DETECTION AND MAPPING OF REGIONAL-SCALE LINEAMENTS USING NOAA AVHRR SATELLITE IMAGERY

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INTRODUCTION

Satellite remote sensing technology has played an increasingly large role in the search for mineral resources over the past two decades (*e.g.*, Goetz *et al.*, 1983). This has been primarily through the use of Landsat Multispectral Scanner (MSS) imagery and, more recently, Landsat Thematic Mapper (TM) imagery. The MSS scans in four spectral regions with a ground resolution of 80 metres, whereas the TM scans in seven spectral regions and has 30-metre ground resolution. These two types of imagery have provided geologists with a valuable tool for investigating surface materials and lineaments. Many studies have shown that though satellite data is generally not successful at locating specific targets for mineral exploration, it is a valuable reconnaissance tool and in many cases is an invaluable aid in more detailed investigations.

Most of the investigations of satellite imagery for mineral exploration to date, especially in areas covered by dense vegetation, have focused on techniques for identifying lineaments. Geologists have realized for some time that many mining districts and individual ore deposits occur along or near linear trends. These faults and fractures may represent conduits through which hydrothermal fluids migrated, and therefore control the spatial distribution of potential ore deposits. Contemporary mineral exploration geologists spend a considerable amount of time and funds seeking and developing techniques for identifying lineaments. The ability to view extensive areas using Landsat imagery has provided geologists with a useful technique for mapping potential fracture and fault patterns, especially in areas where very little is known about the geological environment.

Current trends in mineral exploration in British Columbia, especially in reconnaissance studies, indicate that the recognition of structural zones is, in many cases, a prime objective. This is due in part to the fact that the province is heavily vegetated and the clearly visible alteration patterns associated with deposits in more arid regions are not easily recognized.

The use of lineament mapping from the Landsat imagery for mineral exploration is well documented, although examples from British Columbia were not located. A recent study by Mortensen and von Gaza (in press) which used TM thermal-band data for regional analysis of lineaments in the Klondike district, Yukon, demonstrated that significant, but previously unrecognized structural patterns could be identified and should influence exploration models in the region. Another paper by von Gaza (1988b) demonstrated the value of TM data for mapping lineaments in the Wheaton River district, Yukon.

Standard investigations involving Landsat imagery generally centre on areas less than 100 by 100 kilometres. Most recent studies have focused on using TM data at scales up to 1:50 000. The use of Landsat Thematic Mapper or Multispectral Scanner data would be cumbersome and extremely expensive if applied to a province wide study. It would take approximately 50 to 60 Landsat scenes to compose a mosaic of the province. Alternatively, satellite data from the National Oceanic and Atmospheric Administration's Advanced Very High Resolution Radiometer (AVHRR) is relatively inexpensive and a single scene covers an extensive area (*e.g.*, total imagery cost was approximately $350 for this study). To date, no documentation of attempts to map regional lineaments with AVHRR imagery has been located.

OBJECTIVES

The purpose of this study is to investigate the potential use of AVHRR data as a tool for mapping regional-scale lineaments in British Columbia. The general objectives of this research are to determine:

- If remotely sensed satellite imagery with coarse spatial resolution (*e.g.*, 1 kilometre by 1 kilometre) is valuable in mapping regional-scale lineaments.
- The extent of correspondence between the detected lineaments and the major tectonic features in British Columbia.
- If previously unmapped major lineaments can be identified and whether these lineaments potentially add to the structural knowledge of British Columbia.

STUDY AREA

The study area for this research consisted of the entire province of British Columbia. The Canadian Cordillera within British Columbia comprises five tectonostratigraphic regions (Insular Belt, Coast Belt, Intermontane Belt, Omineca Belt and Foreland Belt) that broadly correspond to the physiographic subdivisions (Western System, Cascade Mountains, Interior System and Eastern System).

The Foreland and Omineca belts are separated by the Rocky Mountain Trench. This is one of the three trenches occurring in the Canadian Cordillera, with the others being the Tintina and Shakwak trenches in the Yukon. The Rocky Mountain Trench extends from Flathead Lake nearly 200 kilometres south of the International Boundary, northwestwards for 1600 kilometres, until it disappears in the Liard Plain. The Tintina Trench begins 300 kilometres northwest of the Liard River and extends for 725 kilometres before entering Alaska. Strong structural control is suggested by the linearity of the features and the occasional displacement in their alignment. Some researchers have theorized that the Rocky Mountain Trench began as a series of Tertiary faults that developed into graben. The graben were expanded and preserved as a continuous valley by stream erosion (Bird, 1980).

DATA

Designed to assist in weather prediction and monitoring, meteorological satellites employ sensors which have a very coarse spatial resolution compared to land-oriented satellites. The trade-off of coarse spatial resolution is highly repetitive coverage. The passive sensors aboard the satellites collect reflected and emitted electromagnetic energy from the earth's surface and atmosphere.

The National Oceanic and Atmospheric Administration (NOAA) series of meteorological satellite data was used in this study. Several generations of NOAA satellites have been launched. The NOAA-6 through NOAA-12 missions contain the Advanced Very High Resolution Radiometer (AVHRR). The swath width of the AVHRR instrument is 2400 kilometres with a ground resolution of 1.1 kilometres at nadir. To provide the global coverage, the satellite orbits the earth at an altitude of 833 kilometres. The system daily provides one image in the visible portion of the spectrum and two images in the infrared portions of the spectrum. One of the infrared images is generated at the same time as the visible light image.

The AVHRR scans four portions of the spectrum:

1. 0.58 – 0.68 nm Green to red light,
2. 0.72 – 1.10 nm Photographic near-infrared light,
3. 3.55 – 3.93 nm Near-thermal infrared light,
4. 10.5 – 11.5 nm Far-thermal infrared light.

Figure 5-1-1 shows the divisions of the electromagnetic spectrum together with the ranges of the sensors on the AVHRR. For more information on AVHRR data the reader is referred to Lillesand and Kiefer (1987).

Data from the NOAA-9 mission were used in this study. This satellite crosses the equator, moving southward, at 2:30 p.m. daily and provides repeat coverage every 12 hours. It passes over Canada at approximately 1:00 p.m. Summer imagery was chosen for this research because the sun is at the highest point above the horizon, which minimizes shadowing. Although shadowing helps to detect topographically expressed lineaments in remotely sensed imagery, an excessive amount may result in misinterpretation.

The image of British Columbia was created from a mosaic of images from July 11 to July 31, 1988. Multiple images were required to create the final composite image due to the presence of cloud cover in parts of the province. The mosaic was rectified to the Lambert conformal map projection and resampled to a pixel (a picture element) size of 1.0 kilometre. Due to time and financial constraints, the researchers only acquired datasets for Channels 1, 2 and 3 from the NOAA-9 AVHRR.

METHODOLOGY

SIMPLE IMAGE ENHANCEMENT

The initial interpretation of lineaments consisted of a visual inspection of the image bands which had been linearly contrast stretched and edge enhanced. High-pass filtering (*i.e.*, edge enhancement) is a technique that applies a local operation to a pixel and its neighbours. The result of the local operation is then placed in the central pixel's location. For this study a three by three kernel was created with weights of 1.88 at the centre and -0.11 at the edges. This kernel is moved throughout the original image bands, row by row, and the central value in the output image is created by multiplying each coefficient in the kernel by the corresponding brightness value in the original image, then adding together all the resulting products.

Only those linear features which were clearly discernible on the computer screen were recorded. Figure 5-1-2 shows a down-sampled view of the three AVHRR bands after contrast stretching and edge enhancement.

NON-TOPOGRAPHIC HILL SHADING

An alternate approach to enhancing lineaments is the non-topographic hill-shading technique (von Gaza, 1988a). In digital images the tonal differences used in visually identifying lineaments, as expressed by topography and spectral differences between surface materials, are not always easily detected. Tonal differences however are manifest in the digital image topology as breaks in slope and can be enhanced for visual identification by illumination from a single synthetic light source. This is done by treating the

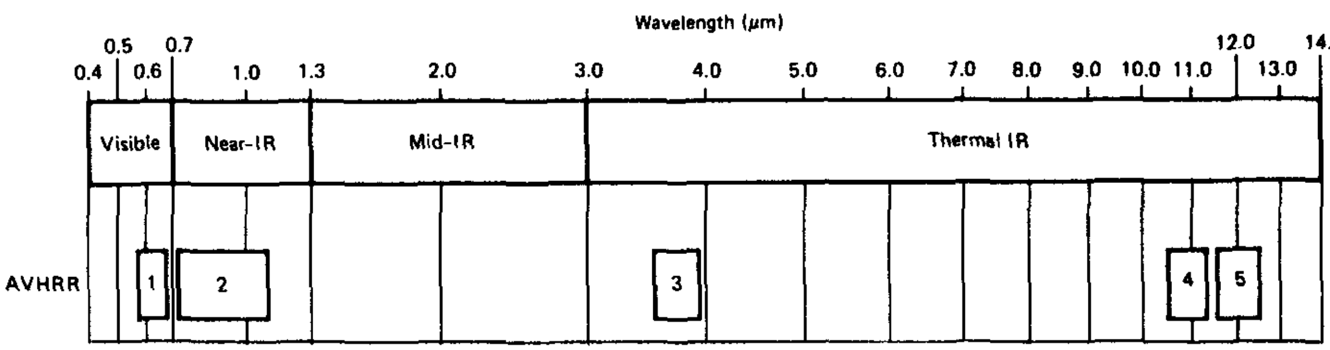

Figure 5-1-1. The divisions of the electromagnetic spectrum and sensing ranges of the sensors for the AVHRR.

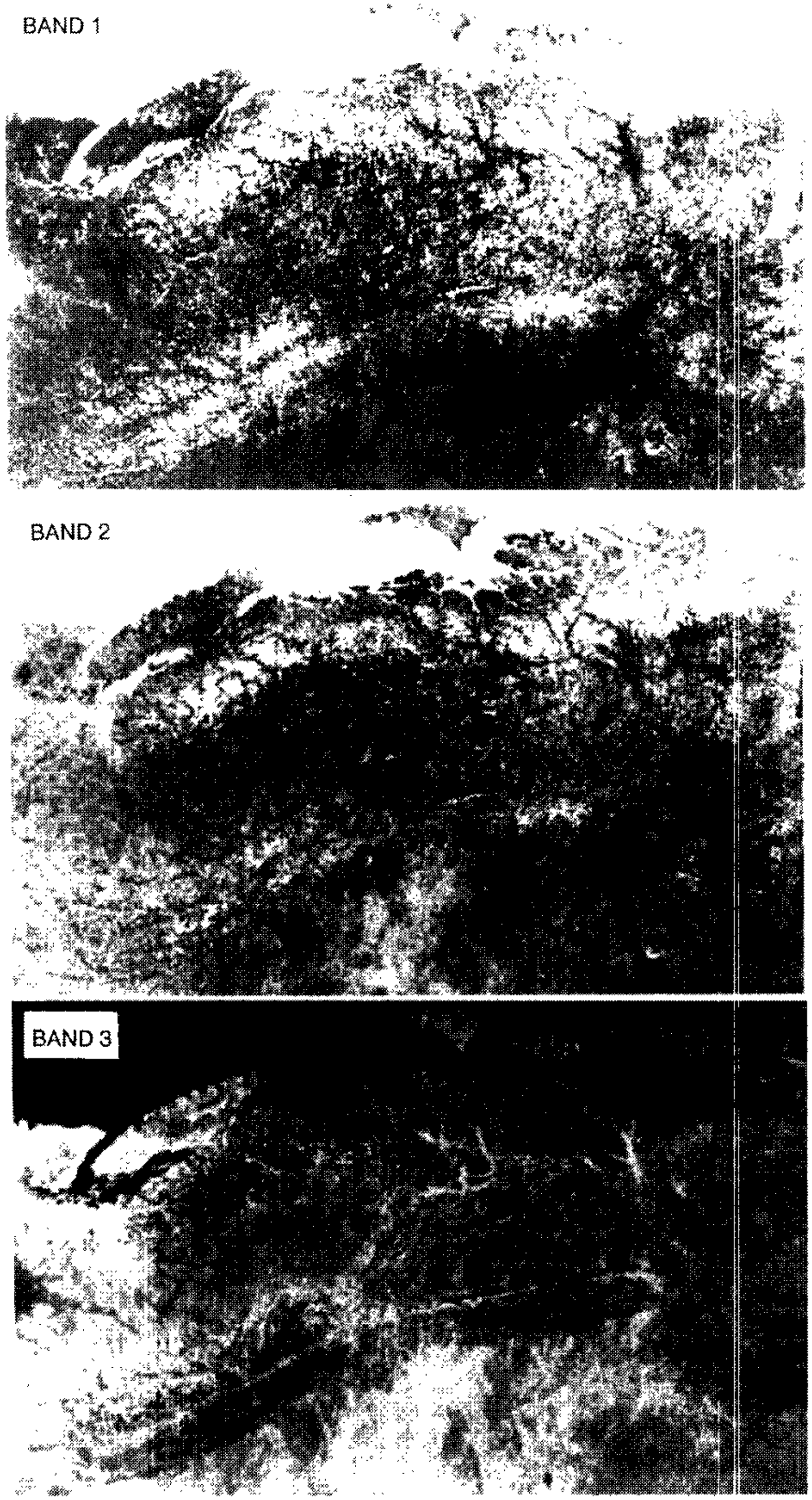

Figure 5-1-2. A down-sampled view of the three AVHRR bands after contrast stretching and edge enhancement.

digital image data as a digital elevation model (DEM) and illuminating the dataset with a hypothetical "sun". Shading of the dataset is calculated using a Lambertian reflectance model. The user interactively specifies the solar azimuth and solar elevation which provides best definition of the lineaments. This technique is basically a refinement of standard directional filtering techniques used in image processing.

In an effort to enhance the visual expression of inherent lineaments in the data, two images were produced using the hill-shading technique. Two hill-shaded images were created for each band, with the first image having a pseudo solar azimuth of 0° and the second a pseudo-solar azimuth of 75°. Two images were created with different solar azimuths in order to avoid directional biases. The authors' experience suggests that more than two viewing angles are not necessary as long as the directions are carefully chosen.

Near orthogonal azimuths were selected in order to maximize the amount of different information presented in the datasets. At the sun azimuth of 0°, patterns which trend in an east-to-west direction are emphasized, while at a sun azimuth of 75°, patterns trending north to south are emphasized. The sun azimuth of 75° was chosen to emphasize the

Figure 5-1-3. A part of the hill-shaded image from Band 3 (sun azimuth = 75° and solar inclination = 30°)

known major lineament patterns in British Columbia. The solar inclination (angle above the horizon) was set to 30°. This value was selected through trial and error. Figure 5-1-3 shows a part of the hill-shaded image from Band 3, with the sun azimuth at 75° and the solar inclination set to 30°.

The lineaments derived from visual interpretation of the contrast-stretched and edge-enhanced bands were stored together with the lineaments extracted from the hill-shaded image bands as rasterized maps.

Digitization of Known Major Lineaments

The Tectonic Assemblage Map of the Canadian Cordillera (Tipper *et al.*, 1981) published by the Geological Survey of Canada was digitized for its curvilinear features. The scale of this map is 1:2 000 000 and it is in the Lambert conformal map projection. The interpreted lineaments from the three AVHRR bands were plotted on a raster output device together with the lineaments digitized from the tectonic assemblage map. The plots of the interpreted lineaments were overlain on the tectonic assemblage plot, one at a time, and the areas of coincidence and divergence were located.

Plots of Known Mining Sites

Some known mining sites were plotted on the tectonic assemblage map in order to compare their location to the location of the known major lineaments. This plot was then compared to the location of the lineaments derived from the interpreted AVHRR imagery.

ANALYSIS OF RESULTS

The interpreted lineaments for the three AVHRR bands are presented in Figure 5-1-4. The major lineaments from the tectonic assemblage map were more readily identified from the contrast-stretched imagery while the more subtle linear patterns were more easily recognized on the hill-shaded imagery. Due to the coarse resolution and the need for ancillary datasets (*e.g.*, aeromagnetic data), we did not attempt to rank the interpreted lineaments or describe whether they were surficial or deep.

Description of Band 1

The Band 1 image has very little tonal or topographic information. Major topographic features are not easily seen, with the exception of the Rocky Mountain Trench. The image, with the exception of snow, is very dark and shows little or no contrast between ground-cover types. It was very difficult to detect any linear patterns in the northwest corner of the image because of snow cover in that geographic area.

Lineaments detected in this band were primarily from the contrast-stretched raw image. Inspection of hill-shaded images from Band 1 did not add significantly to the number of lineaments mapped. The effects of atmospheric scattering also probably contributed to detection of fewer lineaments in the Band 1 image. Solar radiation in the visible portion of the electromagnetic spectrum is more strongly scattered and can result in hazy images with a muddy appearance. Most of the lineaments plotted from Band 1 are long and the lineament pattern is evenly distributed across the province. Overall, this band is not good for detecting topographically expressed lineaments.

Description of Band 2

The raw image from Band 2 shows more scene contrast than Band 1 but also has a significant amount of high-frequency noise. Most of the noise appears as very bright pixels which represent snow. The expression of major topographic features is apparent and there is a better differentiation between ground-cover types. The Band 2 image is generally sharper than Band 1 because it was recorded in the near-infrared portion of the spectrum, which is less affected by atmospheric scattering. The greater tonal range of the image is primarily due to the fact that near-infrared light is reflected more strongly by vegetation than visible light.

More lineaments were detected in the Band 2 image than in the Band 1 image. In contrast to Band 1, it was found that the hill-shaded image was more useful for detecting the possible presence of lineaments. Most of the linear features in Band 2 are located in the southern half of the AVHRR image. The presence of snow in the northwest, as in Band 1, masks the expression of potential lineaments.

Description of Band 3

The Band 3 image is the most useful and the easiest to interpret. Major province-wide topographic features are easily identified and differences in surface materials that are hardly visible in Band 1 and 2 are very evident in Band 3. Areas of snow and water are black and thus the visual annoyance of bright pixels is avoided. The hill-shaded Band 3 image proved to be the best for detecting and mapping lineaments. Most of the lineaments in Band 3 are located in the northern half the AVHRR image and along the Rocky Mountains.

The primary reason that Band 3 is most useful is that emitted thermal radiation is the least affected by atmospheric scattering, resulting in a sharper image. Both Bands 1 and 2 depend on the amount of reflected radiation from ground cover, whereas Band 3 response is governed by the thermal emittance from the ground cover. In the Band 3 image of Figure 5-1-2, snow and water are black (coldest), sparsely vegetated, dry areas are white (warmest) and more vegetated areas are grey (warm).

Band 3 depicts the amount of heat re-radiated from the earth's surface. As most of the ground cover in British Columbia is vegetation, the amount of solar absorption can be taken as a constant. The amount of heat from the surface also depends on the direction of the surface in relation to the position of the sun. North-facing slopes receive less direct solar radiation than south-facing slopes and therefore appear darker (colder). This dependence of thermal emission on terrain suggests that Band 3 can be effectively used to map changes in slope magnitude and direction.

Concordance of Interpreted Lineaments With Known Major Lineaments

We have determined that there are some areas of coincidence between the Tectonic Assemblage Map and the interpreted lineaments from the AVHRR imagery (Figure 5-1-4). The areas of coincidence occur mainly along the Rocky Mountain Trench and the Fraser fault. Most of these lineaments were derived from visual inspection of the contrast-stretched image bands.

Few lineaments from Band 1 matched the Tectonic Assemblage Map. A part of the northern Rocky Mountain Trench near Williston Lake, the southern part of the Rocky Mountain Trench and a segment of the Fraser fault were detected on the Band 1 imagery. Some unnamed faults on Vancouver Island and south of Prince Rupert were also matched.

There were more matches of lineaments from Band 2. The northern part of the Rocky Mountain Trench near Williston Lake, the southern part of the Rocky Mountain Trench and the Fraser fault were successfully identified. There was coincidence along the Yalakom fault and the lineament also showed an east-southeast extension into the interior of British Columbia. There were also matches to other unnamed faults south of the Rocky Mountain Trench and on Vancouver Island.

The lineaments derived from Band 3 had the most agreement with the Tectonic Assemblage Map. A significant part of the Northern Rocky Mountain Trench, the northern part of the Pinchi fault and most of the Fraser fault were mapped from the Band 3 image. There are also matches to other unnamed lineaments east of the Northern Rocky Mountain Trench, on Vancouver Island and south of the southern part of the Rocky Mountain Trench.

Areas of Contrast With the Known Major Lineaments

Lineaments which were not detected by the Band 1 imagery include the Yalakom fault, the Pinchi fault, the central and most of the northern part of the Rocky Mountain Trench. Among the Band 2 lineaments, there was no match along the Pinchi fault. The southern part of the Pinchi fault and the entire Yalakom fault was not detected from the Band 3 imagery. Nonetheless, if the interpretations from all three AVHRR bands are combined into a single map, most the major lineaments can be successfully mapped.

Many lineaments in all three bands cross-cut the linears on the Tectonic Assemblage Map. It is significant that this cross-cutting pattern is common to all three bands. The possible reasons for this contrast merits further investigation.

Agreement With Known Mining Sites

A plot of known mining sites, Figure 5-1-5, shows that many of the mines are not located on or along regional-scale lineaments, as marked by the Tectonic Assemblage Map. These same mining sites also do not coincide with lineaments mapped from the AVHRR data. Some mining sites which are located near the lineaments derived from AVHRR

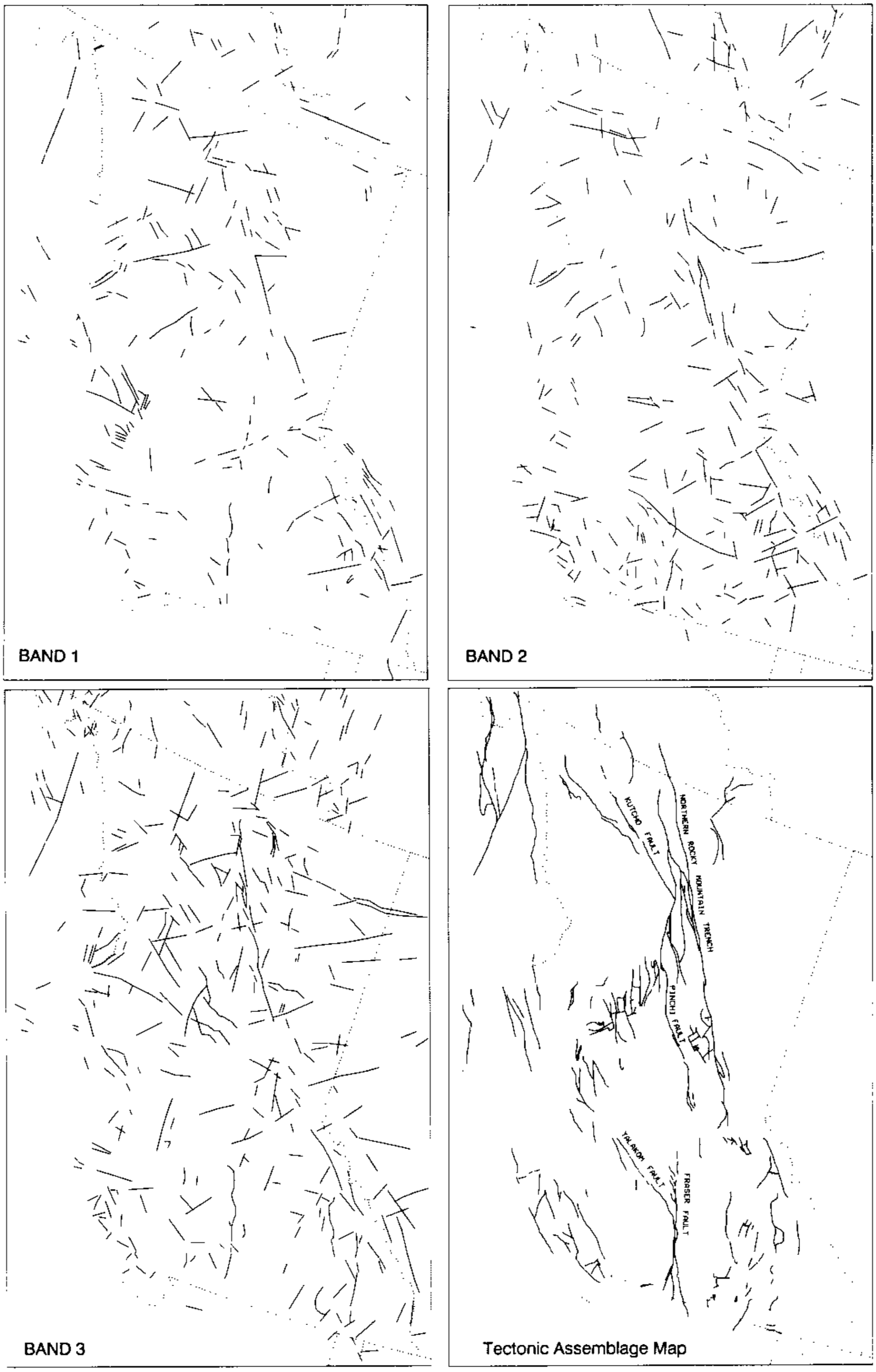

Figure 5-1-4. The interpreted lineaments for the three AVHRR bands and the lineaments from the Tectonic Assemblage Map.

imagery are Myra Falls (Westmin Resources Ltd.), Johnny Mountain mine (Skyline Explorations Ltd.), Babine Lake (Noranda Inc.), Beaverdell (Teck Corporation), Princeton (Similco Mines Ltd.) and Hedley (International Corona Corporation). The Myra Falls mine is located close to lineaments detected in all three AVHRR bands.

CONCLUSIONS

The interpretation of the contrast-stretched and edge-enhanced imagery and the hill-shaded imagery provided useful, complementary information. Known major linear features were easily detected and mapped using contrast-stretched imagery, while hill-shaded imagery allowed detection of more subtle linear features. Users of NOAA AVHRR imagery should use both methods for detecting lineaments.

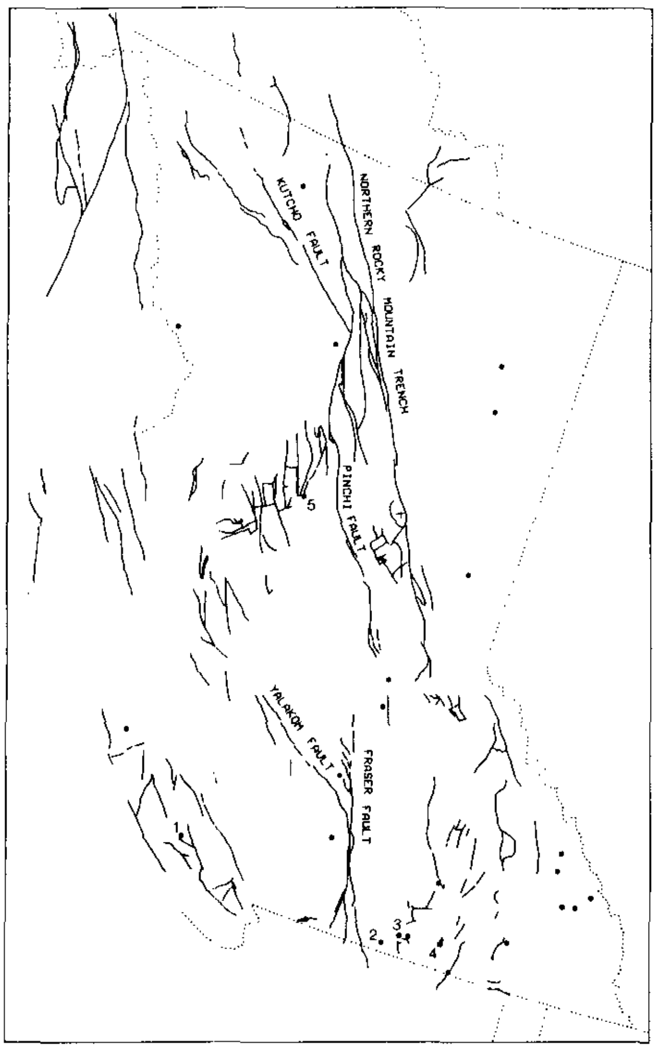

Figure 5-1-5. A plot of known mining sites overlain on the Tectonic Assemblage Map. (1. Myra Falls, 2. Princeton, 3. Hedley, 4. Beaverdell and 5. Babine Lake).

The most detailed information was derived from the Band 3 image. This image had the most readily identifiable details of the three bands. It also appears that the ability to differentiate gross ground-cover types is better using the thermal band than either the reflected visible or reflected infrared bands. If other users intend to map lineaments with AVHRR imagery, it is suggested that the Band 3 image be used in preference to the other two bands.

The major lineaments shown on the Tectonic Assemblage Map are more readily identified from the contrast-stretched imagery while the more subtle linear patterns are more easily derived from the hill-shaded imagery. The areas of coincidence between the interpreted lineaments and the lineaments from the Tectonic Assemblage Map occurred mainly along the Rocky Mountain Trench and the Fraser fault. Many linears in all three bands cross-cut the linears from the Tectonic Assemblage Map.

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