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AN EXAMINATION OF THE OVERALL RELATIONSHIP BETWEEN SPECTRAL REFLECTANCE AND CHEMICAL COMPOSITION OF 58 MINE TAILINGS SAMPLES

H. SCHREIER AND L. M. LAVKULICH
University of British Columbia, Canada

I. ABSTRACT

Spectral reflection curves from 58 mine tailings samples were grouped into 11 unique spectral categories using a cluster analysis technique. A good rela-tionship was found between the spectral categories and Munsel colors (hue and value) but only 70% of all groups could be separated on the basis of a single chemical parameter (Fe). It appears that the overall chemistry has a profound in-fluence on spectral reflection, with total Fe, Al, Si and C playing a dominant part. The parameter interactions are complex and this makes it difficult to predict chemical concentrations from spectral reflection values. Cluster analysis offers a means to predict several parameters and allows an examina-tion of their interaction. However, the prediction accuracy of this technique needs to be improved.

II. INTRODUCTION

A number of authors have found partial relationships between spectral reflection and physical and chemical properties of soil samples (e.g. Shields[1], Baumgardner[2], Kristof[3], Montgomery[4], Pettry[5], Beck[6], Montgomery[7], and Gerbermann[8].) Such relationships are complex and in some cases restricted to certain concentration levels of the elements. Simple linear correlations and regressions are not entirely satisfactory since some of the relationships tend to be curvilinear, and parameters such as carbon, iron, carbon exchange capacity (CEC), clay and moisture interact and in part obliterate fundamental relationships of other parameters.[9] Some authors such as Condit[10], Beck[6], and Montgomery[7] suggest that a number of soils probably form characteristic spectral reflection curves and that soils from different climatic regions should be analyzed separately.

The subject of characteristic spectral curves was investigated in the present study using 58 mine tailings samples from 15 different British Columbia mines. The aims of the project were to:

1. Determine whether characteristic spectral curves could be identified for different types of mine tailings;

2. Determine the usefulness and accuracy of characteristic spectral values in determining chemical conditions;

3. Determine which individual chemical parameters have the greatest influence on spectral reflection.

Mine tailings were used in this study because they are   more discretely variable and show a greater contrast in overall chemistry than soil samples. Samples originating from 15 different mine tailings in British Columbia included material from lead, zinc, copper, molybdenum, coal, iron and gypsum mine operations. Mine tailings from a weathering experiment were also used in the analysis.

III. METHOD OF ANALYSIS

A. SAMPLE PREPARATION AND CHEMICAL ANALYSIS

The mine tailings samples were collected in 1976 and 1977 as part of an extensive study on mine reclamation[11]. Prior to analysis the samples were dried in the laboratory and the > 2 mm fraction was removed by sieving. Chemical anal-yses were performed using standard anal-ytical methods described by Lavkulich[12]. The following parameters were examined: total Ca, Mg, K, Na, Si, Al, Fe, Mn (teflon bombs HF digestion), exchangeable Ca, Mg, K, Na (ammonium acetate extrac-tion), available Ca, Mg, K (Hcl extrac-tion), extractable Fe (citrate-dithionite-

bic rbonate, ammonium oxalate, Na pyro-
phosphate), and total C and S (leco).

B. SPECTRAL REFLECTION MEASUREMENTS

The samples were distributed on a
flat 20 x 20 cm surface and spectral
reflection measurements were made in the
laboratory under artificial growth light
conditions using a Gamma Scientific
Spectrometer (Model 820 A). ERTS-band
filters 4, 5, 6 and 7 were used for this
study and both percent reflection and
band reflection ratios were determined
for each sample. High reflectance white
paint (Eastman Kodak) was used as a
standard for all reflection measurements.
The data was examined in the manner des-
cribed by Hunt[13], with the exception that
both band reflection and band ratios were
used in the analysis.

C. NUMERICAL CLASSIFICATION

The spectral reflection curves from
all samples were classified with an
average distance cluster analysis[14]. The
best results were obtained when all
spectral parameters (band reflection and
band ratios) were used in the multi-
dimensional procedure. The uniqueness
of the cluster groups obtained was ex-
amined with a Mann-Whitney significance
test[15].

IV. RESULTS

A. CHARACTERISTIC SPECTRAL REFLECTION CURVES

The 58 selected mine tailings
samples were grouped into eleven unique
spectral categories using the above des-
cribed cluster analysis. The resulting
dendrogram (Figure 1) provided a measure
of the degree of similarity between the
various spectral properties of all
samples. The individual spectral groups
(A to K) were found to be significantly
different from one another ($\alpha = 0.05$)
and as illustrated in Figure 2 each group
formed a distinct spectral category. The
origin of the menters in each group is
listed in Table 1 indicating that each
category included samples from only one
to three mine tailings. This strongly
suggests that the overall chemistry is to
a great extent responsible for the
spectral reflection values.

Evidence that the overall minerology
influences the spectral reflection is
further strengthened by the data obtained
from a weathering study. Five samples
were subjected to a two-week water and
acidic acid soxhlet extraction experiment
at 90°C. The comparison in Figure 3

shows that the spectral reflection curves
between the original and extracted
samples are slightly different but the
overall shape of the reflection curve
remains reasonably constant despite
changes in selective chemical parameters
resulting from leaching reactions. In all
cases the reflection curves fell within
the class limits determined by the
cluster analysis of the original samples.

Table 1. Distribution of Cluster Group.

CLUSTER GROUP	NO. OF SAMPLES	SOURCE (Name of Mine)
A	7	Endako, Similkameen, Brenda
B	1	Sullivan Gypsum
C	5	Bethlehem, Brenda
D	11	H.B. Hedley, Emerald
E	5	Lornex
F	3	Sullivan - Si
G	3	Sullivan - Fe
H	2	Emerald
I	7	Coal Creek
J	3	Velvet
K	11	Coast-Copper, Texada

B. RELATIONSHIP BEWTEEN INDIVIDUAL CHEMICAL PARAMETERS AND SPECTRAL REFLECTION

A number of chemical parameters
are responsible for the color of soils
and mine tailings, and differences in
colors can readily be observed by spectral
reflection measurements in the visible
wavelength range. It is thus assumed that
a relationship exists between some of the
chemical parameters and reflection values.
What is not clear is whether relationships
can be established between spectral
reflection and single chemical parameters
or whether several chemical elements act
in concert. Clearly the first type of
relationship would be more useful since
it provides a more simple basis for pre-
dicting individual chemical concentrations
from spectral values.

This question was examined in two
ways: (a) A comparison was made between
cluster groups and their corresponding
chemical concentrations, and (b) correla-
tions between spectral and chemical values
were determined using all sample data.

1. Comparison between Cluster Groups and
their Corresponding Chemical Concentra-
tions. The eleven spectral groups ob-
tained from the cluster analysis were
compared to one another in terms of their
chemical composition. As can be seen from
Figure 4 the eleven groups could not be
differentiated on the basis of any one

chemical parameter. About 70% of all categories appear to have unique total Fe values but for most other parameters only a partial class separation was obtained. When total F3, Al, and Si were considered in combination it appears that all categories could be distinguished chemically. However in some cases the within group variations were considerable and this in turn reduced the accuracy for prediction purposes. A good separation was possible using Munsel Hue and Color Value data, but carbon, which is generally considered a significant parameter influencing color, could not be used for separations in this study because only coal mine tailings exhibited significant carbon concentrations. It should be noted however that the overall spectral curves were significantly influenced by small amounts of dried plant litter. Three surface samples from partially revegetated tailings showed reflection values significantly different from subsurface samples without litter. This is readily illustrated in Figure 5 and indicates that care must be taken when analysing samples from vegetated surfaces.

2. Determination of Correlations between Spectral and Chemical Values using all Sample Data. Using spectral reflection versus individual chemical concentration a correlation-regression analysis was performed for all samples. Significant correlations were only obtained in a few cases. Total Fe, extractable Fe, total Si and total Al were significantly correlated with reflection values ($\alpha = 0.05$) but linear regressions to predict chemical properties from spectral values were not very satisfactory. The reasons for the poor relationship become evident from the scatter diagram in Figure 6. Although there appears to be a somewhat curvilinear relationship between spectral reflection and total Fe, at least three groups of mine samples did not fit the general relationship. Gypsum, coal and iron mine tailings behave differently. It is suggested that the discrepencies for the iron mine tailings might be caused by the differences in iron oxidation states, while the high carbon content might be responsible for the discrepencies observed in the coal and gypsum mine tailings. This implies that a rather complex relationship exists between chemical parameters and spectral reflection.

V. SUMMARY AND CONCLUSIONS

The spectral reflection curves of 58 mine tailings were grouped into eleven unique spectral categories with the aid of cluster analysis. Each category was made up of samples from the same or similar mine sites and this leads to the following conclusions.

A. CHARACTERISTIC SPECTRAL CURVES

The overall chemistry appears to have a profound influence on spectral reflection. This observation is further strengthened by the fact that the shape of the spectral curve did not change significantly when samples were slightly altered as a result of a weathering experiment.

B. CHEMICAL PREDICTIONS FROM SPECTRAL MEASUREMENTS

No simple relationships were found between individual chemical parameters and spectral reflection values. Several chemical elements appear to interact in a complex manner thus limiting the use of correlation/regression techniques. Cluster analysis was more useful since it allowed a simultaneous examination of several chemical parameters but the accuracy of this method needs considerable improvement.

C. IMPORTANT CHEMICAL PARAMETERS

Total and extractable Fe, total Si, Al and C were found to influence reflection. A more detailed examination is needed to determine how these parameters interact and what effect different iron oxidation stages have on the reflection. Finally a small amount of dried plant material and organic litter can significantly influence reflection values, which further complicates such analysis.
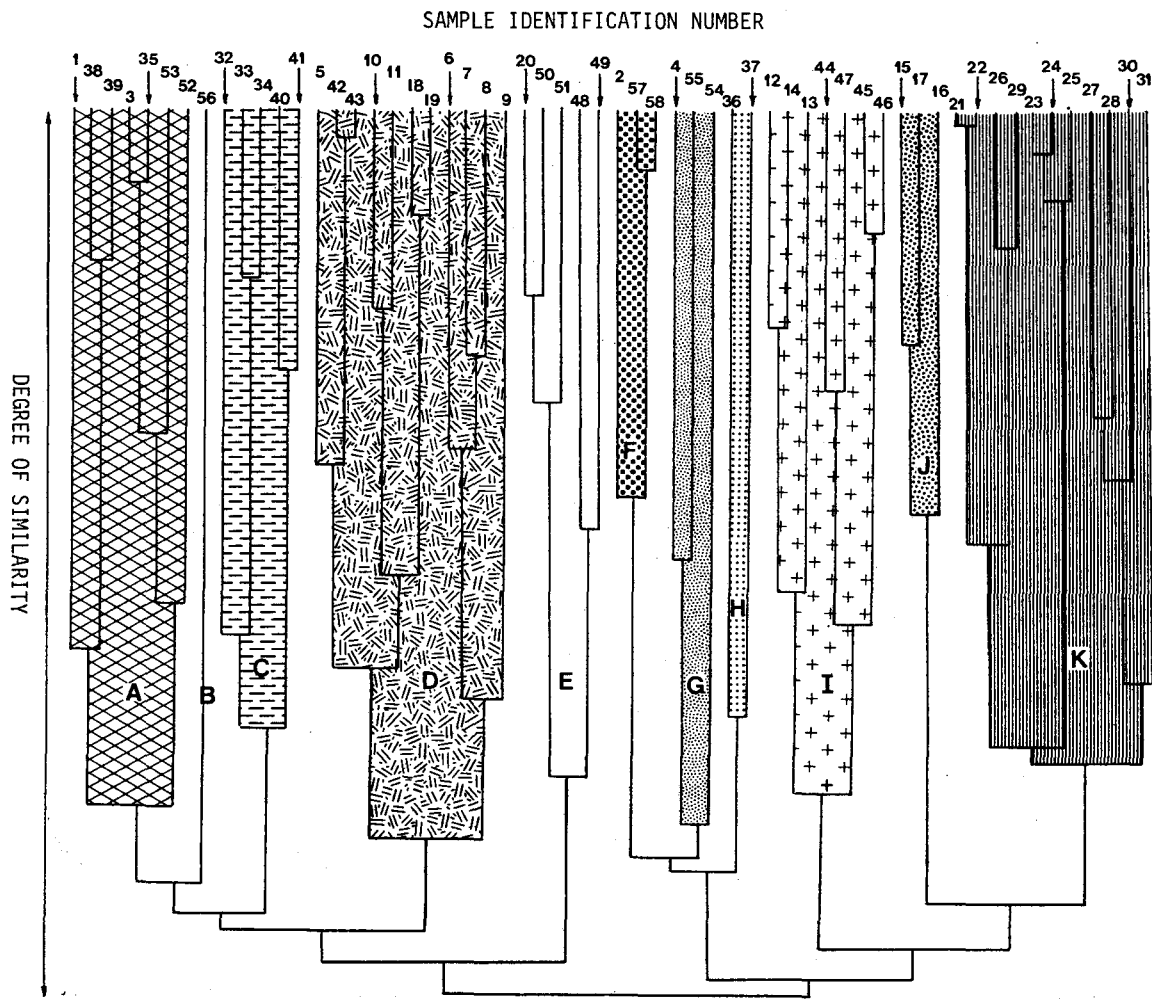
SAMPLE IDENTIFICATION NUMBER

Figure 1. Results from Cluster Analysis using Spectral Reflection Values.
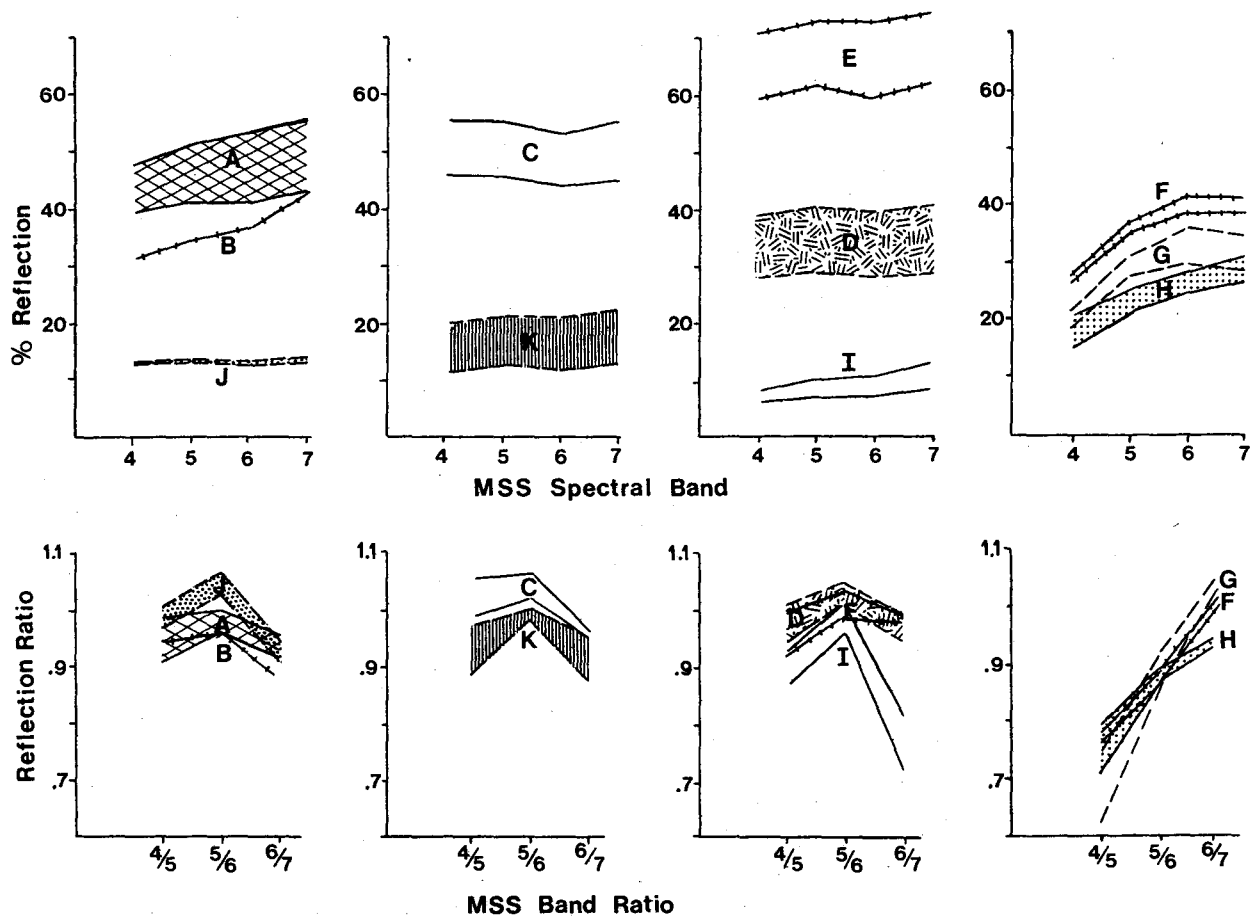
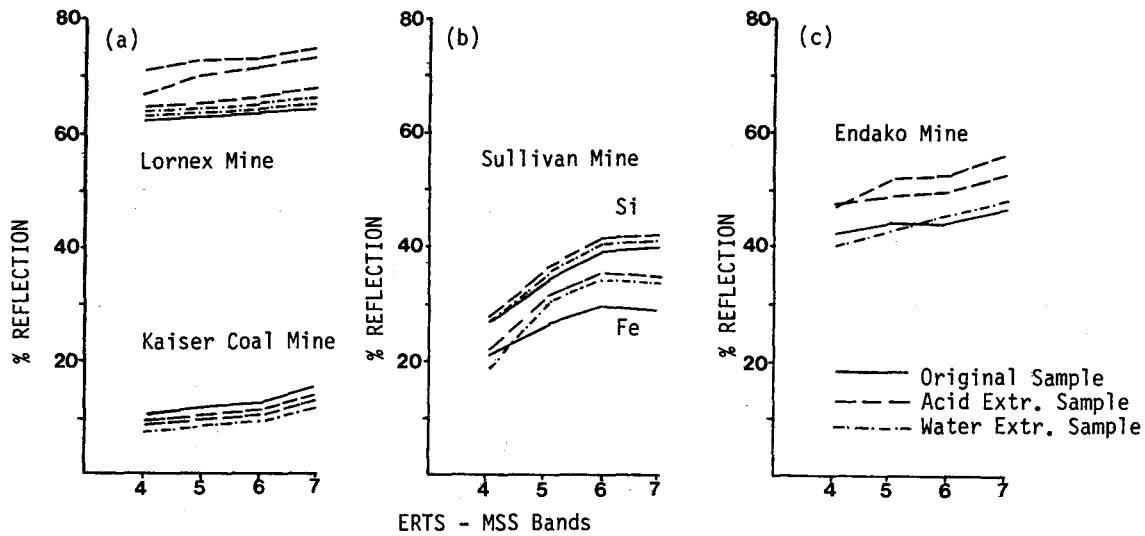Figure 2. Characteristic Spectral Curves of Cluster Groups.

Figure 3 (a,b,c): (a) Lornex Mine, Kaiser Coal Mine — % REFLECTION vs ERTS - MSS Bands (4 5 6 7); (b) Sullivan Mine, Si, Fe; (c) Endako Mine — Original Sample, Acid Extr. Sample, Water Extr. Sample

Figure 3 (a,b,c):Spectral Reflection Curves of Mine Tailings Samples Before and After Extraction

(a) % total Fe — A B C D E F G H I J K

(b) % Extractable Fe — A B C D E F G H I J K

(c) % total Si — A B C D E F G H I J K

(d) Sample Color Value — A B C D E F G H I J K

Characteristic Spectral Groups from Cluster Analysis
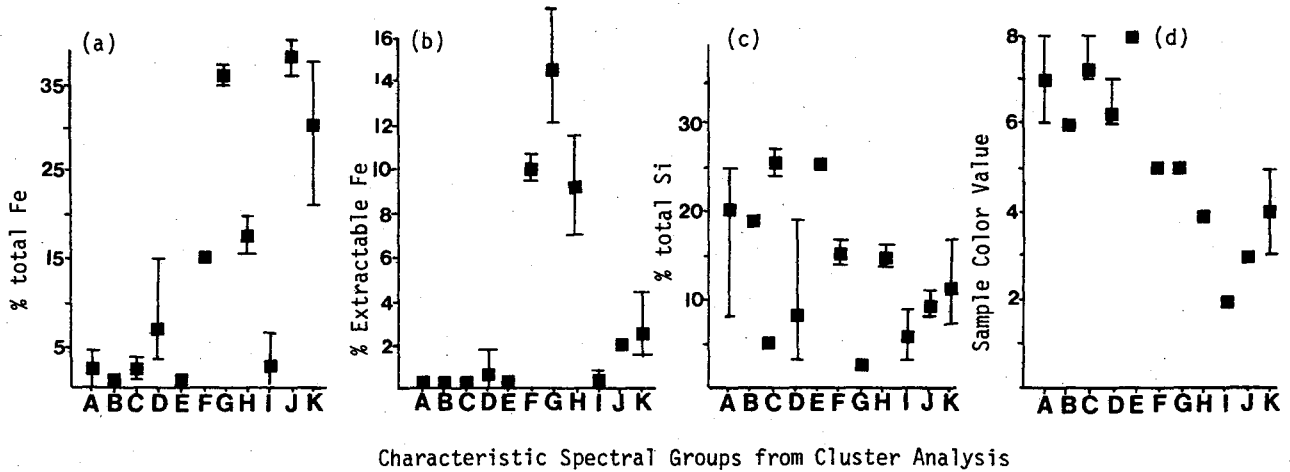
Figure 4 (a,b,c,d): Chemical Distribution of Cluster Groups A -K

Samples with dry plant litter
Samples without plant litter

(a) Coal Creek Mine — % REFLECTION vs ERTS - MSS Bands (4 5 6 7)

(b) Hedley Mine — % REFLECTION

(c) H. B. Mine — % REFLECTION
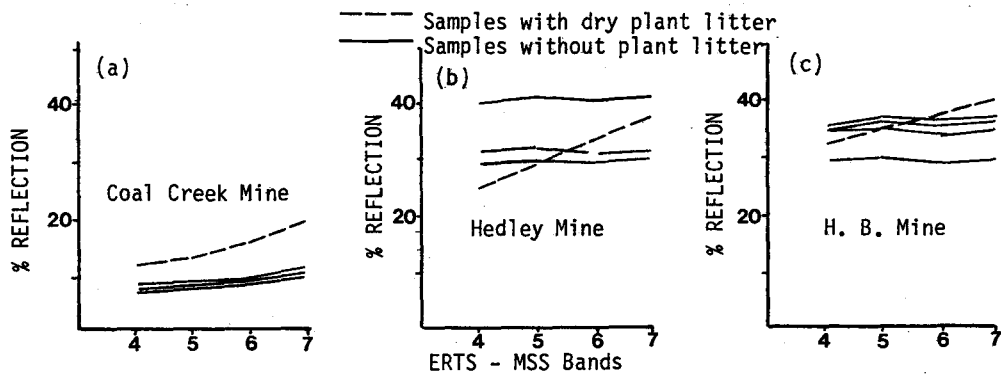
Figure 5 (a,b,c): Effect of Plant Litter on Spectral Reflection Values

● Endako, Similkameen, Brenda
w Sullivan Gypsum
x Bethlehem, Brenda, Giberaltar
△ Hedley, H.B.
▲ Emerald
□ Velvet
■ Texada, Coast Copper
U Coal Creek, Kaiser
F Sullivan Fe
S Sullivan Si
O Lornex

% TOTAL IRON

60
50
40
30
20
10

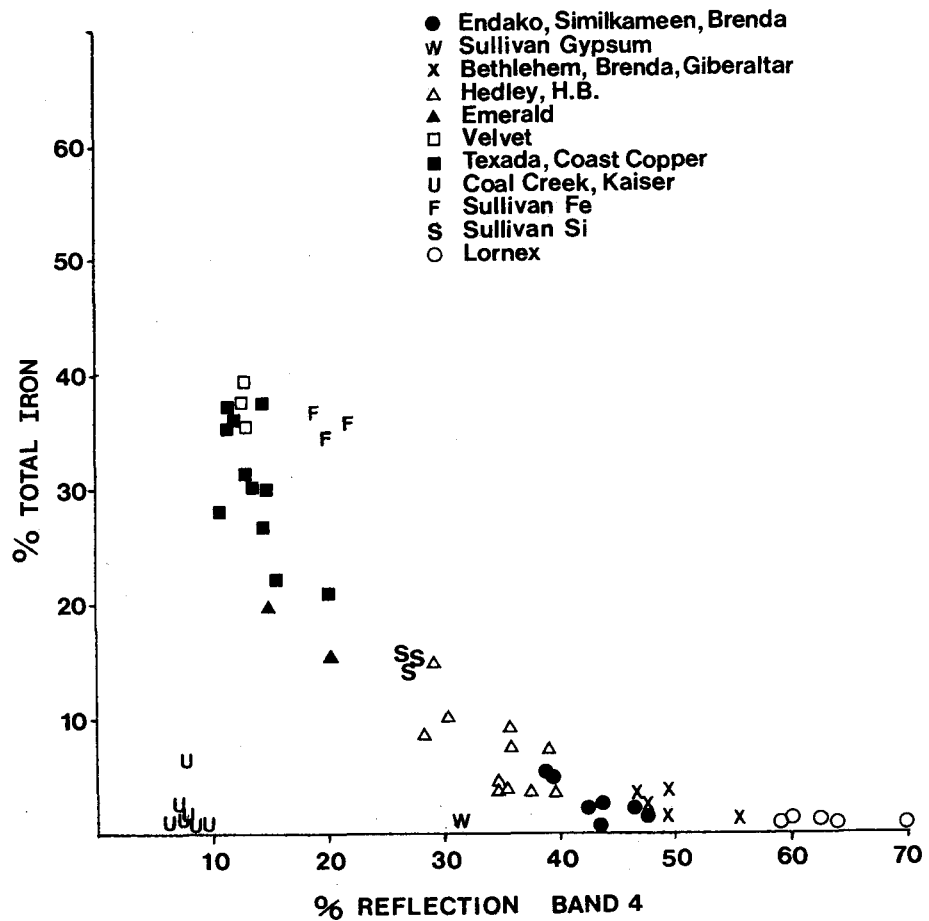10 20 30 40 50 60 70

% REFLECTION   BAND 4

Figure 6. Scatter Diagram: Spectral Reflection versus Total Iron.

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H. Schreier
B.A., 1970 (Colorado), Diploma in Aerial Survey
1972 (ITC, the Netherlands), M.Sc. 1973 in
Natural Resources Surveys (Sheffield, U.K.),
Ph.D. 1976 in Geomorphology (British Columbia,
Canada). Joined Department of Soil Science at
University of British Columbia in 1978.
Research areas include remote sensing, terrain
analysis, surficial geology, and chemical
relationships between land and water.

L. M. Lavkulich
Professor, Department of Soil Science,
University of British Columbia, Vancouver,
Canada. B.Sc. (distinction) 1961, M.Sc. 1963
(Alberta), Ph.D. 1967 (Cornell). Joined
Department of Soil Science in 1966 to teach
and do research in soil genesis and classifica-
tion. Involved in both undergraduate and
graduate programs. Research areas include:
terrain evaluation in Yukon and Northwest
Territories (Canada); mine waste characteriza-
tion; natural soil-plant relationships;
laboratory evaluations of soil genesis,
especially podzol (spodosol) soils.