The next step of the project will be the repetition of the entire survey to demonstrate the replicability of the results. The ground survey will be repeated by methods which will provide an expected accuracy of 1 part in 300,000 or a standard error in position of 3 mm., and the test area will again be photographed this spring. The original and the new photography will be adjusted to the new control positions, and the variations in the positions of the located points will be observed.

Beyond this, new control surveys will be made and the test area will be rephotographed at regular intervals, measured, and examined for systematic changes in positions, particularly across the fault line. Any appreciable movement across the fault detected in the more frequent short line measurements of Phase I will be followed immediately by a new photogrammetric survey.

Several lines of investigation will be followed in the study of precision photogrammetric methods. The block adjustment will be recomputed, once using ground targets alone as pass-points and again using points marked by the Wild PUG alone. In a study of comparative measuring techniques, the current photographs have been remeasured using a Wild STK-1 stereocomparator, and data processing is now in progress. Another line of study is displacement due to image flare and the possible mathematical compensation thereof. Several possible modifications of operational techniques have been proposed and will be tested to determine their effect on precision.

Conclusion

The results of this survey demonstrate that photogrammetric methods are capable of determining the positions of points with an accuracy rivaling that of traditional ground-survey methods, and are adequate for the determination of appreciable, systematic earth crustal movements. The techniques employed will certainly find application in other fields requiring the location of a large number of points, such as cadastral surveys, highway planning, etc.

As the surveys are repeated and more refined techniques evolved, further reports on results and methods may be expected.

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*Infrared Geology**

JOHN L. CANTRELL,
Texas Instruments Incorp., Science Services Div.,
P.O. Box 35084,
Dallas, Tex. 75235

(*Abstract on next page*).

Introduction

It is well known that aerial photography has proved an excellent tool for collecting geologic information. Various camera configurations and multitudes of film/filter combinations have been used to take advantage of different portions of the visible, near-infrared, and ultraviolet portions of the electromagnetic spectrum. However, these systems are restricted to an extremely small portion of the electromagnetic spectrum, generally from 0.3 to 1 micron, because of the limited spectral response of film emulsions.

In the last decade, the military has been continuously developing classified infrared mapping systems using long wavelength detectors for surveillance and target acquisition purposes. It is the author's intention to show by example how longer wavelength infrared imagery could aid in geologic reconnaissance.

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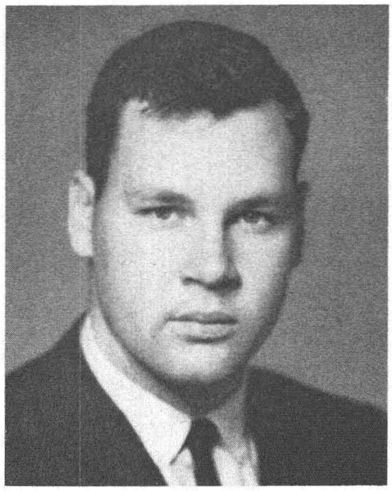
Long wavelength systems should not be confused with shorter wavelength infrared photography.



JOHN L. CANTRELL

Nature and Characteristics of Infrared Radiation

Infrared is that portion of the electromagnetic spectrum bounded on one side by the visible portion of the spectrum and on the other side by microwaves used for high resolution radar. The infrared portion is here divided into three regions: near infrared (0.7 to 1.35μ), intermediate or middle infrared (1.35 to 5.5μ) and the far infrared (5.5 to 1,000μ).

The primary source of natural radiation is the sun. As solar energy impinges upon the surface of the earth, it is either absorbed or reflected. Objects with temperatures above absolute zero which absorb radiation tend to increase in temperature, then re-emit this energy mostly in the infrared portion of the spectrum. Objects which absorb all incident radiation are termed black bodies; however, since a perfect black body does not exist, all materials are considered in terms of degree of "blackness," or gray bodies.

ABSTRACT: *In the not too distant future geologists and, in particular, photogeologists will have a new remote tool—infrared imagery—to aid in solving geologic reconnaissance problems. By comparing airborne infrared imagery with aerial photography, unique information can be obtained about the earth's surface features.*

The military is continually developing infrared imaging systems for suveillance and target acquisition purposes; but only recently have geologists discovered the value of these systems for their purposes.

Interpreters of infrared imagery for geologic purposes must be fully aware of the physical phenomena involved in generating infrared imagery. They must recognize the fact that infrared imagery is created primarily by emitted energy and not reflected energy as in conventional photography.

Systems

There are several types of scanning systems available for generating infrared imagery. Basically, their components are the source of radiant energy (in this case, the earth), the media through which energy is transmitted, the optics and scanner unit, radiant energy detectors, signal processing and image presentation units. Present day IR imaging systems are classified as "passive" where the natural radiation of an object is used as the energy source for image generation. The optical system may be a lens or mirror and collecting optics for directing object-emitted energy to the radiation sensitive detector element. This semiconductor element converts the infrared energy for eventual display as visual signals on a cathode ray tube glowbar or other visible energy source. Photographic film is pulled across an exposure slit by a film drive mechanism operating at a rate proportional to the forward speed and altitude of the aircraft resulting in a strip film presentation, (Figure 1).

The factors for recording long wavelength infrared imagery are the wavelengths (for geologic purposes, maximum earth emissions), infrared energy transfer through the atmosphere, and spectral sensitivity of the detector (Figure 2). Reflected solar energy is normally less desirable than emitted energy because emittance indicates better the physi-

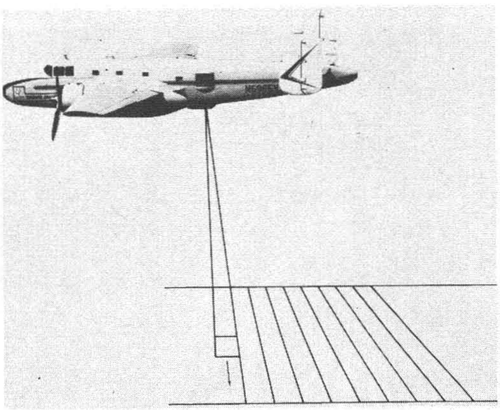


FIG. 1. Illustration of airborne infrared scanning.

cal character of terrain materials. The earth's surface emits in the longer infrared wavelength region with the majority of surface emission at ambient temperature falling between 5 and 20 microns as illustrated in Curve B. Solar reflections peak at approximately 2 microns. Spectral filtering will separate reflected radiation from the object emissions on daytime missions as indicated by the shaded area on the left (Figure 2, Curve B).

ATMOSPHERIC TRANSMISSION

Infrared transmission through the atmosphere, as illustrated in Curve C (Figure 2), is of primary importance in infrared imagery. Although obtaining infrared imagery is possible on a 24-hour basis, the constantly changing atmosphere will affect the infrared radiation from the earth's surface to the system. Attenuation of radiation is produced by absorption and forward scattering by carbon dioxide, water vapor, clouds and fog. This effect is not constant across the infrared spectrum as "windows" or areas of peak transmission are present. "Windows," however, are not perfectly transparent—80% transmission would be more correct. Also, they are not sharply defined and gradually fade out rather than exist as an abrupt decrease in attenuation. The two primary "windows" considered for infrared imaging are at 2–5μ and 7–14μ. The most important "window" concerning the infrared geologist exists at 7 to 14 microns, the region of maximum terrain emission and minimum natural reflection. The "window" is bounded on the short wavelength side by water vapor absorption at approximately 7 microns and long wavelength side by carbon dioxide absorption bands centered at 15.0 and 16.2 microns. A "window," then, is defined as an area of least attenuation across the infrared spectrum.

Topographic features on infrared imagery will vary in tone by the constant interplay in the heat budget of the earth's surface. Figure 3 illustrates the factors affecting the earth's surface heat balance which varies continually with time of day. During the day, direct solar radiation and some sky radiation raise total surface temperature. Evaporation and convection are the only two phenomena associated with the surface during hours of insolation.

At night as the surface begins to cool, this heat balance shifts through effective outgoing radiation, radiation absorbed by the atmosphere and, to a small extent, evaporation. Back radiation from the atmosphere and thermal convection energy are returned to the surface. Dew will form through the interaction of such a warm return flow where moisture contacts the now relatively cooled surface. Most of the energy yielded by the surface is considered a major contributor to the heat balance except back radiation from the atmosphere on cloudy nights. In such cases it will tend to make the surface temperature more uniform.

With all of these interchangeable factors, it is obvious that certain meteorological conditions must be recorded simultaneously with time of the mission. Temperature, humidity, wind direction and velocity are among the

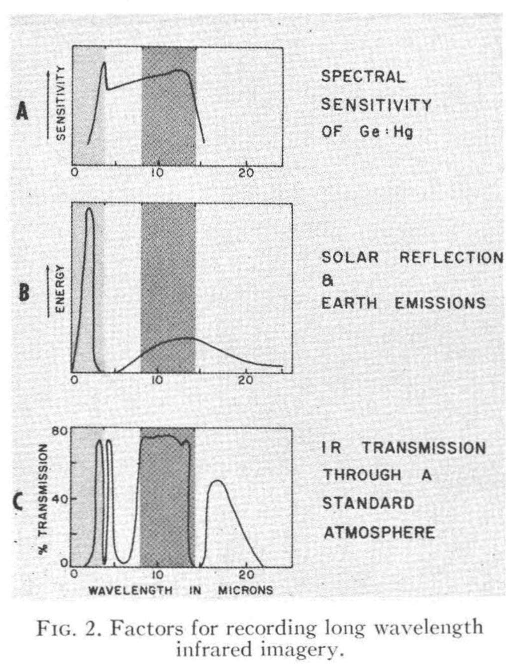


FIG. 2. Factors for recording long wavelength infrared imagery.

most imagery-influencing conditions to be monitored.

Infrared reconnaissance mission schedules, though influenced primarily by mission requirements, are generally designed to take advantage of peak periods of emission, a fact pertinent to infrared geology. Immediately after sundown, when the earth's surface is at highest relative terrain emission with absence of reflection, appears to be an appropriate time for imagery collecting for obtaining signatures of different rock types. However, for certain types of reconnaissance it is desirable to collect imagery during daylight, since shadowing enhances terrain definition.

INTERPRETATION

Infrared imagery has the appearance of low resolution photography but the similarity ends there. An individual attempting to interpret infrared imagery for extracting geologic data must be fully aware of, and understand, the inherent characteristics affecting the imagery. Certain detectors can actually discriminate between terrain materials having radiometric temperature differentials of a fraction of a degree. However, it should be recognized that other limiting factors exist (e.g., inherent gray scale latitude of the recording film and cathode ray tube response), therefore, terrain materials may appear to the interpreter to have the same radiometric temperature on film (same tone), but actually there could be differences of several degrees. Microdensitometers have been particularly useful in discriminating between objects exhibiting nearly the same temperature and emissivity product. An interpreter must realize that infrared imagery is created by emitted energy and not reflected energy as in aerial photography. Although infrared will extend an interpreter's capability, it should be considered at this time as a supplement to conventional photography.

Figure 4 is an aerial photograph of North Lake with the North Lake Power Plant, Dallas, Texas. The reservoir was built specifically to cool hot effluents from the plant's condensers. Water is expelled through the canal into the lake for cooling and then recirculated. Densitometric analysis of infrared imagery performed by Texas Instruments indicates certain deficiencies of the present canal arrangement. The area containing the warmest water is designated 1, with 5 being the coldest. It appears area 4 would be colder than 5 since it is the greatest distance from the plant, but it was found to be the shallow part of the lake. Infrared imagery taken at other times suggests that wind direction and velocity were the primary factors determining witnessed thermal patterns. This illustration of the system's sensitivity to thermal gradients of

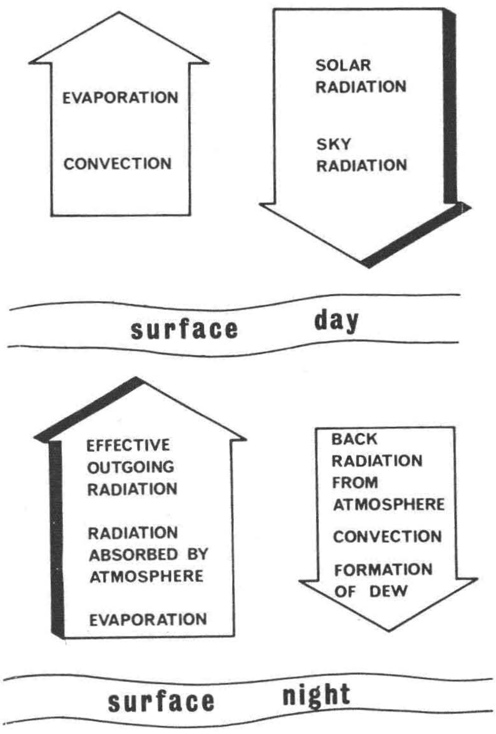


FIG. 3. Some factors affecting the earth's surface heat balance.

FIG. 4. Illustration of thermal pattern of North Lake, Dallas, Texas.

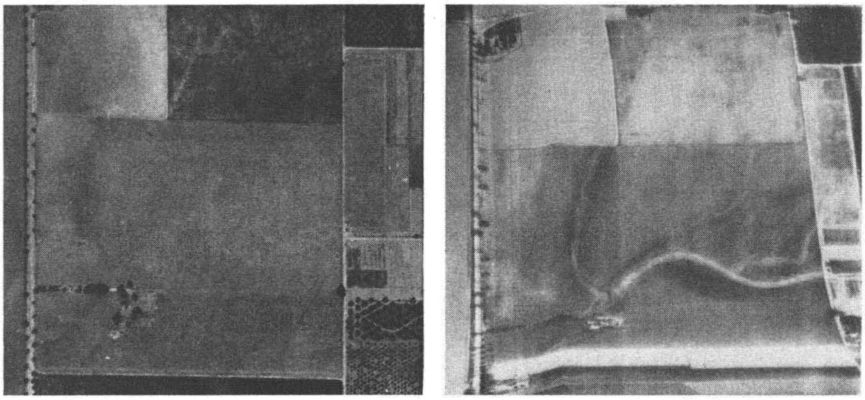


FIG. 5. Comparison of conventional photography with infrared imagery.

water indicates how the system could aid in locating thermal springs and be useful for pollution and sedimentation studies.

Infrared image collected near Fort Worth, Texas, reveals near-horizontal sedimentary stratification and well-defined drainage patterns (Figure 6). It should be emphasized that because it was recorded at night only the terrain emissions are being recorded, and bedding is apparent because of differences in emissivity between terrain materials. Note the lake is located in the background and field patterns on the left.

The photograph (left) in Figure 5 is a vegetation test plot located at the University of California near Davis, California. In preparing this field for controlled test plots many years ago, a meander scar was filled. Close observation of the aerial photograph taken 60 days previously reveals only slight indications of this scar. The infrared imagery (right) shows it very distinctly even though evidence of the channel by ground checking was meager.

Infrared imagery can indicate even slight differences in soils and soil moisture capable of influencing vegetation growth. For example, the dark-toned area around the drainage pattern represents higher moisture content, which in this case, lowers the total radiometric temperatures. The light-toned area represents the original stream bed and is probably more compact and contains finer soil particles which possibly alters the emissivity of the soil.

Infrared image of an area 30 miles north of San Francisco, California (Figure 7) shows a hilly area covered with grass and shrubs. High radiometric temperature, primarily from grass cover, would tend to block out lower radiometric temperatures of the terrain material, thus making it impossible to discriminate any secondary geologic features (e.g., stratification). For geologic purposes, nighttime reconnaissance is more desirable in this area.

Figure 8 shows an infrared image of Mt. Pisgah near Hector, California. The cinder cone and contact between different age and types of basaltic lava flows is apparent. A

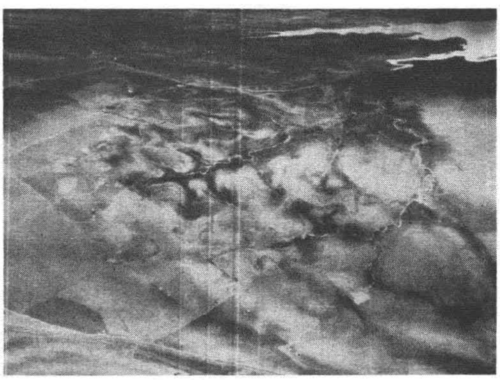


FIG. 6. Infrared imagery of drainage pattern and stratification.

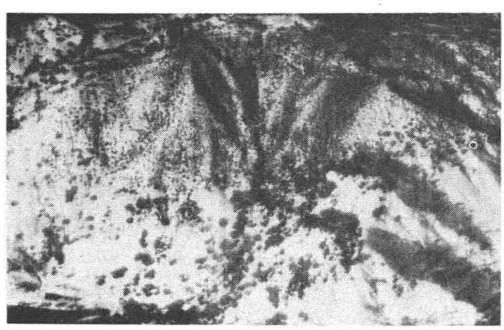


FIG. 7. Infrared imagery illustrating topographic relief.

FIG. 8. Infrared imagery of Mt. Pisgah (inactive volcano) near Hector, California.

smaller cone is observed above the large cone and several pipelike bodies are evident. Although this is an inactive volcano, infrared reconnaissance has proven to be an excellent tool for recording active volcanic features.

The photograph at the left of Figure 9 is of Meadow Valley near Quincy, California, and the other is an infrared image of the same area. The light-toned area is a partially wooded serpentine formation and its contact with the surrounding basaltic soils is quite apparent. Drainage patterns are well defined and a marshy area is identified by the dark area in the lower center of the imagery. This illustrates how infrared will supplement conventional photography in tracing contacts and drainage patterns.

Surface water is an excellent object for infrared imagery as illustrated in Figure 10. A distinct and finely detailed drainage pattern containing some water is observed (Figure 10a). Most important is that details are apparent even when the drainage is obscured by vegetation as illustrated in Figure 10b. Infrared imagery is not being recorded through vegetation as it measures only surface ener-

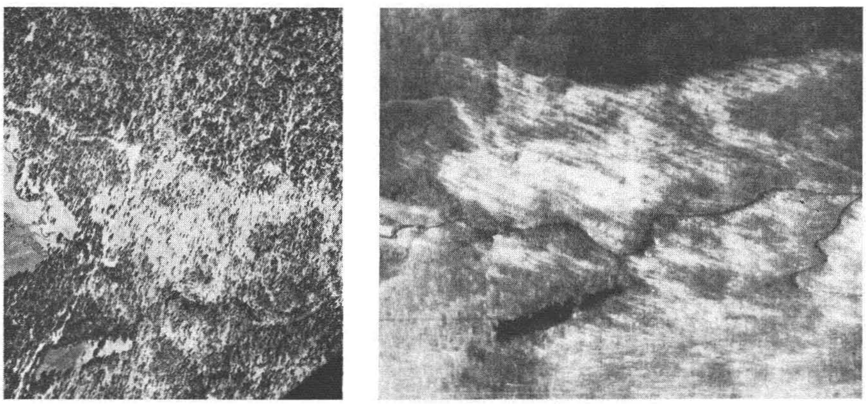
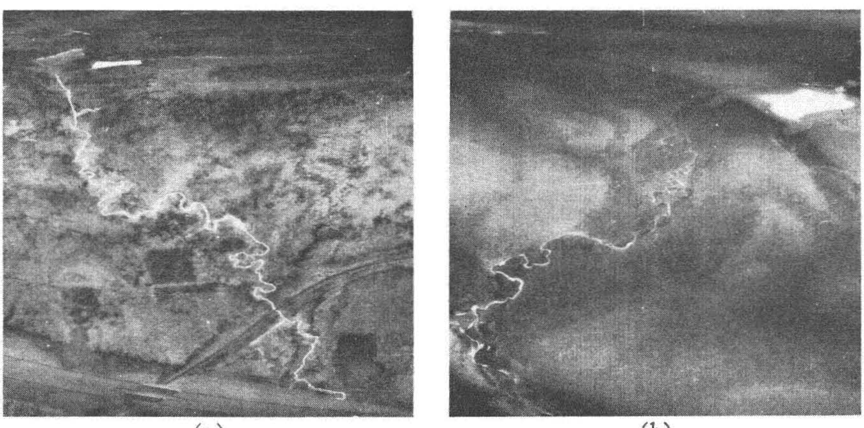


FIG. 9. Comparison of conventional photography with infrared imagery illustrating topographic features.



(a) (b)

FIG. 10a. Infrared imagery illustrating finely detailed drainage pattern.

FIG. 10b. Infrared imagery illustrating drainage pattern which would be obscured on conventional photography.

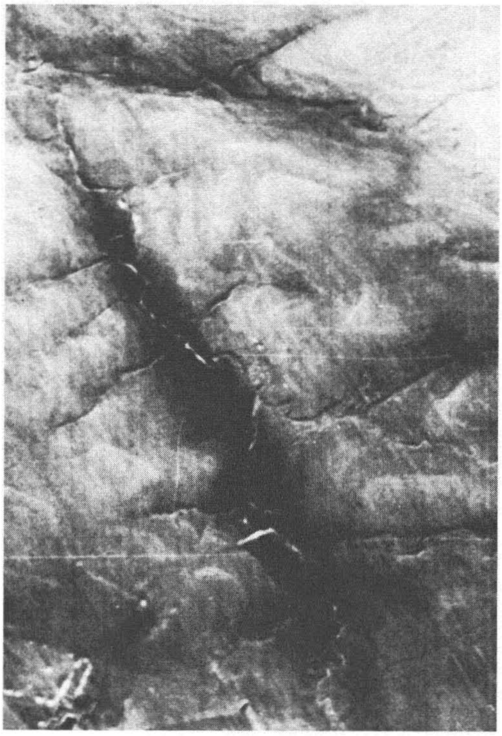


Fig. 10c. Infrared imagery illustrating dendritic drainage.

gies radiated. The explanation is that as water or moisture in the stream begins cooling, the heat rises (effective out-going radiation) and tends to warm the overhanging vegetation and air column beneath and in the tree crowns. This forms a "heat sink," in effect superimposing the drainage pattern on the vegetation.

Collecting imagery for interpretation of geologic features through vegetation should be done on still nights, as wind tends to smear and erase this effect. This infrared system performance could possibly revive the practice of geologic interpretation from drainage patterns, making available information which is normally denied the geologist by overhead cover in the visible spectrum.

This infrared image in Figure 10c illustrates dendritic drainage. The steam contains little water; but the dark area around the pattern suggests higher moisture content. Stratification in the near horizontal sedimentary formation is also apparent. The northwest trending streaks are caused by a combination of high humidity and wind.

Figure 11 is an infrared image near Hinds Springs, Nevada, illustrating jointing. Joints will create surface depressions and collect moisture which will lower the radiometric temperature.

Conclusions

Application of longwave infrared reconnaissance to geologic purposes has only recently been recognized. Although distinct boundaries have not been established, the following is apparent:

1. Interpretation of infrared imagery is extremely complex and an interpreter must be aware of and understand the inherent characteristics influencing this imagery.

(*Continued on page 941*)

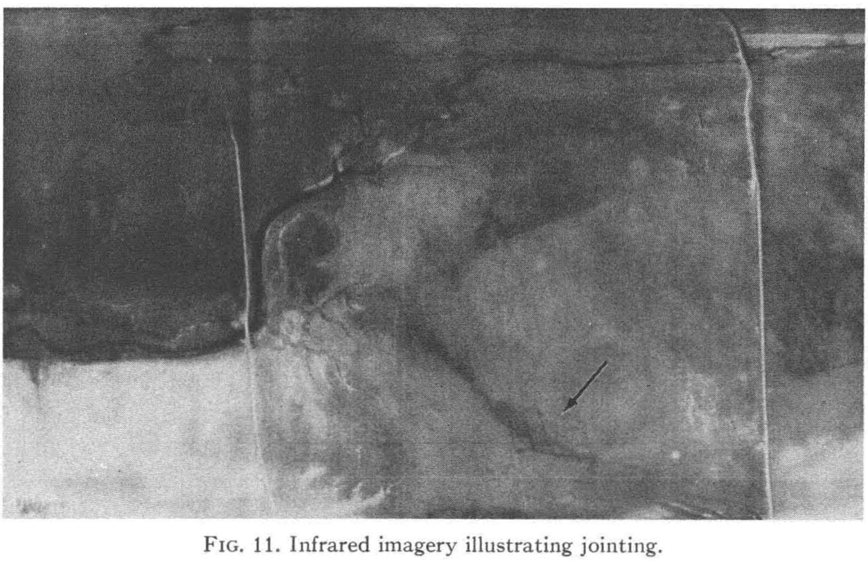


Fig. 11. Infrared imagery illustrating jointing.

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ABSTRACT: *Difficulties in the study of coastal engineering arise from the inadequate means of investigation and the content of data thus obtained. Basic requirements call for coverage of coastal mechanism as simultaneous recordings of waves, currents, topographies, etc., with alongshore as well as perpendicular extensions. A new method, as proposed in this paper, is based on the use of aerial photogrammetry. This paper reviews the historical background of the use of aerial photogrammetry for purposes of coastal investigation. Discussion is presented on the advantages of aerial photographic method in the study of shallow water topographies, rhythmic reliefs. Technical problems and suggestions are made with an outlook to develop aerial photographic methods as routine instruments for coastal investigation.*

Infrared Geology (continued from page 922)

2. Moisture in terrain materials will alter the radiometric temperatures considerably, making infrared an excellent tool for tracing drainage patterns.
3. "Geothermal" features (e.g., thermal springs, active volcanoes) make excellent targets for infrared systems.
4. Underground anomalies are detectable through their surface manifestations (e.g., near-surface salt domes).
5. Surface materials can be distinguished because of differences in radiometric temperatures (e.g., sandstone versus limestone), thus allowing tracing of structural patterns.
6. The most desirable time of day for scheduling general infrared mapping missions appear to be immediately after sundown. This is the period of highest relative terrain emissions. However, daytime imagery records shadowing much like conventional photography and tends to enhance terrain features.
7. Detectors sensitive to the 7–14 micron range are preferred as this range covers the peak emissions of ambient surface materials.
8. Long wavelength infrared imagery should be considered as a prime supplement to conventional photography.

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