Geochemical Variability of Soils in the Maritime Provinces of Canada and the New England States of the United States

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U.S. Geological Survey
The North American Soil Geochemistry Landscape Project (NASGLP)

- The NASGLP was developed as a joint Mexico, USA, and Canada project for characterizing the soil cover over North America.

- Goals of the NASGLP are:
  - develop a continental-scale framework for generating and managing geochemical and mineralogical data.
  - produce a continental array of soil data using consistent sampling and analytical protocols.
  - establish an archive of soil samples for future researchers

- In 2004 two transects (W-E and N-S) that crossed the US and Canada were conducted as a pilot study – results reported in a special issue of Applied Geochemistry, Vol. 24 (8), 2009.

- Spatial sampling in the US and Canada began in 2007 – Maritime provinces sampled by GSC and provincial surveys; New England states + New York sampled by USGS.
Soil Horizons

Three samples in this analysis

H, O, A Soil horizons
- Soluble: Complexes (organic, inorganic ligands)
- B Soil horizon: Organic (humic, fulvic acids), Inorganic (Fe, Mn, Al oxides)
- C Soil horizon: Secondary minerals, Primary minerals

PH{0-5}
Analytical Protocols

- Geochemical analysis of the 3 soil horizons (PH (0-5 cm depth), A & C horizons)
- Samples sieved to < 2 mm & milled to < 150 mm
- 4 acid digestion (HNO₃-HF-HCl-HClO₄)
- ICP-MS/ICP-AES instrumentation
- Hg – Cold Vapour AA (US samples)
- Hg – Aqua-Regia ICP-MS (CD samples)
- As – Hydride generation (US samples)
- As – 4 acid ICP-MS (CD samples)
Sample Sites

~1 sample/1600 km² in US; double density in Canada

EcoRegions

- Atlantic Coastal Pine Barrens (ACPB)
- Eastern Great Lakes and (EGLHL)
- Hudson Lowlands
  - Erie Drift Plain (EDP)
- Lake Erie Lowland (LEL)
- Maine/New Brunswick
  - Plains and Hills (MPH)
  - Maritime Lowlands (ML)
- North Central Appalachians (NCA)
- Northeastern Coastal Zone (NECZ)
- Northern Appalachian (NAPU)
  - Plateau and Uplands
- Northern Appalachian and (NAAMH)
- Atlantic Maritime Highlands
  - Ridge and Valley (RV)
Basic Questions

• What is the chemical and mineralogical variability in soil profile throughout different geological units and ecoregions?

• How can this be understood and visualized?

• What can a statistical analysis of the data tell us?
Compositional Aspects of the Geochemistry

- Soil geochemistry (%, mg/kg) is compositional and subject to closure.
- Centered logratio (clr) and isometric logratio (ilr) transformations were used.
- Relationships in the data reveal processes of deposition, erosion, weathering and alteration (e.g., groundwater effects).
Quantile-Quantile Plots – Soil Geochemistry

Al dominant in C horizon

As nearly equal in all 3 horizons
Quantile-Quantile Plots – Soil Geochemistry

- Organic carbon dominant in the A horizon
- Cd dominant in the PH & A horizons
- Carbon not determined in PH horizon
Quantile-Quantile Plots – Soil Geochemistry

Hg dominant in PH & A horizons

K dominant in the C horizon
Cd – PH Horizon

Cd associated with organic material in the PH horizon
Principal Component Analysis – Soil Geochemistry

New England States & Maritime Provinces Soils [clr transform]

Soil Horizon
- PH
- A
- C

Felsic
- K
- Rb
- Na
- U
- Ba
- W
- Nb

Weathering & Mixing
- Sn
- Mo
- Bi
- Pb
- Ce
- La
- Ga
- Th

Parent Material
- Al
- Ca
- Ti
- Mn
- Li
- As
- Sc
- Y
- V

Mafic
- Mg
- Co
- Cr
- Cu
- Zn

Organic

Physical Processes

Random Processes

Eigenvalue Number
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34

Eigenvalue

USGS
PC1 – PH Horizon

Increased Cd-S-Pb-Se-Sn-Mo-Bi-Sb in NB and NS
PC2 – C Horizon

Carbonates/Mafic rocks PC2 < 0; Felsic rocks PC2 > 0
PC2-PC3 Biplots – Chemistry

Biplot shows bedrock affinities without the influence of the soil profile.
PC3 – C Horizon

PC3 C Horizon Chemistry
Linear Discriminant Analysis (LDA) – ILR Transform – Soil Geochemistry

A Horizon with high C content
### LDA Accuracy Matrix – Soil Geochemistry

<table>
<thead>
<tr>
<th></th>
<th>Points</th>
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</thead>
<tbody>
<tr>
<td>Horizon</td>
<td>A</td>
</tr>
<tr>
<td>A</td>
<td>248</td>
</tr>
<tr>
<td>C</td>
<td>1</td>
</tr>
<tr>
<td>PH</td>
<td>12</td>
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<table>
<thead>
<tr>
<th></th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Horizon</td>
<td>A</td>
</tr>
<tr>
<td>A</td>
<td>77.5</td>
</tr>
<tr>
<td>C</td>
<td>0.29</td>
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<tr>
<td>PH</td>
<td>3.46</td>
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</table>

Overall Accuracy | 85.3
LDA Based on EcoRegions

EcoRegions
- Atlantic Coastal Pine Barrens (ACPB)
- Eastern Great Lakes and (EGLHL)
  - Hudson Lowlands
  - Erie Drift Plain (EDP)
- Lake Erie Lowland (LEL)
- Maine/New Brunswick
- Plains and Hills (MPH)
- Maritime Lowlands (ML)
- North Central Appalachians (NCA)
- Northeastern Coastal Zone (NECZ)
- Northern Appalachian (NAPU)
- Plateau and Uplands
- Northern Appalachian and (NAAMH)
- Atlantic Maritime Highlands
- Ridge and Valley (RV)
## LDA – EcoRegions – Accuracy Matrix

<table>
<thead>
<tr>
<th></th>
<th>EGLHL</th>
<th>ML</th>
<th>MPH</th>
<th>NAAMH</th>
<th>NAPU</th>
<th>NECZ</th>
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<tbody>
<tr>
<td>EGLHL</td>
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<td>15</td>
<td>9</td>
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<td>MPH</td>
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<td>213</td>
<td>46</td>
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<tr>
<td>NAAMH</td>
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<td>15</td>
<td>56</td>
<td>221</td>
<td>9</td>
<td>29</td>
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<tr>
<td>NAPU</td>
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<td>0</td>
<td>0</td>
<td>4</td>
<td>31</td>
<td>0</td>
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<tr>
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<td>2</td>
<td>22</td>
<td>0</td>
<td>54</td>
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<table>
<thead>
<tr>
<th></th>
<th>EGLHL</th>
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<th>NAAMH</th>
<th>NAPU</th>
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<td>27.85</td>
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<td>68.35</td>
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*Overall Accuracy*: 71.23%
LDA – Rock Type Prediction – Soil Geochemistry

New England States & Maritime Provinces Soil Chemistry

- Rock Type: Metamorphic, Plutonic, Sedimentary, Volcanic
- Horizons: PH, A, C

1st Id vs 2nd Id scatter plot with data points for different rock types.
LDA – Rock Type – Accuracy Matrix

<table>
<thead>
<tr>
<th></th>
<th>Metamorphic</th>
<th>Plutonic</th>
<th>Sedimentary</th>
<th>Volcanic</th>
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</thead>
<tbody>
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<td>10</td>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>Plutonic</td>
<td>13</td>
<td>56</td>
<td>67</td>
<td>3</td>
</tr>
<tr>
<td>Sedimentary</td>
<td>10</td>
<td>27</td>
<td>674</td>
<td>3</td>
</tr>
<tr>
<td>Volcanic</td>
<td>1</td>
<td>2</td>
<td>26</td>
<td>24</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Metamorphic</th>
<th>Plutonic</th>
<th>Sedimentary</th>
<th>Volcanic</th>
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</thead>
<tbody>
<tr>
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<td>60.61</td>
<td>15.15</td>
<td>22.73</td>
<td>1.52</td>
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<tr>
<td>Plutonic</td>
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<tr>
<td>Volcanic</td>
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<td>3.77</td>
<td>49.06</td>
<td>45.28</td>
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</table>

Total Accuracy 81.69
Conclusions

• Logratios and a multivariate approach yields patterns that infer geological processes.
• Results of the survey show transitional distinctions between the upper (A, PH) and lower (C) horizons.
• C horizon correlates well with underlying geology.
• These results provide insight into the process of soil formation and the corresponding geochemical response over a substantial area of eastern Canada and the north-eastern United States.
Organic Carbon - A Horizon

Sampling Protocol Problem

Carbon A Horizon by Lithology

High C in A horizon soils in New Brunswick
For more information

• Contact Eric Grunsky
  – Eric.Grunsky@NRCan-RNCan.gc.ca

• Read: