MMI™ ANALYSIS OF SOME SELECTED NORTH AMERICAN SOILS OVER KNOWN GEOLOGY

INTRODUCTION & BACKGROUND

Soils are a product of weathering rock, and as such have the potential to be used to identify parent lithology. There is a wide variety of rock types and a near-continuum of elemental compositions; this study covers only a selected and limited number of rock types. It does however attempt to cover a wide range. For example, using the classification system based on percentage silica, felsic, intermediate and mafic classes have been incorporated. Within each class, soils over rock types with very different minerals and therefore elemental compositions are represented. Felsic rock types include granites, monzonites, and rhyolites with varying K, Ca and rare earth values.

Intermediate igneous rock types include granodiorites, tonalities and andesites, whilst sediments range from carbonates, greywackes and sandstones with varying chemistries, and mafic rock types include basalts with a wide range of compositions, gabbros , with high Cu and Ni and peridotite and diabase. In this study, soil samples were collected over several areas of North America where the underlying lithology is known and mapped; tills were specifically avoided. A consistent and systematic approach was used for collection of all MMI™ soil samples. Samples were sent to the SGS Minerals Laboratory in Burnaby BC for ICPMS analysis for 53 elements after MMI™ extraction.

The purpose of this Technical Bulletin is to provide an MMI™ elemental signature for each soil relating to the underlying lithology. It is contended that with the distinctive elemental signature for each rock type will be reflected in the soil as the available ions migrate and reside in the near soil surface, see TB29 for further details.

This Technical Bulletin describes the suitability of the MMI™ soil samples collected to be used as reference materials. MMI™ users can now compare these reference materials against their unknown MMI™ databases using the Degree of Geochemical Similarity (LithoID) interpretation technique (Caritat de & Mann 2018) previously investigated and discussed in TB30.

SAMPLE COLLECTION

Soil samples were collected over several areas of North America where geology of the underlying rock units are known and mapped. All samples were collected at the MMI™ recommended sampling protocols of 10 to 25 cm depth below air / soil interface or organic / soil interface. Three separate samples were collected at each site approximately 1 meter apart, along with a sample of the outcrop (if available). Pits were dug with a clean rust and paint free shovel to expose a minimum of 30 cm of soil beneath the interface (air/soil or organic/soil). A measuring device (plastic ruler) was used to identify the 10 to 25 cm interval to be sampled. Using the plastic scoop, approximately 300 grams of the soil was taken along the wall of the pit as a channel sample. Samples were placed in a ziplock type bag labelled with a permanent marker on the outside of the bag. Detailed notes were taken at each site to reference the soil characteristics as well as any other potential anthropogenic contamination. Pictures were taken at each site for further reference.

It must be noted that care was taken not to collect samples where commodity elements are anomalous as well in areas of potential anthropogenic contamination.

ANALYTICAL AND QUALITY CONTROL

The soil samples were sent to the SGS Minerals Laboratory in Burnaby BC for MMI-M analysis. Samples were analyzed using the standard MMI-M Accredited method. There is no sample preparation involved in the MMI-M method, samples are analyzed as received at the laboratory. Fifty grams of sample were extracted from each bag and mixed with 50mls of the MMI-M solution. The solution is then extracted and analyzed via ICPMS instrumentation for the following 53 elements: Ag, Al, As, Au, Ba, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hg, In, K, La, Li, Mg, Mn, Mo, Nb, Nd, Ni, P, Pb, Pd, Pr, Pt, Rb, Sb, Sc, Sm, Sn, Sr, Ta, Tb, Te, Th, Ti, Tl, U, W, Y, Yb, Zn, Zr.

Data Reproducibility-Analytical Replicates

With each batch of samples submitted to the SGS Burnaby laboratory for the MMI-M analyses, analytical replicates are analyzed to provide an assessment of the ability to reproduce analyses. It is observed that the replicate pairs exhibit good reproducibility across a wide range in concentration for most of the MMI-M elements. Typical acceptable variations between replicates for weak extractions is within +/- 25%. Very few replicates and elements exceed this level and therefore the reproducibility of the data is deemed acceptable for the intended purpose. Replicate analyses are shown in Table 1 for the major and some trace elements which are those elements typical of the rock forming processes.

Table 1: Replicate Analyses of the Major Elements and Some Trace Elements Typical of the Rock Forming Processes

ANALYTE	Al	Ca	Ce	Fe	K	Mg	Mn	Nb	Ni	P	Ti	Y	Zr
NV-3-1	12.0	1250	<2	5.0	75.2	105	11800	<0.5	206	<0.1	<10	39.0	8.0
REP-NV-3-1	13.0	1250	2.0	5.0	75.8	105	12400	<0.5	221	<0.1	<10	40.0	8.0
RPD (Relative %Diff)	**-8.0**	**0.0**	**0.0**	**0.0**	**-0.8**	**0.0**	**-5.0**	**0.0**	**-7.0**	**0.0**	**0.0**	**-2.5**	**0.0**
NB-5-1	202	19.0	74.0	53.0	19.7	2.8	1800	1.5	130	1.8	470	105	43.0
REP-NB-5-1	207	20.0	75.0	60.0	18.6	2.7	2000	1.6	129	1.8	500	101	43.0
RPD (Relative %Diff)	**-2.4**	**-5.1**	**-1.3**	**-2.4**	**5.7**	**3.6**	**-10.5**	**-6.5**	**0.8**	**0.0**	**-6.2**	**3.9**	**0.0**
NB-13-2	280	<2	179	50.0	4.5	<0.5	400.0	5.2	55.0	1.6	1330	129	45.0
REP-NB-13-2	261	<2	153	42.0	3.9	<0.5	300.0	4.5	62.0	1.6	1090	115	39.0
RPD (Relative %Diff)	**7.0**	**0.0**	**15.7**	**17.4**	**14.3**	**0.0**	**28.6**	**14.4**	**-2.0**	**0.0**	**19.8**	**11.5**	**14.3**
NS-8-1	216	<2	30.0	24.0	3.2	<0.5	<100	9.2	11.0	1.1	670.0	109	15.0
REP-NS-8-1	229	<2	33.0	27.0	3.7	<0.5	<100	10.6	17.0	1.3	770.0	104	17.0
RPD (Relative %Diff)	**-5.8**	**0.0**	**-9.5**	**11.8**	**-4.5**	**0.0**	**0.0**	**-4.1**	**-2.9**	**-6.7**	**-13.9**	**4.7**	**-12.5**
NS-10-1	211	<2	107	44.0	4.8	<0.5	300.0	7.0	29.0	0.8	1020	107	56.0
REP-NS-10-1	212	<2	102	44.0	5.7	<0.5	300.0	4.5	31.0	0.7	680.0	122	47.0
RPD (Relative %Diff)	**-0.5**	**0.0**	**4.8**	**0.0**	**-7.1**	**0.0**	**0.0**	**43.5**	**-6.7**	**13.3**	**40.0**	**-3.1**	**17.5**
BC-2-3	36.0	857.0	46.0	20.0	90.2	177	6100.0	<0.5	580	1.6	10.0	460	59.0
REP-BC-2-3	34.0	848.0	36.0	19.0	89.8	176	4700.0	<0.5	538	1.4	10.0	430	58.0
RPD (Relative %Diff)	**5.7**	**1.1**	**24.4**	**5.1**	**0.4**	**0.6**	**25.9**	**0.0**	**7.5**	**13.3**	**0.0**	**6.7**	**1.7**
BC-4-1	106	360.0	196	70.0	63.2	60.2	5700.0	2.3	79.0	2.5	130.0	104	97.0
REP-BC-4-1	110	347.0	217	72.0	65.0	59.0	6600.0	2.2	88.0	2.5	160.0	114	102.0
RPD (Relative %Diff)	**-3.7**	**3.7**	**-0.2**	**-2.8**	**-2.8**	**2.0**	**-14.6**	**4.4**	**-0.8**	**0.0**	**-20.7**	**-9.2**	**-5.0**
BC-8-1	50.0	390.0	180	45.0	193	97.6	5000.0	0.9	173	3.8	80.0	111	41.0
REP-BC-8-1	52.0	407.0	178	46.0	208	100	5100.0	1.0	182	3.7	80.0	114	40.0
RPD (Relative %Diff)	**-3.9**	**-4.3**	**1.1**	**-2.2**	**-7.5**	**-2.4**	**-2.0**	**-0.5**	**-5.1**	**2.7**	**0.0**	**-2.7**	**2.5**
ON-6-2	169	<2	65.0	24.0	7.3	<0.5	1200.0	1.3	886	1.0	430.0	73.0	21.0
REP-ON-6-2	147	<2	46.0	23.0	8.7	<0.5	1300.0	0.8	939	0.9	300.0	64.0	20.0
RPD (Relative %Diff)	**13.9**	**0.0**	**34.2**	**4.3**	**-7.5**	**0.0**	**-8.0**	**47.6**	**-5.8**	**10.5**	**35.6**	**13.1**	**4.9**

Standard Reference Materials

Each batch of samples submitted to the SGS Burnaby laboratory for MMI-M is analyzed along with standard reference materials. The analyses for MMI™ standard reference materials, MMISRM24, MMISRM19 and AMIS0169 indicate very good accuracy. Accuracy of the majors and some trace elements typical to rock forming processes are listed in Table 2.

Table 2: Accuracy of the Major and Some Trace Elements Typical of Rock Forming Processes

ANALYTE	Al	Ca	Ce	Fe	K	Mg	Mn	Nb	Ni	P	Ti	Y	Zr
DETECTION	**1**	**2**	**2**	**1**	**0.5**	**0.5**	**100**	**0.5**	**5**	**0.1**	**10**	**1**	**2**
UNITS	**ppm**	**ppm**	**ppb**	**ppm**	**ppm**	**ppm**	**ppb**	**ppb**	**ppb**	**ppm**	**ppb**	**ppb**	**ppb**
MMISRM24	32	63	46	4	12.8	7.8	300	<0.5	117	0.3	20	24	25
MMISRM24	34	53	40	8	10.8	10.7	200	<0.5	120	0.5	20	23	27
MMISRM24	27	53	31	4	10.6	8.9	200	<0.5	108	0.4	20	18	21
EXPECTED VALUES	**29**	**52**	**31.2**	**6.7**	**11**	**9.8**	**160**	**0.1**	**107**	**0.6**	**31**	**18.4**	**20.9**
TOLERANCE +/-	**33.6**	**29.6**	**36**	**57.3**	**31.3**	**32.8**	**186**	**1270**	**31.7**	**61.7**	**100**	**33.6**	**43.9**
MMISRM19	24	799	11	10	99	206	4500	<0.5	2150	0.5	<10	63	16
EXPECTED VALUES	**18**	**612**	**19**	**4**	**87.6**	**165**	**5857**	**0.2**	**2038**	**0.4**	**10.1**	**47**	**13**
TOLERANCE +/-	**38.9**	**20.8**	**46.3**	**82.5**	**21.4**	**20.8**	**34**	**6270**	**20.6**	**82.5**	**277**	**25.3**	**58.5**
AMIS0169	62	36	803	42	40.9	30.7	3800	2.5	417	2.4	410	124	51
AMIS0169	57	37	720	36	45.1	30.1	4000	2.1	382	2.1	340	122	46
EXPECTED VALUES	**54**	**38.8**	**685**	**35.8**	**40.2**	**31.1**	**3815**	**2.5**	**388**	**2.1**	**362**	**111**	**44.2**
TOLERANCE +/-	**29.6**	**32.9**	**20.7**	**27**	**23.1**	**24**	**36.6**	**70**	**23.2**	**31.9**	**37**	**22.3**	**31.3**

Analytical Blanks

Analytical blanks are also included in each batch of MMI™ samples being analyzed. This helps to determine if there is any cross contamination between samples as well as carry over from high samples. Table 3 indicates that there is no contamination that has occurred with any of the sample batches.

Table 3: Analyses of Analytical Blanks

ANALYTE	Al	Ca	Ce	Fe	K	Mg	Mn	Nb	Ni	P	Ti	Y	Zr
DETECTION	1	2	2	1	0.5	0.5	100	0.5	5	0.1	10	1	2
UNITS	ppm	ppm	ppb	ppm	ppm	ppm	ppb	ppb	ppb	ppm	ppb	ppb	ppb
BLANK	<1	<2	<2	<1	<0.5	<0.5	<100	<0.5	<5	<0.1	<10	<1	<2
BLANK	<1	<2	<2	<1	<0.5	<0.5	<100	<0.5	<5	<0.1	<10	<1	<2
BLANK	<1	<2	<2	<1	<0.5	<0.5	<100	<0.5	<5	<0.1	<10	<1	<2
BLANK	<1	<2	<2	<1	<0.5	<0.5	<100	<0.5	<5	<0.1	<10	<1	<2
BLANK	<1	<2	<2	<1	<0.5	<0.5	<100	<0.5	<5	<0.1	<10	<1	<2
BLANK	<1	<2	<2	<1	<0.5	<0.5	<100	<0.5	<5	<0.1	<10	<1	<2

SAMPLING LOCATIONS

Samples were collected in the following locations: Nevada USA, New Brunswick, Nova Scotia, British Columbia and Ontario Canada. Sample sites were chosen using published geological maps by the various geological surveys. In certain locations (New Brunswick and Nova Scotia) samples were collected with the area geological survey geologists and other areas (BC and Ontario) with the aid and recommendations of the local Geological Survey Resident Geologists.

See details on the specific locations of the sample collections in each of these areas.

Nevada

The USGS 2007 Geology map of Nevada (Crafford), scale of 1:250,000 was utilized to identify suitable areas of sample collection. Figure 1 below shows the Google Earth map of Nevada outlining the sample collection sites.

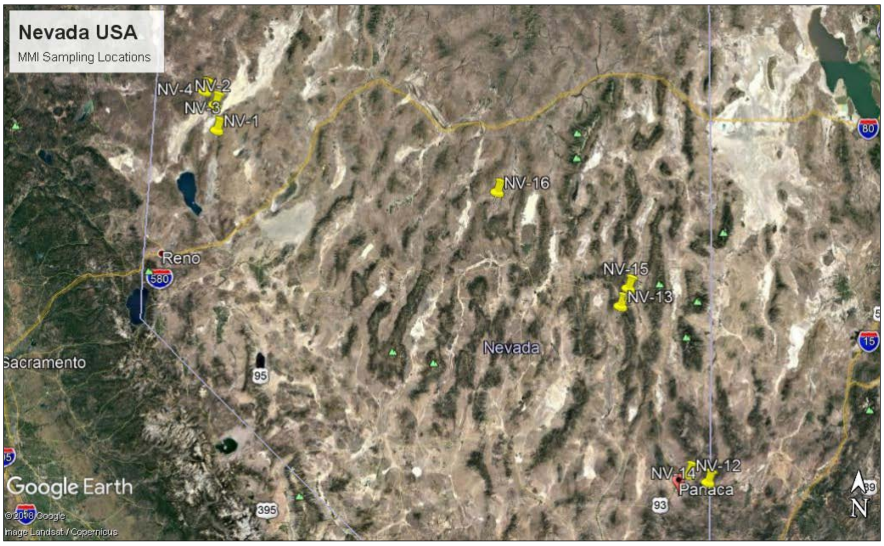

Figure 1: Google Earth Map of MMI™ Sampling Locations in Nevada, USA

Table 4 provides the UTM locations along with the respective rock unit identified by the geological map for each sample location.

Table 4: MMI™ Sampling Locations, Nevada USA

Sample	Long	Lat	Location	Geology	Class	Code
NV1-1	-119.35093	40.35482	Wadsworth, NV	Andesite	Intermediate	2
NV1-2	-119.35093	40.35482	Wadsworth, NV	Andesite	Intermediate	2
NV2-1	-119.37181	40.66728	Gerlach, NV	Felsic Phaneritic	Felsic	1
NV2-2	-119.37181	40.66728	Gerlach, NV	Felsic Phaneritic	Felsic	1
NV3-1	-119.53008	40.82140	Gerlach, NV	Rhyolite	Felsic	1
NV3-2	-119.53008	40.82140	Gerlach, NV	Rhyolite	Felsic	1
NV4-1	-119.52890	40.82167	Gerlach, NV	Basalt	Mafic	3
NV4-2	-119.52890	40.82167	Gerlach, NV	Basalt	Mafic	3
NV12-1	-114.31489	37.78695	Gerlach, NV	Sedimentary	Intermediate	2
NV12-2	-114.31489	37.78695	Gerlach, NV	Sedimentary	Intermediate	2
NV13-1	-115.00729	39.19579	Ely, NV	Limestone	Intermediate	2
NV13-2	-115.00729	39.19579	Ely, NV	Limestone	Intermediate	2
NV14-1	-114.20111	37.77182	Gerlach, NV	Andesite	Intermediate	2
NV14-2	-114.20111	37.77182	Gerlach, NV	Andesite	Intermediate	2
NV15-1	-114.95532	39.27033	Ely, NV	Rhyolite	Felsic	1
NV15-2	-114.95532	39.27033	Ely, NV	Rhyolite	Felsic	1
NV16-1	-116.38761	40.02277	Cortez Mountain, NV	Basalt	Mafic	3
NV16-2	-116.38761	40.02277	Cortez Mountain, NV	Basalt	Mafic	3

New Brunswick, Canada

The Bedrock Geology of New Brunswick Map NR-1 (2008 Edition), scale 1:500,000, as well as the Open File 4182 Geology Bathurst Mining Camp and Surrounding Area Map , scale 1:100,000, and the Bedrock Geology of Southwestern New Brunswick (NTS 21 G, Part of 21B), scale 1:250,000 were used for determining the sample locations within New Brunswick.

Figure 2 shows the Google Earth map of New Brunswick outlining the sample collection sites.

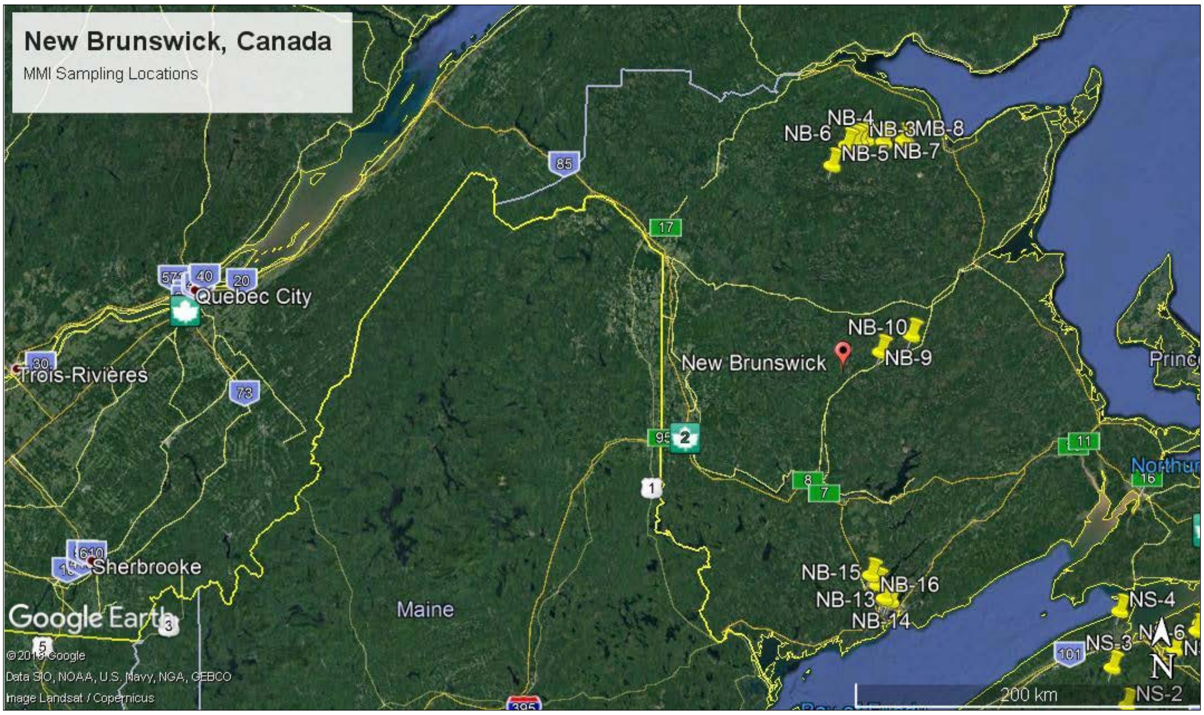

Figure 2: Google Earth Map of MMI™ Sampling Locations in New Brunswick, Canada

Table 5 provides the UTM locations along with the respective rock unit identified by the geological maps for each sample location.

Table 5: MMI™ Sampling Locations in New Brunswick, Canada

Sample	Long	Lat	Location	Geology	Class	Code
NB-1-1	-66.02276	47.57961	Bathurst Camp, NB	Pillow Basalt	Mafic	3
NB-1-2	-66.02276	47.57961	Bathurst Camp, NB	Pillow Basalt	Mafic	3
NB-2-1	-66.33585	47.58218	Bathurst Camp, NB	Rhyolite	Felsic	1
NB-2-2	-66.33585	47.58218	Bathurst Camp, NB	Rhyolite	Felsic	1
NB-3-1	-66.37573	47.57047	Bathurst Camp, NB	Sediments	Intermediate	2
NB-3-2	-66.37573	47.57047	Bathurst Camp, NB	Sediments	Intermediate	2
NB-4-1	-66.39912	47.56841	Bathurst Camp, NB	Mafic	Mafic	3
NB-4-2	-66.39912	47.56841	Bathurst Camp, NB	Mafic	Mafic	3
NB-5-1	-66.55934	47.44793	Bathurst Camp, NB	Felsic	Felsic	1
NB-5-2	-66.55934	47.44793	Bathurst Camp, NB	Felsic	Felsic	1
NB-6-1	-66.4603	47.55391	Bathurst Camp, NB	Mafic	Mafic	3
NB-6-2	-66.4603	47.55391	Bathurst Camp, NB	Mafic	Mafic	3
NB-7-1	-66.18897	47.57073	Bathurst Camp, NB	Felsic	Felsic	1
NB-7-2	-66.18897	47.57073	Bathurst Camp, NB	Felsic	Felsic	1
NB-8-1	-66.00882	47.58119	Bathurst Camp, NB	Basalt	Mafic	3
NB-8-2	-66.00882	47.58119	Bathurst Camp, NB	Basalt	Mafic	3
NB-9-1	-65.90294	46.60825	Miramichi, NB	Carboniferous	Intermediate	2
NB-9-2	-65.90294	46.60825	Miramichi, NB	Carboniferous	Intermediate	2
NB-10-1	-66.19567	45.35296	Miramichi, NB	Carboniferous	Intermediate	2
NB-10-2	-66.19567	45.35296	Miramichi, NB	Carboniferous	Intermediate	2
NB-11-1	-66.34413	45.46115	Welfords, Southern NB	Granite Monzonite composition	Felsic	1
NB-11-2	-66.34413	45.46115	Welfords, Southern NB	Granite Monzonite composition	Felsic	1
NB-12-1	-66.20111	46.26985	Welfords, Southern NB	Tonalite	Intermediate	2
NB-12-2	-66.20111	46.26985	Welfords, Southern NB	Tonalite	Intermediate	2
NB-13-1	-66.17493	45.27048	Welfords, Southern NB	Diabase	Mafic	3
NB-13-2	-66.17493	45.27048	Welfords, Southern NB	Diabase	Mafic	3
NB-14-1	-66.19611	45.2864	Welfords, Southern NB	Granite	Felsic	1
NB-14-2	-66.19611	45.2864	Welfords, Southern NB	Granite	Felsic	1
NB-15-1	-66.2443	45.35066	Nerepis Area Southern NB	Basalt	Mafic	3
NB-15-2	-66.2443	45.35066	Nerepis Area Southern NB	Basalt	Mafic	3
NB-16-1	-66.31625	45.42462	Nerepis Area Southern NB	Syenite	Intermediate	2
NB-16-2	-66.31625	45.42462	Nerepis Area Southern NB	Syenite	Intermediate	2

Nova Scotia

Map ME 2000-1, Geological Map of the Province of Nova Scotia, scale 1:500,000 and Geological Map of the Truro Area (NTS 11E/06) Nova Scotia, scale 1:50,000 were the maps used to identify the sampling locations.

Figure 3 shows the Google Earth map of Nova Scotia outlining the sample collection sites.

Figure 3 : Google Earth Map of MMI™ Sampling Locations in Nova Scotia, Canada

Table 6 provides the UTM locations along with the respective rock unit identified by the geological maps for each sample location.

Table 6: MMI™ Sampling Locations in Nova Scotia, Canada

Sample	Long	Lat	Location	Geology	Class	Code
NS-2-1	-64.42392	44.68972	SW Nova Scotia	Leucomonzo granite	Felsic	1
NS-2-2	-64.42392	44.68972	SW Nova Scotia	Leucomonzo granite	Felsic	1
NS-2-3	-64.42392	44.68972	SW Nova Scotia	Leucomonzo granite	Felsic	1
NS-3-1	-64.52907	44.84571	SW Nova Scotia	Granodiorite	Intermediate	2
NS-3-2	-64.52907	44.84571	SW Nova Scotia	Granodiorite	Intermediate	2
NS-3-3	-64.52907	44.84571	SW Nova Scotia	Granodiorite	Intermediate	2
NS-4-1	-64.45458	45.19168	South Bay of Fundy, NS	Flood Basalt	Mafic	3
NS-4-2	-64.45458	45.19168	South Bay of Fundy, NS	Flood Basalt	Mafic	3
NS-5-1	-64.02508	44.9701	Central South Bay of Fundy, NS	Gypsum	Intermediate	2
NS-5-2	-64.02508	44.9701	Central South Bay of Fundy, NS	Gypsum	Intermediate	2
NS-6-1	-63.9699	45.05823	Central South Bay of Fundy, NS	Limestone	Intermediate	2
NS-6-2	-63.9699	45.05823	Central South Bay of Fundy, NS	Limestone	Intermediate	2
NS-7-1	-63.84938	45.03495	Central South Bay of Fundy, NS	Slate Meguma Group	Intermediate	2
NS-7-2	-63.84938	45.03495	Central South Bay of Fundy, NS	Slate Meguma Group	Intermediate	2
NS-8-1	-63.4831	45.58403	North Bay of Fundy, NS	A-Type Granite	Felsic	1
NS-8-2	-63.4831	45.58403	North Bay of Fundy, NS	A-Type Granite	Felsic	1
NS-9-1	-63.42651	45.59385	North Bay of Fundy, NS	Diorite	Intermediate	2
NS-9-2	-63.42651	45.59385	North Bay of Fundy, NS	Diorite	Intermediate	2
NS-10-1	-63.41972	45.608	North Bay of Fundy, NS	Rhyolite	Felsic	1
NS-10-2	-63.41972	45.608	North Bay of Fundy, NS	Rhyolite	Felsic	1
NS-11-1	-63.36951	45.61008	North Bay of Fundy, NS	Basalt	Mafic	3
NS-11-2	-63.36951	45.61008	North Bay of Fundy, NS	Basalt	Mafic	3
NS-12-1	-63.37063	45.66913	North Bay of Fundy, NS	Siltstones	Intermediate	2
NS-12-2	-63.37063	45.66913	North Bay of Fundy, NS	Siltstones	Intermediate	2
NS-13-1	-63.26803	45.51864	North Bay of Fundy, NS	I-Type Granite	Felsic	1
NS-13-2	-63.26803	45.51864	North Bay of Fundy, NS	I-Type Granite	Felsic	1
NS-14-1	-63.03016	45.40723	NE of Bay of Fundy, NS	Siltstone, Sandstone	Intermediate	2
NS-14-2	-63.03016	45.40723	NE of Bay of Fundy, NS	Siltstone, Sandstone	Intermediate	2
NS-15-1	-63.71222	45.01302	Central South Bay of Fundy, NS	Greywacke	Intermediate	2
NS-15-2	-63.71222	45.01302	Central South Bay of Fundy, NS	Greywacke	Intermediate	2

British Columbia

Samples were collected in BC from two general areas. The first being south of the town of Merritt along Coldwater Road. The geology map used was from the BC Geological Survey Open File 2008-8 (Diakow 2007-08). Map scale 1:50,000.

The second set of samples were collected near Tulameen and Coalmont areas. The geology map used was from the BC Geological Survey Open File 2018-2 (Nixon). Map scale 1:20,000.

Figures 4 and 5 shows the Google Earth maps of British Columbia outlining the sample collection sites.

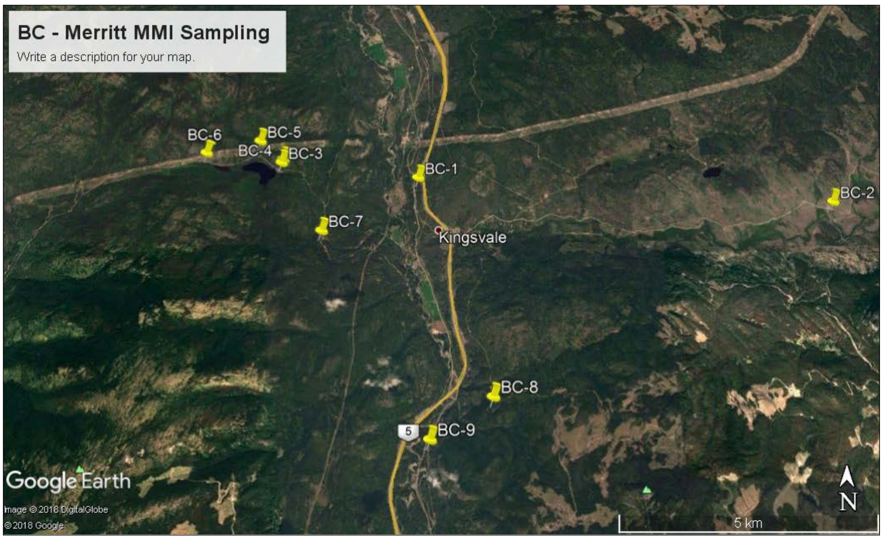

Figure 4 : Google Earth Map of MMI™ Sampling Locations near Merritt British Columbia, Canada

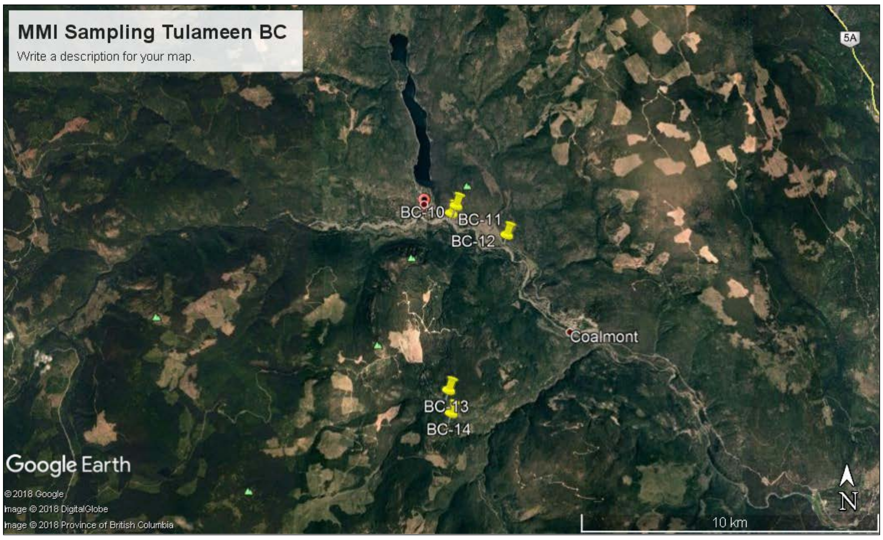

Figure 5: Google Earth Map MMI™ Sampling near Tulameen British Columbia, Canada

Table 7 provides the UTM locations along with the respective rock unit identified by the geological maps for each sample location.

Table 7: MMI™ Sampling Locations in British Columbia, Canada

Sample	Long	Lat	Location	Geology	Class	Code
BC-1-1	-120.92784	49.96708	Southwest Merritt, BC	Dacite	Intermediate	2
BC-1-2	-120.92784	49.96708	Southwest Merritt, BC	Dacite	Intermediate	2
BC-1-3	-120.92784	49.96708	Southwest Merritt, BC	Dacite	Intermediate	2
BC-2-1	-120.79434	49.91421	Southwest Merritt, BC	Andesite	Intermediate	2
BC-2-2	-120.79434	49.91421	Southwest Merritt, BC	Andesite	Intermediate	2
BC-2-3	-120.79434	49.91421	Southwest Merritt, BC	Andesite	Intermediate	2
BC-3-1	-120.95049	49.92099	Southwest Merritt, BC	Diorite	Intermediate	2
BC-3-2	-120.95049	49.92099	Southwest Merritt, BC	Diorite	Intermediate	2
BC-3-3	-120.95049	49.92099	Southwest Merritt, BC	Diorite	Intermediate	2
BC-4-1	-120.95208	49.92275	Southwest Merritt, BC	Pyroxene Andesite	Intermediate	2
BC-4-2	-120.95208	49.92275	Southwest Merritt, BC	Pyroxene Andesite	Intermediate	2
BC-4-3	-120.95208	49.92275	Southwest Merritt, BC	Pyroxene Andesite	Intermediate	2
BC-5-1	-120.96348	49.92642	Southwest Merritt, BC	Rhyolite	Felsic	1
BC-5-2	-120.96348	49.92642	Southwest Merritt, BC	Rhyolite	Felsic	1
BC-5-3	-120.96348	49.92642	Southwest Merritt, BC	Rhyolite	Felsic	1
BC-6-1	-120.97984	49.92354	Southwest Merritt, BC	Granodiorite	Intermediate	2
BC-6-2	-120.97984	49.92354	Southwest Merritt, BC	Granodiorite	Intermediate	2
BC-6-3	-120.97984	49.92354	Southwest Merritt, BC	Granodiorite	Intermediate	2
BC-7-1	-121.01572	49.91401	Southwest Merritt, BC	Diorite	Intermediate	2
BC-7-2	-121.01572	49.91401	Southwest Merritt, BC	Diorite	Intermediate	2
BC-7-3	-121.01572	49.91401	Southwest Merritt, BC	Diorite	Intermediate	2
BC-8-1	-120.89268	49.87615	Southwest Merritt, BC	Andesite	Intermediate	2
BC-8-2	-120.89268	49.87615	Southwest Merritt, BC	Andesite	Intermediate	2
BC-8-3	-120.89268	49.87615	Southwest Merritt, BC	Andesite	Intermediate	2
BC-9-1	-120.90993	49.87245	Southwest Merritt, BC	Rhyolite	Felsic	1
BC-9-2	-120.90993	49.87245	Southwest Merritt, BC	Rhyolite	Felsic	1
BC-9-3	-120.90993	49.87245	Southwest Merritt, BC	Rhyolite	Felsic	1
BC-10-1	-120.74884	49.54229	Tulameen, BC	Gabbro	Mafic	3
BC-10-2	-120.74884	49.54229	Tulameen, BC	Gabbro	Mafic	3
BC-10-3	-120.74884	49.54229	Tulameen, BC	Gabbro	Mafic	3
BC-11-1	-120.86681	49.54004	Tulameen, BC	Siltstone, Limestone	Intermediate	2
BC-11-2	-120.86681	49.54004	Tulameen, BC	Siltstone, Limestone	Intermediate	2
BC-11-3	-120.86681	49.54004	Tulameen, BC	Siltstone, Limestone	Intermediate	2
BC-12-1	-120.72323	49.53379	Tulameen, BC	Granodiorite	Intermediate	2
BC-12-2	-120.72323	49.53379	Tulameen, BC	Granodiorite	Intermediate	2
BC-12-3	-120.72323	49.53379	Tulameen, BC	Granodiorite	Intermediate	2
BC-13-1	-120.76138	49.49983	Tulameen, BC	Olivine basalt	Mafic	3
BC-13-2	-120.76138	49.49983	Tulameen, BC	Olivine basalt	Mafic	3
BC-13-3	-120.76138	49.49983	Tulameen, BC	Olivine basalt	Mafic	3
BC-14-1	-120.74789	49.48186	Tulameen, BC	Sediments	Intermediate	2
BC-14-2	-120.74789	49.48186	Tulameen, BC	Sediments	Intermediate	2
BC-14-3	-120.74789	49.48186	Tulameen, BC	Sediments	Intermediate	2

Ontario

Ontario Geological Survey Map 2491 Sudbury Geological Compilation, Sudbury District, scale 1:50,000 as well as Bedrock Geology of Ontario Map 2544, scale 1:1,000,000 was used to identify the MMI™ sampling locations.

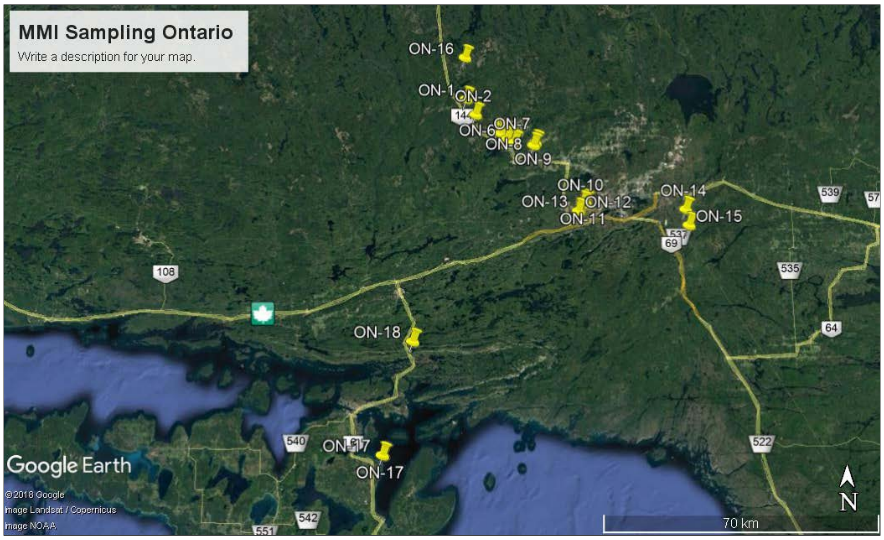

Figure 6: Google Earth Map MMI™ Sampling Locations in Ontario, Canada

Figure 6 shows the Google Earth map of Ontario outlining the sample collection sites.

Table 8 provides the UTM locations along with the respective rock unit identified by the geological maps for each sample location.

Table 8: MMI™ Sampling Locations in Ontario, Canada

Sample	Long (W)	Lat (N)	Location	Geology	Class	Code
ON-1-1	-81.5528	46.70006	Cartier, Ont.	Granite	Felsic	1
ON-1-2	-81.5528	46.70006	Cartier, Ont.	Granite	Felsic	1
ON-2-1	-81.5128	46.65924	Cartier, Ont.	Migmatite	Felsic	1
ON-2-2	-81.5128	46.65924	Cartier, Ont.	Migmatite	Felsic	1
ON-3-1	-81.4443	46.62437	Cartier, Ont.	Quartz Gabbro	Felsic	1
ON-3-2	-81.4443	46.62437	Cartier, Ont.	Quartz Gabbro	Felsic	1
ON-4-1	-81.4282	46.61524	Windy Lake, Ont.	Norite Felsic	Felsic	1
ON-4-2	-81.4282	46.61524	Windy Lake, Ont.	Norite Felsic	Felsic	1
ON-5-1	-81.412	46.61721	HWY 144 & RR 8, Ont.	Quartz Gabbro	Felsic	1
ON-5-2	-81.412	46.61721	HWY 144 & RR 8, Ont.	Quartz Gabbro	Felsic	1
ON-6-1	-81.4118	46.60216	Windy Lake, Ont.	Granophyre	Felsic	1
ON-6-2	-81.4118	46.60216	Windy Lake, Ont.	Granophyre	Felsic	1
ON-7-1	-81.383	46.5933	High Falls, Onaping, Ont.	Onaping Formation	Intermediates	2
ON-7-2	-81.383	46.5933	High Falls, Onaping, Ont.	Onaping Formation, Black Member	Intermediates	2
ON-8-1	-81.3255	46.58592	Dowling, Ont.	Shale, Onwatin Formation	Intermediates	2
ON-8-2	-81.3255	46.58592	Dowling, Ont.	Shale, Onwatin Formation	Intermediates	2
ON-9-1	-81.3081	46.5912	Morgan Road, Chelmsford, Ont.	Greywacke, Chelmsford Formation	Intermediates	2
ON-9-2	-81.3081	46.5912	Morgan Road, Chelmsford, Ont.	Greywacke, Chelmsford Formation	Intermediates	2
ON-10-1	-81.1477	46.44244	Lively, Ont.	Basalt	Mafic	3
ON-10-2	-81.1477	46.44244	Lively, Ont.	Basalt	Mafic	3
ON-11-1	-81.1452	46.44671	Lively, Ont.	Basalt	Mafic	3
ON-11-2	-81.1452	46.44671	Lively, Ont.	Basalt	Mafic	3
ON-12-1	-81.171	46.42847	Lively, Ont.	Basalt	Mafic	3
ON-12-2	-81.171	46.42847	Lively, Ont.	Basalt	Mafic	3
ON-13-1	-81.1626	46.42682	Lively, Ont.	Basalt	Mafic	3
ON-13-2	-81.1626	46.42682	Lively, Ont.	Basalt	Mafic	3
ON-14-1	-80.795	46.42439	Wahnapitae, Ont.	Gabbro	Mafic	3
ON-14-2	-80.795	46.42439	Wahnapitae, Ont.	Gabbro	Mafic	3
ON-15-1	-80.7879	46.39236	Wahnapitae, Ont.	Serpentine peridotite and olivine diabase	Mafic	3
ON-15-2	-80.7879	46.39236	Wahnapitae, Ont.	Serpentine peridotite and olivine diabase	Mafic	3
ON-16-1	-81.5487	46.80549	North Cartier, Ont.	Olivine Diabase	Mafic	3
ON-16-2	-81.5487	46.80549	North Cartier, Ont.	Olivine Diabase	Mafic	3
ON-17-1	-81.8303	45.86019	Manitoulin Island, Ont.	Limestone	Intermediates	2
ON-17-2	-81.8303	45.86019	Manitoulin Island, Ont.	Limestone	Intermediates	2
ON-18-1	-81.7313	46.11985	Whitefish Falls, Ont.	Quartz	Felsic	1
ON-18-1	-81.7313	46.11985	Whitefish Falls, Ont.	Quartz	Felsic	1

STATISTICAL EXAMINATION OF SOILS OVER DIFFERENT ROCK TYPES

In summary there are a total of 158 reference MMI™ soil samples collected in specific regions of North America, 45 of which are soils over felsic units, 73 are soils over intermediates and sediments and 40 are soils over mafic units. See below Table 9 for a breakdown of the samples.

Table 9: Summary of Samples Collected in North America

LOCATION	FELSIC – Class 1	INT/SEDS – Class 2	MAFIC – Class 3
Ontario	14	8	14
New Brunswick / Nova Scotia	19	27	16
British Columbia	6	30	6
Nevada	6	8	4
TOTAL	**45**	**73**	**40**

The soil data has been analyzed using simple statistics (max, min, medians and standard deviations) of the raw MMI™ data as well as plotting the relevant elements versus rock types. In the process of "fingerprinting" soils to rock types we have concentrated on using those elements that determine the various rock types or classes.

Table 10 below is a summary of the median values for each class of some of the rock forming elements. The intermediate class has the highest median values for some elements (e.g. Ba, Ca, Mg, Mn, Sr) compared to those in felsic and mafic classes. Sediments, which includes limestones and dolomites have been included in Class 2.

Table 10: Median Values

Sample	Al	Ba	Ca	Ce	Fe	K	Mg	Mn	Nb	Ni	P	Rb	Sr	Ti	Y	Zr
FELSIC MEDIAN	193	270	7.0	65	40	12	2.3	650	1.6	182	1.2	115	30	500	94	30
INT/SEDS MEDIAN	125	1480	373	82	42	28	33	1550	1	203	2.2	83	1410	80	103	46
MAFIC MEDIAN	197	920	20	87	48	24	5.0	950	3.2	212	2.5	160	60	835	110	42

Soils over Felsic Rock Types

Felsic rocks typically contain >69% SiO_2 and are rich in feldspar minerals. Granite and granite –like rocks, called granitoids come in many varieties. Classifying them can be difficult and is typically based on a balance of quartz, alkali feldspar and plagioclase. Some granites can be very alkali rich (high feldspar and no plagioclase) others can be plagioclase rich such as tonalite. The middle of the road granite (equal portions of alkali and plagioclase feldspar) is called monzogranite.

Monzonite is a granite type rock but contains less silica than granite. Rhyolite is also very silica rich but there are subtle differences between rhyolites and granites. The mica found in rhyolite is black biotite, not the brown muscovite mica typically found in granites, and its potassium feldspar is sanidine while that of granite is orthoclase.

Table 11 below illustrates the increase of values for the rare earth elements in a monzonite rock versus rhyolite rock samples.

The Sudbury Igneous Complex hosts a variety of felsic rocks. A quartz rich felsic norite from the lower zone of north range was collected

Table 11: Median Values for Rhyolite and Monzonite Samples

GEOLOGY	Sample	Ce	Dy	Gd	La	Nd	Sm	Th	Y
Rhyolite	NB-2-1-FEL	34	24.8	12.2	13	25	8	12.5	128
Rhyolite	NB-2-2-FEL	9	12.4	4.4	3	8	2	7.6	63
Rhyolite	NS-10-1-FEL	107	25.2	17.8	36	62	15	10.8	107
Rhyolite	NS-10-2-FEL	68	18.7	12.5	23	38	10	7.1	79
	MEDIAN	**51**	**22**	**12**	**18**	**32**	**9**	**9**	**93**
Granite - Monzonite	NB-11-1-FEL	208	117	116	168	384	101	35.7	761
Granite - Monzonite	NB-11-2-FEL	180	54.4	39.6	77	139	36	56.9	298
	MEDIAN	**194**	**86**	**78**	**123**	**262**	**69**	**46**	**530**

as well a sample from the granophyre - quartz gabbro contact from the middle zone (which occurs all around the complex) and a migmatite sample also from the north zone. The felsic norite contains plagioclase and hypersthene as cumulus phases, intercumulus minerals are augite, biotite and quartz (Dressler, Peredery, Muir 1992). The granophyre consists of three parts K-feldspar and quartz to one part plagioclase, accessory minerals include amphibole, biotite, chlorite and Fe-Ti oxides. The quartz gabbro contains higher levels of magnetite grains and can have large variations of silica content. Migmatite consists of dark gneiss, schist or amphibolite stripped bands of pale colored rock usually consisting of granite.

The MMI™ data suggests variations in a number of elements for the soils over different felsic units within the Sudbury Igneous complex, as shown in Table 12.

Table 12: Median Values between Several Felsic Rock Types

GEOLOGY	Sample	Ca	Ce	Fe	K	Mg	Nd	Ni	P	Sr	Th	Ti
Migmatite	ON-2-1	1	456	19	5	0.25	272	255	0.8	0.5	57	360
Migmatite	ON-2-2	1	141	13	6	0.25	131	164	0.3	0.5	15	500
	MEDIAN	**1**	**299**	**16**	**5**	**0**	**202**	**210**	**1**	**1**	**36**	**430**
Norite - Felsic	ON-4-1	20	70	22	10	0.8	38	571	0.4	220	9	140
Norite - Felsic	ON-4-2	6	144	13	6	0.25	104	985	0.8	10	36	230
	MEDIAN	**13**	**107**	**18**	**8**	**1**	**71**	**778**	**1**	**115**	**22**	**185**
Granophyre - Quartz Gabbro Contact	ON-3-1	8	251	70	15	2.1	165	1460	4.5	120	56	1560
Granophyre - Quartz Gabbro Contact	ON-3-2	7	255	50	17	1.3	163	988	3.4	60	46	1740
	MEDIAN	**8**	**253**	**60**	**16**	**2**	**164**	**1224**	**4**	**90**	**51**	**1650**
Granophyre - Quartz Gabbro Contact	ON-5-1	7	758	46	8	1	353	906	2.7	20	64	1560
Granophyre - Quartz Gabbro Contact	ON-5-2	16	851	50	12	2.3	461	2150	5.2	60	106	850
	MEDIAN	**12**	**805**	**48**	**10**	**2**	**407**	**1528**	**4**	**40**	**85**	**1205**
Granophyre	ON-6-1	1	11	41	21	1.2	6	2360	0.5	0.5	7	180
Granophyre	ON-6-2	1	65	24	7	0.25	39	886	1	0.5	22	430
	MEDIAN	**1**	**38**	**33**	**14**	**1**	**23**	**1623**	**1**	**1**	**15**	**305**

Soils over Intermediate Rock Types

Table 13 highlights the median differences between two intermediate rocks, syenite and diorite. Syenite is a feldspathoid bearing alkali feldspar rock compared to diorite being a feldspathoid bearing plagioclase feldspar rock.

Table 13: MMI™ Data Comparison between Syenite and Diorite Rock Samples

GEOLOGY	SAMPLE	Ca	Ce	Dy	Gd	K	Nd	Pr	Th	Y
Syenite	NB-16-1-INT	25	1340	532	525	8	2110	468	170	2350
Syenite	NB-16-2-INT	27	1180	343	414	8.6	1750	420	89	1810
	MEDIAN	**26**	**1260**	**438**	**470**	**8**	**1930**	**444**	**130**	**2080**
Diorite	NS-9-1-INT	1	70	39.9	23.1	5.1	56	11.7	6.6	194
Diorite	NS-9-2-INT	1	220	81.2	59.9	3.1	169	36.3	10	398
	MEDIAN	**1**	**145**	**61**	**42**	**4**	**113**	**24**	**8**	**296**

Syenite is inherently higher in Ca, K as well as having some significantly higher rare earth values compared to diorite.

Table 14: MMI™ Data Comparison of Median Values between Dacite and Andesite Rocks

GEOLOGY	Sample	Ba	Ca	Dy	Er	Eu	Fe	Gd	K	Mg	Mn	Ti	Y
Dacite	BC-1-1- INT	8040	926	135	99	21	10	128	52	343	5800	1	757
Dacite	BC-1-2-INT	7840	900	100	72	16	11	97	62	334	7800	10	577
Dacite	BC-1-3-INT	6260	1150	72	58	11	17	63	82	358	11000	1	353
MEDIAN		**7840**	**926**	**100**	**72**	**16**	**11**	**97**	**62**	**343**	**7800**	**1**	**577**
Andesite	BC-8-1-INT	3510	390	22	11	6	45	27	193	98	5000	80	111
Andesite	BC-8-2-INT	3860	455	26	13	8	37	35	331	80	2900	70	144
Andesite	BC-8-3-INT	3750	574	11	6	3	39	14	207	97	2200	50	53
MEDIAN		**3750**	**455**	**22**	**11**	**6**	**39**	**27**	**207**	**97**	**2900**	**70**	**111**

Dacite and andesite samples also fall into the class 2 category of intermediate rocks. Dacite rocks are typically lighter in color than andesite rocks and has slightly higher SiO2 than andesite. The British Columbia dacite sample (BC-1) collected is a Princeton Group Eocene dacite lava flow with up to 20% hornblende including trace quartz and biotite phenocrysts. The British Columbia andesite sample (BC-8) collected in the Shovelnose Mountain Area contains 20% plagioclase and <5% pyroxene. Table 14 highlights some of the median values between these two rock types.

Andesite has higher values for Fe, Ti, K, while the dacite rocks are much higher in Ba, Ca, Mg Mn, Y and some of the rare earths.

Soils over Mafic Rock Types

Basalt rocks are part of the mafic rock class. There are various types of basalts which are divided into two magma series; tholeiitic basalt and alkali basalt. Tholeiitic magma (flood and pillow basalts) are sub alkaline (less Na than other basalts) and low in olivine while alkali basalt is typically rich in olivine and alkali metals such as Ca, Mg and K. Table 15 illustrates some of the elemental differences between the two types of magmas.

The MMI™ data has returned higher levels of Ca, K, Mg and Sr in the alkali basalt group. The tholeiitic basalts are higher in Pb, Th, Ti and Zr. Interestingly, the geological map of Nevada does not specify the type of basalt in both samples NV-4 and NV-16. Comparing the MMI™ data in Table 15 signifies that these two basalt samples can be classified as alkali basalts.

Table 15: MMI™ Median Values for Two Different Types of Basalts

GEOLOGY	Sample	Ca	K	Mg	Pb	Sr	Th	Ti	Zr
Tholeiitic Basalt									
Pillow Basalt	NB-1-1-MAF	246	25	63	749	380	21	1900	101
Pillow Basalt	NB-1-2-MAF	175	20	15	1820	180	33	7230	186
Pillow Basalt	NB-8-1-MAF	84	62	16	837	60	60	16900	350
Pillow Basalt	NB-8-2-MAF	50	51	11	751	40	63	12800	333
Flood Basalt	NS-4-1-MAF	12	22	2	239	100	5	60	30
Flood Basalt	NS-4-2-MAF	30	32	8	1350	150	10	260	42
Basalt	NS-11-1-MAF	1	9	3	1680	20	4	4410	65
Basalt	NS-11-2-MAF	4	4	1	381	20	9	3760	107
	MEDIAN	**40**	**24**	**9**	**794**	**80**	**15**	**4085**	**104**
Alkali Basalt									
Olivine Basalt	BC-13-1-MAF	533	219	118	23	5440	4	50	49
Olivine Basalt	BC-13-2-MAF	707	52	143	14	6900	3	10	39
Olivine Basalt	BC-13-3-MAF	926	90	179	16	5950	3	20	52
Basalt	NV4-1-MAF	1490	102	401	14	18900	.25	1	6
Basalt	NV4-2-MAF	996	38	359	46	15600	.25	1	5
Basalt	NV16-1-MAF	826	82	261	20	7210	.25	1	8
Basalt	NV16-2-MAF	957	37	271	16	8340	.25	1	7
	MEDIAN	**926**	**82**	**261**	**16**	**7210**	**.25**	**1**	**8**

CONCLUSIONS

A number of soils samples have been collected over many different rock units, felsics, intermediates and mafics. The MMI™ data derived from this soils can help identify the underlying lithology. An understanding of the geochemistry of each rock type will help in the interpretation of the data.

MMI™ analyses up to 53 elements as part of the MMI-M package. All commodity elements are reported and are obviously very important for interpretation of the data. However, there are many other elements that provide lithological information that is also very useful to geologists. It is apparent that working with large databases and statistics can be onerous with interpretation of the lithology. SGS now provides an interpretation technique called LithoID to help interpret these large MMI™ datasets. Technical Bulletins 30 and 31 have detailed the usefulness of this interpretation method. Technical Bulletin 33 utilizes the MMI™ data from the North American sampling exercise as outlined above to provide a more detailed and robust interpretation with visual comparative graphs.

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