Analyzing Remote Sensing Geobotanical Trends in Quetico Provincial Park, Ontario, Canada, Using Digital Elevation Data*

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ABSTRACT: Field geological mapping of a 10- by 13-km area in Quetico Provincial Park, Ontario, Canada, depicts a broad central band of metamorphosed mafic and occasional ultramafic lithologies, surrounded by granites and granodiorites. Glacial till is thin and capped by loess in places. The soils are mainly Histosols and Boralfs. The vegetation is dominantly Boreal in nature. To investigate subtle site influences on vegetation, topographic information was analyzed using a digital terrain model. The elevation data were filtered to separate ridge tops and other flat, dry areas from flat moist sites. Landsat Thematic Mapper (TM) data were classified into six forest classes of varying deciduous–coniferous cover using nPDF, a procedure based on probability density functions. The distribution of cover classes on each of the two lithologies shows that forests growing on mafic lithologies are enriched in deciduous species, compared to those growing on granites. Of the forest classes found on mafics, the highest coniferous component was on north facing slopes, and the highest deciduous component on south facing slopes. By contrast, granites showed no appreciable variation between site classes. Digital elevation derived site data is found to be an important tool in geobotanical investigations in Quetico Provincial Park.

INTRODUCTION

THE USE OF REMOTE SENSING FOR LITHOLOGICAL MAPPING and the search for economic minerals has been highly successful where vegetation is minimal, especially in desert environments (for example, Rowan *et al.*, 1974; Davis and Berlin, 1989). Small amounts of vegetation, however, tend to suppress the reflectance spectrum of geological materials. For example, Siegal and Goetz (1977) found, by mathematically mixing representative rock and vegetation spectra, that a cover of 30 percent manzinita, or 10 percent green grass, masks the spectral features of low albedo geological materials. Thus, the geological interpretation of vegetated remotely sensed scenes has had to rely on the relationship between rocks, soils, and vegetation: geobotany.

Geobotanical relationships are highly complex. In general, geology (or more strictly, soil parent material) is linked, through soils, to vegetation. However, not only does vegetation, in turn, influence soil development, but also both soil and vegetation are affected by climate and relief. In addition, time since formation, and fire history, affect soils and vegetation, respectively. Clearly, any geobotanical analysis needs to investigate the role of these various influences on the vegetation.

Because of the important role of topography in both relief and climate, a digital elevation model is a suitable tool for investigating geobotanical relationships. In this study of a 10- by 13-km area in Quetico Provincial Park, Ontario, we used a digital elevation model to separate different drainage classes, so as to be able to examine the influence of site factors, as well as lithology, on vegetation.

DESCRIPTION OF THE STUDY AREA

Quetico Provincial Park is a large wilderness area in northwestern Ontario, Canada (see Figure 1). The park lies just to the north of the Boundary Waters Canoe Area of Minnesota. Quetico Park has no roads, and cultural influences are limited.

The study site, in the northeastern section of the park, lies on the boundary between the metavolcanic greenstone Wawa and metasedimentary and granitic Quetico belts, or subprovinces, within the Superior Province (Card and Ciesielski, 1986; Percival and Stern, 1984; and Percival, 1989). Economic deposits, including gold, silver, copper, nickel, and occasionally platinum group metals, are associated with the metavolcanic rocks. The geological mapping of the area (Tanton, 1940; Pye and Fenwick, 1965; Percival, 1988) has been regional in nature, with large discrepancies in the test area, especially when compared to the geophysical and remote sensing data (Department of Mines, 1961).

Geological field mapping has depicted a central east-northeast trending band of mafic rocks extending through the field area (see Figure 2.) At the northeast end of this band, serpentinized dunites and lherzolites are found in a narrow 400-metre zone near the contact with the meta-granites to the north. In general, the mafic rocks are hornblende amphibolites, and the surrounding, slightly metamorphosed, igneous intrusives are mainly granite and granodiorite, with minor tonalities.

Although Quetico was extensively glaciated in the Pleistocene (Zoltai, 1965), ground till is thin and discontinuous over the test site. In a nearby study area, Harrington *et al.* (1989) found a statistical association between the geochemistry of ultramafic intrusions and the till overlying them. This suggests that, in this part of Ontario, glacial till is related to the underlying geology. A thick deposit of sand was found north of the Wawiag River, and in the nearby Kawa Bay there are a number of sandy beaches, a rarity in Quetico. Glacio-fluvial outwash deposits are locally restricted to the Wawiag River floodplain (Walshe, 1980). Soils north of these sites tend to have a cap of silt over 30 cm

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FIG. 1. Location map.

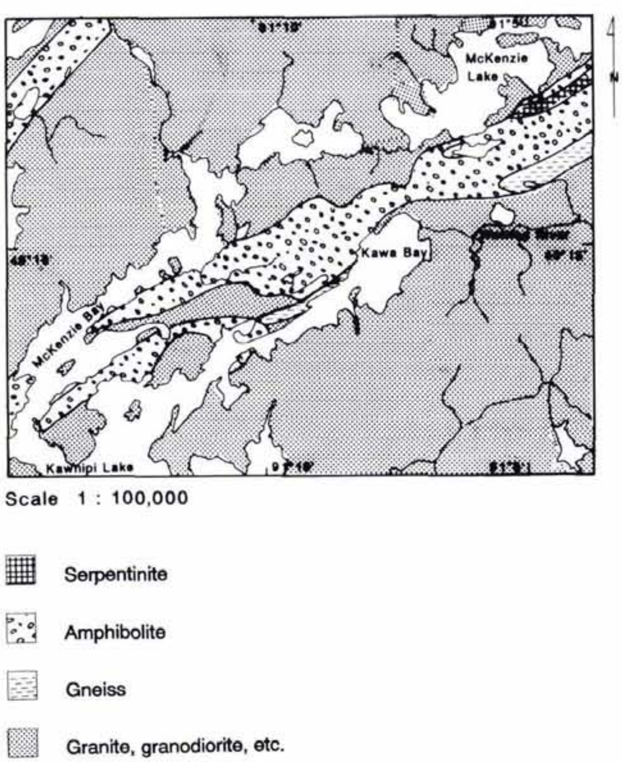

FIG. 2. Geological map.

thick. This would suggest that the silt is loess from the paleo-Wawiag outwash plain, and the sand may be a marginal dune deposit.

The soils are young, poorly developed, and tend to be acidic, especially where developed over granitic lithologies. On well drained sites, Typic Glossoboralfs were found to be common, whereas Histosols are present in the wet areas.

Although it is located on the ecotone between the Great Lakes - St. Lawrence Forest and the Boreal Forest, boreal species tend to dominate in Quetico Park (Walshe, 1980). The most common species are trembling aspen (*Populus tremuloides* Michx.), jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) B.S.P.), and paper birch (*Betula papyrifera* Marsh.) (Woods and Day, 1976). The ecology is essentially fire dominated, and climax communities are rarely found (Larsen, 1980). During the period up to 1971, when logging was finally banned in the park (Ontario Ministry of Natural Resources, 1977), a small area of the test site was cut over. This area is spectrally separable on the satellite data, and was not included in the vegetation analysis.

DATA COLLECTION, DIGITIZATION, AND CLASSIFICATION

FIELD DATA

A preliminary field trip was made in the summer of 1989, and an intensive three-week expedition was undertaken in July of 1990. Aeromagnetic data (Department of Mines, 1961) and complete stereo air photo coverage of the site were used to guide field work. Shoreline geology was mapped throughout the area, and numerous traverses were made into the forests surrounding the lakes. Rock samples were collected for petrographic analysis. A final geological map based on field mapping and photointerpretation was digitized for later comparison with the spectral data.

Although the soil investigation was severely limited by equipment failures, 14 soil samples were collected for laboratory nutrient and texture analysis. A soil probe was used to aid soil boundary identification. Numerous observations were made of vegetation cover to guide photointerpretation of vegetation.

SATELLITE SPECTRAL DATA

A preliminary analysis of the 8 June 1986 SPOT HRV1/XS data over the test site showed it to be noisy, with a dominant striping pattern, apparently due to mis-calibrated sensors. More significantly, the dynamic range of data is extremely limited, having a standard deviation of only 5 and 4 DN in the green and red bands, respectively. Although the Landsat Thematic Mapper (TM) data of 21 August 1986 have approximately five percent cloud cover over the test site, the increased spectral and dynamic range made these data preferable to the SPOT data for spectral analysis. The cloud-free SPOT image was used, however, in the discrimination between land and water.

The seven-band TM data were analyzed and classified using an approach called nPDF, which is based on probability density functions (Cetin, 1990; Cetin and Levandowski, 1991a; Cetin and Levandowski, 1991b). nPDF consists of a suite of programs that has broad application for spectral transformations (Warner *et al.*, 1991), as well as for analyzing and comparing both image and training data spectral distributions (Cetin *et al.*, 1991). nPDF may also be used for supervised and unsupervised classifications.

The nPDF technique is based on an elegantly simple idea: the hyper-dimensional spectral distances are calculated from each pixel to selected extremities of the total possible range of the data, and these distances are then used as new data axes. For this paper, we refer to the corners of the hyper-dimensional data space using the numbering convention of Cetin and Levandowski (1991a). Typically, at least one of the extremities from which distances are calculated is chosen to be corner 1, the origin of the original data distribution.

Figure 3 shows the nPDF1 (distance to corner 1) versus nPDF6 (distance to corner 6) data distribution of the Quetico TM data. The axes on the graph have been stretched over the range of the vegetation spectral distribution. Using the same transformation on selected pixels taken from areas of known cover type, spectral classes may be identified, as is shown in Figure 4. Not surprisingly, forest classes form a continuous range from dominantly coniferous, through coniferous-deciduous mixtures, to dominantly deciduous classes, and then finally to bushes and other lush swamp vegetation.

The deciduous-coniferous range in nPDF1 versus nPDF6 was subdivided into six spectral classes, which correspond to cover classes with an increasingly deciduous makeup. The validity of this classification was checked by comparing selected pixels for each class with field data as well as stereo air photointerpretation. Using this spectral subdivision as a lookup table, an nPDF classification was carried out on the TM data. Swamps with a large amount of dead vegetation, which tend to plot on the lower side of the coniferous-deciduous vegetation trend in Figure 3, were classified using a separate nPDF4-nPDF6 scheme, because the swamps are more separable in that transformation. This is one of the great advantages of an nPDF classification: a classification may be carried out so as to distinguish only the class of interest (Cetin, 1990).

Digital Elevation Data

The Canadian 1:50,000-scale topographic map of the field area (Department of Energy, Mines and Resources, 1979) was digitized using a GTCO Digipad. The 45,943 manually digitized elevation points were interpolated and written to a 30- by 30-m UTM grid using the MINCURV program (Briggs, 1974; Swain, 1976). A subjective comparison of the elevation data with the stereo air photography shows the limitation of using a 1:50,000-scale map for digitization of 30-m pixels. Although the overall topography is well expressed in the digital elevation model, the fine detail is lost. This severely limits the delineation of small topographic features.

The digital elevation model was used for identifying the potential drainage class of each pixel. Because swamps and other moist sites are found at all elevations in the test area, it is not appropriate to assign low elevations to the class of poorly drained sites. Slope, generated from the digital elevation model, is a better predictor of drainage. However, it is necessary to discriminate between flat areas that are found on or near ridge tops, and thus likely to be well drained, from those that are at a lower elevation than the immediately surrounding pixels, and thus presumably sites of moisture accumulation. This latter moist site class should include depressions that occur in high ridges and plateaus.

Our separation of wet from dry flat sites was achieved by passing an 11 by 11 matrix over the digital elevation data. All elements of the matrix were assigned a negative one value, except the central pixel, which was set to positive 121. Filtered digital elevation data with positive values and associated with low slopes are assumed to represent well drained sites. A qualitative comparison of this classification with stereo interpretation of air photography confirmed that this procedure is successful.

Pixels with a north or east aspect and slopes steeper than three degrees were separated from slopes with a south and west aspect. The SPOT generated water mask was then overlaid on the site classification. The final result has four site classes (flat and moist, dry flat areas and ridge tops, north facing slopes steeper than three degrees, and south facing slopes steeper than three degrees) as well as a water class.

RESULTS AND DISCUSSION

The number of pixels of each of the six coniferous-deciduous forest classes growing on each lithology was calculated and then plotted in Figure 5 as a percentage of the total forested pixels for that lithology. Thus, the dominant forest class over granites has only a minor deciduous component. By comparison, the dominant cover class on the mafic lithologies is a coniferous-deciduous mixture.

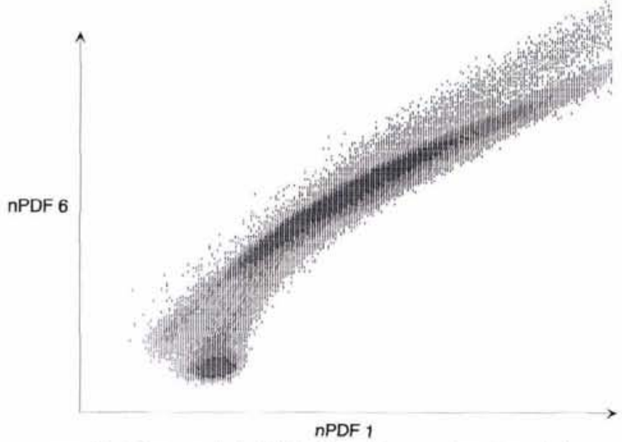

FIG. 3. nPDF spectral distribution of seven-band TM data.

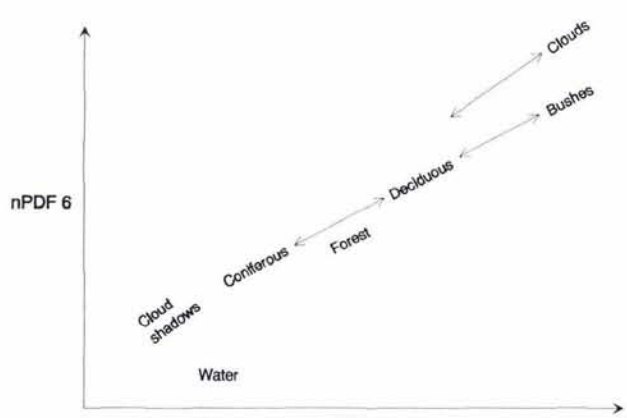

FIG. 4. Information class distribution in nPDF space.

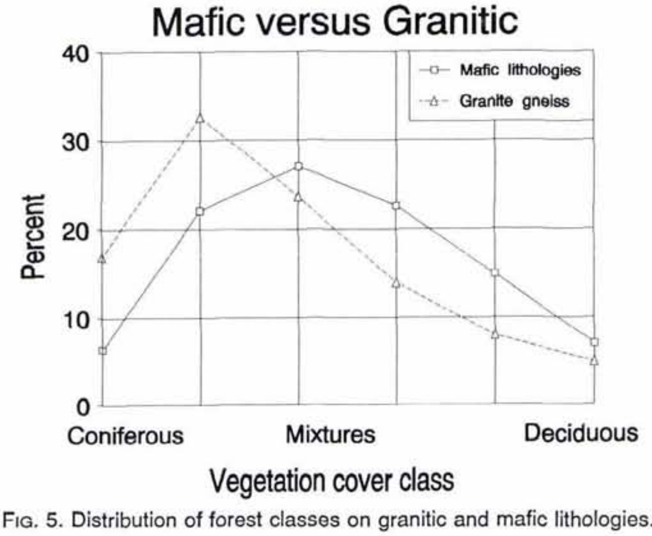

FIG. 5. Distribution of forest classes on granitic and mafic lithologies.

One possible interpretation of these results is that the increase in deciduous species is the fortuitous result of loess deposits being blown north of Kawa Bay onto the mafic lithologies. If this were so, we would expect to see an increase in the deciduous component in the forests northwest of the mafic lithologies which are growing on granites that also received some loess deposits. Figure 6 shows that, although there are minor differences between the north and south granite areas, the overall pattern is similar, thus discounting this theory.

When each lithology is divided into the separate site classes, the influence of topography and micro-climate may be evaluated. For the granitic lithologies, shown in Figure 7, there is no marked difference in the deciduous-coniferous makeup of the forests found on the various site classes. All sites are dominated by the coniferous class that has only a minor deciduous component.

Figure 8 shows that north facing, cool sites underlain by mafic lithologies have the highest coniferous component, and are not significantly different from the vegetation growing on granitic bedrock. Surprisingly, ridgetops and flat, dry sites were similar to moist, flat sites. This points to the limitation of only using a coniferous-deciduous classification scheme, because field work showed that the moist sites on mafic lithologies supported many deciduous species rather rare in Quetico, for example, black ash (*Fraxinus nigra* Marsh.) and American elm (*Ulmus americana* L.)

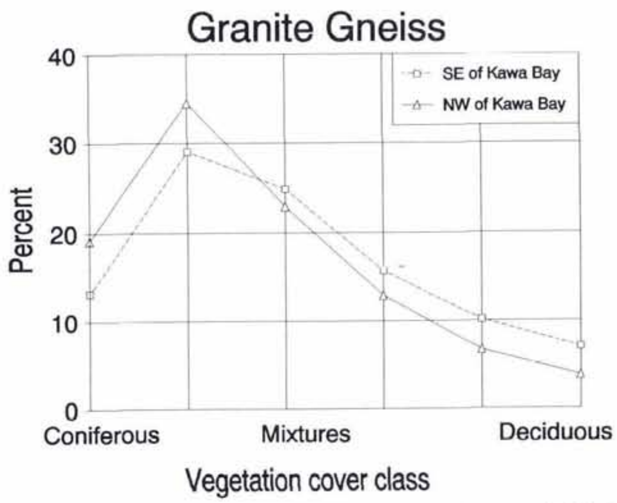

FIG. 6. Distribution of forest classes on two granite classes. A thin layer of loess is found in the area northwest of Kana Bay.

SUMMARY AND CONCLUSIONS

The spectral classification of vegetation into coniferous-deciduous cover classes confirmed that there is a subtle increase in deciduous species growing on mafic lithologies in this part of Quetico Park. In an area along the Quetico Fault, approximately 40 km north of this study site, Bell *et al.* (1989) found an increased deciduous component on ultramafic sites. Where forests grow on granitic rocks, there does not appear to be any significant variation in the cover classes found on the different site classes. The mafic lithologies were found to support a vegetation similar to that growing on granite for north facing slopes steeper than three degrees. Flat sites and ridge tops underlain by mafics are slightly enriched in deciduous species. South facing, warm slopes have the highest deciduous component.

It thus appears that aspect, drainage, and lithology all influence the forest cover in Quetico. Because of the importance of soils in this link, as well as the confounding influence of the loess cap, a field trip to Quetico is planned for the summer of 1991 to investigate this aspect further. The vegetation associations found for the test site will be used, along with topographic and aeromagnetic information, to predict lithologies in unknown areas in order to test the value of this information as a mapping tool in Quetico.

Despite the extensive effort made to produce an accurate digital elevation model, the results were hampered by the lack of detailed topographic information. Efforts are being made to obtain more accurate elevation information, and this may refine the trends described in this paper.

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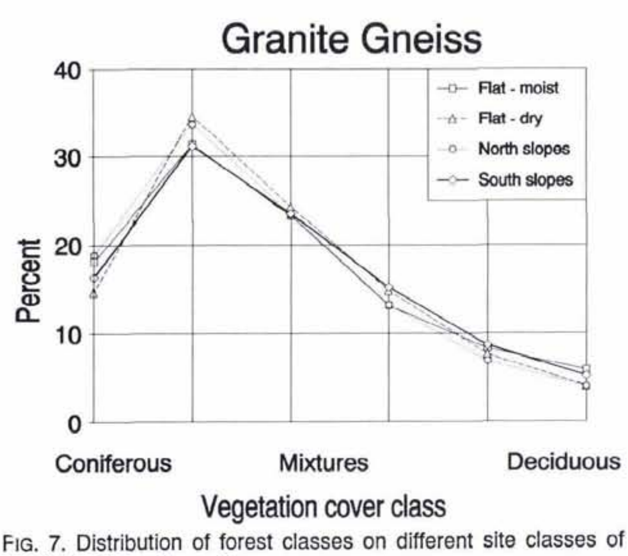

FIG. 7. Distribution of forest classes on different site classes of granite and granite gneiss.

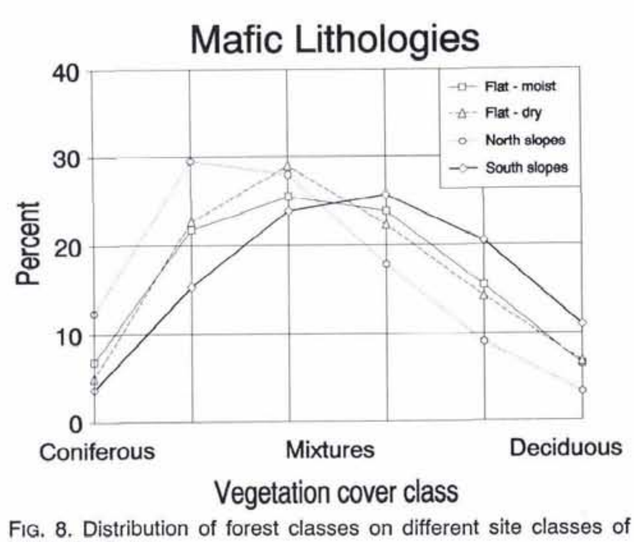

FIG. 8. Distribution of forest classes on different site classes of mafic lithologies.

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