SATELLITE BASED ENGINEERING-TERRAIN MAPPING OF CANADA’S BOREAL FOREST REGION*

Vern Singhroy[1], Peter Barnett[2], Susan Yatabe[3] and Robert Saint-Jean[1]

1 – Canada Centre for Remote Sensing, Ottawa, Ontario, Canada
2 – Ontario Geological Survey, Sudbury, Ontario, Canada
3 – Star Sapphire Earth Sciences, Deep River, Ontario, Canada

ABSTRACT

The Ontario Geological Survey and the Canada Centre for Remote Sensing are currently preparing a series of satellite based terrain maps for a 250,000 square kilometer area of the boreal forest region in Northwest Ontario. The purpose of this provincial and federal mapping program is to produce a series of 1:100 000 standardized, satellite based engineering-terrain maps that will be published as a provincial map series. The terrain maps are being used to plan forestry roads and other civil engineering works in support of forest harvesting programs in the region. They are also used to verify forest productivity models in the boreal forest. This paper presents the interpretation methodologies and examples of the satellite based standardized terrain maps. Our results show that image maps produced from a combination of DEM and TM can provide a base on which to interpret and overlay engineering terrain units at a scale of 1:100,000 for large areas of the boreal forest regions in northern Canada. This method will result in considerable savings in time and cost when compared to traditional air photo methods.

1.0 INTRODUCTION

Northern Ontario Engineering Geology Terrain Studies (NOEGTS) were completed for the part of the Canadian boreal forest region south of latitude 51° N. Each study included a 1:100,000-scale terrain map that was based almost entirely on the interpretation of air photographs with limited field checking. The legends of the maps contain information on surface material type, landform, topography (relief) and drainage conditions. These maps provide useful information concerning the landscape for forest management and civil engineering.

The vast area of boreal forest north of 51° N latitude, for the most part, has no equivalent maps of the terrain conditions. Such maps would be expensive to create using traditional air photo interpretation and field investigations because of the large areal extent and limitations of access. As a result, this study attempts to create engineering geology terrain maps using the integration and interpretation of various types of remotely sensed imagery, digital elevation models and their derivatives and appropriate geological depositional models. The geobotanical remote sensing techniques developed

---

by Singhroy et al., 1992 and 1993; Singhroy, 1996; and Graham and Grant, 1996, were used as a basis for interpretation of satellite based remote sensing for terrain mapping in densely vegetated areas.

In this paper, we provide an image based methodology and interpretation to produce engineering terrain maps. The standard procedures developed in the Trout Lake area will be used to produce produce image based terrain maps for the entire region.

2.0 GEOLOGY

We have selected the Trout Lake area to test several image processing and interpretation techniques that will provide us with the guidelines to produce standardized satellite based terrain maps of the region. The Trout Lake test site, located on the Canadian Shield, is an irregular bedrock-dominated terrain underlain by Precambrian igneous and metamorphic rocks. The area was last glaciated during the Wisconsinan Stage by the Nouveau Québec Sector of the Laurentide Ice Sheet. During deglaciation of the area, a large, ice-contact glacier-fed lake fronted the ice margin (glacial Lake Agassiz). The interactions of the glacier with the glacial lake controlled depositional environments and hence the distribution and types of landform, origin (glacial, glaciofluvial or glaciolacustrine), material type and sediment distribution.

Direct glacial sedimentation was deposited primarily under the glacier (till) or along the ice margin or grounding line (flowtills). Subglacial landforms include till plains and fluted till plains, drumlins and eskers. Ice-marginal landforms include one large end moraine, the Lac Seul Moraine (Prest, 1963) which contains deltas and subaqueous fans, and grounding line fans commonly referred to as DeGeer moraines. The Lac Seul Moraine is considered by some to be a very large grounding line fan produced during a catastrophic release of stored meltwater within the Laurentide Ice Sheet (Sharpe and Cowan, 1990).

Sedimentation into the glacial lake was dominated by density underflows as a result of density differences between the incoming sediment-charged meltwater and the lake water. In this setting, the distribution of fine-grained sediments is controlled by lake-bottom topography and elevation, with sediments being preferentially deposited in topographically low areas. Abandoned shoreline features, beaches, bars and spits of glacial Lake Agassiz are well developed along the Lac Seul Moraine and other isolated hills of ice-contact sediments. Several levels of this lake are recorded. Wave and current action in this lake has also produced large areas of bedrock outcrops, washed clean of any pre-existing glacial sediment. Many small wetlands occur in bedrock-dominated terrain and in areas of low relief, grounding line fans. Larger areas of wetlands occur within the broad plains underlain by glaciolacustrine fine-grained sediments.

3.0 METHODOLOGY

3.1 DEM GENERATION

Hydraulically conditioned digital elevation models (DEMs) were created for the entire area at the Provincial Geomatics Service Centre of the Ontario Ministry of Natural Resources (MNR). MNR used 1:50,000 NAD83 digital topographic maps with a contour interval of 10 m and grid cell resolution of 25 m to derive the DEMs. Vectors marking lakes and rivers, derived from the DEM, were used to geometically rectify the imagery used in this study to the Universal Transverse Mercator (UTM) projection.

The DEM generation is a two step process beginning with the creation of a continuous digital drainage network. The first step involves the creation of virtual water segments, vectors that connect stream arcs through the many lake polygons in the area, using primarily automated techniques followed by checking the created network to remove loops and breaks. Finally watershed discharge points are located and all arcs within each virtual watershed are aligned such that the flow is toward the discharge point. The second step includes the checking and editing of the contour information based on 1:50 000 scale digital National Topographic Series maps and combining it with the created drainage network. The software program ANUDEM is used for the DEM construction. ANUDEM uses elevation information, the drainage network and water polygons in the interpolation process which creates a higher quality representation of the land surface as a result of incorporating drainage enforcement into the DEM algorithm. The DEMs were processed for the entire area in four batches and the individual 1:100 000 scale tiles of the test areas clipped out subsequently.

In addition to interpreting the DEMs directly, several derived products were created to also aid in interpretation of landform, material-type, relief and drainage conditions. These included hillshaded DEMs, slope, aspect, and elevation range models. These derived products are produced using ArcInfo^{TM} and ArcView^{TM} software packages. Landsat 7 Extended Thematic Mapper (ETM) multispectral and panchromatic data, IRS-1C panchromatic and RADARSAT data were also used in the interpretation. Initial geological analysis was based on individual image maps of one degree of longitude and one-half degree of latitude. Image maps were created using each of the four sensor types. A method was then devised to combine the sensors with the shaded DEM data, and image maps of combined products (ETM multispectral + DEM, ETM panchromatic + DEM, IRS 1-C panchromatic + DEM, RADARSAT SAR + DEM), were also created. The color or black and white image maps were printed out at a scale of 1:100,000. The maps were used in the field and interpreted visually by integrating the field information.

3.2 CREATION OF IMAGE MAPS

Geometric correction was performed on each of the three optical datasets separately, as each dataset had a different pixel size. The Landsat 7 ETM multispectral data had a pixel size of 30 m; the ETM panchromatic data had a pixel size of 15 m; and the IRS-1C panchromatic data had a pixel size of 5.8 m. The data had been ordered from suppliers based on a NAD83 datum. For the optical data, the first step involved the collection of ground control points (GCPs) based on the drainage vectors provided with the DEM. GCPs were usually based on such features as the junction of two streams, the junction of a river and a lake or on very small features such as islands or lakes. An effort was made to obtain a network of GCPs that were as regularly spaced as possible throughout the image. As a new GCP was added to the GCP set, the residual, or RMS, error (total, x, y) for the GCP was displayed. Some of the points in the dataset were subsequently deleted or moved. GCP selection using the IRS 1-C 5.8 m resolution data was more difficult than with the TM data because the fine resolution of the imagery made it difficult to establish the exact location of a particular stream junction, lake junction or centre of an island or lake. The next step in the preprocessing of the optical data entailed the registration and projection based on a first-order cubic convolution resampling, using the ground control points. The resampled image retained the same pixel size as the raw image, but was rectified to the proper UTM zone and spatially registered to the vectors of the DEM.

The 25 m spatial resolution RADARSAT S2 data were orthorectified using GCPs based not only on the drainage vectors to establish planimetric locations, but also on elevation data derived from the DEM.

After the ETM, IRS-1C and RADARSAT images were geometrically corrected, they were enhanced (a linear contrast stretch was used for all of the images), then converted into individual images in map format. Each image was printed in color or in black and white at 1:100,000, with a scalebar, title and UTM coordinates, lat/long coordinates and a UTM grid. Several 3-band combinations of the Landsat TM data were compared, and a Band 4-5-7 composite image (as an R-G-B combination) was found to be the most useful for obtaining surficial geology information.

A shaded DEM can be obtained from the original DEM using GIS or image analysis software to simulate the effect of various sun azimuths and altitudes. For instance, one can reproduce the same illumination conditions that existed during the acquisition of an optical image. The sun azimuth and altitude, listed in the header of the optical image, can be used as inputs for the hill-shading routine. Several methods were investigated of combining the shaded DEM image with each of the geometrically corrected images. The method yielding the most visually effective results involved adding scaled versions of the DEM and the images together. The shaded DEM was first resampled to the spatial resolution of the satellite image. The 16-bit shaded DEM and the 16-bit RADARSAT SAR data were scaled to eight bits. If scaling must take place, a linear contrast stretch is applied at the same time as scaling to the DEM and/or satellite image. The linear stretch is based on the minimum and maximum values in the histogram of the DEM and the satellite image. If the satellite image has not already been enhanced at this point, a linear contrast stretch must be applied to the individual channels.

The satellite image and the shaded DEM (which are now contrast-stretched and displayed at a common number of bits and at the same spatial resolution) must be multiplied by scalar factors which sum to 1. For instance, a factor of .625 applied to the three TM bands and a factor of .375 applied to the shaded DEM were found to result in an effective combined image. After the multiplication, the grey levels of the TM bands thus ranged from 0 to 159 (0 to .625(255)) and the grey levels of the shaded DEM ranged from 0 to 96 (0 to .375 (255)). Then the scaled satellite image and the scaled, shaded DEM are added together to produce an enhanced satellite-DEM combination, which is then displayed. A further contrast stretch is applied if necessary to the combination image. In the case of the TM Band 4-5-7 color image, three new channels were produced (scaled TM 4 + scaled DEM; scaled TM5 + scaled DEM; and scaled TM7 + scaled DEM). The three new channels were displayed as red, green and blue and a new contrast stretch was applied to the combination and saved. The scalar factors of .625 (for satellite image) and .375 (for shaded DEM) were applied to all of the optical and SAR images in the enhancement described previously to create enhancements. The resulting satellite image-DEM combination is intended purely for display, not for quantitative image analysis. It effectively combines the qualities of the original satellite image but adds an exaggerated topographic component to the data, which is effective for displaying features such as hills, valleys, ridges and linear discontinuities. The satellite-DEM enhancements were then printed out as 1:100,000 black and white and color image maps and used as ancillary data, in combination with the previously-described satellite image maps, to plan fieldwork and to derive surficial geology information. The enhancement procedures are outlined in Figure 1.

4.0 DISCUSSION

Information on the various legend components: material, landform, topography and drainage, were derived from the interpretation of DEMs, their derivatives and remotely sensed imagery through the use of established landform/sediment relationships or models. The DEM and derivatives, such as hill-shaded DEM, slope, aspect and elevation range models in conjunction with Landsat 7, RADARSAT, and IRS-1C satellite images were used to produce 1:100,000 image-based terrain maps similar to the NOEGTS maps (Figure 4).

Analysis of the DEM, the derived hill-shade, slope and aspect maps aid in mapping the various landscape elements (Figure 2A to D). The hill-shaded DEM provides a general overview of the terrain (Figure 2B). Areas of glacial and glaciolacustrine sedimentation occur as smooth areas on this image; rock-dominated terrain has a very irregular appearance. The Lac Seul Moraine, for example, stands out as a dominant, linear topographic high. On the slope map (Figure 2C), the moraine has steep slopes on the proximal side and gentler slopes on the distal side. Ice-marginal deltas and subaqueous fans have their own characteristic shape but slope relationships are similar to that of the end moraine. The granular nature of the material associated with these landforms (predominantly ice-contact stratified sediments) and their positive relief makes these sites very well drained and allows them to support the growth of jack pine (*Pinus banksiana*).

Glaciolacustrine sediments and subglacially-deposited till form plains which are recognizable on the DEM and slope maps. In the Trout Lake area, plains of lower elevation tend to be underlain by glaciolacustrine materials and plains at higher elevations are commonly underlain by till. Only a few of the larger generally low-relief linear grounding line fans are recognizable on the DEM, however, these forms can be seen as promontories and/or linear islands within the area lakes and as linear tonal variations on the TM and IRS images.

Areas of irregular topography and short complex slopes are either bedrock-dominated areas or stagnant ice deposits (small fans and kettles). Separation of these two area types as well as several of the others discussed above can be done in association with the remotely sensed images based on forest variability.

The relief component of the legend can be derived using a 30x30 pixel filtering technique of the range in elevation values in the DEM. The resultant data can then be classed into the low (<15m; blue), moderate (>15m to <60m; yellow) and high (>60m; red) relief classes used in the NOEGTS maps (Figure 2D). Figures 3 A to D show the LANDSAT 7 image bands 4, 5 and 7 (Fig. 3A) integrated with the hill-shaded DEM (Fig. 3B), the IRS image (Fig 3C), and the IRS image plus DEM (Fig. 3D) of the Trout Lake area.

An engineering terrain interpretation of a smaller area is provided in Figure 4. Examples of most of the terrain units in the region are found in this Figure. The engineering terrain interpretation used materials, landforms, topography and drainage as the main classification elements. Landforms and topography are provided by the DEM and SAR images, whereas materials and drainage/moisture are provided by the remotely sensed information. There is a high geobotanical correlation between the well drained sand plains and gravel and the dense jack pine forest cover; as such, these areas are easily identifiable terrain units (sgME/MD). Other terrain units such as organic terrains (pOT), rock knobs (RN) flat lake plain ((LP) and hummocky ground moraine (MG) are easily interpreted from remotely sensed data. The most useful image sources for terrain mapping are the Landsat/DEM composite and the IRS/DEM composite. Although the high resolution of the IRS does provide the details for terrain mapping at 1:50 000, we have decided to use the Landsat /DEM composite as an image base for cost considerations, suitable for terrain mapping at 1:100000.

The DEM and the DEM/ TM composites (Figures 2 and 3) provide insights on the regional glacial history. For instance, the Lac Seul Moraine extends diagonally through the center of the Figures 2 and 3. A large ice-marginal delta, part of the Lac Seul Moraine (sgME/MD), is located in the southeast corner of the image. The delta provides information on the level of glacial Lake Agassiz during moraine formation (locally approximately 470m a.s.l.). Several lower shorelines of this lake can also be seen ringing the delta and moraine. At the northwest corner of the image an example of a subaqueous fan occurs along the morainic ridge.

Southwest of the moraine, the terrain consists of bedrock-controlled hills (RN) with varying thickness of till cover separated by low relief plains underlain by glaciolacustrine fine-grained sediments (LP). In places the cover of till is thick enough to subdue the bedrock topography and is then mapped as till. Northeast of the Lac Seul Moraine the terrain is dominated by smaller ice-marginal forms composed of sand and gravel as well as fields of DeGeer moraines composed of till, ice-contact gravel and sand or both (MG).

5.0 CONCLUSIONS

This study has shown that TM combined with DEM data can provide a standardized satellite image base map to interpret and overlay engineering terrain units at a scale of 1: 100,000 for large areas of the boreal forest regions in northern Canada. This method will result in considerable savings in time and cost when compared to traditional air photo mapping methods.

6.0 REFERENCES

D.F. Graham and D.R. Grant, "Airborne SAR for Surficial Geological Mapping", *Canadian Journal of Remote Sensing***,** Vol. 20, No. 3., pp. 319-323, 1994.

V.K. Prest, "Red Lake–Lansdowne House Area, Northwestern Ontario, Surficial Geology"*, Geological Survey of Canada, Paper 63-6*, 23p, 1963.

D.R. Sharpe and W.R. Cowan, "Moraine Formation in Northwestern Ontario: Product of Subglacial Fluvial and Glaciolacustrine Sedimentation," *Canadian Journal of Earth Sciences***,** 27, pp. 1478-1489, 1990.

V.H Singhroy, F.M. Kenny and P.J. Barnett, "Imagery for Quaternary Geological Mapping in Glaciated Terrains", *Canadian Journal of Remote Sensing*, Vol. 18, No. 2, pp. 112-117, 1992.

V.H. Singhroy, R. Slaney, P. Lowman, J. Harris and W. Moon, "RADARSAT and Radar Geology in Canada", *Canadian Journal of Remote Sensing*, Vol. 19, No. 4, pp. 338-351, 1993.

V.H. Singhroy, "Environmental and Geological Site Characterization in Vegetated Areas: Image Enhancement Guidelines", *Remote Sensing and GIS: Applications and Standards,* ASTM Special Technical Publication #1279, eds. V. Singhroy, D. Nebert, and A. Johnson, American Society for Testing and Materials. pp.5-17, 1996.

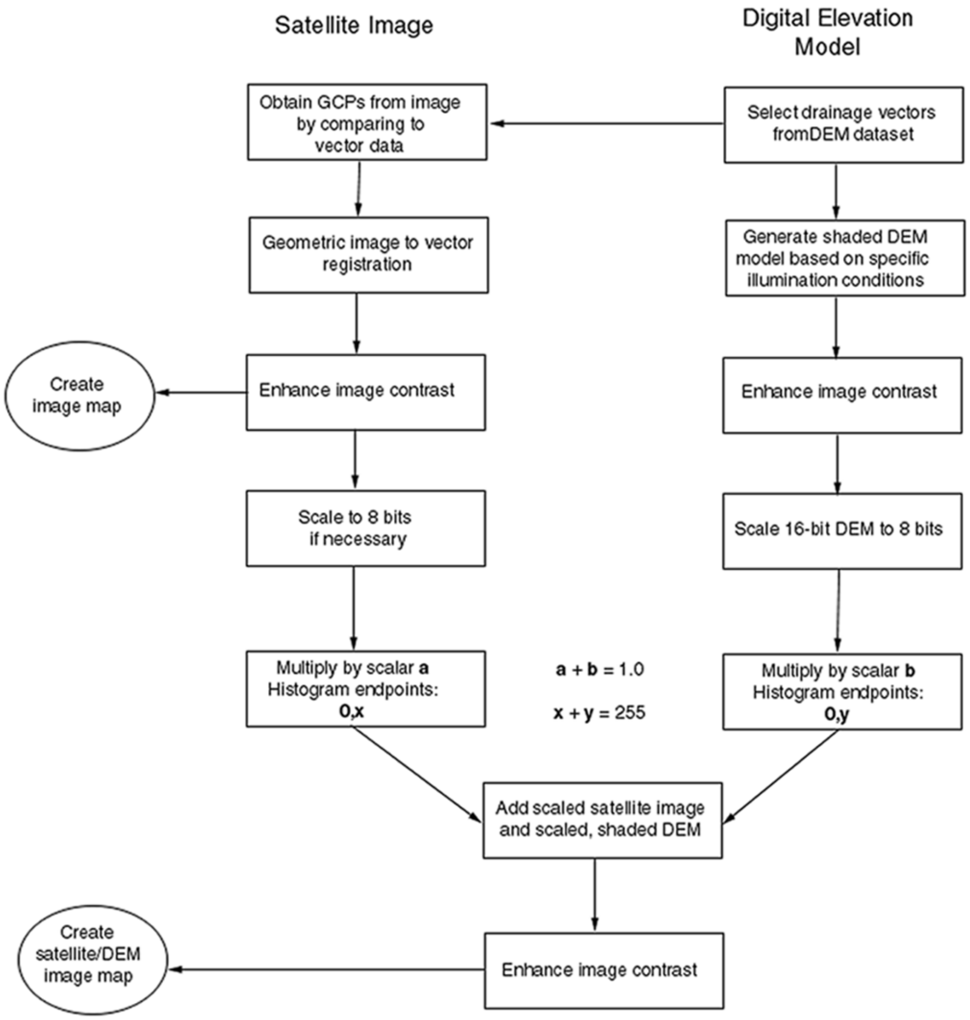

Figure 1. Flowchart outlining the creation of a merged satellite/DEM image map

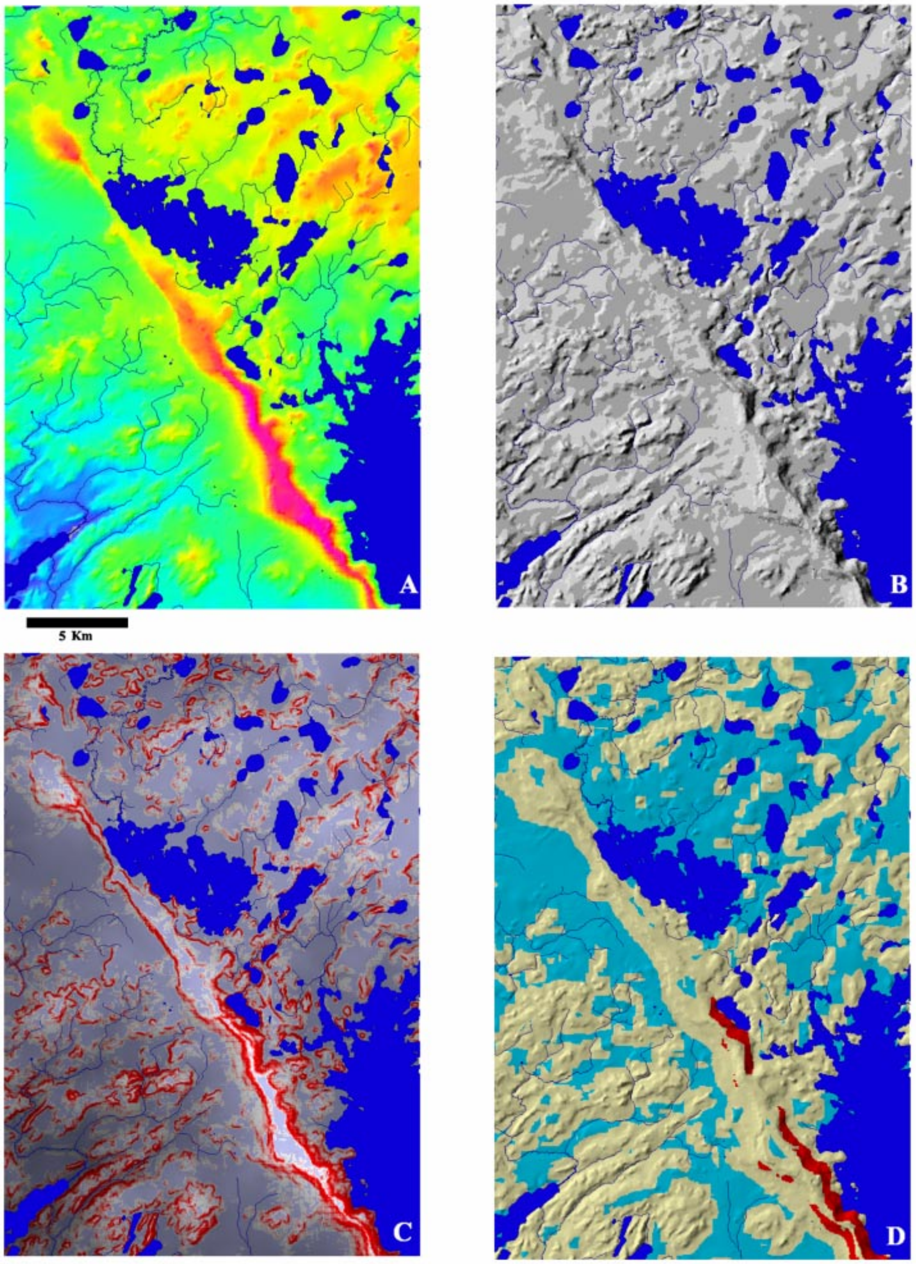

Figure 2. Examples of the Digital Elevation Model and derivative maps used in the interpretation of terrain units in part of the Trout Lake area: A – DEM, B – hill-shaded DEM, C – slope map with DEM as intensity on the colour and D – elevation range map with hill-shade as intensity on the colour.

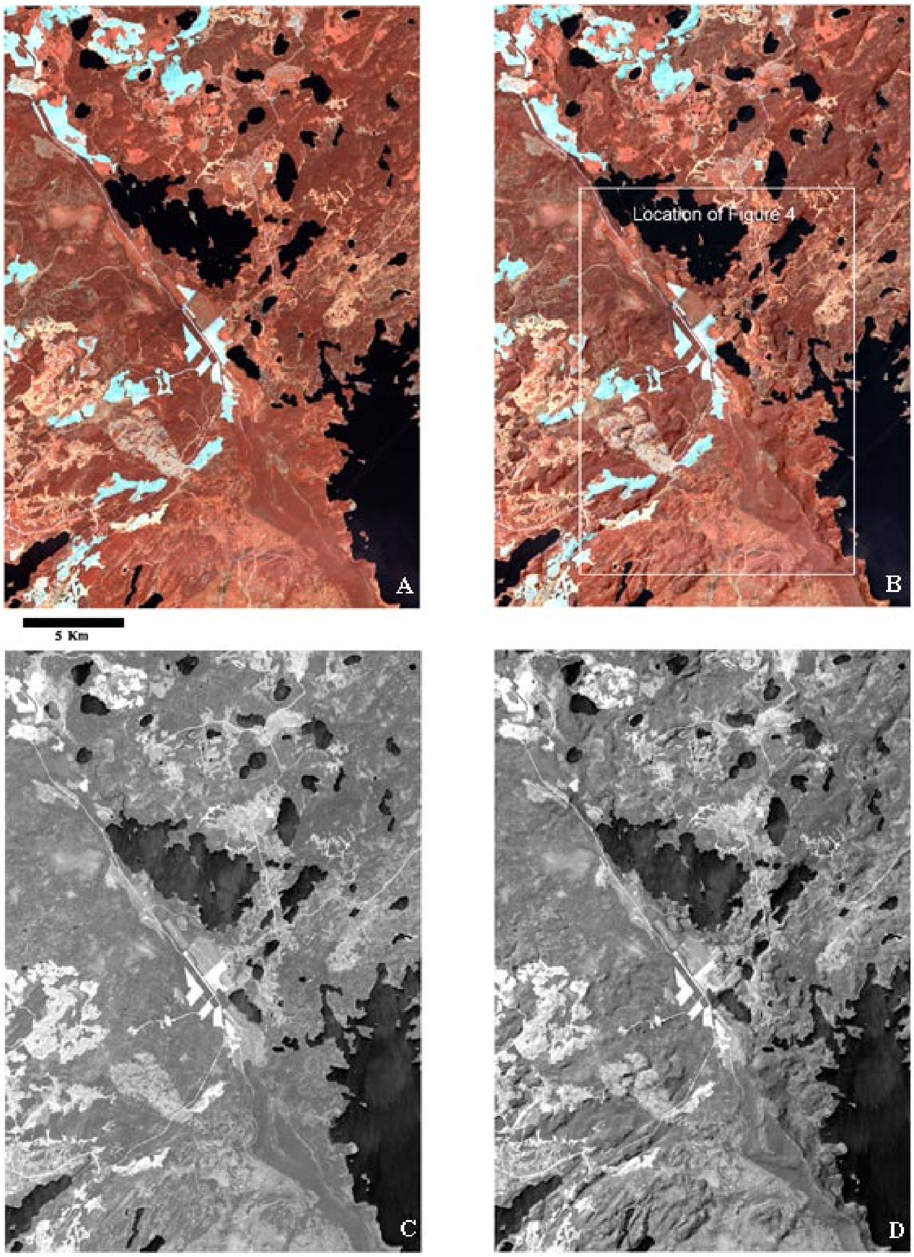

Figure 3. Examples of imagery and merged image/DEM products used to interpret terrain units. A – TM bands 4, 5 and 7. B – TM bands 4, 5 and 7 merged with a hill-shaded DEM. C – IRS-1c panchromatic band. D – IRS-1c panchromatic band merged with a hill-shaded DEM.

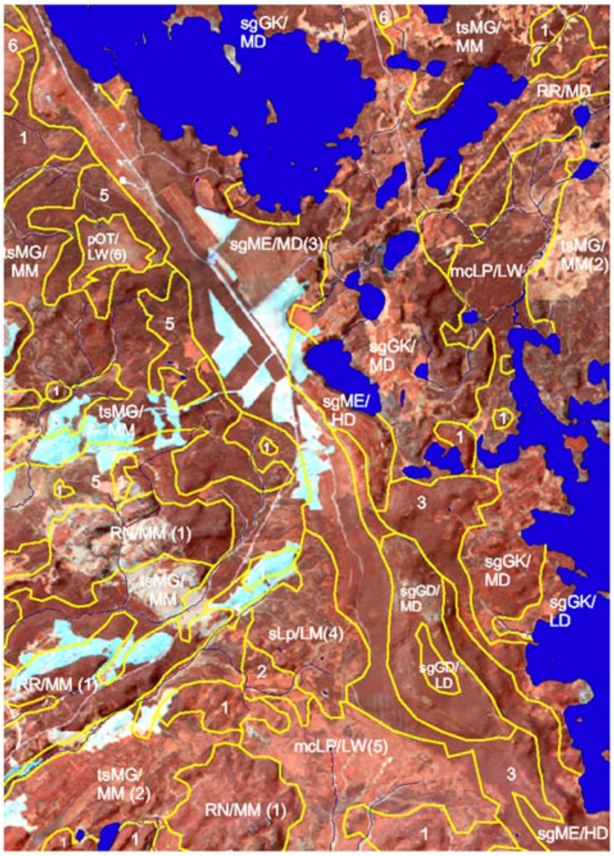

Figure 4. A subarea of the Landsat 4-5-7/DEM merged image shown in Figures 2 and 3 (boundaries are outlined in Figure 3B) displaying engineering terrain units interpreted from remotely sensed imagery, the DEM and DEM derivatives. Terrain unit classification is based on four components: materials, landform, relief and moisture. As an example, the unit classified as sgME/MD (labelled above as (3)) has four components; sg indicates that it is composed of the materials sand and gravel; ME indicates that the landform it comprises is an end moraine; M (following the slash) indicates that the relief is moderate; and D indicates that moisture conditions are dry. A key is provided below.

Materials	Landform	Relief	Drainage
sg– sand and gravel sL- lacustrine silt ts – silty till p - peat	ME – end moraine LP – lake plain GK – glaciofluvial kame MG – ground moraine	L – low M – moderate H – high	W – wet M – moist D - dry