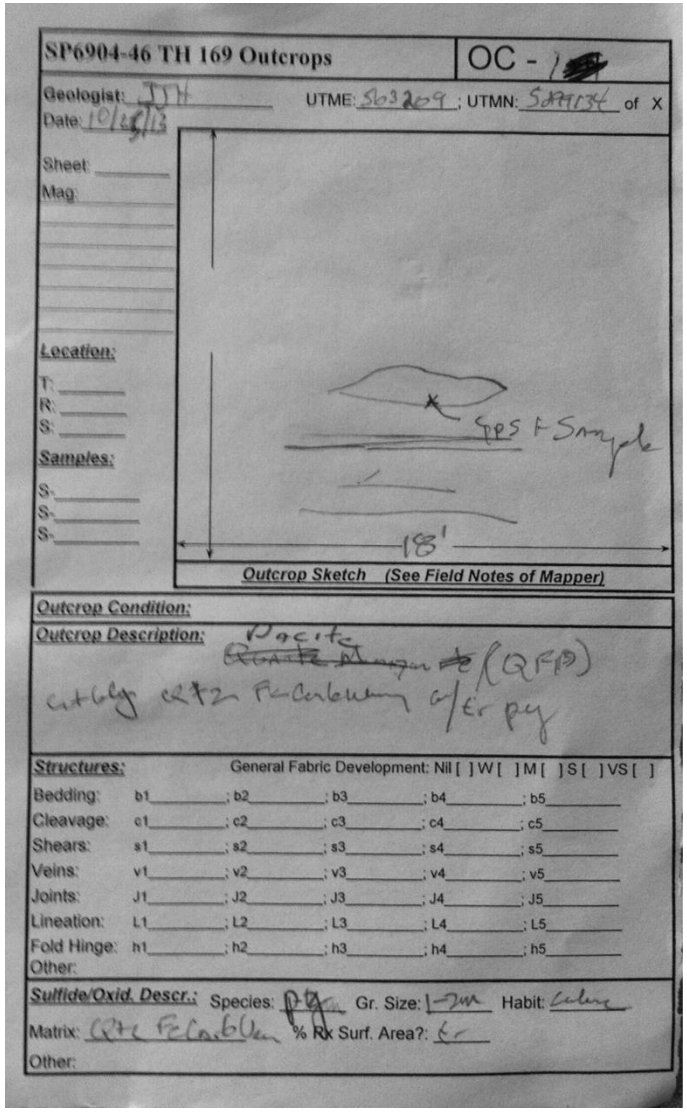
Fold Hinge: h1 _____ ; h2 _____ ; h3 _____ ; h4 _____ ; h5 _____

Other:

Sulfide/Oxid. Descr.: Species: Nil Gr. Size: _____ Habit: _____

Matrix: _____ % Rx Surf. Area?: _____

Other:



SP6904-46 TH 169 Outcrops | OC - 1

Geologist: JJH
Date: 10/4/13
UTME: 563209 ; UTMN: 5299134 of X

Sheet:
Mag:

Location:
T:
R:
S:

Samples:
S:
S:
S:

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition:

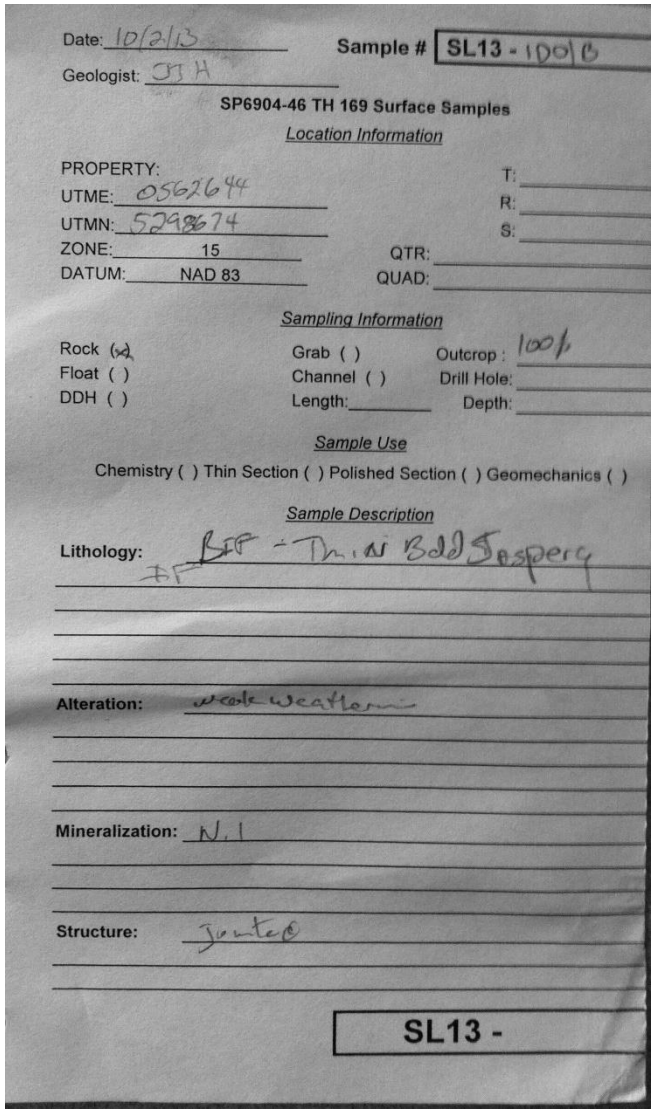
Outcrop Description: Dacite ~~Quartz Porphyry~~ (QFP)
cr+bly cr+2 Fe-Carbonate w/ tr py

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding:	b1	b2	b3	b4	b5
Cleavage:	c1	c2	c3	c4	c5
Shears:	s1	s2	s3	s4	s5
Veins:	v1	v2	v3	v4	v5
Joints:	J1	J2	J3	J4	J5
Lineation:	L1	L2	L3	L4	L5
Fold Hinge:	h1	h2	h3	h4	h5

Other:

Sulfide/Oxid. Descr.: Species: Py Gr. Size: 1-2mm Habit: Cubic
Matrix: Cr+ Fe-Carb % Rx Surf. Area?: tr
Other:



Date: 10/2/13 Sample # SL13 - 1006
Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:
UTME: 0562644
UTMN: 5298674
ZONE: 15
DATUM: NAD 83
T:
R:
S:
QTR:
QUAD:

Sampling Information

Rock (x) Grab ( ) Outcrop: 100%
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: BIF - Thin Bdd Jaspery
IF

Alteration: weak weathering

Mineralization: N.I

Structure: Jointed

SL13 -

Date: 10/3/13 Sample # SL13 - 1001A

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:
UTME: 562641
UTMN: 5298671
ZONE: 15
DATUM: NAD 83

T:
R:
S:
QTR:
QUAD:

Sampling Information

Rock (x) Grab ( ) Outcrop: 1001
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Diabase Dike

Alteration: weakly weathered / weak silicification

Mineralization: tr py 1mm cubic along Qtz-Carb veins and disseminated through the rock

Structure: Jointed

SL13 -

Date: 10/2/13 Sample # SL13 - 1000 B

Geologist: JJH

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY:
UTME: 0562620
UTMN: 5298627
ZONE: 15
DATUM: NAD 83

T:
R:
S:
QTR:
QUAD:

Sampling Information

Rock (x) Grab ( ) Outcrop: 1000
Float ( ) Channel ( ) Drill Hole:
DDH ( ) Length: Depth:

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Reg bedd mgt Banded IF

Alteration: weak weathering

Mineralization: N. I

Structure: —

SL13 -

Date: 10/2/13 Sample # SL13 - 1000A

Geologist: _____

SP6904-46 TH 169 Surface Samples

Location Information

PROPERTY: T: _____
ME: 562635 R: _____
N: 5298637 S: _____
ZONE: 15 QTR: _____
DATUM: NAD 83 QUAD: _____

Sampling Information

Rock Grab ( ) Outcrop : 1000
t ( ) Channel ( ) Drill Hole: _____
DDH ( ) Length: _____ Depth: _____

Sample Use

Chemistry ( ) Thin Section ( ) Polished Section ( ) Geomechanics ( )

Sample Description

Lithology: Iron formation Black 1-4" mgt bands w thin chert Bands. Qtz-carbonate in fold axis

Alteration: Weakly weathered

Mineralization: tr. fine py in Veins

Structure: fold in IF.

SL13 - 1000A

SP6904-46 TH 169 Outcrops OC - 1000

Geologist: JJH UTME: _____; UTMN: _____ of X

Date: 10/2/13

Sheet: _____

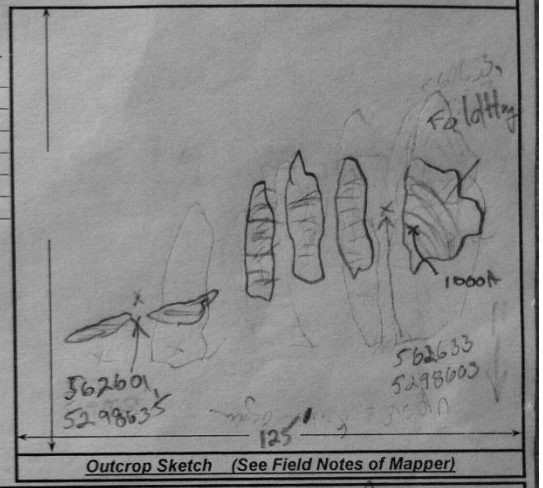
Mag: _____

Location:

T: _____
R: _____
S: _____

Samples:

S- _____
S- _____
S- _____



Outcrop Sketch (See Field Notes of Mapper)

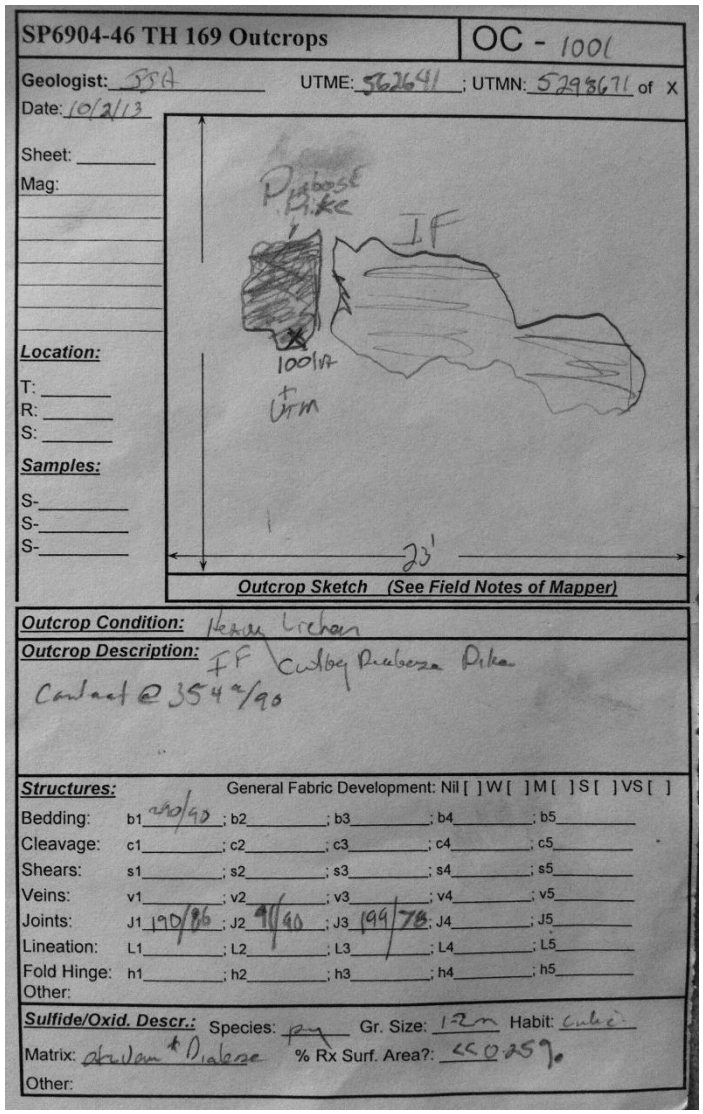
Outcrop Condition: Moss & Lichen Covered

Outcrop Description: Gandum IF - [illegible] Bands of Magnetite and Thin Bands of Chert. Highly Magnetic Bedding near 90° (E-W) minor qtz-carb veining in joints and in fold hinge tr py

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 N90/90°; b2 _____; b3 _____; b4 _____; b5 _____
Cleavage: c1 _____; c2 _____; c3 _____; c4 _____; c5 _____
Shears: s1 _____; s2 _____; s3 _____; s4 _____; s5 _____
Veins: v1 57/62°; v2 _____; v3 _____; v4 _____; v5 _____
Joints: J1 5/82°; J2 57/62°; J3 _____; J4 _____; J5 _____
Lineation: L1 _____; L2 _____; L3 _____; L4 _____; L5 _____
Fold Hinge: h1 51° ; h2 _____; h3 _____; h4 _____; h5 _____
Other:

Sulfide/Oxid. Descr.: Species: py Gr. Size: 1-3mm Habit: cubic
Matrix: Qtz/carbonate % Rx Surf. Area?: Much less than 1%
Other:



SP6904-46 TH 169 Outcrops | OC - 1001

Geologist: SSA UTME: 562641 ; UTMN: 5298671 of X

Date: 10/2/13

Sheet:

Mag:

Location:

T:

R:

S:

Samples:

S-

S-

S-

Diabase Dike

IF

100/1A

Utm

23'

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition: Heavy Lichen

Outcrop Description: IF / cutby Diabase Dike

Contact @ 354°/90

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 290/90 ; b2 ; b3 ; b4 ; b5

Cleavage: c1 ; c2 ; c3 ; c4 ; c5

Shears: s1 ; s2 ; s3 ; s4 ; s5

Veins: v1 ; v2 ; v3 ; v4 ; v5

Joints: J1 190/86 ; J2 91/40 ; J3 199/78 ; J4 ; J5

Lineation: L1 ; L2 ; L3 ; L4 ; L5

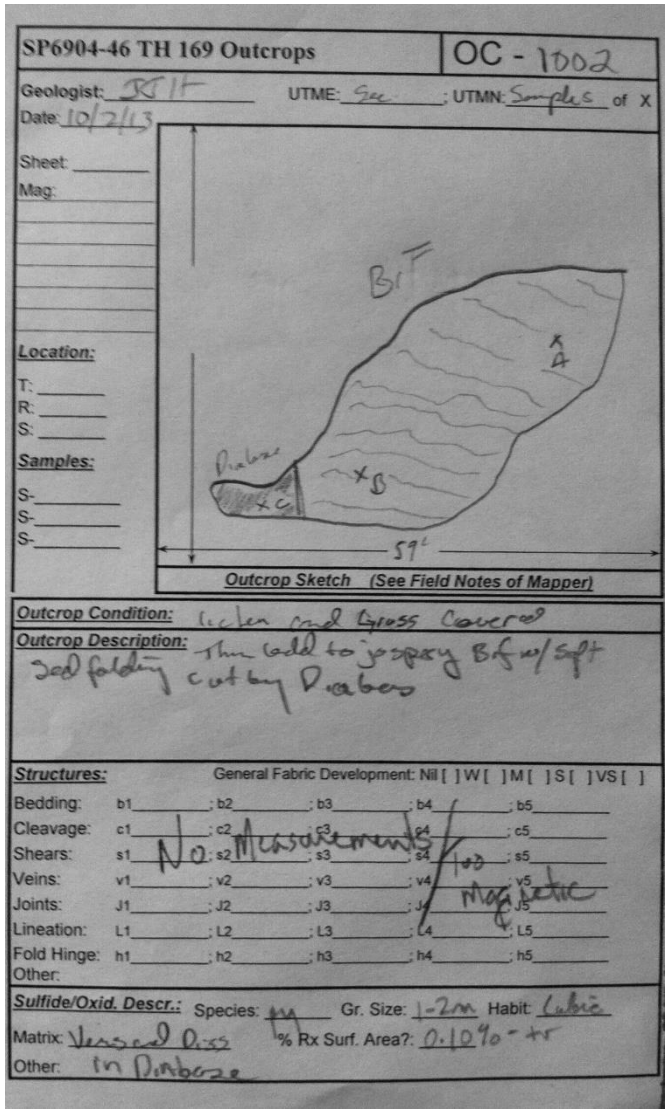
Fold Hinge: h1 ; h2 ; h3 ; h4 ; h5

Other:

Sulfide/Oxid. Descr.: Species: py Gr. Size: 1-2m Habit: cubic

Matrix: abundant Diabase % Rx Surf. Area?: << 0.25%

Other:



SP6904-46 TH 169 Outcrops | OC - 1002

Geologist: JSH UTME: See ; UTMN: Samples of X

Date: 10/2/13

Sheet:

Mag:

Location:

T:

R:

S:

Samples:

S-

S-

S-

BIF

Diabase

xA

xB

xC

59'

Outcrop Sketch (See Field Notes of Mapper)

Outcrop Condition: Lichen and Grass Covered

Outcrop Description: Thin bdd to jasperoy BIF w/ soft sed folding cutby Diabase

Structures: General Fabric Development: Nil [ ] W [ ] M [ ] S [ ] VS [ ]

Bedding: b1 ; b2 ; b3 ; b4 ; b5

Cleavage: c1 ; c2 ; c3 ; c4 ; c5

Shears: s1 ; s2 ; s3 ; s4 ; s5

Veins: v1 ; v2 ; v3 ; v4 ; v5

Joints: J1 ; J2 ; J3 ; J4 ; J5

Lineation: L1 ; L2 ; L3 ; L4 ; L5

Fold Hinge: h1 ; h2 ; h3 ; h4 ; h5

Other:

No Measurements / Magnetic

Sulfide/Oxid. Descr.: Species: py Gr. Size: 1-2m Habit: cubic

Matrix: Veinlet Diss % Rx Surf. Area?: 0.10% - tr

Other: in Diabase

APPENDIX E:

GIS DATA

https://drive.google.com/folderview?id=0B23uzT8P1ra-fkMwSXVNS3NpR2Q4T3RHb0F2SkNaNGV1aFJwSUVMdTl0ckc4TklXR3RieGs&usp=sharing

(Also included on CD with paper copies of this report)