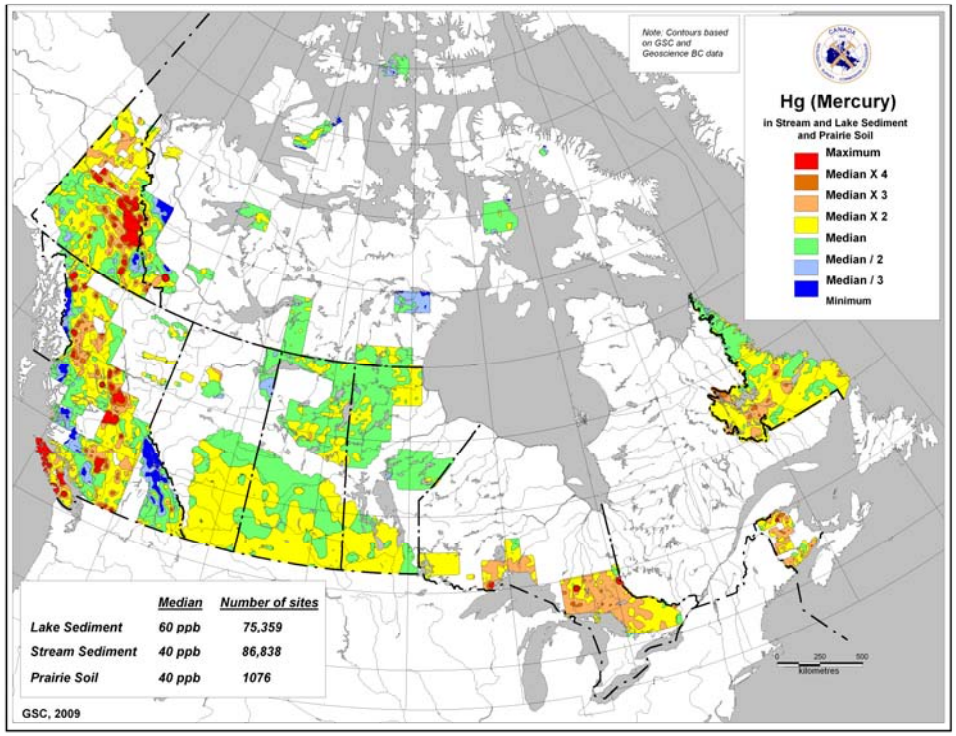
Earth Sciences Sector

GEOCHEMICAL LANDSCAPES: ASPECTS OF VERTICAL AND HORIZONTAL VA

Eric C. Grunsky and Rick J. McNeil

Natural Resources Canada- Geological Survey of Canada



Natural Resources Canada | Ressources naturelles Canada

Canada

Geochemical Landscape

- Geochemical landscape is a geochemical characterization of part of the earth's surface (Polynov, 1960*), based on the joint influences of climate, relief, geology and vegetation on the chemical processes over a region
- The main application of geochemical landscapes is to support studies in:
  - Agriculture
  - Mineral exploration
  - Human health

*Quoted in Nature, v. 188, Issue 4744, 1960, p. 23

Spatial Aspects of Geochemical Landscapes

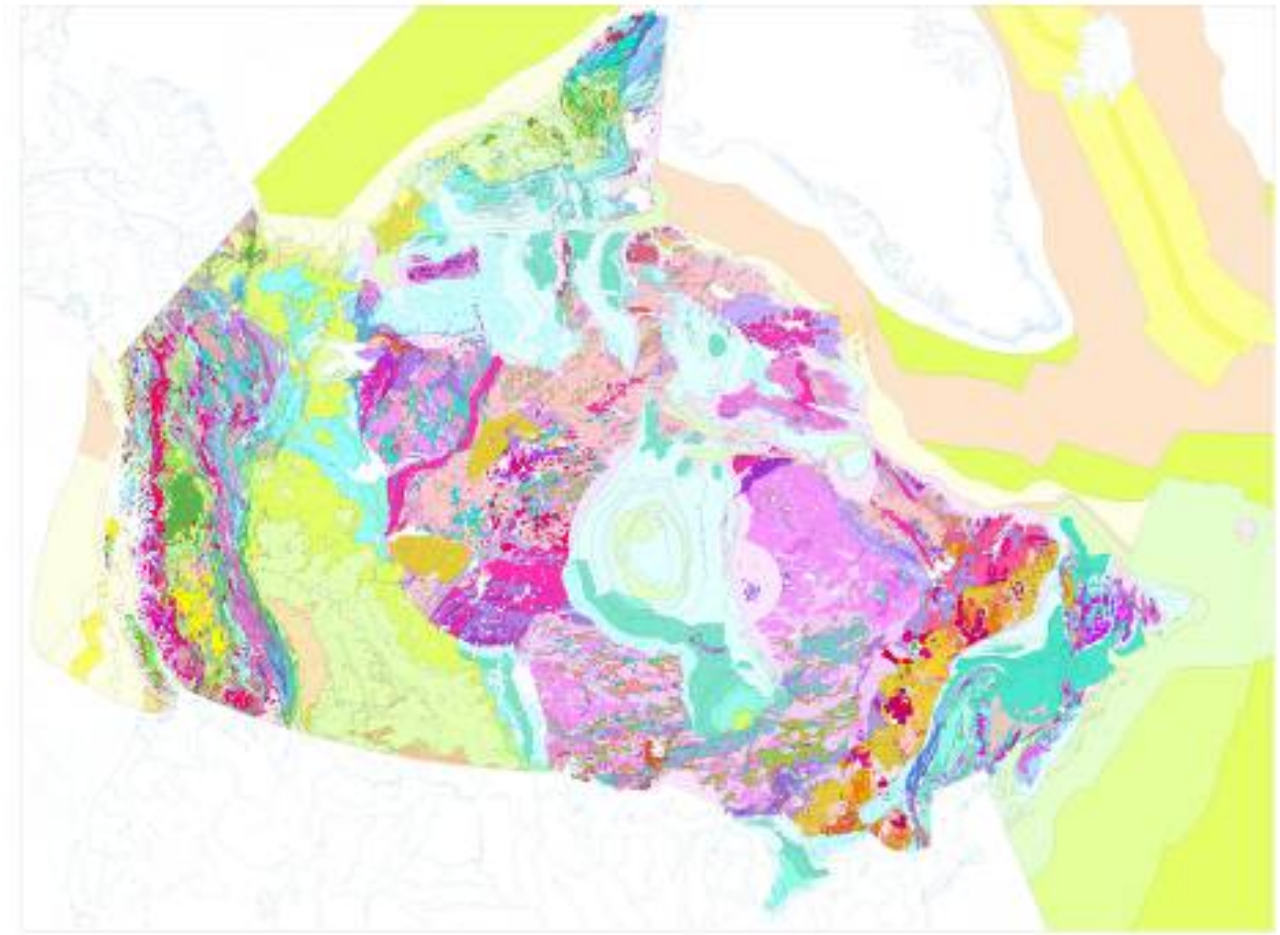
- The scale of the assessment determines the required sample density.
- Search theory sets a working sample density at ½ the size of the target that is being sought.
- Statistically based sample designs permit defensible results (i.e. analysis of variance).
- The number of sites is also dependent on the number of elements being analyzed if the elements are to be studied simultaneously.

Geochemical Landscapes

National Scale

Geology of Canada

Earth Sciences Sector

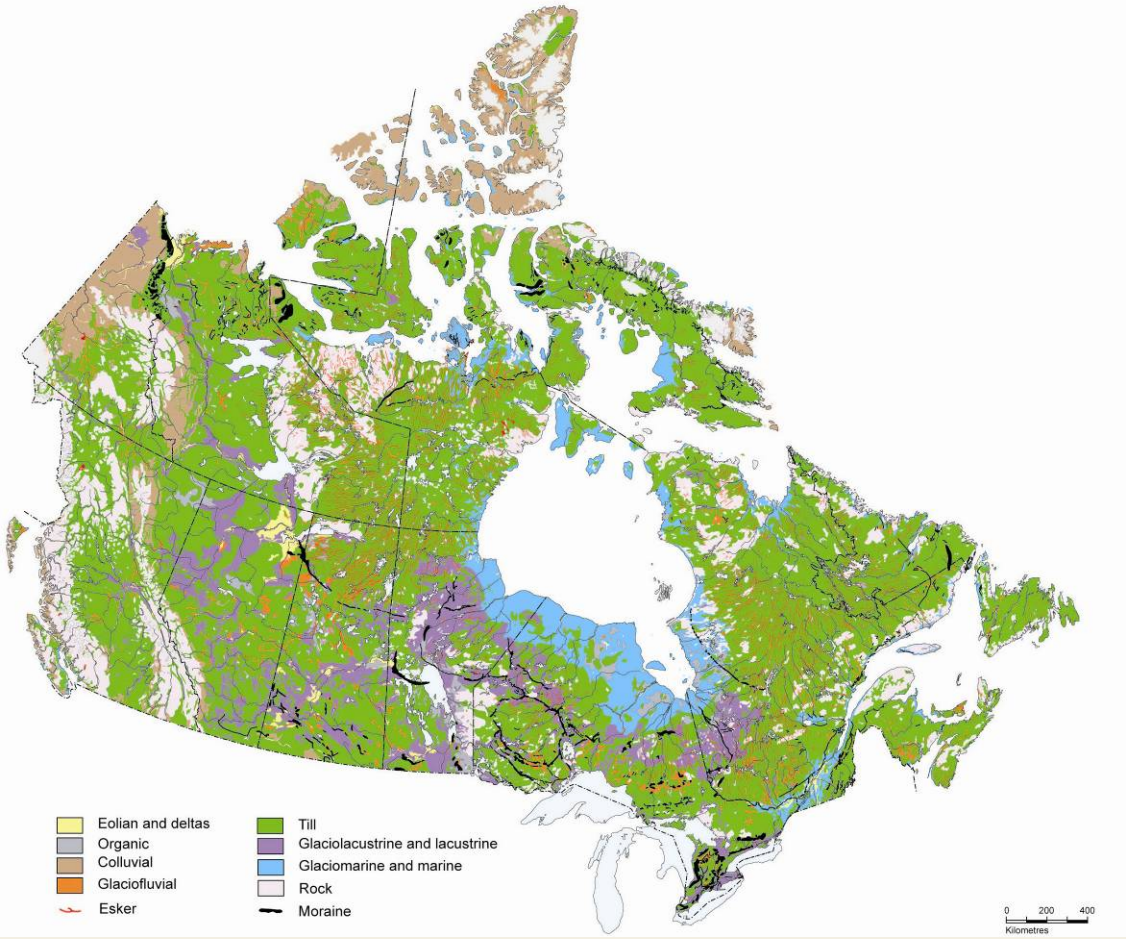


Source: GSC
Map 1860A
(1: 5 000 000)

Download map and legend at http://gsc.nrcan.gc.ca/map/1860a/index_e.php

Surficial Geology of Canada

Earth Sciences Sector

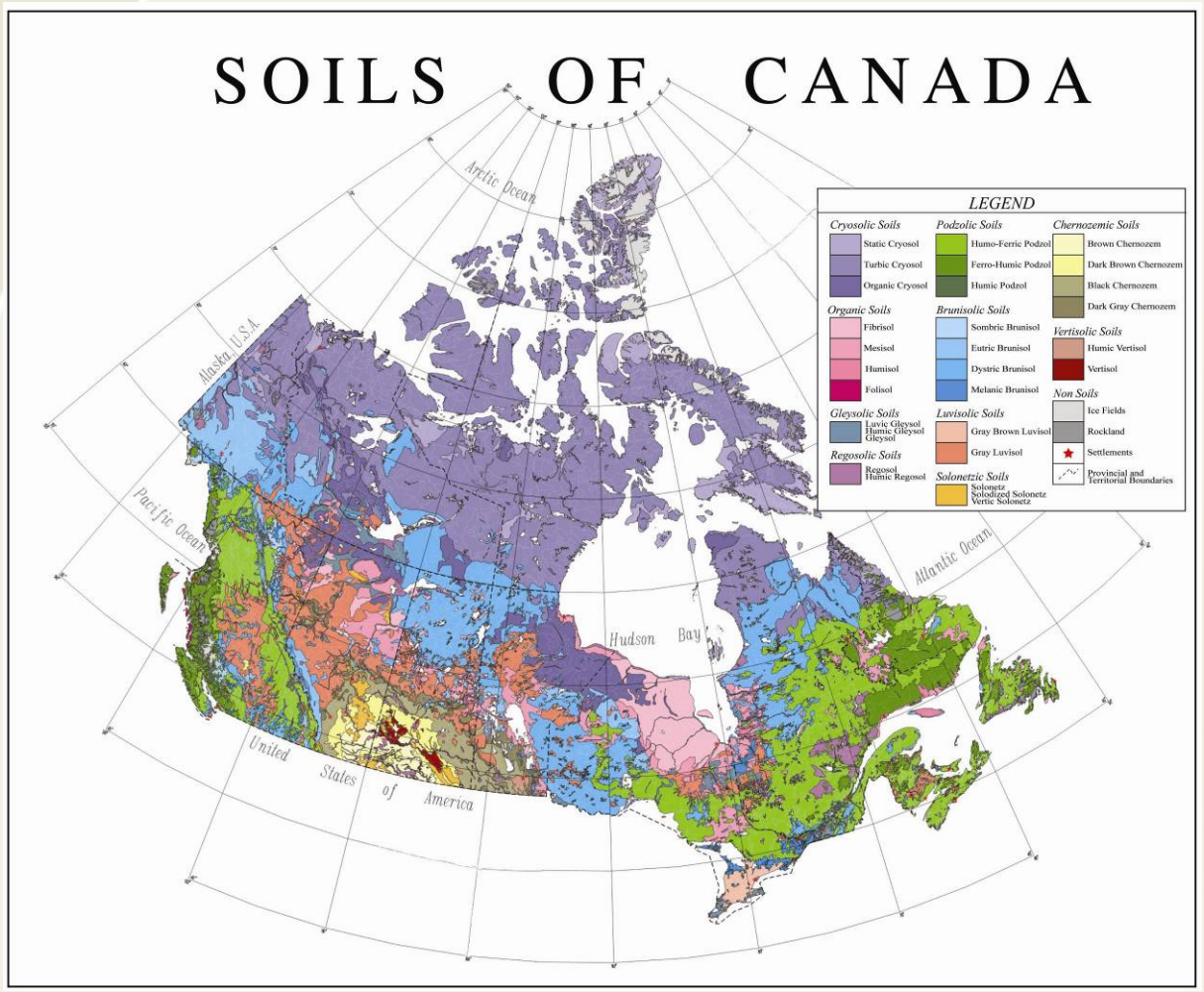


Source: GSC
Map 1880A
(1: 5 000 000)

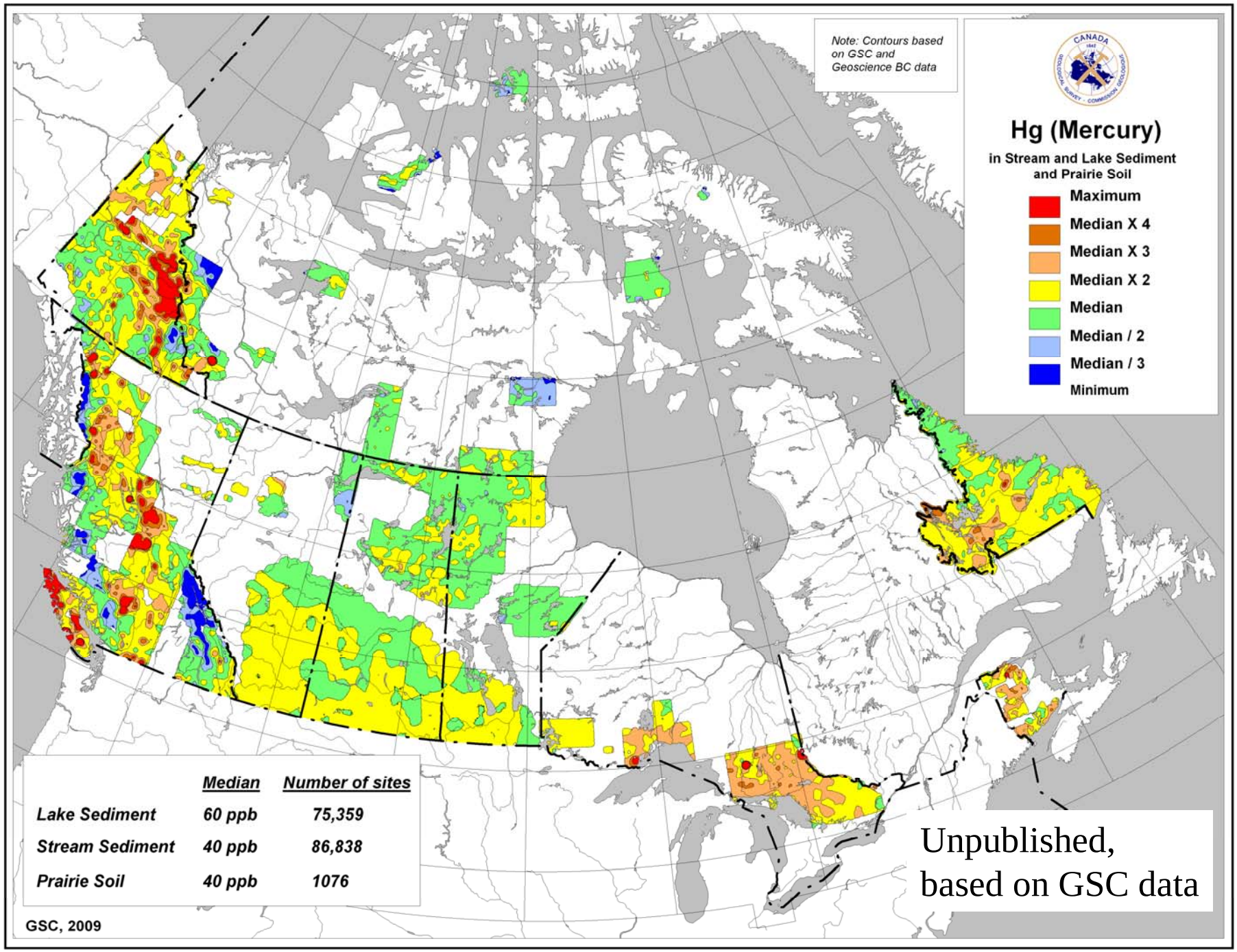
Download map and legend at http://gsc.nrcan.gc.ca/map/1880a/index_e.php

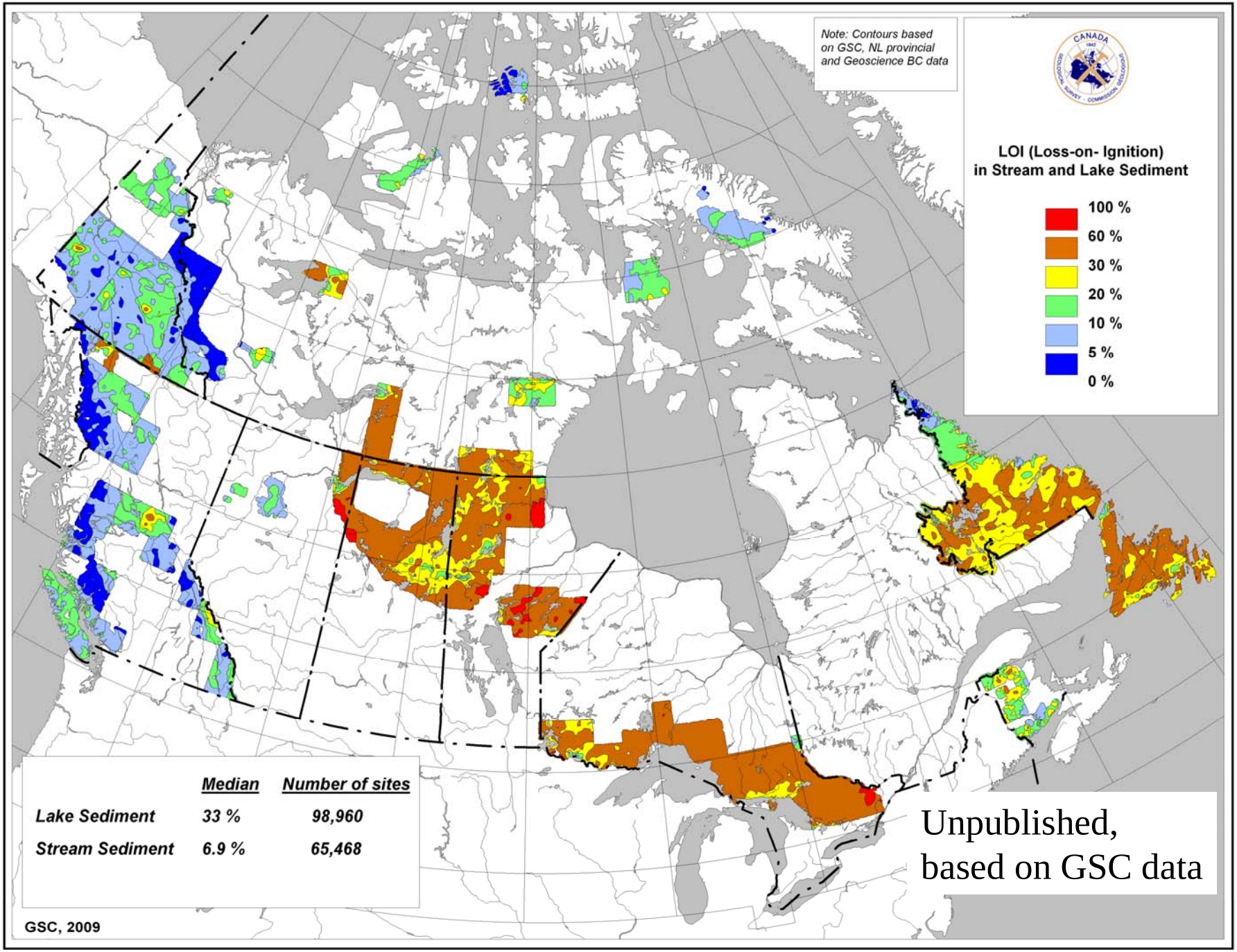
Soils of Canada

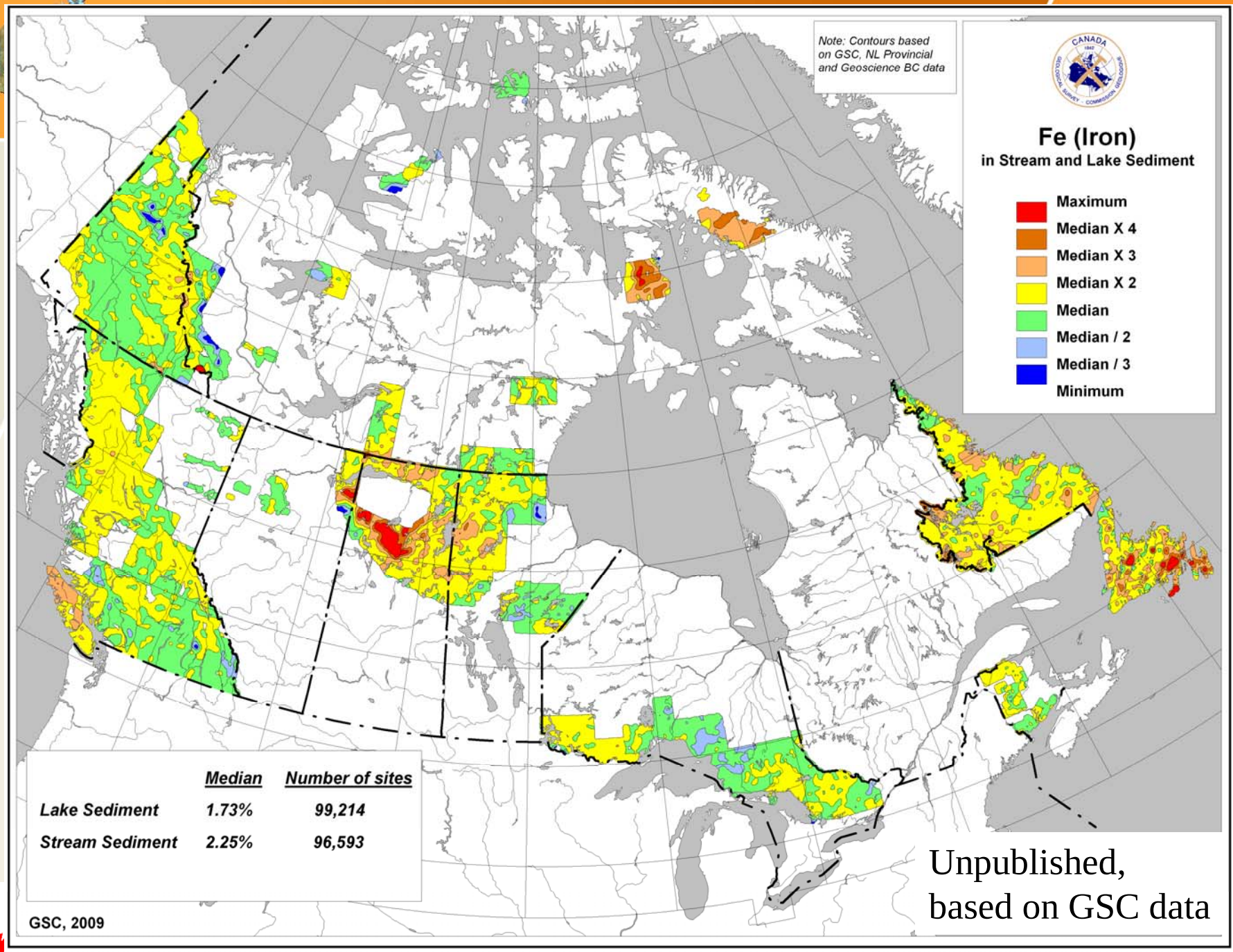
Earth Sciences Sector

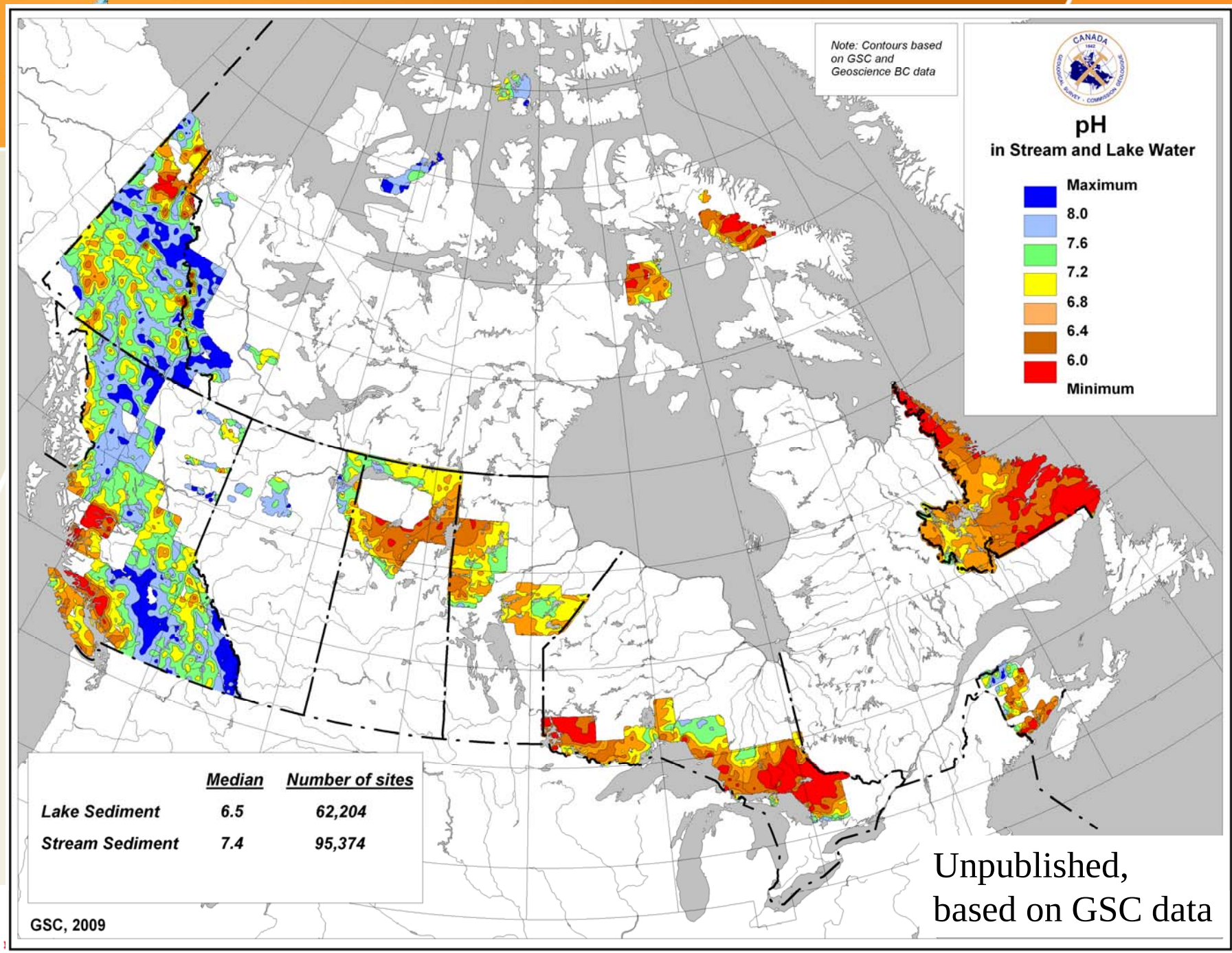


Source: AAFC Map
(1: 6 500 000)


Note: Contours based on GSC and Geoscience BC data
Hg (Mercury)
in Stream and Lake Sediment and Prairie Soil
Maximum
Median X 4
Median X 3
Median X 2
Median
Median / 2
Median / 3
Minimum
Median
Number of sites
Lake Sediment
60 ppb
75,359
Stream Sediment
40 ppb
86,838
Prairie Soil
40 ppb
1076
GSC, 2009
Unpublished, based on GSC data


Note: Contours based on GSC, NL provincial and Geoscience BC data
LOI (Loss-on- Ignition) in Stream and Lake Sediment
100 %
60 %
30 %
20 %
10 %
5 %
0 %
Median
Number of sites
Lake Sediment
33 %
98,960
Stream Sediment
6.9 %
65,468
GSC, 2009
Unpublished, based on GSC data


Note: Contours based on GSC, NL Provincial and Geoscience BC data
Fe (Iron)
in Stream and Lake Sediment
Maximum
Median X 4
Median X 3
Median X 2
Median
Median / 2
Median / 3
Minimum
Median
Number of sites
Lake Sediment
1.73%
99,214
Stream Sediment
2.25%
96,593
GSC, 2009
Unpublished,
based on GSC data

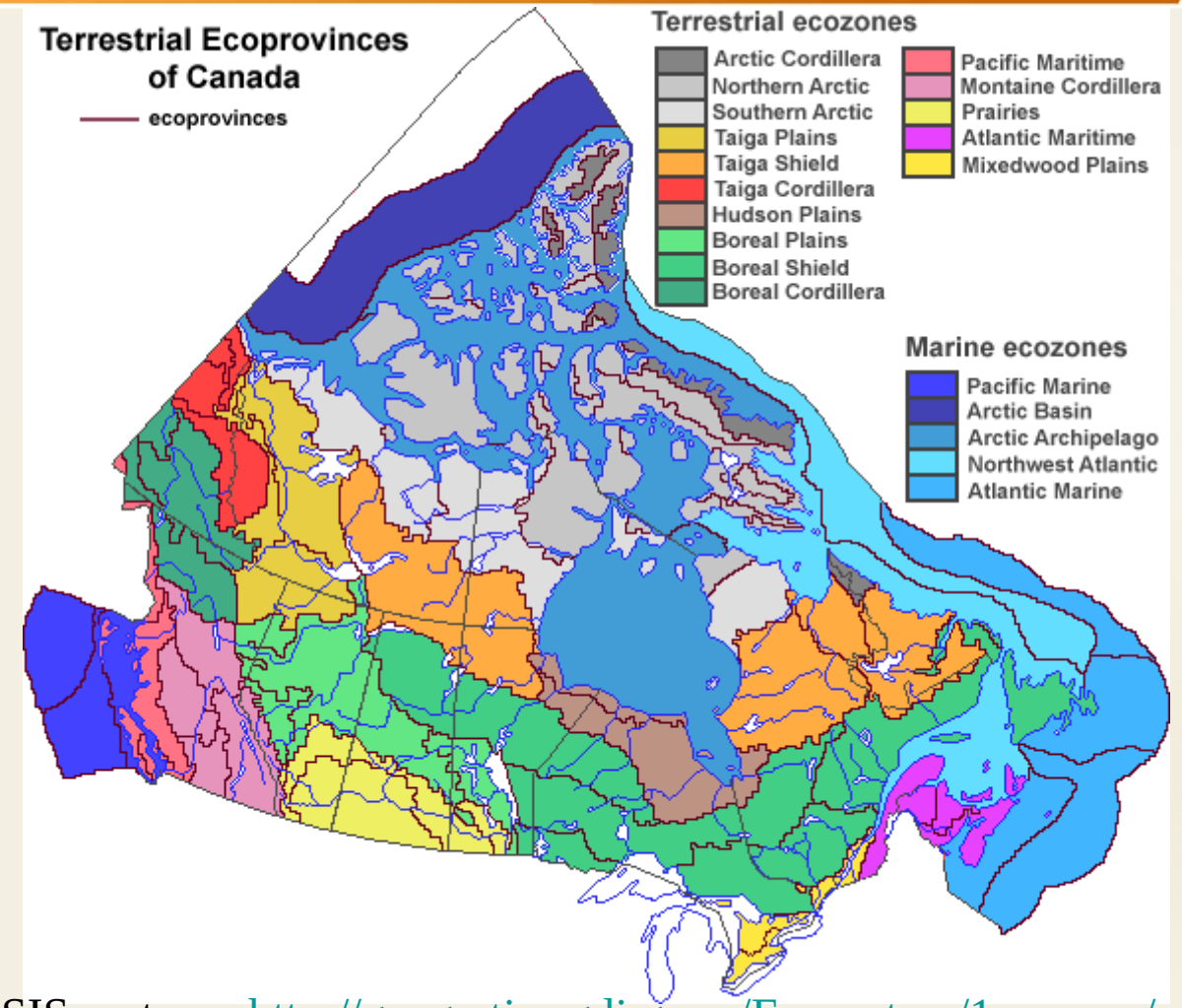

Note: Contours based on GSC and Geoscience BC data
pH
in Stream and Lake Water
Maximum
8.0
7.6
7.2
6.8
6.4
6.0
Minimum
Median
Number of sites
Lake Sediment
6.5
62,204
Stream Sediment
7.4
95,374
GSC, 2009
Unpublished, based on GSC data

Regionality

- In a country as large (9.2×10^6 $km^{2)}$, geologically diverse (the Precambrian Shield, the Cordilleras and the sedimentary basins) and physically variable (from the Arctic to carolinian and rain forests to grasslands), a single background range has little true meaning or relevance.
- In recognition of this, Environment Canada and Health Canada are moving to regionalize their risk assessments on the basis of ecological units, Ecoprovinces and Ecoregions.

EcoProvinces of Canada

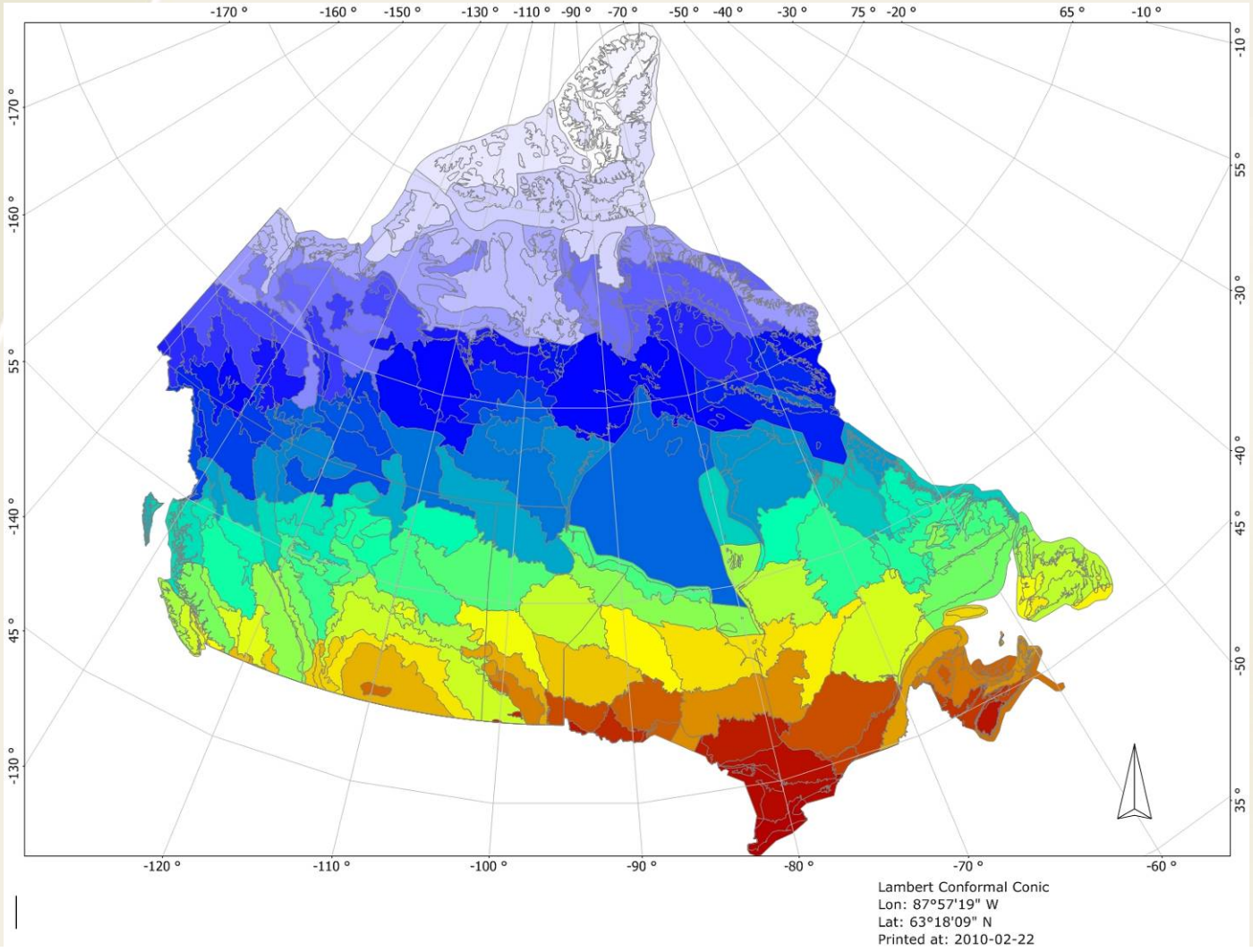
Earth Sciences Sector



Source: CanSIS system: http://geogratis.cgdi.gc.ca/Ecosystem/1_ecosys/ecogifs/ecoprov.gif

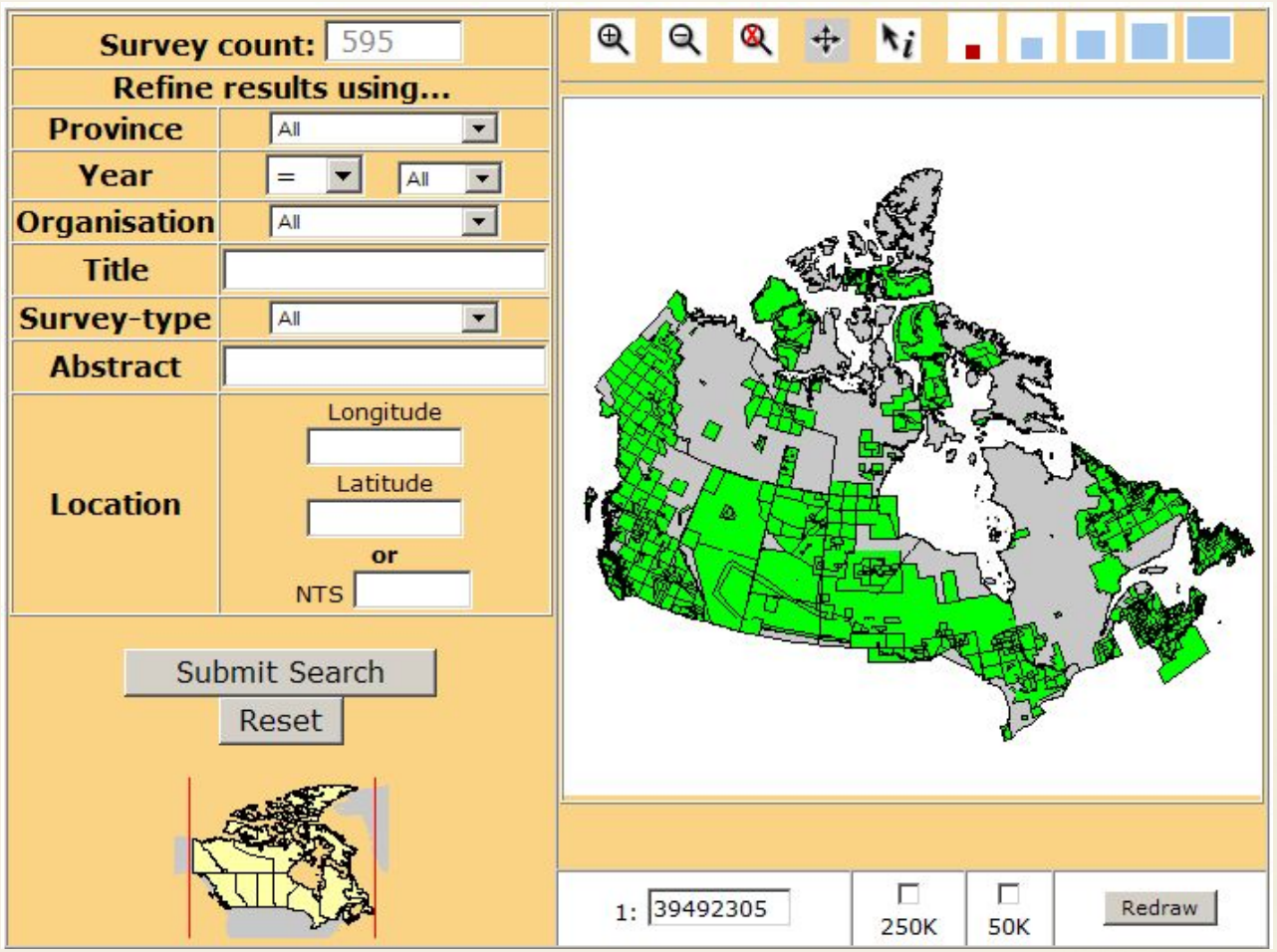
EcoRegions of Canada

Earth Sciences Sector



Source: CanSIS database

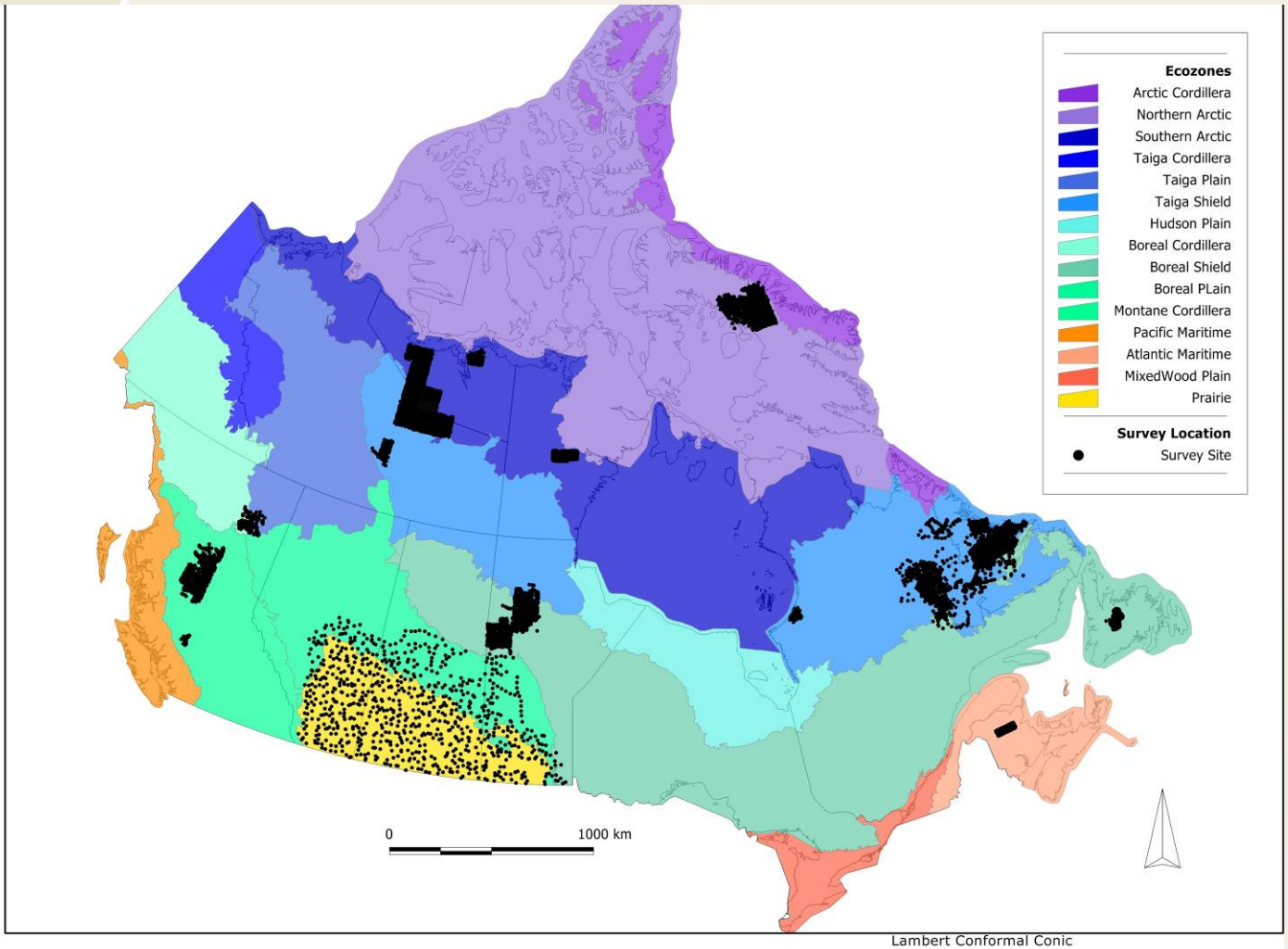
Example - Map-based Interface



•Geoscience Data Repository interface showing location of catalogued geochemical surveys
•On–line at http://apps1.gdr.nrcan.gc.ca/geochem/main_e.phtml [accessed March 26, 2010]

Sites by Ecozone

Earth Sciences Sector



EcoZones

Lambert Conformal Conic
Lon: 87°57'19" W
Lat: 63°18'09" N
Printed at: 2010-02-02

Example

Natural Resources Canada | Ressources naturelles Canada

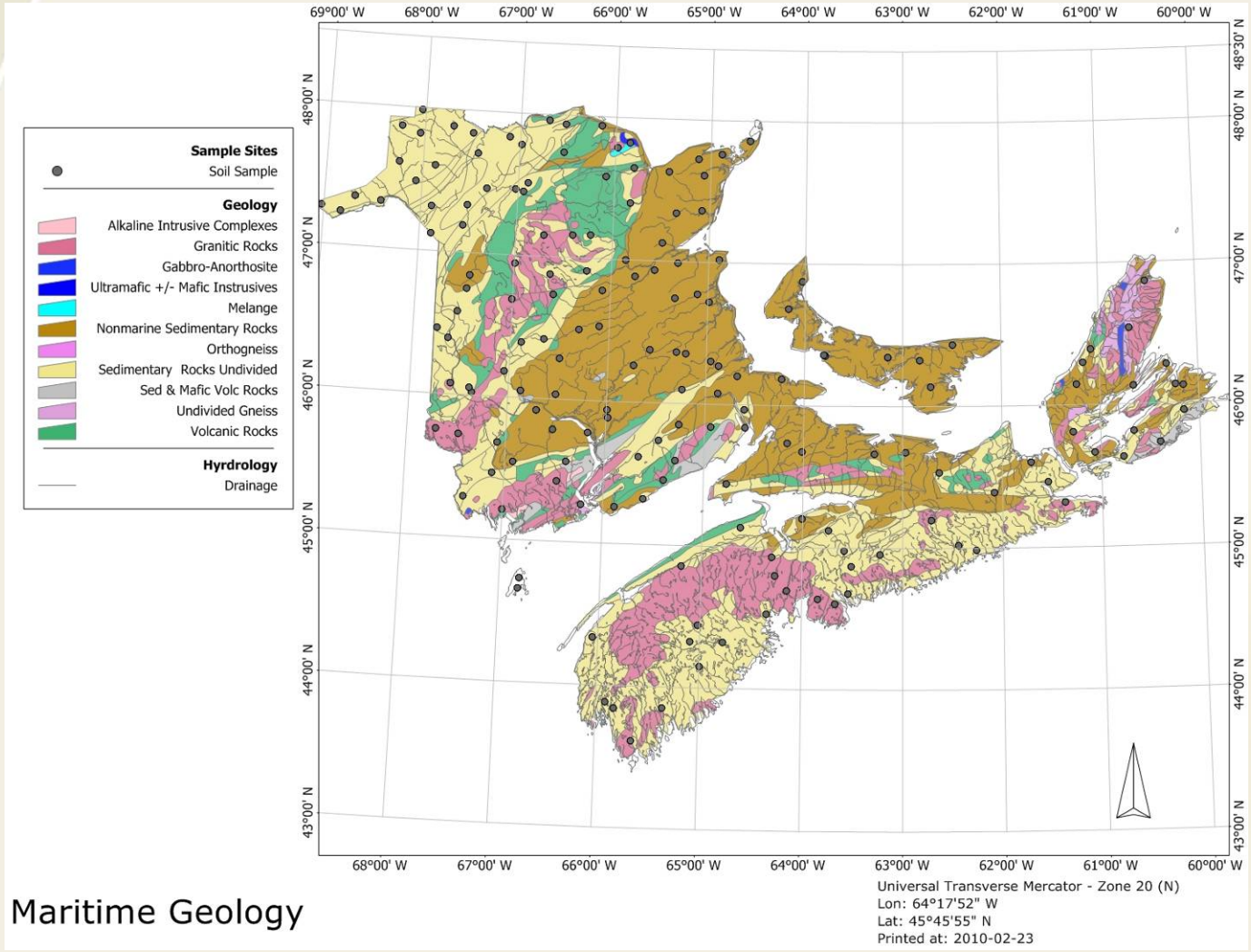
Canada

Geochemical Landscapes

Provincial Scale

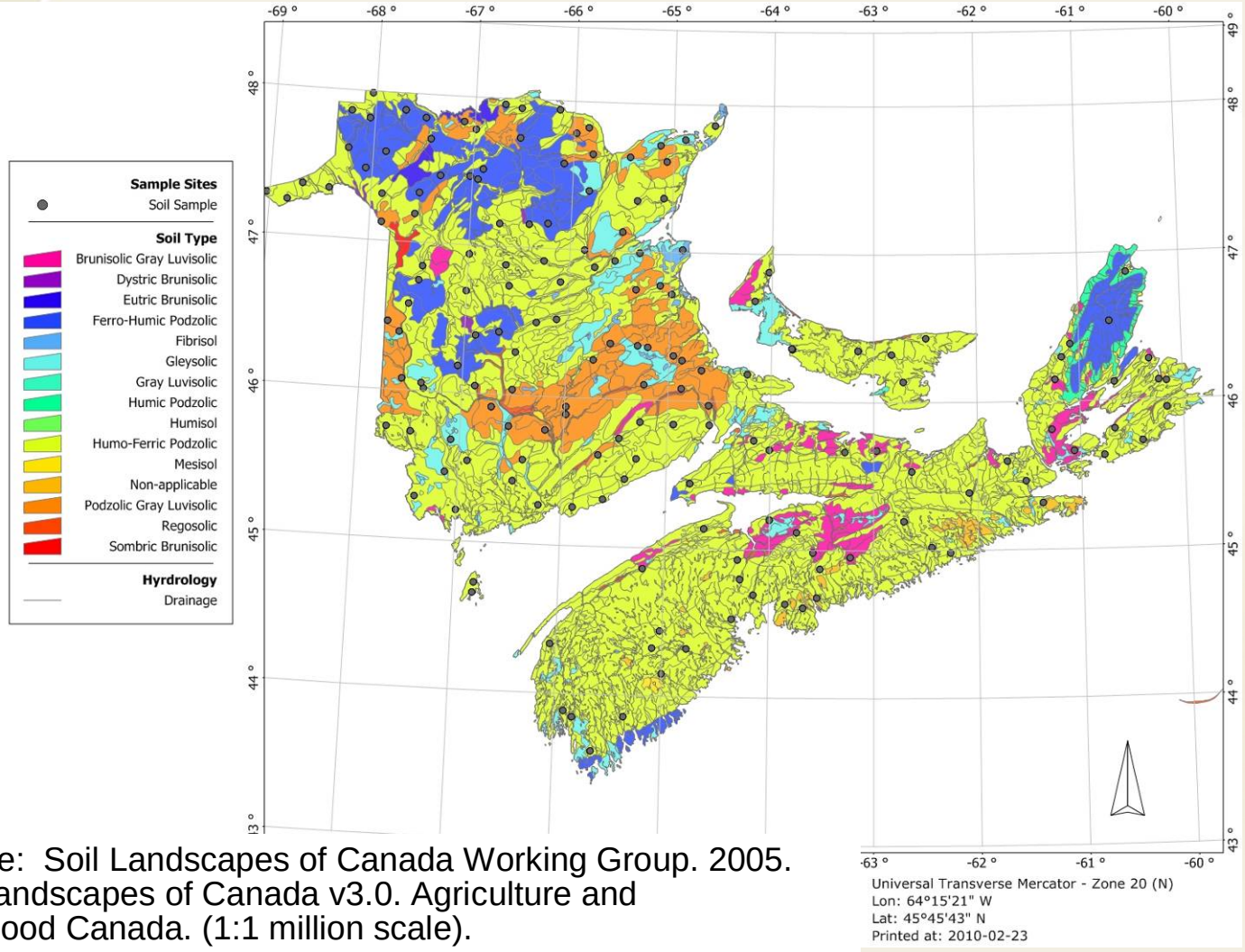
Maritime Geology

Earth Sciences Sector



Maritime Soil Types

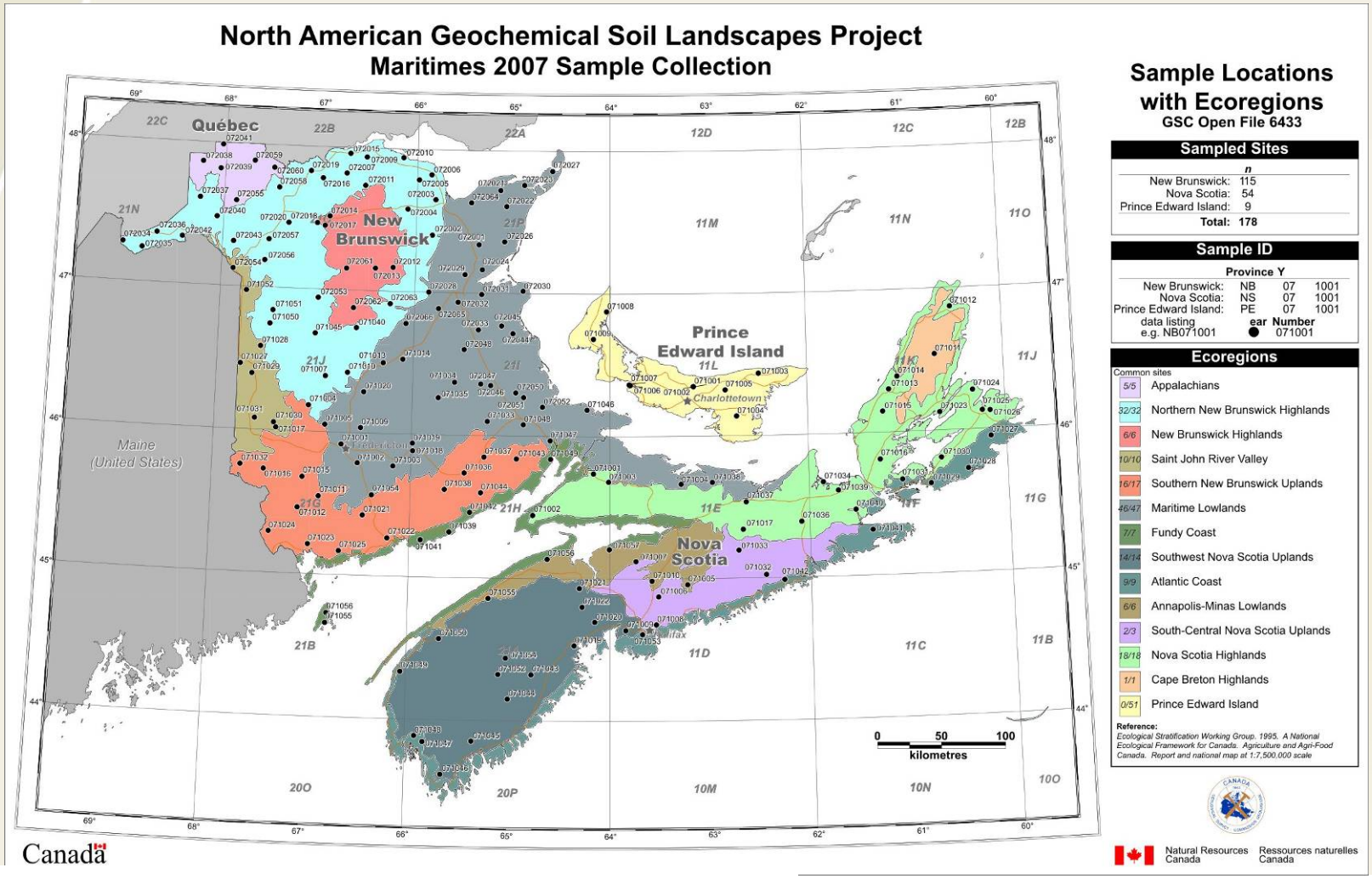
Earth Sciences Sector



Source: Soil Landscapes of Canada Working Group. 2005. Soil Landscapes of Canada v3.0. Agriculture and Agri-Food Canada. (1:1 million scale).

Maritime Soil Survey Sites and EcoRegions

Earth Sciences Sector



Source for Ecoregions: Ecological Stratification Working Group, 1996.

Sampling Strategies

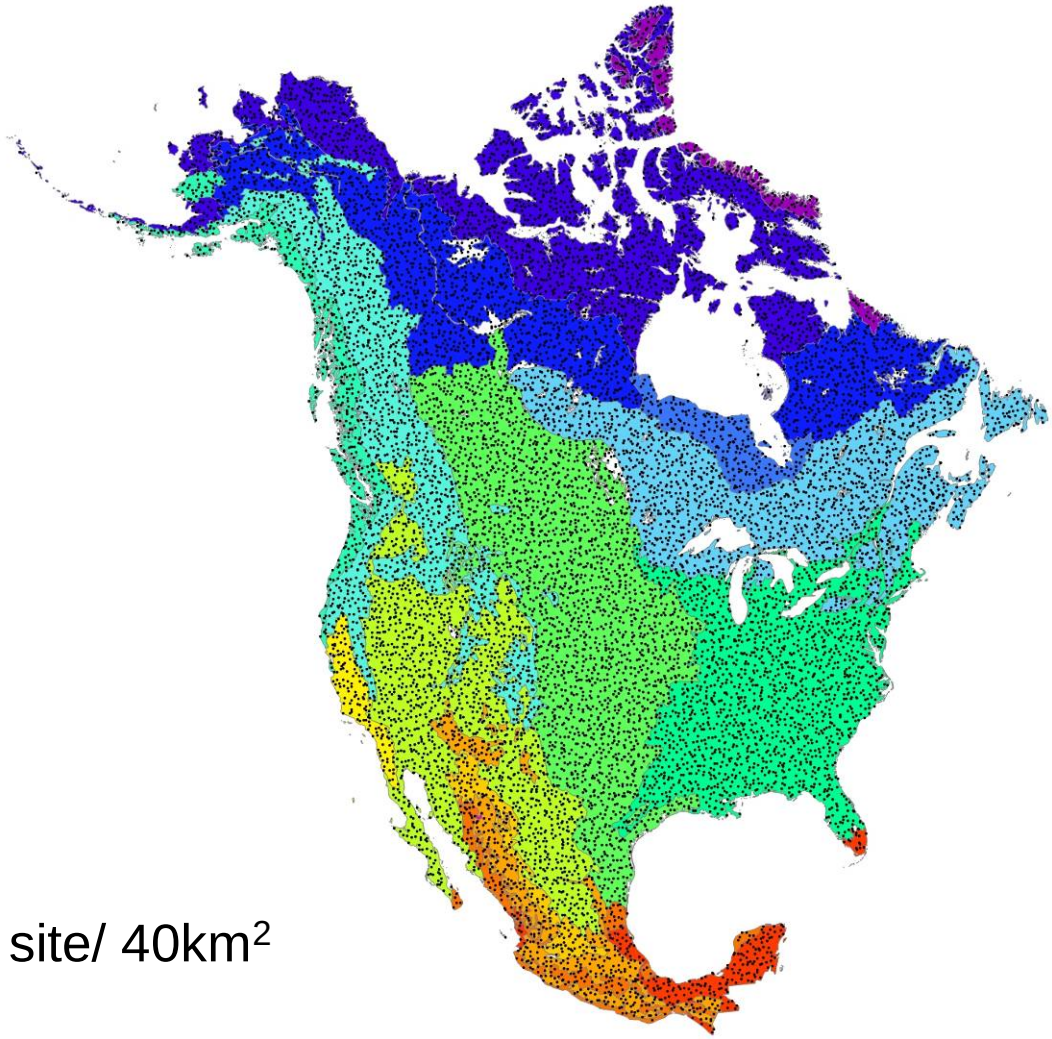
Sample Design for Soil Surveys

- Sample strategy used for the North American Soil Geochemical Landscapes Project in Canada.
  - Generalized Random Tesselation Sample design (GRTS).
- GRTS is a random design based on the following: *A spatial point pattern is a collection of n points within a region D ⊂ R2 (a region D defined in a 2-dimensional real number space). The number of points is thought of as random and the points are considered to be generated by a stationary isotropic point process in R2. This means that there is not preferred origin or orientation in the pattern.* (Venables and Ripley, 2004).
- Initial GRTS design – 1 site / 40km^2
- Maritime GRTS design – 1 site / 20km^2

Sample Designs

- Analysis of variance (AOV) is important in establishing the variance at different levels of design (site spacing) and the repeatability of patterns across an area.
  - Stratified random sample design
  - Balanced nested hierarchical sample design
  - Unbalanced nested hierarchical sample design

GRTS Design – Continental Scale



1 site/ 40km^2

Preselected sites for the NASGLP

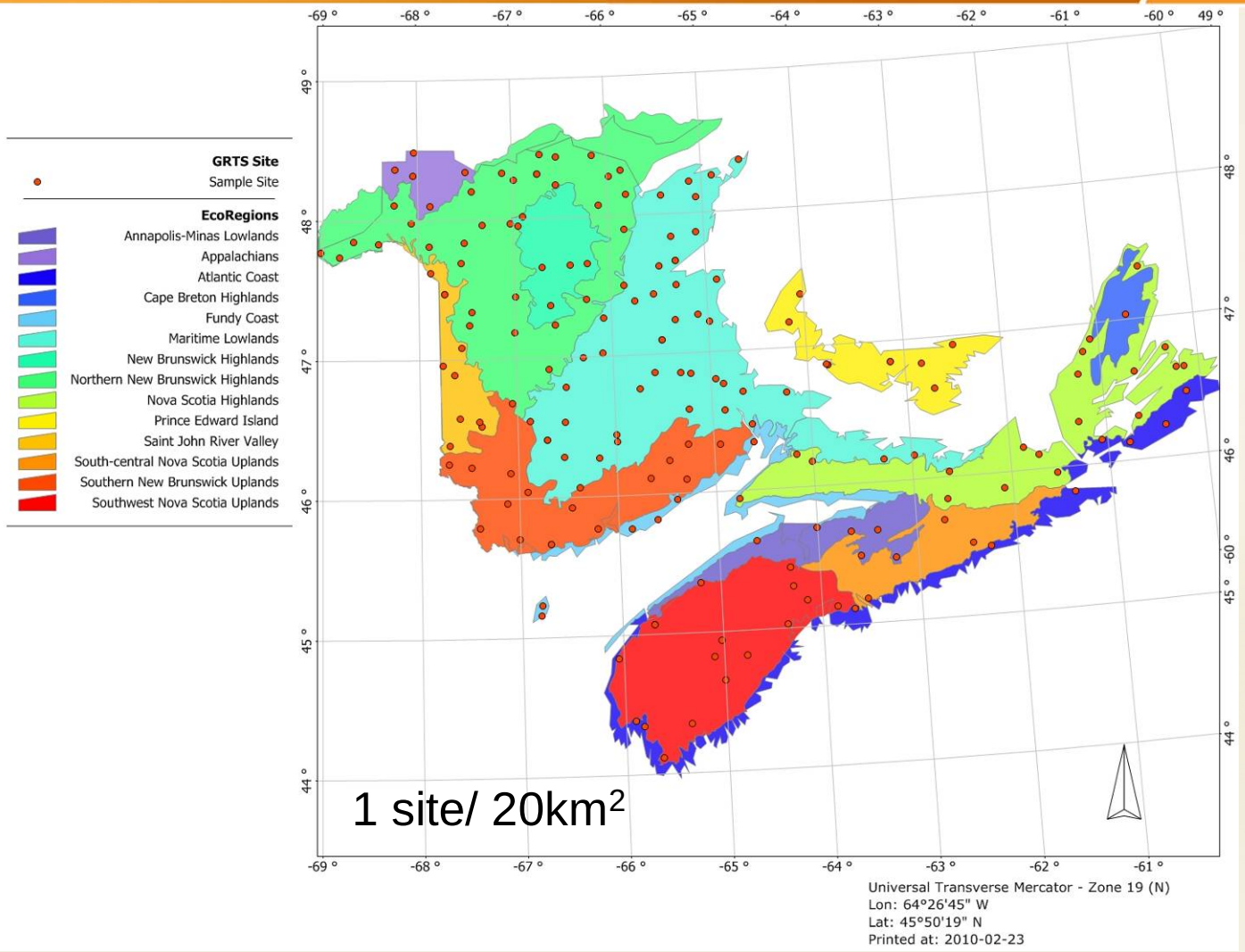
North American Soil Geochemistry Landscape Project

Earth Sciences Sector

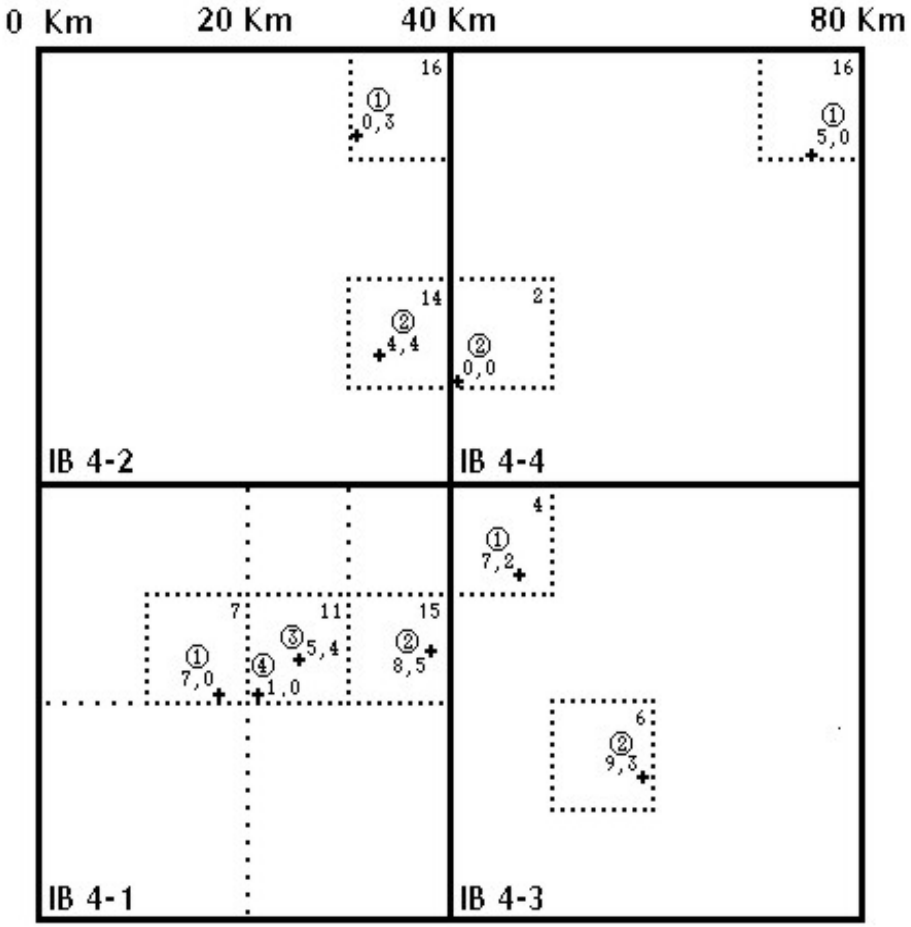
- The NASGLP was developed from a 2001 meeting between the geological surveys of Mexico, USA and Canada for the purpose of characterizing the soil cover over North America.

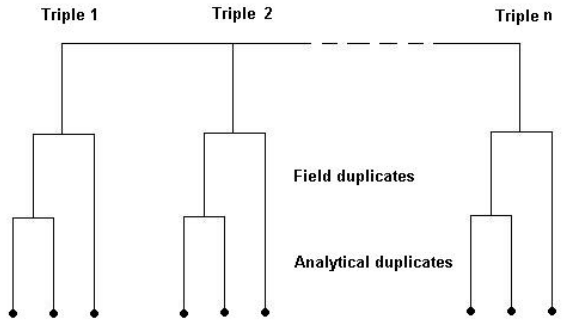
- Goals of the NASGLP are:
  - Identify soil geochemical variability across the continent.
  - Identify soil geochemical variability throughout the soil profile.
  - Describe geochemical processes that are observed through the study of the geochemistry, mineralogy
  - Provide essential geochemical information for determining the range of background for a variety of soil materials across the continent.
  - Contribute to the requirements of both environmental and health risk assessments by providing realistic ranges for background.

GRTS Design - Maritime Provinces



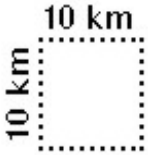
Example - Other Sample Design



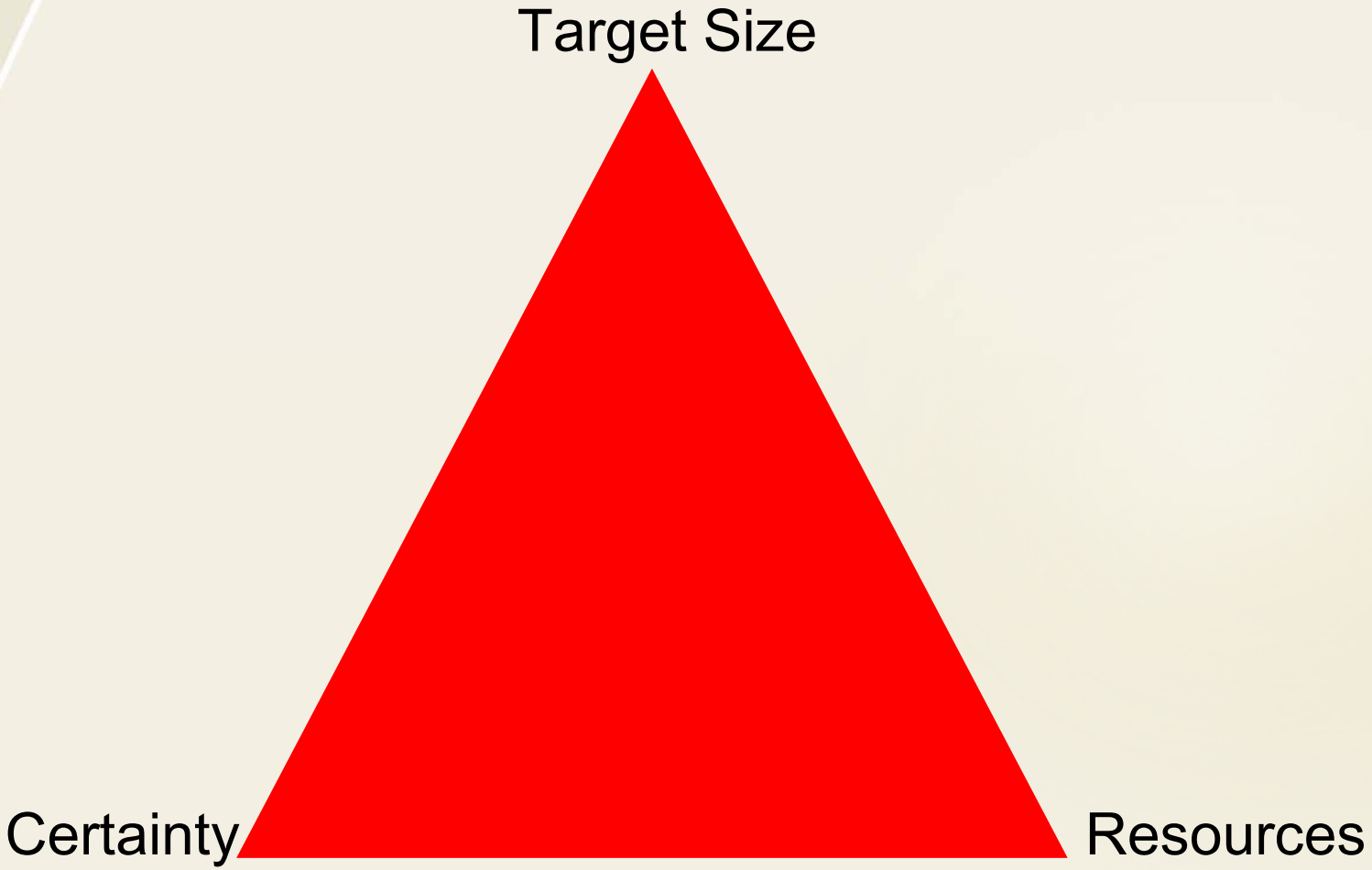


Unbalanced Nested Stratified Sample Design

(Garrett, 1983)



Sample Strategy - Decisions



Geochemical Landscapes

Variation in the Vertical Profile

Soil Development

Soil Horizon:
A layer of mineral or organic soil material approximately parallel to the land surface that has characteristics altered by processes of soil formation. It differs from adjacent horizons in properties such as color, structure, texture, and consistence and *in chemical, biological or mineralogical composition*

A-horizon: forms at or near the surface in the zone of leaching or eluviation of materials *(removal of Fe, Al, clays and organic matter)* in solution or suspension

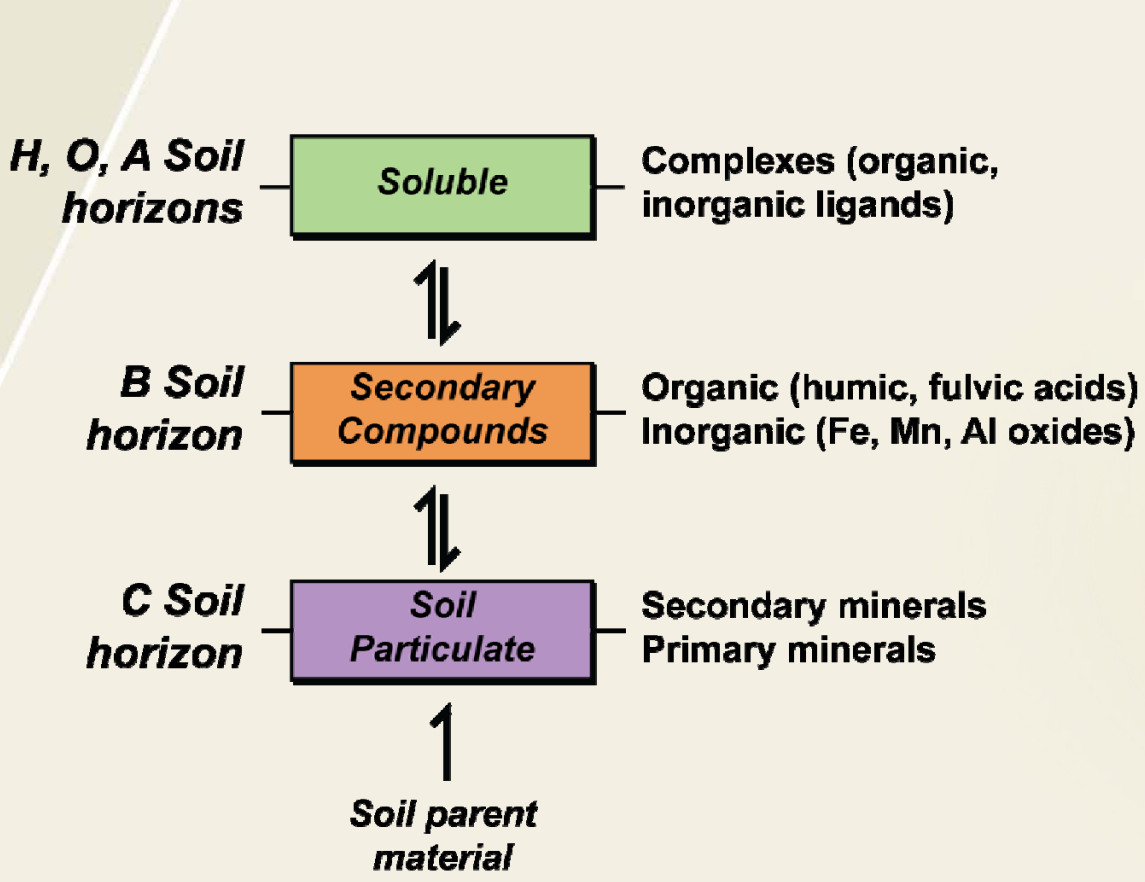
B-horizon: zone of enrichment in organic matter, sesquioxides, or clay; or by the development of soil structure; or by a change of color denoting hyrdolysis, reduction, or oxidation

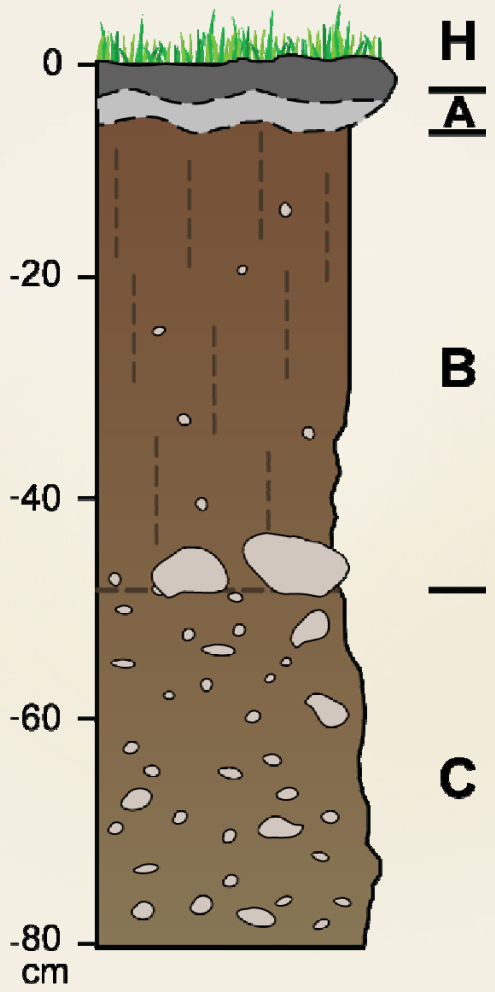
C-horizon: unaffected by the pedogenic processes operating in A and B-horizons

Canadian System of Soil Classification, 3rd ed., AAFC

Generalized Soil Profile and Processes

Earth Sciences Sector





Soil Classification

- Soils are classified according to Order, Great Group, and Sub-group.
- Information is available in Chapter 3 of Canadian System of Soil Classification (third edition). http://sis.agr.gc.ca/cansis/taxa/cssc3/chpt3.html.
- Soil stypes are differentiated on the basis of measured properties of the profile and uses a hierarchical scheme to classify soils from general to specific. The most recent version of the classification system has five categories in its hierarchical structure. From general to specific, the major categories in this system are: orders, great groups, subgroups, families, and series.
- At its most general level, the Canadian System of Soil Classification recognizes 9 different soil orders.

Soil Orders in Canada

The 9 soils orders are as follows:

(1) Brunisol - is a normally immature soil commonly found under forested ecosystems. The most identifying trait of these soils is the presence of a B horizon that is brownish in color. The soils under the dry pine forests of south-central British Columbia are typically brunisols.

(2) Chernozem - is a soil common to grassland ecosystems. This soil is dark in color (brown to black) and has an A horizon that is rich in organic matter. Chernozems are common in the Canadian prairies.

(3) Cryosol - is a high latitudes soil common in the tundra. This soil has a layer of permafrost within one meter of the soil surface.

(4) Gleysol - is a soil found in an ecosystem that is frequently flooded or permanently waterlogged. Its soil horizons show the chemical signs of oxidation and reduction.

(5) Luvisol - is another type of soil that develops under forested conditions. This soil, however, has a calcareous parent material which results in a high pH and strong eluviation of clay from the A horizon.

Soil Orders in Canada

(6) Organic - this soil is mainly composed of organic matter in various stages of decomposition. Organic soils are common in fens and bogs. The profiles of these soils have an obvious absence of mineral soil particles.

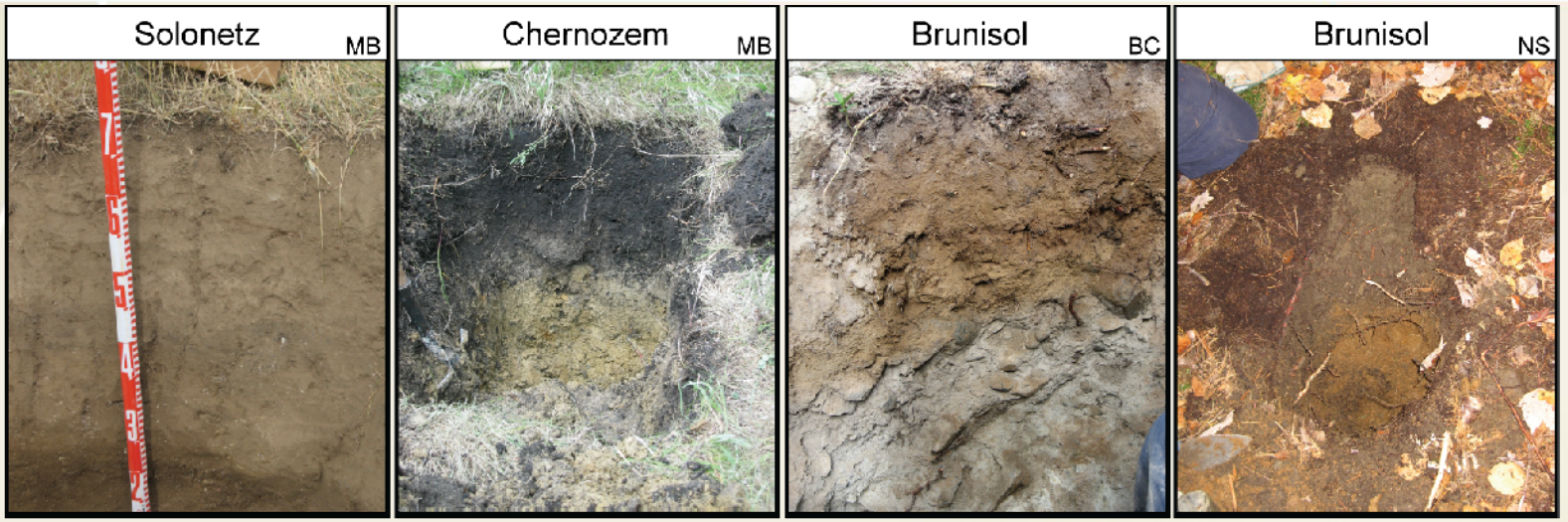
(7) Podzol - is a soil commonly found under coniferous forests. Its main identifying traits are a poorly decomposed organic layer, an eluviated A horizon, and a B horizon with illuviated organic matter, aluminum, and iron. Podzols are common in the forested regions of Southern Ontario.

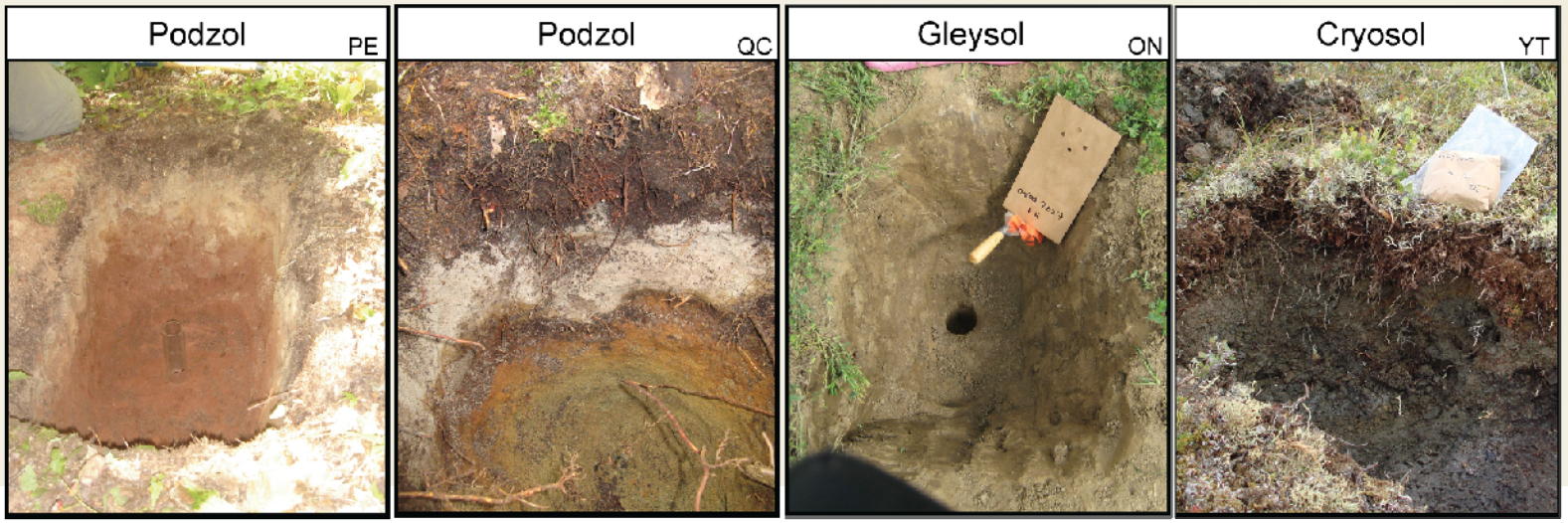
(8) Regosol - is any young underdeveloped soil. Immature soils are common in geomorphologically dynamic environments. Many mountain river valleys in British Columbia have floodplains with surface deposits that are less than 3000 years old. The soils in these environments tend to be regosols.

(9) Solonetzic - is a grassland soil where high levels of evapotranspiration cause the deposition of salts at or near the soil surface. Solonetzic soils are common in the dry regions of the prairies where evapotranspiration greatly exceeds precipitation input. The movement of water to the earth's surface because of capillary action, transpiration, and evaporation causes the deposition of salts when the water evaporates into the atmosphere.

Common Soil Profiles

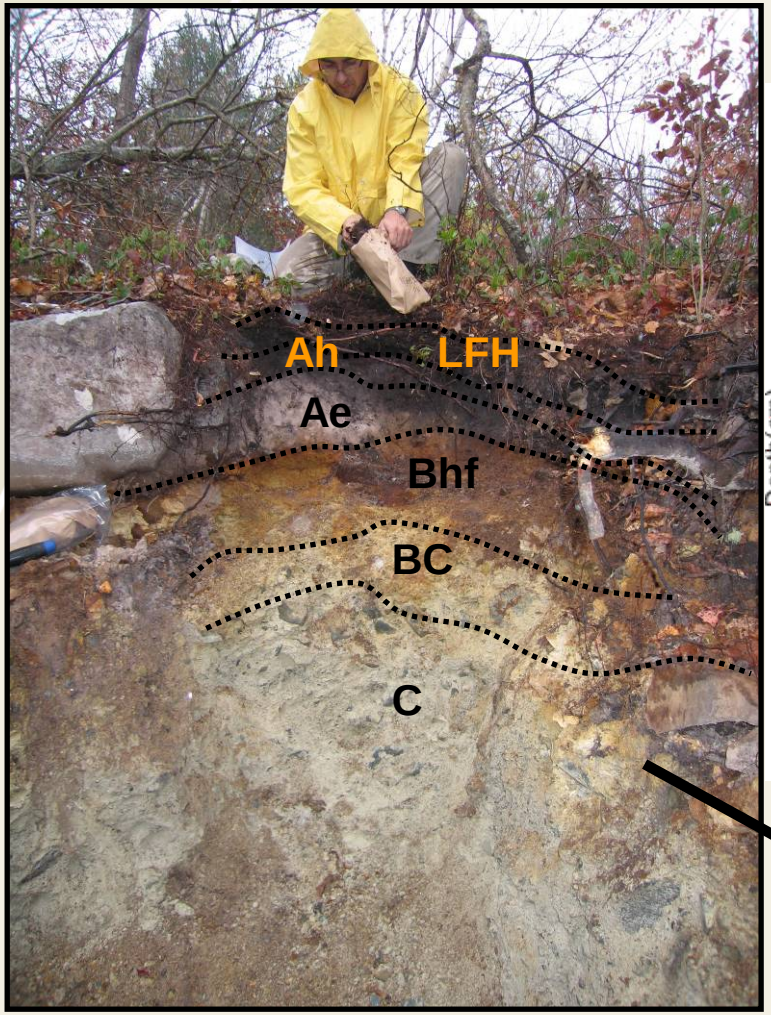
Earth Sciences Sector



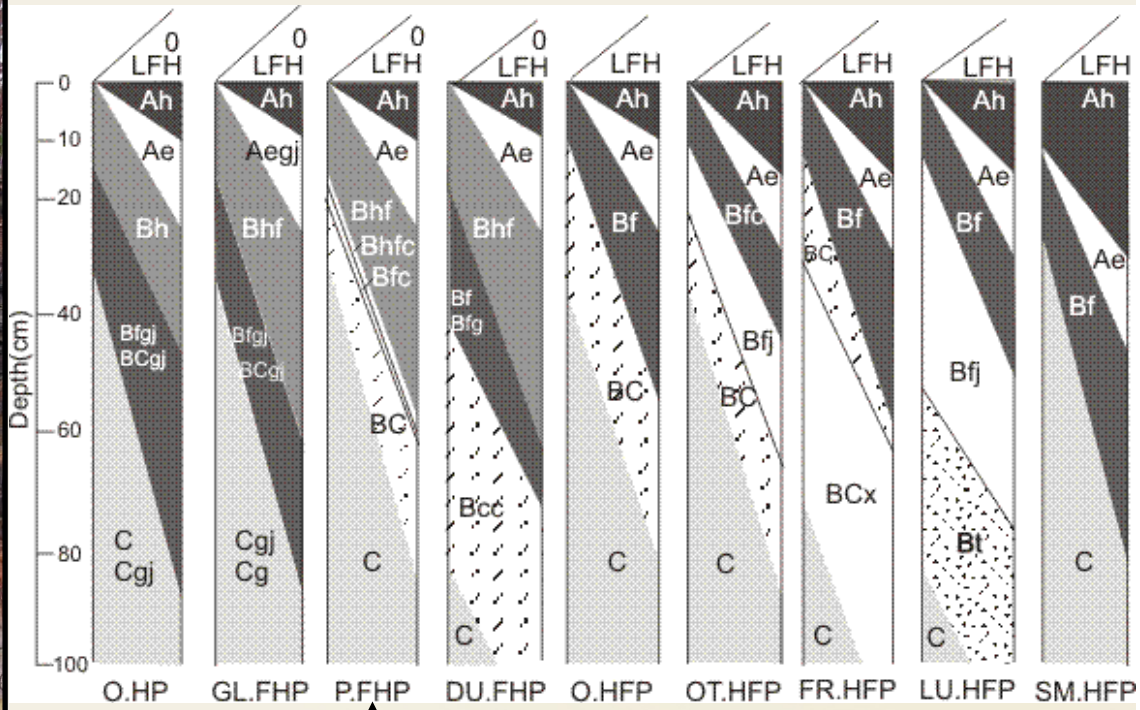


Podzol Profile

Earth Sciences Sector



** Well developped Ferro-Humic Podzol*

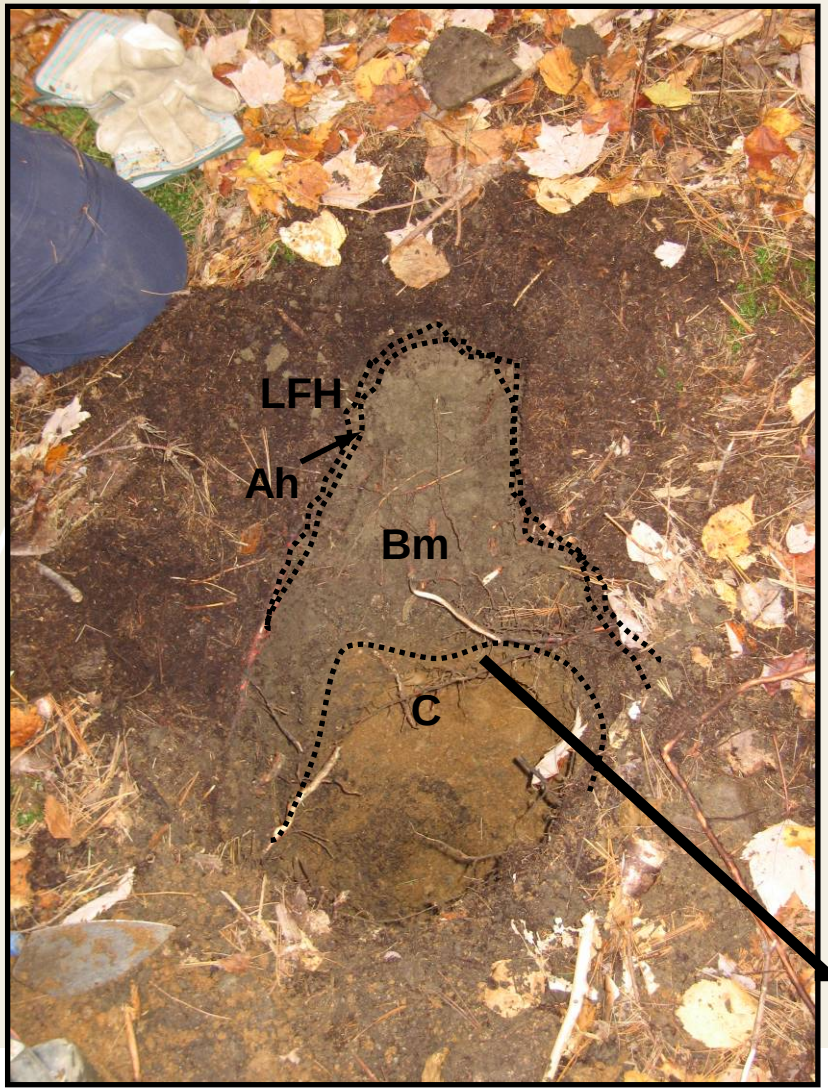


Soil Classification Working Group, 1998

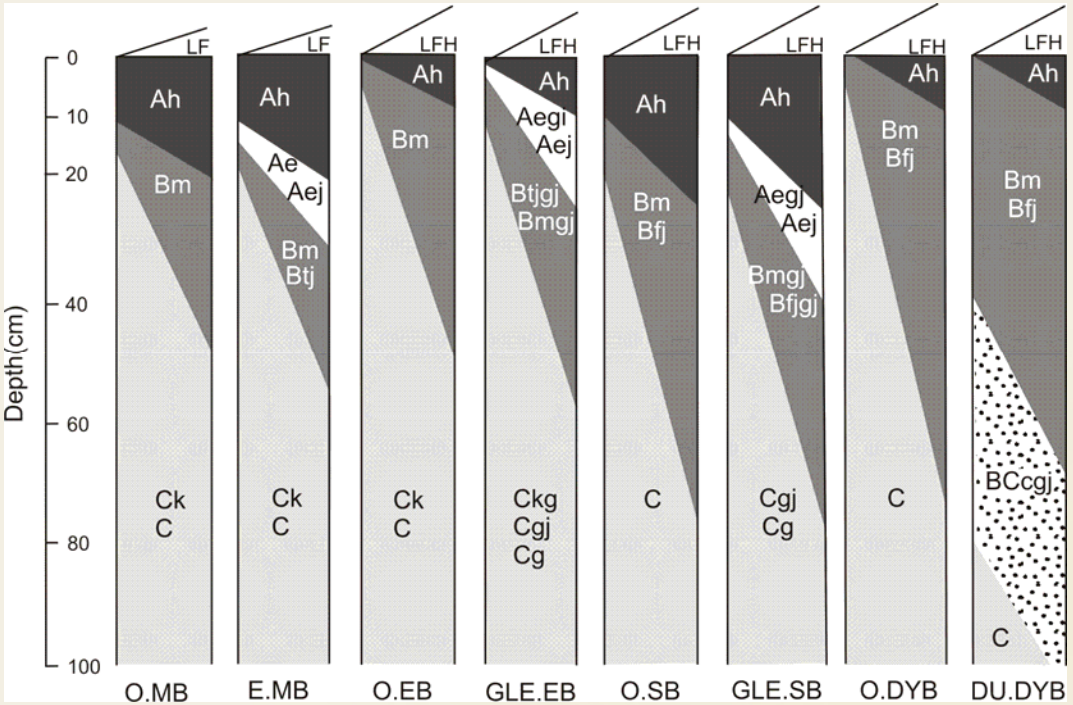
LFH: *~5 cm*
Ah: *~4 cm*
Ae: *~10 cm*
Bhf: *~20 cm*
BC: *~20 cm*
C: *>1.5 m*

Brunisol Profile

Earth Sciences Sector



** Low degree of soil horizon development*



Soil Classification Working Group, 1998

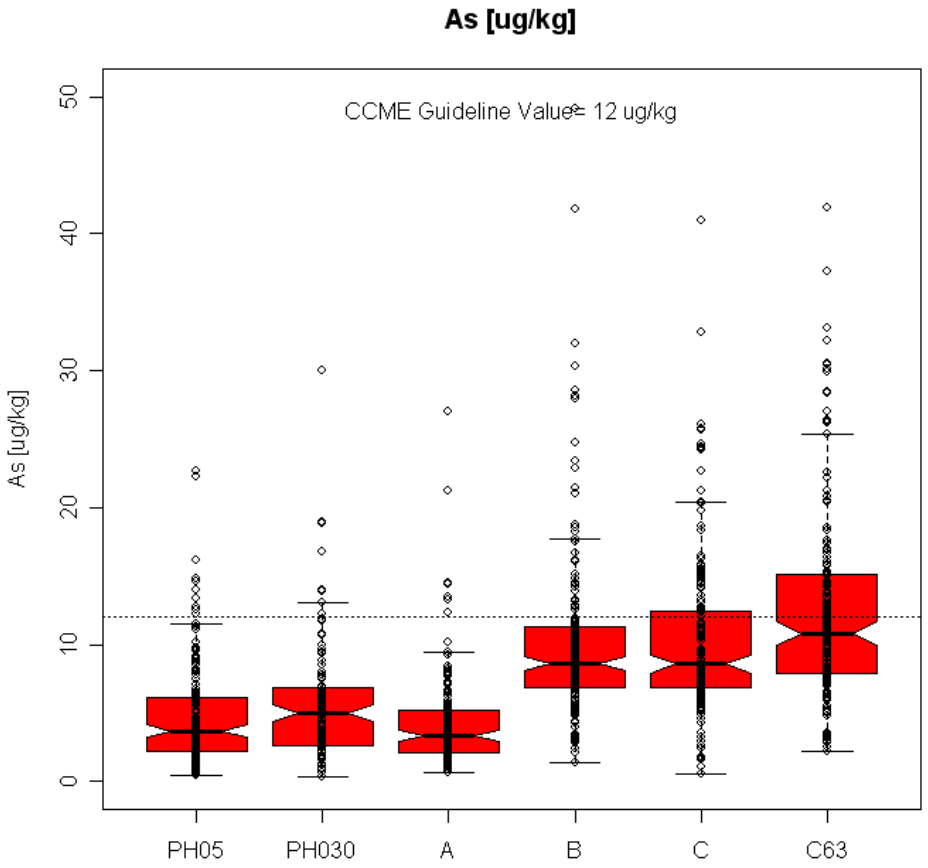
LFH: *~5 cm*
Ah: *<2 cm*
Bm: *~35 cm*
C: >40 cm

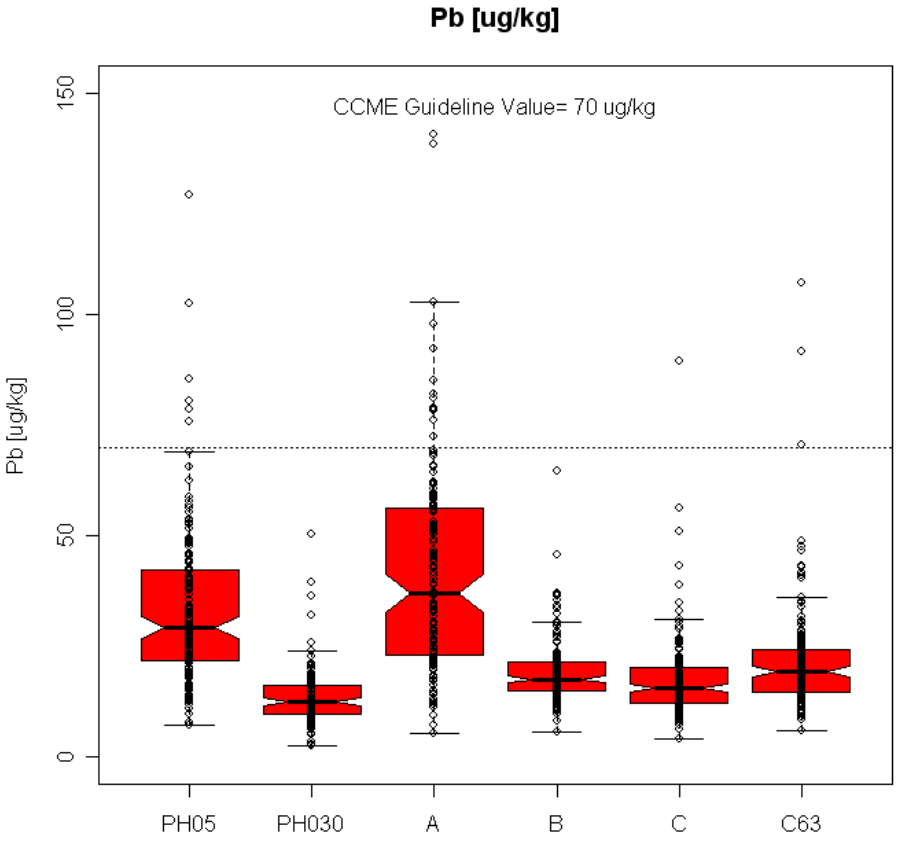
Natural Resources Canada | Ressources naturelles Canada

Canada

Source Identification

Earth Sciences Sector



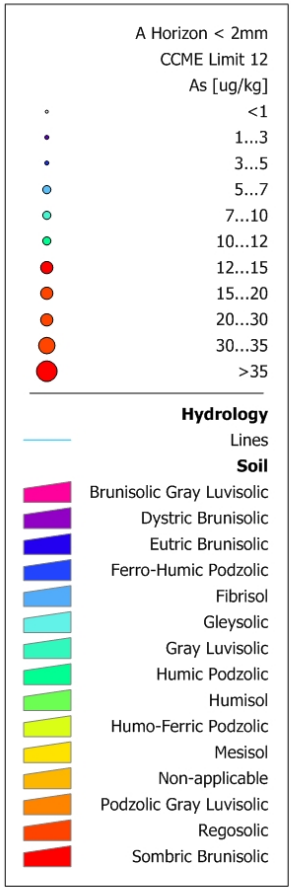


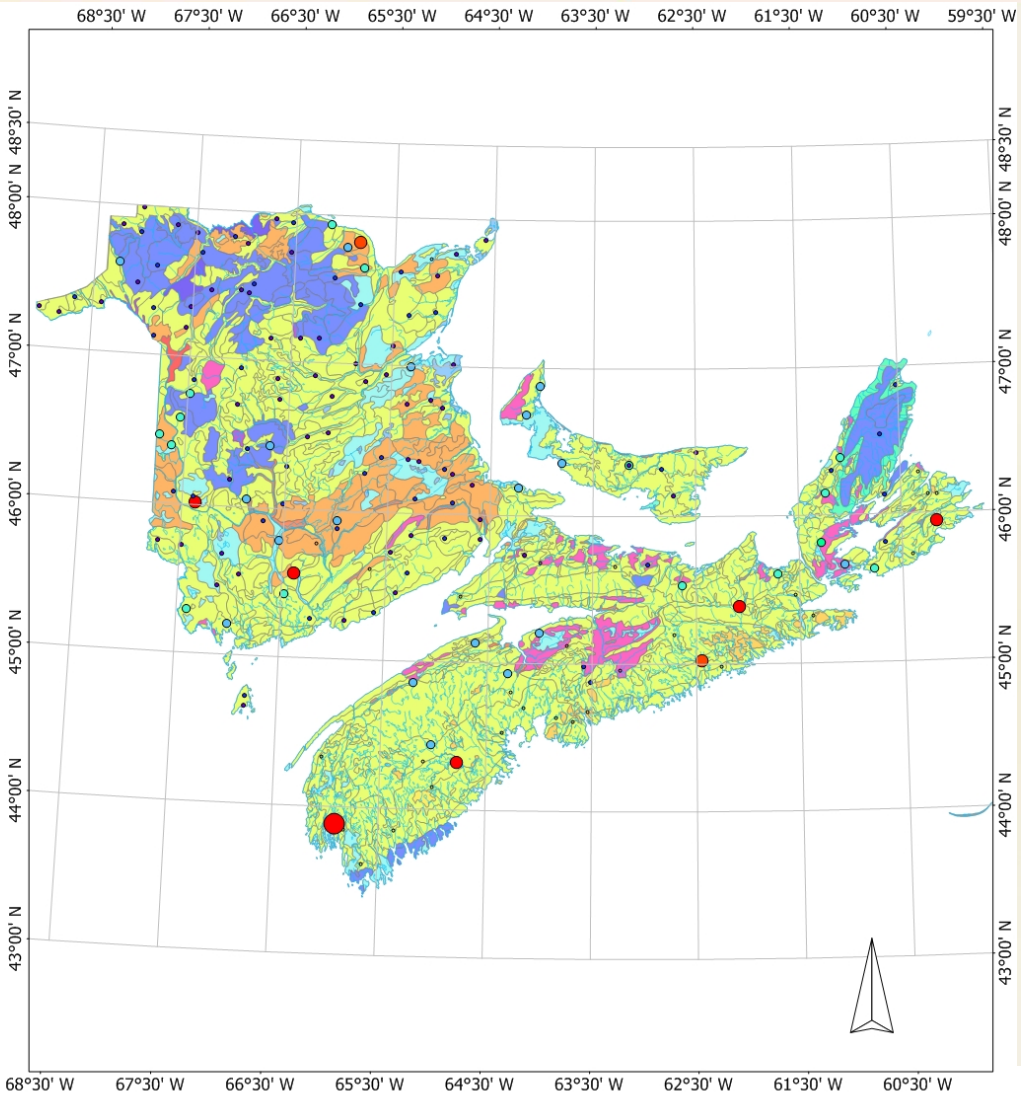
Tukey Box Plots for As, Pb in the <2mm fraction of soil from the 0-5 cm and 0-30 cm intervals and from the A,B, and Chorizons and in the <0.063 mm fraction of the C horizon. Samples were analyzed by ICP-MS after a 4-acid digestion.

As in A-horizon (<2 mm), based on CCME threshold levels

Earth Sciences Sector

Red dots
– above limit
Green dots
– below limit





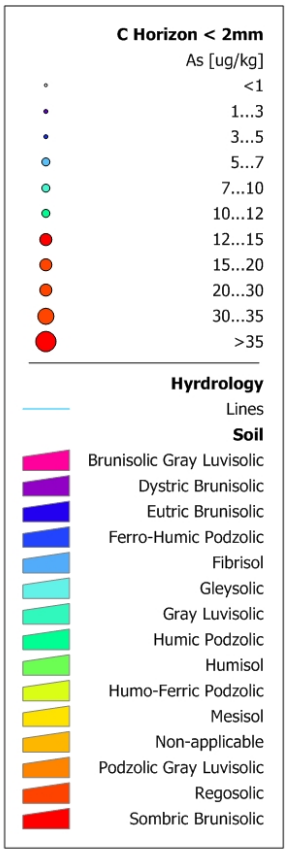
A-horizon, < 2mm fraction, EPA-3050B digestion

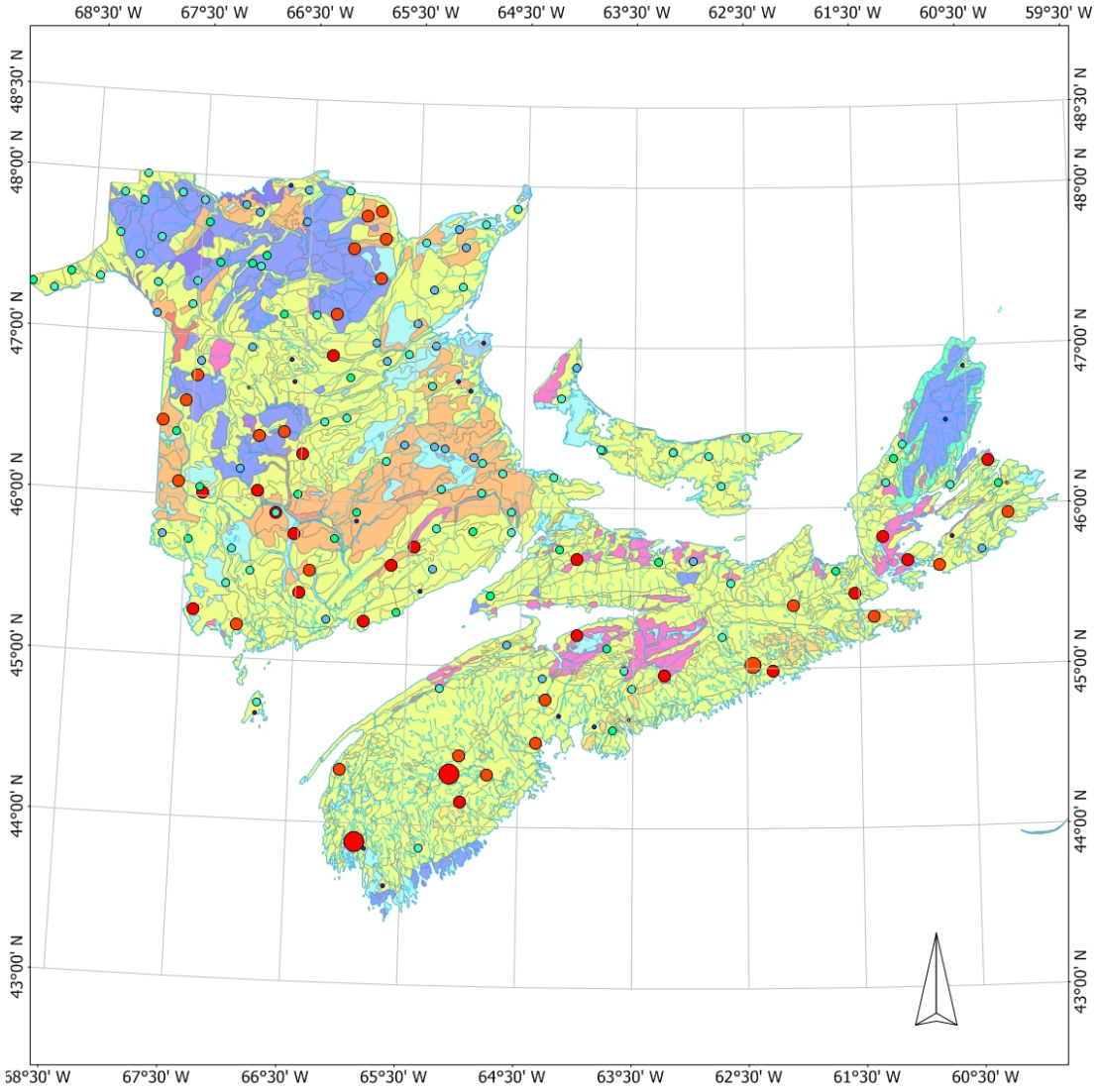
Universal Transverse Mercator - Zone 20 (N)
Lon: 64°17.525' W
Lat: 45°45.910' N
Printed at: 2008-09-12

As in C-horizon (<2 mm), based on CCME threshold level

Earth Sciences Sector

Red dots
– above limit
Green dots
– below limit

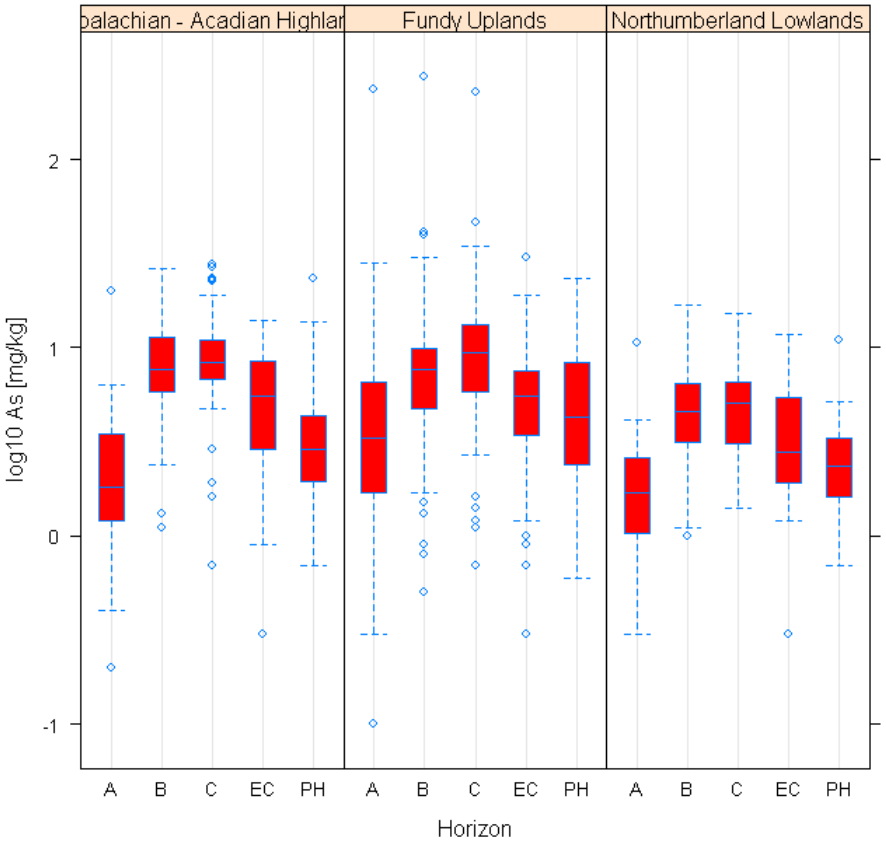




C-horizon, < 2mm fraction, EPA-3050B digestion

Universal Transverse Mercator - Zone 20 (N)
Lon: 64°15.364' W
Lat: 45°45.947' N
Printed at: 2008-09-12

As in the Soil Profile By Horizons and Ecoregions



As, <2 mm fraction
EPA 3050B digestion
ICP-MS analysis

Concentrations vary between horizons and between ecoregions

Recommendations

- Choose a sampling area suitable for the risk assessment and reaching out to background.
- Choose sample density to optimize process recognition through a minimum number of elements and a maximum number of sample sites.
- Understand the regional geology, soil types, climate and geomorphology.
- Choose suitable soil horizons that reflect the anthropogenic impact and regional and local geochemical variability.

References

Ecological Stratification Working Group. 1996. A National Ecological Framework for Canada. Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research and Environment Canada, State of Environment Directorate, Ottawa/Hull. 125pp. And Map at scale 1:7.5 million. http://www.ec.gc.ca/soer-ree/English/Framework/framework.cfm. Pdf copy available from /cansis/publications/ecostrat/intro.html

Fulton, R.J. (comp.). 1995. Surficial Materials of Canada, Geological Survey of Canada, Map 1 880A, scale 1:8,000000.

Garrett, R.G., 1983: Sampling methodology; in Chapter 4 of Handbook of Exploration Geochemistry, (ed.) R.J. Howarth,, Vol. 2, Statistics and Data Analysis in Geochemical Prospecting. Elsevier, p. 83-110.

Soil Classification Working Group, 1998. The Canadian System of Soil Classification; Agriculture and Agri-Food Canada Publication 1646 (third edition), 187 p.; <http://www.pedosphere.com/resources/cssc3rd/> [accessed December 16, 2009].

Soil Classification Working Group, 2000: Soils of Canada. Agriculture and Agri-Food Canada, map, scale 1:6 500 000.

Venables, W.N., and Ripley, B.D., 2002, Modern Applied Statistics with S, fourth Edition Springer-Verlag.

Wheeler, J O; Hoffman, P F; Card, K D; Davidson, A; Sanford, B V; Okulitch, A V; Roest, W R , 1996. Geological Map of Canada Map 1860A.Scale 1:5 000 000.