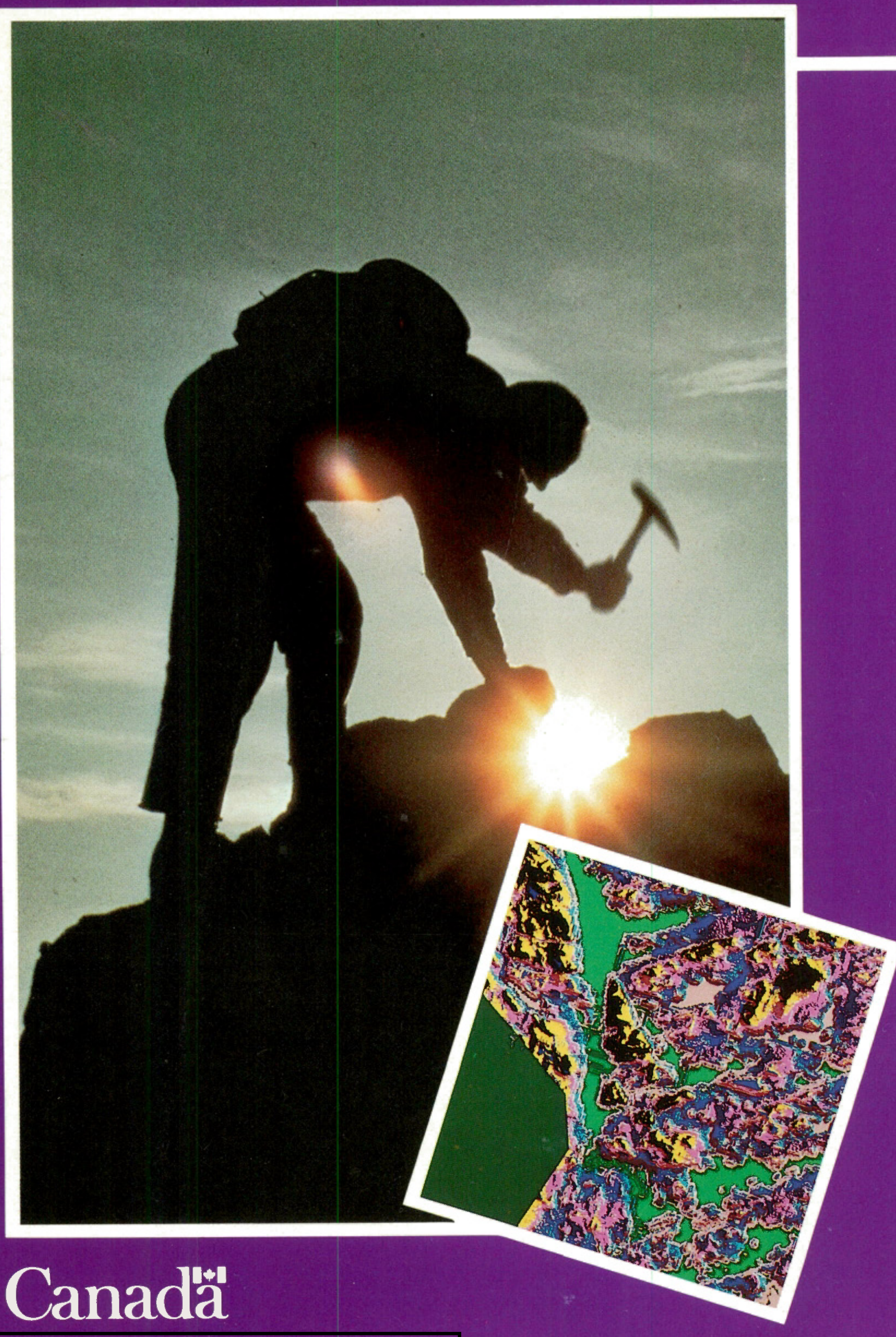
REMOTE SENSING FOR GEOLOGISTS



Canada

REMOTE SENSING FOR GEOLOGISTS

From hundreds of kilometres above the earth's surface, remote sensing satellites have a panoramic view of the world below. They circle the globe capturing images with cameralike devices, and then relay the images back to Earth for analysis and interpretation.

These images of the earth's surface can provide geologists with important clues about the structural and lithological patterns beneath. More and more geologists are using remote sensing to obtain information on:

— regional geology
— local structure
— lithology
— physiography
— overburden
— vegetation

Remote sensing is being used increasingly to help develop and confirm geological hypotheses, to add to existing data, and to enhance conventional research and analysis techniques.

Geologists have long relied on photographs taken from aircraft to augment ground-level surveys. In fact, Canadians pioneered the use of extensive aerial photographic coverage for surveys and mapping. Snapshots from the air have provided an important data source for earth scientists, and aerial photography is now a standard data set used for most geological mapping activities.

However, aircraft imaging creates a mosaic of photographs that vary in scale, angle of view and land cover, depending on time of collection. These limitations, along with the imprecise boundaries formed by piecing many aerial photographs together, led geologists to look for an improved remote sensing source that would deliver a 'bigger picture'.

Satellites provide this wider view. They capture images of the earth's surface millions of hectares in size, which add broader spatial perspective while providing significant detail for geological mapping and exploration. With satellites geologists can collect certain types of information more quickly and more cheaply than with conventional techniques. By starting with the large overview provided by satellite imagery, geologists can systematically focus on specific areas for more intensive investigation. Satellite imagery analyses contribute greatly to regional-scale exploration reconnaissance.

In Canada, most remote sensing satellite data used by geologists come from the U.S. LANDSAT and, more recently, the French SPOT series of satellites.

LANDSAT

The first of five LANDSAT satellites was launched by the United States in 1972. Each one has carried electro-optical sensors that record dramatic and revealing images of Earth. Each satellite was designed to travel in an almost perfectly circular, near-polar orbit, passing over the daytime side of the planet several times daily. The orbit shifts progressively westward so that the entire surface of the earth can be imaged in 16 days.

Two sensors aboard LANDSAT are currently providing such data — the Multispectral Scanner (MSS) and the Thematic Mapper (TM). These cameralike devices divide the images into tiny picture elements (pixels) and measure the brightness of each pixel. The sensors capture light reflected from the green and red, and the near, shortwave and thermal infrared parts of the electromagnetic spectrum. The satellite makes available for analysis large amounts of data about surface features, including vegetation. The data are transmitted to Earth for transformation into the image products that are interpreted by the geologists and other resource specialists.

Multispectral Scanner

MSS images can provide Canadian geologists with useful information on regional geobotany, thanks to the sensor's ability to detect subtle variations in vegetation cover. This information, when supported with field investigations, can yield reliable information on physiography, structural geology and lithology in a regional context.

Similarly, because of the strong association between vegetation and various glacial landforms, MSS also assists geologists in mapping Quaternary geology and in assessing aggregate resources. Many geologists now consult images for terrain mapping and the assessment of land cover, both important prerequisites for route and site planning for large development projects.

Each MSS image covers a 185 km × 185 km area of the earth's surface and produces images in four spectral bands: one in the green portion of the spectrum, another in the red, and two in the near or reflected infrared.

Table 1 LANDSAT Sensors

Multispectral Scanner

Swath Width	185 km
Spatial Resolution	80 m
Spectral Bands	
1	0.50 - 0.60 micrometre *(green)*
2	0.60 - 0.70 micrometre *(red)*
3	0.70 - 0.80 micrometre *(near-infrared)*
4	0.80 - 1.10 micrometres *(near-infrared)*
Radiometric Resolution	64 gray levels

Thematic Mapper

Swath Width	185 km
Spatial Resolution	30 m
Spectral Bands	
1	0.45 - 0.52 micrometre *(blue)*
2	0.52 - .60 micrometre *(green)*
3	0.63 - 0.69 micrometre *(red)*
4	0.76 - 0.90 micrometre *(near-infrared)*
5	1.55 - 1.75 micrometres *(shortwave infrared or SWIR)*
6	10.5 - 12.5 micrometres *(thermal infrared, resolution: 120 m)*
7	2.08 - 2.35 micrometres *(shortwave infrared or SWIR)*
Radiometric Resolution	256 gray levels

The TM spectral bands are normally used in combinations (see Table 5). However, a description of each of the TM bands is given in Table 4 for the reader's general information.

Conducting image analysis on a PC-based image analysis system.

Thematic Mapper

In 1984 TM data became routinely available in Canada. TM images are available in more spectral bands, with finer spatial resolution than that of earlier sensors.

TM images, like the ones produced by the MSS, represent a 185 km × 185 km sector of the earth's surface. The Thematic Mapper, however, can define features as small as 30 m across in the visible and near-infrared bands, and 120 m across in the thermal bands. TM imagery, therefore, permits the resolution of smaller structural and terrain features than does MSS imagery. This is particularly helpful in defining geologically significant associations between vegetation and landforms. Because much of Canada's north is heavily forested and inaccessible, the potential contribution of TM analysis to map revision and exploration is very great. With the improved spatial resolution of TM, analyses can be carried out at scales that are compatible with the sizes of common claim blocks in the exploration industry.

The Thematic Mapper produces images in seven spectral bands: one from each of the blue, green and red regions of the spectrum; one from the near-infrared region; two in the short-wave infrared region; and one in the thermal infrared region. Geologists can use different combinations of these bands to highlight various elements of the earth's surface. For example, band 2 displayed in blue, band 3 in green and band 4 in red — a combination called color infrared — distinguishes between deciduous and coniferous forests, and also between roads and rivers.

Images produced from the short-wave infrared region of the spectrum are also of interest to geologists. In the 2.2 micron wavelength, for example, the TM sensor can detect reflectance from hydrothermally altered rock overlying mineral deposits, and at a wavelength of 1.65 microns, reflectance from drying foliage indicates how much water remains in vegetation.

SPOT

Launched by France in 1986, SPOT (Système pour l'observation de la terre) also follows a near-polar orbit. Two identical sensors on board, known as HRVs (High Resolution Visible), produce multispectral images in bands similar to LANDSAT's MSS green, red and near-infrared bands, but with a higher resolution of 20 m. Alternatively, the sensors can provide black and white images with a high 10 m resolution. The field of view of each sensor is, however, limited to a 60 km swath.

In addition, using an on-board mirror system, the SPOT sensors can produce images from several different angles or perspectives and thereby provide geologists with stereo images that can be processed to provide topographic information.

Table 2 SPOT Sensors

	PLA	MLA
Swath Width	60 or 117 km	60 or 117 km
Spatial Resolution	10 m	20 m
Spectral Bands	0.51 - 0.73 micrometre	0.50 - 0.59 micrometre (green) 0.61 - 0.68 micrometre (red) 0.79 - 0.89 micrometre (near-infrared)
Radiometric Resolution	64 gray levels	256 gray levels

The normal mode of operation has both sensors pointing directly under the satellite. The choice among multispectral, high-resolution (black and white), or stereo view must be requested in advance.

Data Format and Use

Data from both scanners are available from CCRS in either photographic or digital form. Because digital information is captured on computer-compatible tapes, the user must have access to a digital analysis system. Such a system gives great flexibility in data manipulation and interpretation, including image enhancements, multidate image registration, registration with digital maps, and digital image classification.

In photographic form, images are available as either prints or transparencies (see Table 3). Prints are available at larger scales, which are useful for overviews that can be discussed and studied in group settings.

Because transparencies provide better photographic quality, detailed information can more easily be extracted when they are enlarged by projection. They are available from CCRS in smaller scales (1:1 000 000 or 1:500 000 for the Multispectral Scanner and 1:500 000 or 1:250 000 for the Thematic Mapper) and generally must be projected on enlarging equipment for interpretation. With such equipment, transparencies may be enlarged for study to approximately 1:50 000 in the case of Multispectral Scanner images, and 1:15 000 for Thematic Mapper images. (Further enlargement, even by projection, generally makes images too blurry for easy interpretation.)

Table 3 Satellite Data Products

	MSS	TM	SPOT
Transparencies			
	1:1 000 000 1:500 000	1:1 000 000 1:500 000 1:250 000	1:500 000 1:250 000
Prints			
	1:1 000 000 1:500 000 1:250 000	1:1 000 000 1:500 000 1:250 000 1:125 000 1:50 000	1:500 000 1:250 000 1:125 000
Computer Tape			
	System corrected, 4 bands	System corrected, 1 to 7 bands	System corrected, 1 band (Pan) or 3 bands (MLA)
	Geocoded 4 NTS 1:50 000 map sheets, 4 bands	Geocoded 4 NTS 1:50 000 map sheets, 7 bands or 3 bands	Geocoded 1 NTS 1:50 000 map sheet

Prices and method of ordering can be obtained by contacting the User Assistance and Marketing Unit of CCRS.

Collecting and analyzing the data

The Canada Centre for Remote Sensing (CCRS) collects data from the SPOT and LANDSAT satellite at its ground stations in Gatineau in Quebec, and Prince Albert in Saskatchewan. The data are available in photographic or digital form. Satellite data from both LANDSAT and SPOT sensors can be requested in a form geometrically compatible with National Topographic System standard maps.

Image data can also be obtained on computer tape and analyzed with the help of a digital image analysis system. Such computer-aided image analysis makes it possible to enhance and classify images, as well as to perform multi-image registration.

To help geologists use computer-aided methods more effectively, CCRS, with cooperation from Canadian mining companies, has designed the Geological Analysis Aid Package (GAAP), a teaching model for computer-aided image analysis. Geared for geologists new to remote sensing imagery and computers, the methodology package introduces textural and lineament analysis aids, and provides guidelines for the production of color-enhanced images for easier visual interpretation. As users become more comfortable with the computer as an analysis tool, they can use GAAP to develop methodologies for specific lithological, structural, overburden and vegetation scenarios.

A view to the future

Canada's dramatic variations in geology and climate, coupled with heavy vegetation and transported overburden, present a major challenge for geological interpretation. Satellite imagery, with its associated computer technology, is becoming increasingly recognized as a valuable surveying, prospecting and analysis tool for geologists.

Already, models for interpreting satellite data, such as GAAP, have been implemented on personal computer sytems. Devices using computer-based geographical information systems will soon be even more interactive. With these devices, integrated data sets, including remote sensing data as well as data from conventional sources such as aeromagnetic, seismic or geochemical surveys, will be easier to analyze. Eventually, knowledge-based systems using elements of artificial intelligence will enhance geologists' powers of observation, experience and knowledge of conventional techniques. The result will be faster, more informed and more reliable decision making.

Table 4 TM Bands for Geological Applications

Single TM Bands	Micrometres	Spectral Region	Applications
1	0.45 – 0.52	Blue	Not recommended for use alone because of low contrast and sensitivity to haze.
2	0.52 – 0.57	Green	Not recommended for use alone because of low contrast and sensitivity to haze.
3	0.63 – 0.69	Red	Best for showing roads and other non-vegetated features such as outcrop and areas of exposed aggregate. Not particularly useful for identifying waterbodies or vegetation-geological associations.
4	0.76 – 0.90	Near-infrared	Best band for delineation of coniferous-deciduous forest cover variations. Vegetation relationships (regional geobotanical associations) are often indicative of changes in lithological, structural or surficial geological environment. Also useful for delineation of waterbodies.
5	1.55 – 1.75	Short-wave infrared (SWIR)	Perhaps the best single-band image for geological interpretation in vegetated terrains. Roads and outcrops are visible in contrast to surrounding forest cover. Waterbodies and variations in forest composition are visible. The band has good haze penetration and generally good overall contrast.
6	10.8 – 12.5	Thermal (emissive) infrared	This spectral band responds to the thermal (heat) radiation emitted by the target. The spatial resolution of this band (120 m) is, however, lower than that for the other bands (30 m). This band presents some difficulties for multispectral analysis or band combination because of the lower resolution. The band offers some potential in geothermal and hydrogeological applications.
7	2.08 – 2.35	Short-wave infrared (SWIR)	This is another reflective IR band (like band 5) but has superior haze penetration. Image quality, however, is generally poorer than band 5 since band 7 has a lower signal-to-noise ratio. In nonvegetated terrain it may be useful for detecting clay minerals (alteration) due to absorption in these wavelengths.

Table 5 TM Band Combinations

Combination	Displayed Color	Characteristics/Results
TM 1 TM 2 TM 3	Blue Green Red	Approximately natural color. Useful for display purposes if the audience is unfamiliar with false-color presentations but has far less geological information than the false-color presentations. This imagery format is *not* recommended for winter or midsummer. Fall or spring data may be usefully displayed by this combination.
TM 2 TM 3 TM 4	Blue Green Red (false-color infrared)	This is the same color rendition as color infrared film and the familiar LANDSAT MSS combination of bands 4, 5 and 7. It is good for all-round use by persons already familiar with color infrared. It shows forest cover variations, roads, outcrops, waterbodies and burns. It also penetrates haze.
TM 3 TM 4 TM 5	Blue Green Red	This combination, called RIS 1 for red-infrared-SWIR 1, is still in the research stage. It is yielding encouraging results in forested Shield terrain. Sensitivity to forest type, stand density and soil moisture yields very useful imagery.

More and more geologists are adding remote sensing imagery to the methods they rely on for collecting and analyzing earth science data. To find out more about how satellite images could help in your geological research and exploration practices, please contact:

User Assistance and Industrial
Liaison Unit
Canada Centre for Remote Sensing
Energy, Mines and Resources Canada
Ottawa, Ontario
K1A 0Y7 Phone: (613) 952-2717

Satellite Data in Action: Geological Demonstration Projects

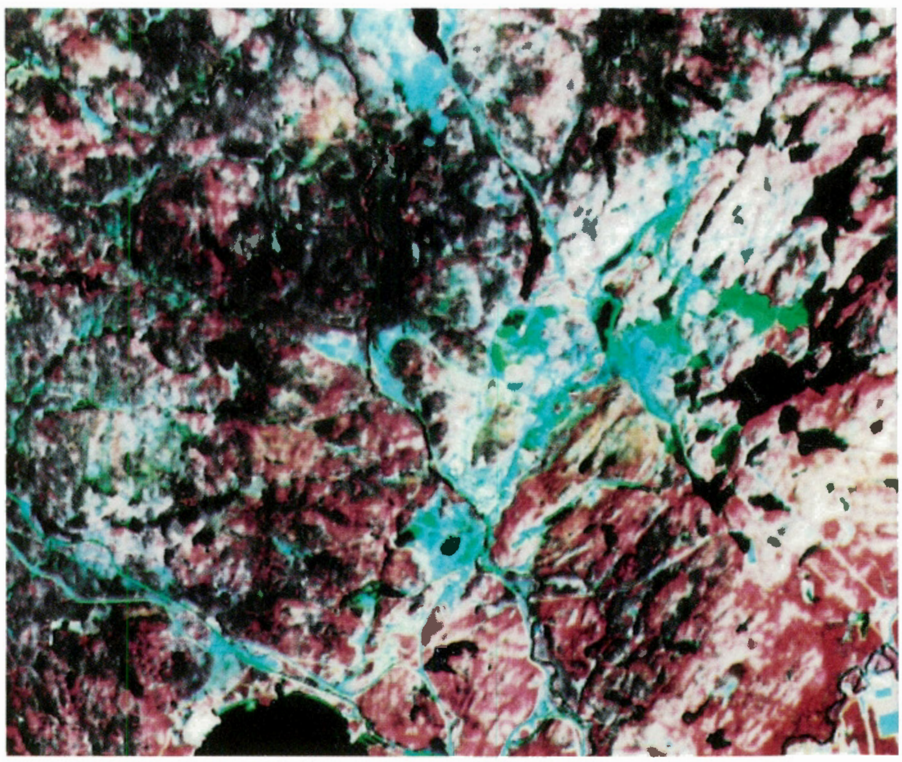
A series of demonstration projects, organized by the Canada Centre for Remote Sensing, is showing geologists how satellite data can complement their exploration and mapping techniques. The projects illustrate a variety of geological conditions and problems, and they present a set of circumstances typical of larger areas and broader geological conditions. Methodologies have been designed to reflect operational needs and capabilities of geologists in the industry. Demonstration projects are currently under way throughout Canada and in Cyprus, and the list of geological demonstration sites will continue to grow.

Sudbury, Ontario

Data from LANDSAT's Thematic Mapper (TM) in the Sudbury Basin of northern Ontario have helped geologists recognize and understand the interrelationships among vegetation, physiography, bedrock and surficial geology of the test area around the Levack mine. In a study to demonstrate the nature and importance of regional geobotanical information in satellite images, geologists confirmed that analysis of vegetation characteristics could provide a reliable source of geological information. Spectral patterns in TM imagery have been shown to correspond to changes in lithology, as well as in structural and surficial geology.

In making comparisons, the scientists found that the distribution of tree species and their growth habits related to lithological and structural boundaries, and even more directly to the type and depth of unconsolidated material. In turn, the bedrock topography influenced where the deposits occurred. These relationships are defined, and aid in the interpretation of the imagery. Geologists who worked on the project have said that as they gained experience the LANDSAT-derived data proved more uniformly reliable for their purposes than even the published surficial geological maps.

The Canada Centre for Remote Sensing receives SPOT data for eastern North America at its Gatineau, Quebec receiving station.



TM bands 3, 4 and 5 of the Levack Study area, Sudbury. The Levack mine appears blue, deciduous trees red, and conifers dark green. Water is black.

Gatineau, Quebec

In the Gatineau Hills north of Ottawa, the structural geological information content of TM imagery is being assessed. Satellite images of the densely vegetated terrain are providing useful information about structural geology in this area.

Analysis of LANDSAT Thematic Mapper data reveals relationships between geological structures and the vegetation cover. Characteristics of the vegetation, such as species mix, crown closure, understory and ground cover, relate directly to known and mappable features of the region's structural geology, according to the geologists involved in the study.

The satellite images help geologists interpret the structure of this densely covered area typical of large sections of the Canadian Shield. Topographic maps and field studies confirm the structures. LANDSAT data present a good vegetation picture, according to the geologists involved, which has turned out to be an excellent structural indicator under these conditions.

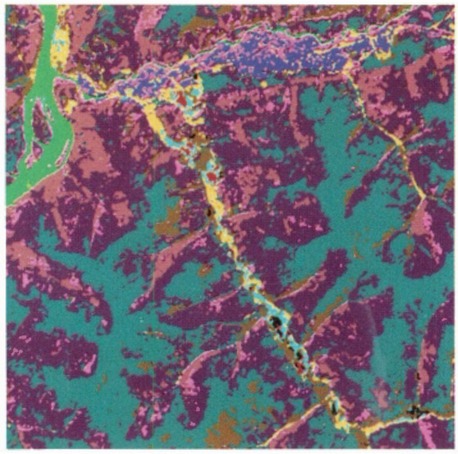
Enhancement of MSS bands 4, 5 and 7 over the Gatineau Hills, Quebec. Structural patterns related to faults and fractures in the Shield rocks are apparent in comparison with the flat agricultural lands of the St. Lawrence Lowlands.

Dawson, Yukon

Outside Dawson City, Yukon, world famous as the heart of the Klondike gold rush, satellite imagery is helping biologists and geologists monitor the regrowth of vegetation on the extensive tailings left by decades of continuous placer mining. The extent of vegetation regrowth after intensive mining is environmentally and historically important. Using LANDSAT TM imagery, geologists and botanists have begun to analyze and understand factors controlling regrowth in this area.

Preliminary evidence suggests, for example, that the material mined and the mining method — not the age of the mine operations — are the most significant factors controlling regrowth. Topography and related microclimatic effects on permafrost are also significant factors.

Together, biologists and geologists can now produce a vegetation regrowth map, which they say will be useful for environmental monitoring and stabilization. Similar geobotanical techniques are proving helpful to prospectors in this still-active gold-producing area.

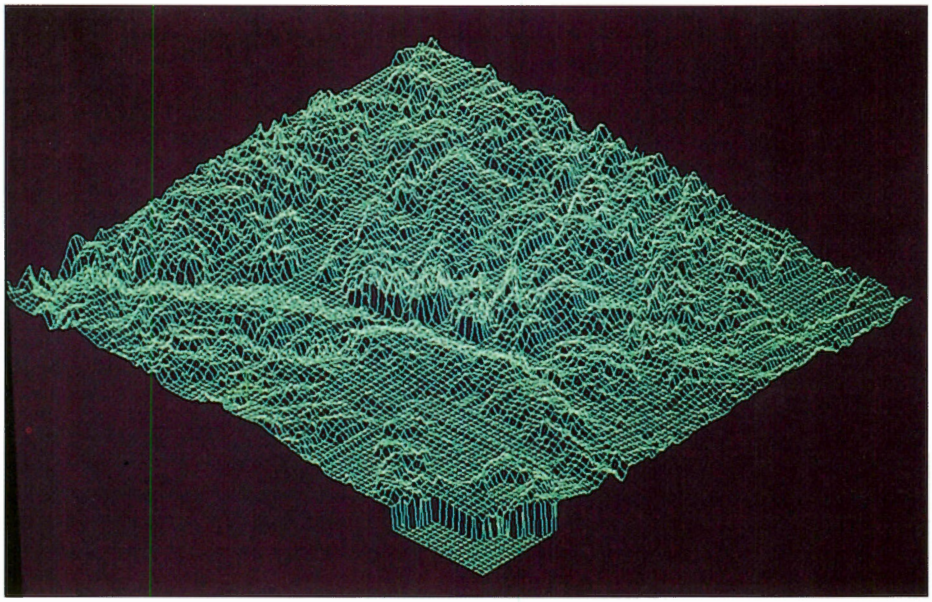


Classification of placer mine tailings and surrounding vegetation communities, derived from LANDSAT TM data. Dawson City is in the top left corner. The image centres on Bonanza Creek, which flows into the Klondike River and finally the Yukon River by Dawson City.

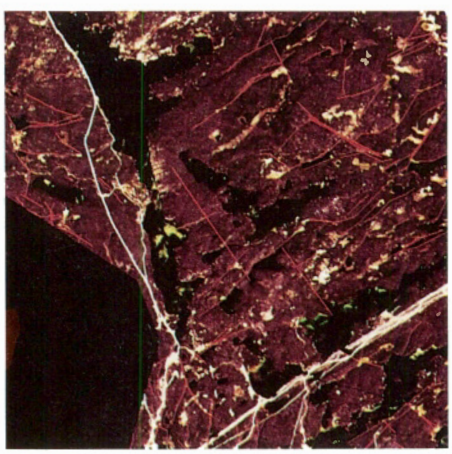
Mazinaw Lake, Ontario

Geologists working in the Grenville Province of the Canadian Shield have used a personal computer to integrate LANDSAT Thematic Mapper imagery with a digital terrain model. The test site, under mixed forest cover, is about 75 km west of Ottawa. This work was undertaken to help scientists evaluate how much lithology, structure and topography influence vegetation, and to demonstrate the practical value of low-cost image analysis systems.

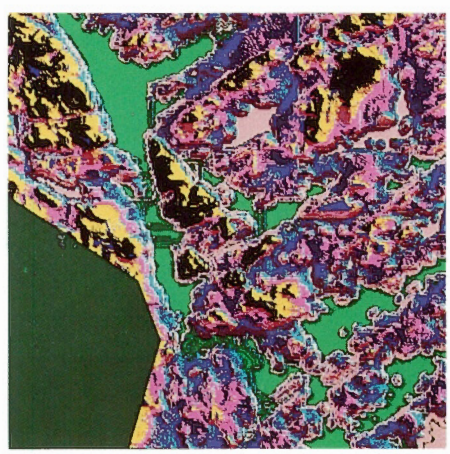
In the preliminary stages of this demonstration, digital image analysis, supported by field investigations, indicated recognizable qualitative relationships between vegetation and geology. The full integration of a digital terrain model gives researchers an opportunity to quantify and explain these relationships. Using the current results, geologists can identify and document several geological controls on vegetation.



Digital terrain model of the Mazinaw Lake study area, Ontario. The terrain is vertically exaggerated for ease of interpretation. View is from the southwest.



Structural lineament interpretation over the Mazinaw study area.



Classification of vegetation communities in the Mazinaw study area based on detailed ground information.

Massif Troodos, à Chypre

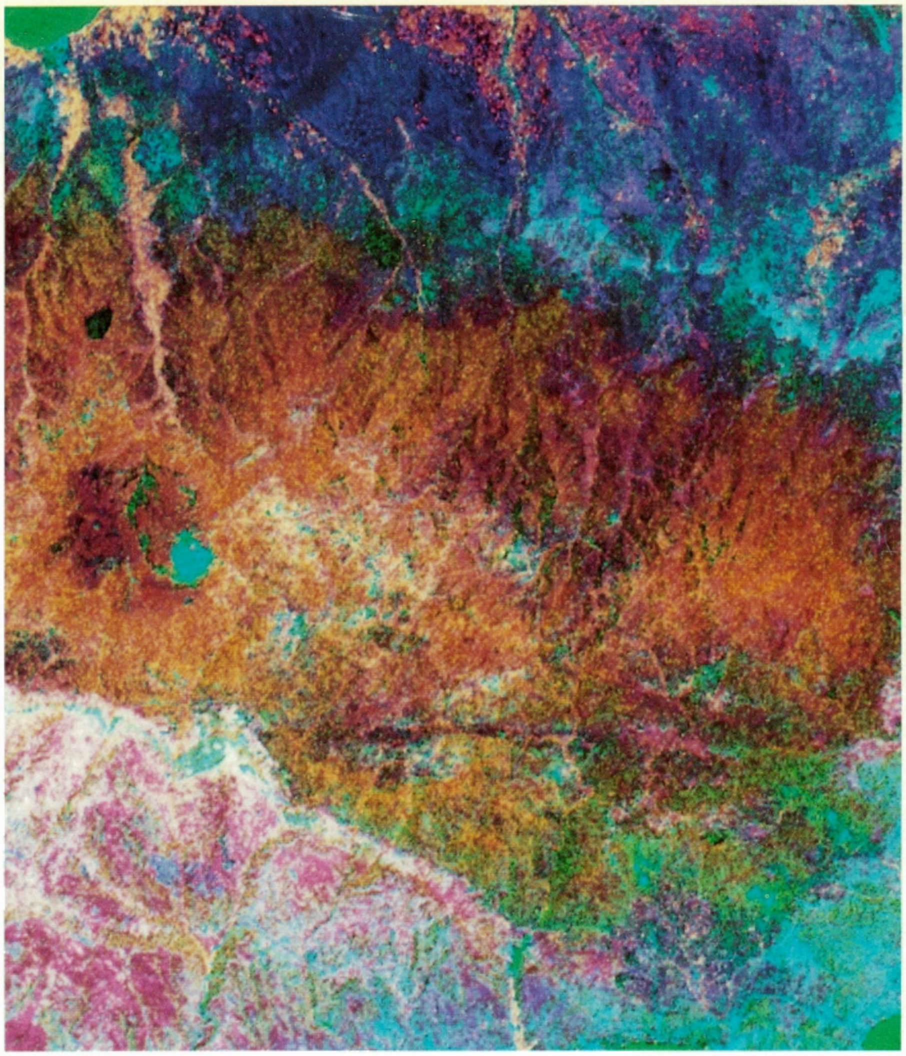
LANDSAT Multispectral Scanner (MSS) imagery has yielded important information for mapping regional physiography, lithology and structure of the Troodos Massif complex in Cyprus. The Troodos Massif is the most widely recognized ophiolite complex in the world, although its origins are still debated. The mines within the complex are major producers of copper and zinc.

An international team of geologists, working with satellite data from the area, found that LANDSAT imagery defined major physiographic regions of Cyprus very well. In particular, the Troodos ophiolite complex was readily separable from surrounding sedimentary beds. With textural information in the LANDSAT images, the spatial boundaries between the Troodos Massif and nearby Kyrenia range could be clearly defined. Important and characteristic lithological boundaries within the complex were also mapped with the aid of LANDSAT data.

The NE-SW lineament trend mapped from the images provided evidence of possible fracture zones and faulting in the area, supporting existing evidence of the tectonic evolution of the Troodos from rifting.

Geologists reported that digital image analysis of the LANDSAT MSS imagery provided valuable geological information about the structure and lithology of the area. The information not only confirms, but extends, interpretations derived from conventional methods, at very little additional cost. This application is one of several cooperative overseas tests that demonstrate how important it is to consult satellite imagery as part of regional geological investigations in environments around the world for which conventional geological data are scarce.

Aussi disponible en français



Principal component enhancement of Cyprus LANDSAT MSS full scene. The enhancement emphasizes the general physiographic divisions of the island.

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Cover photo:
Image indicating terrain influences on regional vegetation patterns.