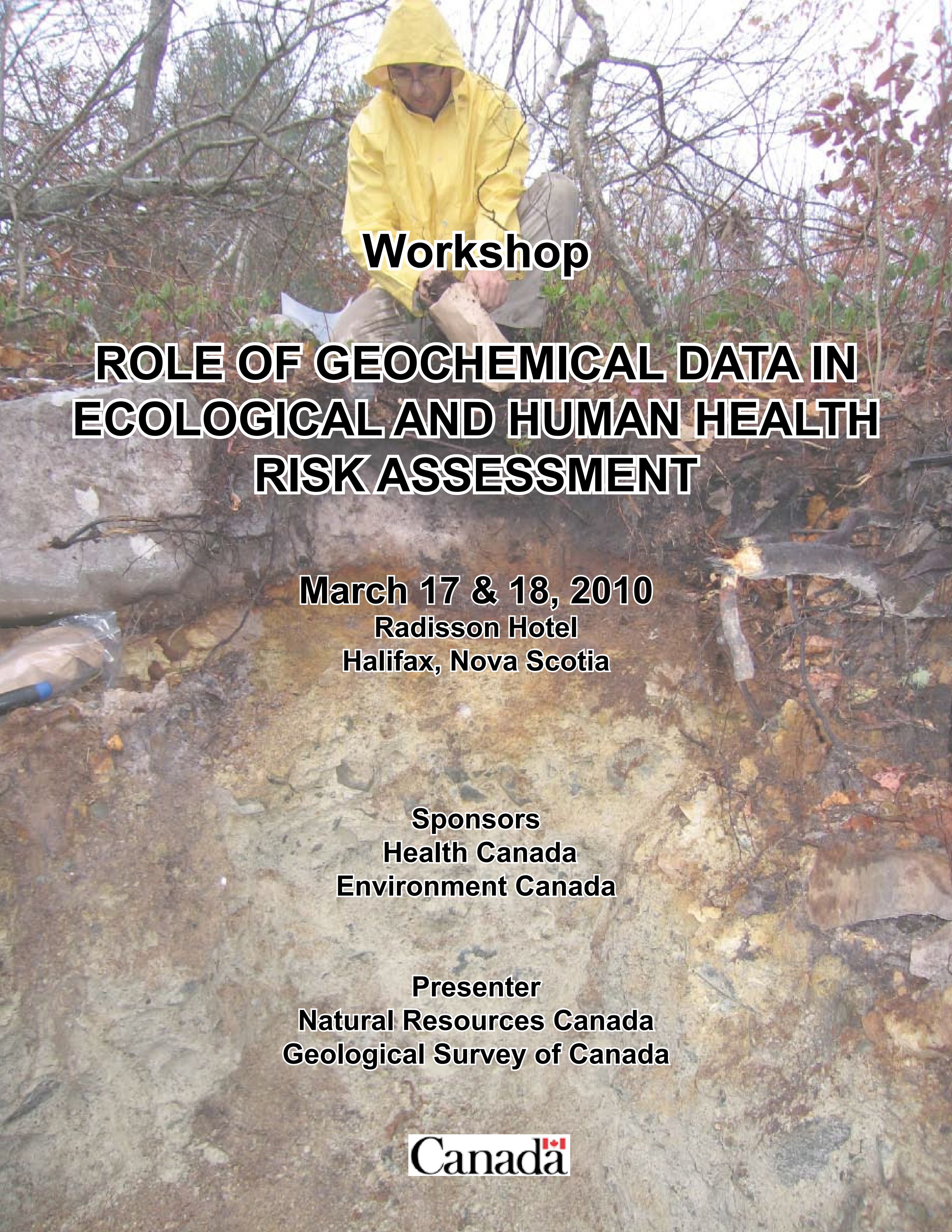


Workshop

ROLE OF GEOCHEMICAL DATA IN ECOLOGICAL AND HUMAN HEALTH RISK ASSESSMENT

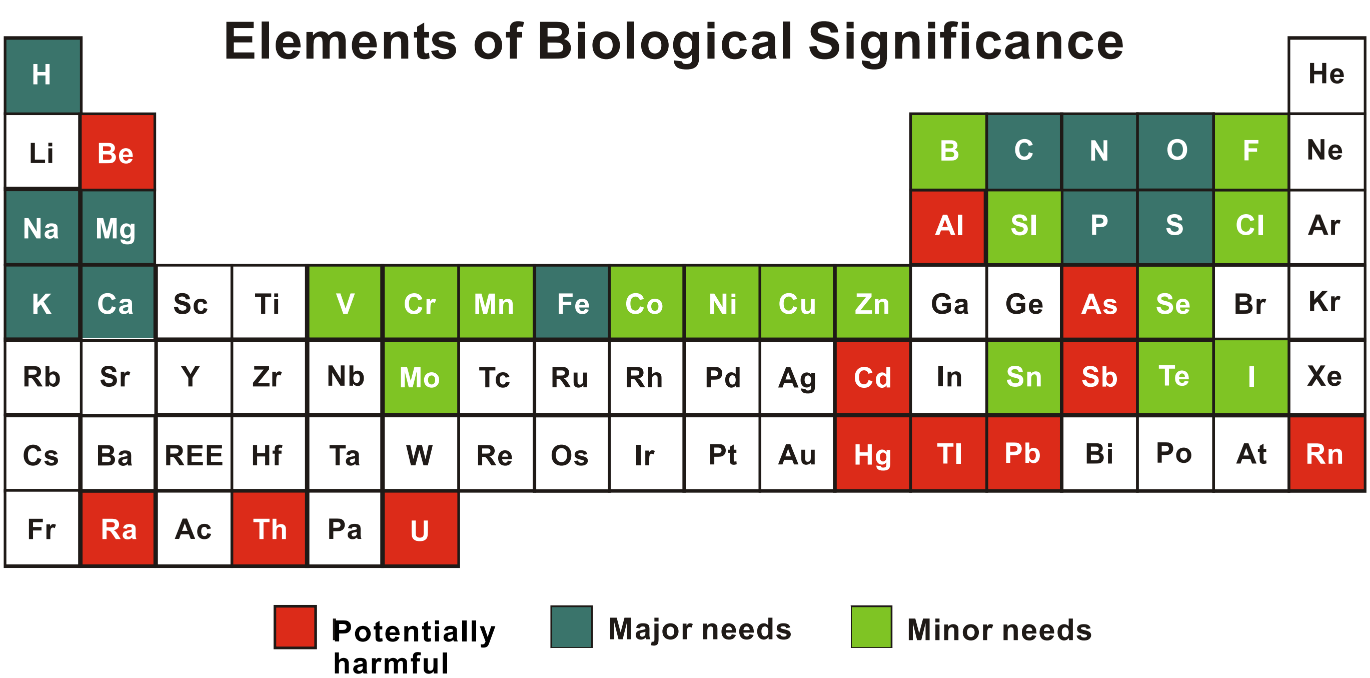
March 17 & 18, 2010
Radisson Hotel
Halifax, Nova Scotia

Sponsors
Health Canada
Environment Canada

Presenter
Natural Resources Canada
Geological Survey of Canada

Canada


Elements of Biological Significance
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SI
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K
Ca
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U
Potentially harmful
Major needs
Minor needs

ROLE OF GEOCHEMICAL DATA IN ECOLOGICAL AND HUMAN HEALTH RISK ASSESSMENT

MARCH 17 – 18, 2010

RADISSON SUITE HOTEL HALIFAX
1649 HOLLIS STREET

Workshop Objective

Knowledge of geochemistry is an important component of ecological and human health risk assessments. While geochemical information is needed to better inform risk assessments, these data are not well represented in many of these assessments.

As a step towards improving practice in this area, Health Canada and Environment Canada are sponsoring a workshop on the role of geochemical data in ecological and human health risk assessments as well as in the development of human health soil quality guidelines. The Workshop will be presented by scientists from the Geological Survey of Canada with recognized expertise in bedrock and surficial sediment geochemistry. The Workshop is by invitation and will include federal and provincial representatives and members of the environmental consulting community.

The Workshop will cover the following topics:

- Use of geochemical data in risk assessments – governmental and consultant's views
- Causes of variation in geochemical data – natural spatial and analytical controls
- Field sampling and analytical protocols
- Estimating background geochemical concentrations
- Case studies
- Discussion of priorities for improving practice and identifying gaps in existing data

One aim of the Workshop is to develop a strategy for improving risk assessments by promoting more rigorous use of geochemical information. More specifically, the focus will be on the application of existing geochemical data, on the need for new types of data and the tools, and recommendations for applying them to risk assessment practice and guideline development. The presentations and discussions will be incorporated into published proceedings of the Workshop. The proceedings will also contain a list of recommendations for making updates to existing human health soil quality guidelines, where appropriate.

For the purposes of this Workshop, geochemical information will be restricted to the chemical elements associated with inorganic substances. The focus will be on As, Cd, Cu, Ni, Pb, and Zn, in particular. Issues related to organic substances will not be considered. There will be presentations on a series of topics relevant to risk assessment and environmental quality guideline development, followed by guided discussions and recommendations for improving practice. There will be several case studies to reinforce the concepts introduced at this workshop and a dedicated panel-lead discussion on the Workshop's recommendations.

WEDNESDAY MARCH 17

900 - 915	**INTRODUCTION**	Andy Rencz (NRCan)
915 - 925	**FCSAP PERSPECTIVE**	Rita Mroz (EC)
925 - 955	**CCME SOIL QUALITY GUIDELINES AND HEALTH CANADA PERSPECTIVE** • HH Risk Assessments • Developing HH Soil Quality Guidelines • Estimated Daily Intake (EDIs)	Darcy Longpre (HC) Yvette Bonvalot (HC)
955 -1030	**CONSULTANT'S PERSPECTIVE** • General Overview • Case Study • Discussion	David Rae (AMEC)
1030 – 1045	***NUTRITION BREAK***	All
1045 - 1100	**WHAT'S IN A NUMBER**	Rod Klassen (NRCan)
1100 - 1115	**SETTING THE STAGE FOR ATLANTIC CANADA**	Terry Goodwin (NSDNR)
1115 - 1145	**GEOCHEMICAL LANDSCAPES** **SPATIAL (VERTICAL) VARIATION** • Geology • Surficial (Quaternary) Processes **SPATIAL (HORIZONTAL) VARIATION** • Weathering Process • Maritime Tri-National examples	 Eric Grunsky/ Rick McNeil (NRCan)
1145 - 1200	**DISCUSSION**	All
1200 - 1300	***LUNCH***	All
1300 - 1330	**BIOGEOCHEMICAL VARIATION** • Multi-media geochemical variations • Geo-environmental models • Ecoregions and Ecodistricts • Recommendations	Andy Rencz (NRCan) Inez Kettles (NRCan)
1330 - 1400	**SAMPLING PROTOCOLS** • Sampling Site Selection • Field Sampling • Field Sample Preparation • Recommendations	Rick McNeil (NRCan)
1400 - 1415	**DISCUSSION**	All
1415 - 1445	**ANALYTICAL TECHNIQUES** • Sample Preparation	 Rick McNeil & Peter Friske &

	• Types of Analyses • Speciation • Quality Control • Recommendations	Robert Garrett & Mike Parsons (NRCan)
1445 - 1500	**DISCUSSION**	All
1500 - 1515	*BREAK*	
1515 - 1545	**BACKGROUND ESTIMATION** • Background Definition • Current Methodologies • Examples • Recommendations • Further Considerations	Eric Grunsky & Robert Garrett (NRCan)
1545 - 1600	**DISCUSSION**	All
1600 - 1630	**GSC DATA AVAILABILITY**	Andy Rencz & Inez Kettles (NRCan)

THURSDAY MARCH 18

CASE STUDIES

900 - 910	**USGS PERSPECTIVE**	Laurel Woodruff (USGS)
910 - 940	**MONTAGUE AND GOLDENVILLE GOLD DISTRICT IN NS**	Mike Parsons (NRCan) & Terry Goodwin (NSDNR)
940 - 1000	**MARITIME DATA**	Robert Garrett & Rick McNeil (NRCan)
1000 - 1030	**BIOACESSIBILITY OF TRI-NATIONAL SOIL SAMPLES**	Matt Dodd (Royal Rhodes)
1030 - 1045	*BREAK*	
1045 -1115	**CANADA WIDE STUDY, N.B.**	Eric Grunsky (NRCan)
1115 - 1145	**REVIEW OF RECOMMENDATIONS**	Andy Rencz (NRCan)
1145 - 1230	**DISCUSSION: WHAT IS NEEDED BY RISK ASSESSORS**	
	PANEL LEAD DISCUSSION:	Panel : NRCan, HC, EC, AMEC
	• Identifying needs, gaps, and limitations in currently available data, knowledge, and availability. • Identifying priories for future work on background soil data collection, availability and knowledge.	All

PARTICIPANT LIST

NAME	DEPT	EMAIL
Major, Chris	Public Works and Government Services Canada	Christopher.Major@pwgsc-tpsgc.gc.ca
Ryan, Dawn	Dept. of National Defense	dawn.ryan@forces.ca
Mooers, Jordan	Defence Construction Canada	jordan.mooers@dcc-cdc.gc.ca
Searle, Jill	Defence Construction Canada	jill.searle@dcc-cdc.gc.ca
Drover,Brian	Environment Canada	brian.drover@ec.gc.ca
Mroz,Rita	Environment Canada	Rita.Mroz@ec.gc.ca
McCormick, Gerry	Environment Canada	gerry.mccormick@ec.gc.ca
White, Louise	Health Canada	louise.white@hc-sc.gc.ca
Longpre, Darcy	Health Canada	darcy.longpre@hc-sc.gc.ca
Bonvalot, Yvette	Health Canada	yvette.bonvalot@hc-sc.gc.ca
Denning, Allison	Health Canada	allison.denning@hc-sc.gc.ca
Phillips, Michelle	Health Canada	michelle.phillips@hc-sc.gc.ca
Hemsworth, Dan	Nova Scotia Dept of the Environment	hemswodd@gov.ns.ca
Check, Gordon	Nova Scotia Dept of the Environment	checkgg@gov.ns.ca
Drage, John	Nova Scotia Dept of the Environment	DRAGEJO@gov.ns.ca
Goodwin, Terry	Nova Scotia Dept of Natural Resources	goodwita@gov.ns.ca
Pronk, Toon	New Brunswick Dept of Natural Resources	toon.pronk@gnb.ca
Little, Megan	Natural Resources Canada	Megan.Little@NRCan-RNCan.gc.ca;
Rencz, Andy	Natural Resources Canada	rencz@NRCan-RNCan.gc.ca
Parsons, Mike	Natural Resources Canada	michael.parsons@NRCan-RNCan.gc.ca
Garrett, Robert	Natural Resources Canada	garrett@NRCan-RNCan.gc.ca
Grunsky, Eric	Natural Resources Canada	Eric.Grunsky@NRCan-RNCan.gc.ca
McNeil, Rick	Natural Resources Canada	RickJ.McNeil@NRCan-RNCan.gc.ca

PARTICIPANT LIST (cont.)

NAME	DEPT	EMAIL
Kettles, Inez	Natural Resources Canada	inez.kettles@magma.ca; inez.kettles@NRCan-RNCan.gc.ca
Klassen, Rod	Natural Resources Canada	Rodney.Klassen@NRCan-RNCan.gc.ca
Cassidy, Sean	Strum Environmental Services	scassidy@strum.com
Olofsson, Emily	Strum Environmental Services	emilyolofsson@eastlink.ca
White-smith, Karen	CBCL	karenw@cbcl.ca
Skinner, Dawne	CBCL	skinnerd@cbcl.ca
Maclean, Brad	Dillon Consulting	bmaclean@dillon.ca
Small, Troy	Conestoga-Rovers & Associates (CRA)	tsmall@craworld.com
Gallahue, Kerena	Conestoga-Rovers & Associates (CRA)	kgallahue@craworld.com
Elliot, Chris	AMEC	chris.elliot@amec.com
Rae, David	AMEC	david.rae@amec.com
Henderson, John	Stantec	john.henderson@stantec.com
Fraser, Kelly	Stantec	kelly.fraser@stantec.com
Marshall, Lisa	Intrinsik	lmarshall@intrinsikscience.com
Willis, Rob	Intrinsik	rwillis@intrinsikscience.com
Ramsey, Al	AGAT Laboratories	ramsay@agatlabs.com
Coughtrey, Jason	AGAT Laboratories	Coughtrey@agatlabs.com
Dodd, Matt	Royal Roads University	Matt.Dodd@RoyalRoads.ca
Orenovich, Jerry	Maxxam	Jerry.Arenovich@maxxamanalytics.com
Hill, Joel	Maxxam	Joel.Hill@maxxamanalytics.com
MacDonlad, James	Maxxam	James.MacDonald@maxxamanalytics.com
Henderson, Kelly	SLR	khenderson@slrconsulting.com
Windisch, Leah	SENES Consultants	lwindisch@senes.ca
Ryan, Anne Marie	Dalhousie University	amryan@Dal.Ca
Woodruff, Laurel	United States Geological Survey	woodruff@usgs.gov

Speaker

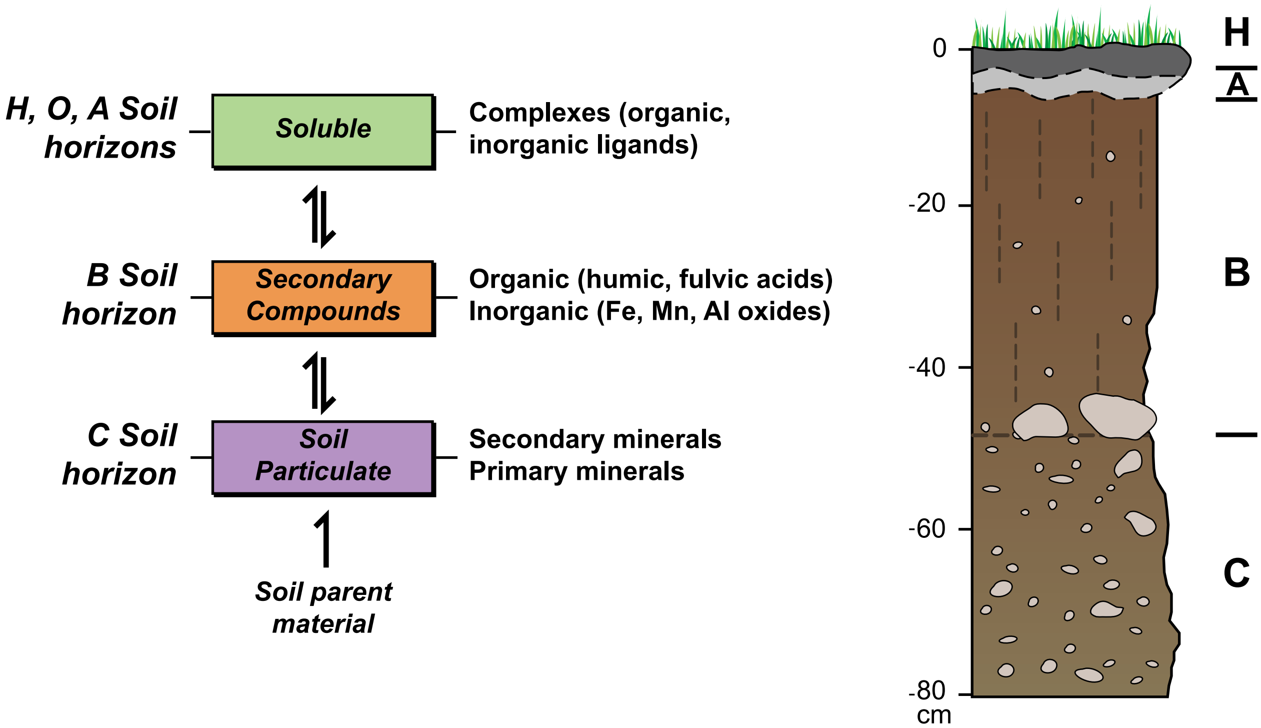
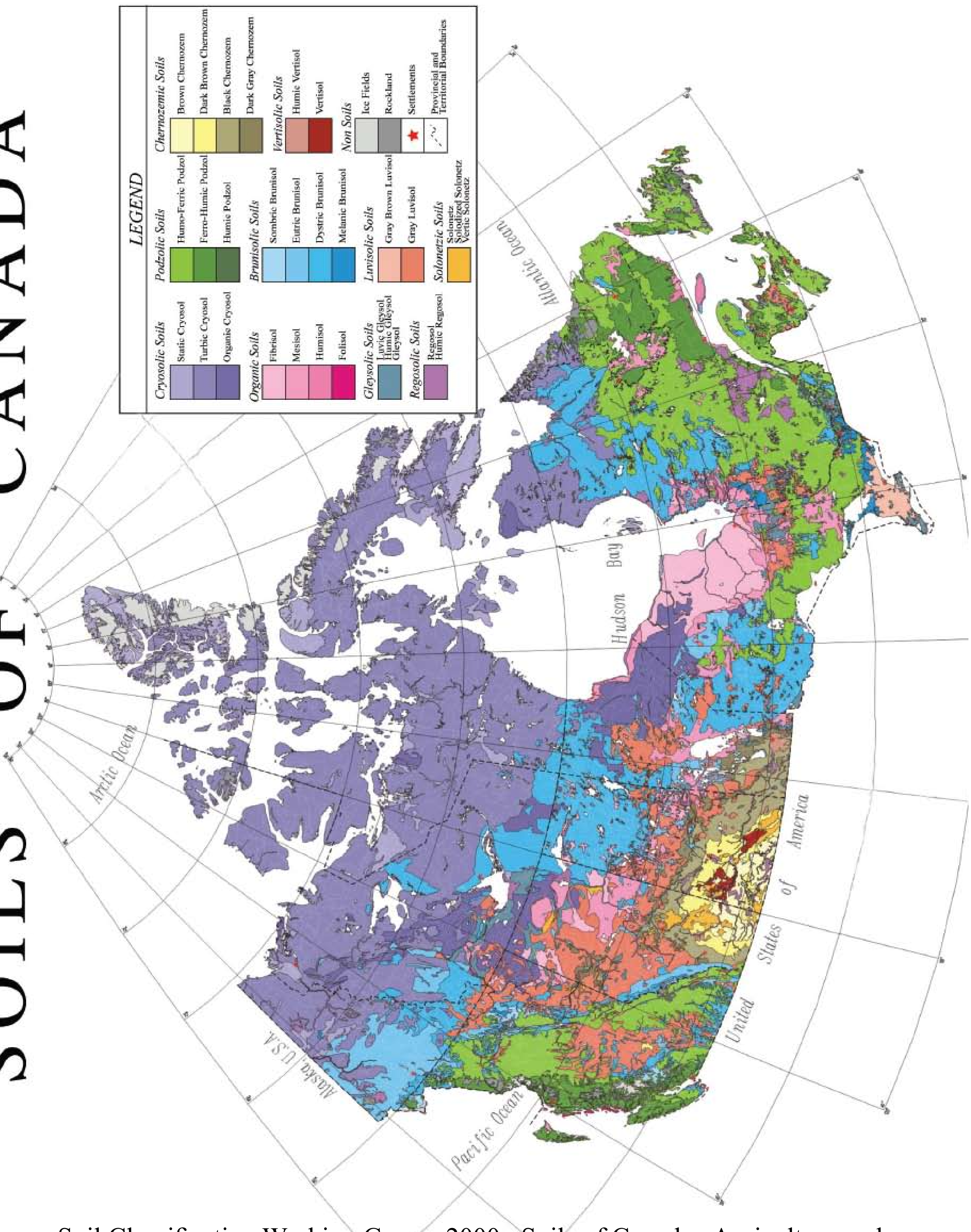


Diagram shows an idealized soil profile (right side) and descriptions of the soil materials and phases.

SOILS OF CANADA



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

PRESENTATION ABSTRACTS

HUMAN HEALTH RISK ASSESSMENTS

Darcy Longpré, Health Canada, Contaminated Sites Division, Soil Quality Guidelines Coordinator, Longueuil, QC

Before a site is considered contaminated, concentrations of chemicals, particularly natural elements, should be compared to data from local or regional surveys of background soil quality in uncontaminated areas, if data are available. On-site levels would be considered to be consistent with background where the maximum measured concentration of a COPC is less than or equal to a representative statistic for background concentration. If it is found that concentrations of Contaminants of Potential Concern (COPCs) at the site are representative of background levels, then the site may not be contaminated despite the fact that generic environmental quality guidelines are exceeded. In a human health risk assessment, if concentrations of a contaminant are within the range of local or regional background conditions, the contaminant should be excluded from further consideration as a COPC.

The concept of background concentrations of chemicals varies among jurisdictions. Potential background levels can be derived from data taken from control sites located close to, but outside the influence of the contaminated site, or may be based on more regional values. Whichever concept is employed, there is a need for a standardized approach to assessing the availability and appropriateness of data on background levels, or evaluating the need for sampling background concentrations at a reference site.

CCME Soil Quality Guidelines – Human Health

Many contaminants, particularly metals, are naturally occurring, and natural levels can exceed CCME soil quality guidelines and other generic guidelines without representing anthropogenic contamination.

When setting national guidelines, the CCME derives guideline values by determining the tolerable or essentially negligible concentration of a contaminant above the background (natural) level (CCME, 2006). The CCME also recognizes that natural levels in soil vary spatially, and recommends that local soil quality objectives be established that incorporate local or regional background concentrations if they are significantly different from the background value used in the derivation of the national generic guideline for a particular contaminant (CCME, 1996).

In principle, for threshold contaminants, the total exposure from direct soil pathways should not generally exceed typical background soil exposures by more than 20% of the residual tolerable daily intake (RTDI), although >20% may be allotted under certain circumstances. If the chemical is identified as a non-threshold substance by Health Canada, then a guideline will be developed representing an incremental risk from soil exposure of 10^{-5} above the background soil concentration.

TOWARDS NEW ESTIMATED DAILY INTAKES FOR THE CANADIAN POPULATION

Yvette Bonvalot, Health Canada, Contaminated Sites Division, Montreal , QC

Canadians are exposed to background contamination through air, water, soil, food and consumer products. This background exposure is quantified, for a given contaminant, by Estimated Daily Intakes (EDIs). EDIs estimate the typical concurrent background exposure from all known or suspected sources (ambient and indoor air, drinking water, soil, food, breast milk, consumer products) via all known or suspected routes (inhalation, ingestion, dermal contact) for the average Canadian. The total EDI of a chemical - the summation of all these concurrent EDIs - is determined through a multimedia exposure assessment in which a lot of information are required.

In risk assessments, RTDI (Residual tolerable daily intake) is considered and corresponds to the dose of a chemical above background to which a person could be exposed without expected adverse effects (i.e., RTDI = TDI – EDI, where TDI is the tolerable daily intake). Additionally, in the derivation of the human health quality guidelines, 20% of the RTDI is allotted to each of the five primary media to which people are potentially exposed (i.e., air, water, soil, food and consumer products).

As can be seen, EDIs are an important piece of the human health risk assessment process. For compounds with available EDIs and for compounds still without, there is a need:

- To assess or re-assess EDIs on a regular basis (data update for example)
- To evolve towards more accurate EDIs (moving from deterministic to probabilistic EDIs for example)
- To be transparent in the way EDIs are estimated in order to be easily revisited and updated on a regular basis (every five years for example)

This talk will briefly explain the various key aspects of the EDI protocol developed by the HC-CSD in order to assess new Canadian EDIs for several chemicals, notably:

- Chemicals priorization
- Data and / or studies selection process
- Canadian population parameters selection
- Mediums and routes of exposure
- Fit of statistical distributions
- Simulations results

Emphasis will be devoted to the current data limitations and their consequences. The urgent need of cooperation between all the federal / provincial / local data generators in order to produce more realistic EDIs will also be highlighted.

ROLE OF GEOCHEMICAL DATA IN ECOLOGICAL AND HUMAN HEALTH RISK ASSESSMENT - A CONSULTANT'S PERSPECTIVE

David A. Rae, AMEC Earth & Environmental, Fredericton, NB

Environmental consultants routinely use geochemical data in human health and ecological risk assessments for a variety of purposes. Data are often used to establish existing baseline conditions, to develop guidelines, or to help determine estimated daily intakes (EDIs) of chemicals of concern (COCs). Data can include air, soil, sediment, surface water, and groundwater and cover a broad range of COCs. However, metals in the environment is the most ubiquitous issue for which geochemical data is required in risk assessments and is the focus of this presentation. The presentation will use case examples to discuss the three main uses of metals data (baseline, guideline, and EDI) and will highlight common issues related to data interpretation including spatial and temporal variation, and sampling and analytical protocols. Basic risk assessment methods will be reviewed to demonstrate how geochemical data is used in risk calculations and the significance, or lack thereof, of variations in that data.

WHAT'S IN A NUMBER

Rodney A. Klassen, Natural Resources Canada-Geological Survey of Canada, Ottawa, ON

In risk assessment, environmental and human health protection is informed by scientific knowledge of hazard. For earth materials, including bedrock and its overlying mantle of unconsolidated mineral particulate, risk for geochemical hazard is based on element concentrations – numbers, established in biological testing.

In showing that hazard potential varies with mineralogy, and that mineral composition varies among geological terranes, geoscience shows that no single element concentration can establish a universal measure of acceptable risk in earth materials.

Risk assessment requires knowledge of sample grain size and mineral partitioning among grain size fractions, as well as of the wet chemical digestion used for analyses. In showing how geology affects both the measure of risk and its interpretation, geoscience also shows that regulatory approaches must evolve to accommodate the natural variability that is an inherent characteristic of earth materials.
As natural geochemical background variation – the reference level for industrial liabilities, originates in mineralogy, its variation may be simplified in terms of geological provenance, process, and past. For unweathered earth materials, geological maps and models establish a stable and deterministic reference framework for ecological hazard potential. With increase in weathering and soil formation, however, there is increasing need incorporate other natural sciences, including pedology and biology, in risk assessment.

BEDROCK AND SURFICIAL GEOLOGY OF THE MARITIME PROVINCES

Terry A. Goodwin, Nova Scotia Department of Natural Resources, Halifax, NS

The oldest rocks in the Maritimes belong to the Blair River Complex, a small pocket of Proterozoic rocks located in the northwestern edge of Cape Breton Island, Nova Scotia. These rocks include high-grade metamorphic gneiss, schist, amphibolite and associated granitoid intrusions associated with the Grenville Orogeny. The rocks of the Grenville Orogen represent the southeastern margin of the Canadian Shield, and were accreted or welded onto the Canadian Shield about 1 billion years ago during the formation of the paleo-supercontinent of Rodinia.

One continent that resulted from the breakup of Rodinia was Laurentia, the original “core” of the North America, surrounded by oceans including Iapetus. During the Ordovician to early Carboniferous interval, several Early Paleozoic and older terranes were accreted to Laurentia in the Appalachian Orogen. From west to east these include several terranes related to the Iapetus Ocean, Ganderia, Avalonia, and Meguma. Today, remains of the Orogen and its constituent terranes extend from Newfoundland through Nova Scotia, Prince Edward Island, and New Brunswick, along the eastern seaboard of the United States to Florida. They also connect across the Atlantic Ocean with the Caledonian Orogen of Greenland, northwestern British Isles and Scandinavia.

Ganderia consists dominantly of Precambrian and Cambrian sedimentary and volcanic rock assemblages. The accretion of Ganderia onto Laurentia occurred approximately 430 million years ago and resulted in the closure of the Iapetus Ocean. Rocks associated with Ganderia occur today in central New Brunswick, western Prince Edward Island and western Cape Breton Island.

The accretion of the Avalon Terrane onto the southern margin of Ganderia occurred approximately 400 million years ago. Volcanic rocks of Avalonia are located along the southern margin of New Brunswick, as well as northern mainland Nova Scotia and the eastern half of Cape Breton Island.

The final Appalachian terrane to accrete was Meguma, the most outboard terrane in the Canadian Appalachian orogen and found onshore only in southern Nova Scotia. The Meguma Terrane accreted to Avalonia approximately 390 million years ago and consists of Cambro-Ordovician metasediments. Meguma rocks display many similarities to rocks currently found in northern Africa (Morocco).

Major structures formed during the accretion of the Appalachian terranes include the Caledonia Fault Zone that separates Ganderia from Avalonia in southern New Brunswick and the Cobequid-Chedabucto Fault Zone that separates the Meguma to the south from the Avalonia to the north. Magmatism occurred in association with the accretion of terranes and Appalachian mountain building. One example, the South Mountain Batholith, is the largest exposed intrusion in the Appalachian Orogen, and is associated with the closure of the Rheic Ocean, which separated Meguma from Gondwana, about 380 million years ago.

As collisions that created the Appalachian Orogen ended, a complex series of fault-bounded basins and uplands developed called the Maritimes Basin. The subbasins (generally called basins) of the Maritimes include the Moncton Basin, Stellarton Basin and the Sydney Basin. Uplands included the Caledonia Highlands, Cobequid Highlands, Antigonish Highlands and the Cape Breton Highlands. During latest Devonian and earliest Carboniferous time, the basins were filled with Horton Group sediments sourced from the eroding upland ranges by large, extensive river systems and lakes.

The basins were subsequently inundated by transgressive and regressive cycles associated with the Windsor Sea beginning approximately 340 million years ago. Deposition of Windsor Group carbonates, evaporates and siliciclastic sedimentary rocks occurred during this much drier climatic period.

Approximately 325 million years ago (late Carboniferous) the Windsor Seas regressed for the last time, the climate became relatively wetter and the Maritimes were once again subjected to large terrestrial rivers (and floodplains) that resulted in the deposition of thick siliciclastic sedimentary rocks of the Mabou and Cumberland groups until about 305 million years ago. During this roughly 20 million year time period, lush vegetation associated with aerially extensive rainforests and swamps were the precursor to the significant coal deposits (Sydney, Springhill, Stellarton) of the Maritime Provinces.

During the Permian, approximately 250 to 290 million years ago, the climate changed once again but this time included some very dry conditions to form the distinct red rocks of Prince Edward Island and northern mainland Nova Scotia.

Approximately 230 million years ago Pangea started to rift apart and about 200 million years ago the pieces began to drift apart. In Nova Scotia, the drifting is indirectly heralded by a major volcanic event that resulted in the formation of the North Mountain basalt around what is today the Bay of Fundy (which coincidently forms the northern margin of the Annapolis Valley) as well as basalt exposures at Five Islands, Wasson Bluff and Partridge Island along the north shore of Cobequid Bay, Nova Scotia, and Grand Manan Island, New Brunswick. The drifting created the Atlantic Ocean, whose margins became the locus of deep sedimentary basins subsequently in-filled with siliciclastic sediments. Deposition of thin deposits of red sandstones and mudstones immediately post-date eruption and deposition of the basalt.

On onshore Nova Scotia for the remaining 200 million years until the present, there is very little evidence preserved in the rock record of much activity except for the development of some sand and mud deposits associated with rivers and lakes approximately 100 – 125 million years ago during the early Cretaceous.

Most of the surficial glacial deposits and associated landforms throughout the Maritimes were formed during Wisconsinan glaciation (Pleistocene) in the last 100 000 years which includes the "recent" Holocene. Several local ice centers, collectively referred to as the Appalachian Glacier Complex, were sufficiently large enough to withhold advancement of the continental Laurentide ice sheet. Throughout the Wisconsian, the ice centers were very dynamic which resulted in a very complex ice flow history for the Maritime Provinces. Reconstruction of the ice flow history of the Maritimes has established a link between ice flow patterns onshore and ice margin terminal moraines offshore.

The oldest observed Wisconsinan ice flow indicators are associated with the Caledonia Phase occurring approximately 70 000 to 65 000 years ago. Ice flow was towards the east and southeast likely emanating from the Notre Dame Mountains Ice Divide. The Escuminac Phase occurred approximately 24 000 to 20 000 years ago and resulted in south and southwest flow associated with the east-west trending Escuminac Ice Divide situated in central northern New Brunswick extending to the north of Prince Edward Island. Ice flow to the north of the divide was characterized by ice streams into the Bay of Chaleurs and into the Gulf of St. Lawrence. The Scotian Phase occurred approximately 20 000 to 17 000 years ago and was characterized by the mobile Scotian Ice Divide situated over mainland Nova Scotia and the Central Northern Maine Ice Divide along the margin of western New Brunswick. In Nova Scotia, this resulted in complex ice flow movement to the north and south as well as southwesterly flow associated with ice streaming into the Bay of Fundy. For New Brunswick, flow was dominantly to the east-northeast during this time period.

Final deglaciation commenced approximately 15 000 years ago with the Chignecto Phase. During this time, glacial ice was likely centered over Prince Edward Island with another smaller ice divide (Fundy Highlands Ice Divide) located in New Brunswick along the northern margin of the bay of Fundy. Remnant ice was thinning and beginning to retreat back from the Scotia Shelf and along the margins of the Bay of Fundy. Ice-dammed lakes likely existed in the St. John River Valley in New Brunswick and Glacial Lake Shubenacadie in Nova Scotia. The Collins Pond Phase, however, was the final phase of glacier formation and likely involved expansion of local ice centers in response to a short-lived period of climatic cooling lasting approximately 1000 years during the Younger Dryas Chronozone around 11 000 years ago. Since the Younger Dryas, ice continued to recede and the Maritimes have been ice free for several thousand years.

Various multiple-flow directional indicators, the result of shifting ice centers, have been mapped and are evidence that the Maritimes was characterized by a relatively complex ice flow history. The complex ice flow history of the Maritime Provinces has, locally, resulted in superimposed till sheets including palimpsest landforms. The surficial geology of the Maritime Provinces is highly variable and includes large areas of variable thick ground moraine and associated streamlined landforms, glaciofluvial deposits (outwash fans and deltas, valley trains, kames and eskers) as well as glaciolacustrine and glaciomarine deposits. Post glacial (Holocene) sediments include alluvial, colluvial, organic and marine deposits.

Enrichment of elements reflecting the bedrock geology is characteristic of many of the surficial deposits throughout the Maritimes. These elements are commonly enriched in soil down ice from their bedrock sources (including zones of mineralized bedrock); the result of mechanical dispersal (erosion, transportation and deposition) by advancing glacial ice. Glacial dispersal distances vary but are commonly hundred's of meters to several kilometres down-ice from source.

The diversity of the Maritime bedrock and surficial geology has yielded a wide array of mineral resources that have been exploited for centuries. Archaeological evidence to support this include clay pots, agate and slate tools and scrapers as well as hematitic paints for decorating skin and burial ceremonies used by the Mi'kmaq.

With the arrival of Europeans, exploitation of coal, iron, manganese and gypsum began.
Coal was initially mined in Minto, New Brunswick, in the early to mid 1600's and later that century from Cape Breton. Exploration for other energy related commodities has resulted in the discovery of natural gas around Sussex, New Brunswick, as well as oil and gas fields off the coast of Nova Scotia. Iron mining commenced in 1825 in Torbrook and Bridgeville, Nova Scotia. Windsor Group evaporates are the source rock for many of the salt (Napan, Pugwash), potash (Sussex) and gypsum (Milford) mines in the Maritime Provinces. Windsor Group carbonates are used for agricultural purposes and as a primary ingredient in the production of cement.

Base metals have been mined from volcanic rocks in Bathurst, New Brunswick, as well as from carbonates in Gays River and Walton, Nova Scotia. Walton was also a significant barite producer in the 1950's. Granitic rocks have seen limited production of tin at East Kemptville, Nova Scotia, tin-tungsten at Mount Pleasant, New Brunswick, tungsten at Burnt Hill Brook, New Brunswick, and antimony at Lake George, New Brunswick. The Meguma Terrane of southern Nova Scotia has produced in excess of 1 million ounces of gold mostly from quartz veins associated with deformed sedimentary rocks. Significant gold mineralization also occurs at Clarence Stream, New Brunswick.

Early Cretaceous silica and sand deposits are currently being exploited near Upper Musquodoboit and Shubenacadie, Nova Scotia, and Cassidy Lake near Sussex, New Brunswick. The melting of glaciers resulted in the deposition of extensive deposits of waterlaid sediments that are currently being exploited as sand and gravel deposits throughout the Maritimes.

Dimension stone used in the construction of building interiors/exteriors, rock walls, sidewalks, foundations and gravestones has been extensively mined from abundant quarries throughout the Maritimes. Crushed stone from igneous and metamorphic rock is quarried for high quality construction aggregate used in products such as Portland cement concrete and asphalt.

Acknowledgements

This abstract borrowed heavily on information contained in The Last Billion Years (Atlantic Geoscience Society, 2001) as well input from a number of geologists including Rob Fensome, Graham Williams, Chris White, Garth Prime, Bob Ryan, Ralph Stea, Dan Utting and Toon Pronk.

GEOCHEMICAL LANDSCAPES

Eric C. Grunsky , Rick J. McNeil and Robert G. Garrett
Natural Resources Canada - Geological Survey of Canada, Ottawa, ON

A geochemical landscape is the geochemical characterization of a given part of the earth based on the joint influence of climate, relief, geology and vegetation on the chemical processes over a region. The primary purposes for assessing geochemical landscapes are for: agriculture, mineral exploration, environmental and human health studies and are carried out through geochemical surveys.

The scale of a geochemical survey determines the sampling density and is generally focused on the scale of the geochemical process that is being measured. A rule of thumb is that the sample density should be 1/2 the size of the geochemical target being sought. Sample density and the spatial extent of a geochemical survey dictate the overall number of sites for the survey,

Influences on the geochemistry of soils in Canada are characterized by the ecozone classification, regional bedrock geology and soils. The North American Soil Geochemical Landscapes Project (NASGLP) was designed to capture the geochemical variability of the continent at the Ecoprovince level at a spacing of one sample site per 40 km^2.

Sample design is an essential element of a geochemical survey. There are at least two ways to design a geochemical survey that is statistically defensible. The Generalized Random Tesselation Stratified Design (GRTS) is based on a spatially balanced selection of points over an area. Alternatively, an unbalanced, nested random sample design based on a designated sample resolution permits the use of statistical techniques such as analysis of variance to test the representivity of the data.

Ecoregion designation is well established across Canada at the zone, region and district levels. Soil and bedrock geology maps have been compiled by various provincial territorial agencies but are not continuous across the country.

The vertical profile of soils varies widely across the country. Northern soils are dominantly cyrosols and brunosols. Both the west coast and eastern part of Canada are dominated by podzolic soils and the western interior plains are dominated by chernozemic and luvisolic soils. The nature of the soil profile plays a role in the geochemical response that is observed from the base of the C horizon to the upper most layers.

BIOGEOCHEMICAL VARIATION AND ECOLOGICAL AND HUMAN HEALTH RISK ASSESSMENT

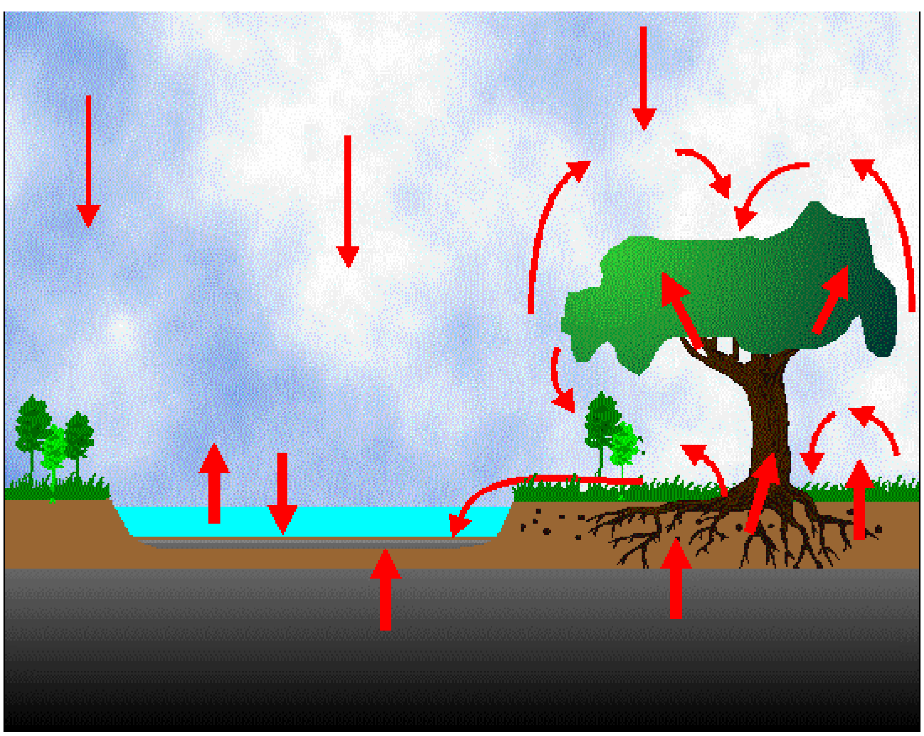
Andrew N. Rencz, Natural Resources Canada - Geological Survey of Canada, Ottawa. ON

An ecosystem is composed of various biotic and abiotic components. Although they are connected, each has a unique chemical signature that can characterize that component. The risk assessor is faced with the option of selecting for study and sampling one or more types of media type to characterize the ecosystem of interest.

It should be appreciated that although the components are linked and elements flow from one system to another, there is not necessarily a strong correlation between the distribution patterns of elements in one pool and those in another. The distribution of elements in the different media reflects complex interactions between the different components of the ecosystem and the factors that control them (soil pH, eH, and the content of organic matter). In addition, the levels of element concentration in biological systems are affected by seasonal variations and by the adaptive mechanisms of biota that allow them to maximize their competitive advantage (certain plants are bio-accumulators of specific elements).

The risk assessor should consider the variation inherent in each of the media types that is being sampled. For example, within one tree species there are different tissue types (eg. leaf, bark, woody layer) and there may be up to a magnitude of difference in the concentration of elements from one type of tissue to the next (e.g. Ni in sugar maples). Hence, if data from more than one type of tissue are compared, the result may show variation in element concentrations that are not realistic.

This workshop focuses on soils and the inherent differences that affect the concentration of metals in soils. Soils have properties that make them a useful sample media for risk assessment. They are present in most places and readily acessible, the seasonal fluctuations in their chemistry are not significant, and they are directly linked to biological uptake. There is variation in the element content of soils with increasing depth caused by the soil-forming processes and horizon development. However, if samples are collected from similar pedologic horizons, the origin of the differences tends to be more easily explained.



Element recycling in the landscape.

NOTE ON ECO-CLASSIFICATION SYSTEMS

Inez M. Kettles, Natural Resources Canada – Geological Survey of Canada, Ottawa, ON

The history of the development and evolution of ecological land classifications that encompass the Canada landmass is outlined in the following:
Marshall and P.H. Schut (1999). A national ecological framework for Canada – overview; on-line at http://sis.agr.gc.ca/cansis/nsdb/ecostrat/intro.html [accessed March 9, 2010].

In the late 1960s there was recognition of the need for a nation-wide ecological framework to provide standardized, multi-scale geographical reporting and monitoring units. One aim was to think, act, and plan based on ecosystems rather than have emphasis on individual elements. Ecological land classification incorporates all major components of ecosystems: air, water, land, and biota, including humans. It is based on a hierarchy with ecosystems nested within ecosystems. In 1976 the Canada Committee on Ecological Land Classification was created to develop (1) a uniform national ecological approach to terrestrial ecosystem classification and mapping and (2) to encourage the use of the ecological approach to sustainable resource management and planning. The first version had 7 levels of generalization and from the start there was recognition that the spatial units needed revisions.

In 1991 a collaborative project was undertaken after the first State of Environment report for Canada published in 1986 by some federal, provincial and territorial governments. The objective was to revise the previous work and establish a common ecological framework for Canada. The working group focused on 3 levels - ecozones, ecoregions, and ecodistricts – and the result was a national report entitled "A National Ecological Framework for Canada" released in 1996. The report described the methodology used to construct the ecological framework maps, the concepts of the hierarchical levels of generalization, narrative descriptions of each ecozone and ecoregion and their linkages to various data sources. The State of the Environment Reporting spatial framework is maintained by the CanSIS group at Agriculture and Agri-Food Canada.

Since 1996, groups in British Columbia, Saskatchewan, Manitoba and Nova Scotia have provided more in-depth descriptions of the ecological units in these provinces. The NAFTA Commission for Environmental Cooperation (CEC) made some modifications to the State of the Environment Reporting spatial framework for Canada to provide an integrated perspective for all of North America. Results were released in 1997 as "Ecological Regions of North America - Towards a Common Perspective". When the North America perspective was being developed, an ecoprovince level of generalization, between ecozone and ecoregion, was compiled for the Canadian framework. For Canada, the CANSIS database consists of 15 ecozones, 53 ecoprovinces, 194 ecoregions, and 1021 ecodistricts. For North America, the Commission for Environmental Cooperation (CEC) database has the following number of units: Level 1- 15; Level 2 – 52; Level 3 – 182, and Level 4 – not as yet completed.

Geochemical data sets that are geo-referenced can be "cookie cut" using any eco-classification system and GIS. The different systems of reporting are similar but not identical and the one being used should be clearly stated. The CanSIS system is widely used in Canada and is recommended for national and regional reporting. The scale or level of data used depends on the project purpose and the amount of data available. If using the more detailed scales of eco-classification information, it is necessary to have sufficient data points within the individual ecosystem polygons to ensure the validity of statistical comparisons.

SAMPLING PROTOCOLS FOR SOIL GEOCHEMICAL SURVEYS

Rick J. McNeil, Natural Resources Canada – Geological Survey of Canada, Ottawa, ON

The protocols used for the field collection of soil samples in Canada for the North American Soil Geochemical Landscapes Project are described in detail in Geological Survey of Canada Open File 6282. This document is available on-line at http://geopub.nrcan.gc.ca/moreinfo_e.php?id=261633&_h=6282 [accessed March 14, 2010].

The collection of soil samples for geochemical analysis involves preparation in the office as well as work in the field. If the purpose of the survey is to provide an estimate of the background range of element concentrations in soil, use of a spatially random and statistically defensible sampling design is required. In the office, target and alternative sites are determined based on the sample design and study of existing maps showing the distribution of bedrock, surficial materials and soils, and also topographic maps showing road access and the lay of the land. It is also necessary to design a field card that includes information on site location and description, the underlying types of surficial materials and bedrock, descriptions of the soil pit and soil materials collected from the pit. The field card can be modified as needed to meet field conditions. Site and pit photographs are important for archiving and referencing to complement the field card information.

Horizon based sampling is recommended, otherwise varying amounts of organic matter, Fe- and Mn-sesquioxides, and clays will influence trace element concentrations due to the varying amounts of their presence. Sampling by horizon allows for an easier interpretation of geochemical variation if samples are collected from similar pedologic horizons. Horizon-based sampling requires familiarization of the soils of the study region through review of the literature. When beginning work in a new study area it can prove to be quite helpful to have a field meeting with soil scientist familiar with local soils and learn what to expect and how to discriminate between horizons and sub-horizons. To provide information on the parent materials, a sample is collected from the C-horizon which at most sites in Canada is reached by a depth of 1 m. Depending on the project purpose, samples will be collected from other horizons (O, A or B). It may also be desirable to collect a sample from the 0-5 cm depth interval referred to as the Public Health (PH) layer. Although the PH layer is not a pedologic horizon, it is the depth that most strongly affects human exposure.

Samples should be collected using a standard set of equipment. A list of suggested equipment is given in Open File 6282. Stainless steel should not be used to avoid contamination and if the sampling tool is covered by paint, have it removed possibly by sand. Once in the field, a pit is excavated to allow visible distinction of different horizons and the collection of samples from the desired horizons for geochemical analysis and other types of tests such as bulk density and carbonate content determinations. Sampling begins with the lowermost horizon and sampling upwards through the profile minimizes cross-contamination of the horizons. Kraft paper bags are recommended for sampling as canvas sample bags are often treated with elements such as As or Sb to guard against mildew. To prevent loss of volatile elements such as Hg and As, samples should be stored, shipped and dried in areas where the temperature remains below 30^{o} C.

TECHNIQUES FOR SOIL SAMPLE ANALYSES

Rick J. McNeil, Robert G. Garrett, and P.W.B. Friske, Natural Resources Canada - Geological Survey of Canada, Ottawa, ON

Geochemical data has a major role in ecological and human health risk assessments. The final soil quality guideline is the lowest concentration value for individual elements deemed acceptable for different types of land use. In addition to the inherent mineralogical characteristics of the soils, concentration values resulting from geochemical analyses are strongly affected by the methodologies used for sample preparation and analyses. However, in most guidance documents for risk assessments, little information is provided on the requirements for sample preparation and analysis.

The choice of appropriate methodology should include consideration of the following factors:

(1) the grain-size fraction analyzed and the efficiency of the grain-size separation. Chemical partitioning studies indicate the greatest concentrations of specific minerals occur within certain grain sizes in glacial sediments. Selection of grain-size fraction is based on the needs of the geochemical survey. The <2 mm fraction is a standard for agricultural and environmental studies and its use is recommended to provide consistency. Finer size fractions including <63 micron and <2 micron have been used for mineral exploration and geological research. Use of the finer size fractions may provide more information on bioaccessibility and inferred information on speciation.

(2) the weight of the sample analyzed. Sample size affects analytical precision. There is a minimum weight of sample for individual analytical methods to achieve reliable, representative and reproducible results.

(3) the temperature of sample drying and analyses. Volatile elements, such as Hg and As require low temperature storage, preparation, and analytical techniques. Air drying at less than 30^{o} C is recommended.

(4) the chemical digestions and other treatments used to decompose the sample prior to analysis. Chemical digestions include total (e.g., 4 acid), near-total (e.g., the relatively strong Aqua Regia and its variants), partial selective extractions for specific mineral or organic phases, and the weak water leach. Digestions are selected based on research goals and geological factors related to mineralogy and they are critical to the application of geochemical analyses results.

(5) the instrument used for analysis. There are common methods, each of which are advantageous in some situations and unsuitable in others. They include the widely-used inductively coupled plasma-optical emission spectrometry (ICP-OES) for major elements and inductively coupled plasma - mass spectrometry (ICP-MS) for trace and minor elements; instrumental neutron activation analyses (INAA) that provides total element concentrations; atomic absorption spectrometry (AAS) that has historical and specialized uses, and x-ray fluorescence (XRF) which is used to measure major elements in whole rock.

(6) the procedures used to ensure quality control and quality assurance (QA/QC). These include the use of blind duplicates and controlled reference materials inserted for analysis in batches of sample for routine analysis. QA/QC results are monitored to ensure they fall within pre-determined tolerances to ensure adequate data quality. Both graphical monitoring tools and statistical summaries are available. When data fall out of tolerance it is essential that situations are discussed with the service laboratory to rectify any problems.

ANALYTICAL METHODS USED TO CHARACTERIZE THE SOLID-PHASE SPECIATION OF METAL(LOID)S

Michael B. Parsons, Natural Resources Canada - Geological Survey of Canada, Dartmouth, NS

The ecosystem and human health risks associated with metal(loid)s in soils, sediments and mine wastes are strongly influenced by their solid-phase speciation. This presentation will review a range of methods commonly used by geoscientists to measure the various chemical (e.g. oxidation state) and physical (e.g. morphology, particle size) forms of an element which together make up the total concentration of that element in a sample. Traditional macroscopic techniques for determining solid-phase speciation include methods such as sequential chemical extractions, which can be used for indirectly assessing the partitioning of metals in solid materials, and X-ray diffraction (XRD), which can be used to identify crystalline phases. Microscopic methods range from optical techniques (e.g. transmitted and reflected light microscopy) to microbeam methods that are used to determine near-surface compositions (e.g. electron microprobe, laser-ablation ICP-MS, proton-induced X-ray emission (PIXE)). Over the last two decades, many environmental investigations have employed synchrotron-based microscopic methods that can be used to determine the *in situ* speciation of metal(loid)s in solid materials. With careful sample collection and preparation, techniques such as X-ray absorption fine structure spectroscopy (XAFS) can provide information on metal(loid) oxidation states and coordination environments that are essential for assessing the environmental risks associated with these elements. Recent studies demonstrate that determination of the total concentrations of metal(loid)s in soils, sediments and mine wastes does not give sufficient information on the environmental availability of these elements, or their potential risks to human health. In the future, ecological and human health risk assessments should incorporate information on the solid-phase speciation of metal(loid)s to ensure that realistic management guidelines are established.

GEOCHEMICAL BACKGROUND

Robert G. Garrett, Natural Resources Canada - Geological Survey of Canada, Ottawa, ON

The concept of geochemical background is discussed, defined and a distinction made between natural background and ambient background. A key issue is that background is a range, not a single value. The range of background should span the measurements likely to be encountered during sampling and analysis in situations devoid of major mineral occurrences and severe impacts by anthropogenic contamination. The acceptance of 'ambient background' as a quantifiable estimate implies that some anthropogenic impact is acknowledged, but it does not 'overwhelm' the natural patterns of variation due to geology, pedology, etc. The role of both spatial, map, and statistical data displays is discussed, and how appraisal of survey data with these tools informs as to whether the data should be divided into subsets before estimating background ranges.

As an example, the data acquired by the US-EPA 3050B Aqua Regia (4:1 HCl-HNO_3) variant for As and Pb in the <2 mm fraction of the 0-5 cm soil interval are discussed and background ranges estimated. It is demonstrated that the Maritimes 2007 data are poly-populational, and different background ranges should to be estimated for the three ecoprovinces present, the Appalachian and Acadian Highlands, the Northumberland Uplands and the Fundy Uplands. Several factors underlie the spatial definition one of which is geology, base metal ore occurrences, the Bathurst camp, lie in the Appalachian and Acadian Highlands ecoprovince; and widespread minor As occurrences associated with gold in mainland Nova Scotia occur in the Fundy Uplands ecoprovince.

Both statistical numerical methods and graphical methods are demonstrated. It is shown that different numerical procedures and whether data are logarithmically transformed, a common practice in applied geochemistry, lead to different estimates. This begs the question, which is right, or at least the best? It is shown how the a combination of graphical inspection to remove outliers likely not representative of background processes, e.g., data related to the presence of major mineral occurrences or discernable anthropogenic contamination, and the use of percentiles leads to useful estimates of background range.

In conclusion, some more complex multivariate approaches to background estimation and gaining an understanding of the data are briefly presented, with their constraints. For univariate, an element at a time, estimates it is recommended that the hybrid approach of map and statistical data displays, the removal of non-background data from the data set(s) and the use of percentiles be adopted.

NOTE ON THE AVAILABILITY OF GEOCHEMICAL DATA FOR SOILS AND OTHER SURFICIAL MEDIA

Inez M. Kettles, W.A. Spirito, and A.N. Rencz, Natural Resources Canada - Geological Survey of Canada, Ottawa, ON

Through evolution of the Internet and improvements in software capabilities, it is now possible to immediately obtain a large amount of the geochemical data generated from field surveys and laboratory studies by federal and provincial government agencies in Canada. One important source is the Canadian Geochemical Surveys catalogue which is found on the Geochemical Data Repository (GDR) at Natural Resources Canada (http://gdr.nrcan.gc.ca/index_e.php [accessed March 11, 2010]). The catalogue contains searchable metadata and raw data for approximately 700 geochemical surveys carried out by the GSC and provincial geological agencies since the 1950s

The geochemical catalogue was initially created in partnership with Health Canada to provide Health Canada - Federal Contaminated Sites Program with information on soil and till geochemistry to support risk management decisions. More recently, the catalogue was expanded to include data for vegetation and lake and stream sediments, in addition to soil and till, and was extensively cross-linked to other databases and the provincial and territorial geological surveys. The database underlying the catalogue is updated on a regular basis.

NRCan – Earth Sciences Sector Library has an extensive web site through which there is access to many databases, mechanisms for searches and other services, most of which are broadly cross-linked. It is possible to download for free selected GSC articles through GeoPub, search for publications using the library catalogue and GEOSCAN, peruse and obtain more than 7000 digital photos and view Really Simple Syndication (RSS) Feeds for frequently updated works. GEOSCAN is the bibliographic database for scientific publications of NRCan - Earth Sciences Sector. It has more than 60,000 records of publications of the Geological Survey of Canada and the Canada Centre for Remote Sensing, Canada topographic maps and external publications authored by ESS scientists and specialists. The following is one portal of entry for all of the databases and services described above: http://gsc.nrcan.gc.ca/bookstore/index_e.php [accessed March 11, 2010].

THE NORTH AMERICAN SOIL GEOCHEMICAL LANDSCAPES PROJECT -- 2010 US GEOLOGICAL SURVEY UPDATE

Laurel G Woodruff, United States Geological Survey, Moundsview, MN

A detailed knowledge of the concentration of chemicals in soil is required for calculation of human exposure to those chemicals via a soil pathway. At present, agencies involved with human and environmental health have no common understanding of soil geochemical background variation for North America and the processes that control this variation. The North American Soil Geochemical Landscapes Project, a tri-national initiative among the United States, Canada, and Mexico, was established to (1) develop a continental-scale design and protocols for generating soil geochemical data and (2) provide baseline soil geochemical data that are useful for a wide range of applications and disciplines, including public health. The Project is based on low-density sample collection over a spatially balanced array of 13,496 sites for the continent (1 sample site per 1,600 sq. km.). The core samples collected at each site include material from a depth of 0-5 cm and soils from the A and C horizons. In the US each sample is analyzed for more than 40 elements and mineralogy. Through partnerships with other federal agencies new data on the distribution of soil bacteria and microbial biomass are being generated. Preliminary results indicate that concentrations of potentially toxic elements in soils commonly vary by 1-2 orders of magnitude. The observed variability is the result of several parameters such as soil parent material, climate, and human activities. Understanding this variation is critical in terms of understanding human exposure and for understanding soil pollution on a national scale. The USGS is committed to the completion of sample collection in the conterminous United States by the end of 2010 field season.

THE TRI-NATIONAL (2007) MARITIMES DATA: SOME IMPORTANT AND INTERESTING OBSERVATIONS

Robert G. Garrett, Natural Resources Canada - Geological Survey of Canada, Ottawa, ON

The data for six elements, As, Cd, Cu, Ni, Pb and Zn, are investigated in soil samples collected by the Geological Survey of Canada (GSC) in the Maritime provinces (NB, NS and PEI) in 2007. Samples were collected from several soil horizons and intervals, 0-5 cm, A, 0-30 cm, B and C, by GSC, Environment Canada, and provincial agency staff, and in collaboration with soil scientists from Agriculture and Agri-Food Canada. A variety of analytical methods were investigated, ranging form a water leach to a ‘total’ mutli-acid digestion and Instrumental Neutron Activation (INA) applied to different sieved size fractions, <2 mm, <250 µm and <63 µm . Attention is focused on the data obtained using the Aqua Regia variant (4:1 HCl-HNO_3) of the US-EPA 3050B protocol applied to the <2 mm fraction, with elements being determined in the digests by ICP-OES and ICP-MS.

An inspection of the data by soil horizon reveals systematic patterns of element distribution. For Pb and Cd levels decrease with depth until the B horizon is reached, they then increase and then fall with depth to the C horizon. For As, Cu, Ni, Pb and Zn levels increase with depth until the B horizon, where they drop, and than increase with depth to the C horizon. As a generalization, levels in the 0-5 cm interval and B horizons are similar, as are levels in the 0-30 cm interval and the C horizon. In general, observed levels in the 0-5 cm interval and B horizon are similar, and levels in the 0-30 cm interval are similar to the C horizon. The role of Fe and Organic carbon was investigated across the 0-5 cm, A, B and C horizons. It is shown that there are systematic variations with depth and that these major soil components exercise a control on trace element levels through their ability to sequester trace elements and bind them in mineral forms or with metallo-organic ligands. A variety of analytical protocols were applied to C horizon soils in an investigation of the amounts of elements that might be bioavailable, i.e. as estimates of bioaccessibility. These data show that bioaccessibility estimates using a water leach are 1.5 (Cd) to 3 (Pb) orders of magnitude than PBET estimates for gastric intake, and that PBET estimates are lower by a half to 1.5 orders of magnitude lower than the results of routine geochemical analyses employing aqua regia-like digestions.

It is concluded that there are advantages to consistently sampling a single soil horizon or interval, and in the case of an interval, it should be as narrow as operationally feasible.

ASSESSING AND REDUCING RISKS AT THE MONTAGUE AND GOLDENVILLE GOLD DISTRICTS IN NOVA SCOTIA

Michael B. Parsons, Natural Resources Canada - Geological Survey of Canada (Atlantic), Dartmouth NS
Terry A. Goodwin, Nova Scotia Department of Natural Resources, Halifax, NS

Recent studies at historical gold mines in Nova Scotia have identified several areas where exposure to mine wastes may pose a risk to both ecosystem and human health. Arsenopyrite (FeAsS) occurs naturally in the ore and surrounding bedrock in these gold deposits, and was concentrated in the tailings during milling operations. The concentration of arsenic (As) in tailings at these sites is generally two to four orders of magnitude higher than the 12 mg/kg Canadian Soil Quality Guideline for As in residential and parkland soils. Two sites, Montague and Goldenville, are of particular concern, as the tailings are located close to residential properties and are occasionally used for racing off-road vehicles. In 2005, the Province of Nova Scotia established the Historic Gold Mines Advisory Committee to examine these risks in more detai (hyyp://www.gov.ns.ca/nse/contaminatedsites/goldmines.asp). Since that time, research has been carried out to examine the concentration, solid-phase speciation and bioaccessibility of As in tailings, airborne particulates and forest soils near these sites to clarify the spatial extent of mine tailings, the mineral hosts for As, and the fate of windblown tailings dusts. Environmental Site Assessments have also been completed at Montague and Goldenville to examine the concentrations of As and Hg in tailings and soils near residential areas.

Delineation of the area impacted by tailings requires an understanding of the naturally occurring concentrations of As and mercury (Hg) in soils overlying the variably mineralized bedrock within these gold districts. In 2007, Natural Resources Canada (NRCan) collected samples of the top 0-5 cm of surface soil (the Public Health layer) from 46 sites near Montague, and 39 sites near Goldenville. Samples of individual soil horizons (H, Ae, B, and C) were also collected from 10 sites in Montague and 6 sites in Goldenville to evaluate the vertical distribution of elements in the soil profile. All samples were air dried, sieved to various grain size fractions (<2 mm, <150 µm, <63 µm), and digested and analyzed for metal(loids) and organic carbon using protocols commonly employed during environmental assessments (e.g. EPA Method 3050B). Results from these surveys show that the concentrations of As and Hg in all soil horizons are generally higher down-ice (south) of the ore zones in both districts, reflecting glacial erosion and transport of mineralized bedrock containing arsenopyrite and other sulphide minerals. Analysis of the top 0-5 cm of soils shows the following ranges in As and Hg concentrations (<2 mm, HNO_3-H_2O_2 digestion): Montague: As, 2-273 mg/kg (median 40 mg/kg); Hg, 72-490 µg/kg (median 164 µg/kg); Goldenville: As, 2-140 mg/kg (median 13 mg/kg); Hg, 60-312 µg/kg (median 123 µg/kg). In general, the concentrations of As are highest in the B and C horizon soils, whereas Hg concentrations are highest in the organic-rich humus (H) layer. Data for As and Hg in soils from Montague are in close agreement with results from previous soil surveys in nine gold districts conducted by the Nova Scotia Department of Natural Resources in 2003-2005. However, as compared to Montague, the concentrations of both As and Hg are significantly lower in most soil horizons at Goldenville.

To better understand the solubility of As in mine tailings and soils at these sites, NRCan partnered with Queen's University and the Royal Military College to characterize the mineralogy and bioaccessibility of arsenic in a suite of 29 samples. The solid-phase hosts of As were determined using a micro-analytical method designed to characterize complex samples at the micron scale combining petrography, electron microprobe, and synchrotron-based grain-by-grain microXANES (X-ray absorption near-edge structure) and microXRD (X-ray diffraction). Mineralogical analyses of the tailings and windblown dusts show that As is hosted in arsenopyrite and a variety of weathering-related phases including scorodite ($FeAsO_4 \cdot 2H_2O$), Ca-Fe arsenates, and As bound to Fe oxides. Bulk XANES shows arsenic in these near-surface samples is mainly in the pentavalent form (As^{5+}), indicating that most of the arsenopyrite (As^{1-}) originally present in the tailings and soils has been oxidized during weathering reactions.

The *in vitro* bioaccessibility of As in the samples was measured using a physiologically-based extraction test (PBET) and ranges from 0.5 to 49% of total As. A weak negative correlation was observed between total and bioaccessible As concentrations, and the As bioaccessibility was not correlated with other elements. The highest As bioaccessibility is associated with the presence of Ca-Fe arsenate minerals. Samples containing As predominantly as arsenopyrite or scorodite have the lowest bioaccessibility (<1%). Other As species identified (predominantly amorphous iron arsenates and arsenic-bearing iron(oxy)hydroxides) are associated with intermediate bioaccessibility (1 to 10%). The presence of a more soluble As phase, even at low concentrations, results in increased As bioaccessibility from the mixed As phases associated with tailings and mine-impacted soils.

Remediation strategies for high-As mine wastes at publicly accessible sites like those in Nova Scotia typically employ clean soil covers to reduce human exposure and dust generation. However, burying the tailings under soil may trigger dissolution of the As-bearing minerals and lead to accelerated release of As to local streams and groundwater. Other conventional tailings remediation designs such as flooding, removal or fencing are also problematic because of the high solubility of some As minerals, dust hazards, expenses associated with removal, and community desire to maintain site access. Our ongoing research at Montague and Goldenville uses laboratory experiments and field tests to investigate the biogeochemical stability of different tailings types to design the best plan to protect downstream surface and ground waters and reduce risks to human health. This research will provide experimentally tested recommendations applicable to many of the thousands of active and abandoned mine sites across Canada.

References

Meunier, L., Walker, S.R., Wragg, J., Parsons, M.B., Koch, I., Jamieson, H.E., and Reimer, K.J. (2010) Effects of soil composition and mineralogy on the bioaccessibility of arsenic from tailings and soil in gold mine districts of Nova Scotia. *Environmental Science & Technology*, published online March 10, 2010 (DOI: 10.1021/es9035682).

Parsons, M.B., Little, M.E. and Goodwin, T.A. (in prep) Background concentrations of arsenic and mercury in forest soils from the Montague and Goldenville gold districts, Nova Scotia. Geological Survey of Canada Open File.

Walker, S.R., Parsons, M.B., and Jamieson, H.E. (2009). Arsenic mineralogy of near-surface tailings and soils: Influences on arsenic mobility and bioaccessibility in the Nova Scotia gold mining districts. *Canadian Mineralogist*, **47**: 533-556 (DOI: 10.3749/canmin.47.3.533).

INFORMATION ON THE NORTH AMERICAN SOIL GEOCHEMICAL LANDSCAPES PROJECT

(From Friske et al., 2010; Geological Survey of Canada Open File 6282)

Field meeting to demonstrate sample collection protocols was held in the Fredericton area, New Brunswick, in June 2007. It was attended by Project participants from Geological Survey of Canada, provincial surveys, and United States Geological Survey. (Photo by A. Rencz)

Field meeting to co-ordinate sample collection protocols was held in the Sonora area, Mexico, in November 2007. It was attended by Project participants from Geological Survey of Canada, United States Geological Survey, Servicio Geologico Mexicano, and University of San Luis Potosi. (Photo by A. Rencz)

NORTH AMERICAN SOIL GEOCHEMICAL LANDSCAPES PROJECT – OVERVIEW FROM THE CANADIAN PERSPECTIVE

Introduction

Soil geochemical properties are critical to the health of the environment and to the health of virtually all organisms, including humans, existing near and on the Earth's surface. The natural concentrations of elements differ among soil constituents and vary markedly between geologically distinct terranes. Currently there is no common understanding of the amount and origin of variation in soil geochemistry within Canada and North America nor is there a consistent methodology used for its determination.

The North American Soil Geochemical Landscapes Project (NASGLP) is a tri-national initiative between the Canada, United States, and Mexico and is the first multi-national, multi-agency collaboration of its kind for this continent. It was established to develop a useful set of geochemical data for North America that is being generated using consistent protocols. The Project is supplying soil geochemical data for the different geological terranes and will provide a broader context to fit data from site specific studies. The aim is to provide data and protocols that are useful to a wide range of users in the fields of sustainable resource development and environment and health.

Collection of samples from a podzolic soil in Nova Scotia for the NASGLP Project in June 2006. (Photo by R. Mroz)

What will the project provide?

- A soil geochemistry database with a broad spectrum of inorganic elements and selected biological and organic compounds; it is based on low-density sampling (1 sample per 1600 km^2) for Canada, United States and Mexico.
- A set of field and analytical protocols and a framework for accommodating geochemical and related data.
- A coordinated common approach for environmental assessments related to sustainable development of natural resources and human health protection that is founded on sound scientific principles.
- Geochemical and related data that provide a stable predictive environmental framework for decision-makers; these data are uniformly applicable by provincial, federal, and international levels of government.
- Data that are web-enabled, user-friendly and valuable for a wide range of applications.

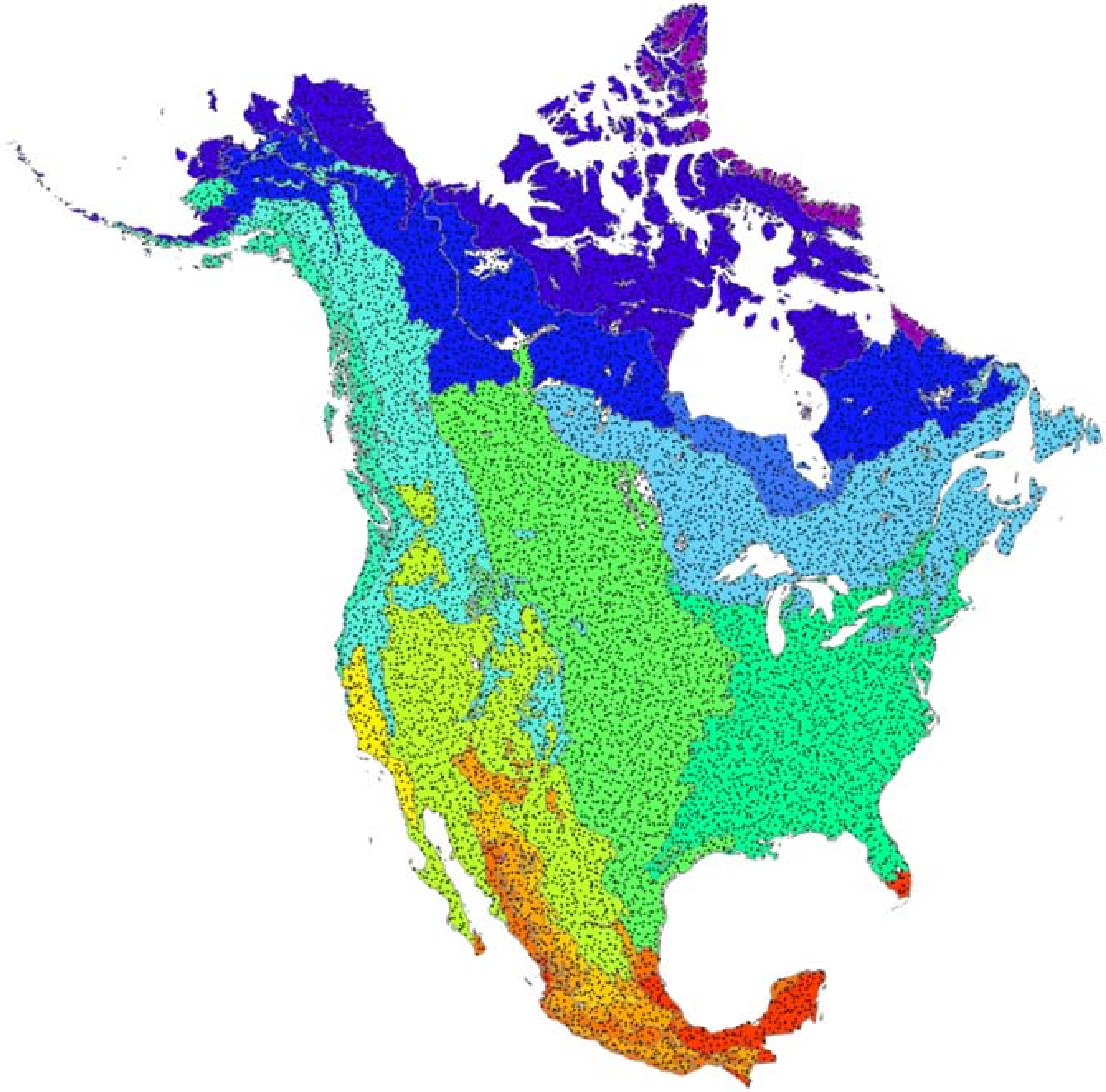
The project nuts and bolts

- The project is based on low density sampling (within a 40 km x 40 km grid). There are 6,018 sites in Canada and a total of 13,487 sites across North America.
- The NASGLP survey has a core protocol that is used in each of the three countries. At each site, soil samples are collected from a depth of 0-5 cm and from the A- and C- soil horizons. The <2 mm fraction (an agricultural and environmental standard) is analyzed for a suite of approximately 50 elements, following a near-total (4-acid) digestion. A sample of 0-5-cm material from each site will be analyzed for the presence of *Bacillus anthracis* (anthrax).
- In addition to the core protocol, each country may add certain procedures and analyses that are particular to its environmental and/or policy needs.
- Field and laboratory data are stored using set protocols and sample splits are preserved for purposes of quality control and future work.
- The methodology and protocols were planned to provide a framework that will support future work, including more detailed sampling and different types of analyses.

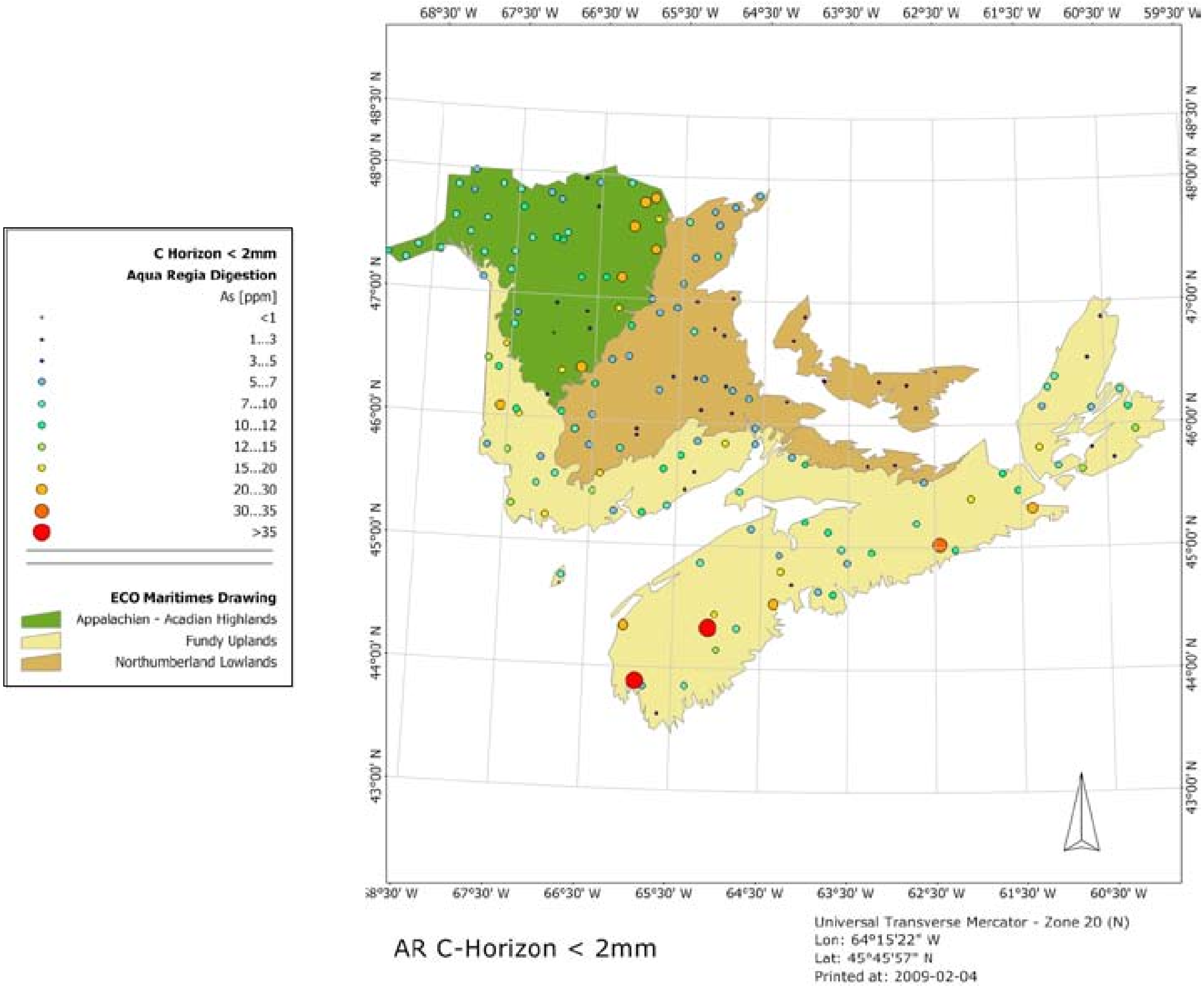
Meeting the project goals in Canada

In addition to the core protocols outlined above, extra procedures include the following: collection and analysis of B-horizon samples; analyses of the <63 µm fractions of A-, B-, and C-horizon samples using total (4-acid) and partial (USA-EPA 3050B) digestions; and analysis of 0-5 cm and C-horizon samples after a water leach.

Also, a major addition to the Canadian project is the in-situ measurement of soil gas radon and the radiometric estimates of soil K, U and Th concentrations. These data will be integrated with NASGLP soil data to support development of a map showing radon-prone areas in Canada.



Distribution of sample sites (black dots) over North America. Ecozones for North America are shown in colour (after Commission for Environmental Co-Operation, 1997). A legend for this map is presented on the following internet site: http://www.cec.org/files/PDF/BIODIVERSITY/eco-eng_EN.pdf.



Map shows distribution of As in the <2mm fraction of C-horizon soil samples analyzed using ICP-MS after a partial digestion (US - EPA 3050B (Aqua Regia variant)). Samples were collected in Maritime Canada as part of the North American Soil Geochemical Landscapes Project.

INFORMATION ON SURFICIAL MATERIALS AND UNDERLYING BEDROCK IN CANADA

(From: Friske et al., 2010; Part 5, Geological Survey of Canada Open File 6282)

Exposure of glacial till overlying bedrock of the Canadian Shield near Crosby, Ontario.

BACKGROUND INFORMATION ON SURFICIAL SEDIMENTS AND UNDERLYING BEDROCK

Some background information on the surficial materials in Canada and the bedrock underlying them are presented in this section. This information provides the users of this manual with a better understanding, within a regional context, of the types of soils they are likely to encounter in different regions of the country. Most material in this section, excluding information on bedrock geology, was previously released in Geological Survey of Canada Open File 5085 (See Kettles in Spirito et al., 2006).

Bedrock geology

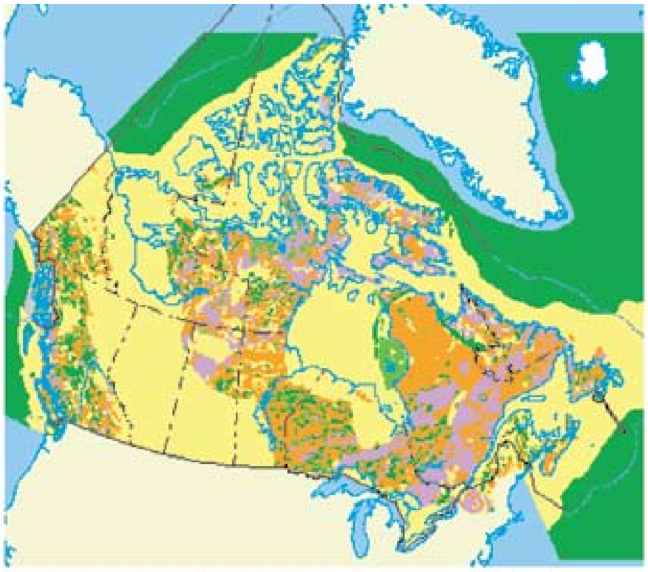
The geology of Canada (Figure 5-1) was summarized by Wallace (1948) . Canada is geologically one of the oldest countries in the world. Half of the country is underlain by Precambrian rocks of the Canadian Shield. This shield formed a large nucleus about which the North American continent was formed. The Canadian Shield consists largely of granite and gneiss, eruptive rocks which came up through older sedimentary rocks which were metamorphosed to marble and quartzite and gneiss, or through great beds of lava. In the beginning, these areas of ancient crystalline rocks formed ranges of mountains which have now been worn down to rounded hills with shallow valleys.

Younger rocks were deposited in the shallow seas around the margins of the Canadian Shield. In southern Quebec and Ontario there are Palaeozoic sandstones, limestones, and shales of Ordovician, Silurian, and Devonian age that were deposited in a shallow sea. The Carboniferous and Permian of the later Palaeozoic cover much of the Maritime provinces. The flat-lying sediments belonging to the latest division of the Mesozoic, the Cretaceous, underlie most of the prairie region of western Canada. Cretaceous beds, deposited at or near sea level, were elevated to form the Rocky Mountains.

Progressing westward from the Rockies, there are the Selkirk and Gold ranges which are older and not quite so high. These are followed by the interior tableland of British Columbia which is cut by deep valleys and canyons, and the Coast range of mountains, formed in Jurassic times by the upwelling of molten rock. The Selkirk, Gold, and Coast ranges form the Cordillera and make up most of British Columbia. In the most westerly part of Canada, there is another range over parts of Vancouver and Queen Charlotte islands.

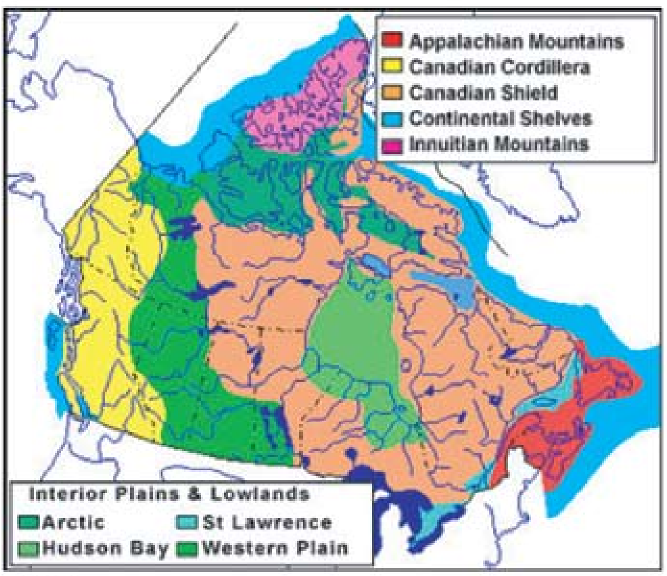
Surficial Sediments

Figure 5-2 shows the distribution of surficial sediments over the Canada landmass. The composition of the surficial cover in Canada differs in several important aspects from most other parts of the world where soils have developed from the in-situ weathering of bedrock. More than 95% of Canada was covered by glaciers periodically during the last 2 000 000 years and, as a result, the cover of surface sediments consists of materials that were eroded, transported and deposited by glaciers (Shilts, 1993; DiLabio, 1989; Dyke et al., 1989). This surface cover is composed of unweathered fragments of crushed bedrock mixed with reworked older soils and sediments. The clay- to boulder-size materials forming these deposits were eroded mostly from the underlying or nearby bedrock (0 to 10s of kilometres) but there is also a component of exotic material transported 100s to 1000s of kilometres by glacial ice or meltwaters before being deposited. Once deposited, these sediments have only been exposed to surface weathering and soil forming processes for the 8 000 to 10 000 years since the last glaciers melted. Since this is a very short period with respect to geologic time, the physical and chemical effects of weathering



http://atlas.nrcan.gc.ca/site/english/maps/environment/geology/majorrockcategories

Figure 5-1. Maps showing the bedrock geology of Canada by major rock category (Atlas of Canada) and by geologic regions (Canadian Encyclopedia, 2008)



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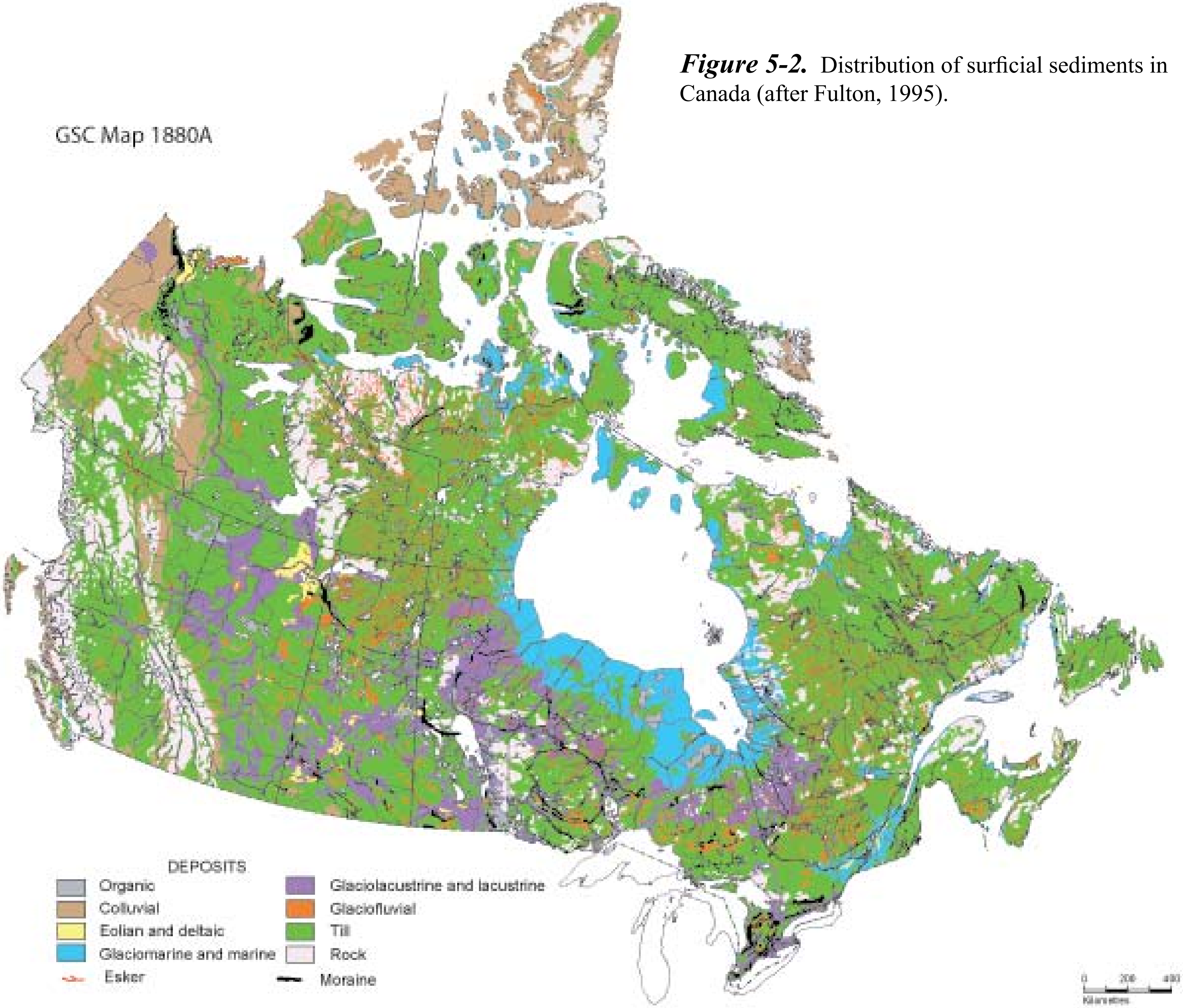

Figure 5-2. Distribution of surficial sediments in Canada (after Fulton, 1995).

are generally confined to the uppermost 0-2 m.

The most widespread surficial deposits are diamictons, which are referred to collectively as till (Fulton, 1989; Dyke and Dredge, 1989; Shilts, 1993). They have been deposited either directly from, or in close association with, glacial ice (Figures 5-3 and 5-4). Tills are composed of pebble- to boulder-size clasts of bedrock in a matrix of variable amounts of fine sand, silt, and clay. Over many parts of Canada, especially over the Canadian Shield, till forms a discontinuous veneer, 0 - 1.5 m thick, which mantles and reflects the morphology and structure of underlying bedrock. In other areas, e.g., parts of the Prairies, the till cover is thicker, from several metres to more than 100 metres thick. At a regional scale, till deposits are thickest in areas such as southern Ontario and the Prairies which are underlain by sedimentary bedrock (Karrow, 1989; Klassen, 1989). The flat-lying, finely bedded, fine-grained nature, and weak cementation (lithification) of these bedrock strata made them more susceptible to glacial erosion than the massive crystalline bedrock that composes most of the Canadian Shield. The textural and lithologic composition of till depends mostly on the bedrock sources from which it originated. Where the till was derived from coarsely crystalline bedrock such as Precambrian granites, it is commonly stony and sandy, whereas in areas such as southern Ontario where it was derived from Paleozoic limestones and dolomites, the till is enriched in silt and clay and is more cohesive.

Figure 5-3. *Road cut exposure of till (in the vicinity of sampler) overlain by glaciolacustrine finely bedded fine sand and silt (bottom right). Both types of sediment were deposited over rugged Precambrian shield bedrock in south-central Ontario.*

Figure 5-4. *Exposure of fine-grained till bearing clasts of Paleozoic limestone and dolomite sampled near Manitouwadge, northeastern Ontario. The limestone and dolomite clasts were eroded and glacially transported from sedimentary bedrock in the James Bay Lowlands before being deposited on Precambrian shield terrain in northern Ontario.*

In some places glacial sediments have been reworked by meltwaters from the retreating glaciers and through other post-glacial processes (Dredge and Cowan, 1989). Glaciofluvial deposits are composed of complexly bedded and faulted, coarse bouldery to cobbly gravel interbedded with sand, gravel, and, in some places, bedded fine sand and silt (Figure 5-5). They are found in the landscape in various forms - eskers, kames, kame terraces, subaqueous fan deposits and outwash plains.

In some parts of Canada, tills or the bedrock surface are overlain by a cover of glacial lake or marine sediments consisting of thin (centimeters) to thick (more than 100 metres) deposits of rhythmically bedded clay and silt to fine sand or stratified gravel (Dyke and Dredge, 1989) (Figure 5-6). Some glacial lakes were local and small while others existed at the scale of the present day Great Lakes. During the last deglaciation, geographically vast areas were covered by Lake Agassiz in the Prairie provinces, Lake Barlow-Ojibway in northern Ontario and Quebec, Lake Iroquois and Lake Algonquin in southern Ontario, and by Lake McConnell in the western Northwest Territories (Dyke and Prest, 1987). In addition, marine waters invaded the isostatically depressed lowland coastal areas. The Tyrrell Sea occupied the Hudson Bay basin covering present-day coastal areas of Nunavut, Manitoba, Ontario and Quebec whereas the Champlain Sea invaded the St. Lawrence River and Ottawa River valleys (Dyke and Prest, 1987).

Figure 5-5. *Borrow pit in Eastern Ontario where glaciofluvial sand and gravel are being excavated.*

Figure 5-6. *Deposit of glaciomarine silt, sand and clay in eastern Ontario*

Along some river and stream valleys, there are older and modern alluvium deposits composed of silt, sand and gravel with minor organic materials (Dredge and Cowan, 1989). In places there are sand dunes and other types of wind blown deposits derived from alluvium or other fine-grained sediments (Wolfe, 2002). Organic deposits composed of peat and muck are also widespread (Tarnocai et al., 2000) (Figures 5-7 and 5-8).

Figure 5-7. *Deposit of peat excavated from the Mer Bleue peatland near Ottawa, Ontario..*

Postglacial modification of glacial sediments and soil formation

Soil-forming processes have altered the uppermost 2 m of till or other surficial materials. Below the upper 1 m or so, these deposits may show only minor effects of weathering. These are most commonly marked by signs of oxidation, which include colour changes from grey to brown, the presence of Fe-Mn oxide precipitates along the joints and fissures in the sediment, and the presence of disaggregated bedrock clasts (Shilts and Kettles, 1990; McMartin and McClenaghan, 2001).

Soil is defined as the naturally occurring, unconsolidated material or organic material at least 10 cm thick that is capable of supporting plant growth (Soil Classification Working Group, 1998). Canadian soils have been classified based on types, the degree of development, and the sequence of soil horizons and other layers in the surface cover. The major mineral horizons of mineral soils are A, B, and C (Figure 5-9) (Soil Classification Working Group, 1998). A-horizon is the mineral horizon formed at or near the surface in the zone of leaching or eluviation, or of maximum in-situ accumulation of organic matter (humus), or both. The B-horizon is the next lower horizon characterized by enrichment in organic matter, sesquioxides, or clays and characterized by a change in colour denoting hydrolysis or oxidation. The C-horizon is a mineral horizon comparatively unaffected by pedogenic processes and is considered as weathered parent material..

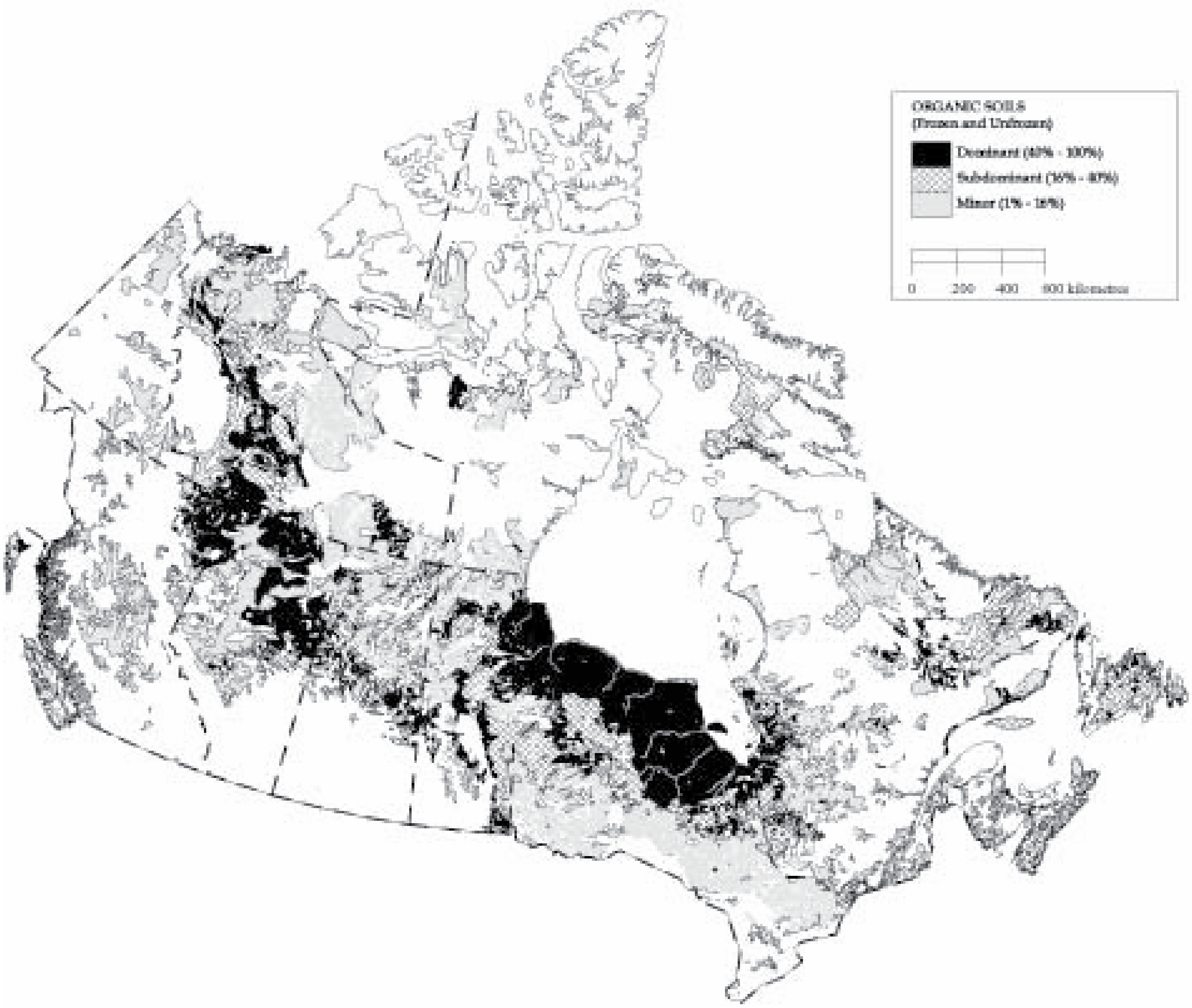

Figure 5-8. *Distribution of organic soils in Canada (after Soil Carbon Data Base Working Group, 1993).*

Distribution of Permafrost

The distribution of permafrost over Canada is shown in Figure 5-10. An estimated 42% of the Canada landmass is underlain directly by permafrost (Kettles et al., 1997). Based on this estimate, there will be more than 2500 NASGLP sites in permafrost-bearing areas. In addition, there are strong interrelationships between the distribution of peatlands and permafrost because of the insulating properties of peat and the poor drainage conditions in peatlands.

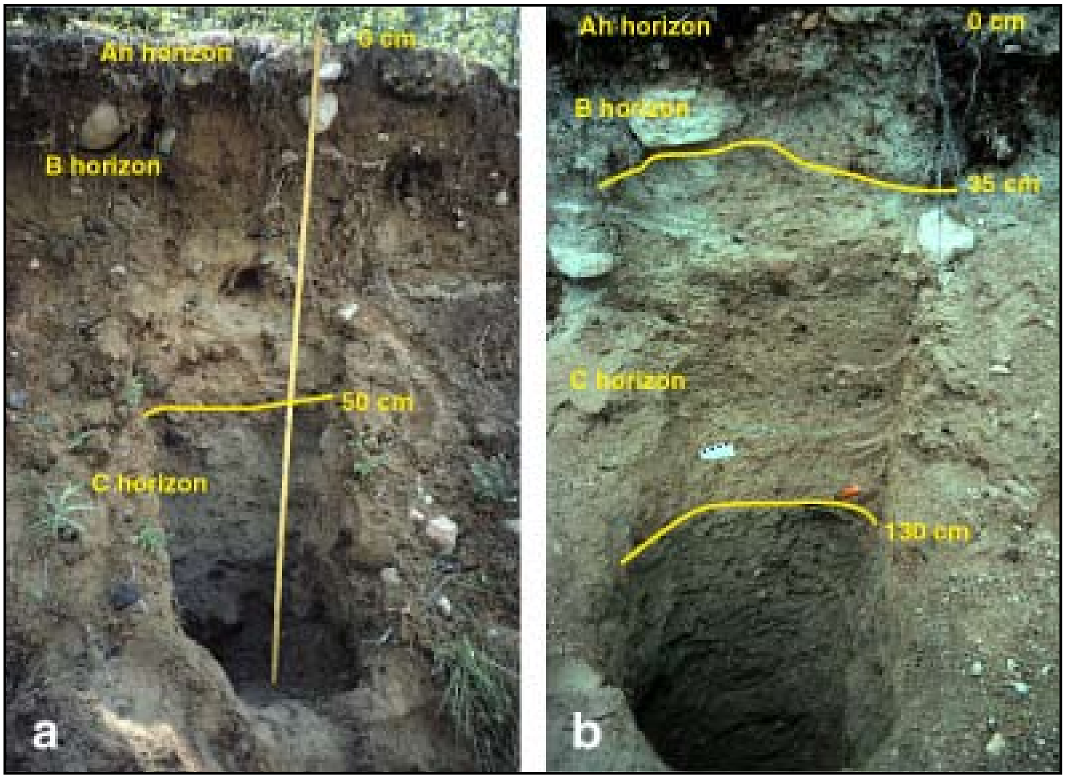

Figure 5-9. *Photographs of (a) a typical soil profile developed in till near Flin Flon, Manitoba, and (b) a soil profile in strongly calcareous till near The Pas, Manitoba, showing the Ah horizon. In soil sampling surveys samples were commonly collected from the Ah (humus) and B horizons (photo from McMartin and McClenaghan, 2001).*

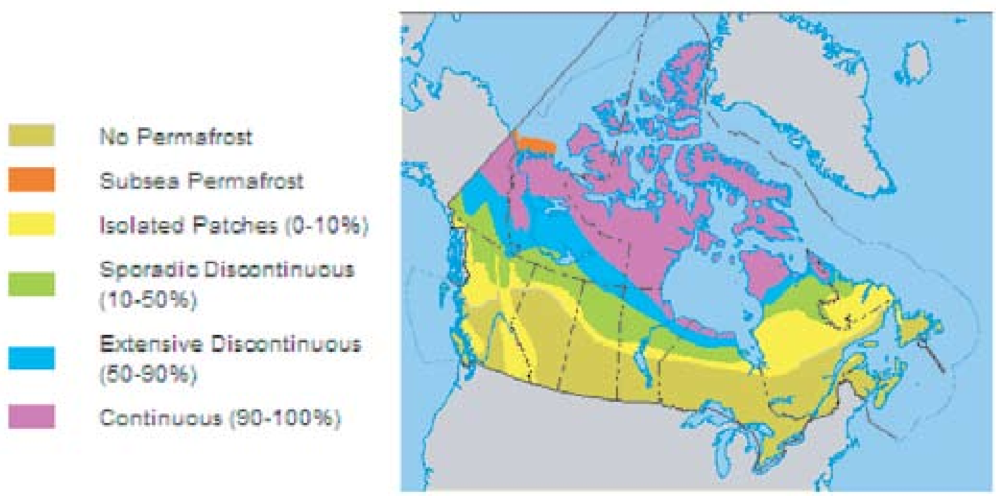

Figure 5-10. Distribution of permafrost in Canada (Atlas of Canada, 2003)

REFERENCES

Atlas of Canada, 2003. Major rock categories; <http://atlas.nrcan.gc.ca/site/english/maps/environment/geology/majorrockcategories> [accessed December 16, 2009].

Atlas of Canada. 2003. Permafrost; <http://atlas.nrcan.gc.ca/site/english/maps/environment/land/permafrost> [accessed December 16, 2009].

Canadian Encyclopedia, 2008. Physiographic regions; <http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1ARTA0006275> [accessed December 16, 2009].

DiLabio, R.N.W., 1989. Terrain geochemistry in Canada; ***in*** Quaternary Geology of Canada and Greenland, Chapter 10, (ed.) R.J. Fulton; Geological Survey of Canada, no. 1 (also Geological Society of America, the Geology of North America, v. K-1), p. 647-663.

Dredge, L.A. and Cowan, W.R., 1989. Quaternary geology of the southwestern Canadian Shield; *in* Quaternary Geology of Canada and Greenland, Chapter 3, (ed.) R.J. Fulton; Geological Survey of Canada, no. 1 (also Geological Society of America, the Geology of North America, v. K-1), p. 214-235.

Dyke, A.S. and Dredge, L.A., 1989. Quaternary geology of the northwestern Canadian Shield; *in* Quaternary Geology of Canada and Greenland, Chapter 3, (ed.) R.J. Fulton; Geological Survey of Canada, no. 1 (also Geological Society of America, the Geology of North America, v. K-1), p. 189-214.

Dyke, A.S. and Prest, V.K., 1987. Paleogeography of northern North America, 18000-5000 years ago; Geological Survey of Canada, Map 1703A, scale 1:12 500 000.

Dyke, A.S., Vincent, J-S., Andrews, J.T., Dredge, L.A., and Cowan, W.R., 1989. The Laurentide Ice Sheet and an introduction to the Quaternary geology of the Canadian Shield; *in* Quaternary Geology of Canada and Greenland, Chapter 3, (ed.) R.J. Fulton; Geological Survey of Canada, no. 1 (also Geological Society of America, the Geology of North America, v. K-1), p. 178-189.

Friske, P.W.B., Ford, K.L., McCurdy, M.W., McNeil, R.J., and Harvey, B.A., 2010. North American Soil Geochmical Lancscapes Project: Canadian field pprotocols for collecting mineral soils and measuring soil gas radon and natural radioactiviity; Geological Survey of Canada, Open File 6282, 177 p.

Fulton, R.J. (ed.), 1989. Quaternary geology of Canada and Greenland; Geological Survey of Canada, Geology of Canada, no. 1, 839 p.

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

Karrow, P.F., 1989. Quaternary geology of the Great Lakes subregion; in Quaternary Geology of Canada and Greenland, Chapter 4, (ed.) R.J. Fulton; Geological Survey of Canada, no. 1 (also Geological Society of America, the Geology of North America, v. K-1), p. 326-350.

Kettles, I.M., Tarnocai, C., and Bauke, S.D., 1997. Predicted permafrost distribution in Canada under a climate warming scenario; *in* Current Research 1997-E; Geological Survey of Canada, p. 109-115.

Klassen, R.W., 1989. Quaternary geology of the southern Canadian Interior Plains; *in* Quaternary Geology of Canada and Greenland,.Chapter 2, (ed.) R.J. Fulton; Geological Survey of Canada, no. 1 (also Geological Society of America, the Geology of North America, v. K-1), p. 138-173.

McMartin, I. and McClenaghan, M.B., 2001. Till geochemistry and sampling techniques in glaciated shield terrain: a review; *in* Drift Exploration in Glaciated Terrain, (ed.) M.B. McClenaghan, P.T. Bobrowsky, G.E.M. Hall, and S.J. Cook; Geological Society Special Publication 185, p. 20-43.

Pidwirny, M. (2006). Soil Classification; Fundamentals of Physical Geography (second edition); <http://www.physicalgeography.net/fundamentals/10v.html> [accessed December 15, 2009].

Shilts, W.W., 1993. Geological Survey of Canada's contributions to understanding the composition of glacial sediments; Canadian Journal of Earth Sciences, v. 30, p. 333-353.

Shilts, W.W. and Kettles, I.M., 1990. Geochemical-mineralogical profiles through fresh and weathered till; *in* Glacial Indicator Tracing, (ed.) R. Kujansuu and M. Saarnisto; A.A. Balkema, Rotterdam, p. 187-216.

Soil Carbon Data Working Group, 1993. Soil carbon data for Canadian soils, Centre for Land and Biological Resources Research Research Branch, Agriculture Canada, Ottawa. CLBRR Contribution Number 92-179, 33 p. plus appendices.

Soil Classification Working Group, 1998. The Canadian System of Soil Classification, 3rd ed. Agriculture and Agri-Food Canada Publication 1646, 187 p.

Spirito, W. A., Rencz, A.N,; Kettles, I.M., Adcock, S.W., and Stacey, AP., 2004. Compilation of soil and till geochemical metadata for Canada - an update; Geological Survey of Canada, Open File 5085, 92 p.

Tarnocai, C., Kettles, I. M., Lacelle, B., 2000. Peatlands of Canada; Geological Survey of Canada, Open File 3834; 1 sheet.

Wallace, W.S. (ed.), 1948. The Encyclopedia of Canada, Vol. III, Toronto, University Associates of Canada, 1948, p. 23-26.

Wolfe, S.A., 2002. Eolian deposits of the Prairie provinces of Canada; Geological Survey of Canada, Open File 4118 (map).