AIRBORNE INFRARED IMAGERY AND ITS LIMITATIONS IN CIVIL ENGINEERING PRACTICE

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•THE RANGE of airborne infrared imaging technology has been greatly expanded in the past decade to include an ever diversifying number of uses. Literature regarding applications abounds, but few authors have addressed the problem of the limitations of the technique.

This paper discusses specific limitations of the infrared imaging technique. Of prime interest is what infrared cannot do for the civil engineer under present state-of-the-art technology. The discussion is divided into the two general categories of geological and hydrological limitations and is based on the experience derived from operational airborne infrared imaging surveys performed since 1963. Comments are limited to information derivable by interpretation from film or positive contact prints of infrared imagery. Generalizations made are meant not to be sweeping statements but to apply only to the specific environments sampled on data collection flights.

GEOLOGICAL LIMITATIONS

As a result of test-flying the various models of RECONOFAX, the line scan infrared imaging systems manufactured by HRB-Singer, Inc., at State College, Pennsylvania, during the past 20 years, this central Pennsylvania region has become one of the most imaged areas in the world in terms of hours of repeated coverage. The area has been flown at all times of the year, both at day and at night, at many different altitudes, and with many different detectors. In addition to this locality, a variety of other geological terranes have come under investigation in the course of contractual projects, primarily in the eastern United States and Canada. Several of these localities will be cited in this paper along with the State College, Pennsylvania, region as examples for the limitations discussed.

State College, Pennsylvania, lies in the Nittany Valley, a predominantly limestone valley surrounded by sandstone ridges with shale slopes. It is a humid region and possesses a soil regolith with a deciduous vegetative cover. The valley is extensively farmed and contains the major population centers of the region; the ridges are wooded. Figure 1 shows a high-altitude daytime infrared image that illustrates this typical ridge and valley topography.

Lithologic Differentiation

No lithologic differentiation has been positively demonstrated on infrared imagery in the State College region. Although in an early paper Lattman (8) indicates that the tonal changes seen on Nittany Mountain are coincident with the contact between a sandstone and a shale, he recognizes that this effect is primarily due to difference in slope and in vegetative cover.

A comparison of imagery and geologic map (Fig. 2) illustrates these interrelations. Figure 3 shows a parallel pass stereo image of synclinal Nittany Mountain. The tonal change follows the ridge crest and not the actual mapped zone of contact in many places. Similar slope-related changes occur in an anticlinal mountain (Fig. 4) where the same sandstone forming the crest of Nittany Mountain here occupies the slope. Although the slope is now sandstone instead of shale, the same warm tone prevails.

Soils differentiation on infrared imagery has not been successful in the Nittany Valley. The masking effect of farmland field patterns and vegetative cover is usually complete.

Figure 1. High-altitude thermal image of typical ridge and valley topography near State College, Pennsylvania, May 5, 1961, 10,000 ft m.s.l., 9:30 a.m., InSb detector.

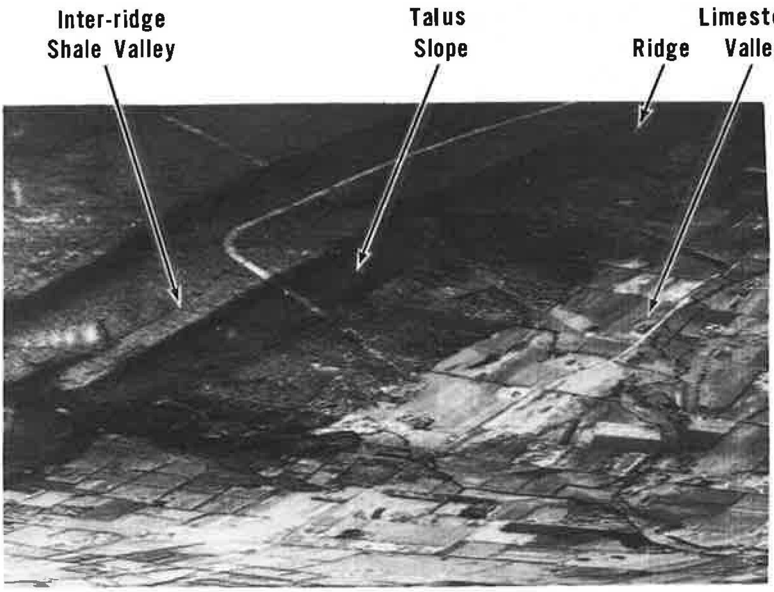


Figure 2. Comparison of thermal image and geological map of Nittany Mountain, October 21, 1959, 5,000 ft m.s.l., 9:30 p.m., InSb detector (O_r = Reedsville shale, and O_o = Oswego sandstone).

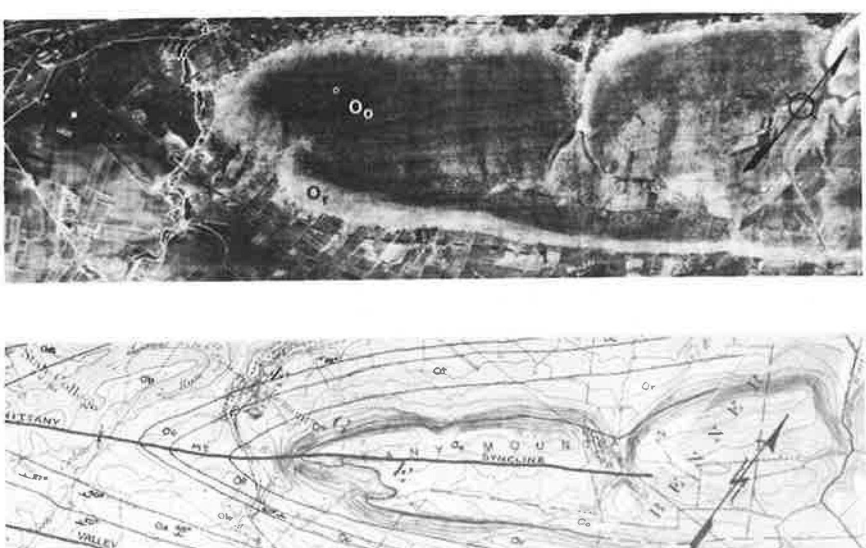


Figure 3. Stereo imagery of Nittany Mountain, October 21, 1959, 9:30 p.m., 5,000 ft m.s.l., InSb detector.

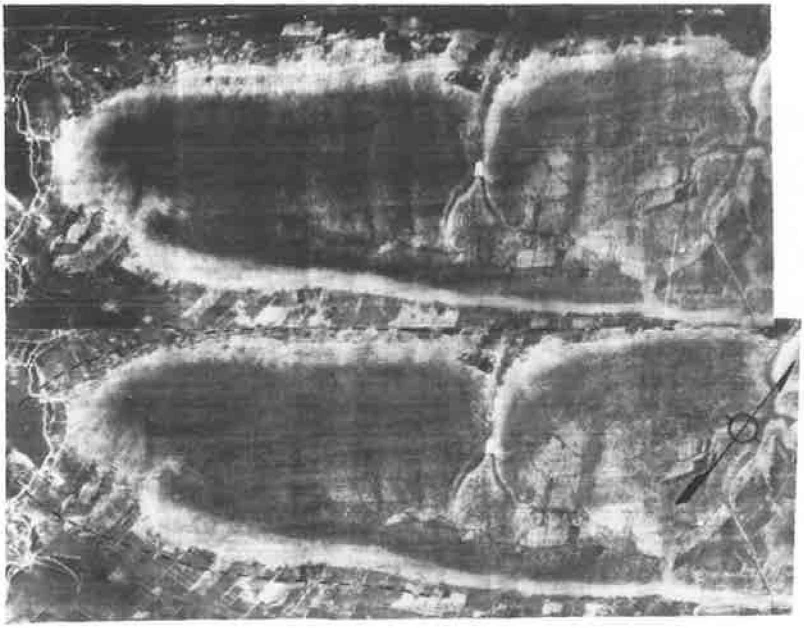
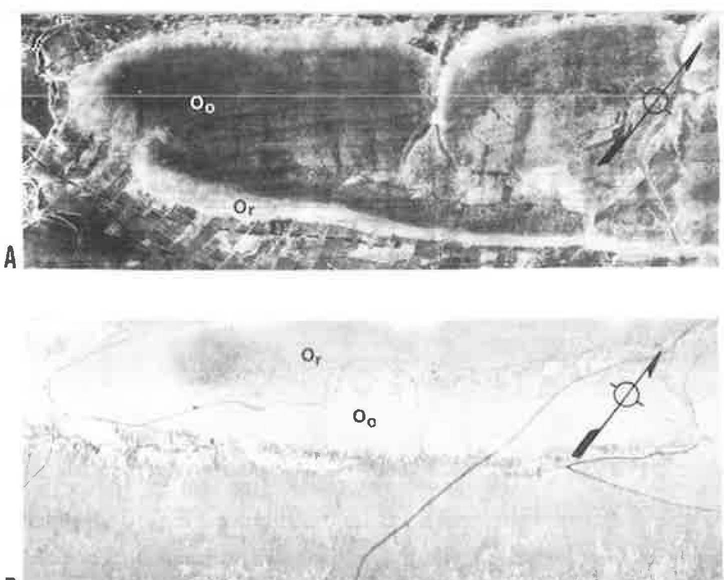


Figure 4. Comparison of thermal imagery of a synclinal versus anticlinal mountain: (a) October 21, 1959, 5,000 ft m.s.l., 9:30 p.m., InSb detector; and (b) January 23, 1967, 3,800 ft m.s.l., 6:17 p.m., InSb detector (O_r = Reedsville shale and O_o = Oswego sandstone).



Humidity and attendant vegetation seem to be critical factors in determining capability for lithologic differentiation. Although Rowan et al. (11) were able to differentiate limestone from dolomite in Oklahoma, no such success has been achieved in the Nittany Valley or at other locations in the eastern United States. It has been by experience that distinct marker beds appear on infrared imagery only when they are also visible on aerial photography either because they are in outcrop or because they are marked by aligned vegetation or exhibit topographic expression.

Void Detection

Evidence of natural caves has not been evident on infrared imagery of the limestone valleys although several known caves were overflown. Extensive use of imagery in searching for buried mine portals, tunnels, and the mines themselves in the bituminous coal fields of western Pennsylvania have all yielded negative results (2).

The use of infrared imagery to find solution cavities beneath the Anchor Reservoir in Wyoming, through which water was being lost, was unsuccessful as a direct method (12). The study was performed while the reservoir was drained, and no surface manifestations of underlying voids were detectable.

In the search for sinkholes, infrared imaging has not proved to be significantly better than aerial photography for detection and positive identification. Suspected sinkholes located in infrared imagery, in most cases, must be checked on stereophotography for positive identification.

Gas Leaks

The use of infrared imagery to detect natural gas leaks in buried transmission lines in New York proved successful only because detection was made of affected vegetation and not of the gas itself (3). Gases, having very low emissivities, are nearly transparent to the infrared detector. Detection, if any, is usually of particulate matter.

Mineral and Petroleum Exploration

Direct imaging of subtle thermal anomalies associated with near-surface oxidizing metallic ore deposits has not been demonstrated successfully in humid climates. Attempts at correlation of near-surface termperature patterns caused by internal heat flow with the disposition of subsurface structures that have heat conductivities different from their immediate environment were unsuccessful in desert climates (10). Friedman (4) has shown that the infrared scanner depicts surface emission directly and heat mass transfer from depths only indirectly and at a threshold level 50 to 100 times the normal conductive heat flow of the earth.

Thermal inertia and solar reflection in minerals are properties claimed to be detectable (5) by an infrared imaging system providing the mineral deposit is exposed at the surface, the outcrop is large enough to be resolvable, and a contrast exists between these properties in the mineral and its surroundings. This may be possible in arid and semi-arid terranes but has not been realized in the more humid climates.

Oxidation of pyrite in strip mines in southeastern Ohio has produced temperature anomalies ranging from 3 to 8 C at a depth of 2 ft (1). Radiant flux calculations theoretically indicate that these areas are mappable with an infrared scanner under favorable conditions. In practice, however, no success has yet been conclusively demonstrated by using infrared imagery. The report in question (1) derived results from interpretation of infrared imagery flown during daylight. The effect of sunlight on a strip mine surface is sufficient to mask any anomaly resulting from an oxidizing mineral.

Subsurface Mine and Coal-Seam Fires

Deep fires in coal seams where overburden of more than 50 ft is present have not been successfully mapped in Pennsylvania (6). Shallow seam and outcrop burning are, however, readily detectable (14). An extensive survey of the burning coal refuse piles in the anthracite region of Pennsylvania (7) has revealed a number of outcrop mine fires. In all instances, however, burning could not be traced much beyond the outcrop.

Experience has shown that useful imagery of subsurface fires is not obtainable at altitudes greater than 10,000 ft above terrain or where ground resolutions exceed 10 ft square. Useful imagery is also not obtainable when direct sunlight is shining on the bank. Data collection flights are scheduled for night, twilight, or cloudy days.

HYDROLOGICAL LIMITATIONS

In this category, surface water and groundwater are included, and the main limitations are in water quality determinations and in shallow aquifer exploration.

Water Quality

Although an excellent technique for detection of thermal differences in water bodies, infrared imaging provides little direct data on water quality. Effluents may be described in terms of radiation temperature differences that in many cases are emissivity related. In acid mine-water discharges, temperature of discharging waters is sometimes relatable to water quality. If this is the case, then the availability of quantitative data such as calibrated imagery or supplemental radiometer data can prove effective in the comparison of temperatures of natural springs in acid-free terrain with those of discharging mine waters. If there are no quantitative data, the relative tones depicted on infrared imagery are usually too subtle to differentiate acid from non-acid waters.

Shallow Aquifer Detection

The search for groundwater in the presence of shallow aquifers has been investigated by O'Brien (9) in New York State. Definite temperature anomalies exist below the surface but were not visually present on infrared imagery of the surface.

An early use of infrared imagery (13) in the search for a buried glacial channel suspected of transporting water from the St. Lawrence River to the Ottawa River near Vaudreuil, Quebec, provided negative results although some evidence for possible emergent waters was observable in the Ottawa River itself.

PRACTICAL APPLICATION

As an illustration of the practical use of infrared imagery and its limitations, I cite 2 recent projects, both in the Appalachians, completed for engineering concerns involving airborne infrared imagery: One was a survey of a proposed highway route, and the other was a survey for a reservoir site.

For the highway site, the primary feature sought was potential landslide areas. These were identified by the delineation of seepage areas as they appeared on the imagery, and cross faults were identified by displacements in these seepage zones. No lithologic differentiation was made. The detection of seepage zones in this case was enhanced by the data collection survey being flown during the late fall, at night, and with air temperature well below groundwater temperature. Under these conditions, groundwater seepage appears as white (warm) tones against a dark background, which makes optimum the interpretability of the image.

For the reservoir site, the same environmental criteria were used to determine the time and the date for data collection. Here springs, sinks, faults, and landslide areas all were of interest. In this area, underlain partially by metamorphic and sedimentary rock, again no lithologic differentiation was possible. Optimum detection of springs and seepage zones was realized together with some success in tracing a fault zone.

In both areas the infrared excelled in depicting surface water and moisture-related linear geologic features. Soils and lithologic differentiation were not possible.

COMPUTER PROCESSING

The trend toward taping airborne infrared signals in order to retain their full range shows some promise in attacking those areas lying at or close to threshold levels of signal/noise. Digital processing of calibrated signals permits great flexibility in

Figure 5. Computer-generated gray scale slices of a coal refuse pile fire in Pennsylvania (slicing is illustrated at discrete voltage levels that can be converted to radiation temperatures).

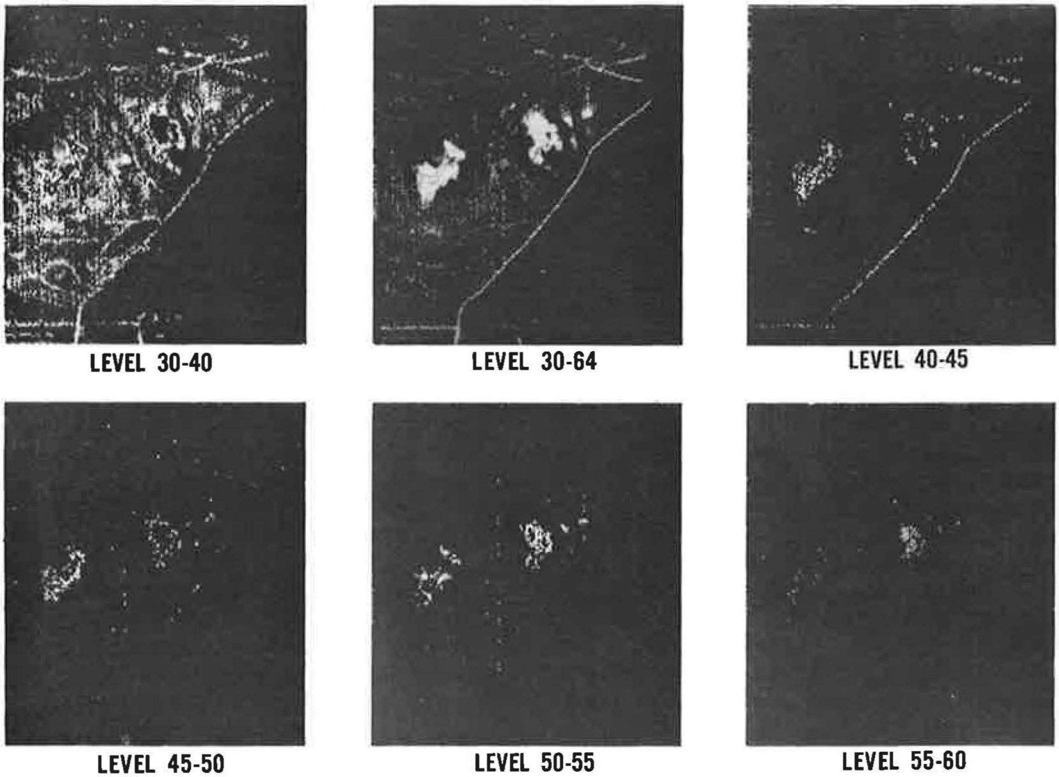


Figure 6. Computer-generated thermal contour lines overlaid on a thermal image of a burning coal refuse bank in Pennsylvania.

handling the data. The individual investigator may experiment on different voltage levels, equivalent to calibrated radiation temperatures, and apply computer programs to glean data heretofore beyond the retrieval level of the human eye. As an example, detail in a coal refuse pile fire can be reconstructed by gray level slicing techniques, and a contour map can be automatically produced by the computer (Figs. 5 and 6). This detail is usually obscured on infrared imagery by the excessive heat of the fire area exceeding the dynamic printing range of the film. Work is currently being done on extending these techniques into some of the areas discussed as limitations in this paper.

SUMMARY

The information available from infrared imagery is limited for certain geological and hydrological applications. At best, it is a marginal technique in the following areas of interest to the civil engineer and geologist: lithologic differentiation including soils in humid climates, subsurface void detection, gas detection, mineral and petroleum exploration, deep mine fire detection, water quality investigations, and shallow aquifer exploration in humid climates.

The technique is, in practice, limited to detection of surface thermal phenomena or subsurface manifestations that are carried to the surface and are present at threshold levels greater than the noise level of the system or interference levels of masking features or both. For those areas of marginal usage discussed, infrared imagery may be useful in conjunction with, but never without, a good aerial photograph.

Some promise is noted, however, in digital processing of infrared signals to glean data from near threshold levels. Computerized analysis programs may be able to retrieve data currently beyond the retrieval level of the human interpreter.

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