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Satellite Geological Mapping of the Yellowknife Volcanic Belt

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ABSTRACT. An ARIES III Image Analysis System was used to manipulate digitized Landsat 5 Thematic Mapper (TM) imagery of the Yellowknife Volcanic belt (YVB) to demonstrate geological applications of this technology in a boreal region characterized by subdued topography, open-canopy forest cover and about 50% outcrop exposure. The YVB was selected for study because detailed geological mapping is available against which computer-generated imagery could be compared and evaluated.

The study area encompasses a northerly trending belt of principally mafic volcanic rocks (Kam Group) flanked to the west by a multi-phase batholith (Western Granodiorite Complex) and to the east by turbiditic sediments (Burwash Formation) and granitic stocks. Intermediate volcanic rocks (Banting Group) and a narrow belt of conglomerates (Jackson Lake Formation) separate the Kam Group from the Burwash Formation.

Initially, images from each of the six TM channels were analyzed, and it was found that channels 7 (short-wave infrared), 3 (red) and 2 (green) yield the best discrimination of geological features. Subsequently, various computer-generated enhancement programs were applied to these channels to intensify geological discrimination, and the resulting images were combined to produce a number of false-colour composite images that were compared to published geological maps.

On the best of these "satellite geological maps" at least three phases of igneous intrusions can be identified, as well as the boundaries of the Kam Group and a number of important structural discontinuities. The adjacent Banting Group volcanics and Burwash Formation sediments could not be chromatically separated but are sometimes distinguishable using textural criteria. Most notably, certain computer-enhanced images highlight two zones of alteration within the Kam Group that have not previously been noted on published maps. These alteration zones appear to be spatially associated with a number of gold showings and one significant gold deposit.

It is concluded that computer manipulation of satellite imagery can add worthwhile information to the geological database of areas that have been mapped at a detailed scale of 1:10 000.

Key words: geology, satellite imagery, Landsat 5, Thematic Mapper, Yellowknife Volcanic Belt, computer, DIPIX, ARIES III

RÉSUMÉ. On s'est servi d'un système d'analyse d'images ARIES III pour manipuler des images de la ceinture volcanique de Yellowknife obtenues avec l'appareil de cartographie thématique Landsat 5, afin de démontrer les applications géologiques de cette technologie à une région boréale où la topographie est peu marquée et le couvert forestier ouvert, et où les affleurements exposés représentent 50 p. cent de la surface. On a choisi la ceinture volcanique de Yellowknife à cause de la possibilité de comparer l'imagerie informatisée avec la cartographie détaillée déjà disponible, et de faire une évaluation.

La zone d'étude englobe une ceinture orientée généralement vers le nord, composée surtout de roches volcaniques mafiques (groupe Kam), bordée à l'ouest par un batholite à phases multiples (complexe granodioritique occidental) et à l'est par des sédiments turbiditiques (formation Burwash) et des stocks granitiques. Des roches volcaniques intermédiaires (groupe Banting) et une ceinture étroite de conglomérats (formation Jackson Lake) séparent le groupe Kam de la formation Burwash.

On a tout d'abord procédé à l'analyse des images obtenues avec chacune des 6 fréquences de l'appareil de cartographie thématique, et on a trouvé que les bandes 7 (ondes courtes infrarouges), 3 (rouge) et 2 (vert) permettaient la meilleure discrimination des caractéristiques géologiques. On a ensuite appliqué à ces bandes des programmes d'accentuation informatisée, en vue d'intensifier la discrimination géologique, et on a combiné les images obtenues pour produire plusieurs images composées en fausse couleur que l'on a comparées à des cartes géologiques publiées. Sur les meilleures de ces «cartes géologiques satellites», on a pu identifier au moins trois phases d'intrusions endogènes ainsi que les limites du groupe Kam et plusieurs grandes discontinuités de structure. On n'a pu séparer par chromatographie les roches volcaniques du groupe Banting et les sédiments de la formation Burwash, tous deux adjacents, mais on a pu les discerner parfois en utilisant des critères de texture. Il est à remarquer que certaines images traitées par accentuation informatisée mettent en évidence deux zones d'altération dans le groupe Kam, qui n'apparaissaient pas jusque-là sur les cartes publiées. Ces zones d'altération semblent être associées spatialement à plusieurs indices aurifères et à un gisement aurifère d'importance.

On conclut que le traitement informatisé de l'imagerie satellite peut ajouter une information très valable à la base de données géologiques de régions ayant été cartographiées à une échelle détaillée de 1:10 000.

Mots clés: géologie, imagerie satellite, Landsat 5, appareil de cartographie thématique, ceinture volcanique de Yellowknife, ordinateur, DIPIX, ARIES III

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INTRODUCTION

The DIPIX ARIES III Image Analysis System (software package version 4.6) is designed to manipulate digital data from satellite imagery. The main purpose of this study was to gain familiarity with the general capabilities of this technology and to evaluate and report on its relevance as a geological tool, particularly from the perspective of an exploration geologist.

The Yellowknife Volcanic Belt (YVB) was chosen as a test area because 1:10 000 scale geological mapping is available (Helmstaedt *et al.*, 1979, 1980; Henderson and Brown, 1966), against which computer-enhanced imagery could be compared and evaluated. The author's familiarity with the geology of this area and the presence of significant gold deposits in the YVB (Nerco-Con Mine, Giant Mine) were ancillary factors favouring the selected test area. Analogous studies have been done in other parts of Canada (Aronoff and Goodfellow, 1985; Aronoff *et al.*, 1985, 1986; Slaney, 1985).

In this study, data used were from Thematic Mapper (TM) imagery taken by the Landsat 5 satellite on 12 July 1987.

The ARIES III features an ability to discriminate 256 "grey levels" (reflectance values) from each of the approximately 10 million pixels that constitute a single TM "scene" (185 km × 185 km). Since each TM scene is imaged on 7 different spectral channels, the ARIES III can actually work with about 70 million pixels of information. Its image-enhancing powers are derived mainly from its capability to apply algorithms to modify the spectral signature of a scene or sub-scene, thus altering the image to reveal features that were obscure on the original image. The user can also "classify" an image by identifying the reflectance characteristics corresponding to a

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known or interpreted feature and instructing the computer to identify all similar reflectance values in order to map out similar features throughout the image. Such classifications can be "supervised" (requiring ground data) or "unsupervised" (relying mainly on computer classification).

The ARIES III can also produce a composite false-colour image by combining three images processed successively through a red, green and blue "gun." In doing so, the computer assigns each grey reflectance value an equivalent red, green or blue reflectance value. Features on the colour composite are easier to detect than features on a black-and-white image because the human eye distinguishes variations in colour more easily than variations in shades of grey. The three images that are combined may be enhanced and/or unmodified.

THE YELLOWKNIFE VOLCANIC BELT (YVB)

The study area comprises a 15 km by 35 km segment of the YVB and adjacent sediments and granitoids (Figs. 1, 2). The topography of the study area appears flat from a regional perspective, but in detail it is rugged, with rocky hills and ridges rising abruptly from lake or muskeg to heights of 15-30 m. The north-trending YVB stands out as a positive topographic feature. It is composed mainly of mafic volcanic rocks (basalt and andesite) and intrusive equivalents (gabbro and diorite), known collectively as the Kam Group. Most of the Yellowknife townsite and both of the principle gold mines (Nerco-Con and Giant) are within the Kam Group (Fig. 2). Flanking the Kam Group to the east is a succession of intermediate to

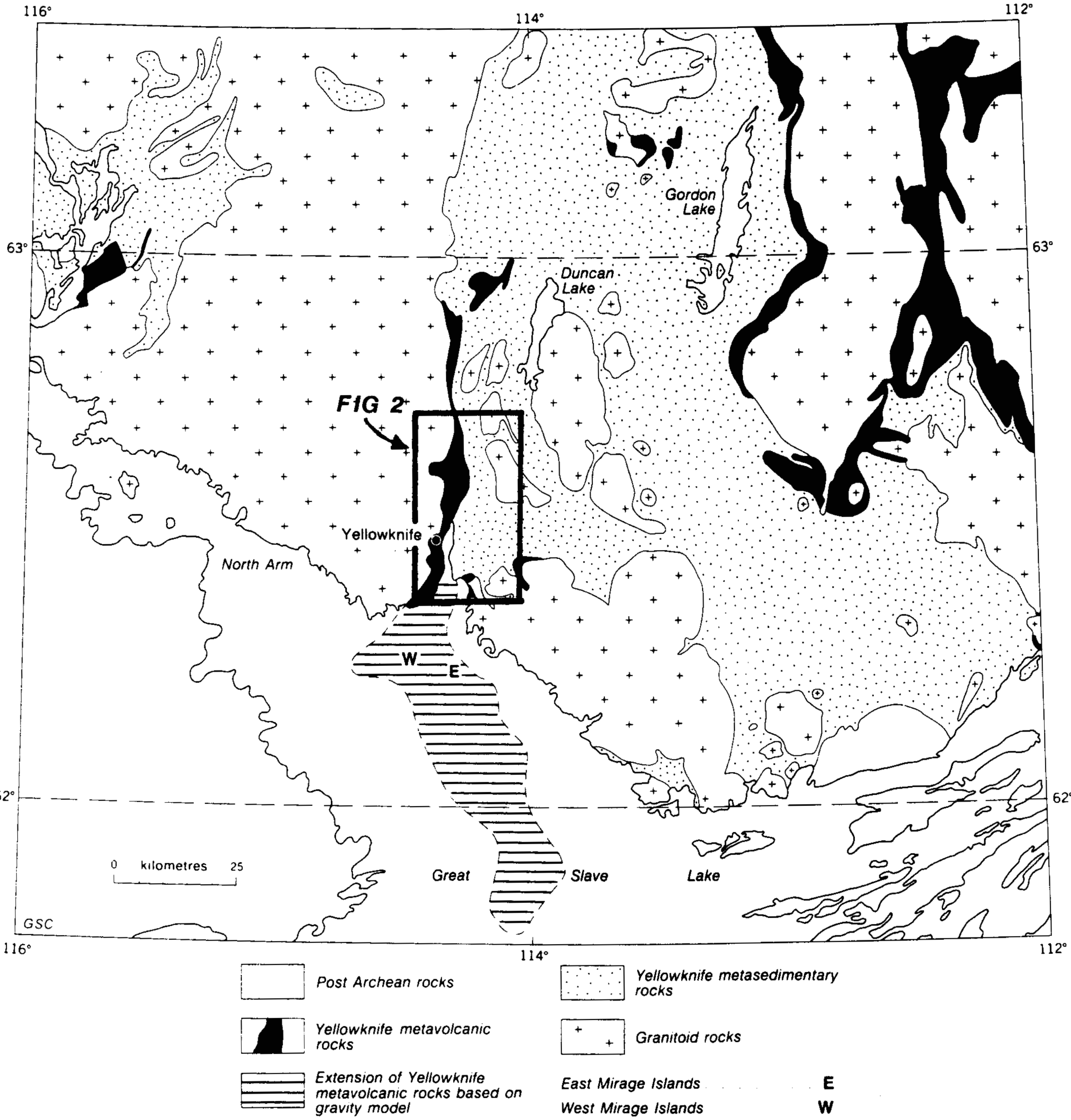

FIG. 1. Geology of the Yellowknife region, showing the location of the study area (from Henderson, 1985).

felsic volcanics (andesite to rhyolite) and minor sediments of the Banting Group. The Jackson Lake Formation, a relatively narrow unit of conglomerate and sandstone, separates parts of the Kam Group from the Banting Group.

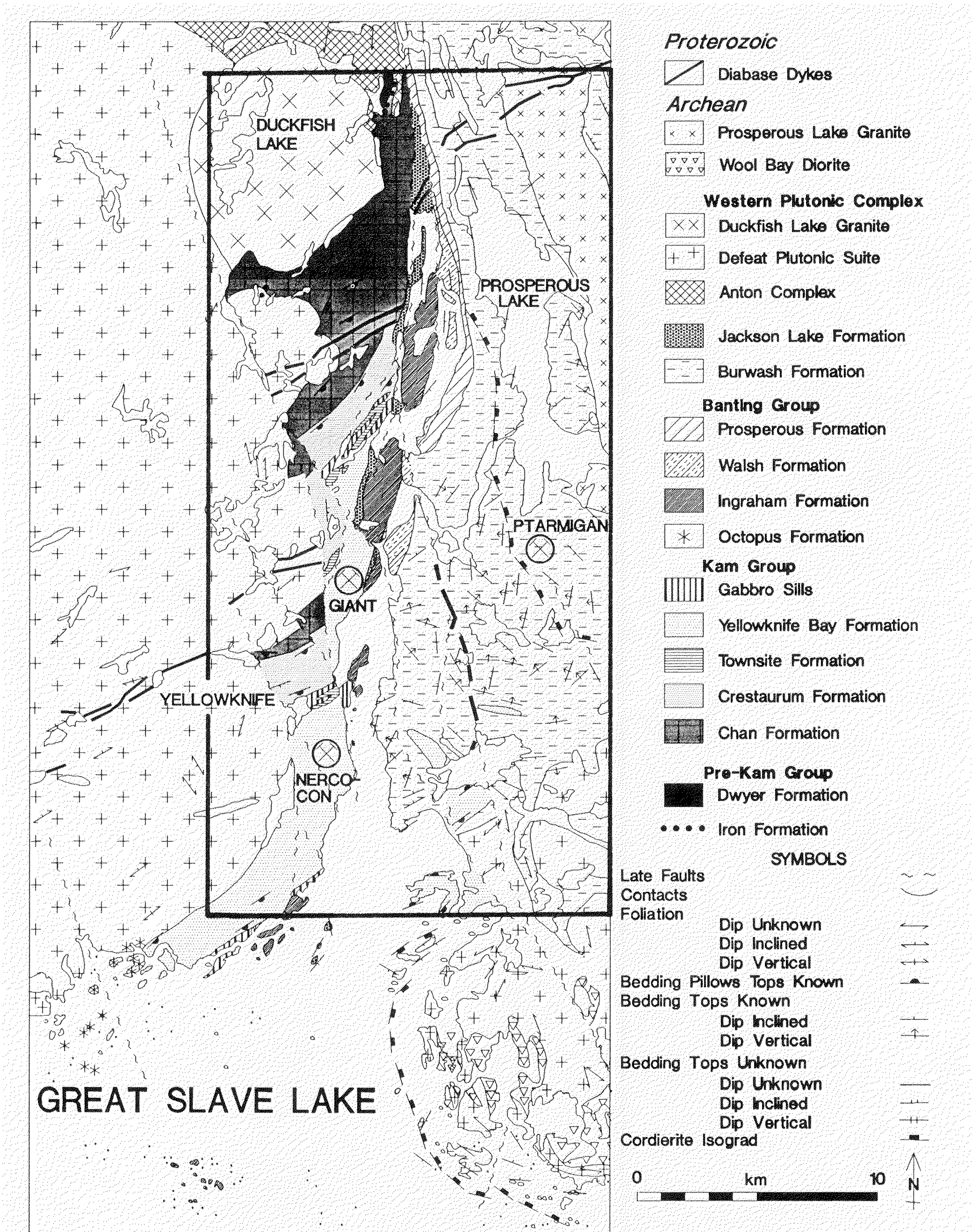

FIG. 2. Geology of the Yellowknife Volcanic Belt. The study area is outlined in bold. The north half of the study area corresponds with Figure 3 (from Falck, 1990).

The YVB is flanked to the east by batholithic intrusions of the Western Granodiorite Complex and farther to the north by the Duckfish Lake Granite. Granitic terrains tend to be very well exposed and to form areas of intermediate topographic relief.

To the east of the YVB lies an extensive region of subdued topography underlain by sediments (mainly arenite and argillite) of the Burwash Formation. These are intruded by other granites, most notably the Prosperous Lake Granite to the north and the Defeat Plutonic Complex to the south. All rock units described above are of Archean age, approximately 2.65 billion years, and are intruded by diabase dikes of Proterozoic age. Linear geological features in the study area include tuffaceous interbeds, shear zones, diabase dikes and post-diabase faults.

Forest cover is of the open-canopy type, constituting mainly spruce, pine, larch and birch. Outcrop exposure is excellent, averaging about 50%, although bedrock detail is typically obscured by lichen, mainly brown rock tripe. The reader is referred to Helmstaedt and Padgham (1986) and Henderson (1985) for more detailed accounts of the geology of the Yellowknife Volcanic Belt.

METHODS

The detailed study area was blocked out from the TM satellite scene and a geometric correction program was implemented to link the study area to a UTM grid and reorient the sub-scene to astronomical north. Individual TM channels (Table 1) were studied to identify those three that best represented geological features. A variety of enhancement routines were tested on the selected TM channels to identify those modifications that produced the best enhancements of geological features. Finally, false-colour composite images obtained by combining triads of the best of these enhanced images were generated at a 1:10 000 scale using a colour plotter. The resulting products were compared to published geological maps.

RESULTS

Analysis of Individual TM Channels

Channels TM 7 and TM 5 give the best definition of linear elements and relief. In addition to local relief, they chromatically separate zones of subdued topography underlain mainly by sediments (dark grey) from zones of more positive topography underlain mainly by mafic volcanics and granites (light grey). Of the two channels, TM 7 provides the better contrast between geological units and was therefore selected as one of the three channels to be used in subsequent test work.

Channel TM 4 produces an extremely monotonous "washed" image that renders little information useful from a geological perspective. Channels TM 3, TM 2 and TM 1 produce images in which the Kam Group volcanics (medium grey) can be clearly distinguished from adjacent granites to the west (light grey). Channel TM 1 provides the least contrast between these two units.

Channels TM 7, TM 3 and TM 2 were therefore chosen as subjects for subsequent enhancement tests.

Analysis of Image Enhancements

In this study, only the image-enhancement routines of the ARIES III were evaluated. These include various contrast stretches (linear, histogram and logarithmic), convolution filtering (enhancement of linears), principal component enhancements and colour unpackings of these enhancements, statistics filtering and input-output transformations. In subsequent discussions, little attempt is made to elaborate computer procedures or to detail the algorithmic functions that produce the enhanced image. Convolution filtering, however, is described in some detail as an example to illustrate the myriad sub-routines and parameter choices typically offered by the computer and to underscore the superficiality, due to time constraints, of this study's sampling of the available enhancement routines.

TABLE 1. Landsat Thematic Mapper channels

Channel	Wavelength (μm)	Colour
TM 1	0.45-0.52	blue
TM 2	0.52-0.57	green
TM 3	0.63-0.69	red
TM 4	0.76-0.90	near infrared (IR)
TM 5	1.55-1.75	shortwave IR (1)
TM 7	2.08-2.35	shortwave IR (2)
TM 6	10.80-12.5	thermal (not used in this study)

In order to facilitate comparison and analysis of the images generated by the various enhancement routines, photographs of the images on the monitor were taken that could later be reviewed at leisure. Because the screen holds a relatively non-decimated image of only half the study area, the north half (Fig. 3), which is farthest away from the cultural disturbances at Yellowknife, was selected for photographic evaluation.

Convolution Filtering

Because the two large gold mines in the YVB, Nerco-Con and Giant, are hosted in crudely linear structures (shear zones) and are spatially associated with a fault linear (the West Bay Fault), some time was spent evaluating a Convolution Filtering program used to enhance lineaments by selectively altering pixel brightness values to "mark" locations of significant changes in "brightness slope." The menu offers 3 sub-routines, 31 choices of filter size and 8 choices of filter direction. In effect, hundreds of alternative enhancements of an original image are possible, only a sprinkling of which were actually investigated.

Using TM 7 as the input image and scanning in four different directions (N, NE, E, NW) with a coarse filter (21 × 21 pixel matrix) and a fine filter (5 × 5 pixel matrix), eight enhanced images were produced. These images resemble lunar landscapes rippled by linear fabrics most clearly pronounced along trends perpendicular to the scanning direction of the filter. Many of the linear elements in the study area were emphasized, including those mentioned earlier. However, most of the linears could very well have been traced from the original satellite image, albeit more painstakingly, without the aid of a computer. Admittedly, some subtle lineaments, obscured by the plethora of more obvious lineaments in this exceptionally well-exposed belt, might have been overlooked in a manual analysis. Moreover, the lineament patterns can be used as a tool to map geology, since rheological differences in the various geological units influence the pattern, quantity and size of linear fabrics.

Other Enhancements

Some enhancements (principle components, cube root transformations and certain contrast stretches, for example) are clearly useful in elucidating the geology of the study area and improving details of the input image. It was found that study of individual monochromatic enhanced images yields more information than study of false-colour composite images. This is because certain enhancements clearly emphasize the mafic volcanics (Kam Group) but obscure the differences between granitic terrain and volcano-sedimentary terrain (Burwash Formation + Banting Group), while others clearly emphasize either the volcano-sedimentary terrain or the granitic terrain. But since none was able to differentiate all three of these main geological units, false-colour composites using the best enhanced images as inputs usually give good chromatic contrast between only two units.

One of the most useful images produced was a "colour unpacking" of the second principal component of channels TM 7, 3 and 2. (Principal component enhancements identify new axes on a scatter plot among input channels that maximize variance in the data set. "Colour unpacking" computes red, green and blue output files by mapping two specified input

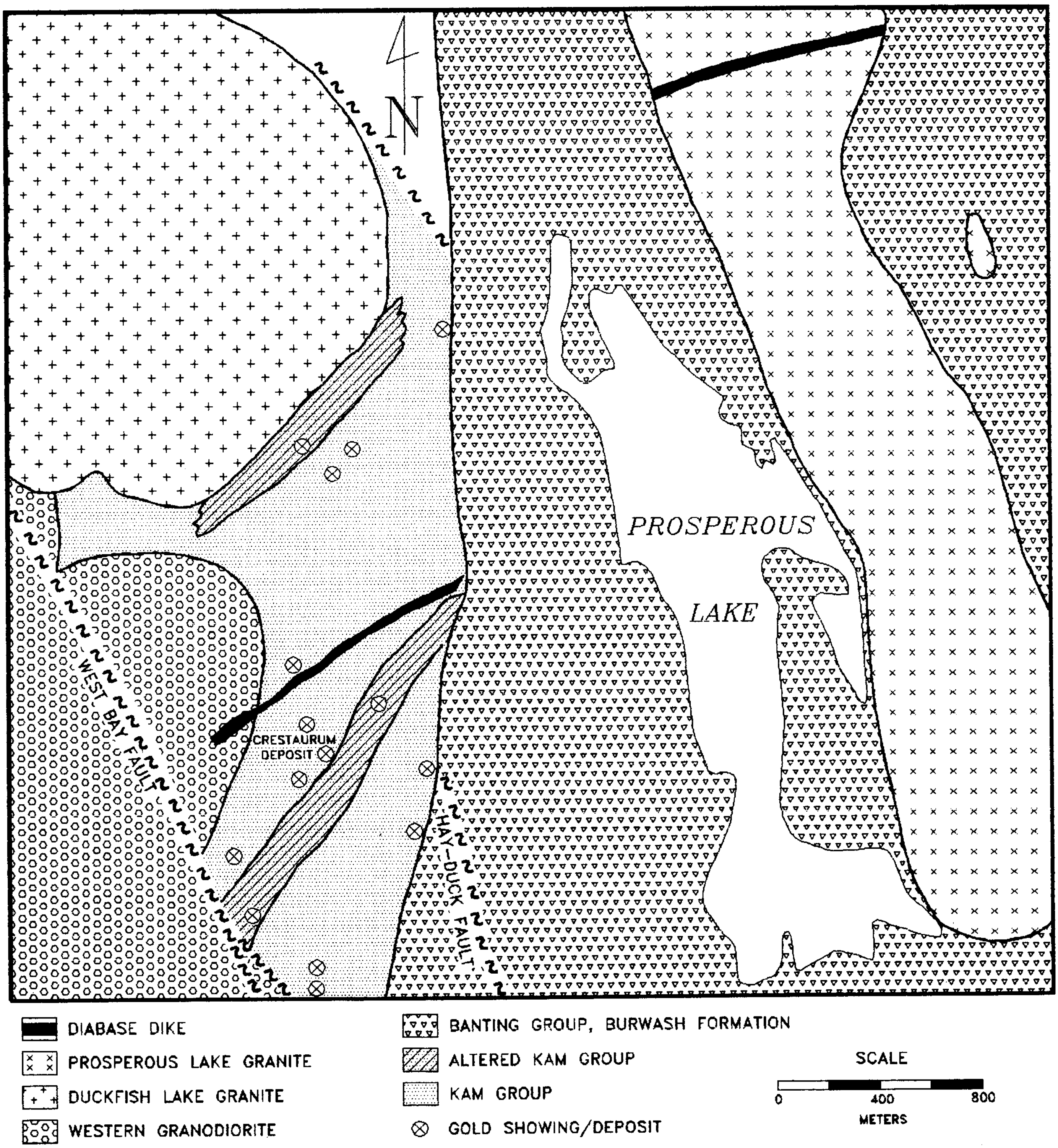

FIG. 3. Geology of the north half of the study area derived from analysis of enhanced satellite imagery.

components to brightness, red-greenness and blue-yellowness.) This enhanced image, referred to as TA 3, clarifies certain internal features of the Kam Group that might be related to gold mineralization, as will be discussed in the next section.

Satellite Mapping

Figure 3 is a geological map of the north half of the study area based on satellite imagery discussed in this report. It can be compared to the geology shown in Figure 2, which is based on 1:10 000 scale mapping.

The satellite imagery was able to distinguish the three main granitic bodies in the area. The Duckfish Lake Granite is characterized by a conspicuous and unique pattern of north-northwesterly trending fractures. The Prosperous Lake Granite is recognized by its isolation from other granite bodies and a homogeneous texture. The Western Granodiorite Complex is distinguishable by a mottled, heterogeneous texture, suggesting, as is known to be the case, that it is a complex of various intrusive phases.

The Kam Group emerges on channels TM 2 and TM 3, and details within the Kam are particularly well emphasized on the enhanced image TA 3. Of particular interest are two zones within the Kam that are evident on the enhanced image but are not shown on detailed published maps. Both zones manifest as clearly demarcated lighter grey reflections against the generally darker reflections that typify the Kam Group on TA 3. The more southerly zone is a stratabound belt of alteration comprising silicification and carbonatization (pers. obs.). The more northerly is confined to the southeast margin of the Duckfish Lake Granite and is possibly an effect or alteration due to contact metamorphism. Figure 3 shows the fifteen gold occurrences that are known within the Kam Group in the study area (Falck, 1990). Three are clearly related to the contact between the Kam Group and the undifferentiated volcano-sedimentary terrain (Banting Group + Burwash Formation) to the east. But six, and perhaps as many as eight, appear to be spatially associated with the two zones of alteration identified in this study. This includes the most significant of these occurrences, the Crestaurum Deposit, which has reserves of 100 000 tonnes grading 19 g/t gold and is described as being hosted in "shears in altered sills" (data from Northern Mineral Inventory Sheets).

The satellite imagery was also able to identify one of the two main diabase dikes that cut east-northeasterly across the study area and was also able to locate the main northwesterly trending Proterozoic faults.

On the negative side, satellite imagery failed to identify the Jackson Lake Formation, partly because of exceedingly narrow exposure and partly because it is associated with a recessive-weathering fault lineament. Nor could satellite imagery separate intermediate volcanics and subordinate sediments of the Banting Group from sediments of the Burwash Formation, although farther south of the area shown in Figure 3, fold patterns in the Burwash can sometimes be used to distinguish it from the generally more competent rocks of the Banting. Henderson (1985) suggests that sediments of the Burwash Formation were derived mainly from intermediate volcanics such as constitute much of the Banting Group, and it is perhaps this commonality of composition that makes it difficult to distinguish them by satellite mapping.

CONCLUSIONS

Satellite geological mapping of YVB succeeded in identifying most of the geological units present in the study area. Moreover, two major zones of alteration were identified within volcanics of the economically important Kam Group that had not been noted in detailed published maps, and both zones appear to be related to gold mineralization. These results, based on enhancement techniques that represent a small fraction of the total capability of computer/satellite technology, suggest that this technology should play a fundamental role in the geological sciences generally, and in mineral exploration specifically.

ACKNOWLEDGEMENTS

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