UTILIZATION OF REMOTE SENSING IN THE PRELIMINARY AERIAL SURVEY-HIGHWAY PLANNING STAGE IN VIRGINIA

D. F. Noble, Virginia Highway Research Council, Charlottesville

The purpose of the study was to determine whether infrared technology could be used to delineate soil areas having a high moisture content. Located in Augusta County, Virginia, the study area is mapped geologically, topographically, and pedologically and is heavily farmed and 80 percent nonforested. Data were collected with a multisensor array, including cameras and multispectral sensors. The electromagnetic spectrum was sensed from the violet through the far infrared. Ground truth in the form of radiometer and thermometer readings and color photographs was taken at the time of the flights. The 8.0- to 13.5-micrometer band was sensed during the day and the night and was interpreted for information about those features associated with high moisture content. Correlation of this information with that obtained from the various types of photographs was attempted.

•AMONG THE many problems confronting highway engineers are soils with high moisture contents, areas of poor drainage, areas of potential landslides, and areas of active landslides. Water is central to all these problems. Thus it was hoped that in this study detection of materials with a high moisture content might be accomplished.

The principal purpose of this study as stated in the working plan (3) was to determine whether remote-sensing techniques, in particular those utilizing the infrared portion of the electromagnetic spectrum, could be used along a proposed right-of-way to differentiate and delineate the areas that contain high moisture at the ground surface and whether this information could be interpreted to provide knowledge of soil moisture conditions at depth. As a by-product of such a study, information might be generated that would contribute to the knowledge of remotely sensed diagnostic properties of natural materials.

SITE SELECTION AND DESCRIPTION

Several criteria were considered to be important in the selection of a test site. There should be good geologic, pedologic, and meteorologic data available. The areas should be extensively farmed so that large tracts of soil would be exposed. As wide a variety of soil types as possible should be embraced. Based on these criteria, a 12-mile (19.3-km) site in Augusta County was selected. Along this site approximately 80 percent of the land is nonforested and is either cultivated or in pasture.

Physiography and Geology

The great Valley of Virginia passes through the middle of Augusta County. The eastern boundary of the county lies within the Blue Ridge Mountains, and its western quarter is within the folded Appalachian Mountains. The central two-thirds, running approximately northeast-southwest, is underlain by great thicknesses of tilted limestone and shale. Because of the moderate natural fertility of the soils derived from these rocks, the area is extensively farmed.

A northwest-southeast flight line was selected to traverse at approximately 90 deg the northeast-southwest trend of the structural elements. Limestones, dolomites, and shales of Cambrian and Ordovician age and sands and gravels of Quarternary age were traversed by this line.

The topography along the traverse is rolling and is influenced by the rock types. Table 1 gives the major rock types and materials encountered. Of the several lithologies, at least 2 (Conococheague and the Beekmantown) have very distinct topographic expressions on stereoscopic aerial photographs. The sandstone beds in the Conococheague tend to form ridges, and the deposits of residual chert from weathering of the Beekmantown give rise to conically shaped hills. Most of these bedded rocks dip rather steeply and have differential susceptibility to weathering; that causes the outcrops of bedrock to be long linear (ledgy) features. Travertine forms along some creeks because the creek water contains sufficient calcium and bicarbonate ions in solution such that the calcium carbonate of the travertine forms when creek water evaporates. There is significant solution of limestone occurring within the area. Incipient karst topography occurs at the northwest end of the traverse where there are 2 small sinkholes. The existence of underground cavities in these areas is a distinct possibility.

Zones of fracture such as the Pulaski-Staunton Fault, joints along the crests of folds, and abandoned and filled channels on the flood plain are areas that might localize water.

Soil Types

Descriptions of the soils most commonly occurring within the study area are given in Table 1 (2). The data are necessarily generalized.

The soils encountered reflect their genesis, which is a function of parent material, climate, relief, plant and animal life acting on and within soil, and time subjected to soil-forming processes. Thus, the soils reflect the presence of chert and quartz sand in the Conococheague limestone and sandstone, chert in the Beekmantown dolomite and the clay, and silt in the Martinsburg shale. The climate is temperate with an average annual precipitation of 37 in. that is relatively evenly distributed over the year. Such conditions are conducive to chemical attack of limestone and dolomite. Therefore, the greatest soil thicknesses occur over portions of the carbonate rocks. Where slopes are level to gentle, erosion is minimized, and there is sufficient time to develop thick, mature soil profiles over the carbonates.

GROUND CONTROL DATA

The staff of the Photogrammetry Section of the Virginia Department of Highways prepared an uncorrected photomosaic at a scale ratio of 1 to 24,000 for field use and also acquired the aeronautical charts for the consultant. Topographic maps and geologic maps of the 7.5-min series were obtained from the Virginia Division of Mineral Resources. The Soil Conservation Service of the U.S. Department of Agriculture was preparing a soil survey report of Augusta County and kindly made the preliminary draft available (2). Very useful data were obtained in the form of soil boundaries on a black-and-white aerial photo format; the soil descriptions contained data on the physical properties of the soils and information on their agricultural, forest, engineering, and urban suitability.

GROUND TRUTH MEASUREMENTS

Ground truth measurements are a necessary complement to the data taken during aerial flights. Knowledge of the surface conditions at the time of the flight enhances the interpretation of the data.

Many parameters could have been checked at the time of the flight. However, checking of a parameter was restricted by the time and the number of personnel. Consideration of equipment and personnel dictated that parameters such as soil moisture content and precise meteorological conditions not be checked. Thus, ground truth checks were organized so as to acquire the greatest amount of information on a few parameters judged to be the most useful in terms of correlation with the flight data. Ground temperature and color photographs were taken, and visual estimates of meteorological conditions were made.

The traverse was field-checked to establish, on the basis of previous years' farming practices, potential ground truth sites that might be bare at the time of the flight. As many types of material and conditions as possible were selected. Aside from the ground truth sites in relatively level fields, a site for a water reading was established just off a bridge over Christians Creek because of the minimum diurnal fluctuations in the water's temperature. Several checkpoints that were established for reading embankments were affected to a lesser degree by solar radiation and nocturnal cooling than were the level fields. The sites had to be located close to the roads because cars and trucks were used as transportation to them.

The day before the flight a final check of the traverse was made. Recent changes in field conditions were noted. Where necessary, the sites of ground truth checks were changed. Stakes were placed to serve as reference points so that the instrument man would take measurements at approximately the same location.

Temperature Measurements

For both the day and the night flights, 2 crews composed of FHWA and Virginia Highway Research Council personnel took surface temperatures at the selected sites. Both contact thermometers and remote infrared radiometers were employed. The surface thermometer was placed on the soil surface, the stem of the dial thermometer was placed just under the surface, and the radiometer was focused on the soil surface but scanned over a relatively large area. These readings were recorded along with site notation, time, and instances when the aircraft was overhead.

Color Photographs

During the day flight, Virginia Highway Research Council personnel, equipped both with 35-mm cameras loaded with Ektachrome film and with 7.5-min quadrangle topographic maps for locating sites, photographed specific fields and conditions on selected segments of the traverse. The purpose of this photography was to provide reasonably close-up photographic evidence of ground conditions at the time of the flight. Some of the photographers had very little experience with the type of cameras provided, and the photographs were of necessity taken in a hurried manner. Results of this photography demonstrated that the best photographs were taken with the most automatic cameras. Use of a hand-held light meter resulted in underexposures.

PLANNING OF FLIGHT

Selection of Sensors and Film Types

The wavelength bands within the electromagnetic spectrum selected for electronic sensing are given in Table 2. Wavelength bands were chosen so that the visible and infrared spectra were covered. At night, the only wavelength bands sensed were the middle and far infrared. The films chosen for the photography are given in Table 3; the personnel of the University of Michigan used the 70-mm film, and the Virginia Department of Highways used the 9- by 9-in. film.

The purpose of the aerial photography was to provide the usual type of data to which the photo interpreter is accustomed. Normal black and white, Ektachrome color, infrared black and white, and infrared color permitted the evaluation of which parameter a specific film showed best and also permitted the combination of the several photographic records so that information on a specific parameter might be better documented.

As a means of calibration, eight 20- by 40-ft, coated, canvas panels of known reflectances were staked in a relatively level field. Five of the panels were of a gray tone and had reflectances ranging from 0 to 80 percent in 20 percent increments. The other 3 panels were red, blue, and green.

Flight Times

Initially it was hoped that one flight could be made during the wet spring and that the other flight could be made after a dry summer or early fall so that the effect of the

Table 1. Description of certain soils in Augusta County.

Soil Description	Depth (ft)	Drainage Class	Permeability	Susceptibility to Erosion	Depth of Seasonal High Water Table (ft)	Genesis
Dandridge silt loam—dark brown to yellowish brown, very friable surface soil, silt loam or shaly silt loam	1 to $1\frac{3}{4}$	Well to excessive	Moderately rapid	High	4 plus	Residual
Frederick—yellowish brown to red in B, friable surface soil, silt loam to clay in B	4 to 30	Well	Moderate	Moderate to high	6 plus	Residual
Floodplain and terrace soils: Braddock, Laidig, Melvin, Monongahela, Newark, Purdy, Tyler—yellowish brown to dark gray, friable to very friable surface soil, sandy to silt loam	6 to 10	Relatively poor	Low to moderate	Low to moderate depending on slope and regional relief	0 to 3, with ponding on floodplain	Transported

Table 2. Spectral bands sensed by electronic sensors.

Time	Spectral Color	Wavelength Band (μm)	Field of View (deg)
Day	Violet	0.40 to 0.44	80
	Blue	0.44 to 0.46	
		0.46 to 0.48	
		0.48 to 0.50	
	Green	0.50 to 0.52	
		0.52 to 0.55	
		0.55 to 0.58	
	Yellow	0.58 to 0.62	
	Orange	0.62 to 0.66	
	Red	0.66 to 0.72	
	Near infrared	0.72 to 0.80	
		0.80 to 1.0	
		1.0 to 1.4	
	Middle infrared	1.5 to 1.8	37
		2.0 to 2.6	
		2.0 to 2.6 low gain	
	Far infrared	8.0 to 13.5	
		8.0 to 13.5 low gain	
Night	Middle infrared	4.5 to 5.5	37
		4.5 to 5.5 low gain	
	Far infrared	8.0 to 13.5	80
		8.0 to 13.5 low gain	
		8.0 to 10.0	
		10.0 to 11.0	

Table 3. Film and camera types.

Film				
Name	Type	Size	Filter	Camera
Black and white	2402	70 mm	W12	P-2
Black and white infrared	2424	70 mm	89B	P-2
Ektachrome	8442	70 mm	1A	KB-8
Color infrared	8443	70 mm	W15	P-220
Black and white (XX)	2405	9 in.	W12	Wild RC-8
Ektachrome	8442	9 in.	Antivignetting	Wild RC-8
Color infrared	8443	9 in.	W12	Wild RC-8

moisture contrast might be observed. Early April was chosen for the wet season flight because little if any snow cover was expected and the trees were not expected to be beyond the budding stage. The time for the day flight considered most desirable was between 10:00 a.m. and 2:00 p.m. The object was to have maximum sun, minimum shadow, and minimum cloud cover. The primary constraint on the timing of the night flight was that all residual energy absorbed during the day should have been dissipated so that the only radiation coming from the earth would be that which was characteristic of the material and its temperature. The night air was quite cool (approximately 0 C), and an equilibrium condition was reached well before the flight time of 11:00 p.m.

The second flight was planned for mid-November; but, because of equipment breakdown, it was postponed until mid-December. The delay was fortuitous in that few fields were bare in November, but winter plowing bared numerous fields by the December flight date. The times during the day for the flights were similar for the reasons mentioned earlier. Unfortunately, soil conditions were much wetter than desired, and a low sun angle caused pronounced shadows.

Post-Flight Data Check

After completion of the day and night flights, the consultant recommended checking several of the electronically sensed wavelength bands in order to verify that data were acquired and that they were on the desired flight line.

Length and Elevation

The general choice of location for the traverse ensured such variety in materials and terrain that the precise length of the traverse was somewhat a matter of convenience. Flying the traverse at 2 altitudes was considered useful so that interpretation of data with different degrees of resolution could be compared and a judgment could be made on the value to highway needs of flying higher with poorer resolution but greater areal coverage. Inasmuch as the reels of magnetic tape on which the data were recorded would accommodate 24 flight-miles (14.9 km) of data, it was decided to make the flight line 12 miles (7.5 km) long. Thus flying 2 altitudes would use a roll of tape.

Because the purpose of the study was to judge whether multispectral remote sensing was applicable to highway planning and engineering, a decision was made to fly the flight line at an elevation above mean ground altitude that would amply cover the minimum right-of-way required for an Interstate highway. Safe operation of the aircraft was also a consideration, and the lowest elevation above mean ground altitude that would cover the right-of-way was too low for safety. Thus, elevations of 2,000 and 5,000 ft above mean ground altitude were chosen. These elevations gave a minimum and maximum ground coverage of 1,338 and 8,390 ft for the 37- and 80-deg angle fields of view respectively.

Details of Preparation

Coordination between the crews collecting ground truth data and the flight crews was important. Therefore, the following procedures were utilized:

1. A local airport large enough to accommodate a C-47 aircraft and as close to the project area as possible was used as a base of operations;
2. Telephone contact was maintained between the ground and the flight crews up to flight time for last-minute consultations;
3. A signal was arranged by which the flight crew could indicate to the ground crews that the mission was completed; and
4. Radio contact was possible among several highway department vehicles and the department plane.

There were several other preparations worthy of note. One was the placement of strobe lights along the flight line as an aid to night navigation. The other was that notifying the local police about the impending night activity saved the citizens some confusion and alarm.

ANALYSIS OF DATA

Format

The electronically sensed data were recorded on magnetic tape. In addition, the data on the tape were converted to gray tone images and presented on 70-mm film (negatives and prints) for visual interpretation. The gray tone images had the advantage of being in a form that was familiar to most people, but they were deficient in that the film did not have sufficient tones of gray to represent the many variations that the magnetic tape was capable of recording (1).

Duplicate tapes, negatives, and prints of both the spectral data and the 70-mm film exposed by the consultant and the 9- by 9-in. film used by the department were supplied to the council and the FHWA. The council had prime responsibility for the visual interpretation of the data; the FHWA planned to concentrate its interpretive effort on the computerized analysis of the data as recorded on the magnetic tapes.

Approach to Visual Analysis

It was decided to choose specific features and conditions on the films for investigation. These included sinkholes, faults, filled oxbow lakes, channel cutoffs, and leakage from reservoirs—all known to have high moisture. This approach was taken because the principal purpose of this study was to determine whether remote-sensing techniques, in particular those utilizing the infrared portion of the electromagnetic spectrum, could be used to differentiate and delineate the areas along the proposed right-of-way that contain high moisture at the ground surface. In addition, this approach was taken because there were so many data that to interpret them all as fully as possible would have taken more time than was available.

Previous studies by Rib and Miles (5) and Tanguay and Miles (6) concluded that infrared imagery cannot be used as a primary source for engineering soils mapping because of its small scale, poor resolution, and lack of stereoscopic viewing capabilities. Its primary value was that it provided supplementary information not obtainable by any other means and converging evidence that aided in the interpretation of soil conditions from the various types of photographs available. Thus, it was decided to study both the 8.0- to 13.5-micrometer band sensed during the day and the night and the 4.5- to 5.0-micrometer band sensed during the night to determine what could be ascertained about those features expected to have water associated with them. After as much information as possible had been garnered from the infrared imagery, the various types of photographs available were examined, and the information interpreted from the 2 types of sensed data was compared.

RESULTS AND DISCUSSION

Surface water had strong emittance during the night because of its relative warmth and low emittance during the day because of its relative coolness; therefore, bright and dark images respectively were on the film strips. Natural and artificial ponding and drainageways containing surface water were easily detected on the night-sensed 8.0- to 13.5-micrometer band. Features that could be observed on black-and-white and Ektachrome color prints, but could not be interpreted as containing water, could be so interpreted on all the night-sensed, infrared imagery but in differing degrees. Color infrared also provided a good indication of surface water.

Soils with a high moisture content were detected in comparisons of the black-and-white photographs and the daytime and the nighttime imagery in the 8.0- to 13.5-micrometer band (thermal infrared). Dark images on the photographs may represent dark colored soils, various types and densities of vegetation, or soils with a high moisture content. On the daytime imagery, relatively dry dark soils have a light-toned image because the dark material absorbs more energy and is at a higher temperature than the lighter colored materials and emits a greater intensity of infrared radiation. Vegetation, surface water, and materials with a high moisture content have dark images because transpiration and evaporation respectively keep the materials relatively cool; thus, they are weak emitters. A check of the various types of photographs can confirm the presence or absence of vegetation, its color (Ektachrome color), and its vigor (infrared color). The absence of vegetation confirms the presence of soils with high moisture content. The presence of vegetation necessitates inspection of the nighttime imagery. On nighttime imagery, relatively dry soils have images of various tones of gray representative of the basic nature of the materials. Water is the lightest because it is relatively warm and emits strongly. Trees are also light but not so light as the water, and the low vegetation remains dark. Therefore, the coincidence of a dark photographic image, a dark daytime thermal infrared image, and a light nighttime thermal infrared image indicates the presence of high moisture content material. Examples of the black-and-white photographs and the daytime and nighttime thermal infrared imagery are shown in Figure 1. Despite some intermittently cloudy and rainy weather for about 2 weeks prior to the December flight and showers the day of the night flight, the floodplain region of the South River was much drier than it was at the time of the April flight.

There was a closed but rather freely draining sinkhole at the northwest end of the traverse. Several of the night-sensed infrared bands contained a medium-gray image that coincided with the location of the sinkhole. This image was best differentiated on the film strip of the 10.0- to 11.0-micrometer band. At least 2 other medium-gray spots coincided with depressions that appeared to result from the same type of collapse associated with sinkholes. A group of 9 irregularly shaped images of a similar gray tone was detected on the 10.0- to 11.0-micrometer band for an area 2 to $2\frac{1}{2}$ miles southwest of the northwest end of the traverse (Fig. 2). There was nothing distinctive about the daytime imagery for this area. The area was somewhat removed from the network of county roads and had not been observed on the ground. A check of the topographic map showed 3 depressions in the area. A field check confirmed that sinkholes and depressions of varying reliefs existed at the sites of 7 of the medium-gray images. The other 2 areas were high on slopes and did not show any depression. Initially it was expected that the depressions would be wetter and warmer than the surrounding areas; thus they would have a stronger emittance and have a lighter gray image than the surrounding, drier and cooler area. The opposite finding might be explained by the occurrence of cavities that insulated the surface from the normal heat flow in the area and caused the depressions to be cooler than the surrounding area. The darker image might also be explained by a higher density of vegetation within the depressions, but no evidence for such an interpretation was found on the Ektachrome color or infrared color prints.

CONCLUSIONS

1. Nighttime thermal infrared imagery, the 8.0- to 13.5-micrometer band, is the best band for the remote detection of surface water. It has great value in establishing water-soil boundaries, determining which drainageways are carrying water, and locating surface water obscured by the image of vegetation on the other imagery and on the photographs.

2. A combination of photographs and daytime and nighttime thermal infrared imagery can be used to detect and delineate soil areas that have a high moisture content. However, currently the principal investigator can detect only zones of extremely high moisture content, such as areas that are in proximity to surface water or areas that coincide with drainageways.

3. It appears that photographs and daytime and nighttime thermal infrared imagery may be used as a guide to the location of subsurface cavities. These cavities cannot be verified by simple visual observation in the field as were the other phenomena, but the sensor data and the presence of sinkholes strongly suggest their existence.

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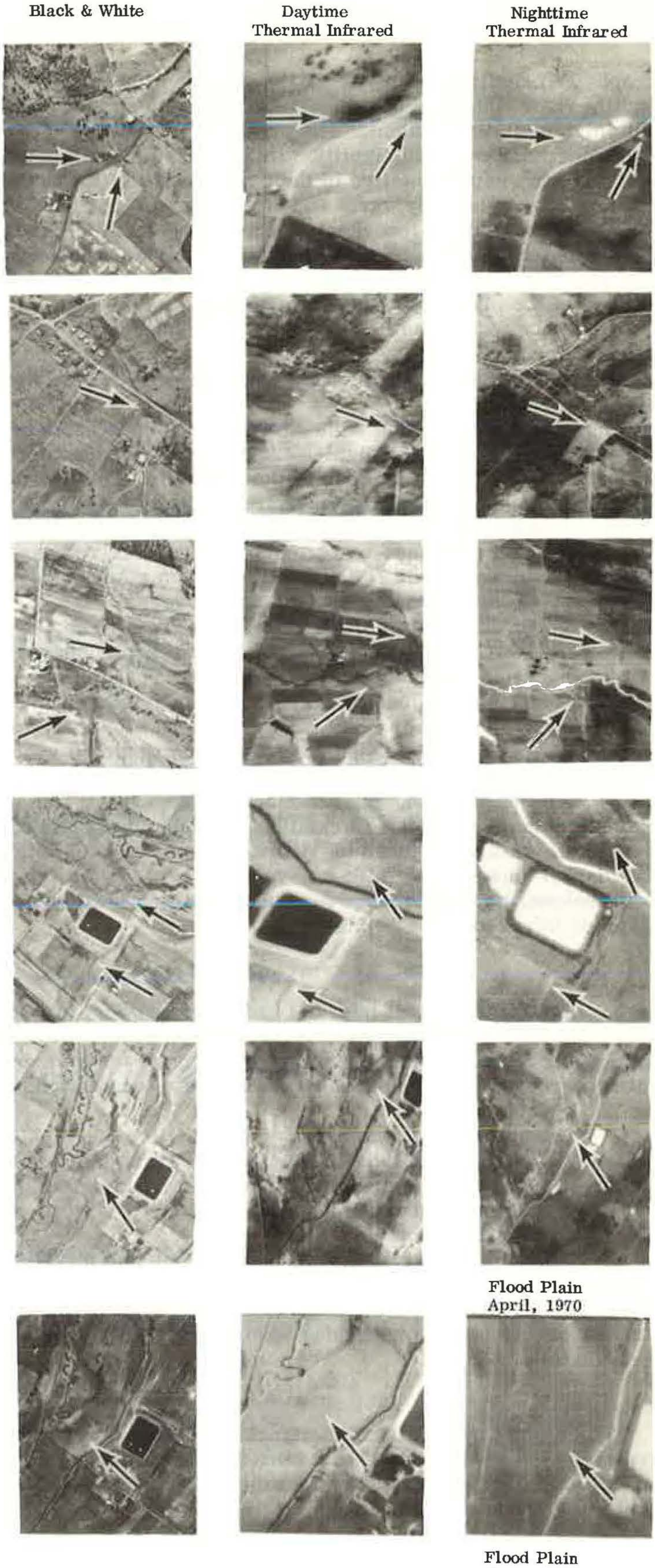
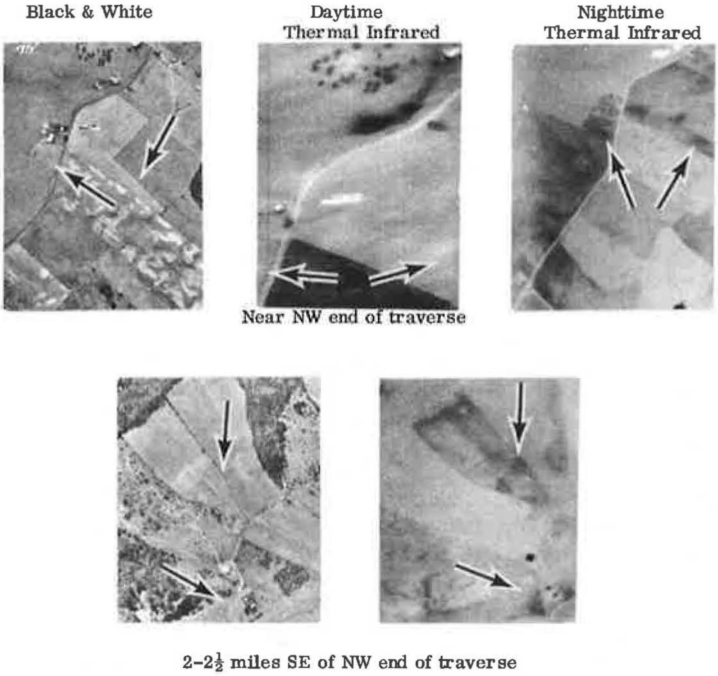


Figure 1. Black-and-white photographs and daytime and nighttime thermal infrared imagery (arrows point to zones of high moisture content).

Figure 2. Gray images that coincided with depressions (arrows point to features).



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