Earth Sciences Sector

Geoscience in Ecological and Human Health Risk Assessment

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Natural Resources Canada Ressources naturelles Canada

Canada

Science in Risk Assessment

- Risk Assessment
  - Informs societal decision-making
  - Combines scientific knowledge of hazard (empirical measures and process knowledge) with vulnerabilities (human, economic, social factors)
  - In regulations and guidelines, scientific knowledge is codified – **Numbers** establish acceptable levels of risk

What's in a Number ?

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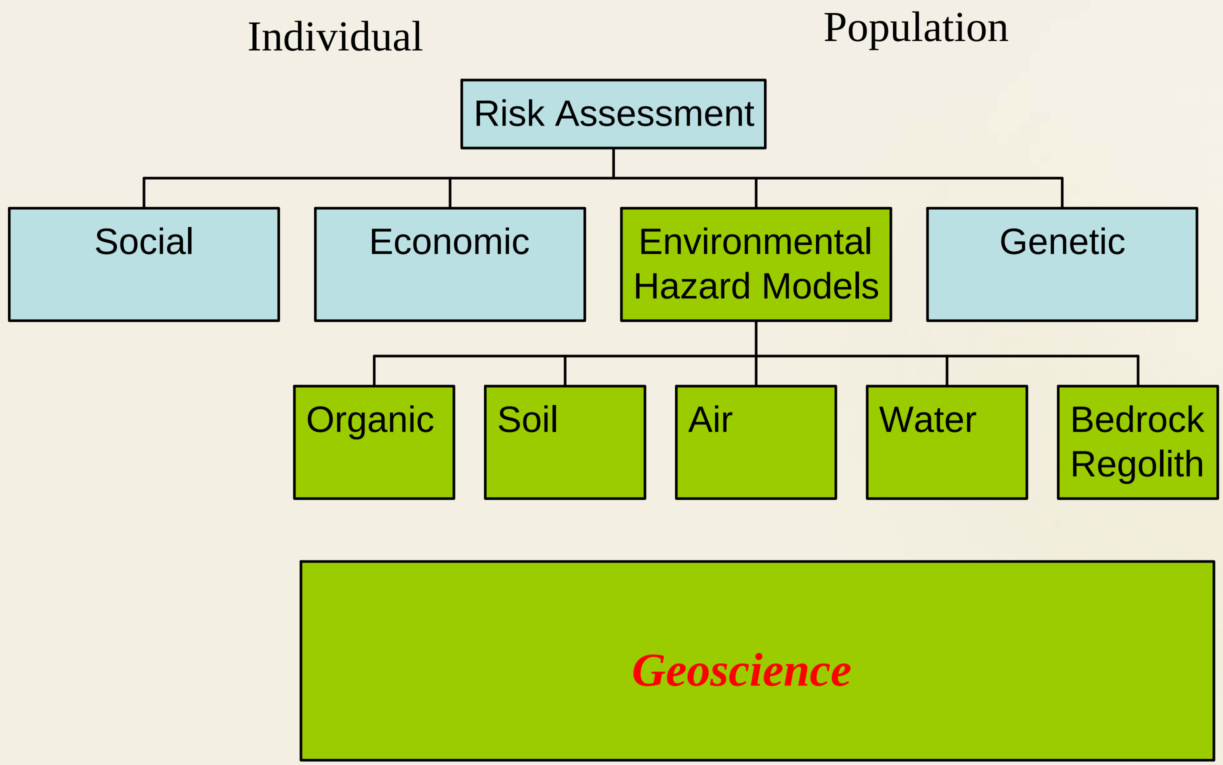
Hazard Characterization and Risk Assessment



Science in Risk Assessment

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Empirical analyses of air, food, water, and soil - **Numbers** - establish:

- exposure risk (ingestion, inhalation, absorption pathways)
    - sample-specific / site-specific
- environmental liabilities attributed to human and industrial actions
    - incremental inputs referenced to natural background

What's in a Number?

Numbers originate in biological sciences

- for air, water, food: results generally equate to dosage - hence, risk
  - elements bioaccessible
  - media matrices predictable
  - exposure pathways readily modeled

What's in a Number?

<u>But</u> Earth Materials are different

They are inherently complex - difficult to simplify for risk assessment

- Mineral particulate matrices AND surfaces (organic, inorganic) – difficult to analyze with environmental roles difficult to establish
- Geographically variable in properties indicative for harm

Biological Measures of Risk

Based on

Phytotoxicological and ecotoxicological laboratory testing

- use of artificial soil media dosed with metal salts in solution

elements in bioaccessible forms

Biological Measures of Risk

The Challenges

- Geological : earth materials are inherently variable
  - artificial soil media used for testing may be unrelated to natural soil
- Biological : exposure cannot be quantified independent of media
  - elements tested are in the most bioaccessible forms
  - the mineral-solution interactions are not accommodated

What's in a Number?

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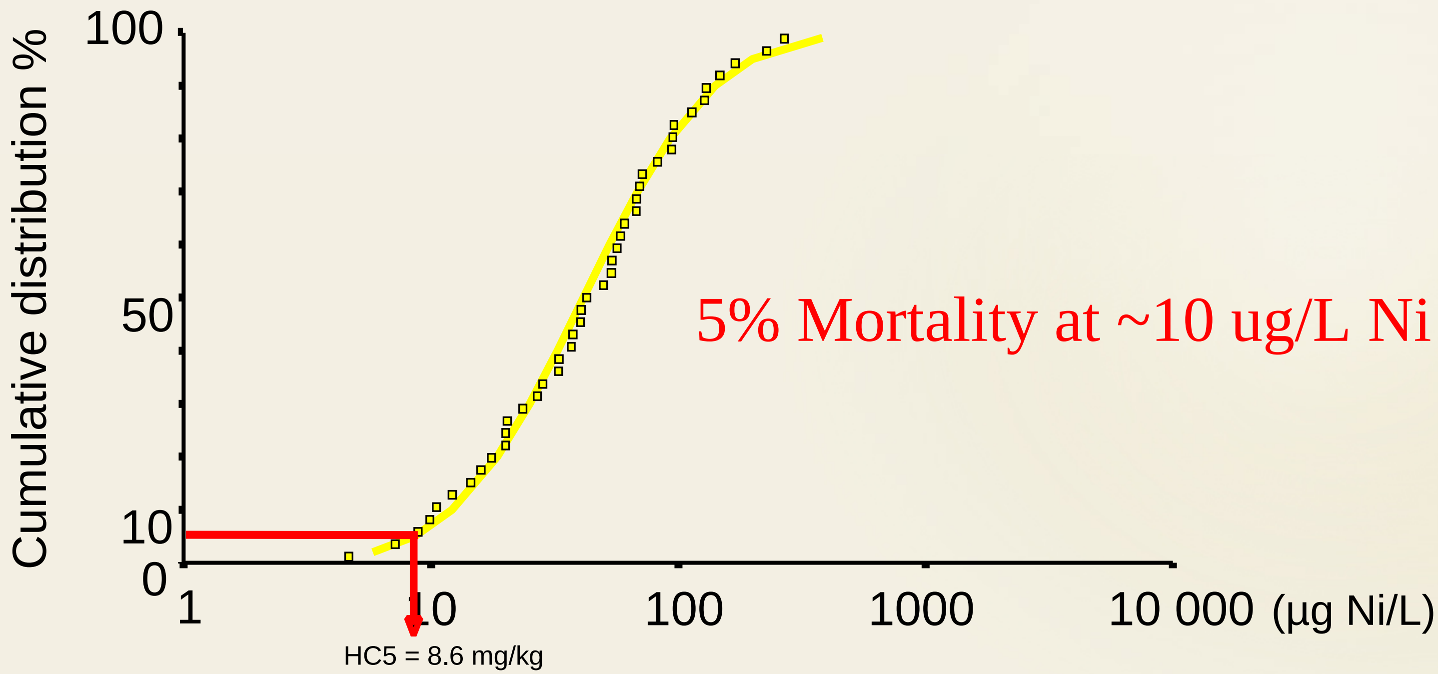
Biological Measures of Risk

Ecotoxicology and Soil Media



European Union
Ni Risk Assessment

What's in a Number ?

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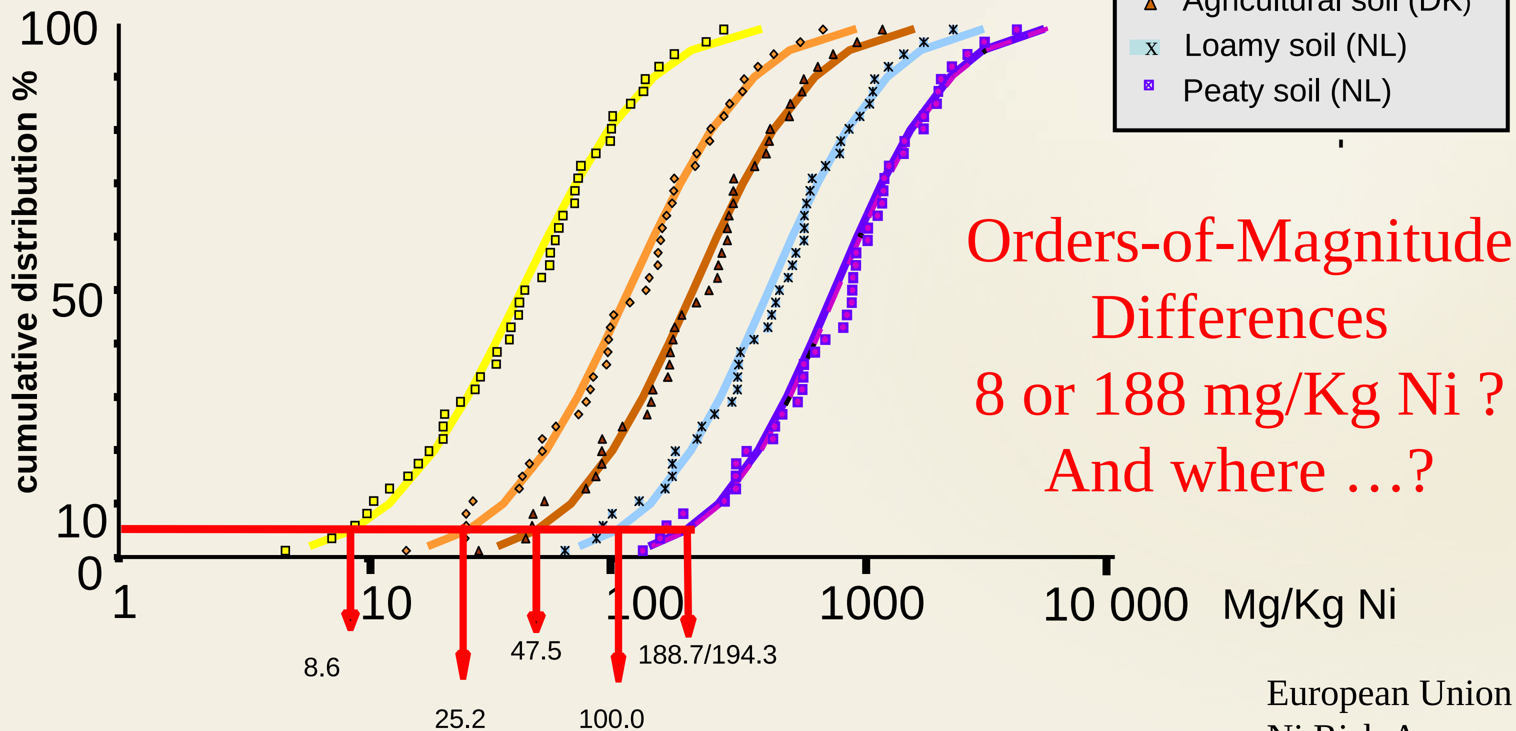
Biological Measures of Risk

Ecotoxicology and Natural Soil Media Testing



Orders-of-Magnitude Differences
8 or 188 mg/Kg Ni ?
And where …?

European Union
Ni Risk Assessment

What's in a Number?

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Earth Materials and Biological Measures of Risk

- Conclusions
  - Different earth materials - different **Numbers** - No single **Number** has universal application in risk assessment
  - Soil Threshold Values - **Numbers** - defined in Guidelines and Regulation may be unrelated to actual exposure and risk

(1) Grain Size and Mineral Partitioning

- Geology: Mineral Partitioning:

  mineralogy varies among grain size fractions (orders-of-magnitude)

  what is moved (<0.002 mm) may differ from the source (<2 mm)

  with decreasing grain size, bio-reactivity and element concentrations may increase (mineral species partitioning, surface area)

- Biology: Grain Size

  hazard potential reflects what is moved along exposure pathways (mineral lodgment site, residence time, reactivity, chemical speciation, etc.)

  Inhalation - <0.002 mm and <0.010 mm - different lodgment sites and residence times in pulmonary tract

  Ingestion - Food and hands - typically < 0.250 mm, with 98% < 0.010 mm

What’s in a Number?

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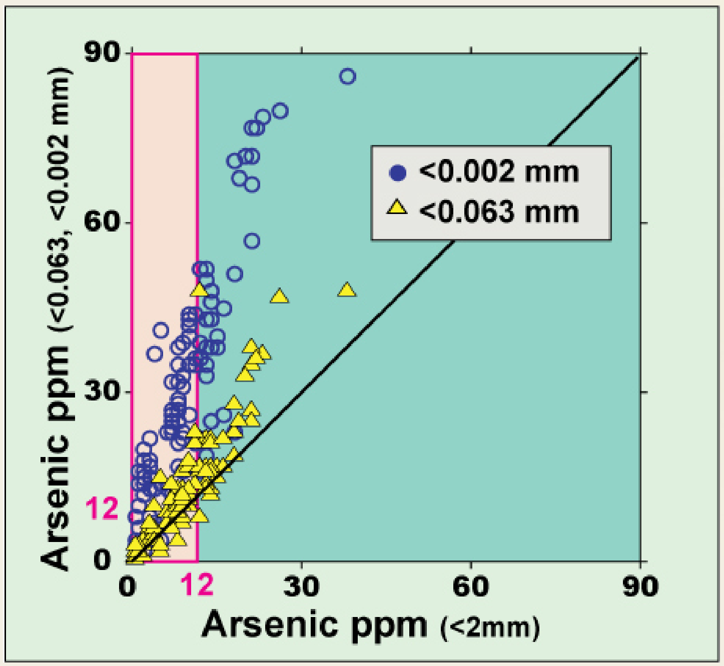
(1) Grain Size and Mineral Partitioning

Comparison of Arsenic in <002, <0.063, < 2.0 mm grain size fractions
Geochemical differences originate in mineral partitioning



Numbers change with grain size

So does the estimate of risk

What's in a Number?

Analytical Protocols and Geological Factors

(1) Grain Size and Mineral Partitioning

Conclusion

The Numbers change with grain size (different grain sizes - different estimates of risk)

To assess actual risk, the grain size analyzed must be specific to the exposure pathway (<2; <0.063, <0.002 mm)

Analytical Protocols and Geological Factors

(2) Chemical Digestion and Mineralogy

Geology: Mineralogy

- Elements are distributed among minerals having different compositions and different environmental reactivities

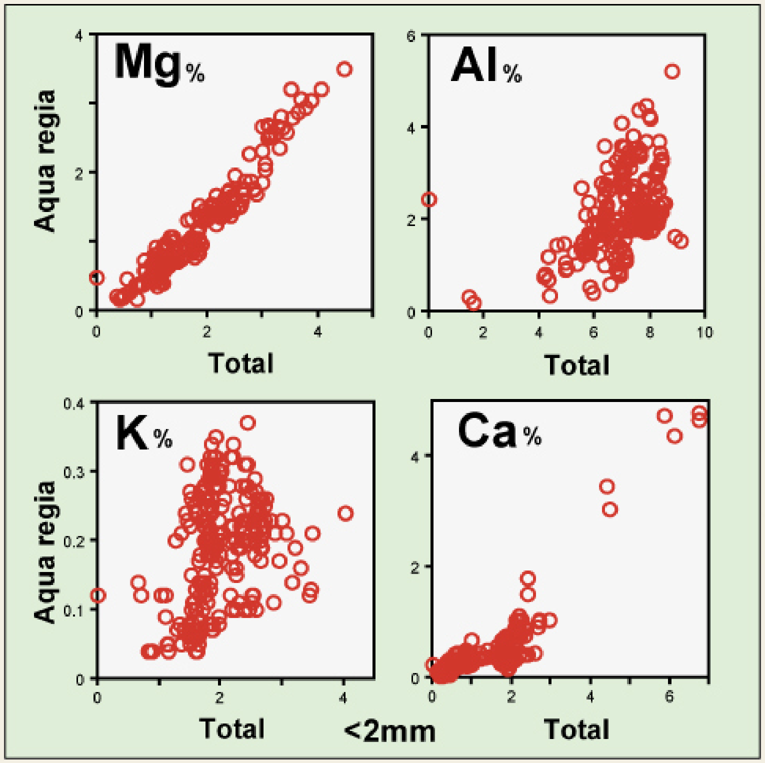
Biology:

- Hazard potential reflects element speciation, mineral host, residence site

Analytical: Chemical Digestion

- With decreasing strength of chemical digestion the minerals decomposed have increasing potential for environmental reactivity

(2) Chemical Digestion and Mineralogy

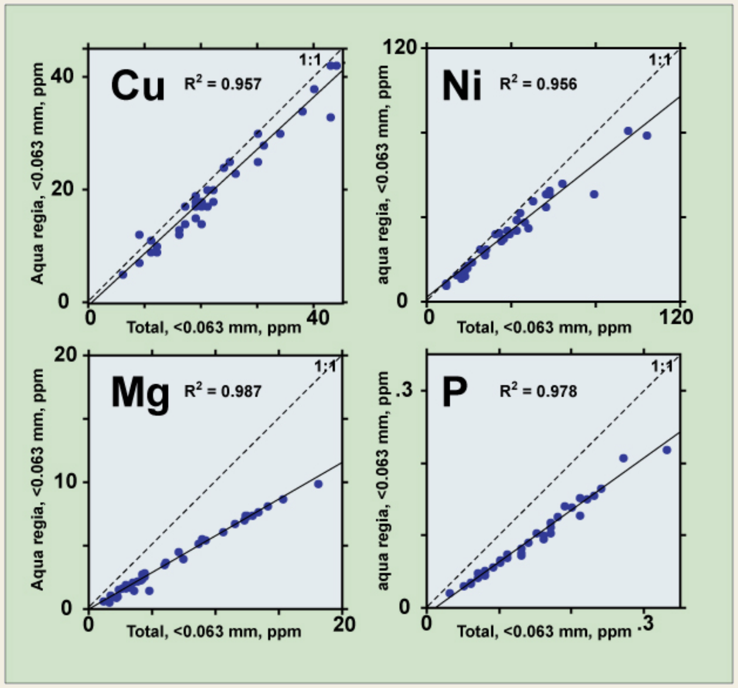


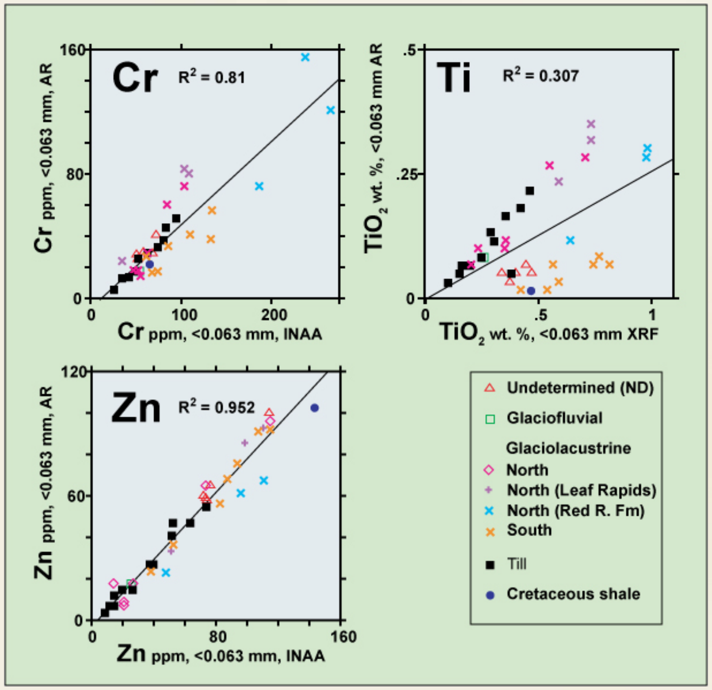
Different elements
Different minerals
Different decompositions
Different results
Different interpretations

Aqua Regia = Total recovery for Mg <u>BUT,</u> not for Al, K, Ca

(2) Chemical Digestion and Mineralogy

Different elements, Different minerals, Different decompositions, Different results, Different interpretations





Analytical Protocols and Geological Factors

(2) Chemical Digestion and Mineralogy

Conclusion

The Numbers are specific to the element, its mineral host(s) and the analytical method (strength of decomposition).

The <u>combination</u> of mineralogy and chemical digestion affects the determination of hazard potential and risk.

Weaker digestions - like water leach, may better characterize bio-uptake potential than stronger, like aqua regia.

Geological Factors, Analytical Outcomes, and Risk

Conclusion

In addition to element concentration, acceptable risk - the Number must be defined by

- grain size and mineral partitioning
- mineralogy and analytical protocol

Natural Background and Environmental Liabilities

Definition of Background

- No clear answers – and a great deal of confusion
- Uncertainty fueled by:

  The combination of factors affecting analytical outcomes

  Pressure for legally defensible, practical definition

  Lack of geoscience (expert knowledge)

  Uncertainty in the meaning and use of regulatory thresholds

  Natural enrichments characterizing large geographic areas – what does it mean, what to do (regulation, safety, etc.)?

Natural Background and Environmental Liabilities

Geochemical Background

- Established by empirical surveys
  - Large samples (averaging)
  - Varied sample media
  - Varied analytical protocols (agricultural, environmental, explorationist)
- Simplified by process models and statistics

Natural Background and Environmental Liabilities

Process Models

A) Bedrock Geology (crustal processes)

B) Surficial Geology (wind, water, ice, gravity)

C) Weathering (predominantly inorganic, effects decrease downward over metres)

(mineral properties, depth, topography, oxygen supply, etc.)

D) Soil Formation (mediated in biology, within a metre of surface)

(soil-forming factors: organic material, topography, climate – moisture, temperature, time, parent material)

E) Biology

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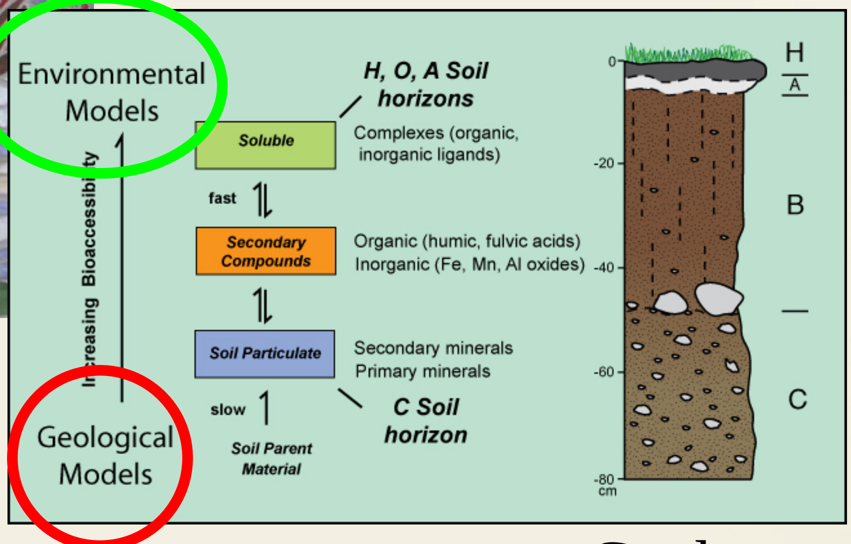
Geochemical Background and Soil Formation

Process Models

Pedology

Soil



Geology

Regolith

Soil Formation

Complex

Transient

Effects Diminish Downward

Weathering

Effects Diminish Downward

Unweathered

What's in a Number?

Natural Background and Environmental Liabilities

Process Models

- Difficult to codify in regulation (e.g., glacial dispersal models)
- BUT - support negotiation between regulators and landowners over natural variability and risk
- Require expert knowledge

What's in a Number?

Natural Background and Environmental Liabilities

Statistics

- Accommodate differences in analytical protocol (uncertainty in methodology) and sampling density (uncertainty in spatial variability)
- May be codified in guidelines and is suited to legal process
- Amenable to non-expert use
- Where NOT guided by geoscience, statistics alone may be unreliable guides to risk assessment and risk management

Natural Background and Environmental Liabilities

Defining Background for Decision-making

- For Human and Environmental Health
  - Inhalation and ingestion pathways (e.g., <0.002 mm)
  - Weaker decompositions (e.g., mineral hosts and bioaccessibility)
  - Near-surface samples and exposure potential
- For Industrial Liabilities
  - Near-surface samples - residence sites of industrial deposits
  - Finer grain sizes - <0.002, <0.063 mm
  - Element associations, isotopes, links to physical record, etc.
- For Policy-Making and Regulation
  - Sample depth: extent of weathering, temporal stability
  - Strong acid decomposition: temporal stability, net hazard

Conclusions - Role for Geoscience

Guides biological testing that establishes the Numbers associated with acceptable risk

Provides stable environmental reference framework

- Unique support for policy-making and regulation

Supports proactive decision-making

- Defining spatial variation in relative hazard potential

Promotes wise use of resources

- Supports targeted testing; land-use regulation; risk mitigation (geological sources and exposure pathways)

General Conclusions

- Need to integrate all natural sciences - geology, pedology, and biology, in risk assessment and the negotiation of risk (Guidelines)

  The role for geoscience varies with sample depth, weathering, and soil formation

- Expert knowledge of process must inform statistical characterizations of background variation