DEGREE OF GEOCHEMICAL SIMILARITY (LITHOID) ANALYSIS OF SOME SELECTED NORTH AMERICAN SOILS OVER KNOWN GEOLOGY

INTRODUCTION & BACKGROUND

Data from TB32 has been subjected to the LithoID (Degree of Geochemical Similarity) statistical interpretation technique (Caritat de & Mann 2018) to examine and interpret the data and identify geochemical similarities (and differences) between soil samples over different lithologies. The ppm and ppb MMI™ data for the 158 samples from a number of locations in North America were first examined, and elements with >50% of values <LLD for that element (i.e. Au, Hg, In, Pd, Pt, Sn, Ta, Te, and W) were removed, leaving a 44 element suite comprising Ag, Al, As, Ba, Bi, Ca, Cd, Ce, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, K, La, Li, Mg, Mn, Mo, Nb, Nd, Ni, P, Pb, Pr, Rb, Sb, Sc, Sm, Sr, Tb, Th, Ti, Tl, U, Y, Yb, Zn, Zr for statistical analysis. These were then imported into the SGS LithoID Macro (July 2018 version) and rankings obtained. Various key reference samples were chosen in turn and Spearman r_{sp} values for all other samples relative to them calculated (via the Macro) and ranking diagrams for selected pairs of samples plotted, (again via the Macro).

It is these ranking diagrams and LithoID r_{sp} values for selected pairs (over known lithologies) which form the basis for this Technical Bulletin.

LithoID EXAMINATION OF SOILS OVER DIFFERENT ROCK TYPES

Soils over Felsic Rock Types

True granite contains quartz, mica and feldspar (both plagioclase and alkali feldspars such as orthoclase) and is "acid" or high in SiO2 (>59%). Orthoclase or K feldspar is often rich in rare earth elements. When a granitoid is devoid or nearly devoid of plagioclase, the rock is referred to as alkali feldspar granite. When a granitoid contains less than 10% orthoclase, it is called tonalite; pyroxene and amphibole are common in tonalite. A granite containing both muscovite and biotite micas is called a binary or two-mica granite. Two-mica granites are typically high in potassium and low in plagioclase, and are usually S-type granites or A-type granites.

I-type granites are formed by partial melting of older igneous rocks. An A-type granite is an anorogenic or anhydrous type of granite. An S-type granite is formed by partial melting of metasedimentary rocks and an M-type granite contains mantle derived material. Leucogranites (Alaskites) are pale coloured granites with almost no darker materials and are formed in orogenies by collision events.

The LithoID interpretation technique allows us to compare granites for their geochemical similarities and differences. Field duplicates will have a typically higher ranking (r_{sp} =+0.8 or higher) than samples over different lithologies. Figure 1 below is an example of two field duplicates over an I-type granite sampled in Nova Scotia.

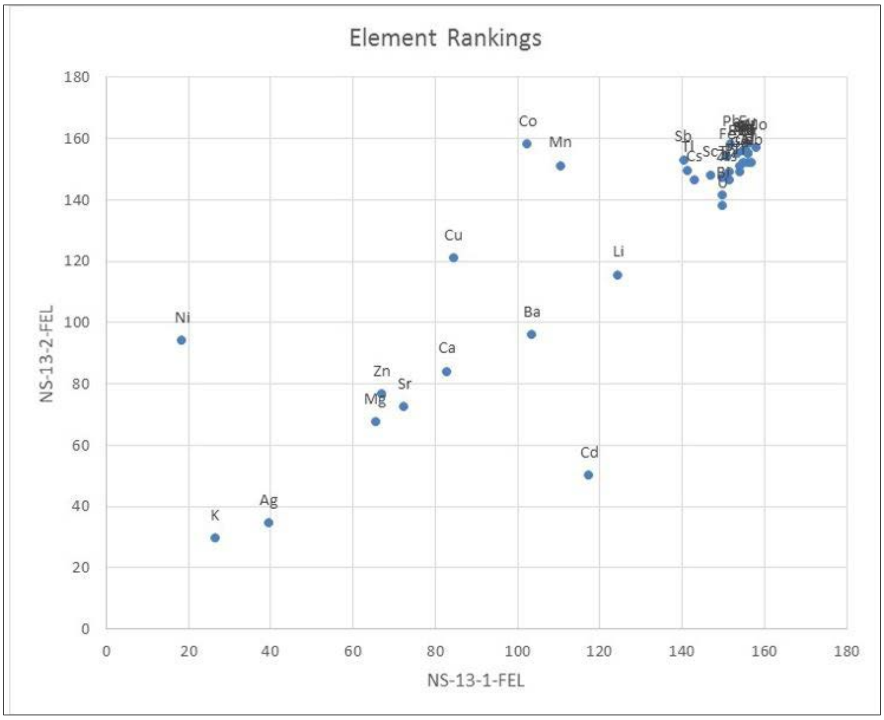

Figure 1: Ranking Diagram for NS13-1 and NS-13-2, Duplicate Soils over an I-Type Granite Sampled Approximately 2 Meters Apart. The LithoID Method Calculates a Correlation Factor (r_{sp} =+0.86)

Many of the elements in Figure 1 are displayed along the 1:1 diagonal, which confers a high degree of similarity, r_{sp} =0.86. The element Ni is ranked more highly in sample NS-13-2, whilst Cd is ranked more highly in sample NS-13-1.

Figure 2 compares NS-8-1 a soil over an A-Type granite versus NS-13-2 a soil over an I-Type granite. The r_{sp} =0.37.

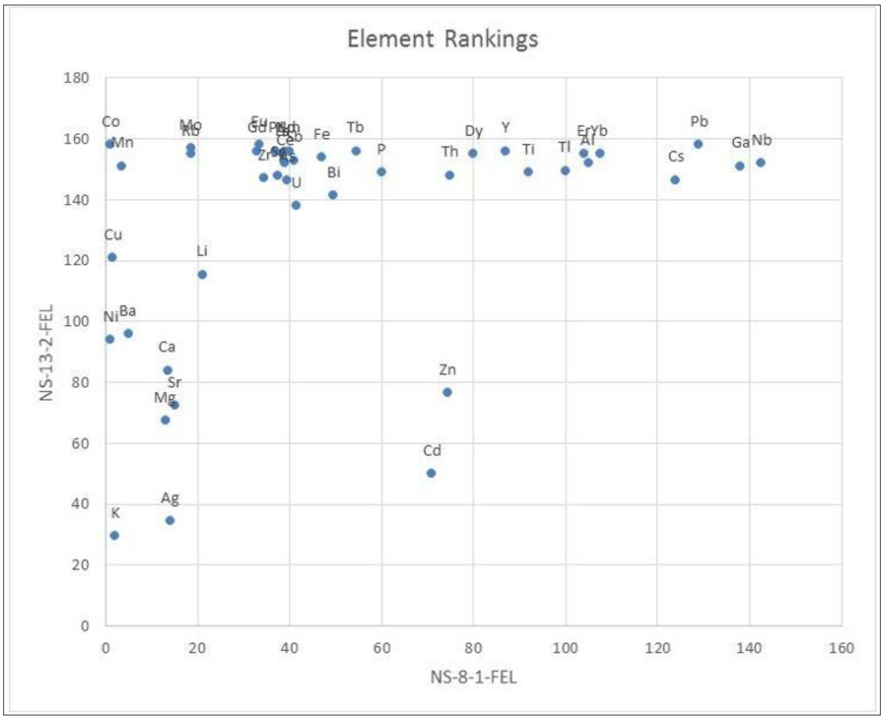

Figure 2: Ranking Diagram for NS-8-1 a Soil over an A-Type Granite, and NS-13-2 a Soil over an I-Type Granite (r_{sp} =0.37)

The most striking feature of this ranking diagram is the much higher rankings of many elements in soil over an I-type granite compared to those in soil over an A-type granite. There is a similar pattern between the sample NS-2-1 soil over a Leucogranite and NS-13-1, soil over an I-Type granite with an r_{sp} =0.30 as shown in Figure 3. As shown in Figure 3, I-Type granites appear to have many elements with higher rankings compared to A-Type Granites and Leucogranites.

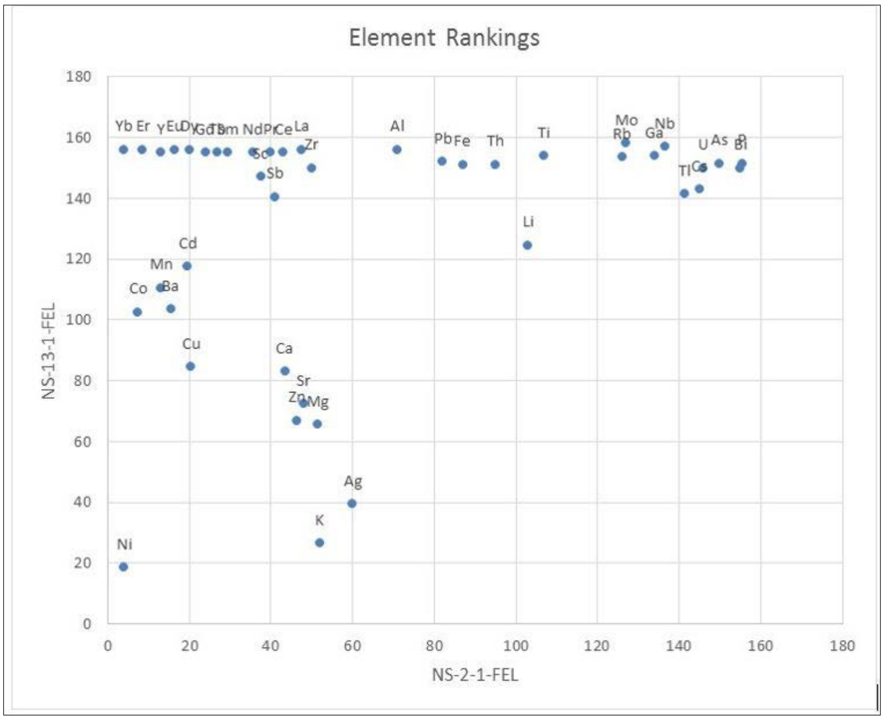

Figure 3: Ranking Diagram for NS-2-1 a Soil over a Leucogranite and NS-13-1 a Soil over an I-Type Granite (r_{sp} =0.30)

A ranking value r_{sp} of typically +0.4 or higher is indicative of a fairly good correlation. Figure 4 below is an example of a comparison between a Leucogranite (sample NS-2) and an A-Type granite (NS-8), r_{sp} =0.33.

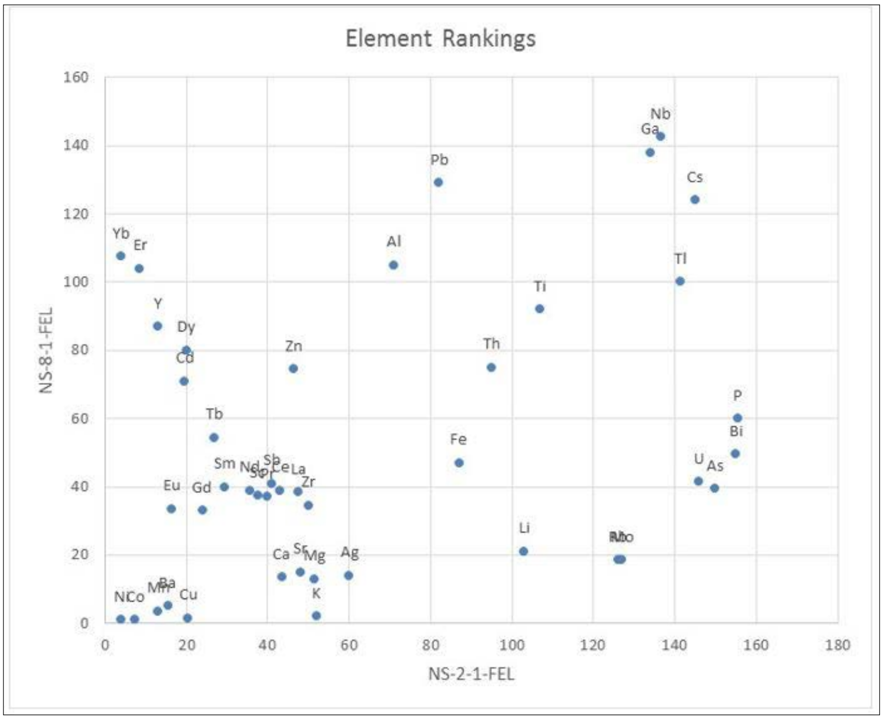

Figure 4: Ranking Diagram for NS-2-1 a Soil over a Leucogranite, and NS-8-1 a Soil over an A-Type Granite (r_{sp}=0.33)

The soils featured in Figure 4 indicate that the parent rocks are similar but not identical. For example the soil over the A-Type granite has higher levels of the heavy rare earth elements such as Y, Er and Dy while the leucogranite soil is much higher in P, Bi, U, As, Cs, Tl Rb and Mo. Both soils have a large number of elements with low rankings compared to other samples in the database.

In comparing soils over rocks of different classes, e.g. felsic versus mafic, one would expect much greater differences in Spearman correlation values.

Figure 5 highlights sample NS-13-1 over an I-Type granite versus sample NS-4-2 over a flood basalt. The ranking correlation is very low at r_{sp} = -0.008. Ni and K are much higher in the flood basalt however the majority of the elements particularly rare earths are much higher in the I-type granite compared to the basalt.

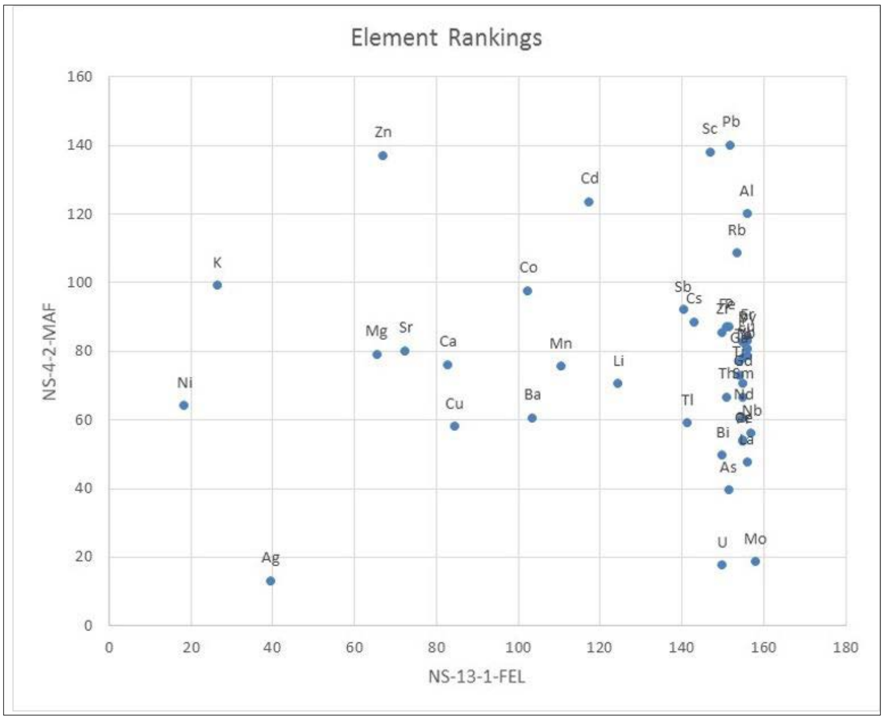

Figure 5: Ranking Diagram for NS-13-1 a Soil over an I-Type Granite Versus NS-4-2 a Soil over a Flood Basalt (r_{sp} = -0.008). The XY Plot and the r_{sp} Clearly Discriminates between Soils over Rocks Belonging to Different Classes, e.g. Felsic Versus Mafic

As shown in Figure 5, there are few elements on the 1:1 diagonal; many elements including most REE's are ranked more highly in sample NS-13-1, the soil over the felsic rock type.

SOILS OVER INTERMEDIATE ROCK TYPES

Intermediate igneous rocks are those with between 52% and 69% SiO2. In Figure 6, soils over two intermediate rocks (class 2), NB-16-1 a Syenite and NB-12-1 a Tonalite are compared.

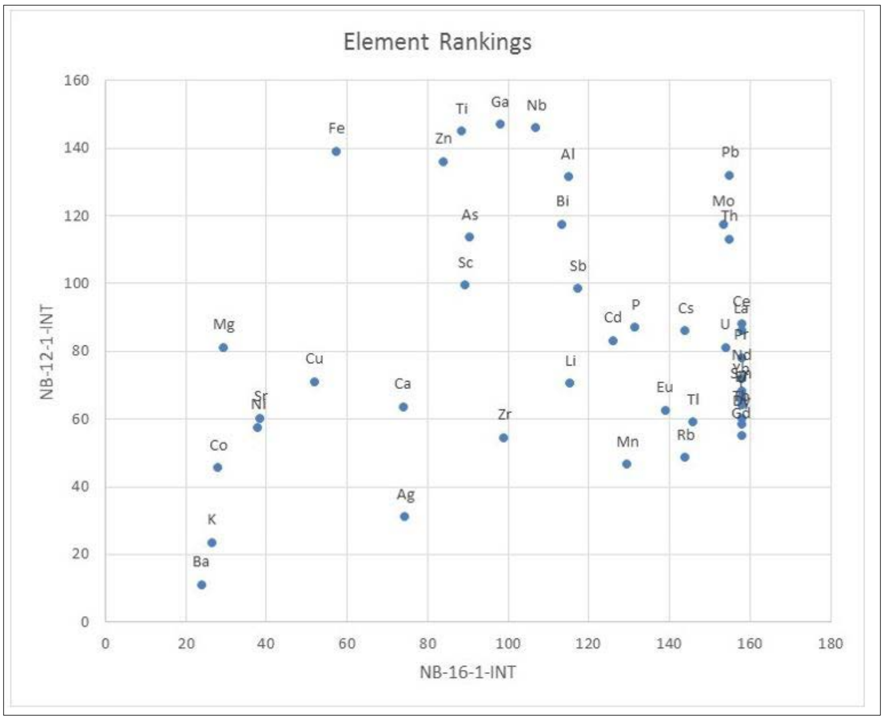

Figure 6: Ranking Diagram for Soil NB-16-1 over a Syenite Compared to NB-12-1 a Soil over a Tonalite (r_{sp} =0.14).

The LithoID interpretation method clearly indicates these are two distinct rock types beneath these soils; the syenite has much higher rankings for rare earth elements, U, Th, Mo, Rb, Tl and Pb. Another example in Figure 7 compares NB-16-1 to sample NB-3-1 being a soil located over sediment.

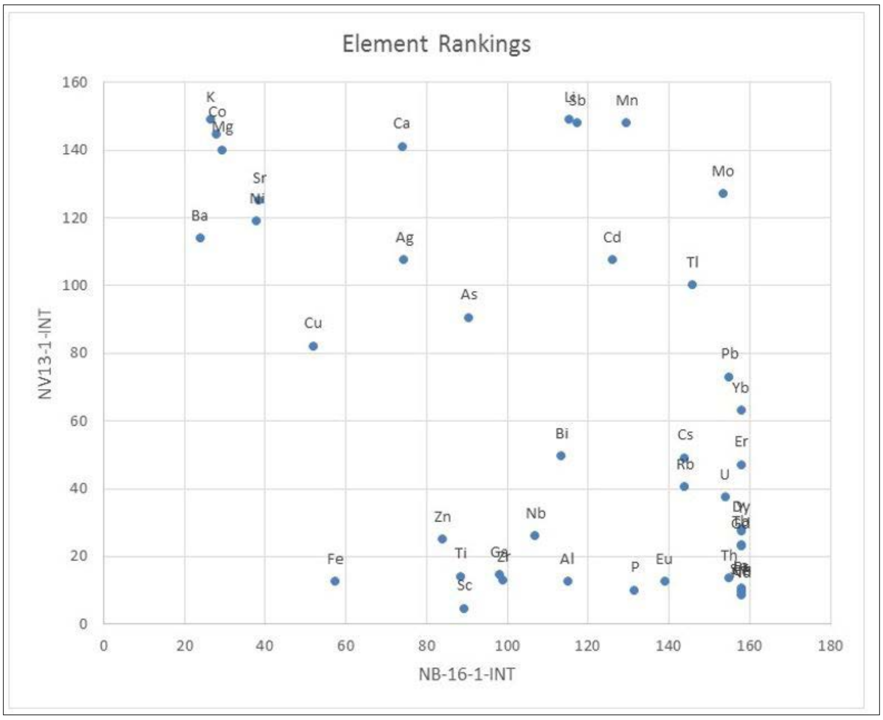

Figure 7: Ranking Diagram for NB-16-1 a Soil over Syenite Rock Versus NB-3-1 which is a Soil over Sediment (r_{sp} = -0.52)

The r_{sp} value of -0.52 clearly demonstrates the geochemical dissimilarity between the soils over these two rock types.

The Spearman coefficient of r_{sp} =-0.52 and the ranking diagram, particularly the paucity of elements along the 1:1 diagonal signify these are soils over very different parent material.

SOILS OVER MAFIC ROCK TYPES

Basalt is one of the most common surface rocks. It is defined as <52% SiO2, whereas ultramafic is defined as <45% SiO2. Basalt is 65% plagioclase feldspar + pyroxene+ olivine. Diabase (dolerite) is a texturally coarser version whilst, gabbro is >2mm in grain size.

There are two main types of basalt:

1. Tholeitic – Ocean type. Ocean spreading centres (shallow type) Na rich, high Ti, MORB=low in incompatibles & alkalis. Includes bonninite which has a high percentage of Mg and lower low Ti.

2. Alkali basalts - mountain type. Collision centres (deeper) – high olivine Mg, Ti (augite). Higher Na2O and K2O than tholeites

Greenstone is a metamorphosed basalt, with green minerals chlorite, actinolite, and/or epidote. Basalts grade into andesites (basaltic andesite), as Si% increases (up to 57%). Basalts grade into ultramafics (<45% Si) as Si decreases. There is plenty of scope for wide variations in basalt compositions.

Nova Scotia

The sample NS-4-2 is from North Mountain on the south side of the Bay of Fundy. The rock substrate is a tholeiitic basalt, from the Triassic. The Early Mesozoic North Mountain basalts of Nova Scotia Canada, are continental tholeiites similar in composition to numerous Triassic diabase dykes of the northern Appalachians. All these rocks probably originated during the initial opening of the Atlantic Ocean (Dostal and Dupuy (1984)).

NS 11 is a flood basalt, located on the North side of Bay of Fundy. Comparison of the element rankings for NS-4-2 and NS-11-1 are shown in Figure 8.

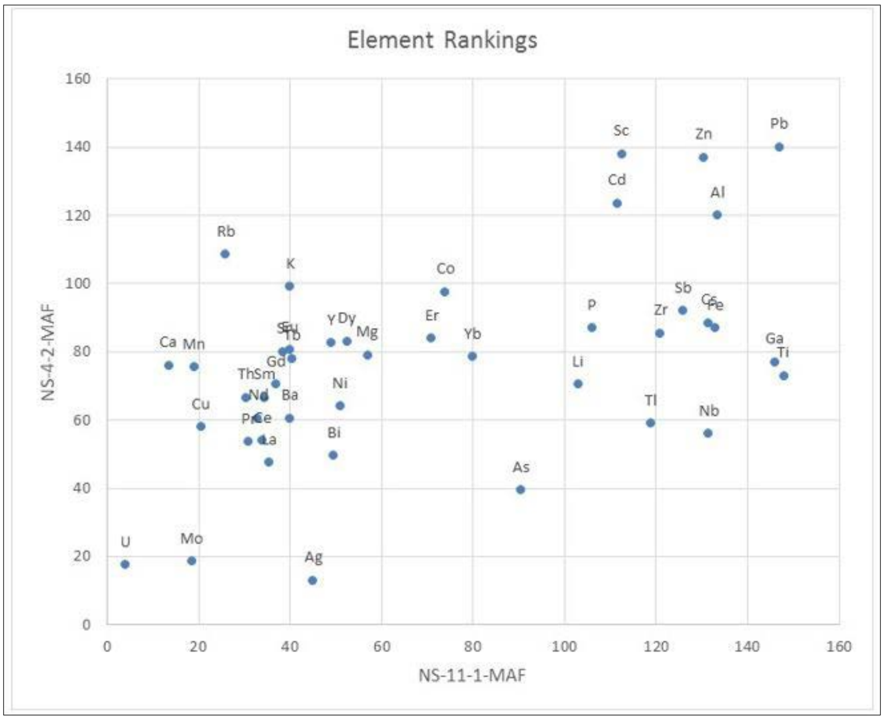

Figure 8: Ranking Diagram for NS-11-1 a Soil Over Flood Basalt on the North Side of the Bay of Fundy Compared to NS-4-2 a Soil Over Tholeiitic Basalt on the South Side of the Bay of Fundy

The Spearman r_{sp} =0.50 suggests these two samples are closely related.

Many elements lie close to the 1:1 diagonal on the ranking diagram, inferring high similarity between these two samples. NS-4-2 has higher rankings for Ca, Mn, K and Rb.

From LithoID ranking diagram NS-11 has higher rankings for Ti, Ga, Nb, W, Tl.

NS-4 and NS-11 are both tholeites and possibly coeval. NS-11-1 will be used as the on-going reference for mafic comparisons.

New Brunswick

Sample NB-15 is near Nerepis in New Brunswick. This basalt is also reported to be tholeiitic.

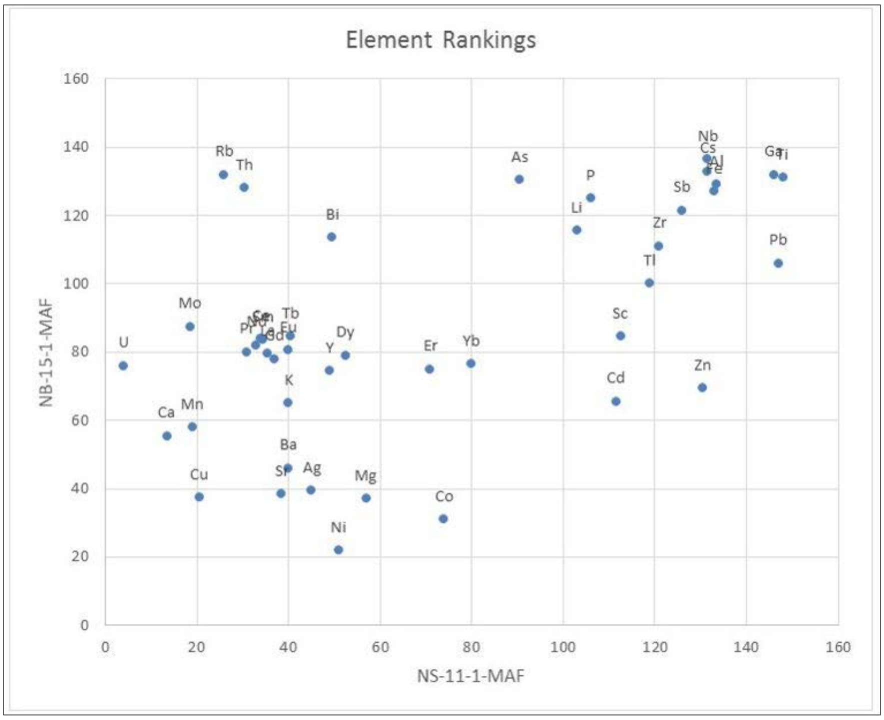

Figure 9: Ranking Diagram for Soils NS-11-1 and NB-15-1 both over Tholeiitic Basalt

The Spearman r_{sp} = 0.56 suggests a fairly high degree of similarity. From the LithoID ranking diagram NS-11-1 has higher rankings for Pb, Zn, Cd, Co whilst

NB-15-1 has higher rankings for Ca, Rb, Mn, and K. Most other elements, Cu, Ni, Mg and REE's lie close to the 1:1 diagonal.

Nevada

NV-16-1 is from the Cortez Mountains in Nevada. This area has small discontinuous bodies of Miocene basalt and larger areas of basaltic andesite.

Both the Spearman r_{sp} =-0.41 and the ranking diagram Figure 10 suggest there is a large difference between this sample and NS-11-1.

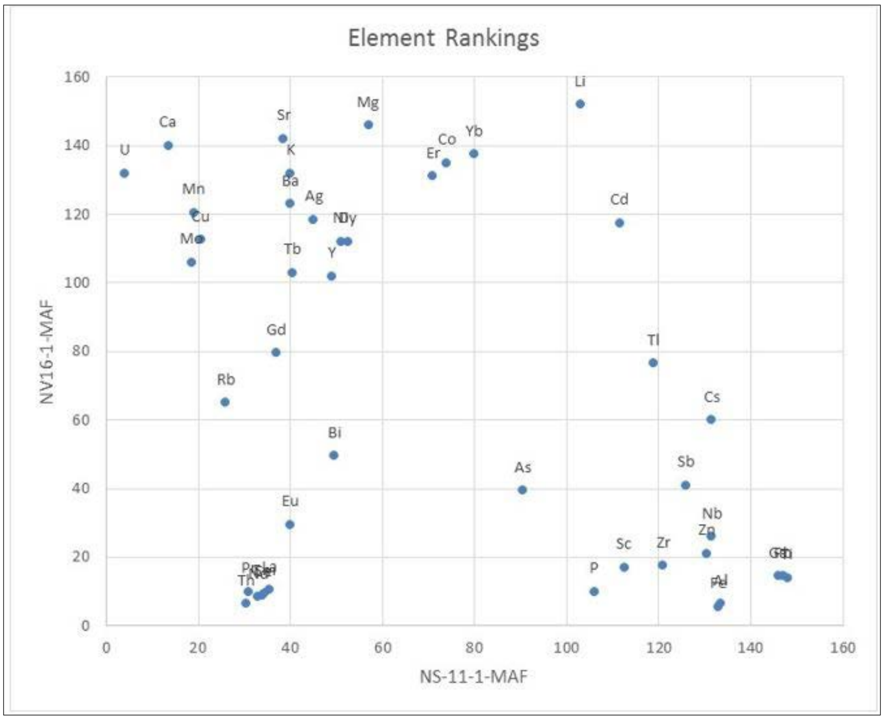

Figure 10: Ranking Diagram for Soils Over NV-16-1 and NS-11-1

Very few elements in Figure 10 are on the 1:1 diagonal. Basaltic andesite has a slightly higher % of Si, but is continuous with the basaltic field. Along with higher rankings for alkali and alkali earth elements, NV-16-1 has higher rankings for most rare earth elements. This suggests NV-16-1 is probably an andesitic basalt, but higher K ranking suggests it is also alkali type.

British Columbia

Sample BC-13-1 is a soil over an olivine basalt from British Columbia.

Again the Spearman r_{sp} =-0.40 and the ranking diagram Figure 11 suggest BC-13-1 is a very different "basalt" to NS-11 (and all others with positive r_{sp} 's). Not many elements are close to the 1:1 diagonal. It is possibly an alkaline basalt based on higher K and lower Ti. The Tulameen ultramafic complex lies at these coordinates.

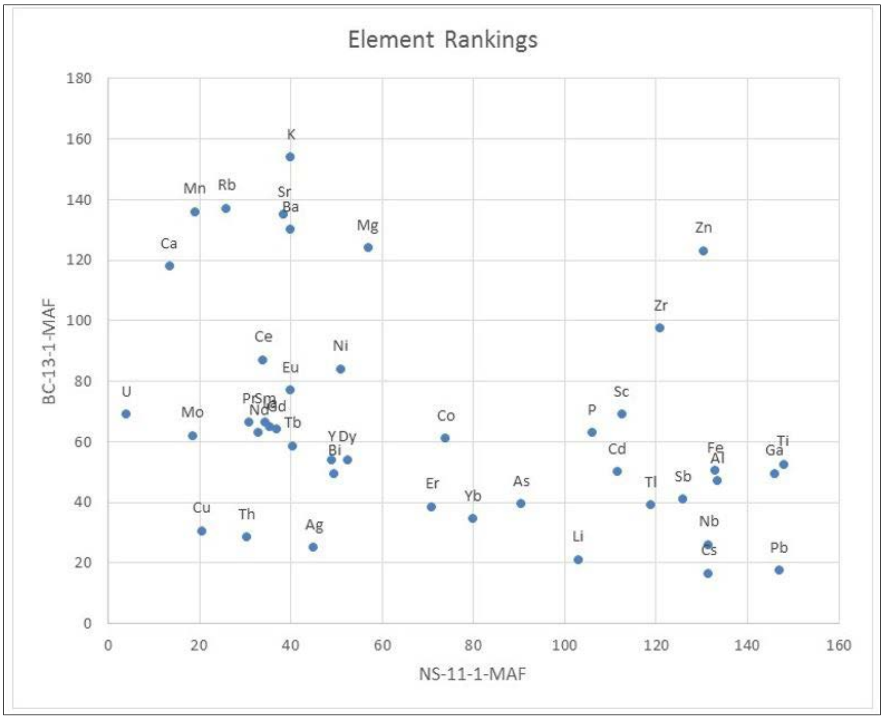

Figure 11: Ranking Diagram for Soil Over an Olivine Basalt BC-13-1 Compared to Soil Over Tholeiitic Basalt NS-11-1

In this case K is very high in BC-13-1 and Mg is among the alkali and alkali earth elements which are higher in BC-13-1 than in NS-11-1. NS-11-1 has higher rankings for Pb, Nb, Cs, Ga, Ti

Ontario

The Lively basalt, ON-13-1, from the southern side of the Sudbury Igneous Complex, has a relatively close similarity to NS-11-1 with an r_{sp} = 0.39.

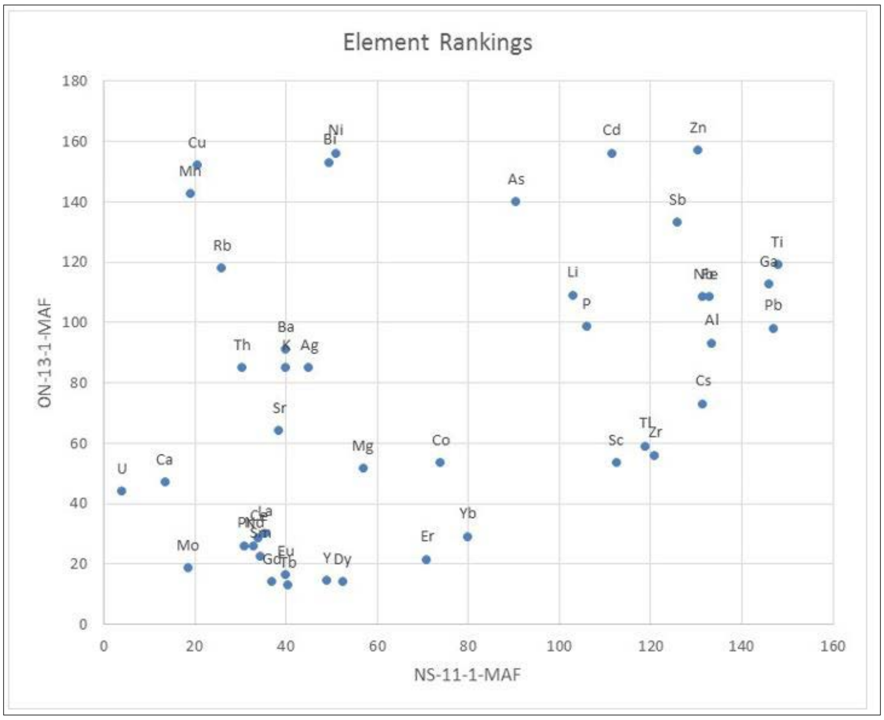

Figure 12: Ranking Diagram for ON-13-1 a Soil Over a Basalt near Sudbury Ontario Versus NS-11-1 Soil Over Known Tholeiitic Basalt at The Bay of Fundy, Nova Scotia

Cu, Mn, Ni and Bi have higher rankings in the Lively basalt than in the NS-11-1 basalt. NS-11-1 has higher rankings for Pb, Ga, Ti, Cs, Tl and Sc, but many elements including Mg and rare earths lie close to the 1:1 diagonal. Sudbury has in all probability been subject of a meteorite impact, but the parent material is likely to be tholeiitic, perhaps as confirmed here by its high r_{sp} with a distant basalt of tholeiitic composition and very different age (Triassic versus Proterozoic).

ON-16-1 is an olivine diabase from north of the Sudbury Igneous Complex. Diabase or dolerite is mafic in composition, but has a coarser texture than basalt. On-16-1 has an r_{sp} =0.49 versus NS-11-1.

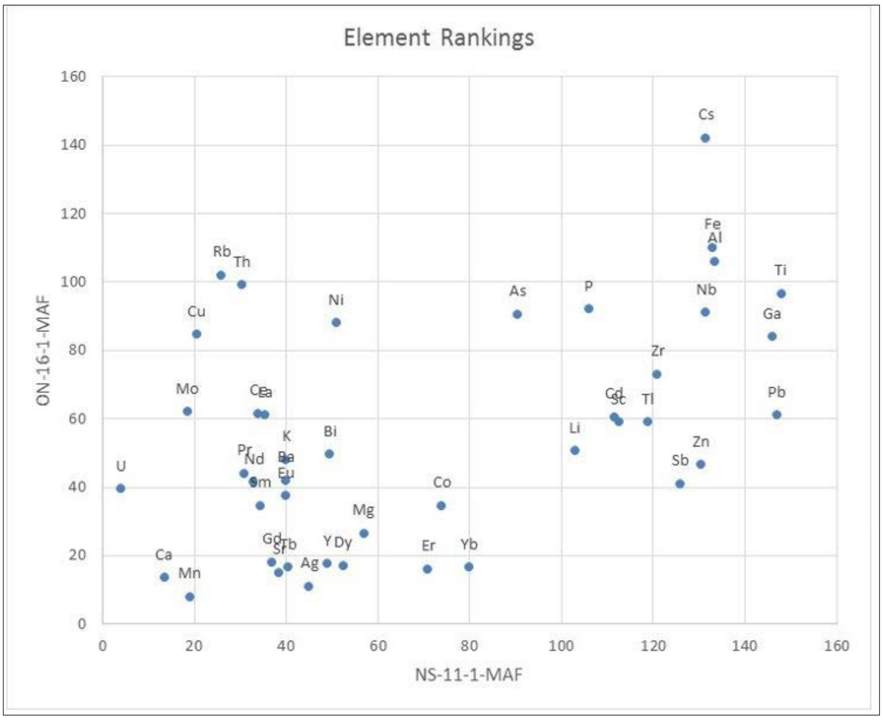

Figure 13: Ranking Diagram for ON-16-1 Soil Over Diabase North of Sudbury Ontario Versus NS-11-1 Soil Over Tholeiitic Basalt Nova Scotia

ON-16-1 has higher rankings for Cr, Rb, Th, Cu, Mo and U, but many elements have rankings close to the 1:1 diagonal. It is probably tholeiitic. ON-14-1 is a gabbro from Wahnapitae, east of Sudbury. It has an r_{sp} =0.44 versus the tholeiitic basalt NS-11-1.

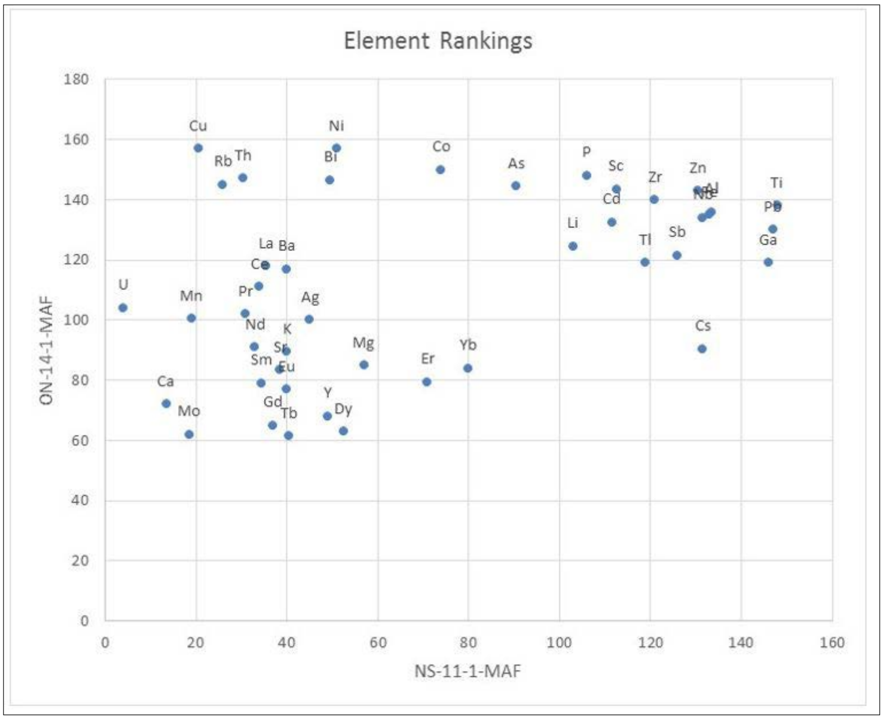

Figure 14: Ranking Diagram for ON-14-1 a Soil Over a Gabbro in Ontario Versus NS-11-1 Soil Over Tholeiitic Basalt in Nova Scotia

Interestingly ON-14-1 has no element with a ranking below 60 i.e. all elements are in high concentrations relative to other samples in the data set perhaps suggesting it is not just a coarser version of a typical tholeiitic basalt, but lower in %SiO2.

CONCLUSION

A number of soils over different felsic, intermediate and mafic substrates have been examined by the LithoID technique. Elemental similarities and differences have been clearly and diagnostically presented and the Spearman r_{sp} coefficient used to assess the Degree of Geochemical Similarity between pairs of samples, some very different, some similar. LithoID is a relatively simple and objective way to analyse and then synthesise diagnosis of rock type from MMI™ multi-element soil data.

REFERENCES

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