AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D. C. 20523

BIBLIOGRAPHIC INPUT SHEET

FOR AID USE ONLY
Batch 51

1. SUBJECT CLASSIFICATION
A. PRIMARY: TEMPORARY
B. SECONDARY:

2. TITLE AND SUBTITLE
Relationship between vegetation reflectance spectra and soil geochemistry: new data from Catheart Mountain,Maine

3. AUTHOR(S)
Canney,F.C.; Wenderoth,Sondra; Yost,Edmund

4. DOCUMENT DATE	5. NUMBER OF PAGES	6. ARC NUMBER
1969	9p.	ARC

7. REFERENCE ORGANIZATION NAME AND ADDRESS
Geol.Sur.

8. SUPPLEMENTARY NOTES *(Sponsoring Organization, Publishers, Availability)*

9. ABSTRACT
(SCIENCE AND TECHNOLOGY R & D)

10. CONTROL NUMBER	11. PRICE OF DOCUMENT
PN-AAD-158	
12. DESCRIPTORS	13. PROJECT NUMBER
	14. CONTRACT NUMBER: PASA TA(IC)-05-73 Res.
	15. TYPE OF DOCUMENT

AID 590-1 (4-74)

SECTION 18 Geology

RELATIONSHIP BETWEEN VEGETATION REFLECTANCE SPECTRA AND SOIL GEOCHEMISTRY: NEW DATA FROM CATHEART MOUNTAIN, MAINE*

by

F. C. Canney
U.S. Geological Survey
Denver, Colorado

and

Sondra Wenderoth, and Edward Yost
Long Island University
Greenvale, New York

ABSTRACT

Studies in 1968 at Catheart Mountain, Maine (where a copper molybdenum deposit is concealed beneath soil on a forested mountainside), suggested that measurement of the spectral reflectance of vegetation might be a useful tool in exploration for concealed mineral deposits from aircraft and, possibly, from spacecraft. The spectral-reflectance curves for red spruce and balsam fir in the 350- to 1100-nanometer region showed differences between specimens growing over and away from the mineral deposit. However, the inferences that could be drawn from the data were limited by the small number of samples (19) and the relatively large variance of the spectroradiometric data. Thus, when improved instrumentation became available in 1969, the experiment was repeated on a larger sample group (15 anomalous spruce, 9 background spruce, 10 anomalous fir, and 10 background fir). Measurements of copper and molybdenum contents in the supporting soil were used to categorize the trees as anomalous or background.

Analyses using parametric and nonparametric statistical tests were performed to establish whether significant differences existed between the anomalous and background groups. At the 95-percent confidence level, significant differences were found to exist for both species, generally in the chlorophyll band centered at about 550 nanometers and in the region from 700 to 900 nanometers. In general, these results confirmed the 1968 study but at a much higher level of confidence.

---

*Publication authorized by the Director, U.S. Geological Survey

INTRODUCTION

The basic long-range objective of our work is to attempt to develop more efficient ways of prospecting for mineral deposits. Traditional prospecting methods, wherein geologists roam across the countryside and examine rocks visible at the surface, can no longer be expected to produce many important mineral discoveries. Most areas of the world amenable to this way of prospecting have been examined repeatedly by several generations of prospectors. However, in large areas of the world, rocks favorable for the occurrence of ore lie concealed beneath a mantle of soil. It is in such areas that many important ore discoveries have been made by utilizing the newer geochemical and geophysical techniques. For example, the discovery of an area of soils abnormally rich in metals--a geochemical anomaly--furnishes a strong clue to the possible presence of a nearby concealed mineral deposit. But to find such geochemical anomalies on the ground requires painstaking and expensive ground surveys. We simply have to develop cheaper techniques of finding such anomalous zones by appropriate sensors mounted on aircraft or space platforms if the world's needs for an increased supply of critical minerals are to be met.

At the last program review I reported on the feasibility of using the reflectance spectra of trees to detect such soil anomalies. Interrelationships between a tree and its environment are complex, and many parameters affect plant health, growth, and trace-element composition; the geological environment is one of the more important environmental parameters. In recent years, it has occurred to a number of individuals that trees growing in an abnormally metal-rich soil should be in a stressed condition and that this stressed condition and, hopefully, the cause of the stress--a mineral deposit--could be detected by analysis of vegetation spectra.

PREVIOUS WORK

Two years ago the U.S. Geological Survey and the Science and Engineering Group of Long Island University under Prof. Edward Yost collaborated in a feasibility study on this supposition. The site used to test the hypothesis was Cathcart Mountain, Maine, where a copper-molybdenum deposit is largely concealed beneath soil on a completely forested mountainside. The soils contain anomalous amounts of metal, mostly copper and molybdenum, and these metals, especially molybdenum, are also concentrated in the trees.

As I reported last year, the reflectance spectra of balsam fir and red spruce trees were measured by placing a spectroradiometer on a "cherry-picker" to get the instruments above the tree level and thus look at the tree as an aerial camera or scanner would see it. Simultaneous measurements of reflected and incident radiation were obtained. The results indicated that a difference existed between the spectra of balsam fir and red spruce growing in soils with anomalous copper-molybdenum contents and the same species growing in soils of normal metal contents. However, although the differences noted were highly encouraging, we could not claim, in general, that they were significant at the 95-percent confidence level. This was due principally to the small number of samples used--(19)--and by the relatively large variance of the data in the 750- to 1100-nanometer region.

Thus, when improved equipment became available the following year it seemed advisable to repeat the experiment on a larger sample group. This was done in August 1969.

1969 FIELD WORK

The equipment employed for measuring incident and reflected radiation in the near-ultraviolet, the visible, and the near-infrared portions of the spectrum was modified considerably for the second test. A truck equipped with a 36-foot periscope tower replaced the cherry-picker, both reflectance spectroradiometers were located within the truck, and the data were recorded automatically on paper tape. The use of this truck greatly increased the efficiency of the operation because, as the upper mirror could be angularly adjusted and the entire tower itself could be rotated, five to ten trees could generally be scanned from one setup.

Two incident spectrometers were set up in a clear area close to the equipment van. These instruments were calibrated separately, and the resultant data were then averaged and treated as one reading.

All reflectance measurements consisted of three scans per target; each scan included 27 data points of three readings each measured at every 25 nanometers from 350 to 750 nanometers and at every 50 nanometers from 750 to 1250 nanometers. At the start of each day the reflectance spectroradiometers were calibrated against a white diffusing plate. Also, because a cooled detector was used, the precision of the infrared measurements was much better in 1969 than in 1968.

Great care was taken in the experiment that several important variables did not influence the data appreciably. Measurements were

made in fully illuminated areas of the tree, and extraneous reflectance from background objects such as other trees, patches of ground, or dead branches was kept minimized by careful selection of the tree area to be measured.

Samples of soil at the base of each tree, as well as samples of tree needles, were collected and chemically analyzed. The division of trees into background and anomalous groups was made on the basis of the metal content of the soil. In this second experiment, 44 trees were measured--15 anomalous spruce, 9 background spruce, 10 anomalous fir, and 10 background fir. The average directional reflectance spectra of each of the 44 trees was computed from the in situ measurements of incident and reflected radiation using the calibrated reflectance standard.

RESULTS

These data were analyzed for significant differences between tree groups using both parametric and nonparametric statistical tests. I am glad to be able to report that differences again appeared between anomalous and background groups, and that this time the differences were generally significant at the 95-percent confidence level.

Figure 1 shows data for red spruce and balsam fir. For red spruce the obvious increase in spectral reflectance of the anomalous group in the visible part of the spectrum (400-700 nanometers) and decrease in the infrared (IR) part of the spectrum (700-1100 nanometers) is evident. The black band at the top shows where the differences are significant. In 1968 our data revealed the decrease in the infrared for the anomalous group but not the increase in the visible. In 1969, however, our anomalous group was growing in soil only slightly anomalous in metal in contrast to the 1969 group. The increase at about 550 nanometers probably indicates a lower chlorophyll content in the needles of the anomalous group caused by the effect of the abnormal chemical environment on the metabolism of the trees. The decrease in IR reflectance undoubtedly reflects some alteration in the mesophyll cell structure.

For balsam fir you note the anomalous group is more highly reflective in both the visible and IR. This is also what we found in 1968 although at a lower level of significance. For balsam fir, as for spruce, the higher reflection in the visible is probably indicating an incipient chloratic condition, although the anomalous trees appeared quite healthy to the eye. Why anomalous fir should show an enhanced IR

reflectance whereas anomalous spruce shows a decrease is most interesting, but we have no good explanation at the moment. One of us (FCC), however, plans to make some studies of needle-cell structure and these may provide some clues.

In order to determine to what extent the soil geochemistry was related to the reflectance spectra, a multiple regression analysis was performed for both tree species using the soil mineralization as the independent variable and the reflectance spectra as the dependent variable. These data are shown in table 1. You can see that, in general, balsam fir shows the greatest multiple correlation between all elements and the reflectance spectra--about 0.8 at a number of wavelengths. The coefficients of red spruce show the same general relationship between soil geochemistry and spectra although the values of these coefficients are somewhat less.

The correlations between reflectance data and metal content in the plant tissue itself have not as yet been studied in detail, but I thought these data (fig. 2) worth showing. You will note the rather good relationship between molybdenum content and reflectance; the copper points, on the other hand, are rather erratically distributed. One may speculate that, at least for balsam fir at Catheart Mountain, molybdenum may be the more important element affecting reflectance.

Of course, in these complex natural environments, it is really quite difficult to evaluate the influence on reflectance of any one element. To do this I think it will be necessary to go to controlled greenhouse studies, and the Geological Survey has plans to get such studies underway very soon.

FUTURE PLANS

Where do we go from here? Obviously, after the successful second Catheart ground experiment, aerial experiments were indicated and these were done the last week in August by the Michigan aircraft. We were plagued by bad weather and could not fly all scheduled lines and runs, but the more important ones were successfully flown. I have not yet received any data from this mission. Provided the results of the Michigan flight are encouraging, the Catheart site will be suggested for an ERTS-type experiment because the size of the anomalous area is about a mile square.

Additional Catheart-type ground experiments for different metals and vegetation species in different geological environments should be

done. A group in the Geological Survey has, in fact, just completed last week one such study in the Front Range in Colorado. There the reflectance of Pinus Ponderosa in the near IR was found to be significantly greater for sites of high copper content--in the 800-1,900 ppm range in the soil--than for sites of low copper content--40-170 ppm.

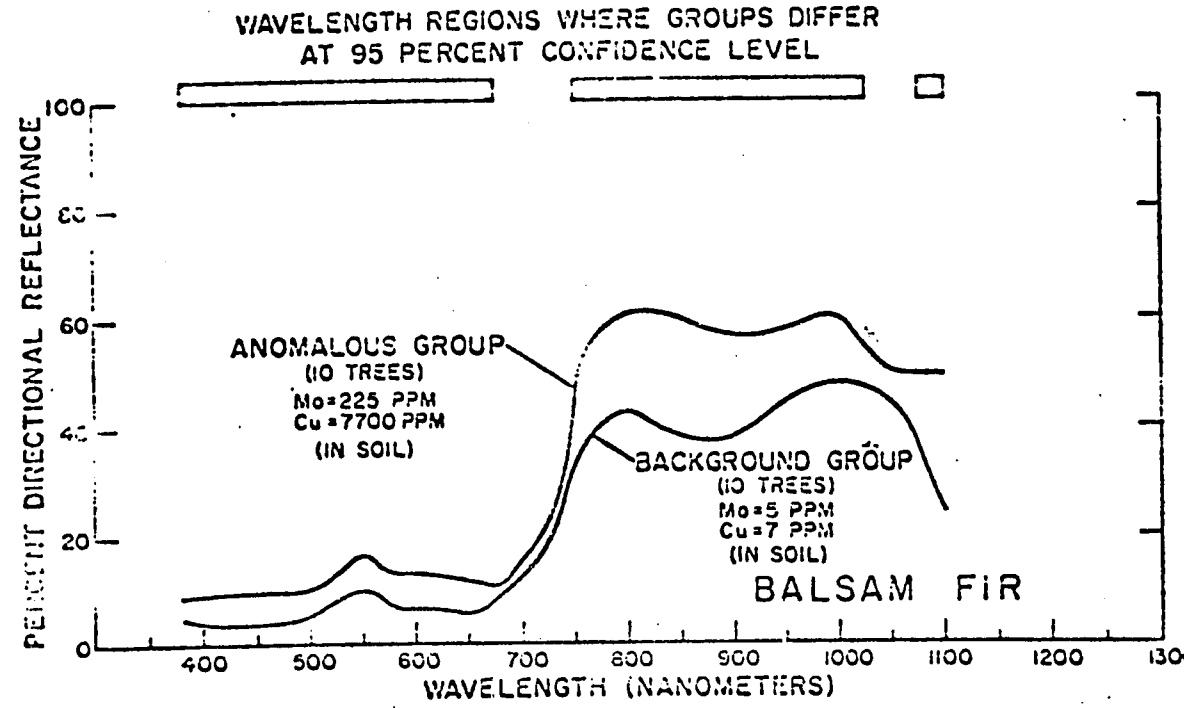
The Geological Survey also has plans to study a site in the Republic of Panama where a copper-molybdenum deposit occurs in a tropical rain-forest environment.

Repetitive coverage of one or more sites is sorely needed to ascertain changes in reflectance during a growing season. It seems that this could be accomplished easily from ERTS, and such an experiment will be proposed.

In conclusion, I am still highly optimistic that continuation of research in this field will ultimately result in a dramatic new way of prospecting for mineral deposits from aircraft or space platforms.

TABLE I.- CORRELATION OF REFLECTANCE WITH TRACE-ELEMENT CONTENT OF SOIL

WAVE LENGTH (nm)	MULTIPLE CORRELATION COEFFICIENT	
	RED SPRUCE	BALSAM FIR
380	0.688	0.777
400	0.738	0.769
425	0.719	0.790
450	0.713	0.800
475	0.717	0.782
500	0.726	0.778
525	0.706	0.828
550	0.680	0.823
575	0.705	0.822
600	0.646	0.810
625	0.650	0.813
650	0.663	0.818
675	0.726	0.348
700	0.667	0.432
725	0.690	0.776
750	0.587	0.839
800	0.651	0.816
850	0.640	0.819
900	0.423	0.833
950	0.703	0.737
1000	0.719	0.765
1050	0.673	0.739
1100	0.510	0.786



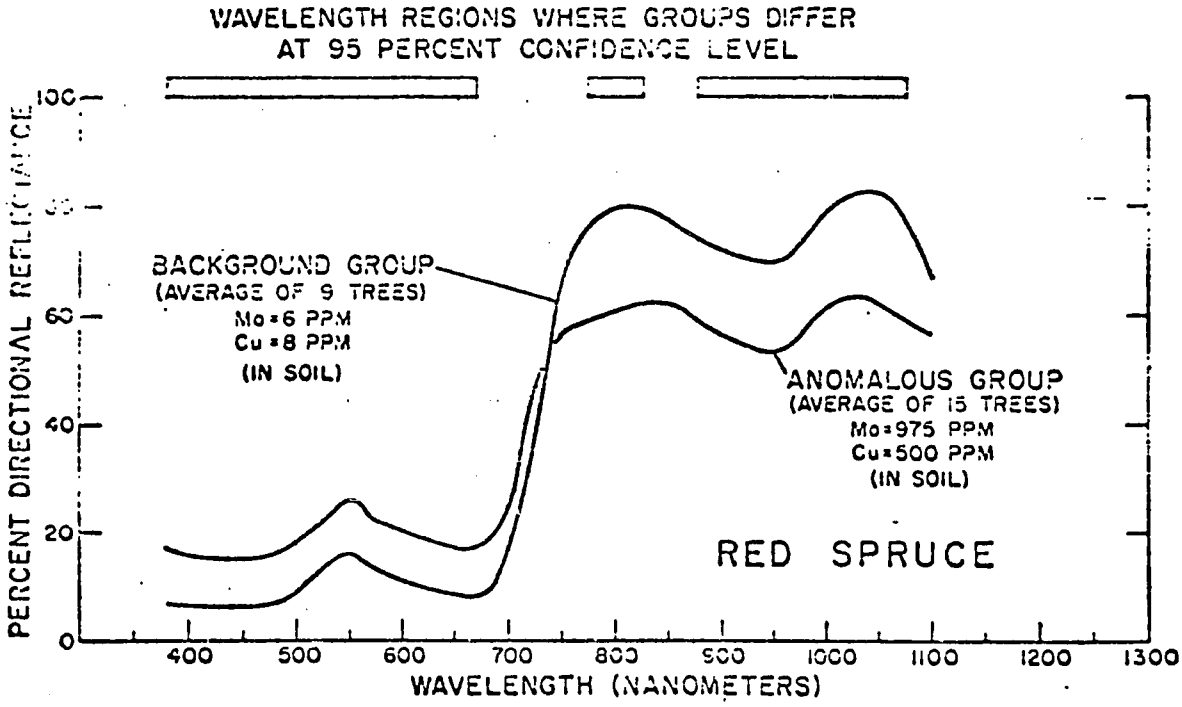


Figure 1.- Reflectance of balsam fir and red spruce

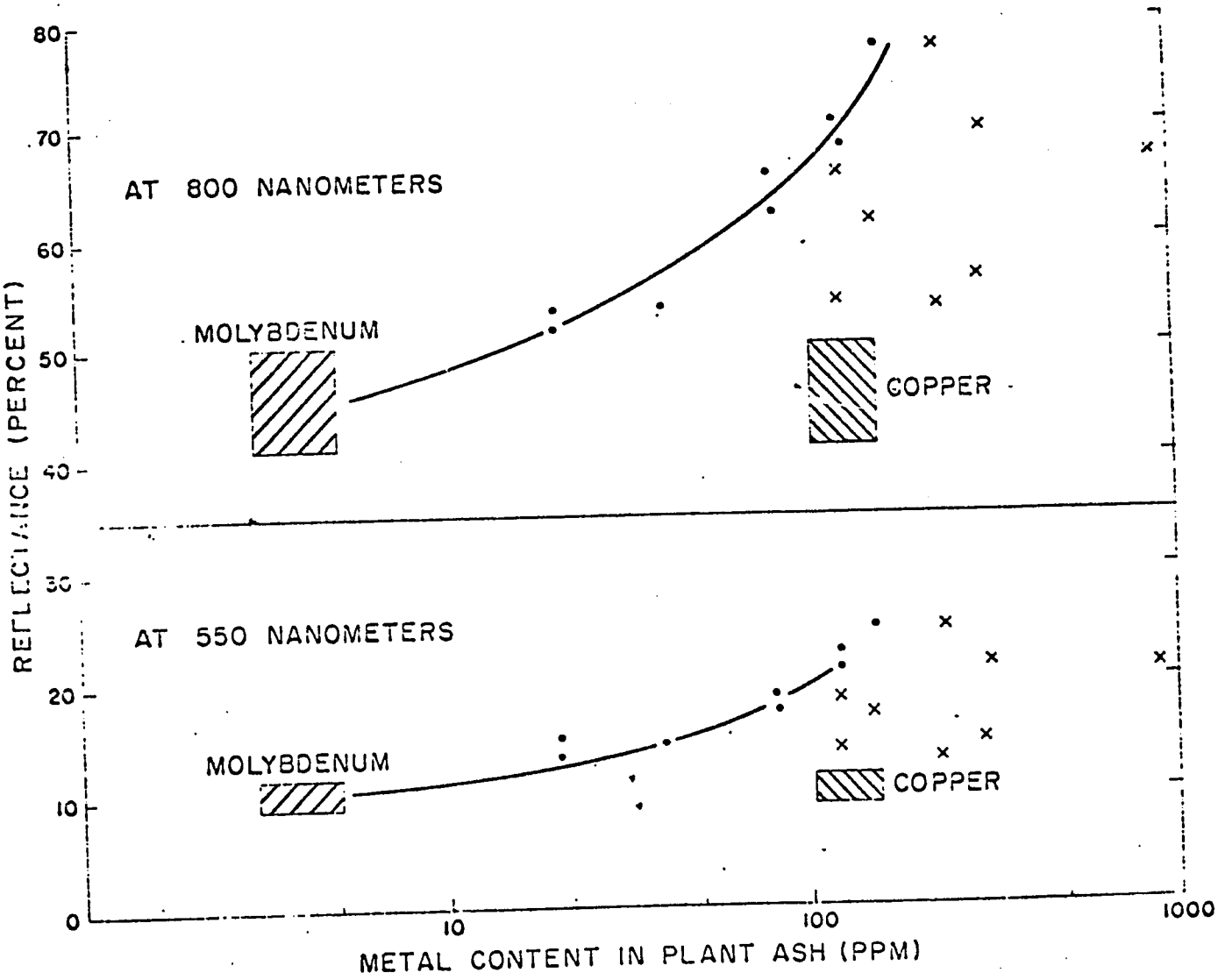


Figure 2.--Relationship between molybdenum (solid dot) and copper (X) contents of balsam fir needles and directional reflectance at 550 and 800 nanometers.