

1-1-1980

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Schreir, H. and Lavkulich, L. M., "An Examination of the Overall Relationship between Spectral Reflectance and Chemical Composition of 58 Mine Tailings Samples" (1980). *LARS Symposia*. Paper 345.
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Reprinted from

**Symposium on
Machine Processing of
Remotely Sensed Data
and
Soil Information Systems
and
Remote Sensing and Soil Survey**

June 3-6, 1980

Proceedings

The Laboratory for Applications of Remote Sensing

Purdue University
West Lafayette
Indiana 47907 USA

IEEE Catalog No.
80CH1533-9 MPRSD

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

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I. ABSTRACT

Spectral reflection curves from 58 mine tailings samples were grouped into 11 unique spectral categories using a cluster analysis technique. A good relationship was found between the spectral categories and Munsell 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 influence 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 examination 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. Shields¹, Baumgardner², Kristof³, Montgomery⁴, Pettry⁵, Beck⁶, Montgomery⁷, and Gerbermann⁸.) 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 Condit¹⁰, Beck⁶, and Montgomery⁷ 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 reclamation¹¹. Prior to analysis the samples were dried in the laboratory and the > 2 mm fraction was removed by sieving. Chemical analyses were performed using standard analytical methods described by Lavkulich¹². 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 extraction), available Ca, Mg, K (HCl extraction), extractable Fe (citrate-dithionite-

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bicarbonate, ammonium oxalate, Na pyrophosphate), 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 described by Hunt¹³, 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 analysis¹⁴. 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 examined with a Mann-Whitney significance test¹⁵.

IV. RESULTS

A. CHARACTERISTIC SPECTRAL REFLECTION CURVES

The 58 selected mine tailings samples were grouped into eleven unique spectral categories using the above described 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 members 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 mineralogy 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 BETWEEN 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 predicting 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) correlations between spectral and chemical values were determined using all sample data.

1. Comparison between Cluster Groups and their Corresponding Chemical Concentrations. The eleven spectral groups obtained 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 ($r = 0.05$) 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 discrepancies 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 discrepancies 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.

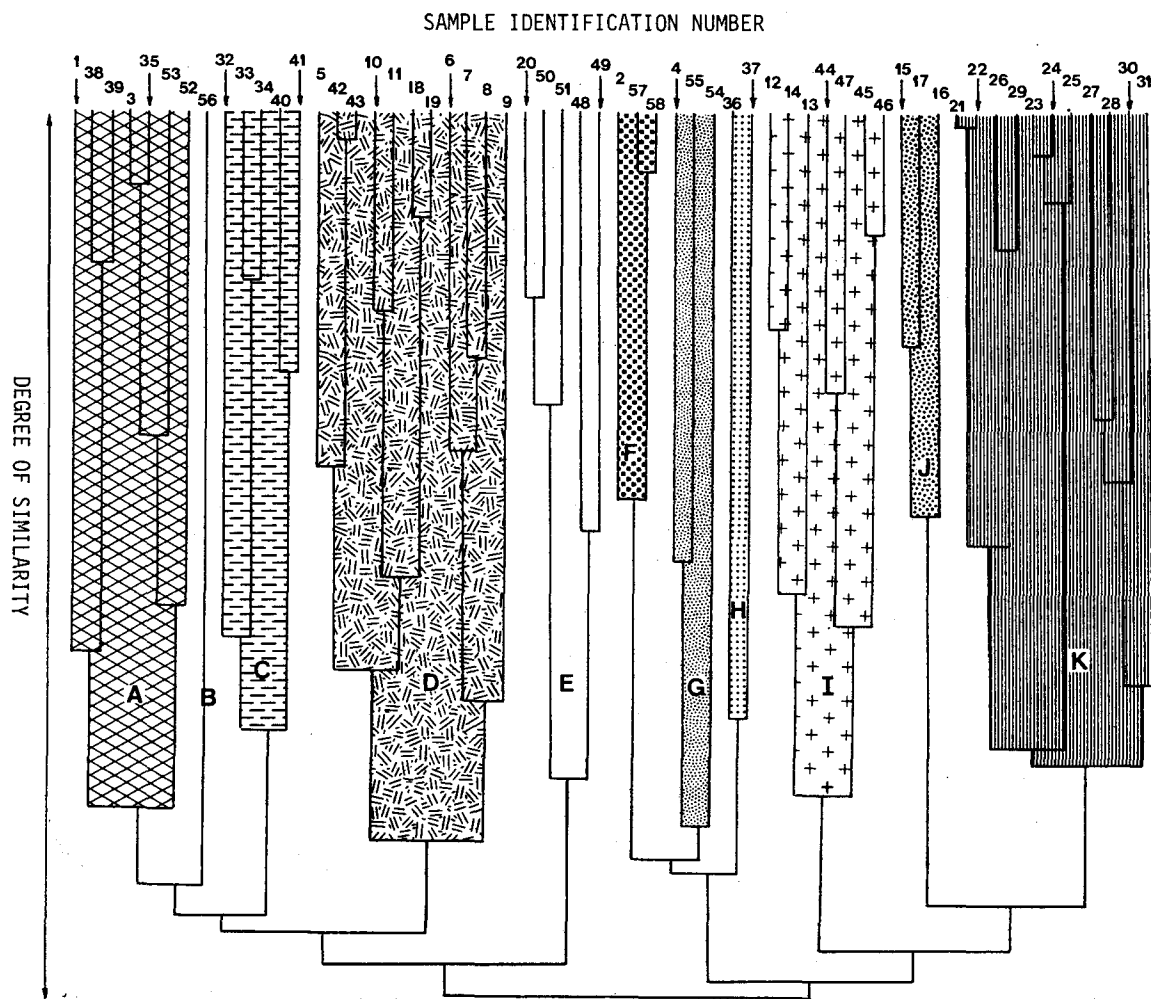


Figure 1. Results from Cluster Analysis using Spectral Reflection Values.

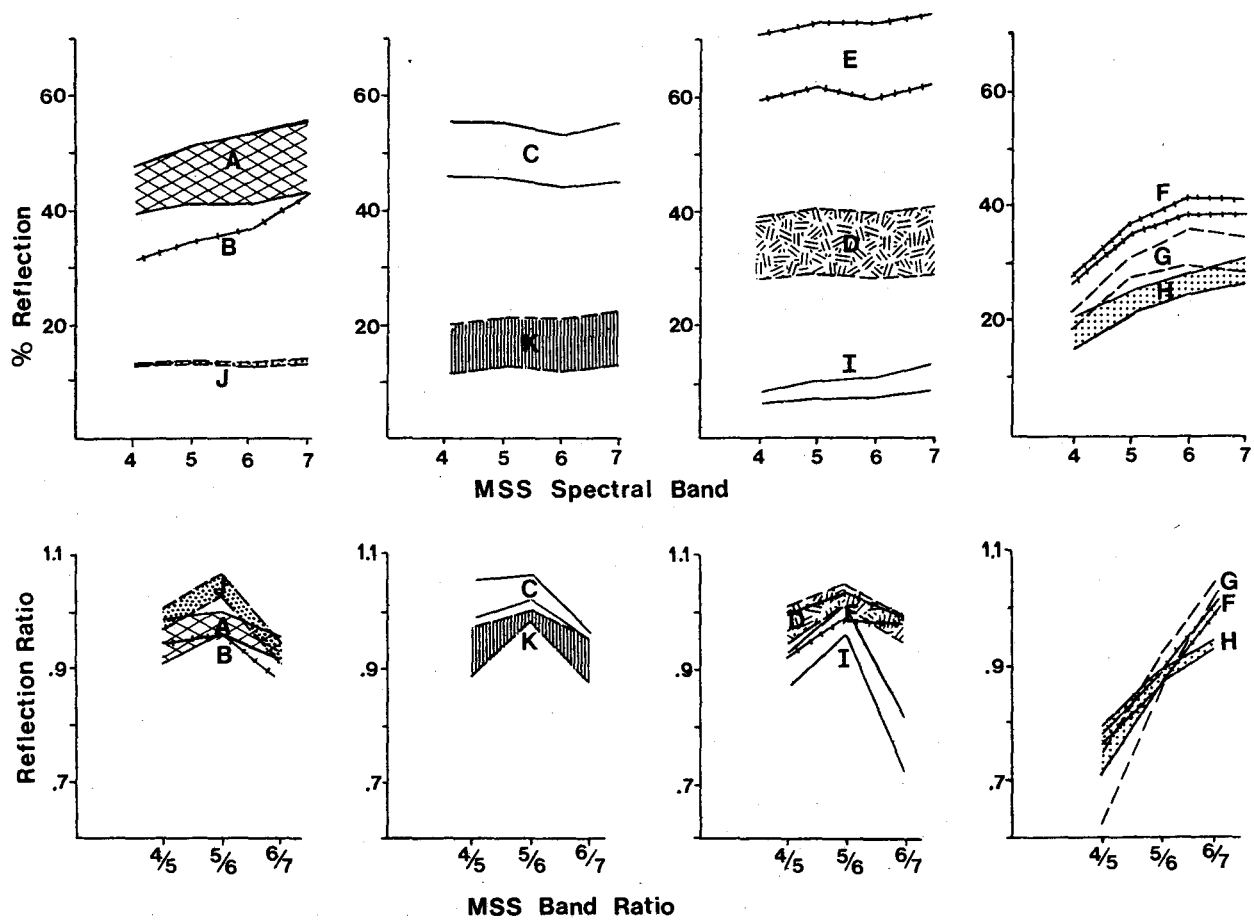


Figure 2. Characteristic Spectral Curves of Cluster Groups.

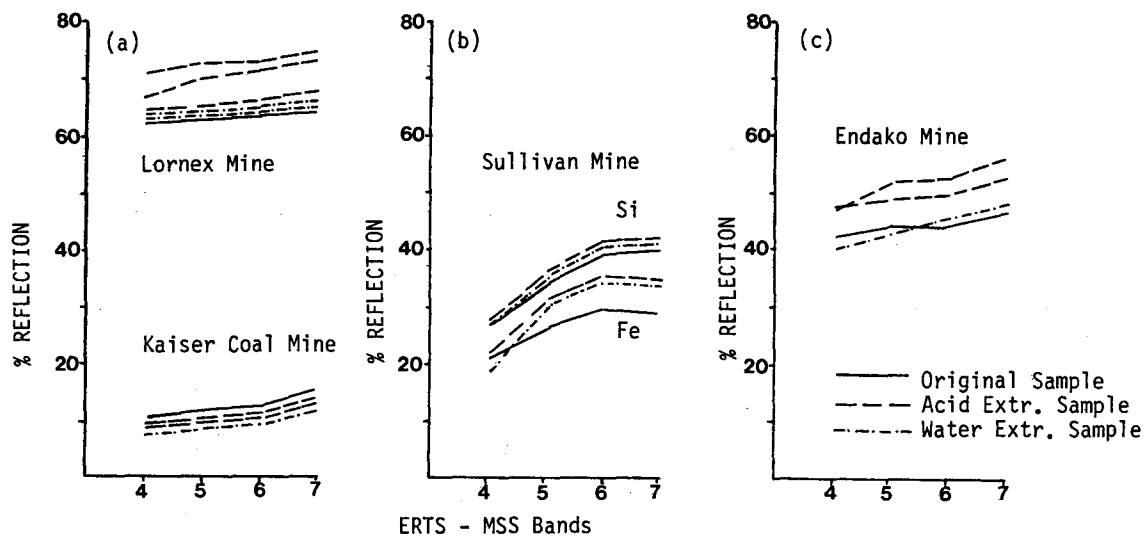


Figure 3 (a,b,c): Spectral Reflection Curves of Mine Tailings Samples Before and After Extraction

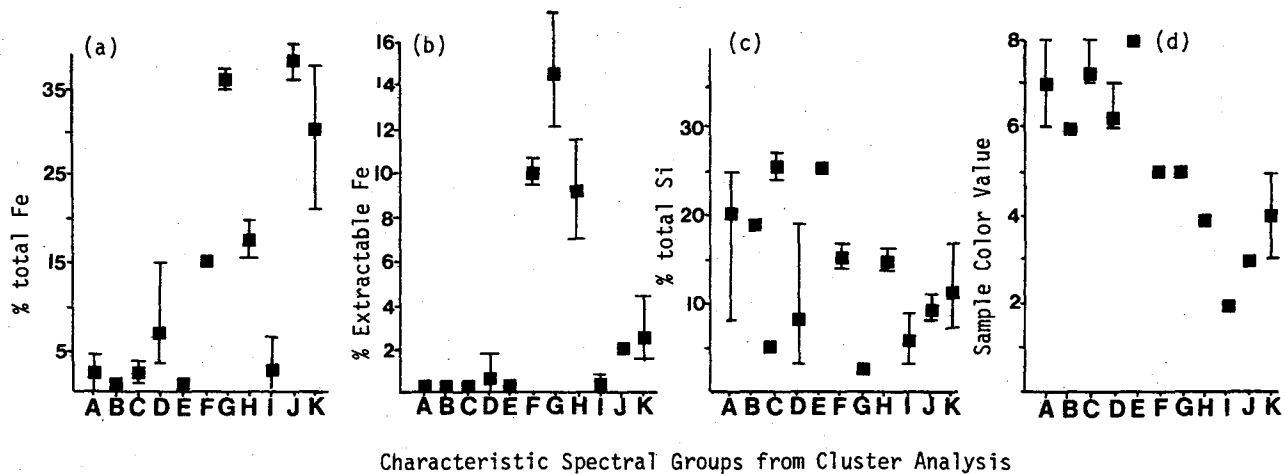


Figure 4 (a,b,c,d): Chemical Distribution of Cluster Groups A-K

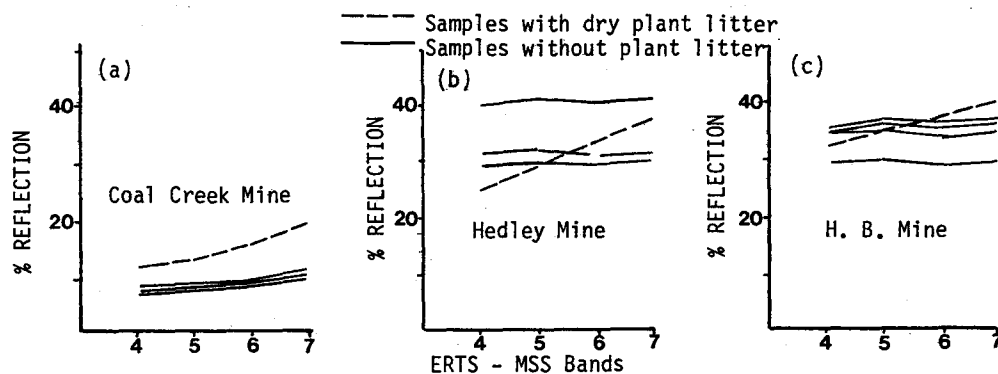


Figure 5 (a,b,c): Effect of Plant Litter on Spectral Reflection Values

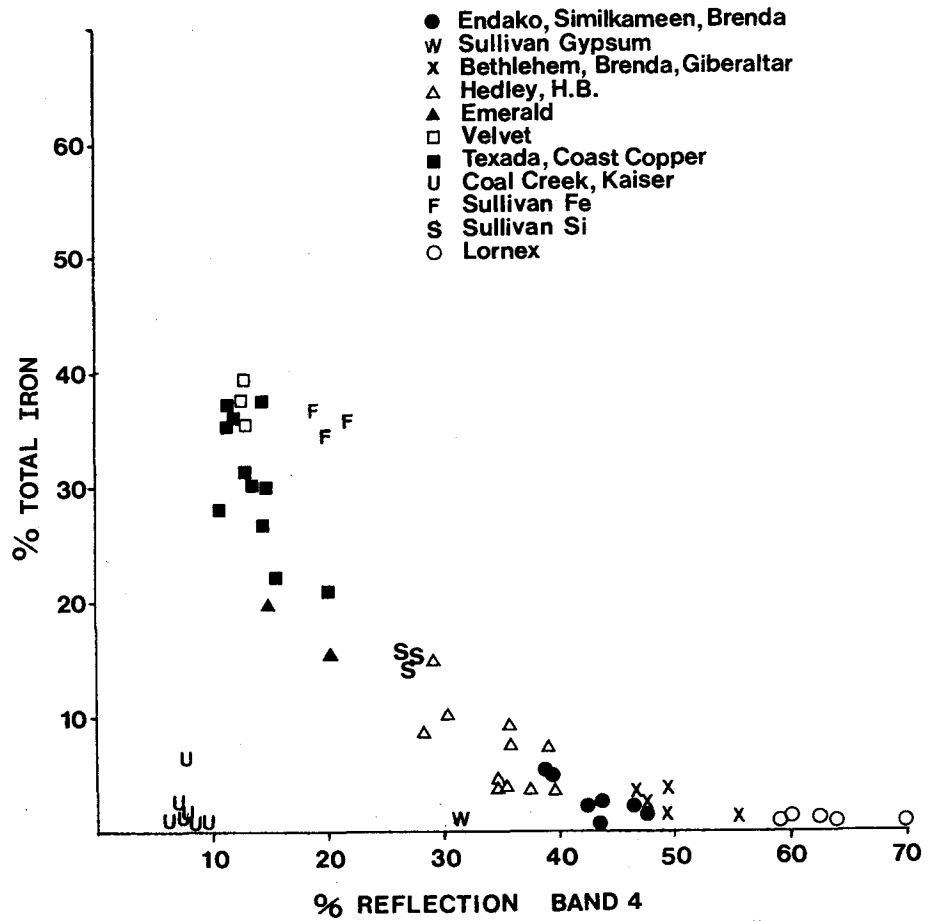


Figure 6. Scatter Diagram: Spectral Reflection versus Total Iron.

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