only under special conditions and far less than the photo makes possible.

Photogrammetry can be one of the most useful tools in the continued economic growth and development of our country. But if photogrammetry is to be fully utilized as a planning and engineering tool, in the progressive development of the smaller communities of this country, as well as in the larger cities, there must be demonstrated the many various applications which can be of beneficial nature to these municipalities. In this manner the greatest good can be derived, and the maximum possible service rendered to the nation.

*A Spectral Reflectance Study Using A Wedge Spectrograph**

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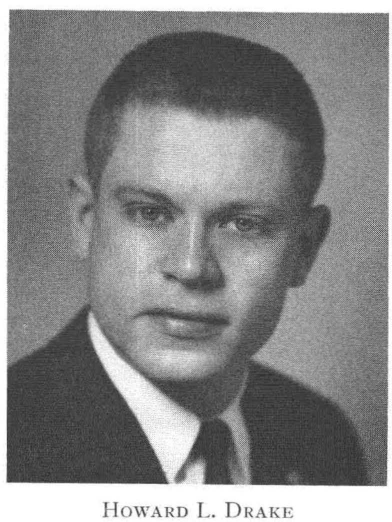
ABSTRACT: *The wedge spectrographic method of measuring the spectral reflectance of airphoto subjects employs a wedge spectrograph and a standard white reflectance surface. This method uses the sun for the source of light. Although time of day and atmospheric conditions affect the composition of sunlight, it is calibrated by exposing a spectrogram of the standard white reflectance surface within ten seconds of obtaining the test surface spectrogram.*

The standard surface can be fixed conveniently within two feet of the spectrograph slit while the object distance may be varied from a few feet to several thousand feet. Thus, the wide range of possible object distances combined with extreme portability make the wedge spectrograph a convenient instrument for both airborne and terrestrial studies of spectral reflectance.

INTRODUCTION

THE property of a material to selectively reflect certain components of incident light and to absorb or transmit the remainder is termed *spectral reflectance*. For this reason, materials have characteristic colors. The complex nature of rock formations cause analytical methods of spectral reflectance determination to be quite difficult. Hence, spectral reflectance is measured directly.

By the proper selection of film and filter the sensitization of an aerial camera may be adjusted, to be most sensitive to certain regions of the spectrum. When the reflectance properties of a formation and its background are known, the formation may be emphasized by photographing in the regions of the spectrum where the greatest contrast occurs.



HOWARD L. DRAKE

Data for a wide variety of films and filters may be obtained from photographic equipment manufacturers. Spectral reflectance information, however, is available only for a limited number of specific types of rocks, vegetation, and artificial materials.[1,2] Since season, degree of weathering, and moisture conditions affect reflectance properties, it is

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difficult to generalize reflectance characteristics, based upon the limited information presently available.

Previous Methods for Measuring Spectral Reflectance

For many years the reflectance spectrophotometer has been the instrument used for the determination of spectral reflectance data. In general, because of its large size, this instrument is considered as being laboratory equipment.

For work with the reflectance spectrophotometer, the area of the reflectance samples is restricted by the size of the sample port to a few square inches. Hence, care must be taken in the selection of such relatively small samples in order that they may be representative of the materials being investigated. In addition, certain materials such as growing leaves and granular soils are difficult to remove, transport, and test without changing some of their original properties.

In attempting to meet the obvious need for field measurements, a portable reflectance spectrophotometer was designed in 1958.[3] The power for its 800 watt standard light source and electronic components is supplied by a 3,000 watt motor generator set.

This portable instrument is mounted on adjustable legs with a maximum height of five feet in order to be capable of measuring the reflectance of small bushes. The reflectance surfaces to be tested are shielded from the ambient light. This is accomplished by attaching, around the bottom edge of the instrument frame, a light proof curtain which is extended to the ground.

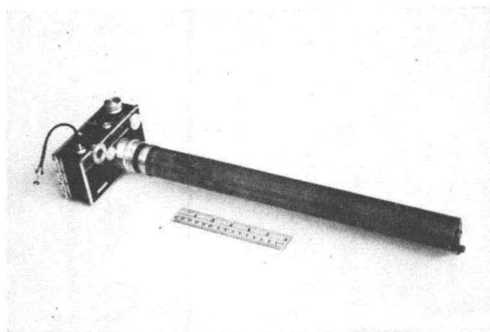

FIG. 1. The wedge spectrograph and the standard white reflectance surface.

Procedure

Instrumentation

The wedge spectrograph, with its standard white reflectance surface, shown in Figure 1, was the instrument used to obtain spectral reflectance data for this investigation. A schematic representation of its component parts is shown in Figure 2.

Construction of this instrument was accomplished by coupling to the direct vision spectroscope a 35 millimeter camera, by means of a lens hood. In order to obtain spectrograms that show intensity in addition to

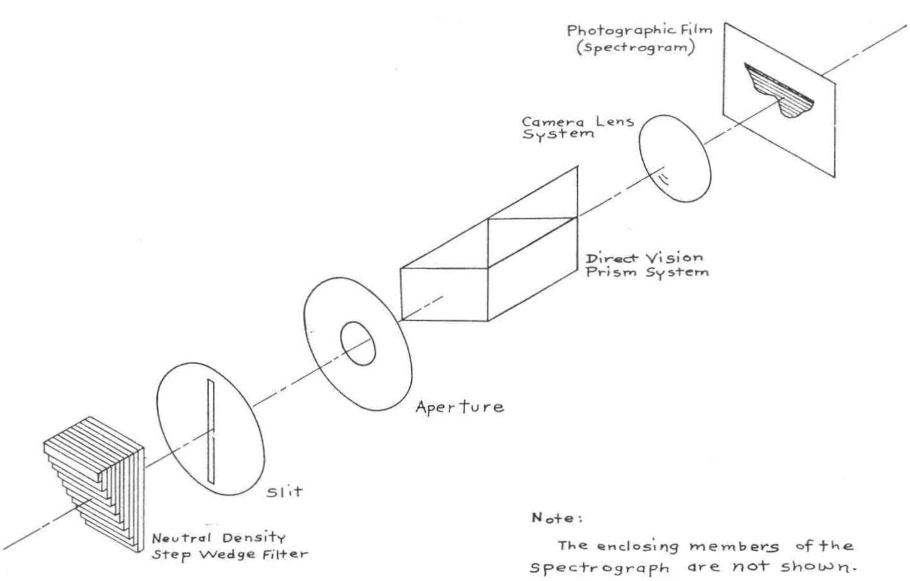

FIG. 2. A schematic representation of the wedge spectrograph.

wave-length, the neutral density step wedge filter was attached to the front of the spectroscope slit. This filter consisted of unexposed, developed, Kodak Plus-X photographic film. This material was arranged in stepped layers in order to form an optical wedge. By photoelectrical measurement of transmitted light, a single thickness of filter material was found to have a transmittance coefficient of 0.50.

The standard white reflectance surface, which consisted of white blotting paper, had a coefficient of reflectance of 0.80. Reflectance characteristics of all test surfaces were compared to this material.

For all spectral reflectance measurements, the sun was the light source. The following, however, are known to cause variations in the properties of sunlight: season, geographic location, time of day, and atmospheric conditions. As a result, a spectrogram of the standard white reflectance surface was taken within a ten second time interval of the test spectrogram recording. By means of this method, the sunlight was standardized for each investigation. Figures 3 and 4 are examples of the test and standard spectrogram pairs.

The following spectrographic data were constant for all spectrograms:

Slit width	0.02 inches
Camera aperture	f/4
Exposure time	0.10 second
Photographic film	Kodak Plus-X

The image-length of the spectrum on the 35 millimeter film was 0.20 inches. The test and standard spectrogram negatives were trimmed and aligned between glass microscope slides. This method allowed the simultaneous printing, on the same positive sheet, of both the test and standard spectrograms.

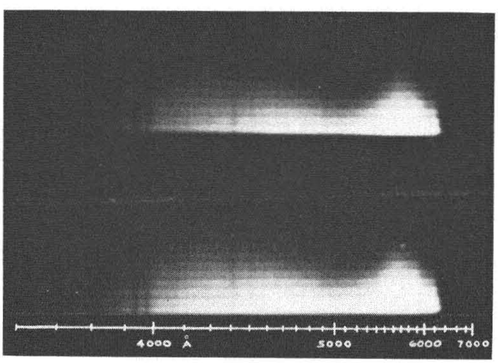

FIG. 3. Spectrogram pair of light tan limestone (top) and the standard white reflectance surface (bottom).

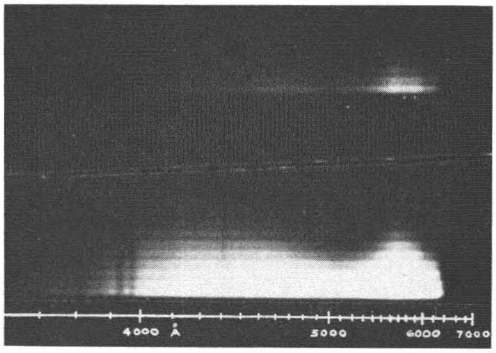

FIG. 4. Spectrogram pair of dark stand (top) and the standard white reflectance surface (bottom).

The spectrogram pairs were enlarged by a factor of 25 on the positive prints in order to facilitate visual interpretation of photographic intensity. Known properties of the step wedge-filter and the relative values of photographic intensity on the test and standard spectrograms, at 100 Angstrom increments, were sufficient data for the calculation of per cent reflectance, at those points.

PER CENT REFLECTANCE DETERMINATION

The following method for per cent reflectance calculation was derived for the step wedge-filter. Figure 5 represents the first three steps of the ten step filter which was used on the wedge spectrograph shown in Figures 1 and 2.

In order to obtain the per cent reflectance of a particular wave-length, the test and standard spectrograms were compared. The sig-

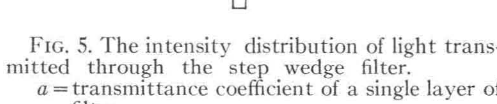

FIG. 5. The intensity distribution of light transmitted through the step wedge filter.

a = transmittance coefficient of a single layer of filter
n = number of layers of filter at a particular step
a^n = transmittance coefficient of the n^{th} step of filter
x_t = intensity of light reflected from the test surface
x_s = intensity of light reflected from the standard surface
r_s = standard surface reflectance coefficient
i = intensity of light incident upon all surfaces

nificance of the photographic density of the n_t step of the test spectrogram being equal to the n_s step of the standard spectrogram is that the intensities of light leaving the filter, at their respective steps, are equal. This condition is represented by the following equation:

Intensity, n_t step of test = Intensity, n_s step of standard

$$a^{n_t}x_t = a^{n_s}x_s$$

Since: $X_s = r_s\, i$

$$a^{n_t}x_t = a^{n_s}r_s i$$

$$\frac{x_t}{i} = a^{(n_s - n_t)}r_s$$

$$\% \text{ Reflectance} = \frac{\text{intensity of reflected light}}{\text{intensity of incident light}} \cdot 100$$

$$\% \text{ Reflectance} = a^{(n_s - n_t)} \cdot 100$$

Results of Spectral Reflectance Study

Studies were made of the spectral reflectance properties of five materials, which were found within the Cornell University Engineering Quadrangle. They consisted of light-tan limestone, concrete, gray-sandstone, grass and dark-sand.

The results of this investigation are shown on the graph in Figure 6. The ordinate and abscissa represent the per cent reflectance and wave-length respectively. For each material, the per cent reflectance values were calculated at 100 Angstrom increments within the range of from 3,800 to 6,200 Angstroms; these values are plotted as points on the graph. The points are connected with straight line segments in order to form continuous curves for each of the five materials. In this way the data are merely presented and no attempt has been made to interpret the shape of the curve between the plotted points, as would be the case if a smooth curve had been fitted into each group of points.

Discussion

The five named materials were selected for this study since they commonly occur in airphotos. Results of this investigation, the per cent reflectance curves, were plotted on the same graph in order that comparison might be made easily.

Comparing the five materials' reflectance curves, it is noted that in general, more contrast exists in the range of from 4,900 to 6,200 Angstroms than from 3,800 to 4,900 Angstroms. By proper selection of film and filter combination for the aerial camera, the former range can be emphasized. This yields a greater contrast among the materials than if, for example, panchromatic film without a filter were used.

Photographic contrast of different materials is best produced by using curves of spectral reflectance, filter transmittance, and film sensitivity. The human eye has a sensitivity range of from 4,000 to 7,000 Angstroms and is most sensitive to light of 5,650 Angstroms. Therefore, because of its different sensitivity

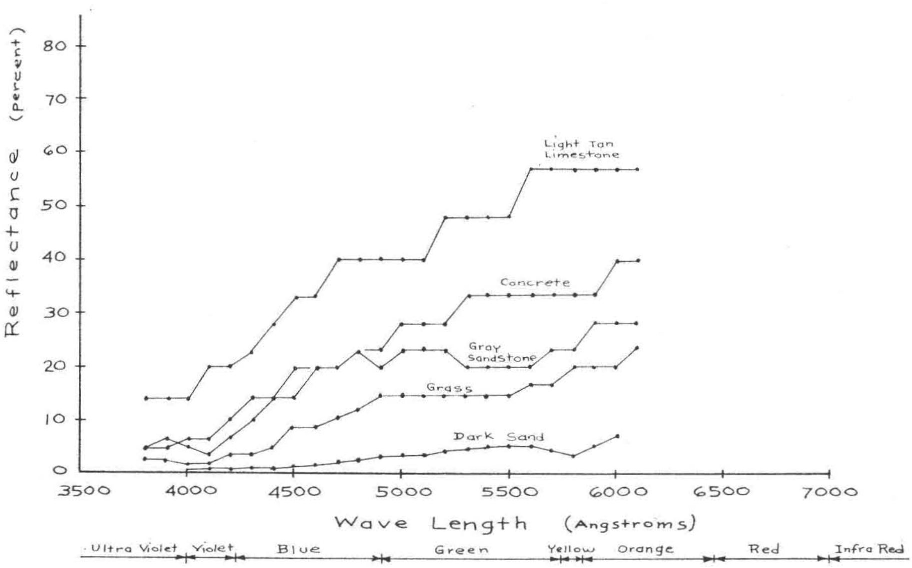

FIG. 6. A plot of spectral reflectance data.

characteristics, the contrast that one observes by direct viewing of a group of minerals may be quite different from that recorded by a particular photographic film.

The spectrogram wave-length scale was established by plotting on semi-logarithmic paper the bright line wave-length values from a mercury vapor lamp spectrogram. These values were 4,047, 4,077, 4,358 and 5,461 Angstroms. By extending the smooth curve, drawn through the plotted points, to the ends of the spectrogram, the complete wave-length scale was established.

Within the range of from 6,000 to 7,000 Angstroms, however, there may exist an error in the wave length scale as a result of the extrapolation method of determining the scale in that particular range. The photographic film has a range of sensitivity of from 3,600 to 6,800 Angstroms, according to the manufacturer's data. Exposure was evident on the spectrogram, according to the established scale, from 3,600 to 6,400 Angstroms; this indicates that the scale may be in error by approximately 400 Angstroms in the longer wave-length region.

The vertical dark lines which appear in the spectrograms called Fraunhofer lines are caused by the absorption characteristics of the sun's atmosphere. Since the Fraunhofer lines are of known wave-lengths they serve as convenient checks on the wave-length scale. Because of the compact nature of the prism spectrum in the longer wave-lengths, the resolving power of the spectrograph, and the stray light from other parts of the spectrum, the Fraunhofer lines were not visible in the range of from 6,000 to 7,000 Angstroms.

Conclusions

The results of this study proved that the wedge spectrograph is a convenient instrument for making field measurements of spectral reflectance. Since this instrument weighs 3.5 pounds, it is truly portable and is quite appropriate for investigations in remote locations. Many investigations are possible within a relatively short period of time, since a spectrogram pair can be recorded within a ten-second interval.

During this study, the distance separating the reflectance surface and spectrograph was constant for both the test and the standard within a spectrogram pair. This distance, however, is not required to be equal in both cases.

If a reflectance surface is uniformly illuminated, then the reflected light intensity varies inversely as the square of the distance from the surface. However, the area of the spectrograph field changes directly as the square of the distance from the reflectance surface. As a result, the amount of light entering the spectrograph slit is independent of the distance to the reflectance surface. This relationship is valid only when the particular reflectance surface is as large or is larger than the spectrograph's field.

There are certain practical limitations placed upon the distance separating the spectrograph and the reflectance surface. The atmosphere tends to filter the light passing through it; hence, air distances of several thousand feet, for example, may alter the reflected light characteristics significantly. As a result, this condition may restrict the maximum separation of the spectrograph and reflectance surface. The minimum distance may be established when the light incident upon the reflectance surface is altered by the close proximity of the spectrograph.

Certain geologic formations, such as granite outcrops and gravel terraces may be composed of relatively coarse grained materials. As a result, the reflectance properties of a few square inches of a particular part may not be representative of the whole formation. The wedge spectrograph, since it uses sunlight as the standard light source, lends itself quite well to the requirements of widely varying instrument field sizes.

In this study, a field size of about four square inches was used for the concrete, limestone, gray-sandstone, and dark-sand. This small area of investigation was possible because of the fine-grained nature of the materials. The grass, however, formed a more coarse textured surface, and a field area of about 100 square inches was used.

Since the standard and test surfaces may be at different distances from the spectrograph, the instrument could be operated from a low flying aircraft. This method would allow rapid investigations of formations which are of sufficient area to be at a considerable distance. During relatively clear atmospheric conditions, the spectrograph may be located several hundred feet above a reflectance surface without encountering appreciable changes in the reflected light characteristics. The standard white reflectance surface may be conveniently located within two or three feet of the spectrograph slit.

Since the spectrograph to reflectance surface distance may vary within wide limits, it is important that the appropriate value be selected by the operator. This distance is judged mainly upon the basis of the size of the instrument field required to give results which are typical of the material being studied and the filtering characteristics of the air space separating the spectrograph and reflectance surface.

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*Biography of a C-4**

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ABSTRACT: *In 1934 a C-4 Stereoplanigraph was imported into the United States by Fairchild Aerial Surveys. Until 1945 it was the only Universal Plotter in the country and is still the only C-4. Despite rapid technological advances in mapping, the instrument is still earning money for its original owners. The history of this unique instrument is the subject of this paper.*

THIS is not a very technical paper. Rather, it is the history of a particular stereo plotting instrument—how it was developed, how it performed some assignments that could not otherwise be performed, and what its recent history has been. Nor is this an obituary, for the instrument is still going strongly.

The beginnings go back to the late 1920's, when the C-3 was the current model of the Carl Zeiss Company, in Jena, Germany. Improvements and changes in the C-3 became obviously necessary as the technology advanced. A Mr. Gulbranson was the chief designer, when the C-4 stereoplanigraph was finally announced by Zeiss in July of 1930. It was a fine instrument, not only by 1930 standards, but even by 1960 standards, as we shall presently see.

In the years 1931 to 1937 a total of 20 C-4 stereoplanigraphs had been constructed but only one came to the United States during that period. That one is the subject of this paper. The others went to places like Mukden, Nanking, Berlin, Delft, Moscow, Madrid and Oslo—all in countries which suffered considerable destruction in wars between then and now. Whether any of these C-4's survived is not known, but it is interesting to contemplate that the one which came to the United States also played an important part in some of that warfare.

But that is getting ahead of the story. In 1931, when Fairchild Aerial Surveys placed its order for the C-4 the instrument wasn't considered a weapon of war. In fact previously the U. S. Army wouldn't consider it at all for any purpose; topographic mapping by aerial methods was not accepted technique by any U. S. Government agency. But Leon T. Eliel of Fairchild had made a trip to Europe in 1930 and was convinced not only that mapping by aerial means was going to be the only technique of the future but that the recently announced C-4 was the instrument to use. The problem, however, was to convince the mapping agencies of the U. S. that topographic work could be done by stereoplotting equipment in general and by the C-4 in particular, faster and cheaper than by methods currently in use.

At the same time, Fairchild had purchased a four-couple camera from Zeiss with the ob-

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