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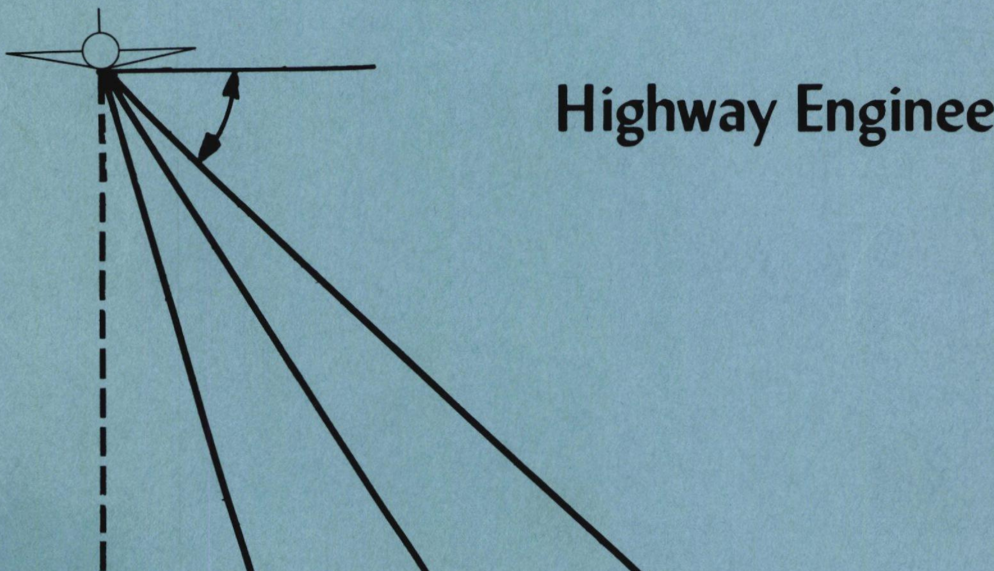
Special Report 102

Remote Sensing and Its Application to Highway Engineering



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Special Report 102

REMOTE SENSING and Its Application to Highway Engineering

Subject Area

21 Photogrammetry
61 Exploration-Classification (Soils)

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Foreword

A new era has arrived in the application of aerial reconnaissance techniques—now referred to as remote sensing—for gathering data useful in the planning, design, construction, and maintenance of highways. This era has been ushered in by the availability of new sensors and camera systems such as infrared, radar, multiband, and multichannel units. These systems expand the regions of the electromagnetic spectrum available to interpreters beyond the normal visible region, and are also capable of providing coverage within narrow bands in the visible region.

The five papers included in this SPECIAL REPORT cover the broad field of remote sensing and its application to engineering. The topics discussed include the types of sensor systems available, the principles of their operation and what they sense, an indication of their potential value in various engineering areas, and examples demonstrating their application to engineering, both individually and in combination. A discussion of this subject is especially timely because most of the sensors described, which were formerly classified and of limited availability for civilian applications, have been recently declassified and are available commercially.

The paper by Matalucci and Abdel-Hady summarizes some of the basic principles of infrared radiation and demonstrates various applications of infrared photography and imagery to surface and subsurface exploration. Numerous examples of infrared imagery are included in the paper to demonstrate the value of this sensor.

William A. Fischer of the U. S. Geological Survey has an extensive background in the application of various remote sensors in the field of geology and engineering geology. His concise summary describes the various sensor types and their applications to engineering projects. Some examples are included to demonstrate the type of information that can be derived.

The paper by Rib and Miles may be considered a summary on the topic of remote sensing. The paper describes the results obtained in evaluating the complete series of available sensors for interpreting engineering soils and soil conditions. A major conclusion of the study is that the optimum information is obtained when a combination of sensors is used simultaneously. For the particular problem investigated, the optimum combination was natural color photography and a multichannel sensor.

The paper by Parker and Prentice describes the various types of sensors developed—both imaging and nonimaging—and their potential applications to engineering. Some discussion is also included on parameters influencing the collection of sensor data. An extensive bibliography is included with this paper that should prove of value to these who wish to delve deeper into this subject.

Barr and Miles present a systematic approach to the interpretation of landforms and the delineation of engineering soil groups from side-looking airborne radar (SLAR). To identify the landforms on the radar, pattern elements are defined in a manner similar to the interpretation of conventional photography. The advantages and limitations of SLAR imagery compared with conventional photography for regional planning purposes are also discussed.

—Harold T. Rib

Contents

Surface and Subsurface Exploration by Infrared Surveys

R. V. MATALUCCI, U. S. Air Force Institute of Technology, and
M. ABDEL-HADY, School of Civil Engineering, Oklahoma State University

This paper summarizes some of the basic principles related to infrared radiation and demonstrates various applications of infrared photography and imagery to surface and subsurface exploration and terrain analysis for highway construction and other engineering projects. Major conclusions from this study are the following: (a) IR photography and imagery highlight variations in soil texture, composition, and moisture that may not usually be recorded by conventional photography; (b) the chlorophyll effect allows IR photography to assist in the appraisal of cultivated land for right-of-way acquisitions; and (c) hidden subsurface conditions and geological features that are of greatest importance during highway site selection and design can be exposed with IR instrumentation—features such as muck pockets, underground cavities, volcanic and hydrothermal activities, subsurface drainage systems, and buried utilities and conduits. With further research in the techniques used for remote sensing in the infrared, surface and subsurface exploration and drainage studies for construction of highways, airports, and other projects may be greatly facilitated.

•IN THIS advancing technological age, there is indeed a requirement for detecting and identifying various objects and conditions in the universe from remote locations. Because our natural remote sensors—our eyes, our ears, our skin—are surprisingly limited in acquiring and recording information about a remotely situated area, it has been necessary over the years to develop measuring devices to supplement them. These measuring devices, better called "remote sensors," detect and record energy that is either emitted or reflected from objects that would otherwise not be revealed through the human senses. As research in the area of remote sensing of environment continues, techniques are beginning to provide otherwise unobtainable information about the world around us.

One of the most useful regions on the electromagnetic spectrum for remote sensing, in terms of engineering application, is the infrared. It has been established that although not detectable by the human eye, all objects having temperatures above absolute zero emit infrared radiation. In addition, an object receives infrared radiation from the sun, reflects a portion of it and absorbs the rest. The latter portion can then be emitted. If a sensing device is appropriately positioned to detect the emittted or even reflected infrared radiation, an identification of some objects could be possible through application of some basic laws of physics and radiation.

It is the purpose of this discussion to summarize some of the basic principles related to infrared radiation and review various applications of infrared photography and imagery to surface and subsurface drainage and terrain analysis for highway construction.

NATURE OF INFRARED

Infrared is an electromagnetic radiation whose spectrum band falls between that of visible light and the microwave region. It is a form of "heat" radiation, but this significance appears less prominent today than it was at the time of its discovery by

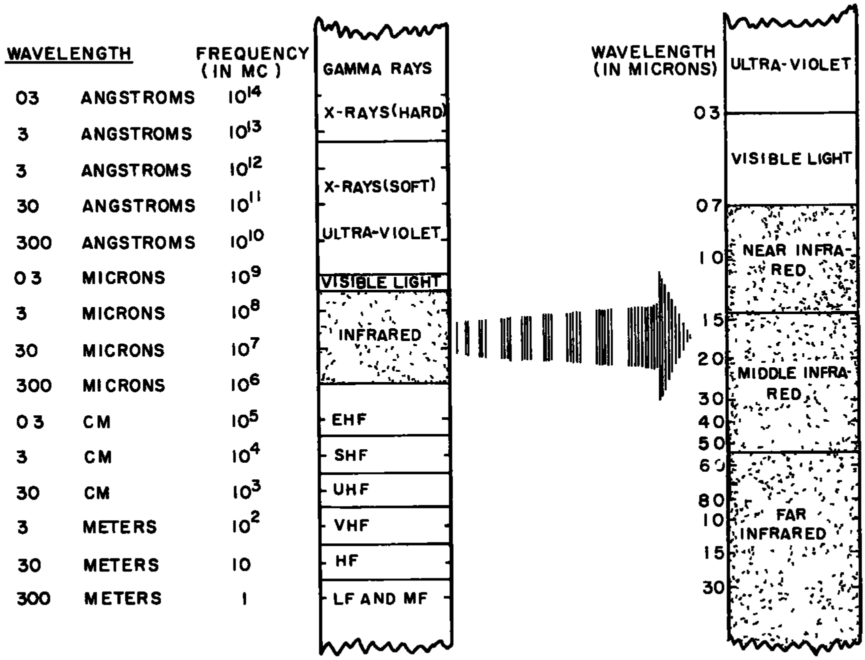


Figure 1. Electromagnetic spectrum: infrared occupies the spectrum band between visible light and microwaves.

Herschel, in 1800. In any event, today infrared (IR) is most generally applied to electromagnetic energy whose wavelength lies between 0.7 and 1000 microns (0.7×10^{-4}cm to 1000×10^{-4} cm). This energy can be reflected from, absorbed by, or emitted by objects of the universe.

Considering IR as a form of electromagnetic radiation, Figure 1 shows its domain in the electromagnetic spectrum. The customary units for wavelengths in the various regions are angstrom, micron, or centimeter as shown (1 micron = 10^{-4} cm, 1 angstrom = 10^{-8} cm). The IR domain is further divided into near, middle, and far infrared, whose limits have been arbitrarily defined by the different types of detection devices used to record them.

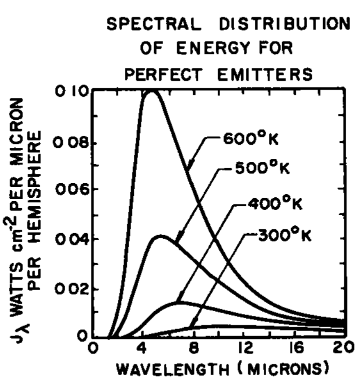


Figure 2. The effect of body temperature on intensity and wavelength of infrared radiation.

Infrared Radiation

At temperatures above absolute zero (absolute zero in degrees Kelvin equals -273 degrees Centigrade), all objects continuously radiate electromagnetic energy as a result of their atomic and molecular motion. The total amount of emitted radiation increases with the object's absolute temperature and reaches a peak at a certain wavelength. With increasing temperatures, the peaks are reached at progressively shorter wavelengths (Fig. 2). The earth, having an average temperature of 300 K, has an emission curve that peaks near 10 microns and gradually decreases toward the microwave region. This permits the detection of emitted radiation of terrestrial bodies in a broad region of wavelengths in the infrared band. The sun, by the same token, peaks in radiant power around 0.5 microns, which permits easy detection of reflected light with conventional photographic equipment.

Two fundamental laws set forth the relationships of Figure 2. The first is Wien's displacement law, which states that the wavelength at which peak radiation occurs equals a constant K divided by the object's absolute temperature in degrees Kelvin ($\lambda = K/T$). The second is the Stefan-Boltzmann Law, which states that the total radiation from an object is equal to the product of the fourth power of its absolute temperature, a constant, and an emissivity factor E ($W = E\sigma T^4$). The emissivity factor is the ratio of an object's radiation to that of an equivalent "blackbody." A blackbody is an object that absorbs all radiation that strikes it without any reflection. The factor, therefore, depends on the material and its surface properties. The emissivity factor for a mirrored surface, for example, would be about 0.05, while for lamp black 0.95. Finally, since total radiation or radiant emittance is expressed as the radiant energy emitted per second per square centimeter of surface area, energy per second is power; hence, emittance is usually measured in watts per square centimeter.

There are several other laws of radiation that in varying situations take on a complicated form. These become more applicable in the quantitative analysis of emittance, absorption, and reflectance characteristics of different objects. A discussion in this area is beyond the scope of this paper. Nevertheless, from some of the principles already presented, the basic strategy for detecting infrared radiation becomes relatively clear.

Each object in nature has its own unique property of reflected, emitted, or absorbed radiation. These properties, once identified, can be used to distinguish one object from another, or obtain information about shape, size, and other characteristics. Furthermore, if the spectral characteristics of an object are known, an appropriate detector can be selected to make the desired measurement.

The best known thermal source of IR radiation is the sun. Here, approximately 40 percent of the sun's energy is in the form of IR heat radiation. Variations in the quantity of radiation can obviously be attributed to the changing distance from the earth, water vapor and particles suspended in the atmosphere, and irregularities in the sun itself.

Atmospheric Absorption of IR

The atmospheric path between source and object, object and detector, or source and detector imposes severe limitations that must be considered. The atmosphere is, of course, far from being a pure substance. It is a mixture of oxygen, nitrogen, water (vapor, liquid, or solid), carbon dioxide, rare gases, and the suspended particles generally classified as haze, smog, or dust. Any radiation passing through the atmosphere could be either scattered, absorbed, or reflected by suspended particles before being finally transmitted.

A typical transmission spectrum of the atmosphere is shown in Figure 3. The darker areas are the regions in which transmission is almost completely blocked by H_2O vapor, CO_2, or a combination of other gases. The remaining regions are referred to as "infrared windows" in which the absorption is slight. Absorption by water vapor virtually closes the atmosphere beyond the 25 micron wavelength to the start of the microwave region, where the absorption of the IR is so complete that for practical purposes the atmosphere is considered opaque. As a result of this natural phenomenon, if transmission of radiation is required through the atmosphere, it would be necessary to channel the wavelengths within the infrared windows.

INFRARED DETECTION AND RECORDING

Infrared radiation can be detected and presented in image form by two methods: photography and imagery. First, IR can be presented by photography using film that is sensitive to reflected IR radiation. Second, IR can be presented by radiometry or imagery with electronic devices that are sensitive to emitted IR radiation and that produce an electrical signal proportional to the incident IR radiation. Both methods

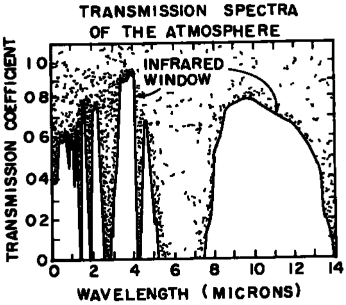


Figure 3. Atmospheric absorption of infrared energy as a function of wavelength: atmosphere is opaque to IR except in the "windows" shown.

can provide a visible photograph of the area in question, providing the latter utilizes a device that converts the IR emission to an electrical signal, which is further converted to light that exposes a photographic film and records an IR image.

An aircraft can be employed for taking IR photography and imagery as involved in taking normal aerial photographs. In IR photography, a camera is used to photograph a large area of the terrain from a single perspective point, whereas in imagery, a radiometer is used that scans the terrain from side to side as the aircraft moves forward. The former method photographs the image of the reflected IR radiation, and the latter produces an image that is similar to a photograph but whose tone is related directly to the IR radiation emitted in the form of heat by the terrain.

In general, therefore, IR photography is similar to normal panchromatic photography except that IR radiation is recorded on an IR-sensitive film while panchromatic radiation is recorded on a visible light-sensitive film. Furthermore, panchromatic and IR photography are both involved with reflected radiation. Infrared imagery, on the other hand, is a heat-measuring system that records IR radiation emitted from the object and is, therefore, a function of the object's emissivity and apparent temperature.

The following table offers a brief comparison of IR photography and imagery:

Photography	Imagery
Records reflected radiation.	Records emitted radiation.
Recording is directly on IR-sensitive film.	Recording is an electric signal converted to light that exposes the film and produces an IR image.
Can only record up to about a 0.9 micron wavelength unless film is shielded from the emission of the camera.	Can record all IR wavelengths except those restricted by the atmospheric absorption bands.
Usable in daytime or when some other source of IR radiation is available instead of the sun.	Usable preferably at night unless filtering devices are employed to eliminate ambient reflected radiation.
Reflection qualities of objects are measured.	Apparent temperature and emissivity of objects are measured.

SURFACE AND SUBSURFACE EXPLORATION AND DRAINAGE STUDIES BY AERIAL INFRARED SURVEYS

Surficial Earth Features

Aerial photography provides a reliable and efficient means of mapping terrain features of many areas. This method is further enhanced by the development of instruments for remote sensing in the IR region. Photographing an area in the infrared region in no way provides a complete image from which accurate identification of objects can be made. Instead, the infrared provides a new dimension to aerial photography where, in correlation with panchromatic photographs, more details about objects can be determined. Quite often, one portion of the desired information is best obtained in one region of the electromagnetic spectrum, while other portions require sensing in other regions of the spectrum. This consideration is often referred to as "multiband spectral reconnaissance" and it has several specific applications.

Colwell (4) illustrates the use of this method as a means of distinguishing between grass, concrete, asphalt, and soil surfaces from an examination of aerial photographs. Figure 4 shows the relative light reflectance of the four surfaces with respect to wavelength. For example, note that a grass surface has the lowest reflectance below 450 millimicrons and the highest reflectance above approximately 720 millimicrons. Consequently it is necessary to select appropriate bands in order to obtain photographic tonal characteristics that would permit differentiation between the four surfaces. The selection of a film sensitive to a specific wavelength where the greatest reflectance difference between surfaces exists provides the best tonal contrast. In this situation, the best tonal contrasts appear to lie at the 400 millimicron and 800 millimicron wavelength regions.

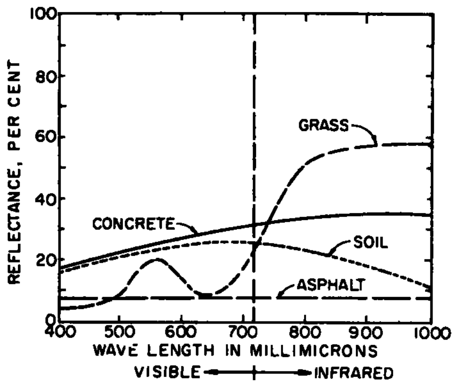


Figure 4. Light reflectance of surface materials [after Colwell (4)].

Figure 5 is a comparison between visible and IR photographs. Both were recorded during a summer day while using an IR detector for the one and a visible light detector for the other. The IR photograph represents primarily reflected IR solar energy, while the visible is the result of reflected sunlight. Note the difference in the appearance of the stream, vegetation, road, and cultural features on the IR.

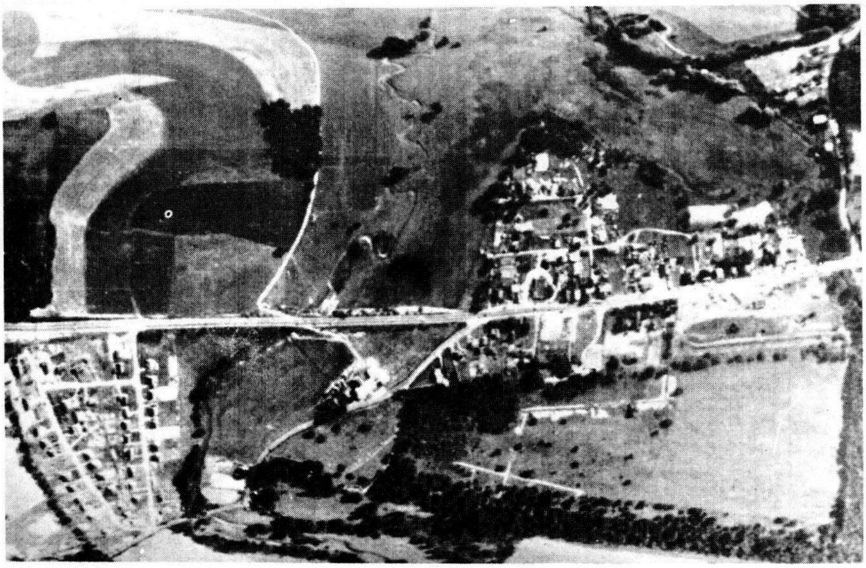
From a study of IR and visible photographs and IR imagery, plowed and unplowed fields can be distinguished. The plowed field would be expected to have higher emission if more of the solar energy is absorbed and subsequently emitted at the surface. A plowed or scarified surface would, therefore, usually appear lighter in tone on an IR image because of the higher emission (Fig. 6). Much of this phenomenon, however, depends on soil composition, density, surface texture, and moisture, which have been known to sometimes reverse expected tonal contrasts.

This same correlation assists in estimating various soil parameters. The configuration, physical state, and trafficability of surficial materials can be ascertained to a great extent simply by interpretation of the tonal contrasts and other features that may appear on an IR photograph or image. Besides comparing IR photographs obtained in daylight with conventional aerial photographs, nighttime IR imagery adds a new dimension that assists in identifying surficial properties.

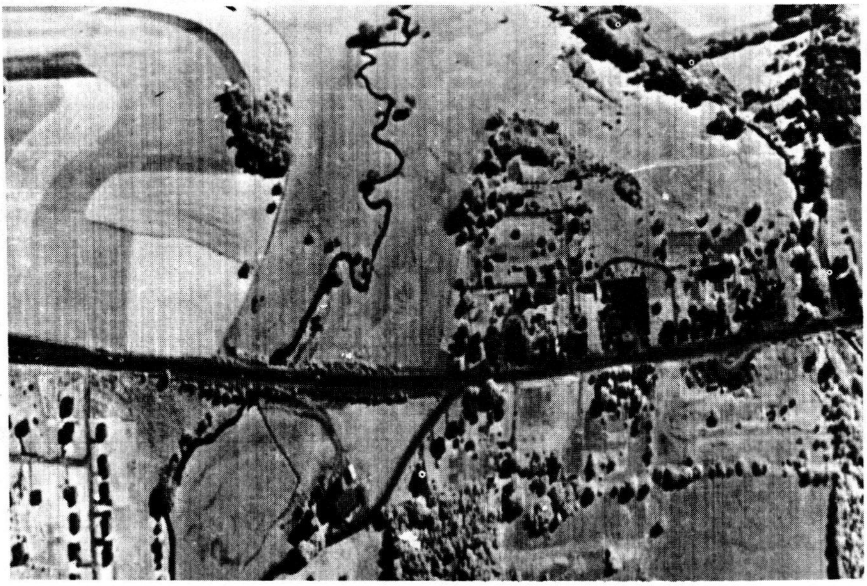
An important fundamental principle that arises in the discussion of IR photography of vegetation is the "chlorophyll effect." In essence, this effect is usually explained by stating that chlorophyll is transparent to IR. As such, the internal tissues of leaves are permitted to reflect IR radiation. When leaves are diseased, however, the internal structure collapses and reflectance of IR decreases. As a result, vegetation will photograph lighter in IR if healthy and darker if diseased (Fig. 7). IR photographs, therefore, could be well used by right-of-way departments in appraising the value of citrus groves, crops, and other cultivated lands.

Geological and Subsurface Exploration

The geological interpretation of aerial photographs for identifying various landforms, rock types, and erosional features and for mapping joints and faults is a well-developed discipline. The location of these and other types of geological structures that may exert major influence on site selection for highway construction and other engineering



(a) Panchromatic Aerial Photograph.



(b) Infrared Aerial Photograph.

Figure 5. Comparison of visible and near infrared photographs of the same area taken on a summer afternoon (courtesy of HRB-Singer, Inc.).

projects can be greatly enhanced by infrared surveillance. Within recent years, the development of IR aerial surveys has provided a means of obtaining geological and subsurface information that was not possible with conventional photography. Much of the additional detail that IR provides is due to the different specific heats and thermal conductivities of the materials associated with the geological formation.

Recent IR imaging instruments have made possible the investigation of subsurface anomalies associated with volcanic regions of Hawaii (6). The aerial extent and relative intensity of the subsurface thermal activity were mapped. From the IR image,

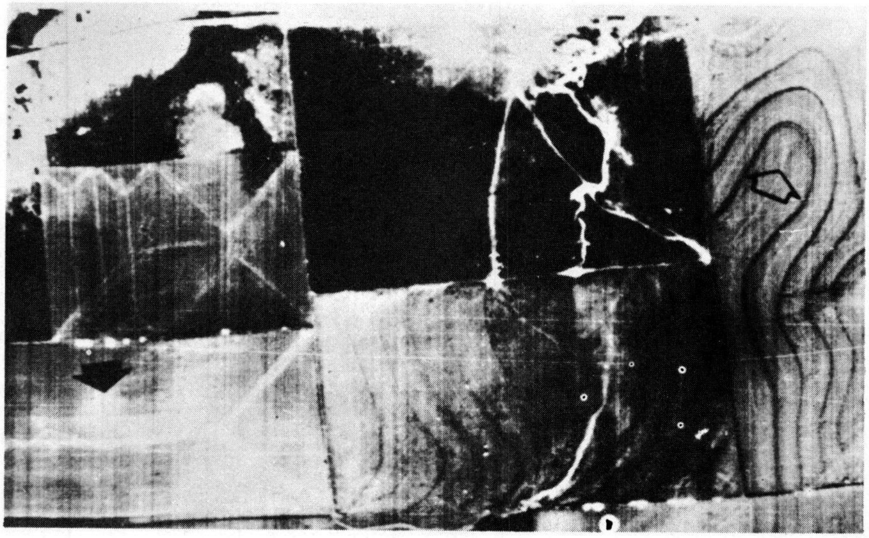


Figure 6. IR image of farmland near Dallas, Texas, reveals a tilled field and contour ridging (courtesy of Texas Instruments, Inc.).

it was possible to locate volcanic thermal patterns and structural features that were not observed on conventional aerial photographs. The degree and extent of thermal activity in many of the areas surveyed were obtained at various periods, and changes were noticed. The causes of a continuous increase in degree of intensity in some areas are not always known, but one could speculate that increasing subsurface activity of some type could be imminent. Airborne IR sensing instruments could be used periodically to monitor subsurface thermal activity in volcanic regions.

The subsurface and near-surface hydrothermal activity in Yellowstone National Park was recorded with IR sensing instruments (13). The image presented high-temperature features such as hot springs and geysers, warm rivers, and above-normal ground temperatures. Various thermal patterns were observed where hot springs discharged into lakes. Many of the hot springs at the lake bottoms had not been previously located. The imagery presented demonstrated the usefulness of IR sensing for mapping hydrothermal features, especially in areas too remote to be otherwise charted.

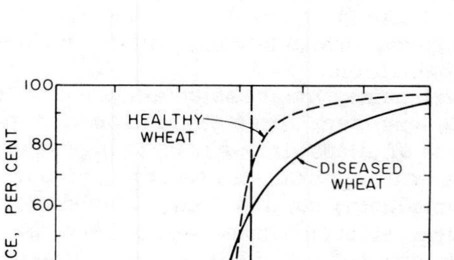


Figure 7. Light reflectivity of wheat leaves [after Colwell (4)].

Although discontinuities in rock and soil masses can usually be mapped using conventional aerial photography, the tonal differences are at times more pronounced on IR imagery. To illustrate this application some investigations made by the Science Service Division of Texas Instruments, Inc., are shown in Figures 8 and 9. Some of the distinction between the different materials could have been attributed to the different types of vegetation supported by each, but much more contrast is evident on IR imagery due to the thermal qualities of the rock and associated soils.

Although the surface and subsurface drainage pattern in Figure 9 is distinct, the tonal contrast between adjacent soil types, which expresses different thermal characteristics, is evident. Thermal variations are a function of specific heats

Figure 8. IR image of Mt. Pisgah near Hector, Calif., reveals a cinder cone of higher thermal property and a clear contact between lava flows ; the lighter tone at the center of the image is indicative of a relatively warmer material (courtesy of Texas Instruments, Inc.).

and thermal conductivities of the two lava flows in Figure 8 and of soil materials in Figure 9. Thermal patterns on IR imagery indicate variation in ground moisture and in the mineralogy and chemistry of the materials.

Infrared imagery is also used to display stream valleys and subsurface water channels that may otherwise be somewhat obscured by overburden or vegetation. Dark-toned areas within the stream valleys on IR imagery are usually expressions of higher ground moisture content. There is, however, the strong possibility that the dark-toned stream valleys do not actually represent moist areas. At times, valleys are filled with colder air that cools the surface in this area more than the surface of the higher land and results in darker tones on IR imagery.

Figure 10 reveals a striking subsurface drainage feature that is not displayed by a visual photograph. Vegetation many times suggests greater surface or subsurface moisture conditions at particular areas. However, vegetation alone does not provide a completely reliable means of exposing hidden drainage systems. The benefits gained from the use of IR imagery for locating underground drainage more reliably during highway site selection and construction are considerable.

The Science Services Division of Texas Instruments, Inc., has obtained much IR imagery for near-surface terrain analyses. Among them, three striking photographs reveal subsurface cultural features that could be of utmost importance to highway engineers. Figure 11 reveals the location of a drainage channel beneath an airport runway; Figure 12 exposes the location of a buried pipeline, and Figure 13 shows the location of a buried conduit. Many other cultural features whose location is vital for highway planning can usually be more distinctly exposed with IR imagery. Futhermore, considerable time could be saved in making surveys for designing highways if IR instruments were used to detect lost or forgotten buried utilities and other facilities.

The Florida State Road Department has been investigating the possibility of detecting near-surface underground voids, caves, and caverns in the limestone areas of the State with IR imagery. In a recent pilot surveying using a Bendix LN-1 sensor filtered to 3.7-5.5 microns, muck pockets were located that were previously overlooked in the soil survey (19). Further research to determine the type of IR instrument and wavelength bands most suitable for detecting underground voids and muck pockets will undoubtedly provide a valuable tool for the highway engineer.

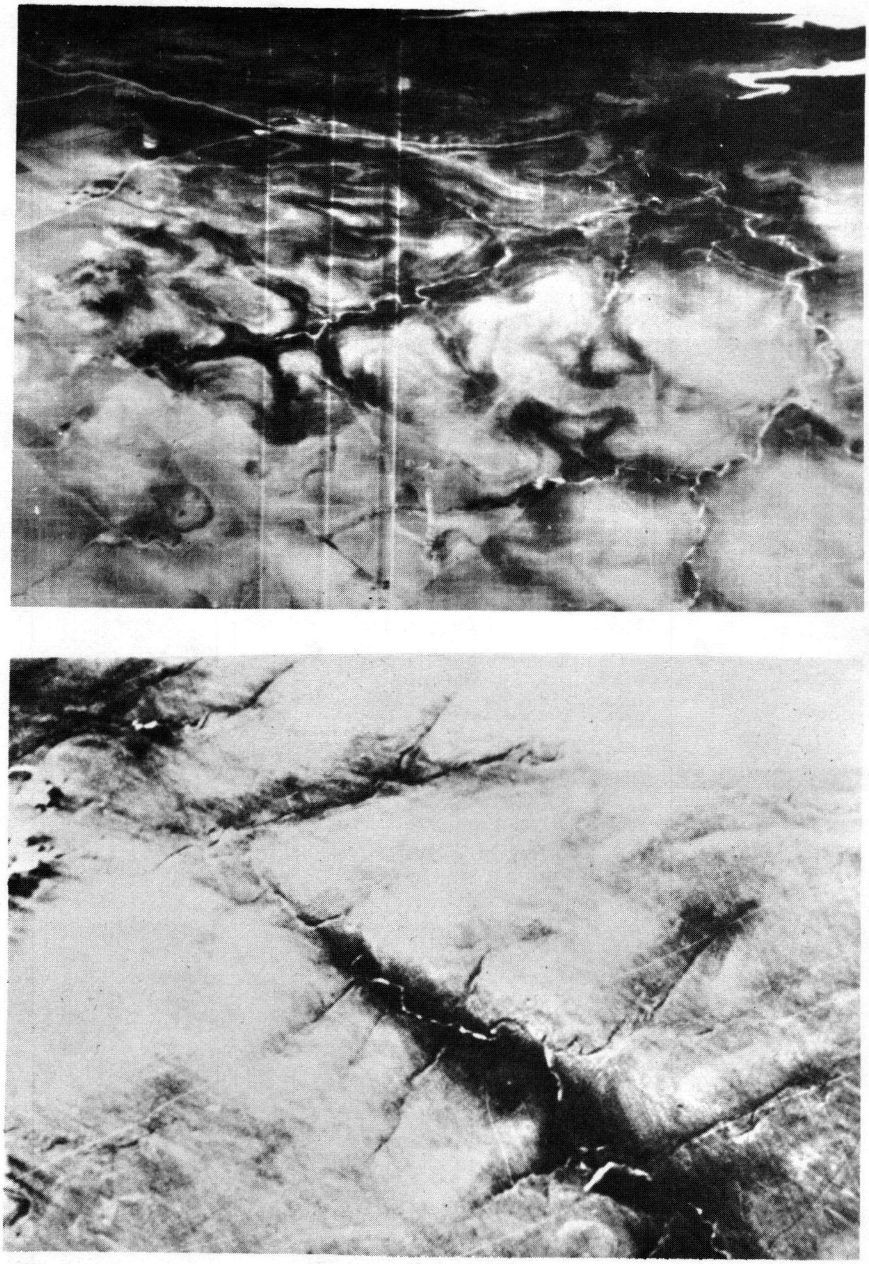


Figure 9. IR image of terrain near Fort Worth, Texas (top), shows the thermal character of flat-lying strata; IR image near Grapevine, Texas (bottom), shows soil thermal character (courtesy of Texas Instruments, Inc.).

Figure 10. IR image of terrain near Walley's Spring, Nevada, expressing a subsurface drainage feature (courtesy of Texas Instruments, Inc.).

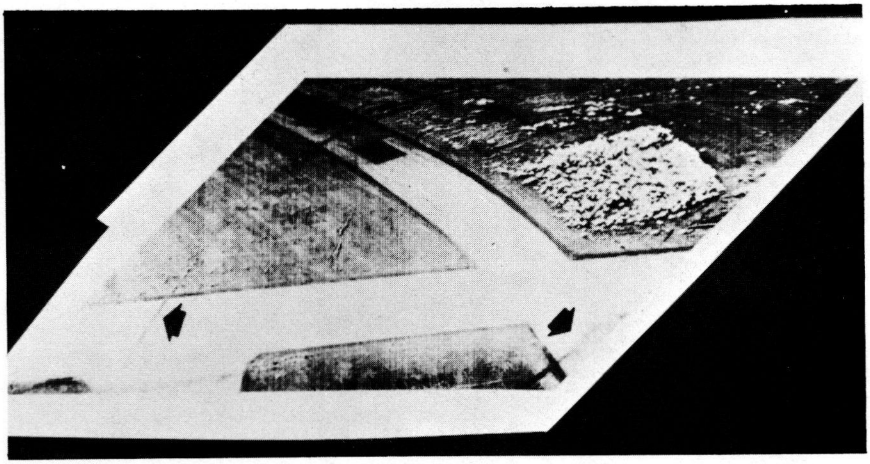


Figure 11. IR image of airport runway; arrows indicate location of existing subsurface drainage channels (courtesy of Texas Instruments, Inc.).

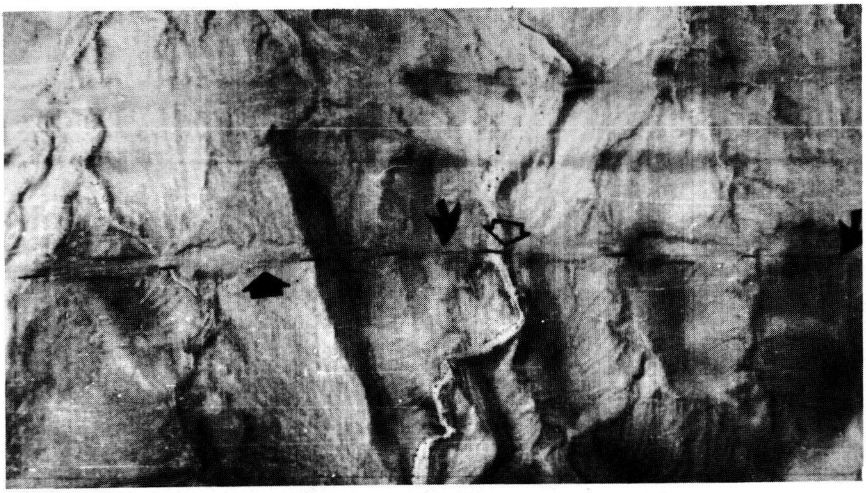


Figure 12. IR image of terrain at Death Valley, Calif., exposing the location of a buried pipeline; arrows from left to right indicate the pipeline right-of-way, pipeline beneath terrain, and pipeline exposed at stream crossing (courtesy of Texas Instruments, Inc.).

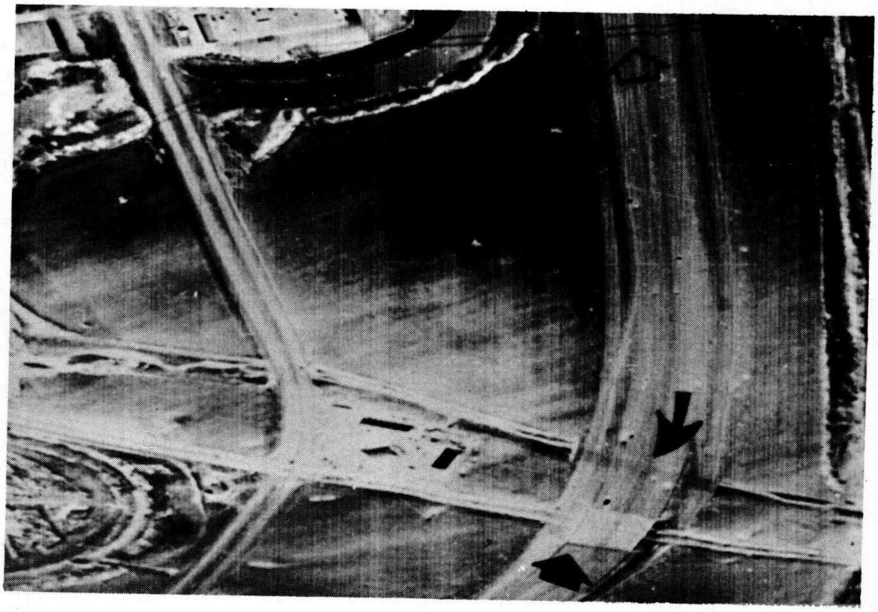


Figure 13. IR image of an industrial area of Dallas, Texas, showing highway overpass , power transmission lines , and subsurface conduit (courtesy of Texas Instruments, Inc.).

The application of IR instruments for detecting cavities under edges of concrete pavements is also promising. The advantage in detecting these cavities before pumping develops or actual failure takes place, both from a safety and maintenance standpoint, is obvious.

CONCLUSIONS

Infrared radiation, which lies between visible light and microwaves, can be considered one of the most useful regions of the electromagnetic spectrum for remote sensing for engineering purposes. Within the past few years there has been an increasing awareness of the potential applications of IR surveys for many practical purposes. Numerous investigations are presently being conducted by private and governmental agencies that are expanding IR sensing techniques into many areas of highway engineering.

It is of great value in highway planning to identify surface materials reliably and rapidly. IR photography and imagery highlight variations in soil texture, composition, and moisture that are not usually recorded by conventional photography. The chlorophyll effect allows IR photography to assist in appraising cultivated land for right-of-way acquisitions. The additional information that IR techniques provide about surface conditions can greatly reduce highway construction costs.

Hidden subsurface conditions and geological features that influence highway planning and design can be exposed with IR instrumentation. The location of muck pockets, underground cavities, volcanic and hydrothermal activity, subsurface drainage systems, and buried utilities and conduits is of utmost importance during highway site selection. IR sensing in many instances can expose these items, which are usually omitted during normal exploration surveys or drainage studies. The application of IR sensing for mapping boundaries of rock formations and soil types cannot be overemphasized.

Although experience in the geological interpretation of imagery and photography may appear to be somewhat limited at present, it is evident that valuable surface and subsurface information not noticeable on visible aerial photographs may be displayed using IR. This potential method of gathering such information should not be overlooked and its value in preliminary investigations is obvious. With further research in the techniques used for infrared remote sensing, surface and subsurface exploration and drainage studies for construction of highways, airports, and other projects may be greatly facilitated.

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Examples of Remote Sensing Applications to Engineering

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•MOST observations that can be made with remote sensing systems can provide information that is relevant to engineering endeavors. Figure 1 shows the basic parameters that may be "observed" with operational and/or experimental devices operating in one or more parts of the spectrum or one or more "dimensions." The dimensions of remote sensing include (a) the spatial dimension, (b) the spectral dimension, which includes two sub-dimensions—polarization and luminescence, and (c) the dimension of time. The ability of the scientific community to interpret items of engineering significance from remote sensor data varies greatly from one part of the spectrum to another and from one dimension to another. The purpose of this paper is to summarize the state of the art in each of the major spectral increments and dimensions and to discuss the engineering value of these classes of observations.

SPECTRAL/SPATIAL DIMENSIONS

Systems making use of the spectral/spatial dimensions of remote sensing include cameras, optical-mechanical scanners, and radar and microwave imaging systems. General comments on each of the commonly used systems follow.

Panchromatic Photography (or Television)

Panchromatic photography is the most widely used remote-sensing technique because of its availability, relatively low cost, and high information content. Interpretive and mensuration techniques are well developed and it is widely used for mapping. Formal training in its use for engineering and other purposes is available.

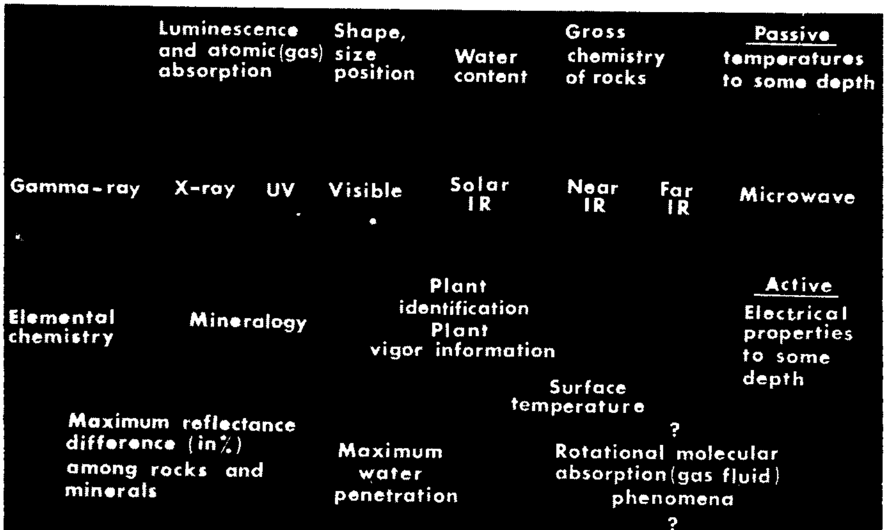


Figure 1. General types of information that may be obtained from observations made in various parts of the electromagnetic spectrum.

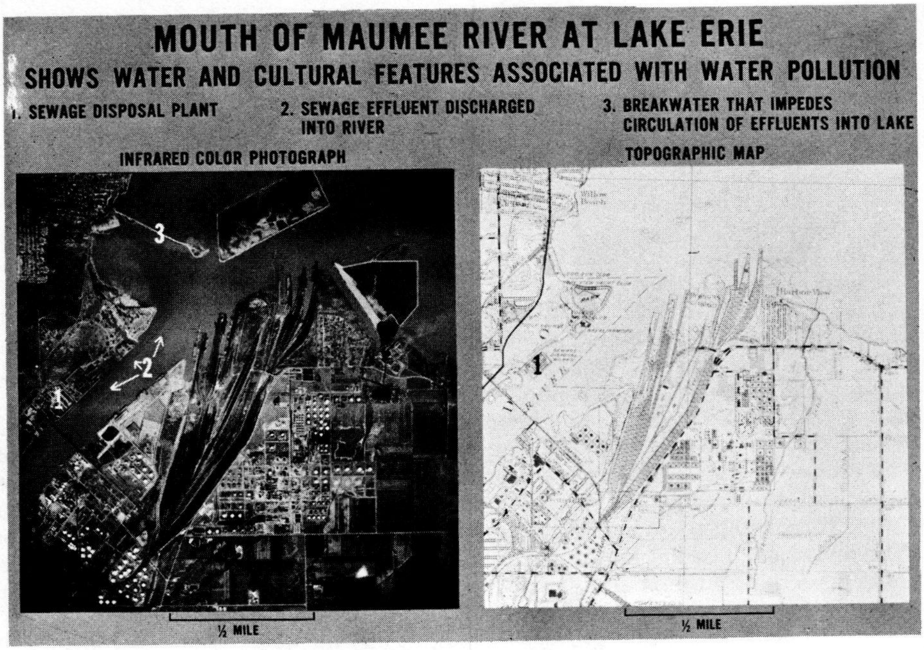


Figure 2. Black-and-white copy of an infrared color aerial photograph showing distribution of pollutants in Maumee Bay; the sewage plant (1) discharges effluent (2) into Maumee Bay that is trapped behind the recently built breakwater.

Infrared Photography (or Television)

Infrared photography is primarily of value in mapping drainage features and shorelines. Water is always black in a positive print. Some vegetation characteristics are discernible that are, in turn, valuable in land-use determinations. The presence of vigorous vegetation (characterized by high infrared reflectance) may, for example, denote high soil-moisture conditions.

Color Photography (or Television)

Color photography, in spite of its built-in spectral redundancy, promises to be a major tool of the earth scientist in many special fields, and is sufficiently better for recognition of significant features such as soil types and underwater features that it may replace panchromatic photography for many engineering uses.

Infrared Color Photography (or Television)

Infrared color photography may be superior to standard color photography for many purposes. It shows differences in vegetation and vegetation vigor more clearly and provides a slightly higher contrast on water surfaces than conventional color. Infrared color is also useful for "seeing" alien fluids in water. Figure 2 is a black-and-white copy of an infrared color photograph of the Maumee River in Toledo, Ohio. The distribution of effluents from a sewage treatment plant is clearly visible.

Ultraviolet Imagery

Reflectance contrasts among many natural objects are commonly greater in the ultraviolet than in the visible part of the spectrum. Thus, ultraviolet imagery acquired with scanners or cameras may be especially useful for discriminating rock and soil types. Spectroscopic measurements suggest that the reflectance of rocks that have a high silica content decreases rapidly with decreasing wavelengths in the ultraviolet, in

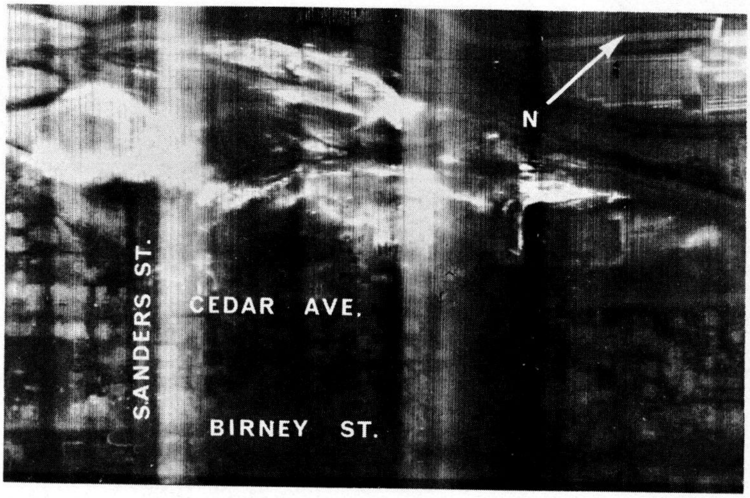


Figure 3. Infrared image of a portion of Scranton, Pa., showing thermal anomalies associated with burning culm banks and underground mine fires; the rectangular anomaly in the right-central part of the image outlines a bowling alley—since removed.

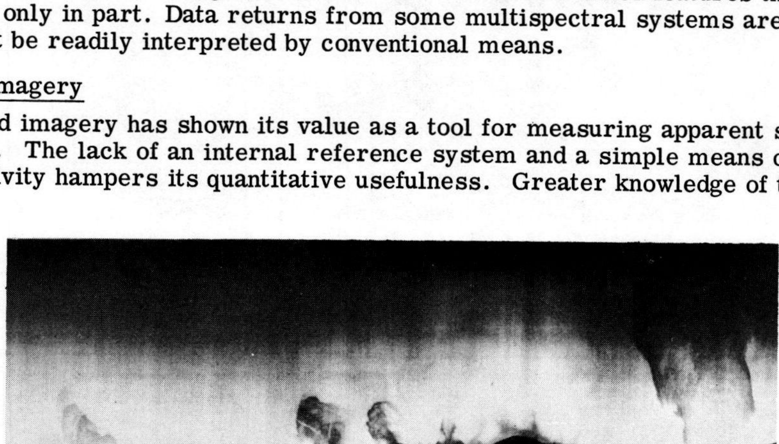
contrast to basic rocks whose reflectance changes little with decreasing wavelength. Multispectral systems recording in the ultraviolet may permit gross rock type identification.

Multispectral Photography (or Television)

Multispectral photography is commonly acquired with 9-lens cameras or clusters of lesser numbers of small cameras. Interpretation of multispectral photography requires a background of spectral-signature studies of terrain and water features that has been developed only in part. Data returns from some multispectral systems are voluminous and cannot be readily interpreted by conventional means.

Infrared Imagery

Infrared imagery has shown its value as a tool for measuring apparent surface temperatures. The lack of an internal reference system and a simple means of determining emissivity hampers its quantitative usefulness. Greater knowledge of the physical



Infrared image obtained with a line scanning radiometer. 8-13 micron band.

The infrared image records the patterns of cool surface and ground water discharge into warmer ocean water. This method may be applied to the locating of new sources of fresh water along coastal areas.

Figure 4. Infrared image of fresh water discharge into ocean, Balayan Bay, Luzon Island, Philippines.

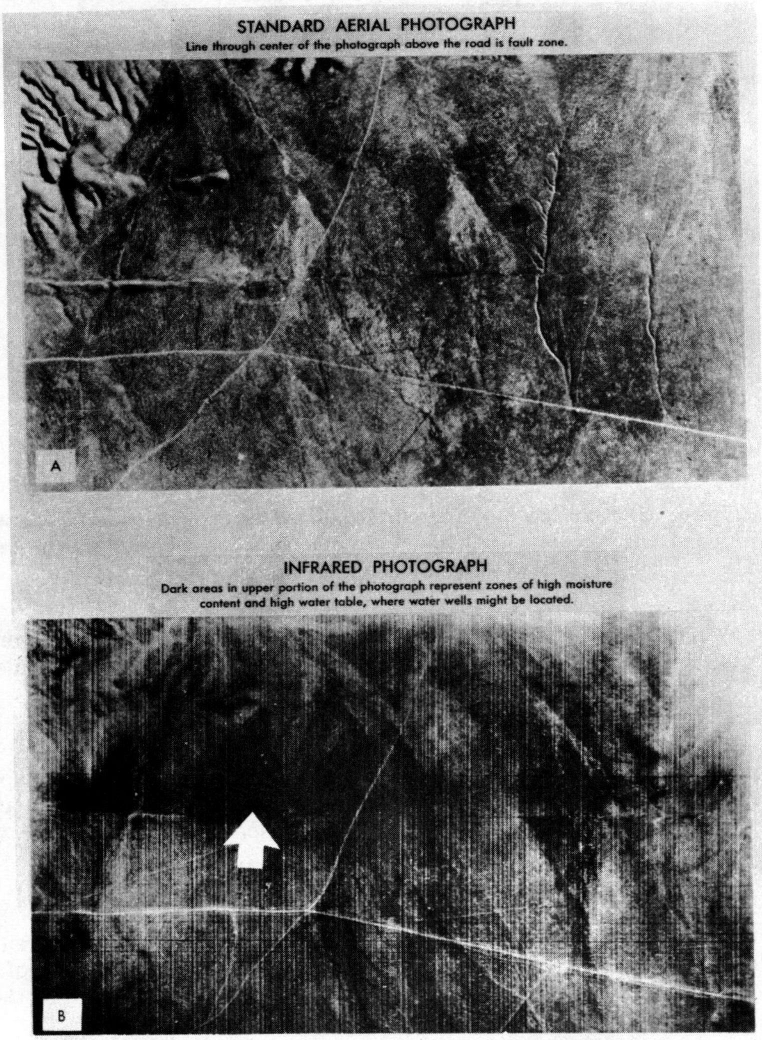


Figure 5. An infrared image of a segment of the San Andreas fault; the temperature difference on either side of the fault has been interpreted to reflect differing proximity of the water table to the surface.

and chemical parameters that have an effect on radiant temperatures needs to be developed to assure proper use of the reduced data. Infrared imagery is becoming routinely applied in surveys of abnormal geothermal features, such as volcanos and underground fires. Figure 3 shows thermal anomalies associated with burning culm banks and underground fires. Images of this type are helpful in planning control of at least some mine fires.

Infrared scanners have proved particularly useful in imaging the distribution of fresh water springs issuing into the ocean and streams; Figure 4 shows one example of such an image. Scanners have been used in highway route surveys of thermal areas and to map concealed fault structures and local differences in the proximity of the water table to the surface (Fig. 5). Areas having abnormally high soil moisture content and considered to be landslide prone have also been located from infrared images (Fig. 6). Flown repeatedly at different times of day, infrared images provide information on the "compaction" of the surface. Scanner data are difficult to relate to map positions.

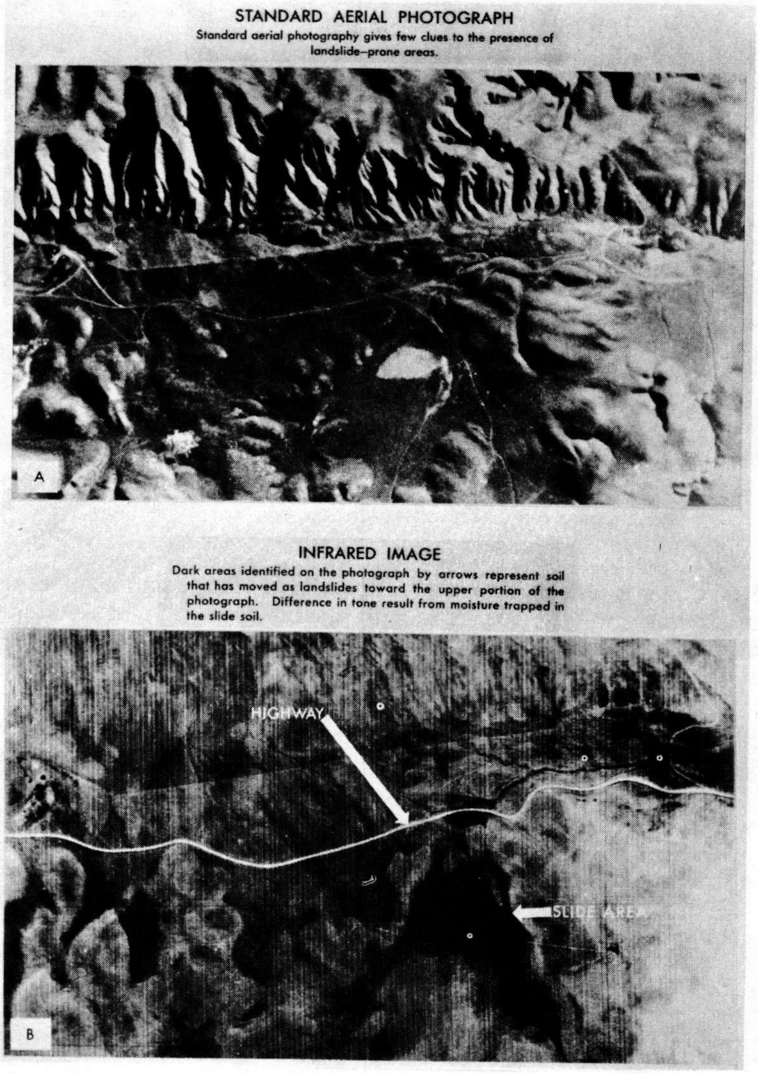


Figure 6. Areas believed prone to landslides are distinguished from stable ground through differences in soil moisture content; the ability to identify these areas near highways, residential areas, and industrial construction and to make the information available quickly would have obvious benefits.

Multispectral, Optical-Mechanical Scanner Imagery

Multispectral, optical-mechanical scanners permit data to be acquired throughout a broader band of the spectrum ($\sim 0.3\,\mu$ - $16\,\mu$) than photographic systems. Data can be acquired simultaneously in 18 or more channels. The resulting high data rates require use of automatic data processing techniques. Such a system has been used to automatically survey distributions of water, agricultural crops, rock types, houses, and other cultural features. Automatically processed, multispectral scanner data hold high promise of aiding in land-use surveys.

Radar Imagery

Radar imagery is an excellent tool for all-weather coverage of large areas. It has demonstrated value in mapping structural features, has been of some use in differentiating crops and rock types, and has delineated areas of abnormal soil moisture.

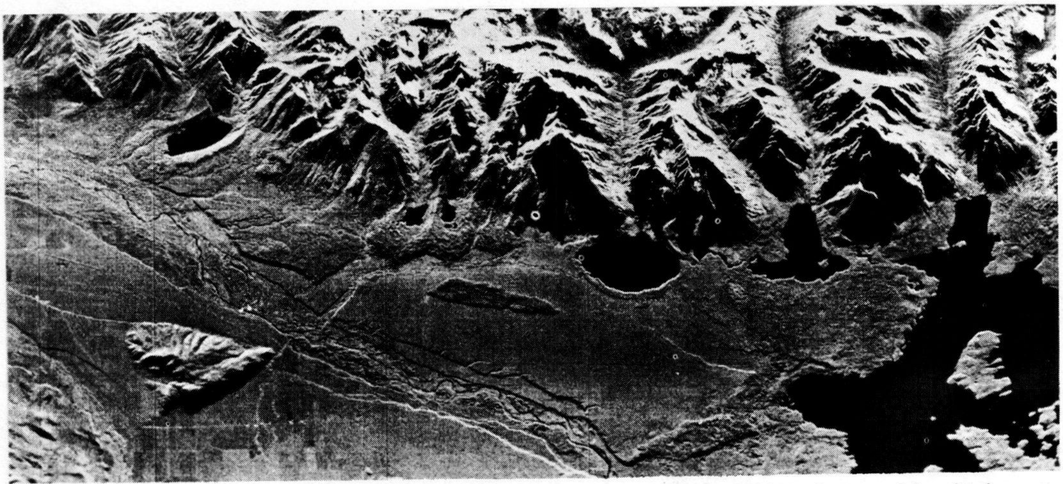


Figure 7. A radar image of an area near Jackson Hole, Wyo.; note the clarity with which some geomorphic features such as terraces and kames are shown.

Geomorphic features such as eskers, terraces, and old stream channels often show clearly on radar images (Fig. 7). It is quite usable for small-scale planimetric charting, especially as an adjunct to conventional maps. As longer wavelength radars become available, they may permit detection of some subsurface features.

Passive Microwave Images

Passive microwave images record energy emitted from the earth in the radio frequencies. The quantities of energy emitted depend on the temperature of the object and its emissivity. Temperatures and emissivities are integrated to some depth. Systems may be useful for mapping soil moisture distributions. The wide range of emissivities of materials in this part of the spectrum suggests that microwave observations may be useful for identifying solids and fluids. Recent research suggests that microwave images may provide sea-state information on lakes and oceans. Much laboratory work remains to be done before the data can be used effectively for engineering or resources purposes.

SPECTRAL DIMENSION

Systems making use of the spectral dimension are nonimaging in the conventional sense. They include spectrometers, radiometers, and interferometers. Commonly, these systems are more easily calibrated than imaging systems and make useful adjuncts to images. Following is a description of those under intensive study.

Infrared Radiometry

Infrared radiometry is very useful for sequential measurements of changes in land and water surface temperatures because it is a simple measurement technique and data reduction is simpler than for infrared imagery. Some systems used multi-wavelength arrays. Radiometry is routinely used for periodic radiant temperature surveys of near-shore oceanic areas. These data are commonly recorded on conventional strip charts.

Infrared Spectral Radiometry

Infrared spectral radiometry measurements are made with spectrometers, interferometers, and filter-wheel radiometers. Observations have meaning with respect to plant identification, rock composition, and apparent surface temperature. Wavelengths

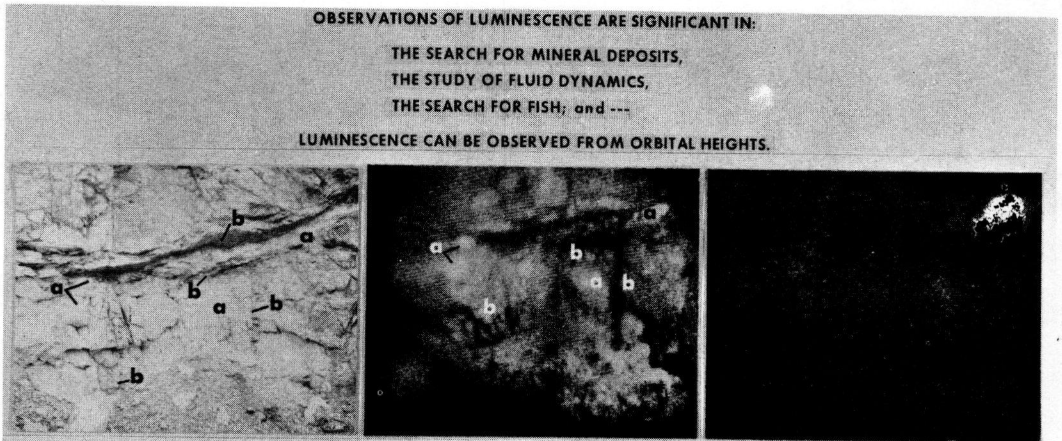


Fig. 1. Conventional photograph of a quarry face near Baltimore, Maryland.

Fig. 2. Image of same area as Fig. 1, recording both reflected ultraviolet energy and ultraviolet stimulated luminescence, shows, a - luminescing mineral (deweylite, a hydrous magnesium silicate) and b - fractures.

Fig. 3. Image of same area as Fig. 1 and 2, recording only UV stimulated luminescence (deweylite)

Figure 8. Example of observation of luminescence as an aid in geologic study.

observed are from 1 to 16 μ. Computer-stored libraries of "spectral signatures" are being compiled. Some systems have a field-of-view of 1 deg or less and integration times of $\frac{1}{6}$ sec or less.

Passive Microwave Radiometry

Passive microwave radiometry is a means of measuring apparent temperatures at selected frequencies in the radio spectrum. Multi-wavelength arrays are commonly used. Depth to which temperatures are integrated is a function of wavelength; the longer the wavelength the greater is the "penetration." Passive microwave radiometers have been used successfully to detect subsurface voids and are being tested extensively to affirm their usefulness for measuring water content of snow. Microwave radiometric data are commonly recorded on strip charts or magnetic tapes.

LUMINESCENCE DIMENSION

Luminescence Imagery and Luminescence Detectors

Images showing the distribution of luminescing solids (various rock types) have been produced using active systems that illuminate the scene with ultraviolet light and record luminescence in the ultraviolet, visible, or infrared wavelengths; Figure 8 shows a quarry face near Baltimore, Md., as it appears in a conventional photograph and in images recording reflected ultraviolet light and ultraviolet-stimulated luminescence. Detectors that record ultraviolet-stimulated luminescence within Fraunhofer lines in the visible spectrum are being readied for flight test. These detectors have been used to detect luminescing substances in water in concentrations of three parts per billion. Laboratory tests suggest that some dolomites may be differentiated from limestones by observing their luminescence characteristics and that feldspars may be identified by measuring the decay time of ultraviolet-stimulated luminescence.

TIME DIMENSION

Time is probably the most powerful dimension within which to discriminate and identify objects or conditions. All sensors can be used to assess change in objects with time, provided their successive records can be efficiently compared.

Recognition of the value of repeated observations has led to proposals to place long-life sensors, such as television systems, in orbit. From orbit, repetitive images can

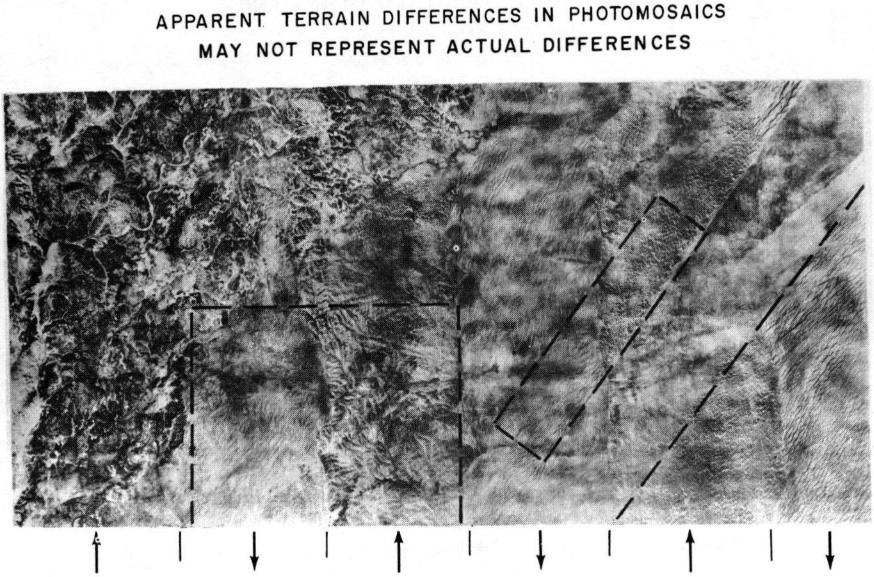


Figure 9. Mosaic of aerial photographs of part of the Arabian Peninsula; arrows show direction of flight; dashed lines outline areas of homogeneous terrain.

be obtained at relatively low cost. By using narrow-angle viewing systems, which can be economically employed from orbit, images may be acquired that are quite uniform and near-orthographic and hence may be easily compared for studying changes with time. Placing the satellite in sun-synchronous orbit so that repeated observations are made at the same local time also adds to the ease of comparing sequential images.

Intended to illustrate the significance of "controlling" time in studies relating to landform classification, Figure 9 is a carefully matched mosaic of aerial photographs of a part of the Arabian Peninsula. The directions of flight are indicated. There was approximately a three-hour difference in time between the northward and southward flights. All other flight and processing parameters, except time, were uniform. The outlined areas are homogeneous—the vast differences in appearance relate solely to changes in sun angle. From space, of course, all of this area and more would be visible from one point at one instant of time. Further, if the satellite were placed in sun-synchronous orbit, that is, an orbit where the earth/sun relationship stays constant, the entire earth can be viewed repeatedly at the same local time. Thus, successive observations would be easily comparable and changes with time readily assessable.

POLARIZATION DIMENSION

Comparison of radar images recording radar energy returns in two planes of polarization has resulted in improved discrimination of man-made objects from natural backgrounds and differentiation of rocks having differing surface roughness.

Studies of the polarization of sunlight and depolarization of "earth" (ashen) light reflected from the moon have aided in classifying elements of the lunar surface.

Laboratory and theoretical studies suggest that observations of polarization/depolarization, in all wavelengths, may evolve to useful techniques for classifying earth features, defining surface characteristics, and recognizing water pollutants.

SPATIAL DIMENSION

The development of the laser as a coherent source of light has made possible significant advances in optical processing techniques, including holography. These techniques

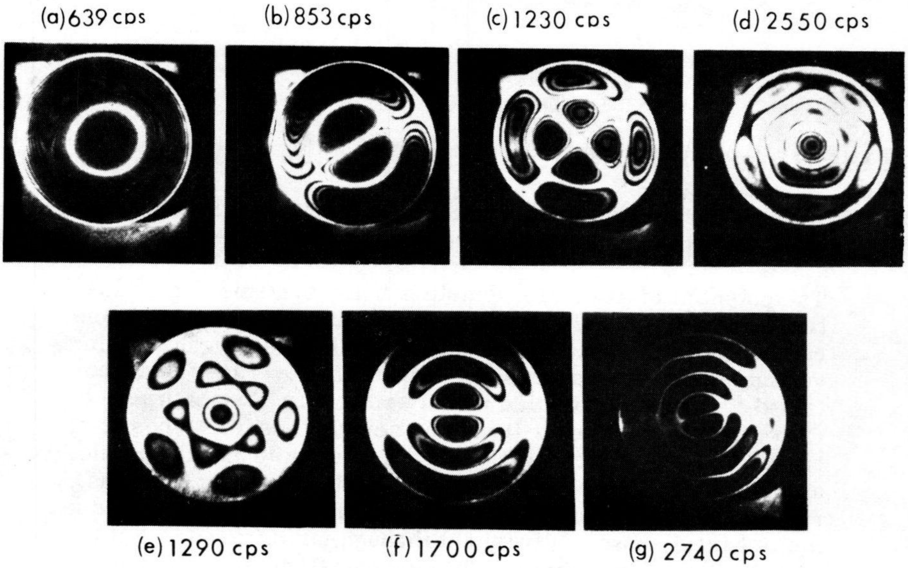


Figure 10. Hologram showing changes in patterns of vibration on the top of a tin can with changes in vibrational frequency (courtesy of Robert L. Powell, American Optical Company).

permit the emphasis of objects having orderly spatial arrangement and the measurement of change in positions, in terms of wavelengths of light. Several studies have been undertaken in which spatial filtering techniques have been applied to study of joint systems in rocks; to date, few evaluations of results have been published. Many illustrations of the value of holography as a mensuration tool, however, are published.

Figure 10 (Robert L. Powell, 1967) is a hologram showing the changes in vibrational patterns on the top of a tin can with changes in vibrational frequency. Holograms can provide the engineer and scientist with mensuration/interpretation data precise to wavelengths of light. In the opinion of the author, holography and related spatial filtering techniques are probably the most significant advances of recent years in the broad field of remote sensing. Although in their infancy, these techniques will soon provide to scientists and engineers an opportunity for quantum advances in their respective fields.

CONCLUSION

In summary, essentially all potentially usable parts of the electromagnetic spectrum are under investigation. Instruments are available to "sense" in most, if not all, of the spectrum, and in the various dimensions of remote sensing. Looking ahead, it seems likely that the increasing demands for resources and engineering data will accelerate the demand for timely survey data. This increasing demand for timely survey data will likely cause many of the current experimental systems to be placed in operational use in the near future.

Multisensor Analysis for Soils Mapping

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ROBERT D. MILES, School of Civil Engineering, Purdue University

The potential of available remote sensing systems for evaluation of soils and soil conditions was studied and an optimum combination of sensors for analyzing soils was sought. To investigate the various sensors, nine flight coverages were obtained over three controlled test sites during a 13-month period. Coverage was obtained with various aerial films (color positive, color infrared, color negative, black-and-white panchromatic, and black-and-white infrared), a multiband camera (9 lens), radar sensors (K-band), infrared sensors (far infrared), and a multichannel sensor (ultraviolet through far infrared). Not all combinations were obtained in any one flight program; however, several combinations were obtained during each flight. The major conclusion was that the optimum system for delineating and mapping soils was a multichannel sensor flown simultaneously with an aerial mapping camera taking natural color photography. Of the aerial film types investigated, natural color was the most useful single film type.

•IN recent years, remote sensors such as infrared, radar, and multichannel and multiband instruments have become available for civilian use. In addition, newer and improved aerial films have been produced and special film-filter combinations for image enhancement have been evaluated. Several studies have been performed where each of these new sensors and film types has been evaluated individually; however, little has been reported in the unclassified literature on the evaluation of combinations of these films and sensors.

To investigate the potential of these aerial films and sensors for detailed soils mapping, a project sponsored by the Bureau of Public Roads and the Indiana State Highway Commission was instituted at Purdue University entitled "Annotated Aerial Photographs as Master Soils Plans." The first phase of this project was to evaluate the potential of the available types of aerial sensors and to propose a multisensor system for performing detailed engineering soils mapping. This paper describes the results obtained in the first phase of the study, which was completed in December 1966 (1).

FLIGHT PROGRAM

Three test sites were selected in the vicinity of Purdue University to investigate the applicability of the various remote sensors. Nine flight coverages were obtained over the sites during a period from May 1965 to June 1966. Concurrently with the aerial program, a field program was conducted to evaluate some of the parameters influencing the data collected and to determine some of the conditions existing during the flight coverage.

Field data collected during the program included surface soil moisture contents, photographic and multiband ground coverage, field radiometer readings in the 8-14 μ band, and meteorological data from local weather stations.

A summary of the flight programs is given in Table 1. Five different types of aerial photography (taken at three different scales), multiband photography, infrared imagery (three different sensor systems), radar imagery (two different sensor systems), and multispectral imagery (ultraviolet through far infrared) were obtained. Although,

TABLE 1

FLIGHT COVERAGE OF TEST SITES

Date	Photographic Coverage[a,b]						Imagery Coverage[c]			Agency[d]
	B&W	B-I	C-P	C-N	C-I	Nine-Lens[e]	Infrared[f]	Radar[g]	Multichannel[h]	
5/13/65	–	–	m	–	–	–	3	k	–	WPAB
7/1/65	m, l	m, l	m, l	–	–	–	3	k	–	WPAB
7/26/65	–	–	m, l	–	–	–	3	–	–	WPAB
9/1/65	m	–	m, l	–	m, l	–	–	k	–	WPAB
9/14/65	–	–	–	–	–	–	–	k′	–	i
10/7/65	–	–	–	–	–	–	–	k′	–	i
10/25-26/65	m, l	m, l	–	m, l(1)	m, l	m	–	–	–	ISHC
5/2/66	h, m, l	–	–	–	–	–	–	–	–	ISHC
5/3/66	–	–	–	h, m, l(2)	h, m, l	–	–	–	–	ISHC
5/4/66	–	–	h, m, l	–	–	m	–	–	–	ISHC
5/6/66	l	h, m, l	–	–	–	–	–	–	x	ISHC, UM[j]
6/1/66	–	–	–	–	–	–	1, 2	–	–	FS
6/2/66	0	–	–	–	–	–	1, 3	–	–	FS

a. Film types and filters
B&W—Plus-X Aerographic Film, No. 12 antivignetting filter on 10/65 and 5/66 flights.
B-I—Infrared Aerographic Film, No. 12 antivignetting filter on 10/65 and 5/66 flights.
C-P—Ektachrome Aero Film (HF-3 used on 5/13/65 flight).
C-N—(1) Agfacolor Negative Film CN 17, used 10/25-26/65.
—(2) Ektachrome MS Aerographic Film Type SO-51 (Aero-Neg), used 5/3/66.
C-I—Ektachrome Infrared Aero Film, No. 12 antivignetting filter on 10/65 and 5/66 flights.

b. Photographic scales flown, 9 x 9 format
h—high altitude 1 24,000.
m—medium altitude 1 10,000
l—low altitude 1 4,000.
0—70 mm format, low altitude.

c. All imagery obtained on this project is "classified." Prints from radar imagery of 9/14 and 10/7/65 and infrared imagery of 6/1 and 6/2/66 have been "declassified."

d. Agency
WPAB—Avionics Laboratory, Wright-Patterson Air Force Base.
ISHC—Indiana State Highway Commission.
UM—Infrared and Optical Sensor Laboratory, Institute of Science and Technology, University of Michigan.
FS—Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, U.S. Forest Service.

e. Nine-Lens camera coverage from 0.38 to 0.89 microns in 8 steps.

f. Infrared imagery
1—4.5-5.5 micron band, daytime.
2—8-14 micron band, nighttime.
3—8-14 micron band daytime.

g. Radar coverage
k—K band, (HH) polarization.
k′—K band, (HH) and (HV) polarization.

h. Multichannel coverage from ultraviolet through far infrared.

i. Obtained with equipment developed by U.S. Army Electronics Command.

j. Imagery by University of Michigan Institute of Science and Technology, NASA Grant 715, permission of U.S. Army Electronics Command.

during any given flight program, simultaneous coverage of all film types and imagery was not obtained, sufficient combinations of sensors were evaluated in the program to arrive at an optimum system for soils mapping.

EQUIPMENT AND VIEWING TECHNIQUES

Stereoscopic coverage was obtained for all aerial photographic film types. The viewer used was a zoom stereoscope capable of magnification from 2.5 to 20 times. The stereoscope was mounted on a carriage on a light table permitting scanning in an X and Y direction. The light was an argon-mercury source, which provided 900 foot-lamberts at maximum intensity and permitted variable intensity at a 20 to 1 ratio in two overlapping ranges. Both transparencies (positives and negatives) and positive prints were viewed on the light table. The prints were placed on the table and illuminated by an external source.

A technique utilizing Wratten filters in the viewing system was used to assist in the interpretation. These filters increased the contrast between objects of interest on color photography and made it easier to delineate various soil boundaries. The filter was placed in only one of the eyepieces of the stereoscope to obtain the desired contrast without excessive suppression of light.

The approach used in this multisensor study was to attempt to identify various soil and rock units through their unique responses in various portions of the electromagnetic spectrum—e.g., their properties of reflectance of solar energy in the visible region, their emission properties in the infrared region, on the amount of transmitted signal energy they reflect back to the antenna in the radar region. This approach is not straightforward, since information on soils is not directly observable on photography or imagery. Soils and rocks are interpreted by deduction and inference based on the evaluation of the pattern elements of form and tone and texture (2). Form includes the elements of topography, drainage, and erosion. The elements of tone and texture include the values (color) and textures related to land use and vegetation, and the tones (color) related to materials (3).

The qualitative analysis of the data collected was based on the premise that an optimum system would be one having the greatest potential for evaluating the separate pattern elements. The potential of the various film and imagery types studied was evaluated by comparison with black-and-white photography, the standard type heretofore used for soils mapping.

In subsequent sections, the following symbols are used to identify various film and print types in the discussion:

Black-and-white panchromatic photographs	B&W
Black-and-white infrared photographs	B-I
Color transparencies (positives)	C-P
Color negative film	C-N
Color infrared transparencies (positives)	C-I
Color print made from color negative	C-P/C-N
Black-and-white print made from color negative	B&W/C-N

ANALYSIS OF ELEMENT OF TONE

Comparison of Film Types

The element of tone is very important in the interpretation and delineation of soils. The major factors contributing to the tonal patterns on aerial photography, as indicated by Rib (1), include (a) color of soil and rock; (b) composition of soil and rock; (c) moisture condition of soil and rock; (d) culture; and (e) vegetation. Therefore, an important step in soils interpretation is the discrimination of tones due to soil composition from tones due to the other factors.

The value of the various film types for discriminating between the major tonal factors is demonstrated in Plate 1. The area covered is in a transitional zone between soils developed under prairie cover and those developed under forest cover. The parent materials are the same in both areas. In the field, it is observed that the soils derived under prairie conditions have darker intrinsic soil colors and higher organic contents.

Comparison of the various film types for distinguishing between the tonal factors indicates that natural color film (C-P or C-P/C-N) has the advantage over the other types. This is demonstrated by comparing points 1 through 6 on the various film types. On C-P, the presence of natural color tones makes it possible to distinguish between glacial till soils developed under forest cover (vicinity of point 1) from those developed under prairie cover (vicinity of point 2) as well as differences within each of these zones due to topographic position (points 3, 4, and 5). The darker color prairie soils (point 2) can be distinguished because of overall darker tone commensurate with the darker color of the natural soils. Soil differences due to topographic position are evident by the darker color of the depressional soils due to higher organic content (point 3); the lighter color of the silty surface soils in the topographic high position (point 5); and the orange-yellow color of the soils on the eroded slopes (point 4) where the silty clay subsoils are exposed. These differences, significant to soils mapping, are readily distinguished on C-P film. The presence of a slight greenish tinge in the area of point 6 indicates that the tonal differences are due to the presence of vegetation just starting to grow and not due to soil differences.

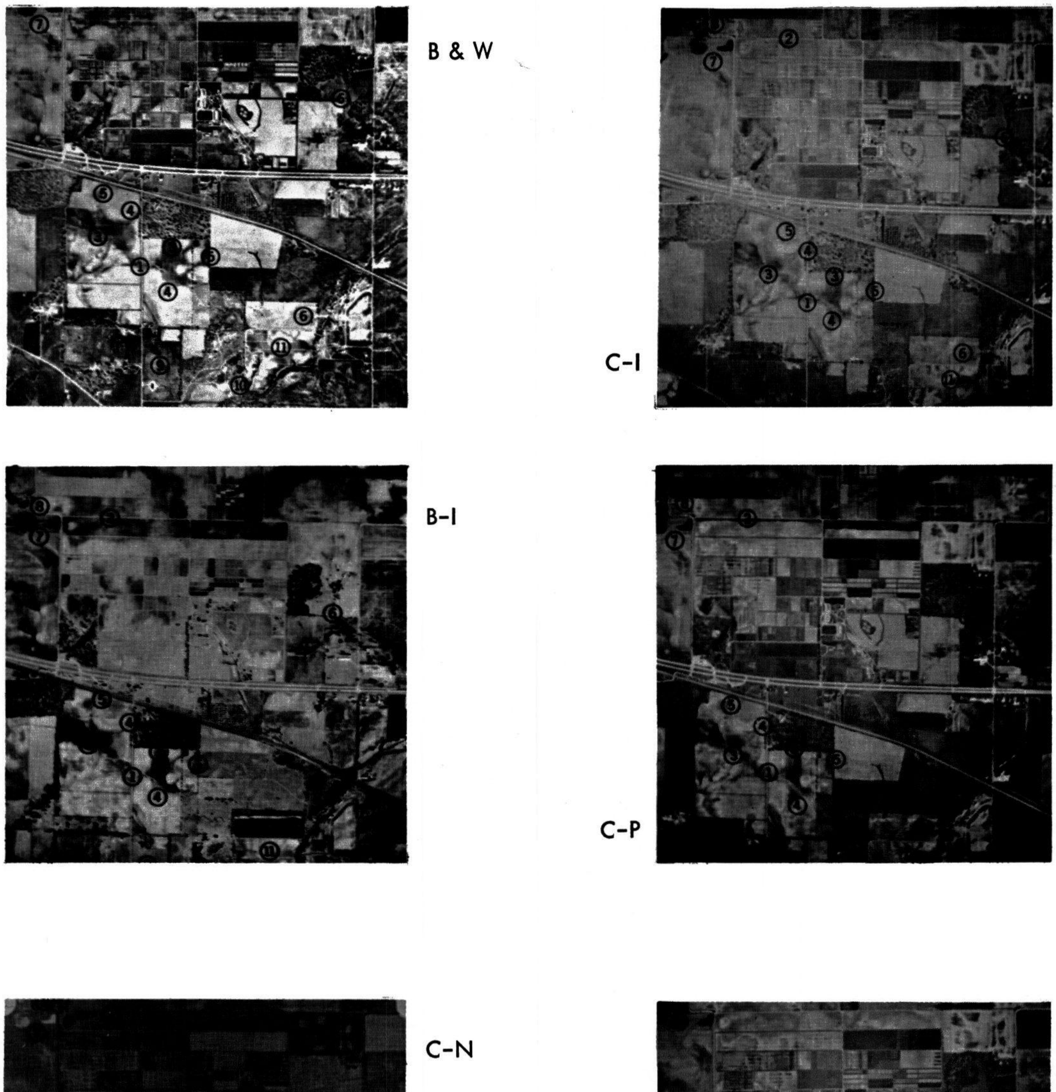


Plate 1. Comparison of various film types (May 1966).

Purdue University provided funds for the printing of this color plate.

The different tonal patterns noted are also apparent on C-I and C-N films. The unnatural or false colors present on these film types, however, make it difficult to correlate the color differences observed with differences in soil composition. The presence of vegetation (point 6) is especially distinct on the C-I film due to the reddish tones. This feature is significant if information on vegetation is required.

The analysis of B&W and B-I film types demonstrates the difficulties encountered in soils mapping with such film. In some cases, soils having different intrinsic soil colors appear in the same tone (e.g., points 4 and 5). In many cases, tonal differences are noted on these film types; one of the major problems encountered, however, is determining what factors are causing the tonal patterns. For example, are the darker tones in the vicinity of point 6 on B&W due to moisture, soil color, vegetation, or soil composition? This cannot always be evaluated on B&W alone and thus may require more field checking.

Highly organic soils are evident on all positive film types by dark tones (above point 7). Points 8, 10, and 11 indicate other soil types and tonal relationships. Point 8 is a high soil area in the prairie glacial till zone, point 10 is a gravel pit area with granular materials exposed, and point 11 is an area of glacial till deposits over other deposits. A feature to note in this group is that the granular materials (point 10) are light on all film types except the B-I where they have a medium tone.

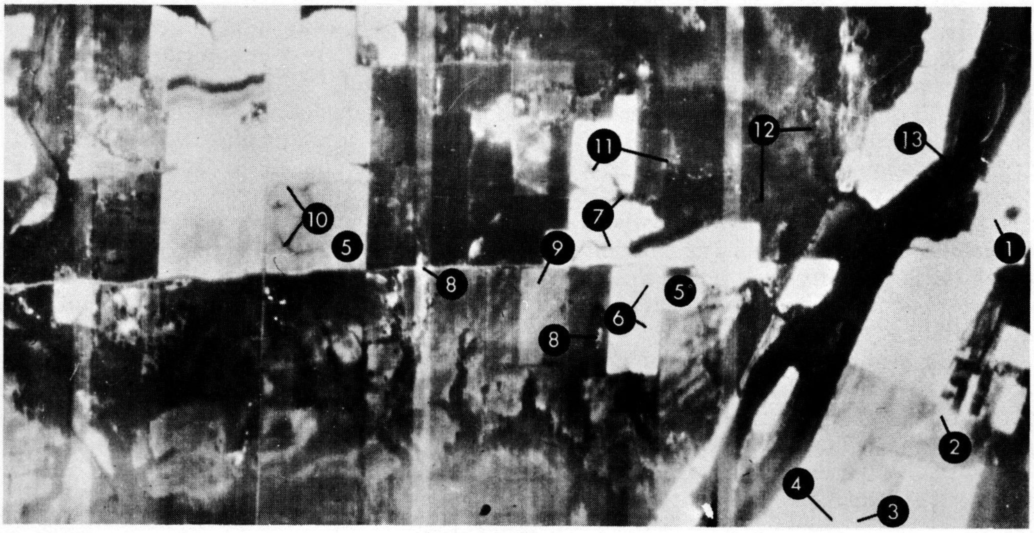
Comparison of Infrared Imagery and Aerial Photography

Comparisons of infrared imagery and aerial B&W photography are shown in Figure 1. Comparisons of daytime and nighttime imagery in the 8-14μ band are included in Figure 2. The visible photography included in Figure 1 was taken a month earlier than the infrared imagery. Therefore, some differences in tone may be due to changes in vegetation, moisture conditions, or farm practices during the interim. The tonal relationships noted for most of the points selected, however, remained relatively unchanged.

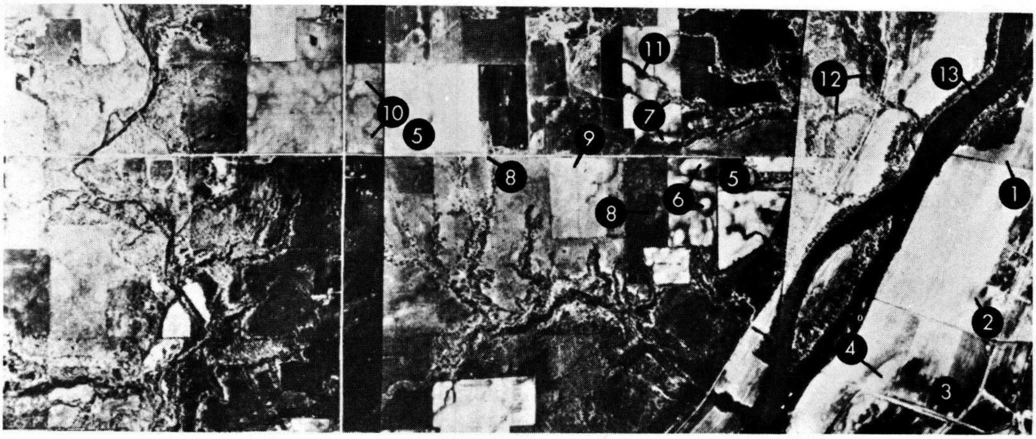
Comparing the 8-14μ band imagery and the visible photography in Figure 1, several tonal relationships are present that are of assistance in separating significant engineering soils and rock units. As noted on the visible photography, the glacial till soils in high topographic position (point 5) have light tones because of their low organic content and predominance of well-drained silts. The glacial till depressional soils (point 6) have dark tones because of high organic content, finer texture, and darker colored soils. These same areas show a reversal in tones respectively on the infrared imagery. This reversal in the infrared region is because the darker colored soils absorb more heat than the lighter colored soils, emit more energy in the infrared region, and thus have a lighter tone on the imagery. Another example of tonal reversal is shown by point 1, which is a depressional, dark-colored, fine-textured soil in the flood plains.

Other factors can change the tonal relationships on the imagery. Examples where tonal reversals do not occur for dark, fine-textured soils are demonstrated by points 3, 7, and 10. Point 3 is a muck deposit and points 7 and 10 are soils located in low drainageways in glacial tills. For these soils, the tones are not light on the infrared imagery but medium to dark and for different reasons. The darker tones in areas 3 and 10 are due to a high moisture content while that of point 7 is due to the presence of vegetation. Both of these factors cause a cooling effect on the surface soils, thus resulting in darker tones on the imagery.

Similar variations are noted in light-colored soils. Not all light-colored soils on the photography are dark on the infrared imagery. Many are light or medium-light on the infrared (points 2, 4, 8, and parts of 9). Point 2 is sand, 4 is shale bedrock covered by thin alluvium, 8 is sandstone bedrock, and 9 is a field where sandstone is very shallow. These areas remain lighter on the infrared imagery for various reasons, such as differences in emmisivity, heat capacity, thermal conductivity, or surface-to-volume ratio. The factor causing the lighter tone cannot be evaluated by comparing the infrared imagery and visible photography alone. However, the overall effect and not the causative factor is important, and the various soil and rock units indicated can still be delineated.



Daytime IR (June 2, 1966)



B&W photography (May 2, 1966)

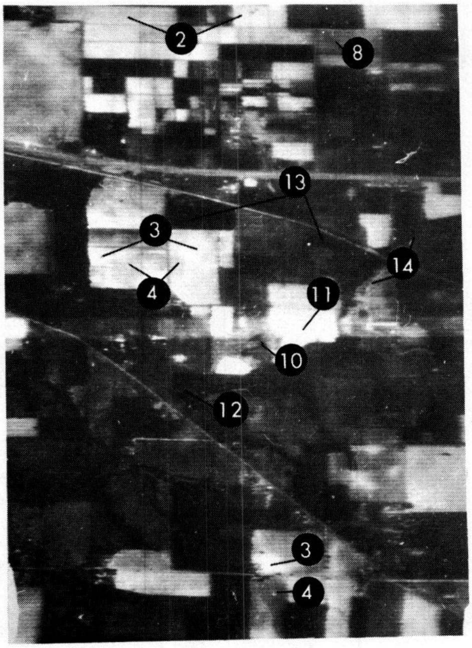
Figure 1. Comparison of visual photography and infrared imagery in 8-14μ band.

Points 11, 12, and 13 were included to show that, in daytime infrared imagery, differentiation is difficult between low vegetation, trees, and water.

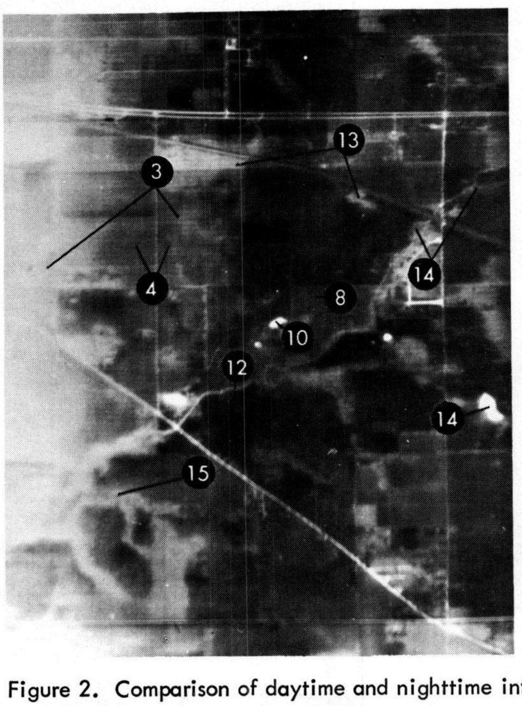
Analysis of imagery in other bands of the infrared region were made but are not illustrated. Comparison of imagery in the 4.5-5μ band with the 8-14μ band indicated that most of the tonal constrasts seen on the 8-14μ band were evident but not as distinct on the 4.5-5μ band. This was anticipated, since the peak for the terrain temperatures normally encountered is about 10μ, and thus the maximum emitted energy would be recorded in the 8-14μ band.

Daytime imagery in several other bands in the middle infrared (1.5-5.6μ) below the 4.5-5.5μ band was investigated. The tonal patterns recorded in these bands were very similar in appearance to the photographic infrared region, since solar reflectance and not emitted radiation was sensed. Considering all infrared bands where soils were analyzed, the maximum information was obtained in the 8-14μ band.

Many of the tonal relationships noted in Figure 1 are also present in Figure 2. Comparing the daytime infrared imagery in Figure 2 with the visible photography of the same area (Plate 1), it is noticed that the dark-colored depressional soils developed

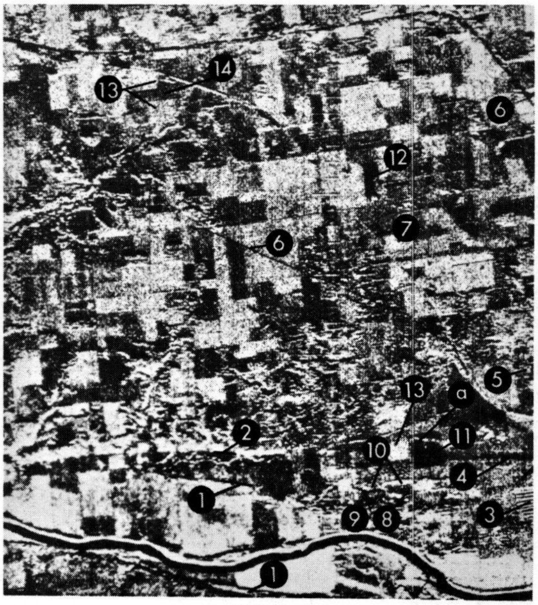


Daytime IR
8-14μ
(June 2, 1966)



Nighttime IR
8-14μ
(June 1, 1966)

Figure 2. Comparison of daytime and nighttime infrared imagery.



HH Radar
(Sept. 14, 1965)

B&W Photography
(Sept. 1, 1965)

HV Radar
(Sept. 14, 1965)

Figure 3. Comparison of visual photography and HH and HV radar imagery.

under forest cover (point 3) are lighter on the daytime imagery and the lighter colored high soil areas (point 4) are darker on the imagery. Similarly, depressional soils in the prairie region are light on the imagery (point 2) and high soil areas are dark (point 8). Granular materials in the gravel pit area (point 10) are medium tone on the imagery while they are light on the visible photography where exposed. Point 11 illustrates the difficulties that can be encountered when attempting to analyze photography and imagery taken at different times. On the imagery, a uniform light tone is evident while on the photography, various tonal patterns are seen. This change is due to the plowing of the field between flights. The plowing action exposed the darker colored subsoils, thus producing a lighter tone on the imagery.

Comparison of the daytime and nighttime imagery indicates that certain features are more easily differentiated at night. During the day the tonal difference between low vegetation (point 12), trees (point 13), and water (point 14) are indistinguishable on the imagery. At nighttime, the water appears the lightest, the trees are also light but not as light as the water, and the low vegetation remains dark. In fact, an indication of drainageways where water is not flowing can be interpreted from the nighttime imagery (point 15). In this case, the drainageway is dark instead of light.

Differences between soil units (point 3 and point 4) are still evident on the nighttime imagery but not as clear. The depressional soil (point 3) is still the lighter. The granular areas (point 10) have become lighter and more distinct on the nighttime imagery.

Comparison of Radar Imagery and Aerial Photography

Radar imagery is developed from an active sensing system, and therefore the frequency utilized and the characteristics of the sensor system greatly influence the amount of useful information on soils obtained. All radar imagery obtained during this study utilized K-band frequencies. Consequently, the imagery indicated only the influence of surface conditions.

Figure 3 shows an example of radar imagery illustrating horizontal transmission and receiving (HH polarization) as well as horizontal transmission and vertical receiving (HV polarization) covering the test sites. The examples shown are enlargements prepared from unclassified "degraded" imagery obtained on September 14, 1965, through thick cloud cover. Visual photography (B&W) of a portion of the site taken September 1, 1965, is included for comparison. Although the "degrading" and enlarging greatly reduced the resolution of the radar imagery, several major features can still be evaluated.

Comparison of the radar imagery obtained by HH polarization with HV polarization demonstrates that, except for linear-oriented objects, the only difference noted between the two types is that the HV polarized imagery shows less tonal contrasts than the HH. This is due to the weaker signal return received for HV systems. The airport (point 4) and road (point 6) systems are less noticeable on HV imagery, while the railroad (point 7) is more noticeable on this type. Although the return from the buildings (point 5) is much brighter on the HH, the decrease in return makes the building shapes more distinct on the HV imagery.

Major topographic breaks are evident on radar. Point 1 indicates the topographic break between the flood plain and terrace and point 2 the break between the terrace and ground moraine (valley wall). Attempts to distinguish different types of soils on the radar imagery were not successful except as could be inferred from landform analysis. At K-band frequencies, all soils in the test areas are fine-textured in relation to the length of the radar waves and thus specular (mirror-like) reflection occurs such that the radar signal is reflected away from the radar antenna. Hence soils appear dark on the imagery and cannot be separated from other items that also produce specular reflection, such as water and roads. The dark tones representing various types of soils include areas of sand dunes (point 8), plowed sandy fields (point 9), sands and gravels in gravel pits (point 10), plowed silty loam surface soils on a granular terrace (point 11), and plowed silty clay soils in glacial tills—both highs and depressions (point 12). The lighter tones present on the imagery are due in part to the scatter and return of the signal by various types of vegetative cover. For example, the fields with corn exhibit light tones (point 13); areas covered with trees also show light tones. Pastures and fields with low vegetation have darker tones (point 14).

Special image tones to note on the figure are the light tones present around the gravel pit areas (point 10) and from the ridges in an old gravel pit (point 3). These returns are not due to texture of the material or presence of vegetation, but to geometric relationships that reflect the signal back to the antenna (4).

Another image of interest is the point marked "a" in the plowed field (point 11). This feature demonstrates how radar assists in the interpretation of B&W photography. On the B&W photograph, point "a" is evidenced as a dark tone that could be interpreted as either due to moisture or vegetation conditions. Because of its low topographic position (a drainageway) and no apparent height on stereoscopic examination, one might conclude that the dark tone on the photograph is due to moisture. From a study of the radar imagery, however, the presence of a light tone indicates that there is vegetation in the channel. If the condition were due to moisture, the tone would be dark on the imagery, which is typical for water (point 15). This item caused no problem on the color photography obtained at the same time, which showed that a greenish color was present at point "a," indicating the presence of vegetation.

Comparison of Multispectral Data

In the previous discussions, comparisons were made between various types of films and infrared and radar imagery. For the examples illustrated, the various types compared were not taken at the same time. This factor contributes to the difficulty in comparing the photography and imagery because of the changes that occur between procurement of these various types. The discussion in this section describes the information obtainable from a multispectral system where photography and imagery are simultaneously obtained in several spectral regions.

Multispectral data were obtained with the University of Michigan multichannel sensor. This sensor simultaneously obtains up to 18 channels of imagery ranging from the near ultraviolet to the far infrared. Unlike the other multisensor systems where images of different scales, resolution, and format were obtained, this system provided imagery in all bands at similar scale, resolution, and format. This permitted a better comparison of tonal relationships to be made between channels.

To examine some of the tonal relationships existing for various terrain features, the reflectance of various items was measured in each band with a reflection densitometer. The density values obtained by the densitometer were converted to reflectance by the relationship

$$\text{Reflectance} = \frac{1}{\text{antilog}_{10}\ \text{Density}} \tag{1}$$

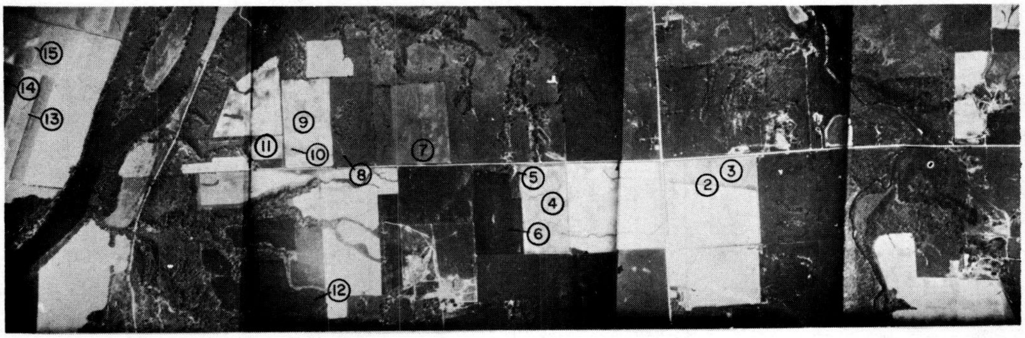
These values were then normalized for each band by determining the reflectance of the lightest object (R_L) and the darkest objects (R_D) in each band and using these as the 100 percent and zero percent reflectance points, respectively. The normalized reflectance (R_n) for each object was then determined by the following method:

$$R_n = \frac{(\text{Reflectance of Object} - R_D)}{R_L - R_D} \times 100 \text{ percent} \tag{2}$$

Since both reflectance and emittance were being evaluated, the values plotted were referred to as normalized response. These normalized values were plotted in the respective region of the spectrum and the points connected to obtain a spectral response curve or signature for the various terrain features of interest.

An aerial photographic mosaic showing the conditions existing at the time the multichannel imagery was obtained and the location and description of the various terrain features measured with the reflection densitometer are shown in Figure 4. Examples of the spectral response signatures obtained for the various target materials are shown

B & W MOSAIC (MAY 6, 1966)



POINT	SOIL OR ROCK UNIT	CONDITION
1.	THICK LOESS/GLACIAL TILL	HIGH POSITION - BARE
2.	GLACIAL TILL	HIGH POSITION - PLOWING IN PROGRESS
3.	GLACIAL TILL	HIGH POSITION - RECENTLY PLOWED
4.	GLACIAL TILL	HIGH POSITION - PLOWED A FEW DAYS AGO
5.	SANDSTONE	SMALL EXPOSURE
6.	GLACIAL TILL	COVERED WITH WINTER WHEAT
7.	GLACIAL TILL/SANDSTONE	PASTURE, SANDSTONE EXPOSED IN PLACES
8.	GLACIAL TILL/SANDSTONE	PASTURE
9.	GLACIAL TILL	HIGH POSITION
10.	GLACIAL TILL	DEPRESSION
11.	GLACIAL TILL	HIGH POSITION
12.	GLACIAL TILL	COVERED WITH WINTER WHEAT
13.	FLOOD PLAIN	PLOWING IN PROGRESS
14.	FLOOD PLAIN	RECENTLY PLOWED
15.	SAND DUNES	BARE IN PLACES

Figure 4. Location of points measured on multichannel imagery.

in Figure 5. These curves are divided into three groups. Figure 5a includes spectral response signatures for bare soils and rock units; Figure 5b includes spectral response signatures for bare soils whose tones vary from those in Figure 5a due to farming practices; and Figure 5c includes spectral response signatures for various vegetation conditions present in the area. The abscissa representing spectral bands is not plotted to scale. The wavelengths shown at the bottom are only intended to indicate the regions of the spectrum included in each of the spectral bands delineated.

The five zones delineated in Figure 5—light (L), medium light (ML), medium (M), medium dark (MD), and dark (D)—represent the division of the quantitative normal response measurements into qualitative ratings. This facilitates comparisons between spectral response measurements and other forms of photography and imagery where comparative quantitative measurements are not possible.

The spectral response curves in Figure 5a demonstrate the similarities and differences present for sandstone (curve 5); glacial till soils of various topographic positions, including eroded slope (curve 9), depressional area (curve 10), and high topographic position (curve 11); and a glacial till soil overlain by 4 to 5 feet of loess (curve 1). All of these units can be separated because of distinct differences in various portions of the spectral region. For example, curves 1, 5, and 11 are similar throughout the visible region, but curve 5 shows a darker tone than 1 and 11 in the photographic infrared region, while curve 11 shows a darker tone than curves 1 and 5 in the far-infrared region. Curves 9 and 10 similarly have distinct differences to aid in separating them from each other and from the other units.

The spectral response signatures for the soils and rock units confirm many of the tonal relationships previously noted in comparing various film and sensor types. For example, comparison of glacial till soils indicates that, in the visible region, the high soils are light and depression soils are generally medium to medium dark. In the far infrared, there is a tonal reversal and the depression soils are light and high soils dark.

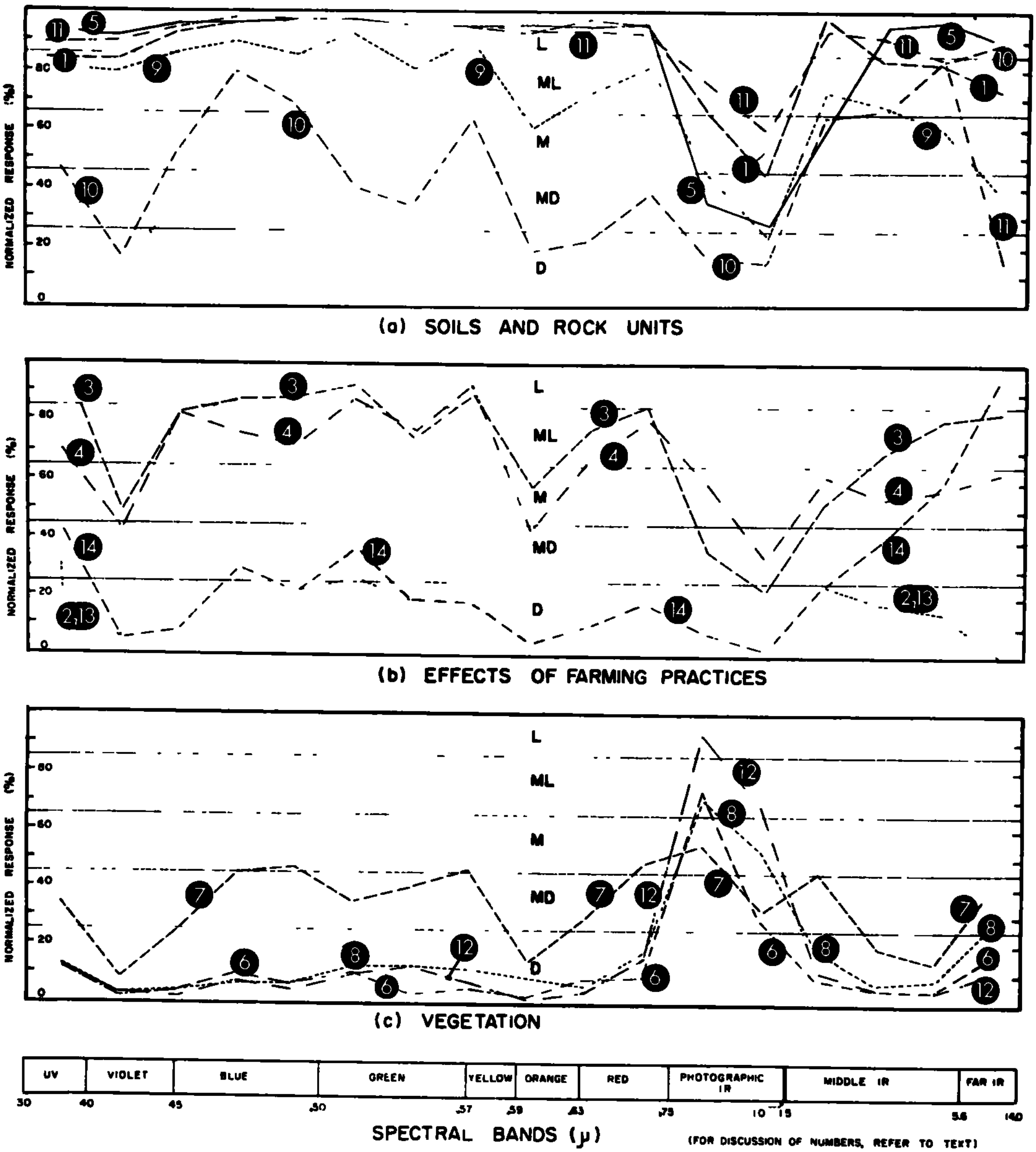


Figure 5. Spectral response signatures for various features.

The effect of farm practices on the tones obtained in the various bands is demonstrated in Figure 5b. All of these curves represent soils recently plowed. Curve 4 represents a field plowed a few days before the flight. Curves 3 and 14 represent fields plowed the morning of the flight (flight performed in the afternoon), and curves 2 and 13 represent areas being plowed during the flight or a very short time before. Soils represented by curves 2, 3, and 4 are glacial till soils predominantly in the high topographic position, and those represented by curves 13 and 14 are sandy soils of the flood plains.

The effects of the plowing are to expose at the surface the wetter and darker colored subsoils. When the soil is first turned over, the moisture effect is the controlling factor, resulting in darker tones in all bands regardless of texture (e.g., curves 2 and 13). As these soils dry out, the effect of moisture is decreased and the effect of soil color becomes preeminent (e.g., curves 3, 4, and 14). Curves 3 and 4 (drying 1/2 day and 2 days, respectively) are fairly similar and both resemble curve 9 in Figure 5a, the eroded glacial till soil, in which the subsoils are exposed.

The curves in Figure 5c show the differences in spectral response signatures obtained due to various vegetation conditions. Curves 6 and 12 represent fields of winter wheat, whereas curves 7 and 8 represent pasture fields. It is noted that pasture can generally be distinguished from winter wheat by low reflectance in the photographic IR region. All the curves indicate that the presence of vegetation results in dark or medium dark tones in all bands but the photographic IR. Since the previous curves for soils indicate that soils have low response in the photographic IR, this is an excellent band for distinguishing tonal effects due to vegetation from those due to soil conditions.

The difference in response between the pasture fields, curves 7 and 8, is that the field containing point 7 has bedrock close to the surface and its influence is indicated by the light streaks in the field (Fig. 4). This affects the overall tonal response, resulting in slightly lighter tones. The differences between the fields of winter wheat, curves 6 and 12, are a little more difficult to explain. These curves are fairly similar in all bands but the photographic IR. In that band curve 6 is darker. From investigation of this phenomenon in the field, it was determined that field 6 was planted two weeks earlier than field 12. In addition, it was discovered that this field had been planted in corn the year before while field 12 had been planted with a low cover crop. It has been suggested by a botanist that the tonal patterns may be reflecting vegetation differences due to varying nitrogen levels in the soils. This could not be verified, but similar effects of previous planting history on variations in tonal patterns obtained for similar crops has been reported by Olson (5).

One final feature can be noted in reviewing the spectral response curves in Figure 5. Many of the curves for soils (but not all) show a dip in the yellow-orange bands. Thus tonal differences between some soils are increased in this band. This may explain why it is easier to delineate some soil boundaries on color photography when a red Wratten filter is inserted in the eyepiece.

The examples illustrated by Figures 4 and 5 clearly demonstrate the influence of cultural factors (e.g., farming practices) on the density patterns obtained and the difficulty in attempting to arrive at diagnostic tonal patterns. Plowing the field or the sequence in planting crops affected the tonal patterns obtained. The examples further point out the need for field control during flights to determine the existing ground conditions. These examples show, however, that multichannel imagery does provide a method whereby various factors can be distinguished even though they are not easily interpreted. The spectral response signatures obtained by density measurements combined with normalizing procedures demonstrate a method for evaluating the response of various terrain features in different regions of the spectrum from an airborne platform. This should prove to be a good method for determining spectral bands of maximum contrast for the separation of features of interest.

ANALYSIS OF ELEMENTS OF FORM

The elements of form are as important in the interpretation of soils and soil conditions as those due to tone and texture, and sometimes more important. To evaluate properly the elements of form, stereoscopic capabilities are necessary. Since stereoscopic coverage is not usually obtained when imagery is collected, this limits the use of imagery for interpreting elements of form. It does not eliminate these types, however, because general information on topography, drainage, and erosion are often evident on the imagery, either directly or indirectly.

The main comparisons discussed are those for the delineation of drainage patterns and the effect of scale of photography on interpretation of soils. This latter item affects the ability to distinguish features of topography and erosion.

Delineation of Drainage Systems

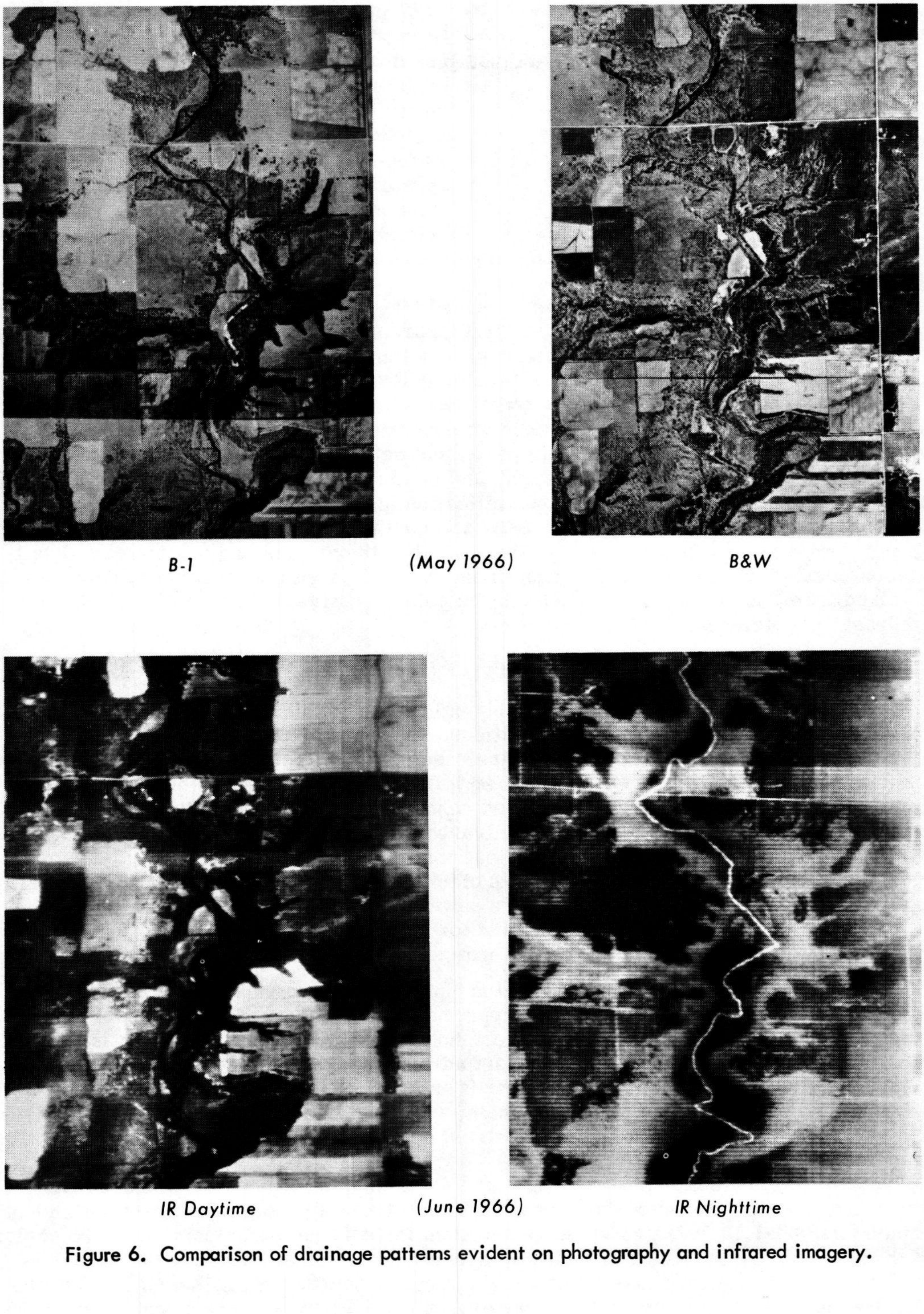
Drainage conditions were evaluated on the various film and imagery types obtained. For the actual drawing of the detailed drainage system (with proper position and orientation) stereoscopic study was required. This eliminated the imagery as far as preparing the drainage maps, but not with respect to location of drainageways or drainage patterns. Figure 6 shows a comparison of drainage evident on B-I and B&W photography and daytime and nighttime IR imagery. It is evident from this figure that the creek with all its intricate bends is more easily distinguished on the nighttime infrared imagery than on any of the other types. The details of the creek are least evident on the B&W photograph. Intermediate between these extremes and about equally distinct is the evidence of the creek on the daytime IR and B-I photograph.

To evaluate the various film types for the purpose of drainage delineation, separate drainage maps were prepared for a selected site from B&W, C-P, and C-I film types; B-I was not analyzed as it was considered comparable to C-I for drainage delineation. Results indicated that C-P and C-I films provided the most drainage detail and the most confidence in separating perennial and intermittent streams. The detail mapped on B&W was about 90 percent of that on the other two types, the main difference being the confidence in determining the perennial or intermittent nature of the streams. It was noted that the date of the photography was more critical than the type of photography used. For all practical purposes, B&W is satisfactory for preparing the drainage map during the period of the year (May in this case) when the leaves are not on the trees. At other times of the year when the leaves are out, B-I or C-I would be better because the black tones produced by water on these films are more easily distinguished through the tree foliage.

Effects of Scale

The influence of scale of photography on the interpretation of soils is a tenuous item. Since soils are not features that can be directly seen and interpreted on photography, the use of a larger scale does not necessarily insure an increase in soils information interpreted. It is true that at a larger scale more microfeatures and details can be identified and analyzed, but contrariwise, a smaller field of view is obtained and more photographs have to be analyzed for the same area. Several different scales have been reported in the literature for soils mapping ranging from 1:50,000 down to 1:5,000; however, no optimum scale has been reported.

To investigate the effect of scale on soils mapping, two scales of photography were obtained in the 1965 flights and three scales in the May 1966 flight (Table 1). Evaluation of the various types of films at these different scales with respect to soils mapping led to some very enlightening results. It was determined that the optimum scale for performing detailed soils mapping was not just a function of the scale of the photography, but was also a function of the type of film used and the magnification capabilities of the viewing system (other pertinent items being the same for all film types). For this project, the viewing system utilized—zoom stereoscope with range of magnification from 2.5× to 20×—was not a limiting factor because all the film types investigated degraded or became uninterpretable before the maximum magnification potential



B-1 *(May 1966)* *B&W*

IR Daytime *(June 1966)* *IR Nighttime*

Figure 6. Comparison of drainage patterns evident on photography and infrared imagery.

TABLE 2

QUALITATIVE RATINGS OF VARIOUS FILM TYPES

Rating	Interpretation of Details[a]	Magnification[b]
Excellent	C-P, C-I	C-P, C-I, B&W(n)
Good	C-P/C-N	C-N, B-I(n)
Average	B&W, B-I	B&W, B-I
Poor	B&W/C-N	B W/C-N, C-P/C-N

[a]Positive prints considered only
[b]Includes positives and negatives (n)

of the viewer was reached. Thus, in the final analysis, the main feature other than scale was film type.

A qualitative rating of the various film types, based on the amount of detail evaluated (function of magnification and contrast) is shown in Table 2. The ratings shown were based on comparisons of the various types with B&W photography used as the average. All films compared were approximately the same scale (1:10,000). Only positive films were considered in the first rating. The second rating shown in this table indicates the relative suitability for image magnification of the various film positives and negatives compared with B&W photography (positive print).

In comparing the film types it was observed that the greatest magnification possible was obtained in viewing the C-P and C-I transparencies. In addition, the various color tones on these types increased the contrast between various objects and their background, making it easier to delineate smaller objects. These characteristics made it possible to identify more details from these types than from the other film types studied. In fact, it was noted in an area where soils maps were prepared from the various film types that approximately equivalent details could be interpreted from small-scale color photography (1:24,000) and medium-scale B&W photography (1:10,000). Table 2 also shows that (a) greater magnification (good to excellent) was obtained on the negatives than on prints; (b) both B&W and C-P prints made from the color negatives (C-N) could not be magnified as much as the other types; and (c) the least detail was obtained from the B&W print made from the color negative, while good detail was obtained from the color print made from the color negative because of the increased contrast the colors provided.

SUMMARY AND CONCLUSIONS

This paper reports on a study of the potential of available remote sensing systems for the evaluation of soils and soil conditions. To investigate the various sensors, nine aerial flights were obtained over three controlled test sites during the period May 1965 to June 1966. Coverage was obtained with various aerial films, a multiband camera, radar sensors (K-band), infrared sensors (4.5-5.5u and 8-14μ), and a multichannel sensor (near ultraviolet to far infrared). The various film and imagery types were evaluated individually and in combinations to determine which type or types provided the most information on the pattern elements of tone and form. Because soils are interpreted from an analysis of these pattern elements, the basic premise of the investigation was that the optimum system for soils mapping would be one that had the greatest potential for evaluating the pattern elements. Results indicate the following:

1. For the interpretation and detailed mapping of soils, natural color aerial photography was the most useful single film type, because of the greater number of distinguishable color tones present on the color photography and the natural color appearance of the soils and soil conditions. Important advantages noted for color photography in comparing the various film types are that (a) smaller details can be identified on color photography than on B&W at the same scale, and (b) special filters can be used in analyzing color films to increase the contrast between certain soils and facilitate soils mapping.

2. The optimum scale of photography for soils mapping is a function of film type, magnification capabilities of the stereoscope, and flight altitude. Medium-scale photography (1:8,000-1:15,000) proved to be optimum for detailed soils mapping. The choice of the lower or higher range of the scale depends on the other two factors.

3. Infrared imagery cannot be used as a primary source for engineering soils mapping because of its smaller scale, poor resolution, and lack of stereoscopic viewing

capabilities. Its primary value is that it provides supplementary information not obtainable by any other means and provides converging evidence that aids in the interpretation of soils and soil conditions. The 8-14μ band is of greatest value for obtaining information on soil conditions. The 4.5-5.5μ band is suitable, but tonal differences are not as distinct.

4. K-band frequency radar was of little value for interpreting soils in the study area. Tonal patterns for exposed soil areas were dark for all soil types at this frequency except for the special case when the radar signal was normal to the surface of the soils. Radar was of some value for evaluating soil conditions (e.g., vegetation, land use) although small scale and poor resolution limited the value. The all-weather and 24-hour capability of radar (except under conditions of heavy rain or snow) is an advantage of this type over other types analyzed.

5. The optimum system for performing detailed engineering soils mapping, considering the equipment presently available, is one that simultaneously obtains multispectral imagery and aerial color photography. The development of normalized response curves from multispectral data is a powerful tool for evaluating the various tonal factors and determining which bands demonstrate the maximum contrast between soils of interest. When a multispectral sensor is not available, a valuable alternate system is one that simultaneously obtains color photography, infrared color photography, and infrared imagery in the 8-14μ band. Detailed soils mapping of equivalent detail and accuracy as the optimum system can be obtained but more field control is required.

ACKNOWLEDGMENTS

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Progress in Remote Sensing and Its Application To Highway Engineering and Research

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•CAN airborne remote sensors be used to provide information about surface conditions otherwise obtained through reconnaissance and route surveys, and information about the subsurface otherwise obtained by drilling, resistivity surveys, and refraction-seismograph surveys? The desired knowledge of surfaces includes information about general topographic, geologic, pedologic, hydrologic, vegetative, and cultural relationships; landforms and land use; geologic structure; rocks and soils and their geographic and genetic relationships; and drainage patterns and surface water conditions and their effect on the engineering problem. The relevant subsurface conditions that can only be inferred from visual observation of surface relationships include the downward extent of the rock and soil materials exposed at the surface, groundwater distribution, and the engineering properties of the materials to suitable depths.

If an aerial survey could economically furnish all of these surface and subsurface engineering data, it would be possible to prepare comprehensive engineering evaluations at all stages of a project, from first considerations for routes through subsequent phases in its evolution to post-construction activities. Such comprehensive evaluations can be made if airborne sensor data can be used to:

1. Determine land use along routes under consideration so that land values can be assigned, the effects of disrupting current land use can be assessed, and the cost of relocating existing facilities and bridging intercepted traffic routes can be calculated;
2. Determine surface geometry along proposed routes for requirements of grade, cut and fill volume, and number of culverts, bridges, and tunnels;
3. Identify rocks and soils along the route and determine their relevant engineering properties in order to compute cost of excavating, determine quantity of suitable road-building materials, and disclose natural impediments that will affect engineering costs (bearing strength of the subgrade materials, fault and fracture zones, slide zones, unusual groundwater conditions, impervious layers, etc.);
4. Determine periodically the condition of the road surface and roadway to detect changes that might affect load-carrying capacity and useful life.

Considerable skills have been developed for extracting at least some of these types of information from aerial photographs (1, 2, 3). The topographic, geologic, hydrologic, and soils maps used in highway engineering are prepared at least in part from aerial photographs. However, broad-band panchromatic aerial photographs have certain limitations. Inferences must be made about subsurface conditions, and reliability of such information depends on contextual relationships, the experience of the interpreter, and his familiarity with the area surveyed. Thus, we continue to rely heavily on drill-core data and surface geophysical surveys.

THE SENSORS AND WHAT THEY SENSE

The electromagnetic spectrum (Fig. 1) suggests numerous possibilities for obtaining the kinds of information needed. It extends through many decades of wavelength from radio waves through gamma radiation. The inventory of airborne sensors available for measuring in the various wavelength regions of the spectrum (Fig. 1) is quite impressive.

The data collected by these sensors are displayed in various forms, but the sensors may be considered in two general categories: imaging and nonimaging. Imaging

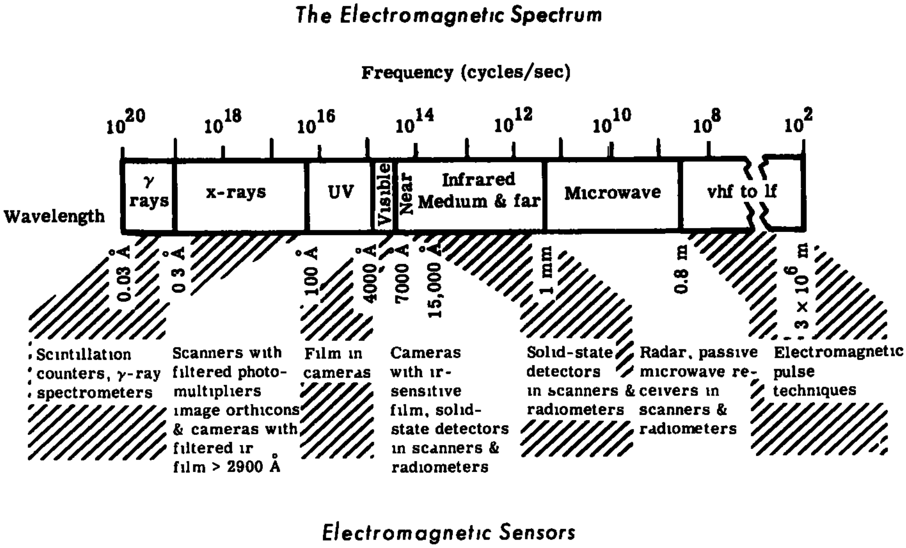


Figure 1. The electromagnetic spectrum and sensors.

sensors produce two-dimensional map-like representations of variations in the radiation within the field of view of the sensor. Cameras, optical-electromechanical scanners, passive-microwave scanners, and radar fall within this group. The data produced by these sensors are recorded (usually) on photographic film, either through direct imaging (as with the camera) or through photographing the output of a cathode ray tube (CRT) or crater lamp (as with scanners and radar). The resultant film is the medium interpreted, and from it the relevant information is extracted.

Nonimaging sensors produce essentially one-dimensional records of radiation received from points along the flight path of an aircraft. Gamma-ray spectrometers, infrared and microwave radiometers, laser and microwave profilers, radio-frequency sounding devices, and induction devices fall within this group. The data produced by these sensors are usually recorded on chart paper.

Imaging Sensors

If we could exploit photography thoroughly, we could probably obtain most of the information we need. Photography is so versatile that it has been called the ubiquitous component of remote sensing. Cameras can record reflected radiation in the spectral region from approximately 300 to 1100 millimicrons, encompassing the near-ultraviolet, visible, and near-infrared portions of the electromagnetic spectrum. The camera records what we are accustomed to seeing, so photographs lend themselves quite readily to interpretation. The inherent geometry of photography allows us to measure images and determine areas and volumes of the objects they represent and their relationship to each other. The resolution of detail available in photographs makes it possible to identify and delimit objects with high reliability. Further, the aerial view provides a permanent, comprehensive record of the total area of interest. Important engineering information that would be missed in ground observations may be observed in this overview.

The science of photogrammetry has progressed to an advanced degree of refinement. Accurate horizontal and vertical measurements can be obtained from photographs with a minimum of ground control. The art of interpreting photographs to obtain other engineering information has not progressed as far. The traditional panchromatic photograph contains information that is not now exploited, and techniques involving different film and filter combinations make it possible to obtain even more information. Color, black-and-white infrared, Ektachrome (color) infrared, or selective spectral filtering of panchromatic or infrared film may provide important information not obtainable with ordinary panchromatic film.

A rather new concept, multispectral or spectrozonal imaging, involves recording a scene at more than one wavelength simultaneously to record diagnostic information that is not disclosed with broad-band panchromatic or color film. Spectrozonal cameras and special optical-electromechanical scanners have been developed to exploit the concept. Various aspects of the multiband approach to solving problems have been discussed in the literature (4-11). Multispectral techniques, new film emulsions, improvements in film speed, grain size, and optical quality of cameras provide a capability for recording, in numerous ways, minute details of the surfaces within the area under investigation. These advances can greatly increase our information potential if we can couple them with significant advances in interpretation techniques.

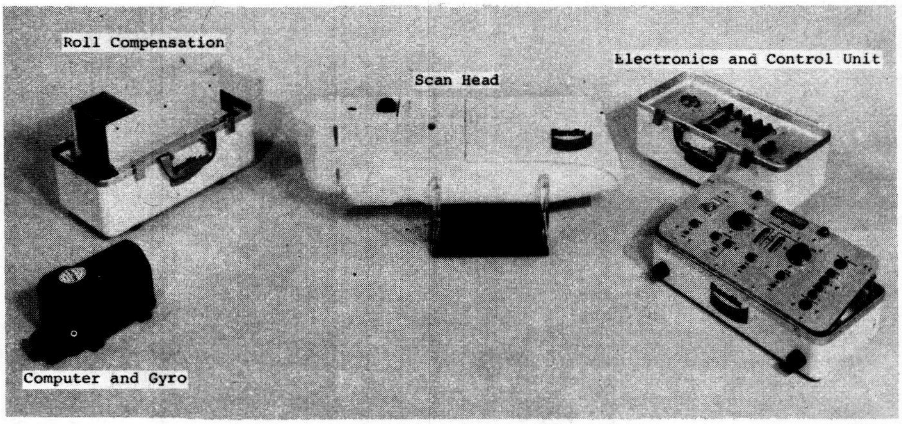
At wavelengths longer than about one micron, imaging directly on film is not possible. Imaging at these wavelengths involves detecting emitted and/or reflected infrared or microwave radiation, transducing it to an electrical signal, and using the electrical signal to modulate the intensity of a CRT or crater-lamp light source. The modulated light is used to expose film and produce a photographic rendition of the imaged scene. It represents the relative or absolute levels of infrared or microwave radiation emitted and/or reflected from the imaged scene. [Principles of infrared and microwave imaging are discussed in other works (12-18).]

The optical-electromechanical scanner evolved from a search for ways to generate infrared imagery from an airborne platform (now also used with a prism spectrometer as a multispectral scanner to generate imagery in the visible and near-ultraviolet spectral regions). Figure 2 shows an infrared scanner. It is compact and light in weight, has low power requirements, and was designed specifically for use in light aircraft. Operated as a thermal mapper (practically, within the spectral region between ~3.5 μ and 14 μ), the scanner produces a record of the relative levels of thermal power emitted by the surfaces scanned. For daytime operation, if emitted thermal power is the quantity to be recorded, it is necessary to filter out the strong reflected infrared component of solar radiation that lies between the visible red and ~3.5 μ.

The spatial resolution achievable with infrared scanners is much less than with cameras, but the capability of detecting small differences in radiation temperatures is quite good (< 1 C). Differences in the apparent temperatures of objects arise from many factors, including density, thermal conductivity, heat capacity, surface roughness, composition of the material, and the placement and orientation of the radiating surface. Changing the density, moisture content, or surface characteristics of a material may give rise to detectable differences in the apparent temperature. If these temperature differences can be related to factors relevant to engineering and repeatedly and reliably identified through infrared imagery, we have a potentially useful technique. Infrared imagery has, for example, demonstrated a capability of indicating the presence of damming of groundwater along fault lines and anomalous moisture content associated with slide areas (19). Figure 3 shows an example of thermal imagery revealing material boundaries not contrasted in panchromatic photography. It also shows the general nature of the thermal imagery format.

Passive-microwave scanners are essentially scanning radiometers. The imagery records levels of microwave radiation emitted by the objects scanned. The quantity measured is the microwave component of thermal radiation. It includes radiation originating below the surface in many materials. The amount and depth or origin depends on the materials and the wavelengths recorded.* Thus, microwave temperature can more easily be related to a property of a material than surface temperature, because it is not so perturbed by prevailing meteorology. The property that most directly influences the emission of microwave radiation is the dielectric constant. Materials

*Depth of penetration $S = 1/\sqrt{\pi f \mu \gamma}$ meter (MKS units), where f = frequency (Hz), μ = permeability, and γ = conductivity.



Bendix Thermal Mapper

SPECIFICATIONS

Film Running Time—1 hour at max v/h
Liquid Nitrogen Hold Time—2 hours or more at average v/h
Instantaneous Field-of-View (Resolution)—3 milliradians
Lateral Scan Angle—120 degrees
Temperature Difference Sensitivity With Indium Antimonide Detector Filtered to 3 to 5.5 microns—0.5 C
Total Available Spectral Coverage With Indium Antimonide Detector (Manual Setting of Choice of One of 4 Filters Available in Flight)—0.7 to 5.5 microns
Maximum v/h (Aircraft Velocity in fps/Altitude in Feet)—0.275 radians/sec
Standard Detector—indium antimonide
Detector Cooling—liquid nitrogen
Power Requirements (With Roll Compensation)—10 a at 24-28 v DC
Scan Head Weight—35 lb
Weight of Control Box Electronics—22.5 lb
Recording—70 mm tri-x film
Film Capacity—100 feet

MODIFICATIONS AND ACCESSORIES AVAILABLE

Roll Compensation—compensates for aircraft roll up to ± 6 degrees (extended range available)
8 to 13 Micron Coverage by use of mercury doped germanium detector and closed cycle cryostat; 400 cps power required
Tape Recorded Output
Real Time Display
Internal Calibration Sources

Figure 2. Bendix Thermal Mapper. (Materials courtesy of Bendix Aerospace Systems Division.)

with high dielectric constant are good radiators in the microwave region, so imagery can be interpreted in terms of this property. For example, the large difference between the dielectric constants of ice and water at microwave frequencies gives rise to large differences in the apparent temperature of these two materials and consequently their image tones. Variations in the water and air content of materials cause variations in their dielectric constants; consequently differences in soil moisture and compactness may be recorded by the microwave scanner. In fact, the scanner can be calibrated to provide indications of absolute moisture content in the upper soil layer (20). Some interesting possibilities for applying this sensor can be postulated merely on the basis of its unique capabilities for discerning these variations.

Because of the dearth of existing systems and specifications, articles relating to them are scarce. Meisels (21) reveals that a system has been developed for the Coast Guard as an all-weather iceberg reconnaissance device. Communications with Space General Corporation indicate that it has developed a system for meteorological applications for the National Aeronautics and Space Administration. Specifications for this system are given in Figure 4.

Airborne mapping radar systems date back to World War II, when plan-position-indicator (PPI) systems were developed for all-weather navigation and bombing. In the 1950's the side-looking airborne radar (SLAR) systems came into being. These

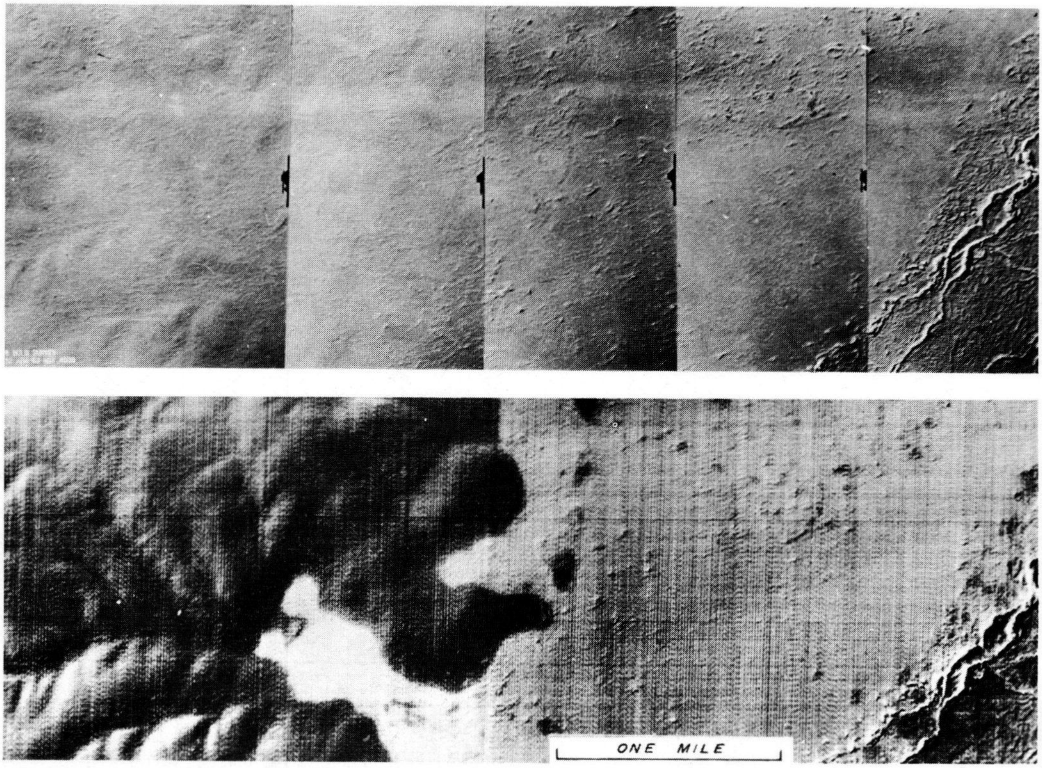


Figure 3. Snow-covered ice-bound coastline visually indistinguishable (even in stereo) in the panchromatic photography (upper) but well defined in the thermal imagery (lower). (Illustration courtesy of U. S. Army Terrestrial Sciences Center.)

have demonstrated a capability of producing imagery that contains useful and quite detailed information about the terrain and the materials that comprise it. Radar is called an active sensor because it records the reflected component of a transmitted pulse of microwave radiation. The imagery is a record of the relative strength of these sig-

LINE-SCANNING MICROWAVE RADIOMETER SPECIFICATIONS

	Original Specs	Breadboard	Aircraft
Sensitivity	0.7°K	0.7°K	1.4°K
ΔT	0.1°K	0.1°K	2.1°K
Scan Time	8 sec	8 sec	1 sec 2 sec
Scan	±50°	±50°	±50°
Beam Width	2.85°	2.85°	2.85°
Data Acq. Sys.	None Paper Printout	None Paper Printout	Real Time Map Nixie Readout Digital Tape Recording
Dynamic Range	100°K to 300°K	100°K to 300°K	100°K to 330°K

Figure 4. Line-scanning microwave radiometer specifications. (Courtesy of Space General Corporation.)

AN/APQ-56 RADAR SPECIFICATIONS

Operating Frequency	35 4 Gc
Beam Width	1^{o}
Resolution	
Azimuth	~100'
Range	~70'
Power Requirement	20 V DC + 115 V AC @ 400 cycles
Weight	~490 lb
Recording Format	70 mm or 9 5" film
Coverage	~15 mi wide strip each side of aircraft or 5 mi wide strip 10-15 mi out from each side of aircraft

Figure 5. AN/APQ-56 radar specification. (Courtesy of Robert Leighty, U.S. Army Terrestrial Sciences Center.)

nals. The nature of the radar return is related to the dimensions and composition of the illuminated object's surface and its orientation relative to the SLAR system. The wavelengths employed in SLAR are around 1 cm, so many surfaces that appear rough at shorter wavelengths appear smooth at SLAR wavelengths. Furthermore, at the low angles of illumination employed in some SLAR systems, certain surfaces are nearly specular reflectors, so that little if any signal is returned.

Orientation is an important factor in determining the way that the received SLAR signal will be presented. The surfaces of interest can be illuminated from just about any conceivable angle merely by selection of flight path and altitude. This in itself is a salient feature for highlighting subtle features of preferred orientation. The low angle of SLAR illumination tends to emphasize small variations in surface relief and may disclose those not observable in other imagery, such as gullies, low fault scarps, and joint patterns. There are also reports that terrain materials can be uniquely displayed through their roughness characteristics at SLAR wavelengths (22). The SLAR imagery possesses constant scale geometry, and Simons (23) has noted that chart accuracies meeting standards governing class A maps at a scale of 1:250,000 can be achieved from it. These considerations, plus those of wide-area continuous coverage and mapping capability independent of time of day and weather, indicate that SLAR may be useful for purposes of highway engineering.

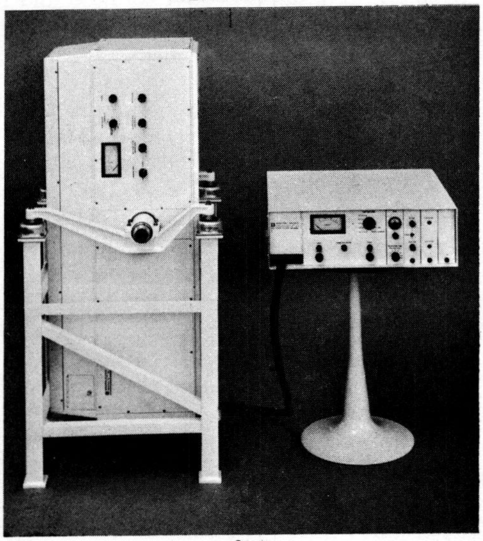
Specifications for most SLAR systems are classified. One, the militarily obsolete AN/APQ-56, likened by Simons (23) to the pinhole-camera state of photographic development, has been declassified. Specifications for it are given in Figure 5. The AN/APQ-97, currently in use for projects such as the NASA Earth Resources Aircraft Program, can be used for nonclassified purposes although some specifications remain classified.

Nonimaging Sensors

Passive-microwave radiometers, radio-frequency sounding devices, gamma-ray spectrometers, and electromagnetic induction devices are some of the nonimaging sensors currently under development that show promise for providing useful highway engineering information. They may be able to provide some of the information that is at present, routinely obtained with seismic or resistivity surveys or by drilling. They are not now routinely employed for highway engineering tasks although such applications are being investigated.

A number of frequencies in the millimeter-wave and microwave regions of the spectrum are being investigated to determine their usefulness in providing information about subsurface conditions in soils. In 1962, Vivian (24, 25) discussed the use of microwave radiometer techniques in analyzing terrain. He stressed the fact that inability to interpret the data rather than inadequate equipment is the big problem standing in the way of widespread use in geophysical applications. In another discussion, Hodgin (26) treated the subject theoretically, concerning himself with its applicability to studies of layered soils and soil moisture. Since 1965 a considerable amount of field testing has been done by Space General Corporation with ground-based, passive-microwave radiometers operating at selected frequencies between 13 and 94 Hz (27, 28). Most of these tests have involved in situ measurements of soil and snow to determine the microwave characteristics of these materials under various conditions of moisture

GEODOLITE 3A PRECISION ALTIMETER



(a)

GEODOLITE 3A PRECISION ALTIMETER

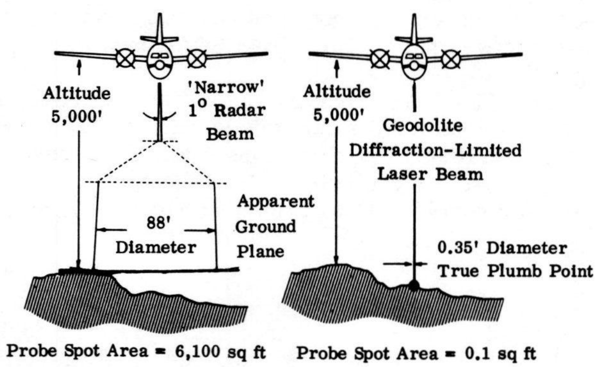
Specifications

Transmitter Beam Width	Less than 10^{-4} radians
Analog Voltage Output	0 to +10.00 volts
Full Scale Range Steps	Choice of 10, 100, 1000, 10,000 and 100,000 feet
Resolution and Accuracy	Better than 1 in 10^4
Range	Greater than 15,000 feet in full sun. Greater than 25,000 feet at night.
Response Time	1, 2, 5, 10, 20, 50, and 100 millisecs.
Mounting	Vibration-isolating vertical mounting frame.
Dimensions and Weights	Telescope Assembly with Mount: 46 x 14 x 10 inches 110 pounds Control Unit: 17 x 16 x 5¼ inches 40 pounds
Input Power	115 ±10 volts, 50 to 400 hertz
Price	**Geodolite 3A** . . . . **$79,000** (Recorder not included)

Prices and other data are subject to change; consult Spectra-Physics Sales Office for further details.

(b)

"NARROW BEAM", 1° APR vs GEODOLITE LASER PROFILER



(c)

Figure 6. Geodolite 3A precision altimeter (a), specifications (b), and comparison with radar altimeter (c). (Materials courtesy of SpectraPhysics.)

content, layering, density, and surface roughness. One of the important findings of these tests is that there is a direct relationship between apparent temperature and soil moisture at the wavelengths used. The equipment used in conducting these ground-based tests can be adapted for airborne operations.

Sounding possibilities using pulsed-radar techniques have been discussed by Cook (29) and were said to be potentially useful in such areas as measuring the thickness of fresh-water ice, determining the depth of the permafrost layer or to the water table, locating caves in limestone country, and possibly finding shear zones. Monopulse radar techniques have been applied successfully to measuring the thickness of lake ice and snow (30). They have not yet been successfully applied to sounding sea ice or other layered materials with complex dielectric constants that introduce attenuation, so it remains to be seen whether monopulse radar can provide answers to sounding problems more generally related to highway engineering.

The Army Engineer Waterways Experiment Station has initiated considerable research in the use of radar techniques for making terrain trafficability investigations. A theoretical study, for example, indicated that monochromatic pulsed-radar systems operating in the very high frequency (VHF) band are not suitable for measuring subsurface soil conditions, but that swept-frequency techniques might be (31). Laboratory testing has confirmed that monochromatic pulsed-radar sensors cannot disclose whether interfaces exist or how deep they are, but can provide information about the water content in deep homogeneous soils (32). These laboratory experiments also corroborated the predictions that swept-frequency techniques can provide information about the depth to subsurface interfaces.

In 1964, radio-frequency sounding devices operating in the VHF band (30 MHz and 35 MHz) were used to sound through 4600 feet of ice on the Greenland icecap and produced a continuous record along the line of surface traverse (33). The equipment has been refined for airborne use by a team from the Scott Polar Research Institute. In 1967 this system was flown over the Antarctic icecap. Continuous profiling of the top and bottom surface of the ice was achieved through ice up to 12,000 feet thick.

Gamma-ray spectrometers are being investigated to determine their utility in soil trafficability studies (34). Barringer (35) has stated that an airborne gamma-ray spectrometer has demonstrated the ability to provide criteria for identifying bedrock even when bedrock is covered with ground moraine.

Another system that has demonstrated a capability of obtaining data about the subsurface from the air is called INPUT—an acronym for induced pulse transient (35, 36, 37). INPUT was designed primarily as an airborne sensor for detecting conducting ore bodies. It also has demonstrated a capability for detecting gravel aquifers buried in glacial clays. Further development and employment of this system may turn up other uses potentially valuable in highway engineering.

Finally, lasers show potential application to highway engineering. They will find many uses in the areas of optical ranging and profiling. One instrument, called an airborne laser terrain profiler, has already been developed by Spectra Physics and Aero Services Corporation (38). Some of the specifications are given in Figure 6. Because the laser light spot illuminates such a small area, it can give a much higher resolution of terrain profile than the longer wavelength radar profilers can, especially in rugged country. The small areas of illumination coupled with the high information rate of the equipment make it suitable for measuring surface roughness on the order of inches.

ARE AIRBORNE SENSORS ECONOMICAL?

Economical employment of sensors must be considered. Is there a decided savings in time, money, or intangibles by using the various sensors, particularly the airborne ones? At present we can only point to the case of aerial photography because, to our knowledge, no figures exist for the other sensors. As an adjunct to preparing this paper we queried a number of state highway departments regarding savings that they realized by using remote sensing techniques, and the significant ways in which the sensors figured in a calculable or noncalculable saving. Our inquiries were very graciously acknowledged by the highway departments of Alabama, Idaho, Louisiana, Michigan, Montana, New York, North Carolina, Pennsylvania, Virginia, and Wisconsin, which represent a good cross section of terrain conditions and engineering problems. It is interesting that savings estimated as high as 75 percent were reported for cases where aerial photographic surveys were used for developing plans for highway construction. Savings estimated at 50 percent of the cost of a ground survey were reported for aerial photographic surveys conducted in areas of extremely rugged terrain or high cultural development; the savings became less and finally became losses for surveys in flat terrain with little cultural development. It is significant that most of the reported savings involved the photogrammetric rather than the interpretive attributes of aerial photographs. Uses for which noncalculable savings were mentioned included materials investigations, studies of landslide areas, condemnation cases, land appraisals, and preliminary surveys for design and preparation of construction plans.

Results of the inquiry reveal two facts. First, when aerial photographic surveys are used in highway engineering, savings result. That was the consensus. Some respondents seem to have a better feeling for the dollar value than others, and some reported more ways in which they could use aerial photographs and save money than others did. The second fact is that none reported using airborne sensors other than cameras. This illustrates that there is a lot of growth potential for the field of electromagnetic sensing applied to highway research and engineering.

WHERE DO WE GO?

The uses of aerial photography in engineering applications are well documented and the economics of their employment are well established. New developments in photographic spectral techniques and uses for color, Ektachrome infrared, and other special-emulsion films are exciting. The job of determining their utility in engineering applications is challenging.

Developments in the other sensor technologies also show great promise, especially those sensors that can provide information about the subsurface. Before we can realize the full capability of the sensors, and particularly appropos the nonphotographic sensors, we must learn much more about the in situ characteristics of the materials of primary interest so that we can confidently interpret the sensor data.

Each research problem or engineering application should be considered separately in light of existing sensor technology and our knowledge of the way that the object, the condition, or the phenomenon under consideration manifests itself spatially and spectrally. It is only through this approach that a systematic analysis of the applicability of the sensors will evolve. Generalizations about capability are of little value in the solution of specific problems. It is essential that specific highway research and engineering problems be made known to those doing research in sensor technology and basic spectral phenomena so that progress can be made.

In the near future it should be possible to exploit economically the special problem-solving potential of some of the sensors discussed in this paper. It may turn out that economics will be the catalyst that accelerates the use of remote sensors in highway research and engineering. As one of our reporting highway departments pointed out, it is becoming increasingly difficult to find people to perform ground surveys and the cost of ground methods is steadily increasing.

ACKNOWLEDGMENT

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Techniques for Utilizing Side-Looking Airborne Radar (SLAR) Imagery in Regional Highway Planning

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SLAR is a self-illuminating, imaging sensor capable of operating over a wide wavelength range in a side-scanning mode. Feasibility studies have demonstrated the potential value of SLAR in terrain analysis, geologic and planimetric mapping, vegetation classification, and a multitude of related earth science disciplines. This paper presents a procedure in which SLAR imagery strips or mosaics can be utilized as the primary presentation of terrain data for the regional planning of transportation systems. The SLAR image strip or mosaic can serve as a base map of existing major cultural features as well as a presentation from which regional classifications of engineering soil types, drainage, and topography can be made. Techniques for measuring and interpreting these factors from SLAR imagery are presented along with an evaluation of their reliability. Included are image texture and return analyses as well as interpretation keys. Advantages and disadvantages of SLAR imagery are compared with the conventional photography and topographic maps currently used for regional highway planning.

•SLAR (side-looking airborne radar) is a self-illuminating, imaging sensor capable of operating within a wide range of frequencies. Wavelengths in the radar band of the electromagnetic spectrum range from about one-half centimenter to several meters. The side-scan geometry of SLAR, illustrated in Figure 1, produces a small-scale image similar in appearance to a shaded relief presentation of the terrain. Contrasts in radar return (reflectivity) values are electronically processed to produce gray tones on film that can be related to a number of land surface conditions.

Although many studies have demonstrated the potential of SLAR for geologic and planimetric mapping, vegetative classification, and related earth science disciplines, few studies have been conducted utilizing SLAR imagery as a civil engineering tool. Moreover, very few reports exist in which a systematic approach toward the interpretation of SLAR has been the primary objective.

This paper presents an approach to the interpretation of regional engineering soil groups from SLAR imagery. SLAR imagery strips or mosaics are utilized as the primary presentation of terrain data for regional transportation system studies and regional mapping of engineering soil groups. An engineering soil group is defined for this purpose as an assemblage of similar soil types or parent materials, which constitute a unique landform and express a recognizable pattern on the radar image.

This paper represents only the opinions of the authors and does not reflect the official approval of the U. S. Army Engineering Topographic Laboratories, sponsor of this research, or of Purdue University.

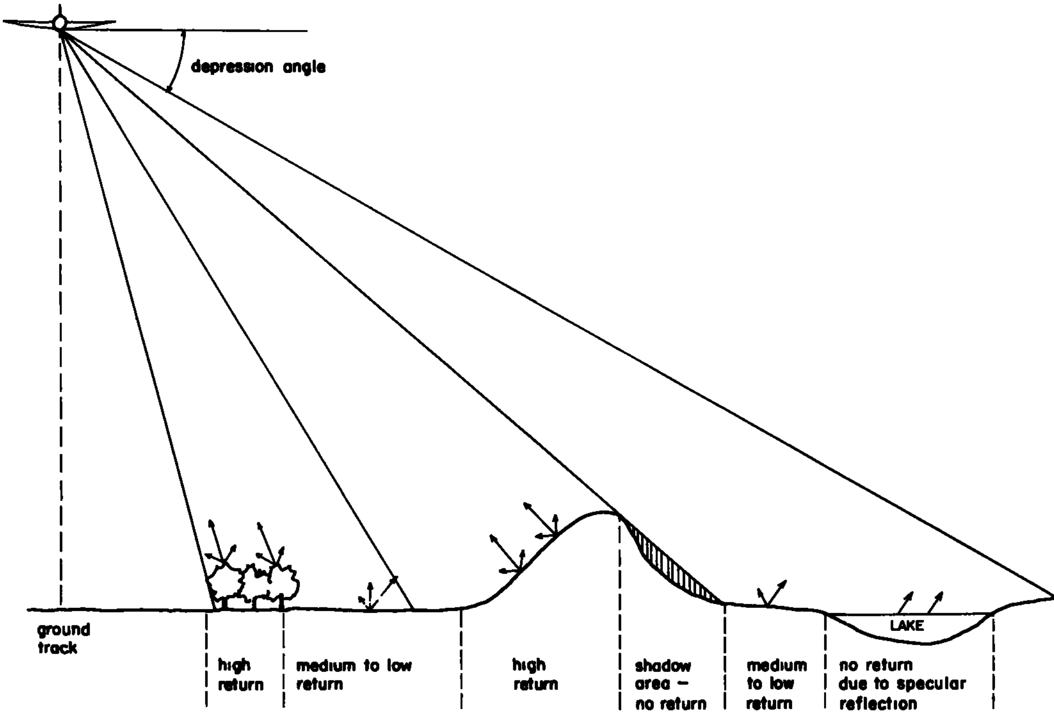


Figure 1. Basic radar geometry.

CONCEPT

It is proposed that SLAR imagery affords the materials and transportation engineer a useful display of terrain data on which preliminary route locations and regional material boundaries can readily be delineated. Because of its imaging geometry and manner of recording reflected electromagnetic energy, the SLAR image can serve as the base map of existing cultural features as well as natural terrain information.

SLAR is indeed unique and useful for regional planning and engineering materials mapping. The following characteristics are exploited in the utilization of SLAR imagery for civil engineering purposes:

1. The SLAR system is operational in virtually all kinds of weather day or night. Imagery can be obtained from those portions of the earth that are perennially cloud covered.
2. SLAR imagery is generally produced at a relatively small scale. Typical scales range from 1:100,000 to 1:400,000 and afford a synoptic display of terrain data.
3. Relief of imaged terrain can be estimated in a relative sense from a SLAR image. The image geometry produces a display similar in appearance to a shaded relief topographic map.
4. Many objects that tend to be good reflectors of electromagnetic energy (including most cultural features) are emphasized on SLAR imagery. Objects or clusters of objects that would normally be lost on conventional small-scale mosaics of aerial photography appear as high returns (bright spots) on SLAR imagery.
5. Although highly reflective surfaces such as buildings are emphasized on SLAR imagery, SLAR characteristically tends to average returns from natural terrain, thus producing an image that is not confused by infinite detail. Thus, in comparison with a photographic mosaic at the same scale, the radar imagery strip will present a relatively unconfused display of regional terrain patterns and landforms.
6. The relatively small-scale SLAR image possesses characteristic regional patterns that can be analyzed by inference techniques for the interpretation of regional engineering soil types.

IMAGERY

Much of the SLAR imagery used for development of the interpretation approach has been from K-band radar (0.83-2.75 cm). A variety of SLAR imagery strips representative of many geographic regions has been analyzed. This imagery, originally obtained by the National Aeronautics and Space Administration in cooperation with the

TABLE 1

RADAR IMAGE CHARACTERISTICS OF CULTURAL FEATURES

Cultural Feature	General Radar Image Characteristics	
	Return	Pattern
Urban area	Very high	Linear and rectangular grid patterns produced by intersecting streets, clusters of high return spots from buildings
Suburban area	Medium to high	Linear and rectangular grid produced by intersecting streets, few high return clusters but dependent upon density
Highways—improved	Very low	Linear traces, generally smooth curves
Highways—unimproved	Very low	Linear traces, possibly sharp curves and poor alignment, similar to adjacent terrain
Railroad	Very high	Linear traces, very gentle curves
Power transmission lines	Very high	Beaded pattern resulting from individual towers
Bridge structures	Very high	Usually individual high return spot or short linear trace
Airport		
Runways	Very low	Linear traces, X-pattern
Structures	High to very high	Clusters of returns
Industrial area	Very high	Clusters of high returns in localized area
Agricultural area	Variable—high to low	Rectangular blocks with uniform return, variation in return from block to block

TABLE 2

DATA GUIDE FOR RADAR IMAGE ANALYSIS

Evaluate Relative Radar Returns

1 Overall return values
2 Special areas of high or low returns
3 Regional uniformity or variability of return
4 Extent and shape of radar shadow (no return) areas

Evaluate Image Texture and Local Pattern

1 Extent of smooth, rough, granular, etc , regional and local image textures
2 Effect of surface drainage and topography on regional and local image texture
3 Effect of surface drainage and topography on regional and local patterns
4 Effect of vegetation on regional and local image texture

Delineate Surface Drainage System

1 Evaluation of drainage patterns, i e , geomorphic types (dendritic, parallel, etc)
2 Areas showing evidence of lack of drainage or intense drainage
3 Estimation of drainage density

Analyze Topography

1 Degree of dissection
2 Estimate of relief based on size and shape of shadow as well as drainage density
3 Relation of topography to vegetation and culture
4 Effect of topography on radar return

Infer Vegetation, Culture, and Land Use

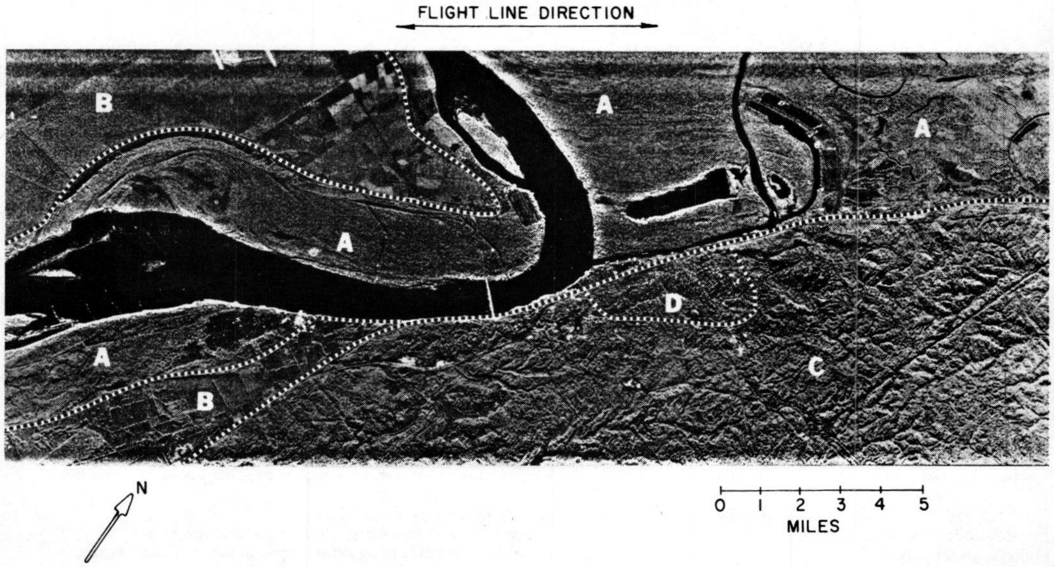
1 Types of crops and field patterns, i e , rectangular fields, contour farming, strip farming
2 Percent vegetation types
3 Location and extent of cities and surface transportation systems

Interpret Landforms

1 Landform types—genetic and morphological
2 Local association with other elements

Infer Parent Material

1 Consolidated material
2 Unconsolidated material



INTERPRETATION EXAMPLE

Area	Regional Drainage	Regional Topography	Land Use	Special Conditions	Landform and Inferred Engineering Soil Type
A	Oxbows meander scars prevalent	Relatively flat; curvilinear patterns indicative of low ridge and swale	Limited; predominantly forest with some grassy areas	Borrow pit for levee adjacent area; tonal contrasts indicative of selective growth of vegetation.	Flood plain, ridge and swale type; unconsolidated, fine-grained alluvium.
B	No evidence of surface drainage	Flat	Retangular field patterns, some trees along fencerows	Area protected by levee, fields not affected by topography.	Flood plain; unconsolidated, fine-grained alluvium
C	Dendritic with pinnate tributaries, high density of streams	Moderate relief, highly dissected steep valley walls	Limited activity, predominantly forested	Steep valley walls indicated by thin shadows and light tones.	Dissected loess surface; unconsolidated, fine-grained eolian material
D	None	Same as C	Light tonal elements and gridded pattern indicative of urban area		

Figure 2. SLAR image of Lower Mississippi Valley.

U. S. Army Electronics Command, was acquired from the U. S. Army Engineering Topographic Laboratories for use on a research project under contract with Purdue Research Foundation.

Although imagery from one system constituted the primary source of information for this paper, a comparative analysis has indicated that imagery from other radar systems is not significantly different in character for regional soils interpretation. Thus, the soils interpretation procedure is judged to be applicable to the use of imagery from several SLAR systems.

INTERPRETATION

Cultural Detail

The correct identification of cultural detail that may influence location decisions on SLAR imagery is affected primarily by an interpreter's ability to recognize typical returns. Although not all individual objects (houses, etc.) will be identifiable on the imagery, all urban areas and concentrations of cultural objects are interpretable. Table 1 lists some of the cultural features pertinent to route location studies along with their radar image characteristics.

The mapping of cultural features is based on the identification of radar returns from objects and is somewhat less involved than the interpretation of regional soils. Point return spots are the major clues.

It must be stressed again that all cultural features are not interpretable from the SLAR image. Some of the cultural information needed for determining preliminary route locations is not directly available from the SLAR imagery. However, the imagery can form an excellent base map, if corrected for geometric distortion, upon which collateral data can be displayed. It is important that major features are recorded on the imagery, for in some cases these are the first items of interest.

Regional Engineering Soils (Parent Materials)

The interpretation of regional engineering soil groups is accomplished by analyzing radar imagery in a systematic manner. The technique is based on the correlation of radar patterns of terrain from which engineering soils information is inferred. Basically, the only information to be gained directly from the radar image includes return value (brightness of each resolution element on the image) and the spatial arrangement of resolution elements. In other words, the image tones and image textures are the only data directly obtainable from the radar. From this, however, one can interpret relief, drainage, and landforms as well as infer general vegetative cover, engineering soil groups, and general physical condition of the land surface. The more one can relate "ground truth" data to the radar image, however, the more accurate will be the inference of engineering information.

The radar interpretation technique presented, being patterned after conventional photo-interpretation techniques, requires a step-by-step evaluation of radar returns and radar image textures as well as a systematic analysis of the local and regional patterns formed by the radar returns. In practice, the technique is most efficient when gross features and patterns are evaluated first, followed by the delineation of areas of apparent homogeneity on the SLAR imagery. Once these boundaries have been established on the basis of regional radar patterns, a closer look at radar returns and textures helps in the inference of engineering soil group and land surface condition.

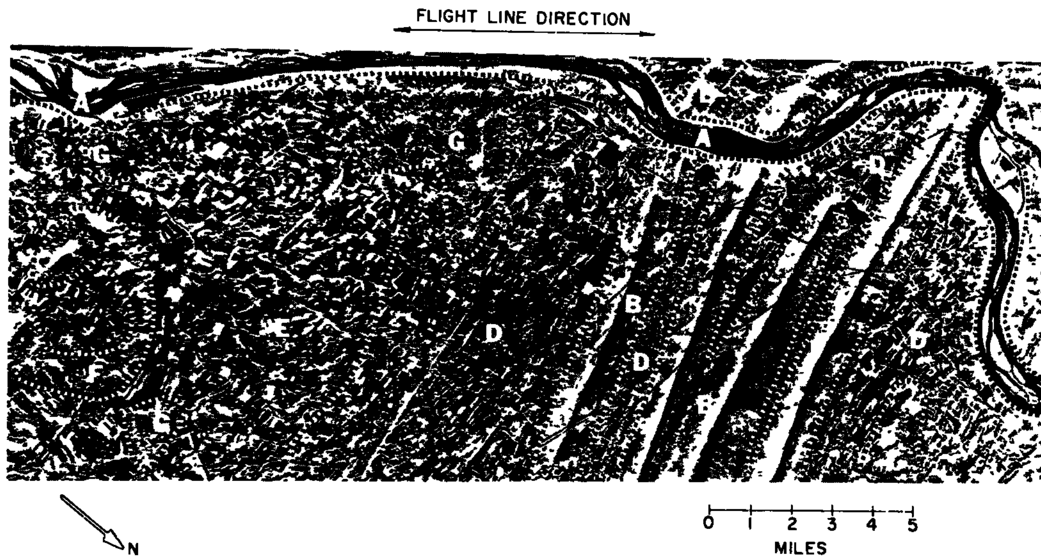
Table 2 outlines a basic data guide used for organizing a process of information extraction from SLAR imagery. As the topics in the data guide are evaluated, an interpreter can delineate those areas on the imagery that appear to exhibit uniform radar characteristics. As previously mentioned, relative radar return and textures are the basic radar data presented in the photographic format, whereas drainage system, topography, vegetation, culture, land use, landform associations, and regional parent materials are inferred from the basic radar information. All of the elements that combine to form a radar pattern are interrelated. However, the arbitrary subdivisions in the data guide tend to force the organization of radar interpretation information into an efficient format.

The elements of terrain that include topography, drainage, and landforms can be inferred from SLAR imagery. It requires only a little instruction in basic radar imaging principles to recognize and evaluate these elements. The evaluation of local terrain surface roughness and land surface condition by means of relative image tones and textures, however, is unique to the radar system. A partial list of the radar characteristics of these terrain elements is given in Table 3.

The effects of the various terrain elements on radar reflection and the resulting radar image are interrelated, with topographic effects being dominant. The unique effect of one particular element cannot always be ascertained. Thus, the interpretation of engineering soils from the image requires considerable judgment based on the best evidence available on the imagery and from collateral information.

Examples of Engineering Soils Interpretation

SLAR imagery of Mississippi Valley and Pennsylvania study sites has been selected to illustrate the interpretation technique. Figure 2 is an unretouched SLAR positive image of a portion of the Lower Mississippi Valley. The image was evaluated with respect to the items shown in Tables 2 and 3. The annotation of Figure 2 summarizes the analysis of regional drainage, regional topography, land use, and special conditions, and presents an interpreted landform and inferred engineering soil type for each delineated area.



INTERPRETATION EXAMPLE

Area	Regional Drainage	Regional Topography	Land Use	Special Conditions	Landform and Inferred Engineering Soil Type
A	Meandering stream and tributary	Relatively flat, terraces and flood plain exist, several islands	Agricultural activity along flood plain and terraces	Strong control exerted on the stream in several areas	Flood plain and terrace, unconsolidated fluvial drift
B	Trellis	Linear ridges with high relief	Predominantly forest	Ridges parallel and separated by linear valleys	Sedimentary mountains, resistant sedimentary rock
C	Dendritic	Hills with moderate relief	Predominantly forest	Associated with linear ridges of area B but does not express linearity	Sedimentroy hills, relatively resistant bedrock
D	Dendritic with locally rectangular	Low-relief valleys associated with adjacent linear ridges	Agricultural activity, limited riparian vegetation	Many cultural features scattered throughout area	Sedimentary valley, non-resistant sedimentary rock
E	Dendritic, tributary streams bifurcate between areas E and D, major stream exhibits marked pattern of retangularity	Relatively low relief, valley	Agricultural activity, field size larger and more regularly shaped		Sedimentary valley, non-resistant sedimentary rock
F	Drainage part of dendritic pattern of area E, but annular in form	Hills in circular shape	Predominantly forest	Topographic expression suggests igneous intrusive activity	Ring dike, resistant bedrock consisting of metamorphosed or igneous instrusive rock
G	None	Same as E	Light tones and gridded pattern indicative of urban areas	Grid	

Figure 3. SLAR image of Pennsylvania site.

With respect to regional terrain analysis, it can be seen in Figure 2 that the high-relief areas are represented on the image as containing a high density of drainage and radar shadow produced by topography. The determination of high-relief areas along with the ability to define and locate major cultural features allows preliminary regional transportation corridors to be established on image overlays. These corridors can be selected on the basis of regional topographic and cultural influences, thus eliminating the need for detailed examination of the entire region in question. Conventional photo-interpretation techniques can be utilized in establishing possible highway routes within the previously defined corridors.

A SLAR image of an area in Pennsylvania is illustrated in Figure 3. It is inferred that each of the delineated areas of the image contains similar parent materials and regional engineering soil types. The annotation summarizes the evaluation of factors used in the deductive process.

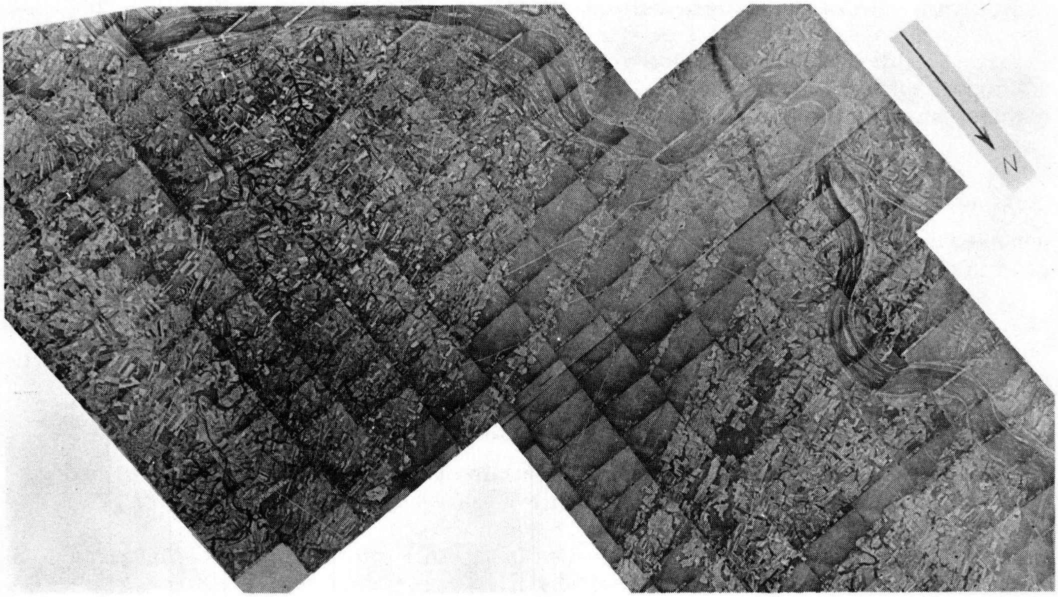


Figure 4. Index photo mosaic of Pennsylvania site.

TABLE 3

TERRAIN FACTORS AND REPRESENTATIVE TONAL RANGES
(Factors are not mutually exclusive)

Factor	Reflection Characteristic	Tonal Range
Topographic		
Flat surface	Specular reflection if surface is smooth; no return	Dark tones
Sloping surface facing antenna	Relatively high return due to orientation effects	Medium to light tones
Sloping surface facing away from antenna	Relatively low return due to orientation effects	Medium to dark tones
High relief	No return from shadow areas	Dark tone
Geologic		
Rough surfaces (> 1 wavelength)	Diffuse reflection; medium to high returns	Medium to light tones
Smooth surfaces (< 1 wavelength)	Specular reflection if surface is flat; no return; reflection influenced by topographic effects	Dark tones; lighter tones produced by orientation effects
Natural corner reflectors produced in bedrock by weathering	Maximum reflection; high return	Very light tones
Vegetation		
Trees Woods and forests	Diffuse reflection High returns	Light tones
Brush	Higher returns with increasing density of occurrence	Light tones in humid to subhumid areas; medium to dark tones in arid environment
Natural grass	Diffuse reflections; medium to low returns; dry sparse vegetation produces less scatter than lush moisture-rich vegetation	Medium tones in humid to subhumid areas; dark tones in arid environment
Broad-leaf crops with naturally high moisture content	Diffuse reflection; high returns	Light tones
Small-leaf crops	Diffuse reflection; medium returns	Medium tones

The value of this image for preliminary regional transportation corridor evaluation can be seen when comparing it with the photo index of the same area illustrated in Figure 4. Although the resolution of the SLAR image is poorer, land-water contacts and topography are accentuated on the monoscopic imagery. In addition, major cultural features stand out in contrast to the natural terrain.

SUMMARY

SLAR imagery, because of its relatively low resolution, is useful for presenting a synoptic display of terrain information. It can be utilized for maximum benefit when used in concert with aerial photography.

A systematic procedure for SLAR image interpretation can be used to advantage in regional terrain and engineering soils studies, which in turn can aid in highway planning of regional scope. The technique provides the potential for the preliminary selection of routes as well as the mapping of construction material sources.

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