Use of Airborne Gamma Radiometrics to Infer Soil Properties for a Forested Area in British Columbia, Canada

Research Report

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Abstract

We obtained radiometric data from a public-domain archive maintained by Natural Resources Canada and processed them to produce a ternary image for a portion of the Cariboo region. A field program was used to evaluate what information could be reliably inferred from the available data. This initial investigation confirmed that the radiometrics for this area exhibited consistent and useful patterns to interpret the lithology, mineralogy, depth, and moisture status of the surficial materials. Different colour patterns in the ternary image correlated well with different compositions of the various tills. We noted a clear association between higher values of radioactive emission and more recently deposited aeolian, alluvial, and glaciofluvial sediments that contained higher concentrations of relatively unweathered minerals. We observed a clear pattern of lower emission from wetlands and areas of wet soil. Airborne radiometrics, even at 500-m line spacing, provided invaluable and precise information—not otherwise obtainable—for mapping or modelling spatial variation in properties of the surficial material within the forested study area in British Columbia. We recommend further investigations to develop operational procedures for the use of such data in mapping surficial materials.

KEYWORDS: gamma radiometrics; predictive ecosystem mapping; soil mapping; soil texture

Introduction

Airborne gamma radiometrics was developed for geological exploration and mapping (Darnley & Grasty 1971; Grasty 1979; Jaques et al. 1997). More recently, the technique has been applied to mapping and modelling of regolith and soil parent materials in various parts of the world, notably in Australia (Wilford 1995; Cook et al. 1996; Wilford et al. 1997; Dickson & Scott 1999; Cattle et al. 2003). Applications in mapping soil parent materials are reported for the United Kingdom (Rawlins et al. 2007, 2009) and for French Guiana (Martelet et al. 2006). Some explanation of the use of airborne radiometrics for geological mapping are given on a site maintained by Victoria Resources Online (http://vro.dpi.vic.gov.au/dpi/vro/vrosite.nsf/pages/landform_glossary_radio). Despite the early use of radiometrics for geological mapping in Canada (Grasty 1979; Graham & Bonham-Carter 1993), more recent reports of its use for mapping of surficial materials in Canada are difficult to find.

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A project to produce predictive ecosystem maps (PEM) for the entire extent of the former Cariboo Forest Region undertaken between 2004 and 2008 had a requirement for spatial data inputs that described the depth, texture, and mineralogy of the surficial parent materials (MacMillan et al. 2007). This requirement was not fully satisfied by manually reinterpreting air photos and existing maps of soils and surficial geology for the area. One of the recommendations made by the Cariboo PEM project was that investigators were to identify improved methods of mapping or modelling the spatial distribution of soil parent materials that would be beneficial for future PEM projects. In most forested areas in British Columbia, soil texture and mineralogy are not mapped with sufficient precision to meet current operational needs such as determination of soil sensitivity to disturbance so that appropriate logging practices can be planned. Two emerging issues that would benefit from better textural and mineralogical data are 1) determining site sensitivity to biofuel harvesting and 2) suitability for intensive management. Additional potential applications are myriad; for example, two management issues that are currently important in British Columbia are identification of ecologically important soils for badger and pine mushroom habitat.

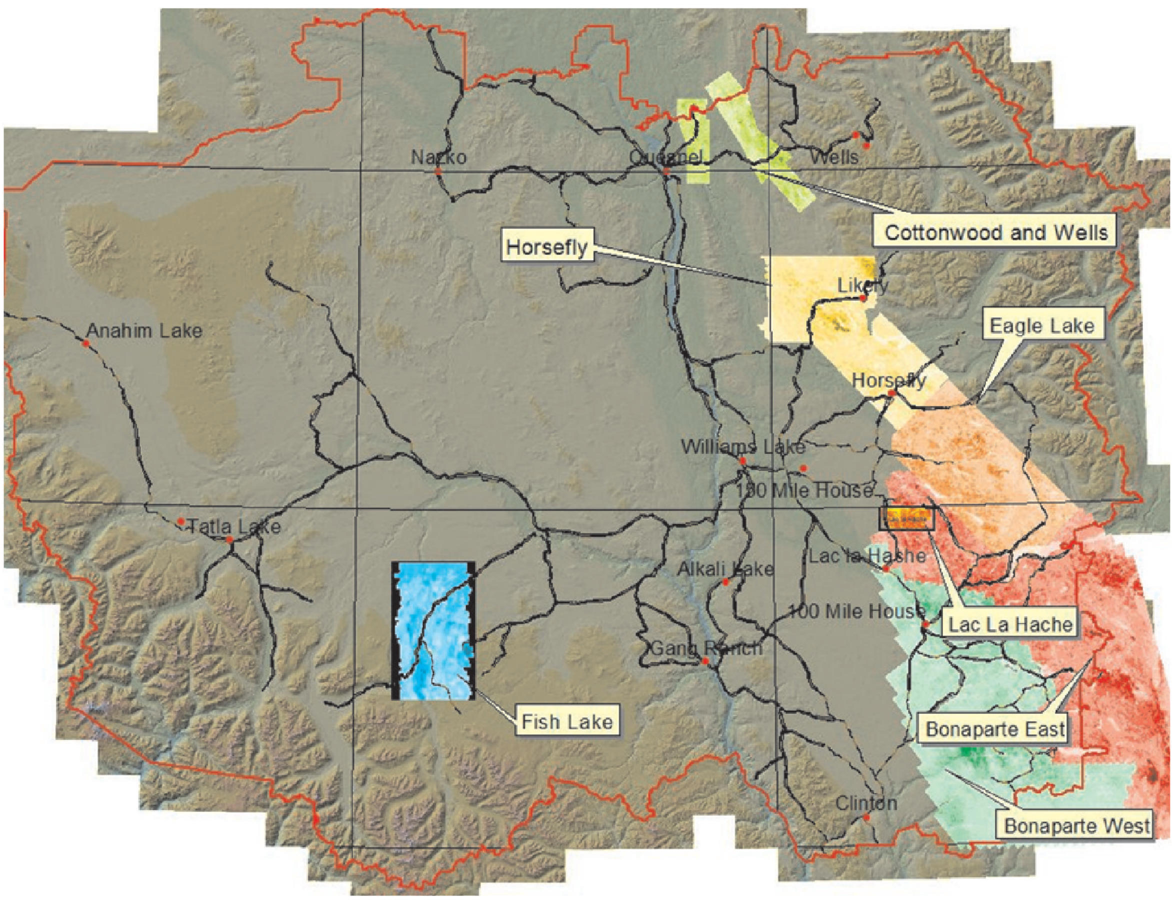

Figure 1: Location of airborne radiometric survey data in the former Cariboo Forest Region

PEM mapping imposes a need to differentiate deep versus shallow soils; organic materials; coarse, medium, or fine soil textures; and mineralogy at the level of base-rich or base-poor. Being aware of the successful use of airborne radiometrics to model parent material in various situations, the current study was initiated to assess the potential of airborne radiometrics to improve our ability to infer or model specific aspects of surficial parent materials within forested landscapes in British Columbia. A second objective was to compare our findings with those reported for other regions with different environments.

Methods

Study area

The PEM map covered an area 416 km east–west by 304 km north–south (8.2 million ha) within the Cariboo Region in the south-central portion of the province of British Columbia, Canada. Previously collected, free radiometric data were available for areas shown in Figure 1.

Most of the area for which radiometric data were available consists of the broad, level to gently rolling Fraser Plateau, with elevations ranging from 900 to 1500 m. Data were also available for a smaller area of high (2500–3000 m), steep terrain in the Columbia Mountains to the north and east.

Digital radiometric data sets

Airborne radiometric surveys typically measure and report the intensity of natural gamma radiation emitted in three wavelengths, corresponding to the radioactive elements potassium (K), uranium (U), and thorium (Th). Interpretation of these data may be assisted by producing ternary images in which specific colours are assigned to each radioactive element: conventionally, red represents K, blue represents U, and green represents Th. Airborne radiometric survey data used in this project were downloaded from a website previously maintained by Natural Resources Canada (http://geogratis.cgdi.gc.ca/geogratis/en/product/search.do?id=83A7350A-2BF1-8CBA-371F-C9E4B48A4EA5). These data for seven separate project areas (Table 1) were collated and used to produce a single ternary image mosaic for the study area (Figure 2).

Two composite ternary image mosaics were produced with grid resolutions of 50 and 100 m, respectively. Only the 100-m resolution ternary image is used here because the line spacing at which most of the

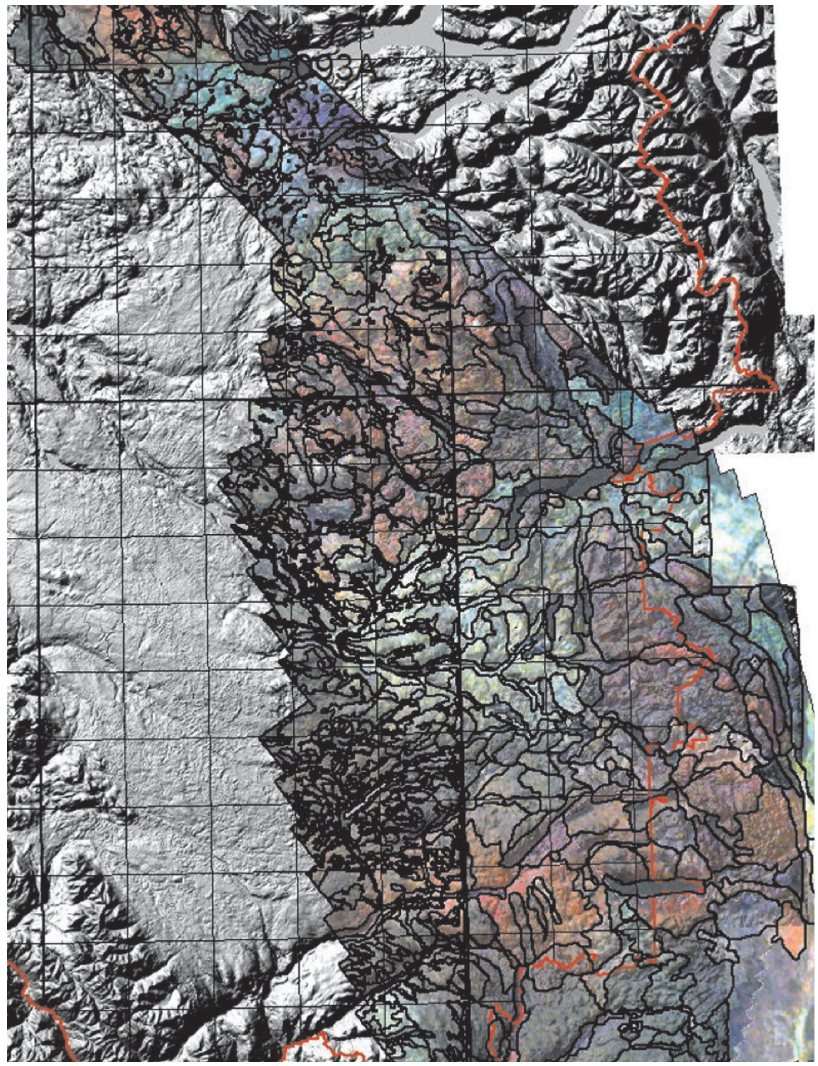

Figure 1: Location of airborne radiometric survey data in the former Cariboo Forest Region.

Table 1: Listing of British Columbia project areas for which airborne radiometric data were obtained

No.	Project area name	Year	Flight line spacing (m)	Metres interpolated to
1	Cottonwood and Wells	2005	150	40
2	Eagle Lake, McKinley Creek	2005	500	50
3	Fish Creek	1993	500	100
4	Hydraulic (also called Horsefly)	2005	500	50
5	Lac La Hache	2005	500	50
6	Bonaparte Lake East	2006	420	50 & 100
7	Bonaparte Lake West	2006	400	50 & 100

data were collected (400–500 m) did not support the implied level of detail present in the 50-m resolution mosaic.

Digital elevation model

The project made use of a 25-m horizontal-grid digital elevation model (DEM) that had been previously prepared for use in the Cariboo PEM project (MacMillan et al. 2007). The TOPOGRID interpolation program (Environmental Systems Research Institute 2000) was employed to produce the DEM, using point elevations, break line data, and stream hydrography sourced from the original Terrain Resource Information Management (TRIM II) elevation data. The raw point data were interpolated to a 25-m grid that was then smoothed using successive passes of a 3 x 3 pixel and 5 x 5 pixel mean filter to reduce local noise and bring out the longer range signal.

The original 25-m DEM was re-sampled to a 100-m horizontal grid for use in all area-wide topographic analyses. The 25-m DEM was too large to process as a single file for the entire area and it was necessary to produce a smaller and more generalized DEM for area-wide analyses.

Soil survey digitized polygon maps

Portions of the overall study area were covered by manually prepared soil maps that had been digitized and loaded onto the Canadian Soil Information System (CanSIS) website (http://sis.agr.gc.ca/cansis/nsdb/detailed/bc/zipfiles.html; last accessed January 2013). These soils maps covered only a portion of the area for which radiometric data were available.

Visual review of the soil map vectors overlaid on the ternary radiometric image (Figure 2, left) revealed that the existing soil boundaries appeared to create meaningful delineations of the major colours and patterns evident in the ternary image. The boundaries of the existing soils map were extended by manually digitizing new boundaries for polygons located in the areas covered by radiometric data but not by the existing soils map. Manual digitizing made use of the radiometric ternary image draped over a hillshade of the 25-m DEM to inform and guide the delineation of new boundaries for the extended soils map.

The manual digitization started at the boundary of the previously mapped area and extended existing soil polygons by outlining patterns in the previously unmapped area that resembled similar patterns in the mapped areas. Figure 2 illustrates the full extent of the area for which new soil-like polygons were created (the right half) along with the associated area (the left half) already covered by soil maps; the correspondence between vector boundaries and changes in the colour, texture, or pattern of the ternary image is readily evident in the image.

Fieldwork

The fieldwork was designed to collect georeferenced field observations to satisfy the following objectives.

- Assess the degree to which the radiometrics permitted differentiation of areas of different lithology and mineralogy in the surficial materials (soil mineralogy).
- Assess the degree to which the radiometrics permitted differentiation of areas of different parent material texture (soil texture).
- Assess the degree to which the radiometrics could be used to infer relative depth of parent material overlying bedrock (soil depth).
- Assess the degree to which the radiometrics could be used to infer differences in soil moisture regime or moisture status between different areas (soil moisture).

A large area was sampled by traversing 325 km of road. Hundreds of observations were made on types of parent material, soil texture, depth to bedrock, and soil moisture regime.

Results

Our field investigations confirmed that the radiometrics for this area exhibited consistent patterns that were useful in interpreting lithology and mineralogy, texture (to a limited extent), depth to bedrock, and moisture status of the surficial geological materials. The fieldwork did not produce enough site observations to support quantitative statistical analyses of relationships between the radiometrics and parent material lithology, texture, or depth observed in the field: only qualitative assessments are possible at this time.

Lithology and mineralogy

Field observations confirmed that different colour patterns on the ternary image correlated well with different lithologies. We noted that the polygons outlined on the extended soil map appeared to effectively delineate areas of different lithology and mineralogy (Figure 2). We assigned each polygon of the extended soil map to a descriptive class of soil parent material (Figure 3 and Table 2).

We are confident that the areas of different dominant colour on the ternary image corresponded quite closely to recognizable differences in the lithology and mineralogy of the dominant surficial materials (usually till) in any given region. For example, we were able to differentiate surficial materials dominated by granites (rich in potassium felspars) from those derived from more basic sedimentary and volcanic-rich materials. These observations were supported by differences in counts of till pebble lithology and by field tests of the pH of parent materials and of surface waters collected in each area. This differentiation is of sufficient resolution to be of use for PEM mapping.

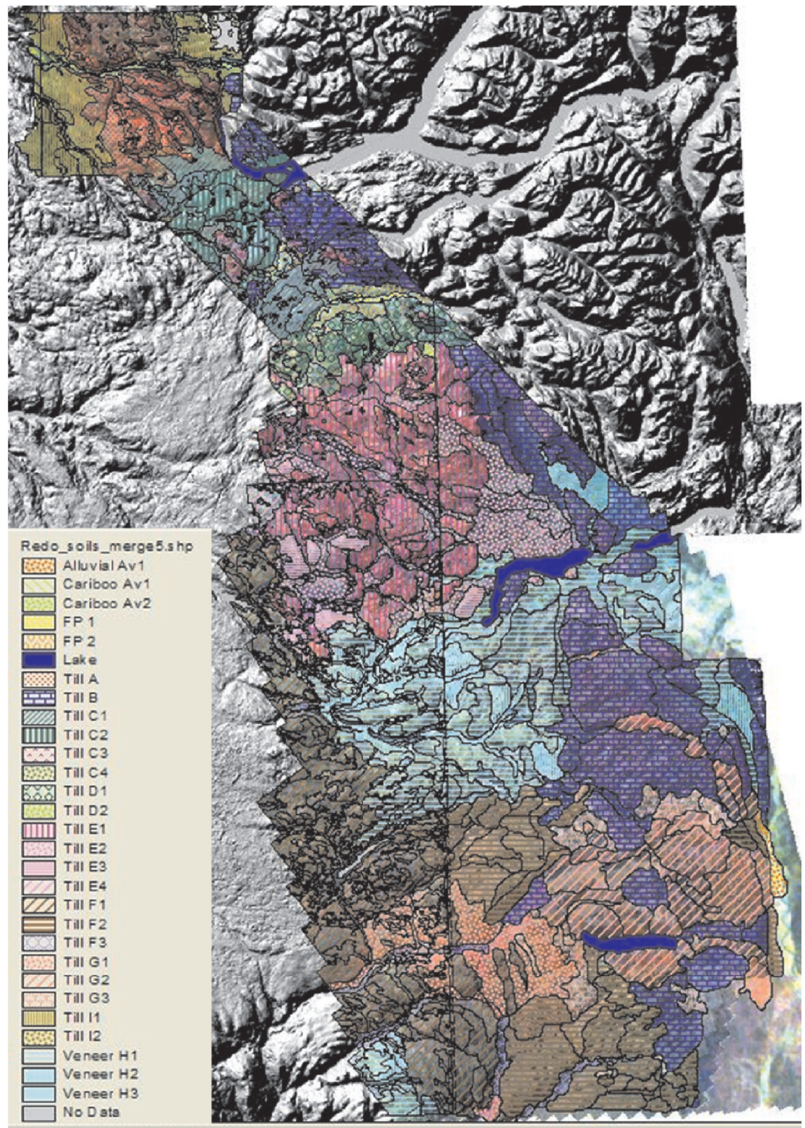

Figure 3: Parent material lithological domains as interpreted from the ternary gamma-radiometric mosaic, DEM, and extended soil map polygons. See descriptions of these parent materials in Table 2.

Areas of brighter colours (whites, bright cyan, bright green) were consistently associated with areas of more recently eroded and deposited aeolian, alluvial, or glaciofluvial sediments. The ability to consistently differentiate areas of recent deposition is consistent with previous findings reported by Bierwirth (1996), Dickson and Scott (1999), Pickup and Marks (2000), and Cattle et al. (2003).

Table 2: Parent material description and legend for Figure 3

Parent material group	Description and colour on the ternary image	Lithology and mineralogy observed in field	Dominant texture[a]
Alluvial Av1	Bright white, cyan, and yellow in major river valleys along east edge of image.	Valley train alluvium and gravels, well sorted.	FSL/Gravel
Cariboo Av1	Bright green to yellowish green in Cariboo River valley.	Sandy loam alluvium over very poorly sorted coarse gravel.	SL/Gravel
Cariboo Av2	Bright green to yellowish green on Cariboo River terraces.	Very poorly sorted sands and gravels embedded in till.	Coarse Gravels
FP 1	Bright cyan, yellowish green, and white in small floodplain in Horsefly area.	Fine sandy loam to sandy loam alluvium in valley bottom floodplain.	FSL/Gravel
FP 2	Bright cyan, yellowish green, and white on upper terraces in the Horsefly area.	Gravels and sand mixed with till on upper terraces of the Horsefly area.	Gravel, Sand
Lake	Black to very dark blue or green lakes.	Large bodies of open water.	Water
Till A	Bright red to pink mixed with magenta and dark blue mottles. North and south of the Cariboo River near Likely.	Mixed: sediments and meta-sediments (siltstone, phyllite, shale, sandstone, slate); acid plutonic (granite), basic, and intermediate volcanic (lavas and breccias).	SL–L
Till B	Dominantly bright blue to purple with mottles of bright pink and dark green. Occupies the eastern side of the image.	Mixed: sediments and meta-sediments (sandstone, siltstone, shale, slate); basic volcanics (basalts); minor intermediate-acid volcanics (andesite and trachyte).	SL–L
Till C1	Dark to light green mixed with cyan, bright blue and some pink.	Basalt and mixed sediments (phyllite to limestone)	L–CL
Till C2	Dominated by cyan, bright yellow, green, and bright blue with some darker green.	Till is derived from mixed sediments and meta-sediments as per C1. Bright cyan, yellow green, and white areas may be more recent sorted sediments (aeolian and alluvial).	SiL/VFSL over SL Till
Till C3	Dominated by cyan, bright yellow, green, and bright blue with some darker green.	No observations but assumed to be thinner till overlying K-rich acid igneous rocks.	L–CL
Till C4	Bright cyan to white in minor drainages and stream valleys.	Recent alluvial sediments in minor drainages and stream valleys in areas dominated by the light greenish Till C1.	SiL–FSL/ Gravel
Till D1	Mixed bright and dark green with pink, purple, and yellow mottles. Extension of Till C1 south of Horsefly River.	Basalt and Andesite, Minor sediments. May be same as Till C1 with colour differences arising from different source used for ternary image.	L–CL
Till D2	Single anomalous area of bright yellow to white in area of bright green Till D1.	No observations but assumed to be thinner till overlying K-rich acid igneous rocks.	L–CL
Till E1	Dominantly pink to red with mottles of dark green, blue, and gray.	Granodiorite and syenite; sandstone/shale/phyllite; minor basic igneous rocks. Found in Lac La Hache area.	SL–L
Till E2	Darker colours, mainly dark green, blue, gray, some red and cyan.	Dominantly basalt. Appears to be thicker and deeper till in valleys and lower landscape positions.	L–CL
Till E3	Dominantly lighter colours, white, bright green, cyan, pink. Thin over bedrock.	Unknown lithology. May contain greater proportion of sorted more recent deposits (aeolian?) shallow bedrock.	SiL–SL
Till E4	Dominantly pale green to dark green. Looks different from main Till D1.	Dominantly basalt. Sandy loam to loam till.	SL–L
Till F1	Dark brown colour caused by mixture of dark green, blue, and light green.	Basalt with minor intermediate volcanics. Dominant till along west edge and in southwest of mosaic area.	SL–L
Till F2	Similar to F1 but more green and blue and less brown colour. Mixed in with Till B?	Basalt with minor intermediate volcanics. Occupies eastern portion of brown till area in southwest of mosaic.	SL–L
Till F3	Bright blue areas in minor to intermediate valleys in areas of brown Till F1 or F2.	Brighter colours indicate possible recent sorted alluvial or aeolian sediments deposited over the till.	SiL–FSL
Till G1	Light pink to bright red to white. Inclusions within areas of Till F1 along east edge.	Outcrops of bedrock and shallow, stony till over bedrock. Acidic syenite/diorite and granodiorite.	Gravelly LS–SL

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Table 2: Parent material description and legend for Figure 3 (cont.)

Parent material group	Description and colour on the ternary image	Lithology and mineralogy observed in field	Dominant texture[a]
Till G2	Similar to Till G1 but more dark red and dark blue and less light pink or white.	Outcrops of bedrock and shallow, stony till over bedrock. Granidorite and andesite. Occurs east of Till G1 in association with bluish Till B areas.	L–SL
Till I1	Uncharacterized, dark green to dark blue till in extreme north end of ternary mosaic.	No observations and so not characterized. May possibly be similar to brown Till F1. Could be northern extension of F1.	N/A
Till I2	Very dark, black to dark green small valleys.	No observations. Dark, presumably wet, valleys in I1.	N/A
Veneer H1	Dark green mixed with bright cyan, bright green, and white. Till with sorted veneer?	Mixture of till and sorted recent sediments (alluvial or aeolian) in vicinity of Bridge Creek.	SL–LS
Veneer H2	Remarkably light, bright cyan and white colours above drainages and valleys.	Mixture of sorted recent sediments (alluvial and aeolian) associated with upper valleys, terraces, and dunes mixed with till in vicinity of Bridge Creek.	SiL–VFSL–FSL
Veneer H3	Very light and bright cyan and white colours occurring in floodplains of minor valleys.	Alluvial sediments in floodplains of minor to intermediate valleys in the vicinity of Bridge Creek.	SiL,VFSL
No Data	Not separately mapped or described.		

[a] Soil texture abbreviations: FSL – fine sandy loam; SL – sandy loam; L – loam; SiL – silt loam; VFSL – very fine sandy loam; CL – clay loam; LS – loamy sand.

Texture of the parent material

We were not able to consistently associate a particular texture of parent material directly with a particular colour or pattern on the ternary image mosaic. The radiometric data do not reveal texture but do provide markers for particular soil parent materials of specific mineralogical composition, which allows inference of soil texture where a particular texture of interest is consistently associated with a specific soil parent material.

To some extent, coarser textured surface materials could be associated with lithologically distinct areas of more recently eroded and deposited aeolian and alluvial sediments (Figure 4). A clear association was evident between higher values of radioactive emission (brighter colours) and more recently deposited sediments that contained higher concentrations of less weathered minerals. These more recent sediments also tended to be distinguished by the presence of higher levels of silt and sand than the adjacent till and colluvium. So, by association, we can make predictions that areas of brighter and lighter colours are more likely to represent deposits of coarser textured materials than adjacent darker areas. In Australia, coarse textured sands and gravels tend to be associated with the very lowest values of gamma ray emissions and show up as black to very dark grey on ternary images (Wilford et al. 1997, 2001). In old landscapes (Cretaceous or older; Twidale 1994) in Australia, coarse sands and gravels tend to represent the oldest and most highly weathered siliceous parent materials with very few radioactive minerals and, consequently, they appear black on ternary images. Conversely, coarser textured materials in younger (Holocene; Valentine et al. 1978) environments in British Columbia tend to be associated with recently eroded and deposited materials that still retain weatherable radioactive minerals and so appear as white or bright in colour on the ternary images. A combination of geomorphological analysis and radiometric data would likely work well for determining texture, but this needs to be further tested.

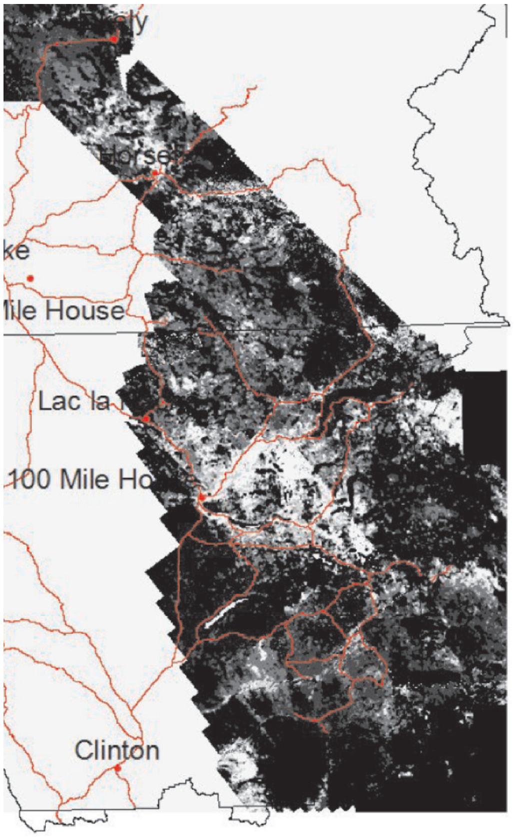

Figure 4: Predicted likelihood of sorted deposits of silt, sand, or gravel, based on landform and brightness values in the ternary radiometric image (brighter areas more likely).

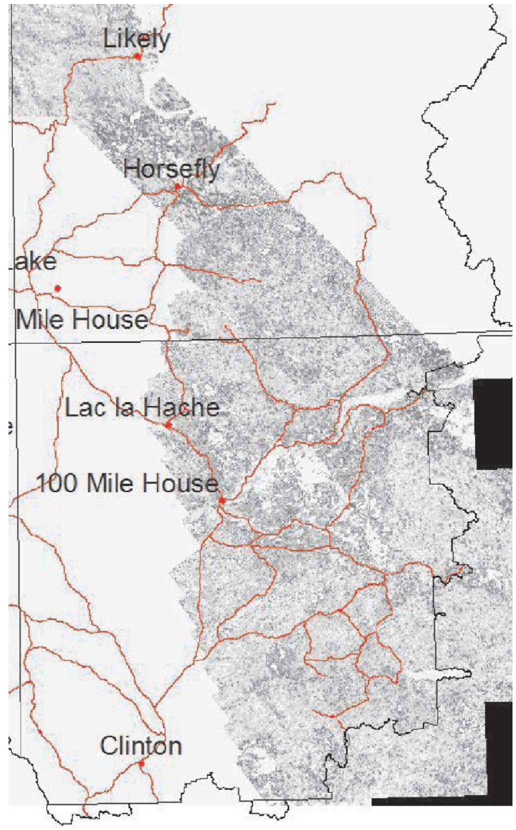

Figure 5: Predicted likelihood of bare rock or shallow till over bedrock (darker areas more likely).

Depth

Higher values of gamma ray emissions were also associated with areas of exposed or shallow bedrock. Gamma rays are generated by K, U, and Th found in a few, specific minerals. In glacial till, the signal is diluted by the non-radioactive matrix that may include substantial weathered material from which K, in particular, may have been leached. Fresh bedrock typically gives a much brighter signal, particularly if the rock is rich in K (e.g., granite). The same applies to shallow till over bedrock, which is typically stony with a higher proportion of unweathered material. Figure 5 shows the likelihood of shallow till over bedrock. Darker grey colours in Figure 5 represent a higher likelihood of being shallow.

Moisture regimes and moisture status

We observed a clear pattern of lower emission (darker colours) associated with lakes, wetlands, and areas of wet soil. Water absorbs gamma rays strongly, so the ternary image shows water bodies in black. The signal is also attenuated by wet soil, and a cursory examination of the gamma-draped DEM shows footslopes and wetlands as darker-coloured (gray, blue) shadows (Figure 6). We considered that many of the darker-coloured pixels in the ternary image might represent artefacts that could be attributed to generalizing mixed signals from both land and water or to interpolating between pixels that represent separate water bodies (darker) and upland areas (lighter colours).

To establish whether the shadow effect was a real indicator of wetland conditions or an artefact, the relationships between dark colours on the ternary image, measured gamma emissions, surface wetness, and depth to the water table were investigated along two transects from lake margins to well-drained upslope sites. Observations along these transects, and throughout the study area, indicated a fairly consistent coincidence between the low gamma emissions and site wetness.

Discussion

Publicly available airborne radiometric surveys were flown not for soil survey but for mineral prospecting. Their relatively wide line-spacing means that they provide information only on larger features (> 500 m across) that are detectable on small-scale images. This study used visual interpretation of ternary images that combine the signals from K, U, and Th; more detailed information could possibly be extracted by computer-aided analysis of the fractional data.

In combination with landform analysis (using the 25-m DEM), airborne radiometrics clearly help identify and delineate the major spatial patterns exhibited by glacial tills, alluvial, and aeolian deposits of different lithology and mineralogy. Furthermore, for large bodies such as individual till sheets, airborne radiometric data provide detailed information on spatial structure, purity, and inclusions. This information cannot be obtained otherwise except by costly field survey and, even then, not with the same accuracy and detail.

Soil texture is not directly predictable from radiometric imagery, but inferences about soil texture may be made for homogenous geographic areas if a consistent relationship exists between areas of identifiable lithology and mineralogy and a particular texture or textures of interest. Airborne radiometrics does not map sands, clays, or other soil attributes *per se*; however, rock outcrops and shallow tills over bedrock are effectively delineated on ternary images.

Interpretation of soil wetness from gamma attenuation shows promise for identifying wetlands and sites that accumulate moisture in low-lying landform positions.

In combination with other layers of available information (e.g., DEMs), radiometrics offers considerable potential to model or infer the spatial distribution of several important aspects of soil parent materials. In Canada, airborne radiometrics has been under-utilized and under-appreciated for mapping soil parent materials. This is the more surprising, considering that soil parent material dominates so many soil attributes in our geologically young landscapes. Airborne radiometrics offers the capability to map different parent materials with an accuracy and detail unattainable even by costly field survey; further efforts to develop operational procedures for mapping soil parent materials in Canada are recommended, particularly in automated digital mapping. The next step in evaluating the usefulness of this technique should be to conduct a similar exercise to the one reported here, except with higher-resolution imagery.

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Test Your Knowledge

How well can you recall the main messages in the preceding article?
Test your knowledge by answering the following questions.

Use of airborne gamma radiometrics to infer soil properties for a forested area in British Columbia, Canada

1. Soil mineralogy is not useful in helping to determine:
   a) Soil sensitivity to logging disturbance
   b) Suitability of a site for biofuel harvesting
   c) Suitability of a site for intensive soil management
   d) Carbon credit value of well-managed forest land

2. The radioactive elements of potassium (K), uranium (U), and thorium (Th) are common in British Columbia soils, and so:
   a) Anything growing in British Columbia soil is dangerous
   b) The intensity of the emissions from these elements can be used to infer something about soil properties
   c) Soil organisms in British Columbia mutate at a higher rate than in other parts of the world

3. Differences in gamma radiation were able to help distinguish differences in:
   a) Mineralogy
   b) Soil texture
   c) Moisture content
   d) Soil depth

ANSWERS: 1=d; 2=b; 3=a, c, d