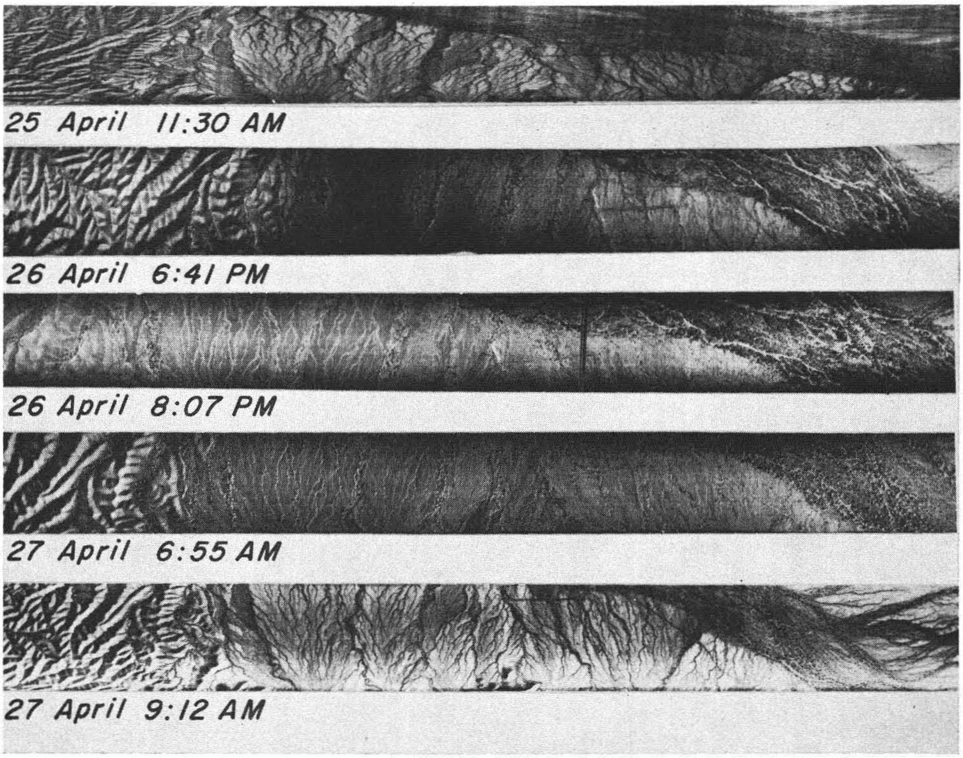

FIG. 1. Infrared thermal imagery illustrating diurnal changes during early summer for a desert terrain near Yuma, Arizona.

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# Infrared Thermal Sensing

## The imagery can contribute qualitative information about terrain and sea-ice features.

*(Abstract on next page)*

IN THE PAST SEVERAL YEARS, much progress has been made in developing infrared thermal sensing† and its application in mapping the earth's surface features. The purpose of this paper is to illustrate this progress by discussing some applications of infrared sensing in three different environmental situations.

The techniques of terrain mapping by use of infrared radiation has been described in papers published in PHOTOGRAMMETRIC ENGINEERING (Harris and Woodbridge 1964) and (Cantrell 1964).

The U. S. Army Cold Regions Research and Engineering Laboratory has been con-

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† Infrared thermal sensing refers to the line scanning techniques using infrared scanners with detectors. The illustrations shown are true thermal images; i.e., the imagery was obtained using selected portions of the 3- to 14-micron region of the spectrum. This should not be confused with infrared photography.

ABSTRACT: *In the past several years, much progress has been made in developing infrared thermal sensing and its application in terrain analysis. Infrared imagery does portray terrain features; however, to interpret the imagery properly it is necessary to know the time of day and conditions under which it is obtained. Diurnal changes can create thermal pattern reversals. Infrared imagery is useful in inventory of hot springs and water resources. Sea-ice reconnaissance can be conducted by use of infrared sensors during periods when visual observations and photography cannot be obtained.*

ducting airborne infrared sensing since 1958. Most of this work has been conducted jointly with the Infrared Physics Laboratory, Institute of Science and Technology, University of Michigan. This work has been conducted over a variety of environmental conditions including tropic regions, deserts, and arctic regions.

In the spring of 1961 a study, called Operation Hot Deck, was conducted; this consisted of a series of aerial missions over selected natural high temperature terrain features. The next few illustrations show some of the imagery obtained during this study.

Figure 1 is representative of infrared imagery of desert terrain near Yuma, Arizona. This figure is presented mainly to demonstrate two findings: (1) the imagery does discriminate major terrain features such as an eroding terrace, an old alluvial fan (covered with desert varnish), a major wash, and roads and trails; and (2) that to interpret infrared imagery it is necessary to know the time of day and the conditions under which it is obtained. Conditions affecting the interpretation are temperature, sky condition (clear or overcast), ground fog, and rainfall just prior to obtaining imagery. The five strips in Figure 1 were taken at various times of the day and illustrate what the diurnal changes can do to the imagery. Note the tone reversals between the center of strips 3 and 5. Strip 3 was taken during the night and the central portion which consists of an old alluvial fan, with the flat original surface covered by desert varnish, is shown as a cold surface while the gullies show as warm. In strip 5, taken at 9:00 A.M., the surface covered by desert varnish appears very warm and the gullies appear very cold. Vegetation in the wash appears warm at night and cold during the day.

In several areas of the world hydrothermal features are used as sources of power, or are potential sources of power. In such areas it is necessary to maintain an inventory of these features to locate new sources and to know which features may be decaying. At present this is conducted mainly by ground observations. Infrared imagery was obtained over parts of Yellowstone National Park to study the usefulness of infrared imagery over such features and to determine if subsurface thermal anomalies could be imaged.

Figure 2 is a conventional aerial photograph over the Midway Geyser Basin. The area of hot spring activity is apparent due to the absence of trees and to the light tone of the geyserite materials, but individual hot springs and geysers cannot be determined. On infrared imagery obtained at 10:10 A.M. on 22 May 1961 (Figure 3) the hot springs stand out in sharp contrast to the background and can be seen to be much hotter than the Firehole River that winds through the center of the strip of imagery. The temperature of these springs cannot be determined but each hot spring can be mapped as shown in Figure 4.

Again, the diurnal effect can also be demonstrated for this area. The lower strip in

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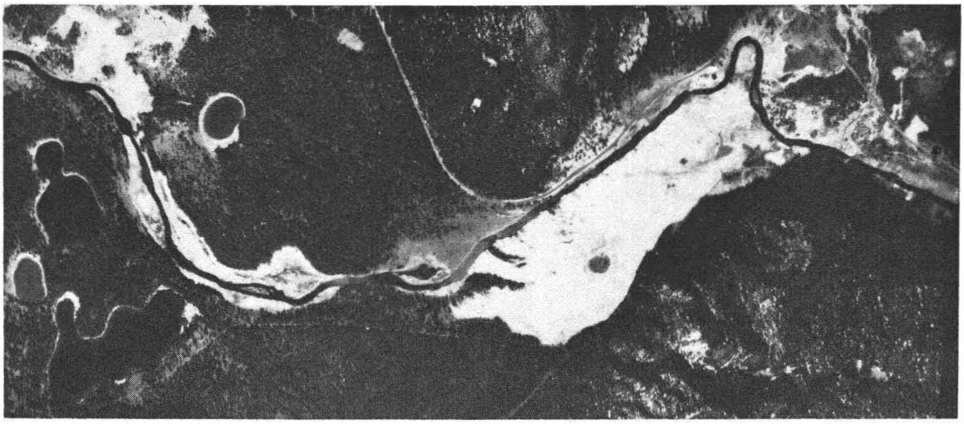

FIG. 2. An aerial photograph of Midway Geyser Basin, Yellowstone National Park. The Firehole River winds through the strip. Compare this aerial photograph with the infrared imagery of Figure 3.

Figure 3, which was taken at 6:27 A.M. over the Midway Geyser Basin while the air temperature was 32° F, shows all water bodies to be hot with respect to the background. The Firehole River shows as warm, on the imagery, as the hot springs. Under such conditions open water bodies at normal temperatures (such as pools, lakes, and rivers) could not be separated from hot springs. This however was taken at an optimum time to locate all water features in the area, regardless of temperature.

The imagery of Yellowstone National Park disclosed one thermal anomaly not evident as such by surface features. Gibbon Hill south of Norris Geyser Basin stood out on the imagery as a pronounced thermal anomaly as shown in Figure 5. This hill is a rhyolite dome which is nearly a mile in diameter at its base and rises about 800 feet above the surrounding countryside. The dome is in contact with the plateau flows on its northern, eastern, and southern margins, and is considered older than the flows.

The relatively high apparent temperature of Gibbon Hill may result from heat retained

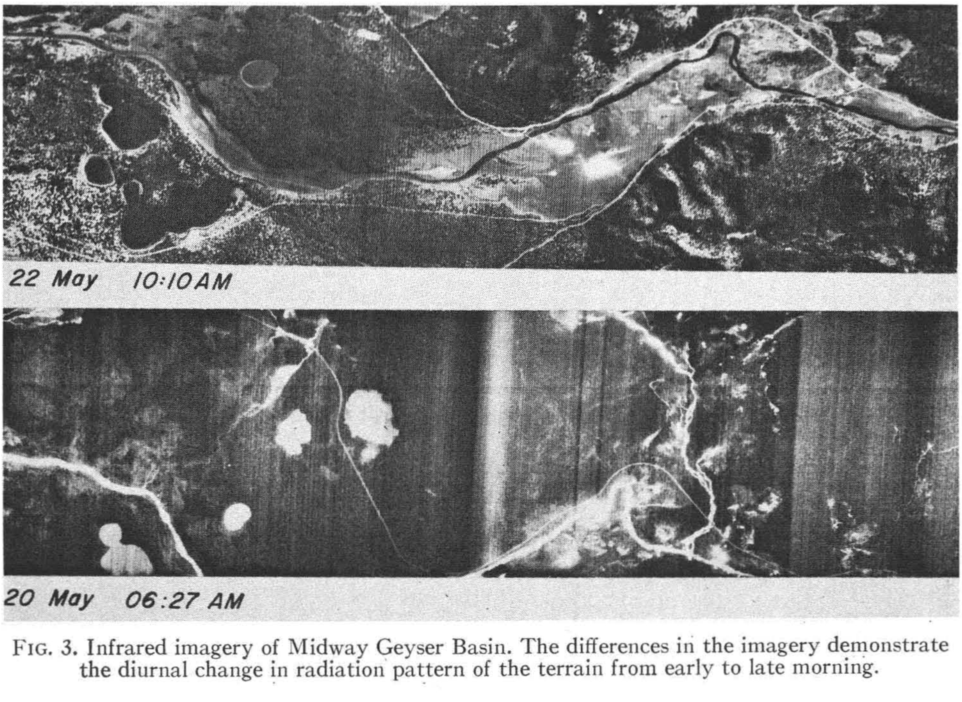

FIG. 3. Infrared imagery of Midway Geyser Basin. The differences in the imagery demonstrate the diurnal change in radiation pattern of the terrain from early to late morning.

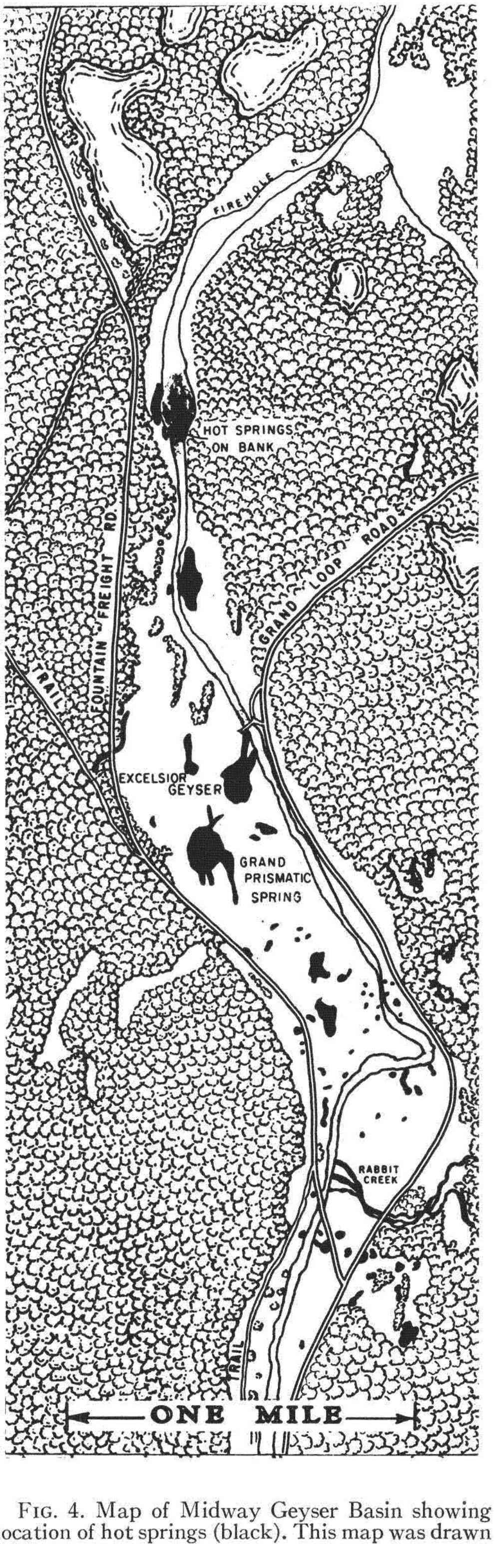

FIG. 4. Map of Midway Geyser Basin showing location of hot springs (black). This map was drawn from interpretation of infrared imagery shown in Figure 3.

by the rhyolitic mass from the time of its formation and transferred to the surface by conduction, or may relate to the transmission of warm water from the subsurface to the crest of the hill. This latter interpretation is supported by several obviously warm springs that can be seen issuing from the ground near the base of the hill.* Also seen in this imagery are the hot springs of the Norris Geyser Basin.

During the period between November 1960 and February 1964, USA CRREL and the University of Michigan participated in several remote sensing projects in the Arctic. Since 1962 these missions have been a part of a joint U. S./Canadian study (Project *Bold Survey*). Cooperating Canadian agencies are the Defence Research Board, Department of Transport, the Royal Canadian Air Force and the Joint Photographic Intelligence Centre.

During these studies infrared imagery has been obtained over sea ice in the Gulf of St. Lawrence and in the Arctic from 76° North to the North Pole. This work has demonstrated the usefulness of infrared imagery to map sea-ice features during both daylight conditions and during the Arctic winter dark period.

Figure 6 is a comparison of infrared thermal imagery and conventional aerial photography of sea ice. Both were obtained simultaneously during April 1962. By interpretation of the aerial photography it can be concluded that most of the ice is thin winter ice with little or no snow cover. The lack of snow cover is a good indication that this is thin ice and ice finger-rafting,† also characteristic of thin winter ice, is seen as light tone bands irregularly criss-crossing the area. Within the area are several pieces of thicker snow-covered winter ice shown as small rounded areas that are nearly white. Snow-covered land is seen in the upper right corner.

The infrared thermal imagery of this same area has nearly a reversal of photographic tones. The very thin ice that appears dark gray to black in the aerial photography is now white to light gray, indicating a warm surface. The snow-covered thicker ice, which was nearly white in the aerial photograph, is black, or cold, in the thermal imagery. This very cold signal is due primarily to the insula-

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* The interpretation of this thermal anomaly was prepared by Mr. William A. Fischer, U. S. Geological Survey.

† Rafting is a term used when one sheet of ice overrides another. Ice finger-rafting denotes that alternate narrow sections of one sheet override and underride the adjacent sheet giving a finger-like pattern to the ice.

FIG. 5. Infrared imagery of the Norris Geyser Basin and Gibbon Hill, Yellowstone National Park. Gibbon Hill is shown as a nearly round thermal anomaly in the right portion of the strip. The imagery portrays a strip one mile wide.

tion effect of the snow cover. The finger rafting is shown on the thermal imagery by dark gray bands representing older thicker rafting and by hot irregular lines outlining each finger caused by a wet zone created along the edges of new rafting. This thermal image of sea ice illustrates a good relative correlation between ice thickness and the apparent temperature of the surface.

Figure 7 is a strip of infrared imagery of sea ice obtained during winter nighttime conditions with air temperatures near the ice as low as −42° C. The warm continuous line through the imagery is the footpath of the ground party who were on the ice obtaining ice thickness and surface radiation temperatures at the time the imagery was obtained. The infrared imagery clearly portrays the actual ice conditions in the area. The ice in this strip of imagery varies in thickness from 4 to over 12 feet and consists of both polar ice and winter ice. Polar ice is shown by a darker (colder) tone and by a characteristic pressure ridge pattern on the larger areas. The winter ice varies from that with a very smooth surface to that with frequent low pressure ridges. These pressure ridges are clearly shown on the imagery.

## CONCLUSIONS

The usefulness of infrared imagery in three environmental situations has been demon-

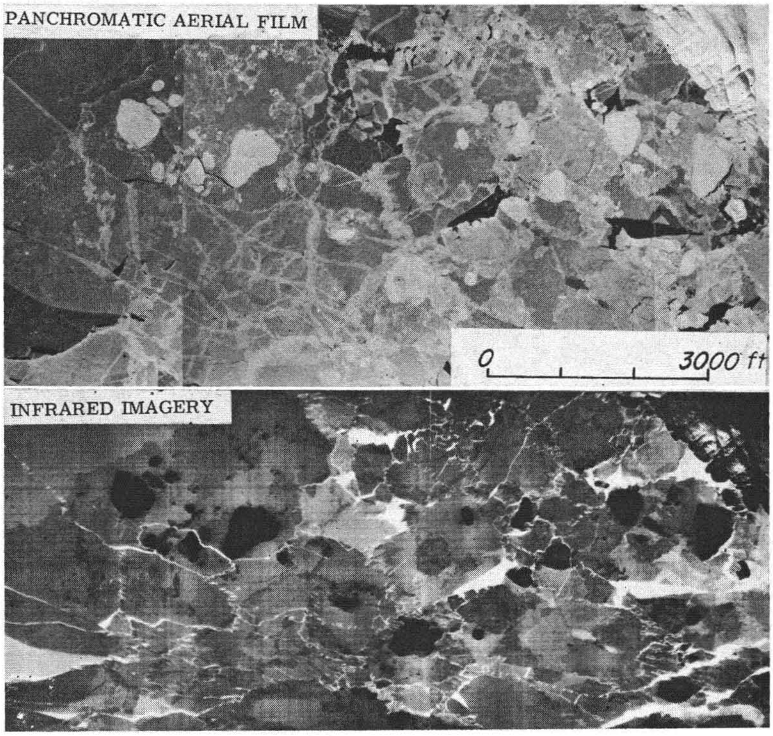

FIG. 6. Conventional aerial photography and infrared thermal imagery of sea ice obtained simultaneously.

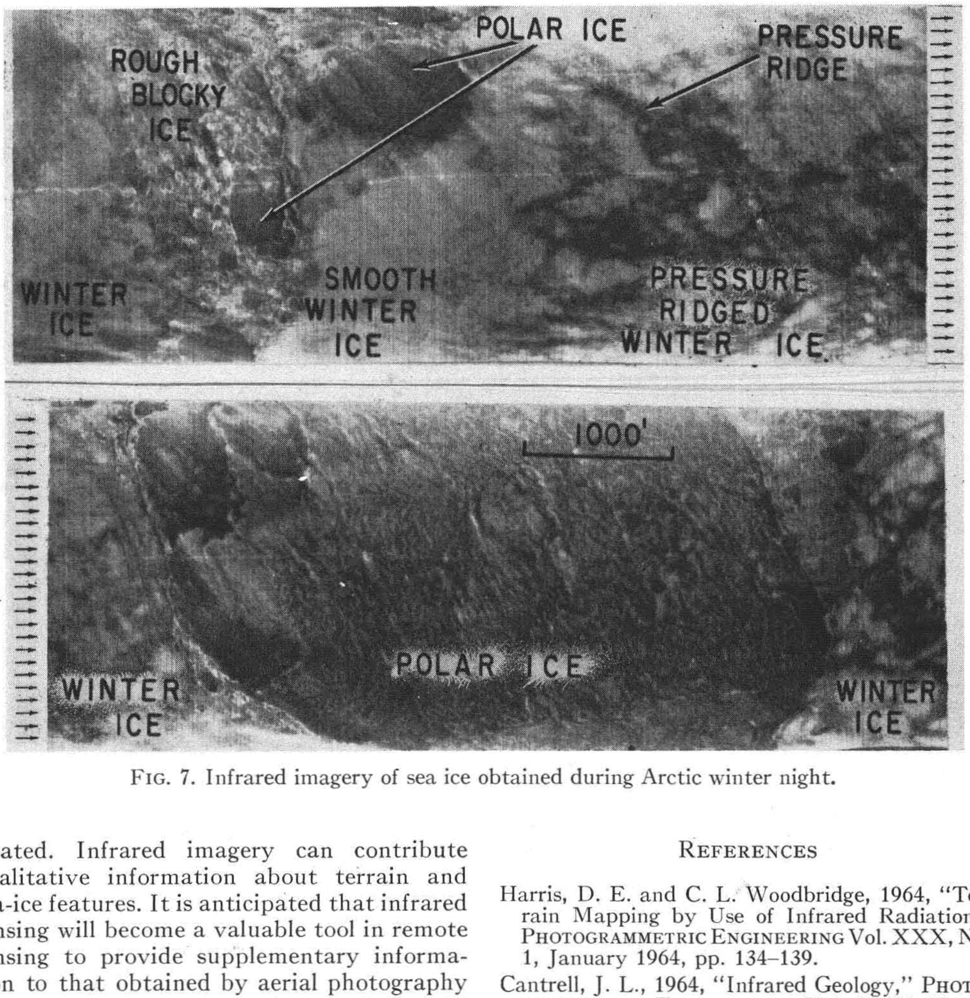

FIG. 7. Infrared imagery of sea ice obtained during Arctic winter night.

strated. Infrared imagery can contribute qualitative information about terrain and sea-ice features. It is anticipated that infrared sensing will become a valuable tool in remote sensing to provide supplementary information to that obtained by aerial photography and to obtain information at times when aerial photography cannot be taken. However, the interpreter must be aware of the environmental conditions prevailing during the time the imagery was obtained.

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