MULTISPECTRAL IMAGERY AND AUTOMATIC CLASSIFICATION OF SPECTRAL RESPONSE FOR DETAILED ENGINEERING SOILS MAPPING

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Technical Paper

MULTISPECTRAL IMAGERY AND AUTOMATIC CLASSIFICATION
OF SPECTRAL RESPONSE FOR DETAILED ENGINEERING SOILS MAPPING

TO: J. F. McLaughlin, Director
Joint Highway Research Project

February 17, 1970

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FROM: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-32U

The attached technical paper entitled "Multispectral Imagery and Automatic Classification of Spectral Response for Detailed Engineering Soils Mapping" by Messrs. M. G. Tanguay, R. M. Hoffer and R. D. Miles is presented to the Board for approval of publication.

The paper has been prepared from a Progress Report on the HPR research project "Annotated Aerial Photographs as Master Soil Plans". That Progress Report has been reviewed and accepted by all cooperating agencies and pertinent comments considered in the preparation of this paper.

The paper was presented October 14, 1969 at the Sixth International Symposium on Remote Sensing of Environment conducted by the Center for Remote Sensing Information and Analysis, The University of Michigan, Ann Arbor, Michigan. The paper is planned for inclusion in the Proceedings of the conference if such approval is granted by the cooperating agencies. Approval of such publication is recommended.

Respectfully submitted,

Harold L. Michael

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MULTISPECTRAL IMAGERY AND AUTOMATIC CLASSIFICATION OF SPECTRAL RESPONSE FOR DETAILED ENGINEERING SOILS MAPPING

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ABSTRACT

Multispectral imagery was obtained with the cooperation of the Willow Run Laboratories, University of Michigan for a 70 mile route in central Indiana. The project, sponsored by the Bureau of Public Roads and the Indiana State Highway Commission, involved the evaluation of imagery taken in fifteen discrete bands of the spectrum as a source of data on engineering soils. The multispectral data was evaluated by (1) visual means, (2) by densitometric measurements and (3) principally with the use of an automatic spectral response classification method developed at the Laboratory for Applications of Remote Sensing(LARS), Purdue University. Classification maps representing seven soil types of different engineering significance were obtained. There is an indication that useful automatic classification of soils can be made and printed on a computer map using multispectral data collected between the ultraviolet and the far infrared range of the spectrum. Information on limited laboratory reflectance measurements is also reported.

INTRODUCTION

In the Spring of 1967, a research project on remote multispectral sensing was initiated in cooperation with the bureau of Public Roads and the Indiana State Highway Commission. The study objective was to evaluate and prepare detailed engineering soils maps from the combined information of both aerial photographs and aerial scanner imagery.

Multispectral scanner imagery was obtained by contract with the Willow Run Laboratories, University of Michigan for a 70 mile route in central Indiana. The study involved imagery in fifteen discrete bands of the electromagnetic spectrum, from the ultraviolet to the 8-14 micron thermal infrared range. The location of the test area is shown on Figure 1. The selection of this test site was based on the variability of earth materials, the diversity of land forms and the construction of road improvements.

Simultaneously with the imagery, aerial photography was obtained by personnel of the Indiana State Highway Commission. The films used were Kodak Ektachrome MS, developed to a negative and from which both color and black and white prints were obtained. Kodak Ektachrome and Kodak Color Infrared were also exposed. Photo-interpretation techniques presently have an advantage in that they provide three dimensional information. Stereo observations allow for inference of engineering materials on the basis of land forms. The scanner imagery supplements the aerial photographs and enables classification of materials by the spectral response approach. The purpose is thus to determine the incremental information obtained on the soils and soils conditions from the multispectral data and to evaluate such data as a means of automatically classifying the soils information. This phase of the study and information on laboratory reflectance measurements made during the investigation are reported herein.

DATA COLLECTION

The study route from Indianapolis to Bedford was covered in two single flight lines; one north to south at an altitude of 3200 feet; the second from south to north at an altitude of 1600 feet. The imagery was obtained in fifteen different bands of the electromagnetic spectrum as listed on Table 1. The interpretation of the multispectral imagery was conducted in three different ways; (1) by visual examination, (2) by densitometry on the negatives, and (3) by automatic computer classification of spectral signatures, as developed by the Purdue University Laboratory for Applications of Remote Sensing(LARS).

The spectral reflectance of the characteristic materials of the study area was investigated in the laboratory. Field thermal measurements were conducted and an attempt to evaluate variables in thermal radiance was performed.

A total of seven days were used to collect field data on soil temperatures, particularly with a Barnes PRT-4 portable radiometer measuring the thermal radiance of soils in the 8-14 micron region. These readings were studied in combination with glass thermometer temperatures and moisture content of the surface soils.

The results of the field temperature study indicated the need for knowing more about the cyclic heat history of different soils. For this reason, a 24-hour period of repeated radiometer and glass thermometer readings was undertaken. Although of value, these results were considered incomplete and a second experiment was conducted, this time with the improved Barnes PRT-5 radiation thermometer. Instead of traveling from station to station to take the readings, a set of twelve 18" x 18" x 8" wooden boxes containing the representative soils studied were laid outside the Purdue University Civil Engineering building. Radiometer readings, glass thermometer temperatures and moisture contents were measured every thirty minutes for a period of 48 hours. The results are presented and discussed in a later section.

IMAGERY INTERPRETATION METHODS

There are several ways in which imagery interpretation can be conducted. Figure 2 was prepared to show some of the techniques reported in the literature. It is divided into two mail sections: the left one refers to conventional photo-interpretation techniques as they are generally applied; the right one indicates some of the most recent automatic and semi-automatic approaches.

The technique of interpretation for aerial photographs is the approach most used to interpret infrared and multiband imagery, especially when only one, two or a small number of imagery bands are obtained. It is a qualitative approach and in certain cases is definitely the best approach. Colwell speaks of two schools of thought: one that considers the imagery as a photo-like image which requires highly subjective interpretation by a human analyst. The analyst must have the ability---"to apply obscure logic, far beyond any present machine capabilities." The second school maintains the recognition of an object from a photo-like image is done by observing its size, shape, shadow, tone and texture and other characteristics such as relative position. All of which, it is maintained, can be adequately determined by a machine.

It might be useful here to point out some distinctions that have to be made. One is on the content of the interpretation. If only discrete objects, as is suggested by the second school of thought, are to be identified, the problem is quite different than for a complete analysis of the entire content of either the photo or imagery for mapping engineering soils and soil conditions.

A second distinction should be made concerning "mono band" imagery(imagery obtained in one discrete band of the spectrum, as is generally the case for infrared imagery from a thermal scanner, or radar imagery) and multiband imagery for which many, in this case, 15 distinct film strips are obtained. There is a need to emphasize the difference in amount of data that has to be "looked at" in 15 different bands as compared to one or two bands.

Third, the purpose of the interpretation will have considerable influence on how the interpretation is to be done. If it is for enhancement as opposed to simple delineation of "similar" areas, or if for automatic classification and for automatic interpretation, the approach will be different.

INTERPRETATION BY VISUAL INSPECTION

During the visual examination of the imagery, the following techniques were tried: (1) examination of the original 70mm. negative film strips on a light table with and without magnification and (2) examination and interpretation of contact prints and enlarged (2 diameter) prints made from the negatives.

The maximum number of bands that could be handled and examined simultaneously in a convenient manner was six bands and ideally only four bands. Attempts were made to visually examine the 12 visual bands simultaneously but the information obtained on the first few bands was forgotten by the time the 10th, 11th or the 12th band were being examined.

The first examination enabled the sorting of bands that were very closely related and thought to be essentially similar. In this manner, the following six bands were thought to be valuable for further examination:

the thermal infrared band	8-14 microns
the reflective infrared band	0.8-1.0 micron
the red band	0.62-0.66 micron
the green band	0.52-0.55 micron
the blue band	0.40-0.44 micron
the ultraviolet band	0.32-0.38 micron

Before any discussion of what was detected and identified or just detected and not identified on the different bands or combination of bands, it is important to emphasize that what follows applies only to the case history under study (the 70-mile strip along Indiana State Road 37) and to the imagery as collected on April 28, 1967 between the hours of 10:55 a.m. to 12:35 a.m., under the prevailing weather conditions.

In order to substantiate the conclusions of this section, two typical examples of imagery are reproduced in Figures 3 and 4. These are reproductions of the high altitude imagery(3200 feet) at a resultant scale of 1:28,800(1 in. = 2400 ft). The low altitude imagery (1600 ft) at a resultant scale of 1:14,400 (1 in. = 1200 ft) was also examined but is not illustrated.

On Figure 3 test area one is displayed in six different bands of imagery. It is characterized by the White River flood plain and features granular material(f), sand stock piles(d), ponds, a river, a few streams(h), dark wet soils areas(g,m), and many man-made features(a,b,c).

Figure 4 shows test area four in six different spectral bands. It is characterized by two main land forms; a flood plain(f), and a glacial moraine(a). Several bare soil areas featuring different soil conditions are visible (a,g). Soil drainage conditions and soil mottling are evidenced.

Each individual spectral band was studied by close visual inspection on a series of test segments, such as Areas 1 and 4. It was found that handling a number of bands greater than six was not practical. This does not mean that additional bands are not useful. It simply indicates the human limitation of simultaneously analyzing a great number of bands for a very large number of features appearing on each band. It indicates a need for an automatic means of data analysis.

Let us consider next the utility of each of these wavelength bands that were studied in detail, and the features most prominent in these bands.

The Thermal Infrared, 8-14 Micron Band. The thermal infrared (8-14 micron) band was particularly useful to detect bodies that were relatively hot and emitting strongly and bodies that were relatively cool. Water bodies and vegetation are considered relatively cool and showed as dark areas or items on the imagery. Certain roofs and certain roads were warmer and showed white on the imagery. Most soil areas were of the same intermediate grey tone except for a few special features. This band was considered useful as it allowed detection of some features that were not detected on other imagery bands. Two examples are shown as item "p" on Figure 3 and item "h" on Figure 4. The first one is a slightly depressed area which corresponds to a very wet zone. At first it was not detected on any other band nor on any other type of film. However, once it had been located on the 8-14 micron imagery, it could be detected on some of the other bands and on the color infrared and color films. The feature would have been missed entirely without the 8-14 imagery. The second feature is a soil drainage feature that could not be detected at all on the other bands nor on the photography, even the color infrared.

Tonal differences in this band will change over a period of 24 hours very drastically as the temperature of materials changes. Eventually such temperature changes may result in tonal inversions at night.

The Reflective Infrared Band, 0.8 - 1.0 Micron. The reflective infrared (0.8-1.0μ) imagery was very useful to detect vegetation covered areas and bare soil areas. When examining this band, various materials appeared as follows: water bodies are very dark and uniform in tone, soils and road systems are intermediate grey tones, wet soils are darker grey ("g" on Figure 3), and vegetation is very light grey to white. Coniferous trees are medium grey to dark. Good reflectors like some galvanized steel roofs are very bright.

The Visible Red Band, 0.62-0.66 Micron. The red (0.62-0.66μ) imagery band was found to be most useful for soil studies. Soil contrasts were shown better on this band than any other except the 0.52-0.55 micron band. In the red band, water bodies are dark and soils are of various shades of grey from light to medium dark. Bare dry soils are light ("d" of Figure 3, "m" of Figure 4). Wet soils are darker ("c" and "n" of Figure 4). Vegetation is rather dark. It is important to note that the tone inversions for soils and for vegetation occur in the 0.8 - 1.0 and 0.62-0.66 micron bands. These two bands in combination yield extremely significant information as discussed in the section on automatic classification.

The Visible Green Band, 0.52-0.55 Micron. The visible green (0.52-0.55μ) imagery is quite similar to the previous one but soils did not show as wide a range of contrast, although all the important soils features on the 0.62-0.66 band were also present here. For instance, the mottled tones of the ground moraine of Figure 4(item "a") still shows just as well.

The Visible Blue Band, 0.40-0.44 Micron. This band is definitely not as valuable in terms of soil mapping. Much of the contrast between dark and wet soils and light colored soils is gone (see items "g" on Figure 3; "c", "m", "n" on Figure 4). Because of a reduction of the overall contrast and the greater reflectance of pavement materials in this range, the road systems show much better. Water bodies are all of the same dark grey tone and cannot be distinguished from the vegetation.

The Ultraviolet Band, 0.32-0.38 Micron. Only a few features show as bright tones on this band. Certain high ultraviolet reflectors are recognized such as certain roofs, concrete pavements, some bituminous concrete pavements, limestone quarries, and sand bars (see item "f" of Figure 4).

In summary, the six bands indicated that if there is a change in soil type due generally to color, this is evidenced in bands 0.8-1.0, 0.62-0.66, and 0.52-0.55 micron and in a subdued manner in the 0.40-0.44 band. If there is an appreciable change in the drainage of soils in the upper foot or upper few feet of soils or if a highly saturated zone is created, this is evidenced in the 8-14 micron band. The different bands have been treated separately but they become much more significant when several bands are considered in conjunction with each other such as was stressed for the 0.8-1.0μ and 0.62-0.66μ bands.

From the visual examination the following conclusions were drawn:

(1) The most informative bands for engineering soils studies were obtained by grouping the 8-14μ, the 0.8-1.0μ, the 0.62-0.66μ and either the 0.40-0.44μ or the 0.32-0.38μ bands.

(2) Soil contrasts were best detected in bands 0.62-0.66μ and 0.52-0.55μ.

(3) Water bodies showed best in the 8-14μ and 0.8-1.0μ bands. The 0.8-1.0μ band is preferable and should be used for detecting water bodies because of the high reflectance of vegetation and the strong absorption of water in that band.

(4) The imagery suffered from lack of resolution, due to the overall small scale and scanner distortion, even for the low altitude imagery(1:14,400).

(5) It is quite obvious that no information was obtainable from the imagery either directly or indirectly about the topography. Topography is an important element in engineering soils mapping and is not shown on the imagery. Soil features are often detected only locally and without continuity. This is a major problem when mapping soils. It is obvious that multispectral imagery cannot replace aerial photography for engineering soils mapping. In fact, it was not meant for that purpose and, therefore, should be considered only as a supplement to aerial photography.

(6) There are some soil conditions that are enhanced and more easily detected on the imagery than on aerial photography.

(7) There are limited soil features that show only on the multispectral imagery which are difficult to detect on other sensor type data.

(8) In order to use the far infrared 8-14 micron band to maximum capability for soils, this imagery also should be obtained at night in the hours before dawn (3:00-6:00). Until more is known about the interpretation of the thermal infrared imagery, it should be flown, if at all possible both during the day and at night and considered as two bands complementing each other. This would allow much better insight on infrared behavior of materials.

Interpretation by Densitometric Measurements. In an attempt to study the validity of the spectral signature characteristic of each material class and to study the capability of the densitometric approach as a potential automatic data classification method, a series of density measurements on the multispectral imagery were taken. The approach used measured the transmission density on a calibrated transmission densitometer with a 1 mm. aperture.

The density readings were normalized against a standard gray scale: in this manner each of the imagery sections in each band and their respective calibration grey scale levels were made compatible. This was done for all the imagery bands and for each spot of interest or target. This allowed for comparison of the relative response for each target in each band and for comparison of the overall spectral signatures of the target materials.

Figure 5 illustrates the results for one sample area (Area 1-A), in two spectral bands. All the prime density levels that appear were normalized against the same grey scale. The letters refer to the targets indicated on the imagery. Some problems appeared due to the narrow width of the 4.5-5.5μ and 8.0-14.0μ imagery which is due to a narrower scan angle(only 37° against 80° for the other channels). This narrower scan angle is due to the two calibration plates placed inside the scanner for calibration purposes.

Multispectral response for similar soils and soil conditions matched both in terms of intensity and shape of the response curve. Materials that were different in nature had different spectral response graphs. This is illustrated in Figure 6 for three soil types: a dark colored wet silt, a dry light brown silt, and a wet muck.

These results and a series of additional, similar measurements performed during this research confirmed again that the concept of multispectral signature of first surfaces is a valid premise in remote sensing, that the signatures can be measured on the imagery and that they are significant in terms of engineering soils.

This phase of the research also showed the difficulties of the densitometry approach. It is slow and cumbersome. Long strips of imagery have to be searched and it is a tedious job to measure the density of each point and then to normalize and plot the results.

AUTOMATIC CLASSIFICATION OF MULTISPECTRAL DATA

The Purdue University Laboratory for Applications of Remote Sensing(LARS) is sponsored by the National Aeronautics and Space Administration(NASA) in conjunction with the U. S. Department of Agriculture. LARS was originally developed for research on agricultural applications of modern remote sensing techniques for the benefit of national and world-wide agriculture. It is now multi-discipline oriented and research is conducted on other applications of remote sensing such as geology, hydrology and others. A system of computer programs has been developed by LARS for purposes of remote multispectral data analysis for various applications, such as automatic species identification and mapping, automatic soil mapping, crop moisture and disease studies, and other applications.

In the research pursued on engineering soils mapping, the purpose was to determine if the automatic classification procedures developed for agricultural applications could be used also for engineering soils mapping and if the multispectral data could be automatically analyzed to yield a significant soils map. Two of the LARS computer programs were used. A flow diagram of the automatic analysis and the computer system of programs are summarized on Figure 7.

The analysis is based on a pattern recognition technique in which training samples are used as a means of sorting and classification. Through these training samples for various classes of materials, the computer is "trained" to recognize all areas of similar spectral response and to automatically classify them into one of the categories designated by the researcher. The theory and development of these programs and techniques are discussed in the literature by several of the engineers and researchers at LARS(see references).

The first of the computer programs used was designed to produce grey level printouts of each spectral band desired to aid in the location and selection of the training areas. This program (PICTOUT) produces a computer printout roughly similar to the imagery film except that the grey levels are indicated by the relative density of the printer characters. One or several bands can be displayed in this manner. Generally the displays for two or three spectral bands are sufficient for the researcher to designate sets of training areas in terms of coordinates based on lines and rows on the printouts.

Training samples should be conceived of as a set of spectral data, representative of a given ground object or ground feature and identified on the computer printouts by a system of coordinates assigned to each scan line of scanner data (lines and rows). The material represented by a set of training sample areas is referred to as a "class".

This concept is illustrated on Figure 8 which shows (a) an area on an airphoto, (b) an enlargement of the infrared imagery film strip and (c) its corresponding PICTOUT computer printout. Training samples are indicated by rectangles. Training samples "a", "b", "c" and "d" are representative of a class, in this case, the class is "bare soil" on a road embankment under construction. Training samples "e" and "f" represent a second category composed of trees. As many classes as desired can be defined.

The success of this phase is based on the researcher's experience in the particular field of activity; pedology, forestry, agronomy, civil engineering or others. The available field information, multispectral classification techniques and the researcher's background constitute together the basis of proper and useful selection of training samples.

The second main program utilized in this project is called LARSYSAA. This central monitor program is subdivided into a set of supervisor programs and four processor programs as illustrated in Figure 7.

Once the training samples are selected and their coordinates (lines and rows) are punched on cards, the statistics are obtained on the reflective characteristics of each class. The statistics include the mean vector of each class and the coveriance and correlation matrices. Histograms of each sample and/or class and their spectral response graphs can also be printed at this time to help the researcher in his analysis of the data. Options are available either to obtain all this information in terms of each sample in each class, or for both samples and classes. The results from the statistics allow the researcher to verify the quality of each training sample and each class. If improvement is desired, it can be performed at this point by a reselection of better training samples. Otherwise the next step is undertaken.

From the spectral plots for the various classes, the researcher can select the spectral bands which he believes will be the best combination of bands for the classification or sorting of the data. A much faster and more reliable way of selecting the most dependable set of spectral bands is available in the LARSYSAA system. This is the purpose of the second processor ($ SELECT). Fundamentally the selection of optimum bands is based on the degree of spread or degree of divergence between the spectral classes and the variation within the class response for all possible combinations of the different bands. (Further explanations can be found in references: Cardillo and Landgrebe 1966; Min et al. 1968; Landgrebe et al. 1967).

The band selection step is followed by the classification ($ CLASS) phase. Each data point in the entire flight line is classified into one of the classes that were determined by the researcher and for which training classes were established. Each data point is classified into the class for which it has the highest probability of belonging. The probability of belonging to that class may or may not be very high. For example assume the researcher established three classes and obtained training samples for vegetation, soil and water. Each data point must be classified into one of these three classes, and a probability of belonging to that class is also calculated. The data which may actually correspond to a car may not appear spectrally to belong to any one of these three classes but it must be put in one of the three. Because of the low probability of belonging to any of the established classes, the point can be "thresholded", and thereby avoid erroneous classification results. This stresses the importance of having significant classes and of properly using the thresholding option in the display. The classification results are then stored on assigned magnetic tapes for fast retrieval.

The next sequence is to display this classified data, in either a map or tabular format. $ DISPLAY provides for this in assigning to each class a selected set of printer characters for output printing, and obtaining a map of the classification results as well as a tabular display of the performance results. The printer characters are assigned by the operator (researcher). A judicious set of printer characters helps emphasize the desired classes of materials.

Figures 9, 10, and 11 are examples of automatic multichannel data classification. They indicate some of the potential applications for engineering soil classification.

Figure 9 is a case in which drainage features of an area are evidenced by the automatic classification of the imagery. To appreciate these features, a close comparison should be made with the photo mosaic. All the areas represented by the character "H" on the left hand computer printout correspond to drainage ways or very wet areas. Examples of this are shown by features on both the printout and the photos by letters "a" and "b". Item "c" corresponds to a dry soil in a bare field. This was revealed by examination of the color and color infrared airphoto. Item "d" corresponds to a wet soil condition at the time of flying. Item "f" corresponds to a meander scar on the flood plain; it also corresponds to wet ground. This indicates how detailed the automatic classification can be with selection of proper training samples. It indicates that minute features of engineering significance such as areas requiring special drainage or containing poorly drained soils can be automatically located by this method and can be delineated by a judicious selection of printer characters.

Figure 10 is a special case where the approach was to classify the soils in terms of their spectral response as related to the land forms. The result was only partially successful but indicative of some interesting potentials. If a relationship can be established between land form and spectral responses of corresponding materials, then the land form-parent materials relationship used in photo-interpretation would be valid here too.

In Figure 10, the upper two areas on map 1 marked as training samples "S" and "T" belong to the ground moraine terrain (Km) indicated by the mottled tone on the photo-mosaic. The lower field "Q" belongs to the flood plain (Fp) and is darker in tone. The automatic classification results are shown in map 2. The inconsistency in classification is outlined between the dash line and the solid line. This area actually should be classified as flood plain but is classified as material that belongs spectrally to the ground moraine. This discrepancy is attributed to possibly two things; the materials from the upland (ground moraine M_k), are washed onto the flood plain by conventional geomorphologic agents or the thin windblown silt mantle that covers the area masks the true land form borders, spectrally speaking. The main point here is that spectral responses for broad classes of materials may possibly be related to land forms.

Figure 11 presents five computer printout maps for a section of a highway at the time of its construction. Map 1 is the general classification of the earth materials and the vegetation into eleven different classes. The distortion effect is quite obvious. It does not prevent the spectral data to be interpreted. This indicates the need of good aerial photography to be taken simultaneously with the multispectral data. Map 2 indicates the bare soils and the vegetation; this permits evaluation of the amount of interference by the vegetation cover.

Map 3 is significant for engineering purposes: it locates rapidly the two soils that are troublesome in the area. The area contained several muck pockets and areas of dark and wet soil not as deep as the muck but still sufficiently wet to require either drainage or removal. The muck is shown by the letter M and the wet soil by slashes. Map 4 indicates only the muck which was thought to be more critical and should receive special attention in an engineering project.

Map 5 shows an interesting feature. The materials used to build part of the by-pass were obtained from the ridge moraine and served as fill between the higher ground (ridge moraine) and the lower ground (outwash and lacustrine plain). This section of the fill which used the sands and gravels of the ridge moraine appears very clearly on Map 5. It was shown for the purpose of indicating how selective this method of automatic classification based on spectral signatures can be. Note the location of the training samples (asterisks). Note that along the by-pass, training samples were selected all the way from the north end to the southern end (bottom of map) and yet only the northern-most area shows the presence of sand (dots) coming from the ridge moraine. This is an extremely important point. The color airphotos could not show this because there was not enough visual color contrast between the sand of the upper section and the silty ground of the southern section. This indicates that some materials devoid of vegetative cover can be classified automatically according to their reflectance and that they may be classified in terms of their texture if limited ground information is available.

LABORATORY REFLECTANCE MEASUREMENTS

In order to establish the engineering significance of spectral classes, a large amount of ground truth had to be collected. Repeated field trips to the test areas where necessary, hand anger bore holes were dug in the critical areas and soil profiles were determined. Soils samples were also tested in the laboratory for standard engineering classification.

Due to the lack of information on soil spectral characteristics and to understand better the spectral relationships of the test site soils, laboratory spectral reflectance curves were obtained on a Beckman DK-2A spectrometer for specimens of the typical soils and rocks.

Figure 12 shows the spectral reflectance of red clay as a function of the wavelength for various water contents. The water content in percent is indicated for each curve. The number followed by the % character was the target percentage attempted by mixing water and soil. The number in parenthesis is the actual water content (oven dried) at the end of the reflectance measurements. Figure 13 shows reflectance curves for a silt and Figure 14 indicates the variability in the reflectance for two sets of limestone samples from the same geologic formation (Harrodsburg).

In this brief investigation specimens were measured with a smooth surface and a rough surface. Soil clods were shaped with a spatula to fit the spectrometer sample holder. The spatula shaped surface was called the smooth surface. On each sample a minimum of three surfaces were used with their natural roughness. The rock specimens were cut and flat surfaces were ground with standard #80 abrasive to provide the smooth surfaces. The numbers in the upper right of the diagrams refer to the different samples. These measurements indicated that:

- low plasticity (sandy) soils are less affected by the surface roughness,
- moisture content is a major factor affecting the reflectance; the higher the moisture content the lower the reflectance,
- for rocks the smooth surfaces had a higher reflectance and the color of the rock was found to be more important than the roughness,
- moisture on the rock specimens substantially decrease the reflectance.

These are some of the conclusions reached on spectral reflectance for laboratory specimens. Further research is needed on other rock and soil types, and field measurements are necessary to study conditions that cannot be accounted for in the laboratory.

FIELD THERMAL INFRARED MEASUREMENTS

In order to better understand the diurnal thermal radiation behavior of typical soils of the study area, two separate experiments were conducted to obtain radiometer readings at close intervals. These experiments were conducted to procure (1) a better understanding of soils diurnal thermal phenomena, (2) an evaluation of factors influencing thermal radiation and (3) additional information on the optimum time for taking infrared imagery.

The first experiment was designed to take radiometer readings, with the Barnes PRT-4 instrument, every hour, on eight different targets, over a period of 24 hours or longer, at the test area. Problems were encountered during this experiment: problem of portability of the instrument combined with the problem of taking notes, as well as problems of traffic at peak hours. The results of this experiment are illustrated on Figure 15. From these results the following statements are appropriate:

(1) All materials showed, as expected, a similar daily temperature change, but the maximum temperature levels differed substantially. The morning temperatures for all the materials were about the same within a range of four degrees. The maximum temperatures varied over 12 degrees and more; since the maximum temperature for red clay went off scale, the total range could not be determined.

(2) The temperature for the moist silt, was found to be five degrees cooler than the dry silt at the same stations. Also, the rate of cooling and warming was greater for the dry silt than for the moist silt. Temperature inversion points for these conditions were found at 5:30 p.m. and 9:30 a.m.

(3) Concrete and three different limestone outcrops had somewhat similar behavior and peak temperatures and they could not, for all practical purposes, be differentiated on the basis of their temperature. The siltstone was a little warmer than the limestones and concrete but cooler than the red clay at peak temperature.

(4) The temperature inversion times for this August 12-13 data are considered to be important: they are listed below for the materials investigated. The inversion temperature in degrees Centigrade is given in parenthesis.

a - dry silt-wet silt	:	7:30 pm (17.5) and 9:30 am (24)
b - dry silt-limestones	:	6:00 am (13.5) and 9:30 am (26)
c - dry silt-siltstone	:	6:30 am (14.5) and 10:00 am (29)
d - wet silt-limestones	:	7:30 am (13.5) and 9:30 am (28)
e - wet silt-siltstone	:	6:00 am (13) and 10:00 am (26.5)
f - limestones-red clay	:	3:30-5:00 pm (38.5-33) and 3:30-6:30 am (14.5-18)
g - limestones-siltstone	:	5:00-8:30 pm (37-26) and 3:30-10:00 am (15-36)
h - red clay-siltstone	:	4:30 pm (37) and 4:00 am (14.5)

(5) It appears that the time at which peak temperatures occur is the optimum time for taking imagery for the purpose of distinguishing materials on the basis of their maximum temperature, but it is not true for all materials. The peak temperature time range for the materials investigated was from 1:00 to 3:00 pm on the day of test. These data indicate that more has to be known on soil heat capacity under different field conditions.

(6) The after-sunset and pre-dawn period (from 10:00 pm to 6:00 am for August 12-13, 1967) seems to be of major interest in terms of "quiet" infrared behavior of materials: the cooling is at a minimum and the direct solar energy effects are absent.

Considering these results, it was thought that other diurnal measurements should be obtained with more numerous moisture content measurements, better weather records and a longer elapsed time for the experiment. Measurements over a continuous period of two days and under more controlled moisture conditions were undertaken.

This experiment was conducted during a 48-hour period on September 6 and 7, 1968. Plywood boxes (18" x 18" x 8") were made to contain samples of the representative soils of the study area and a few other contrasting materials. The prevailing weather for September 6th was sunny with clear skies, except for an estimated 30-40 percent cumulus cover at 3:30 pm which dissipated by 7:30 pm. No major wind effect was noticed. Dew was first noticed at 2:30 am (September 7th) and reached a maximum at 7:30 am.

The prevailing weather for September 7, 1968 was sunny with clear skies. Cirrus clouds appeared at noon. Gusts of wind were also observed at the same time and affected the apparent temperature readings. They were estimated at the site to be between 5 to 10 mph. The cloud cover at 3:30 pm was estimated at 30-40 percent and by 7:30 pm it had increased to an estimated 60-70 percent, but was less than about 15 percent at 9:00 pm.

Glass thermometers were used to monitor the temperature at different depths of the soil samples. Moisture contents of the surface layer were checked periodically over the 48-hour period. The apparent temperature was measured with a Barnes PRT-5 thermistor bolometer radiation thermometer operating on AC current (110 volts) and recording radiation in the 8-14 micron band.

Figures 16, 17 and 18 illustrate results obtained for some soils. They also indicate the glass thermometer temperatures at the one-quarter inch depth and the soil moisture variation over a 48-hour period. From these results the following general conclusions are drawn:

(1) All materials showed the expected sinusoidal curves following the daily temperature variation.

(2) The soil moisture variation also followed a sinusoidal pattern but the variation was in opposite phase to the apparent temperature.

(3) The glass thermometer temperature differed somewhat from the apparent temperature (generally less than five degrees) and lagged the apparent temperature variations: this is explained by the damping effect of the soil layer covering the glass thermometer.

A series of diagrams similar to Figure 18 were prepared and assisted in understanding the behavior of these soils. Among the conclusions reached, one notes that:

(1) The effect of color on the apparent temperature, which to a certain extent may reflect the mineral nature of materials, appeared to be significant only at peak temperature periods, between 11:00 am to 3:00 pm. In terms of color of the materials, the peak temperatures did not permit differentiation of all the materials.

(2) The effect of moisture was found to be very important. Moisture proved to have a damping effect on the apparent temperature contrast for the different materials. For the wet samples, the damping was even greater. It is concluded that moist and wet materials cannot be distinguished on the basis of their daily peak temperatures but important information can be gained on the degree of moisture. The 8-14 micron region would be most useful, at peak temperature time, to obtain information on moisture conditions of soils provided that sufficient ground truth is available.

(3) It is indicated that the apparent temperature is relatively little affected by the surface texture and/or the grain size of materials. It indicates that color is much more important.

(4) The effects of weather on the apparent temperatures were observed during this 48-hour experiment. On Figure 18, the weather effects that could be noticed are indicated by capital letters. Point (A) corresponds to the formation of a cumulus cover (30-40% estimated coverage) which came in at a low altitude (approx. 2000-2500 feet). Its effect was to slow down the cooling as clouds act as good thermal radiators. Point (B) corresponds to the time at which the wind was relatively calm. The 0-5 mph wind had stopped by 7:30 pm and this reduced the rate of cooling. Point (C) corresponds to the gusts of wind at around noon until 1:00 pm. Point (D) corresponds to the formation of cumulus clouds similar to the previous day. Point (E) corresponds to an increase in cloud cover up to about 70 percent with the absence of wind.

CONCLUSIONS

This research project indicated that it is feasible to use multispectral data and imagery to supplement aerial photographs in the preparation of engineering soils maps. It showed that the automatic computer analysis method developed at LARS for multispectral data is most efficient and permits preparation of engineering soils maps based on the spectral responses of soil types where vegetation is not a limiting factor. It indicates the need for further research in other geographic areas, on other soil types and soil conditions. The laboratory reflectance measurements were useful in understanding factors which influence the reflectance properties of soils and rocks but they also showed the need for field measurements of these properties. The field radiometer measurements contributed to the understanding of soil surface thermal behavior. They showed soil moisture and the color to be of greatest importance and also showed that meteorological changes have a critical effect on the soil thermal behavior. Much additional research is needed to quantify and predict the spectral and thermal properties of many soil types and textures under various conditions of moisture and irradiance.

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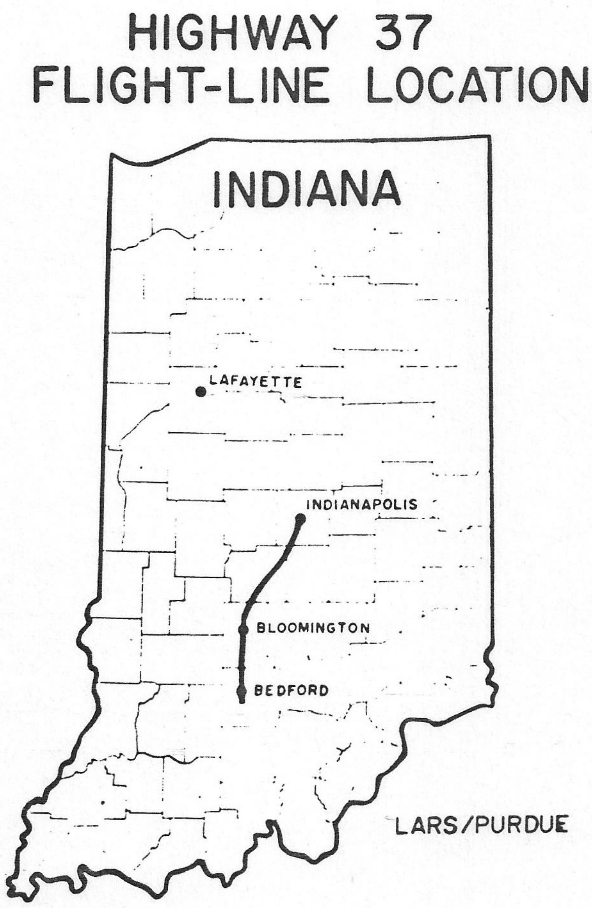

FIGURE 1 FLIGHT LINE AND AREA OF STUDY ALONG HIGHWAY 37; INDIANA.

TABLE 1

SPECTRAL BANDS FOR IMAGERY OF INDIANA PROJECT
AS COLLECTED BY PROJECT MICHIGAN SCANNER

RANGE	BAND NUMBER	SPECTRAL BANDWIDTH
ultraviolet	-	0.32-0.40 micron
visible (violet)	1	0.40-0.44
visible (blue)	2	0.44-0.46
visible	3	0.46-0.48
visible (blue-green)	4	0.48-0.50
visible	5	0.50-0.52
visible (green)	6	0.52-0.55
visible	7	0.55-0.58
visible (yellow)	8	0.58-0.62
visible (red)	9	0.62-0.66
visible (red)	10	0.66-0.72
near infrared (reflective)	11	0.72-0.80
near infrared (reflective)	12	0.80-1.00
middle infrared (thermal)	-	4.50-5.50
far infrared (thermal)	-	8.00-14.00

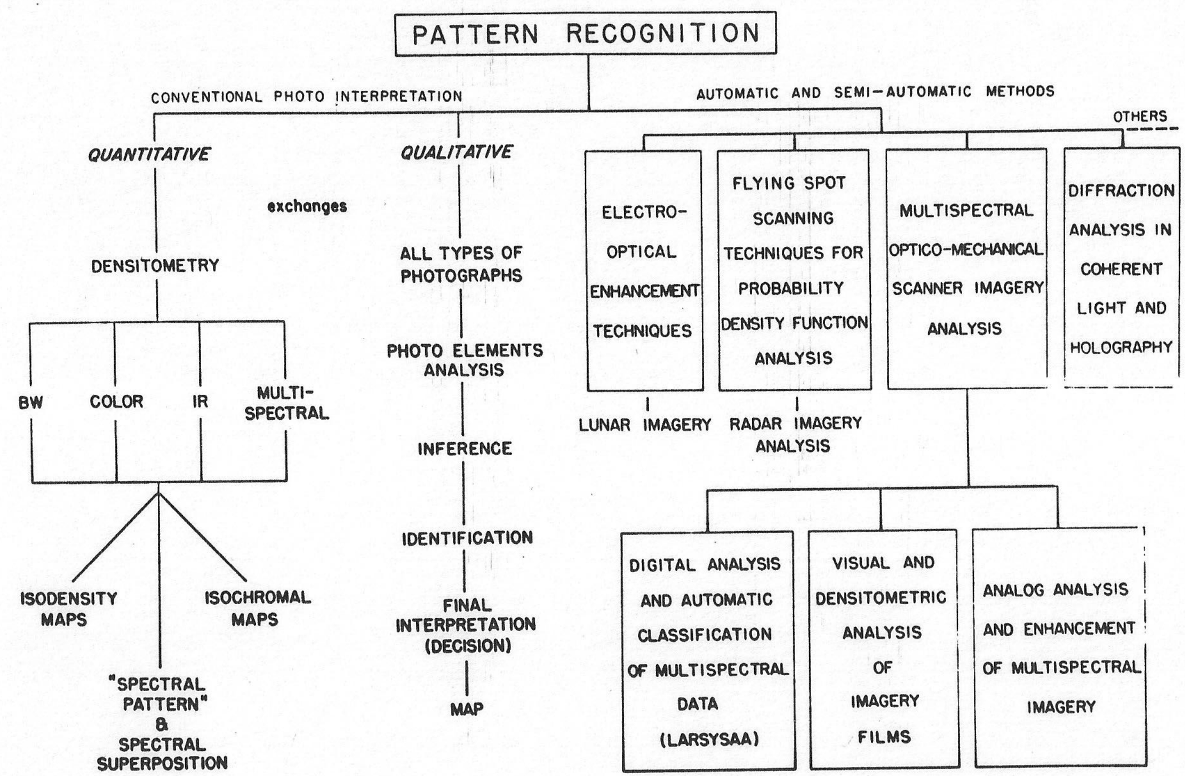

FIGURE 2 SOME INTERPRETATION AND PATTERN RECOGNITION TECHNIQUES.

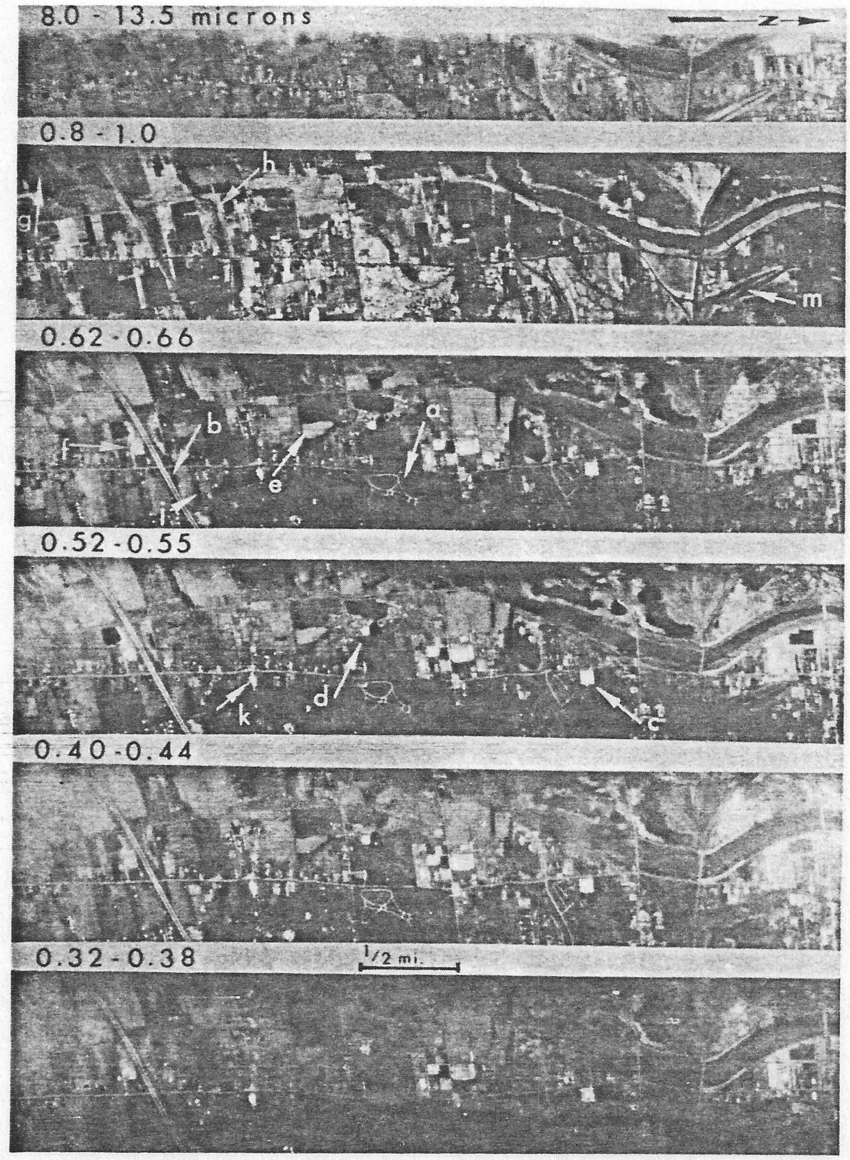

FIGURE 3 MULTISPECTRAL SCANNER IMAGERY FOR AREA 1. ONLY SIX OUT OF FIFTEEN BANDS ARE SHOWN.

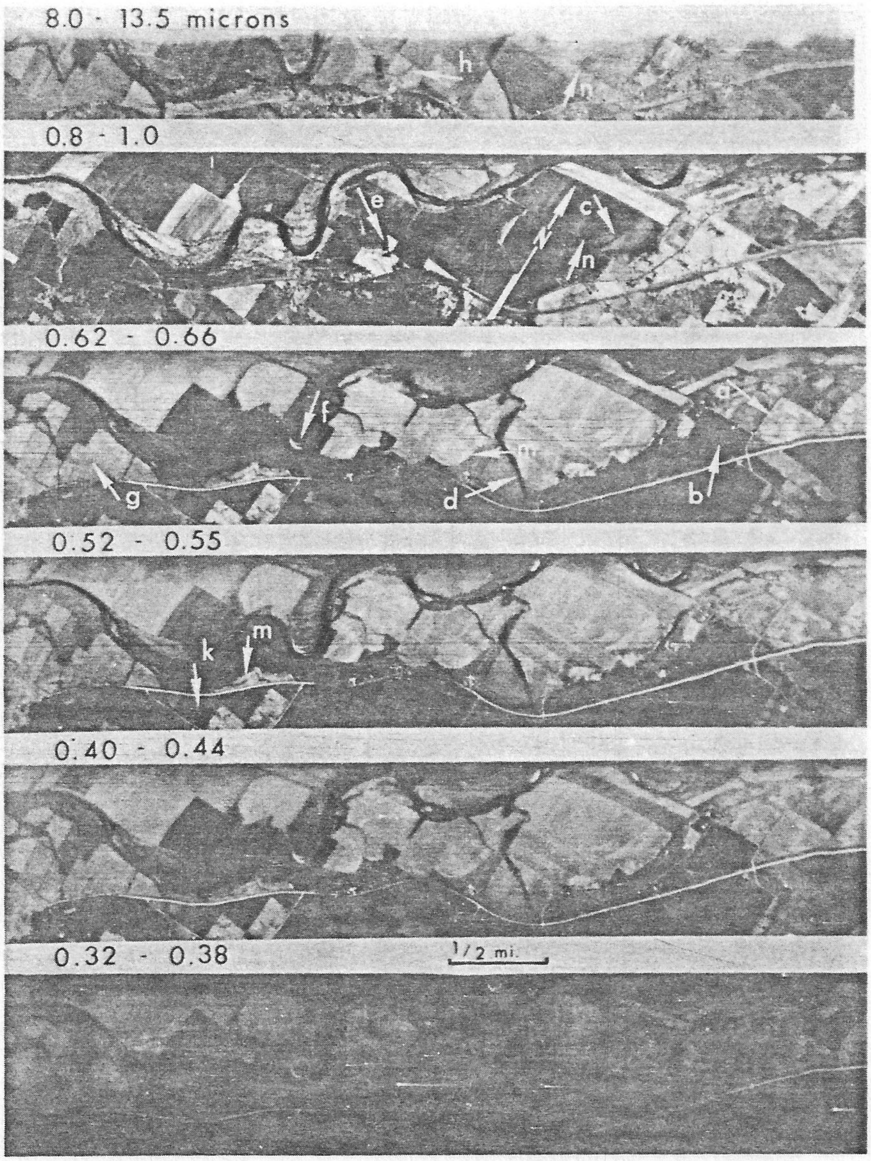

FIGURE 4 MULTISPECTRAL SCANNER IMAGERY FOR AREA 4.

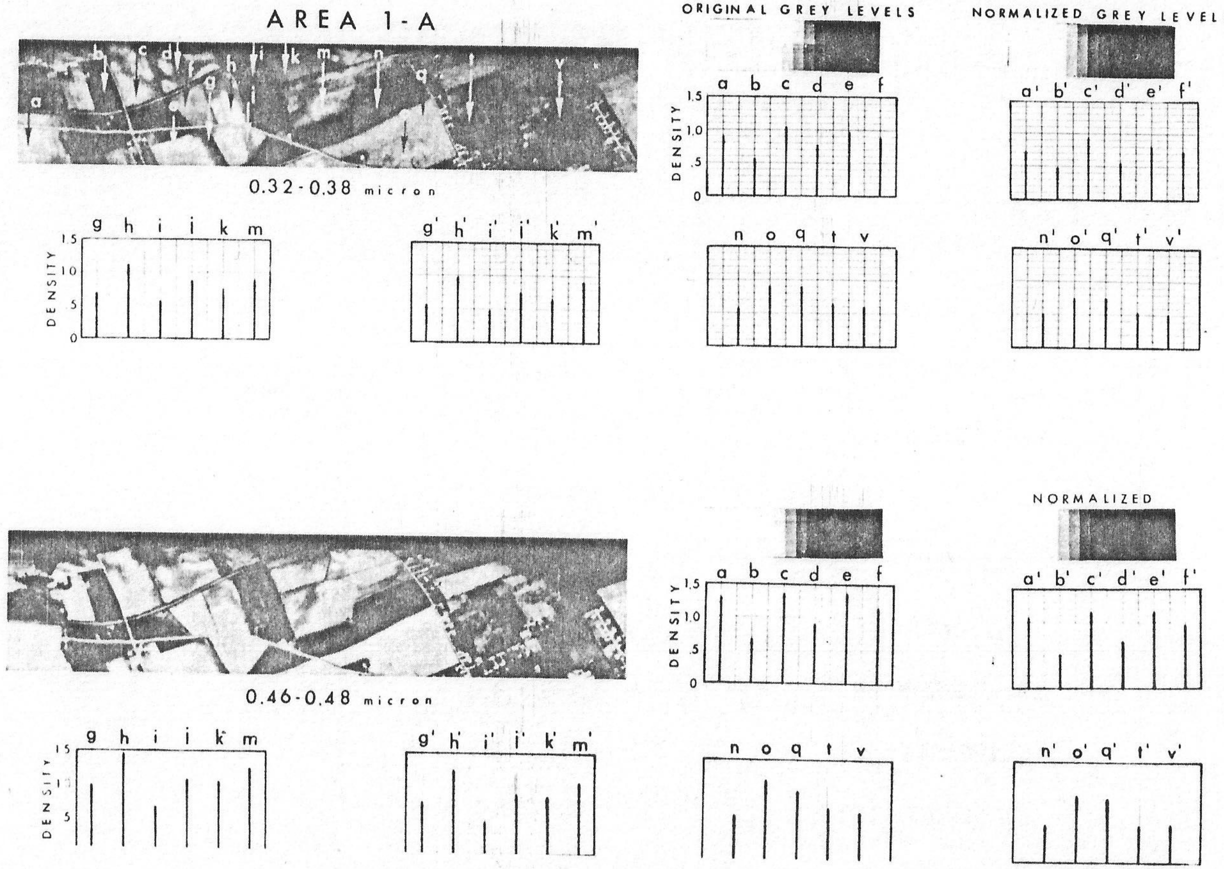

FIGURE 5 DENSITOMETRIC MEASUREMENTS ON 0.32-0.38 AND 0.46-0.48 MICRON BANDS FOR AREA - 1 - A.

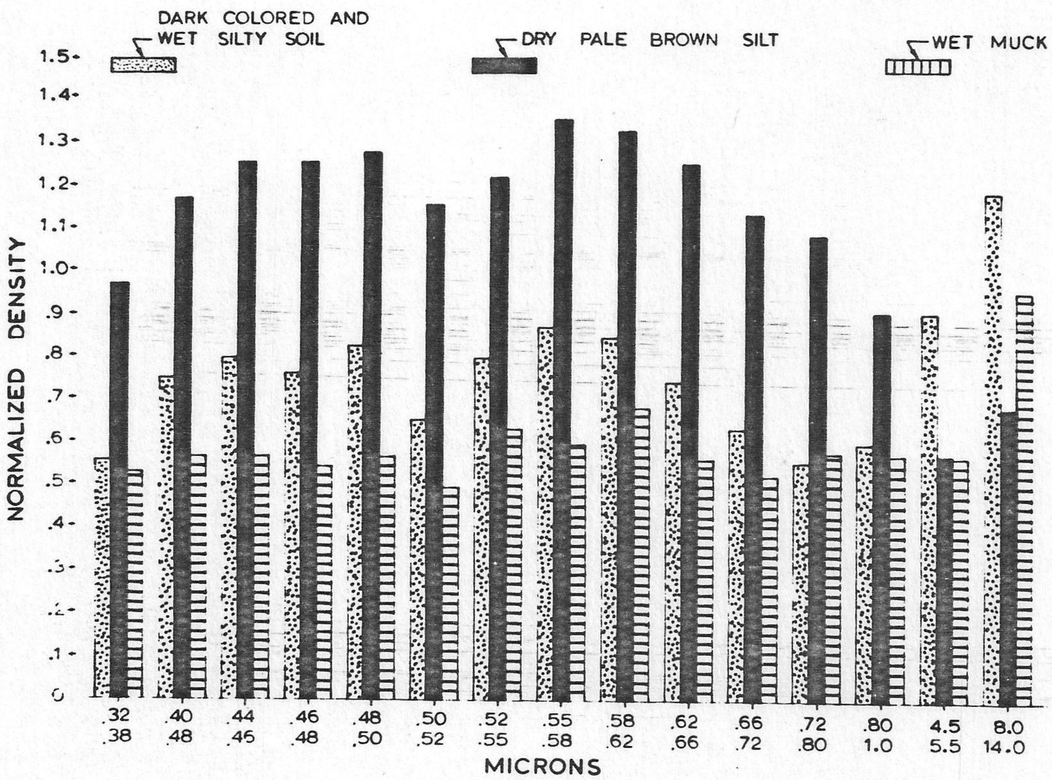

FIGURE 6 SPECTRAL RESPONSES FROM DENSITY MEASUREMENTS FOR THREE SOILS.

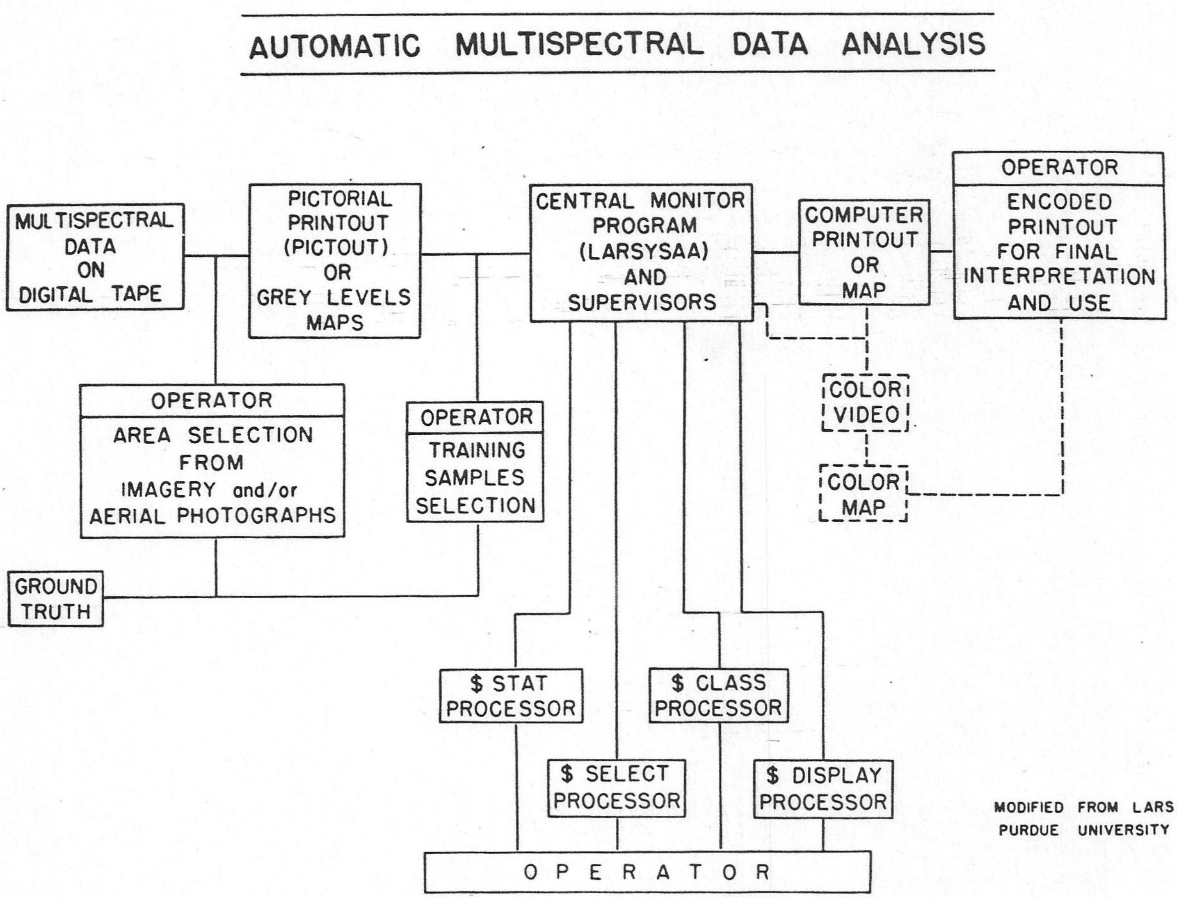

FIGURE 7 AUTOMATIC MULTISPECTRAL DATA ANALYSIS SYSTEM IN OPERATION AT 'LARS' WITH FUTURE POSSIBLE IMPLEMENTATIONS INDICATED WITH DASHED LINES.

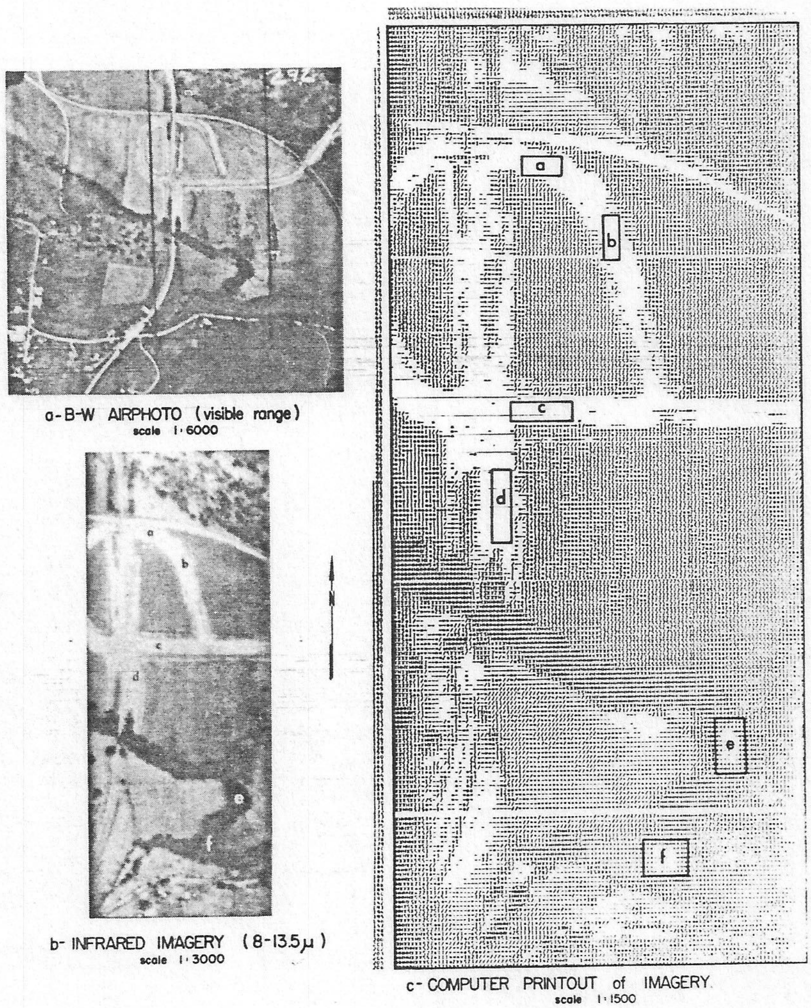

FIGURE 8 COMPUTER GREY-LEVEL PRINTOUT USED FOR THE SELECTION OF TRAINING SAMPLES.

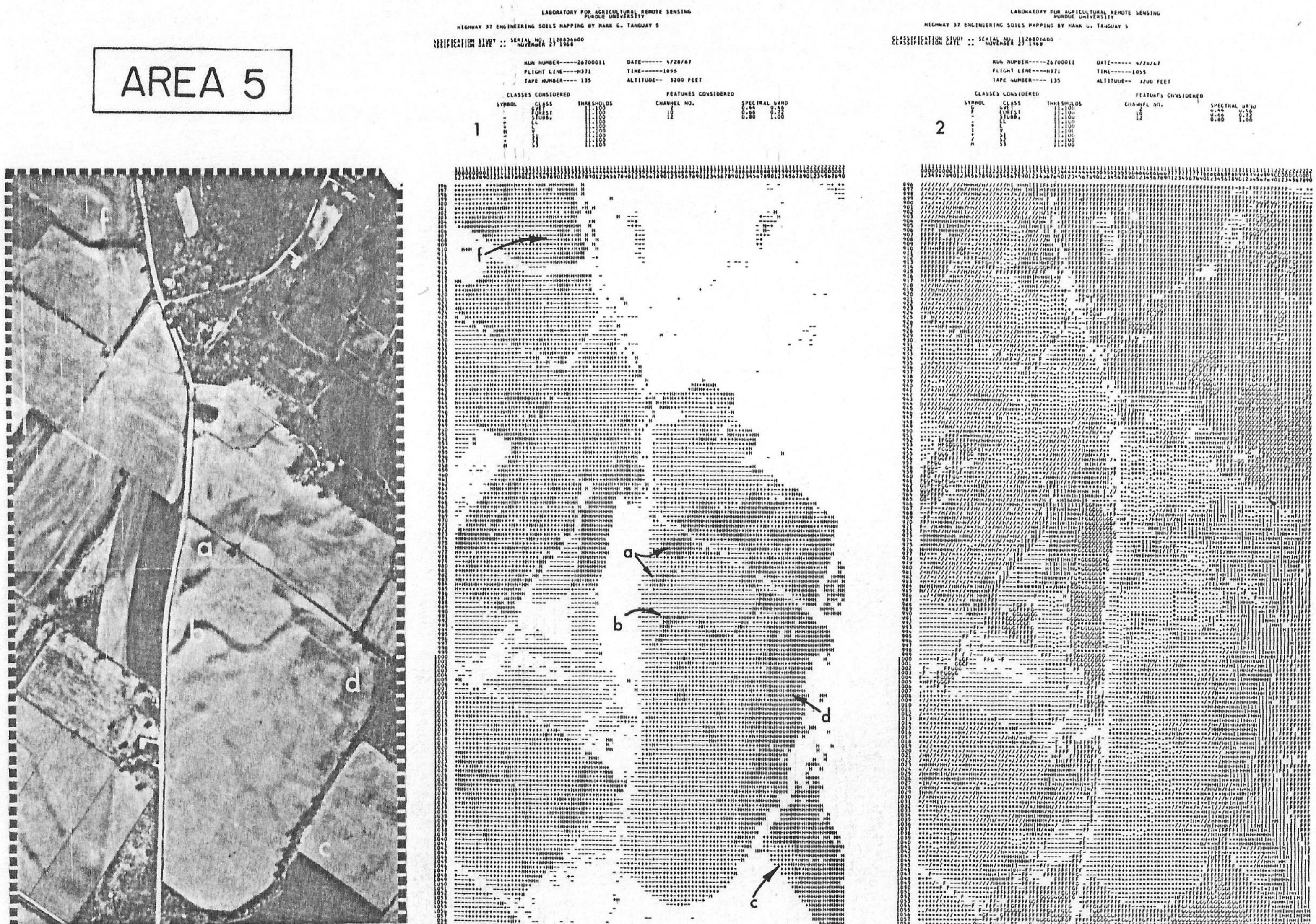

FIGURE 9 AUTOMATIC MULTISPECTRAL DATA CLASSIFICATION ON COMPUTER PRINTOUTS FOR ENGINEERING SOILS AND DRAINAGE FEATURES.

FIGURE 10 PRINTOUTS OF AN ATTEMPT TO DELINEATE LAND FORMS ON A SPECTRAL RESPONSE BASIS.

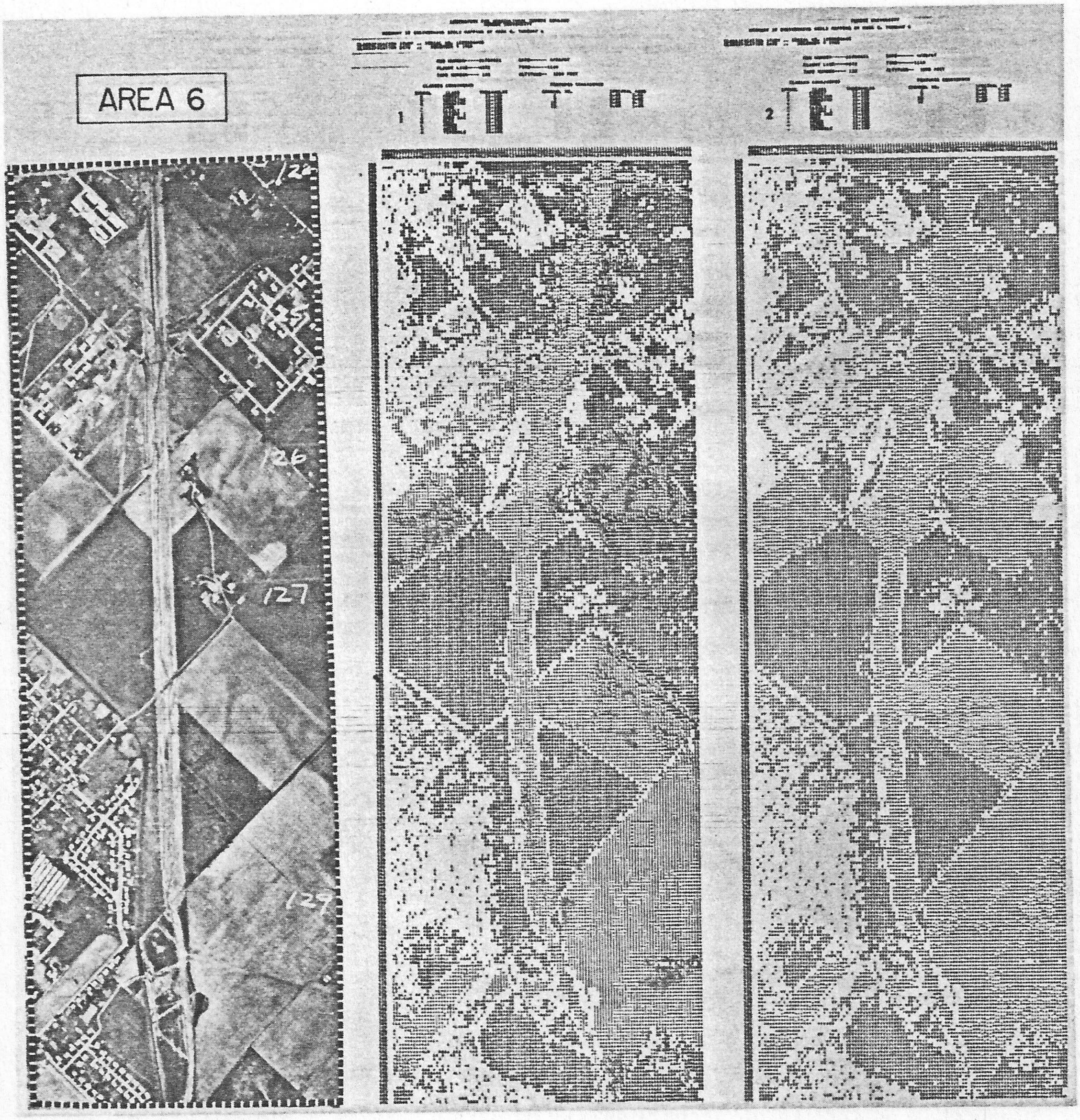

FIGURE 11 PRINTOUTS OF (1) GENERAL CLASSIFICATION, (2) LAND USE AND SOILS, (3) AND (4) MUCK AREAS, (5) SAND AREAS.

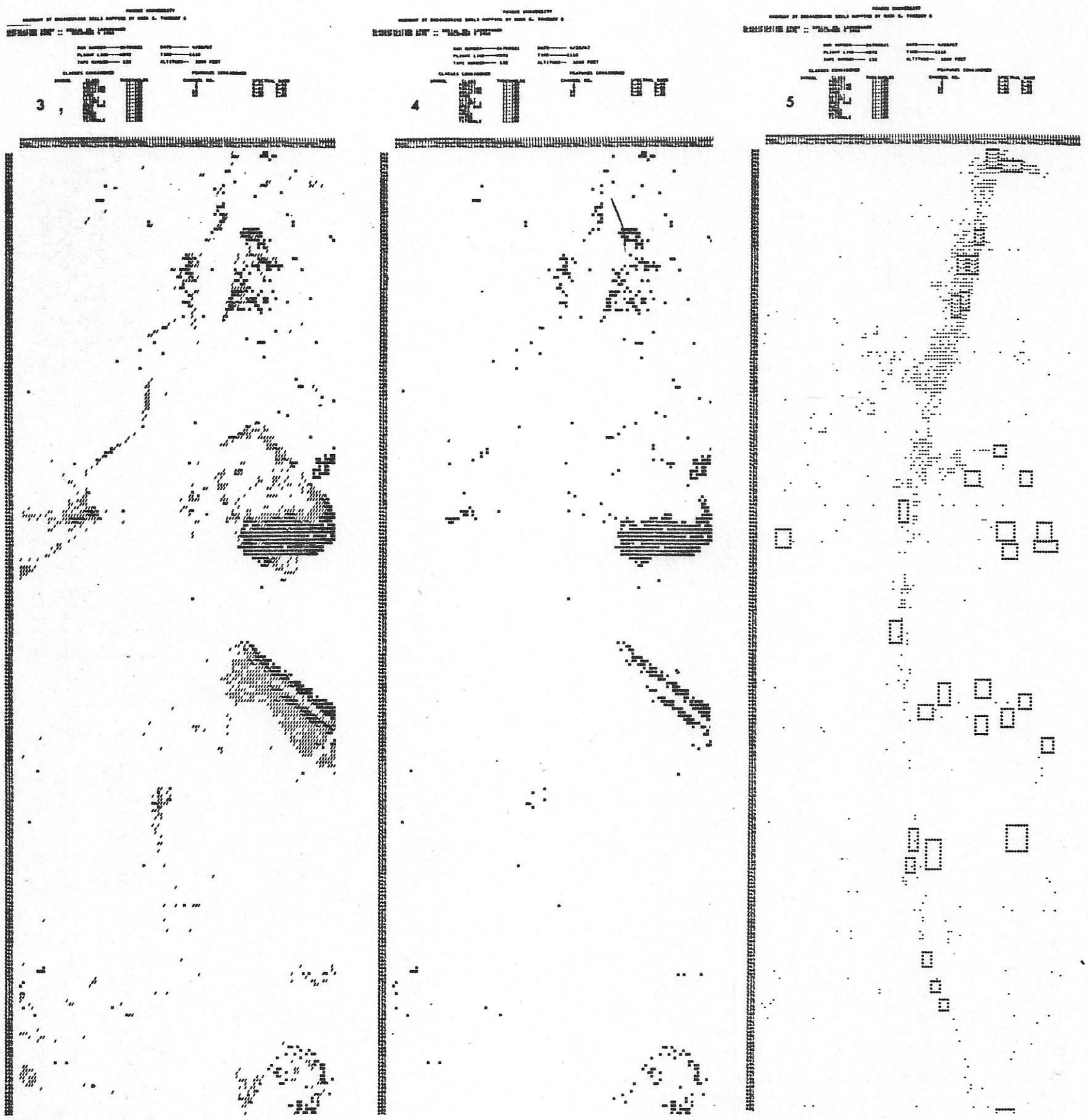

FIGURE 11 (cont'd) PRINTOUTS OF (3) AND (4) MUCK AREAS, (5) SAND AREAS.

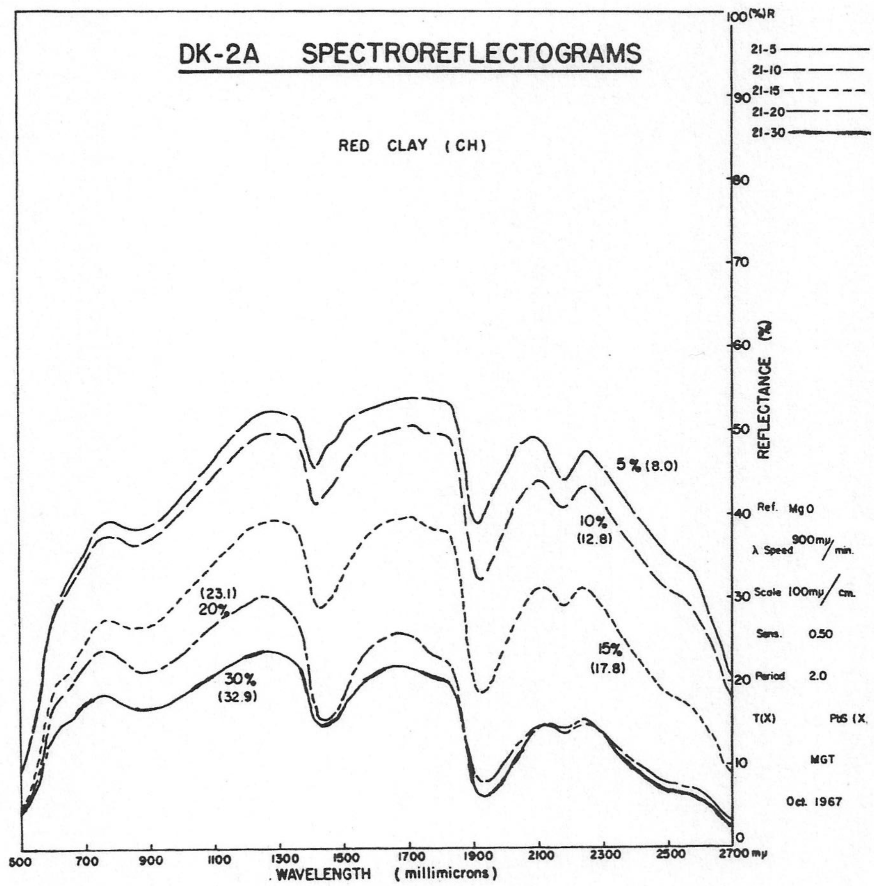

FIGURE 12 SPECTRAL REFLECTANCE OF A RED CLAY SAMPLE AS A FUNCTION OF WAVELENGTH FOR VARIOUS WATER CONTENTS.

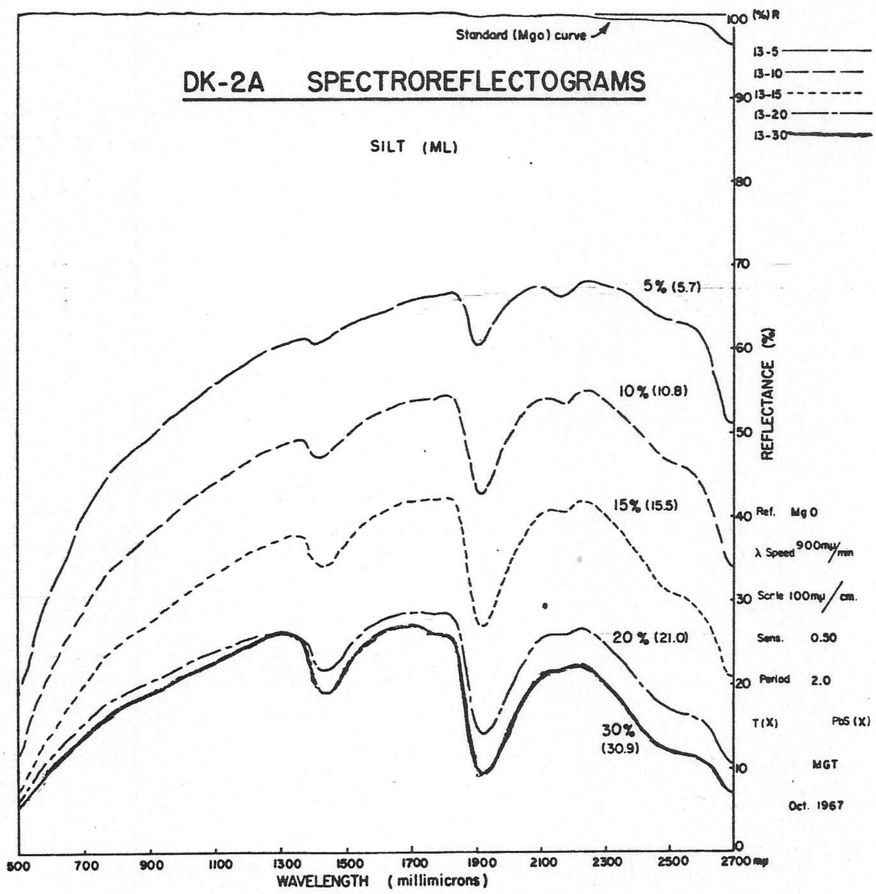

FIGURE 13 SPECTRAL REFLECTANCE CURVES FOR A SILT SAMPLE.

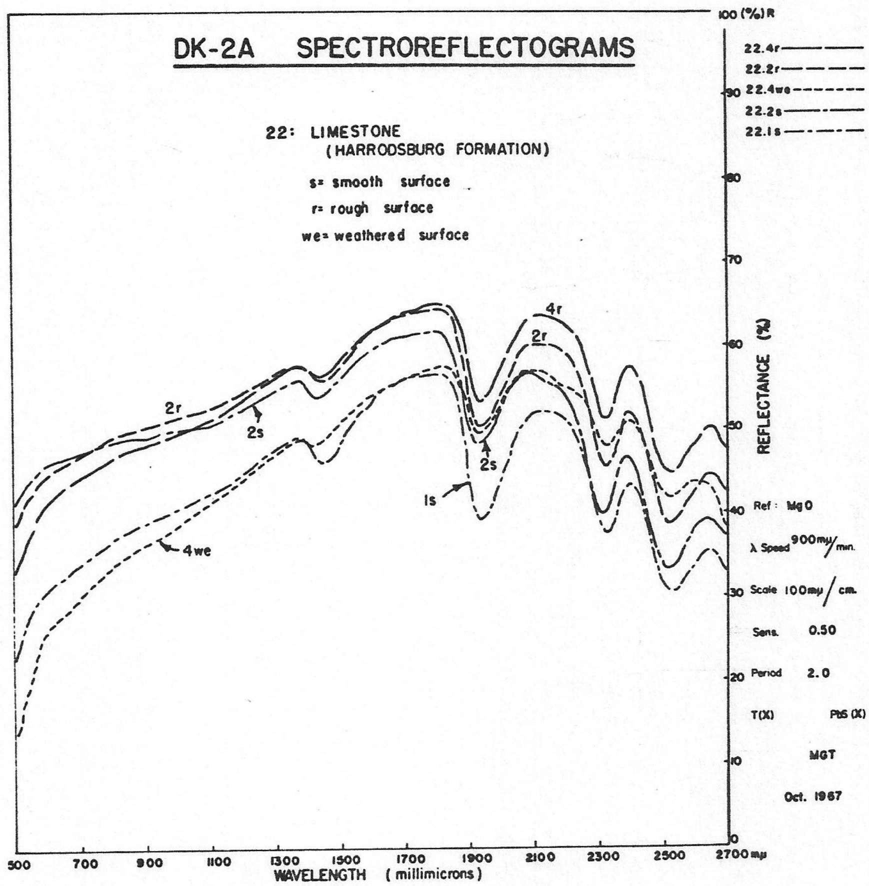

FIGURE 14 SPECTRAL REFLECTANCE FOR LIMESTONE SAMPLES OF THE HARRODSBURG FORMATION.

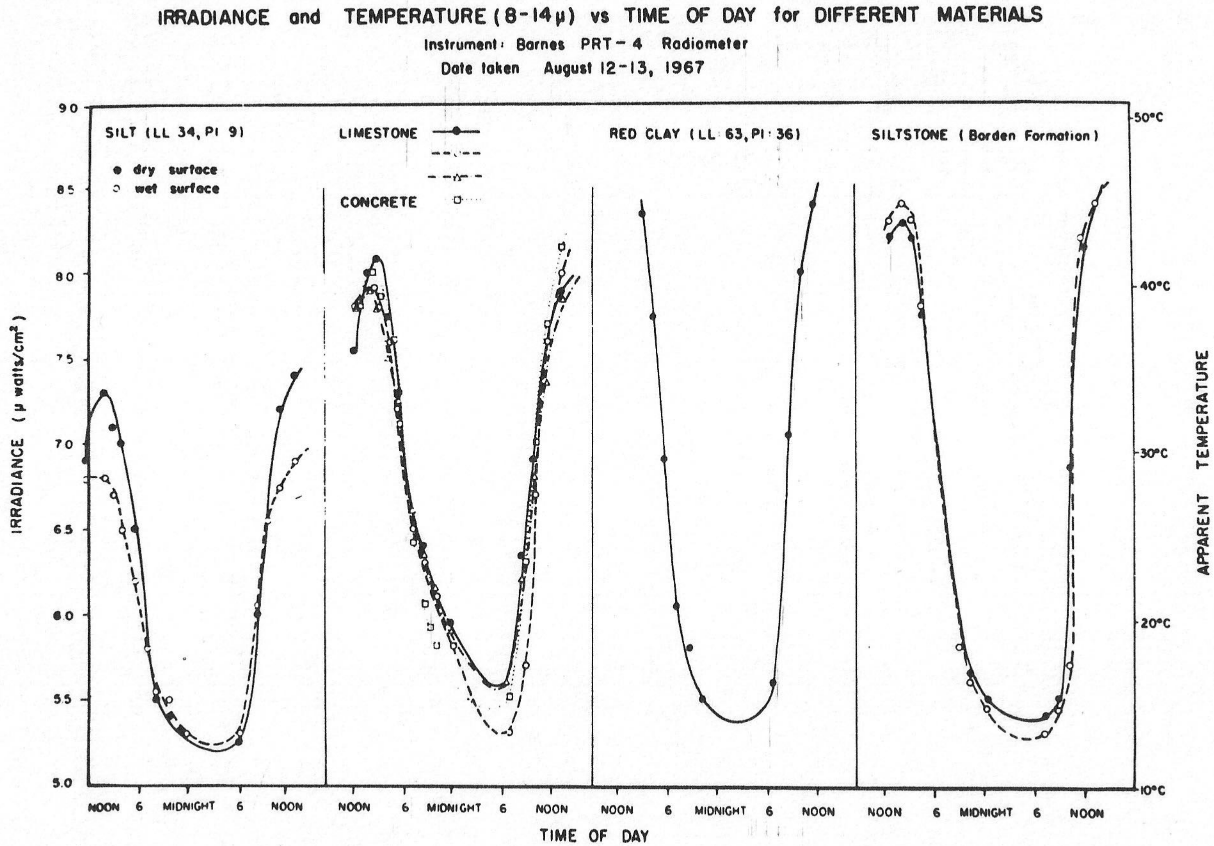

FIGURE 15 FIELD INFRARED RADIATION MEASUREMENTS.

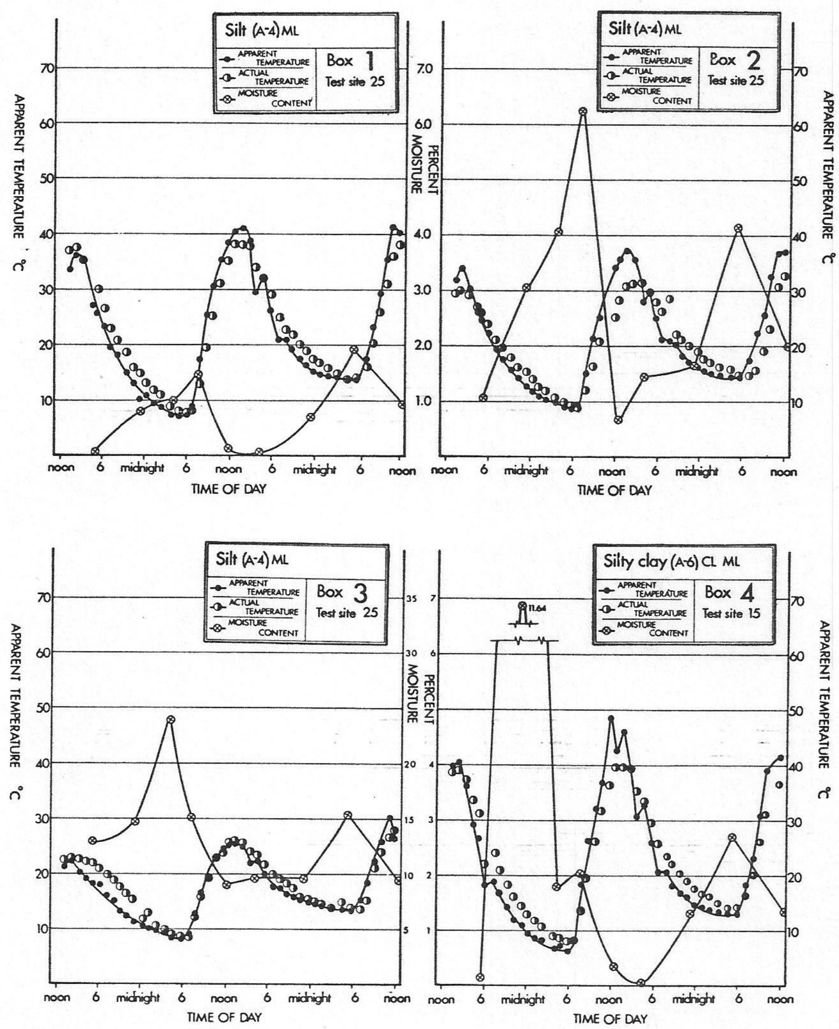

FIGURE 16 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

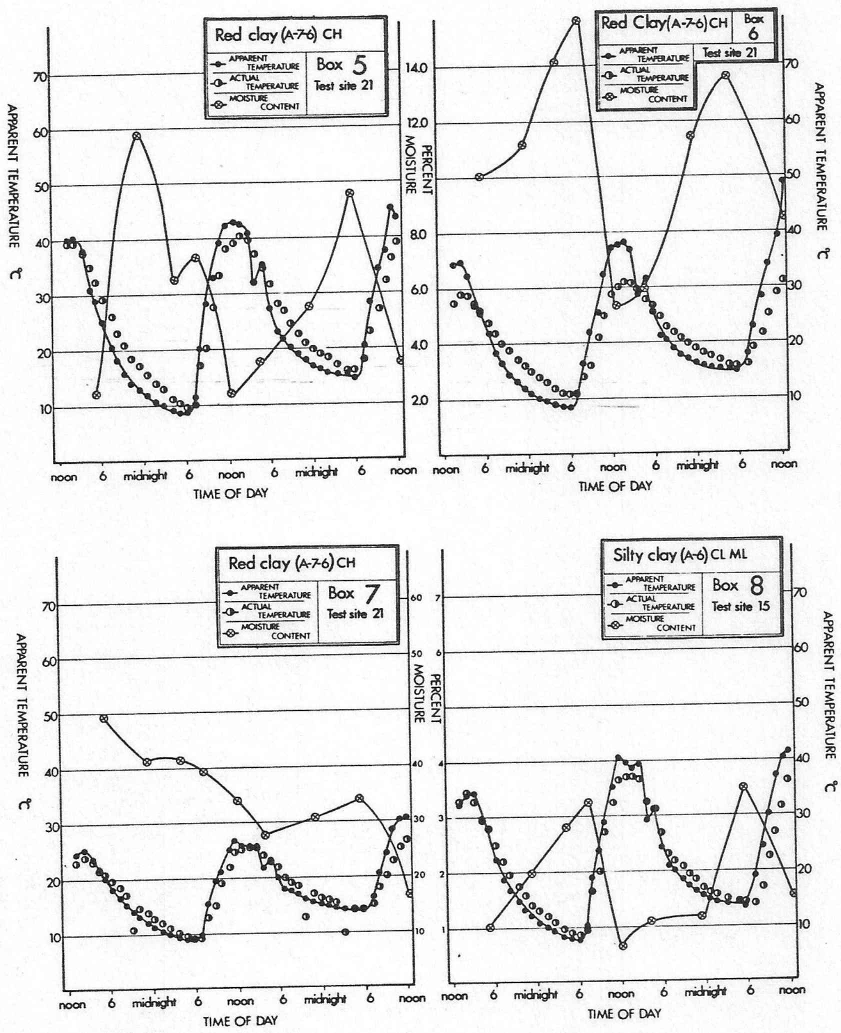

FIGURE 17 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer

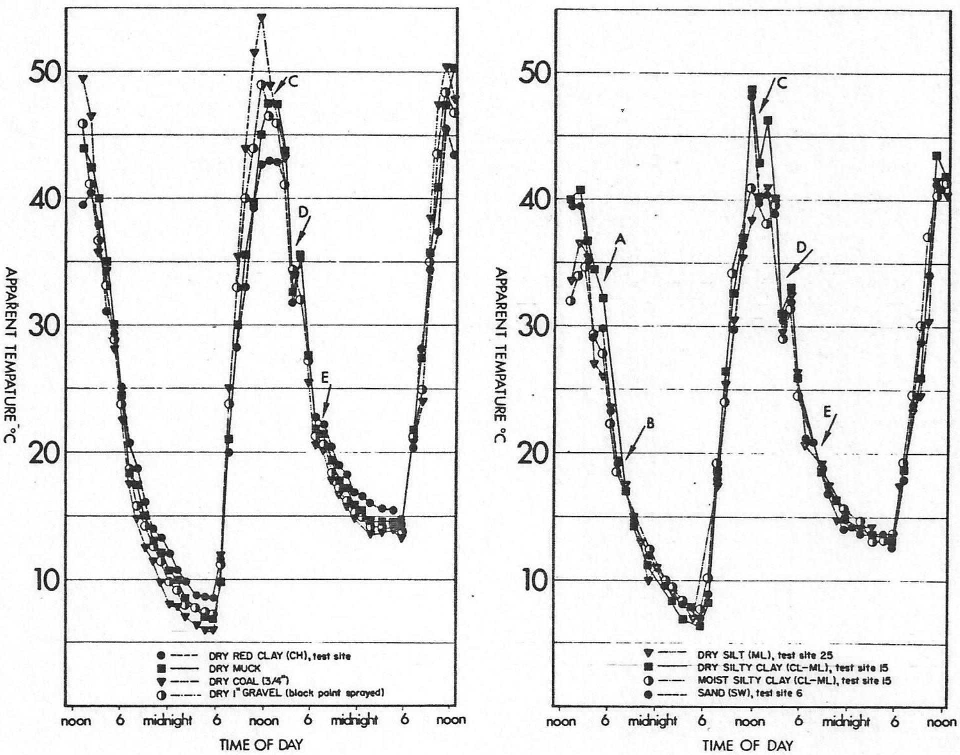

FIGURE 18 APPARENT TEMPERATURE (8-14μ) vs TIME OF DAY FOR VARIOUS MATERIALS

Recorded September 6-7, 1968 with the BARNES PRT-5 Radiometer