crown-closure by another two-fold or more (because of the excessive apparent lean of trees viewed as obliquely as these from only half the altitude as that from which stand "*A*" is viewed). Nor can any comfort be found in the thought that whatever errors he might make by such oversights will be compensating. They will not be in this instance, because all stands growing at an elevation of 8,000 feet above sea level in the Sierra (such as stand "*B*") have far different merchantability characteristics and species compositions than stands such as "*A*," which are growing at an elevation of only 4,000 feet above sea level.

Summary and Conclusions

The foregoing examples are only a few among many that might be given to illustrate why all of us, as we employ aerial photographs, need to think more critically about the uses and limitations of photo measurements. If these examples will prompt even a few of us, through wiser use of photo measurements, to improve our ability to extract useful information from aerial photographs, the paper will have served its primary purpose.

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Geologic Interpretation of Airborne Infrared Imagery

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Abstract: *Modern airborne infrared (IR) imagery allows the photogeologist to view the earth's surface in a vast, new range of the spectrum. This imagery is a function of the energy emitted from, not reflected by, the terrain object. As this energy is a function primarily of the object's emissivity and temperature, the photogeologist must retrain himself to interpret terrain features in a new aspect.*

A photogeologic interpretation of an IR image of Mt. Nittany, Pennsylvania reveals that shale may be distinguished easily from sandstone, and that valley-side springs are more clearly shown than on conventional aerial photography. As more IR imagery becomes available, more geologic information will undoubtedly be obtained from this medium.

Introduction

Geologic interpretation of aerial photographs taken by means of visible light is a well developed art. Visual photography has been extended slightly into the infrared region by use of special films but most infrared radiation cannot be directly photographed. Within the past few years airborne equipment capable of producing good terrain images in the infrared range of the spectrum has been developed.

It is the purpose of this paper to discuss the potential geological value of infrared (IR) imagery and give an example of geologic interpretation of an IR image.

Technique of Obtaining IR Imagery

Because the terrain is not photographed directly by airborne IR sensors, the term "IR imagery" is used to describe the final photograph obtained.

The airborne IR sensing equipment is

flown over the terrain in straight parallel lines (Figure 1). A scanning device such as a rotating mirror scans the terrain in continuous strips perpendicular to the line of flight. The image from the mirror strikes an element sensitive to IR radiation, and the signal from the sensitive element is electronically amplified and produces a visual image on a cathode ray tube or by means of a glow tube. A final photographic record is made by the glow tube or from the cathode ray tube.

The scanning mirror sweeps an angle on either side of the vertical. Hence, except along the nadir line directly beneath the flight line, the final image is an oblique view of the terrain and the scale varies with distance from nadir line. The geometry of the final photographic image is understood and planimetric maps may be prepared by simple calculation.

Characteristics of IR Imagery

The photographic tone of an object sensed by IR equipment is primarily a function of the intensity of the object's IR radiation emission which in turn depends upon the object's emissivity and temperature. The emissivity of a material is measured relative to a theoretical blackbody which is assumed to have an emissivity of 1.0 and is a function of the object only. Hence, for the same object or material, the tone seen on the final photographic image is a function primarily of the object's temperature and therefore IR imagery may be obtained during daytime or nighttime.

If the IR image is obtained during daytime the total radiation (visual and IR) from the object may be sensed, or all radiation other than IR radiation may be filtered out. At nighttime only IR radiation is sensed.

The most difficult adjustment a geologist familiar with ordinary aerial photographs must make when studying IR imagery is the realization that he is not seeing objects by reflected light. The experience of the human eye is in sensing objects by reflected light, but the eye has no experience in sensing objects by their IR radiation. The geologist must train himself to realize that, in IR imagery, he is looking at objects whose photographic tone is a function only of their emissivity and temperature. The image is a function of emitted, not reflected, radiation.

Because IR imagery looks at the terrain in a new, and vast, range of the spectrum, it may be expected that many geologic features not visible to, or difficult to see by, the human eye will be apparent, and herein lies the potential value of this new technique.

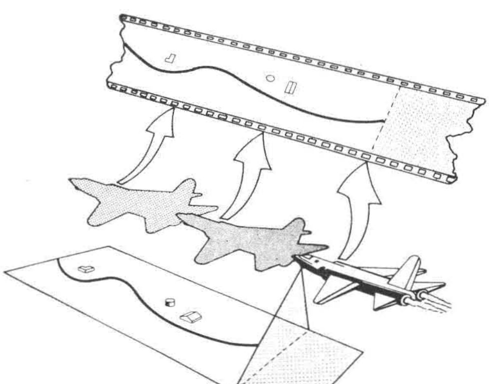

Fig. 1. DIAGRAMMATIC ILLUSTRATION OF AIRBORNE IR SENSING TECHNIQUE
A rotating mirror in the IR sensing equipment scans the terrain perpendicular to the line of flight.

Interpretation of an Example of IR Airborne Imagery

An example of IR imagery is shown in Figure 2 and for comparison the visual aerial photography of the same area is shown on Figure 3. The area is the western end of Mt. Nittany, a synclinal Appalachian ridge a few miles east of State College, Pennsylvania.

The ridge is composed of Ordovician rocks. The highest beds, the caprock of the synclinal ridge, are Oswego sandstone. The slopes are underlain by Reedsville shale. Middle Ordovician carbonate rocks underlie the low relief areas surrounding Mt. Nittany. The contact between the Oswego and the Reedsville is indicated on Figure 2.

General Features

The IR image shown in Figure 2 was taken in April 1959, at 11 o'clock at night. All imagery is due to thermal radiation only. The airborne IR sensing equipment was flown along the middle of the IR strip image. Comparing Figures 2 and 3, the displacement of the ridge crests of the synclinal ridge away from the center line on Figure 2 is apparent and the north and south facing slopes are foreshortened. This is due to the fact that, except along the nadir line, the IR image is an oblique view.

The southern side of Mt. Nittany on Figure 2 has a generally lighter tone than the northern side. This is probably due to the fact that the southern side received more solar radiation during the daytime preceding the flight and was therefore heated to a higher

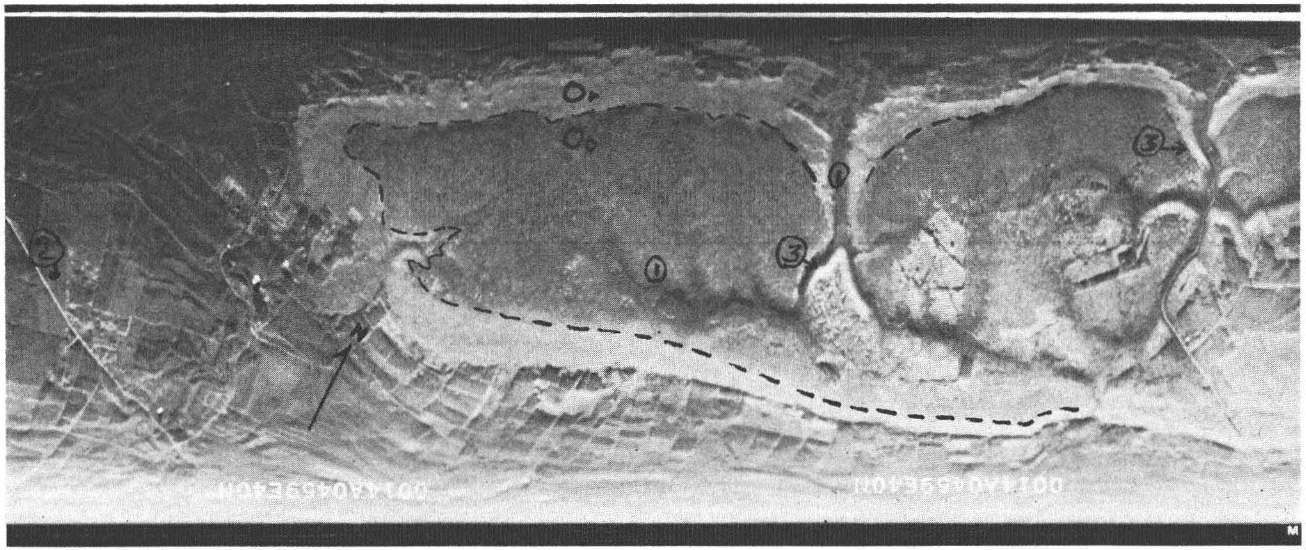

FIG. 2. IR IMAGE OF MT. NITTANY, PENNSYLVANIA. The dashed line is the contact between the Oswego sandstone (Oo) and the underlying Reedsville shale (Or). Numbers are referred to in the text. (IR image by courtesy of HRB-Singer, Inc.)

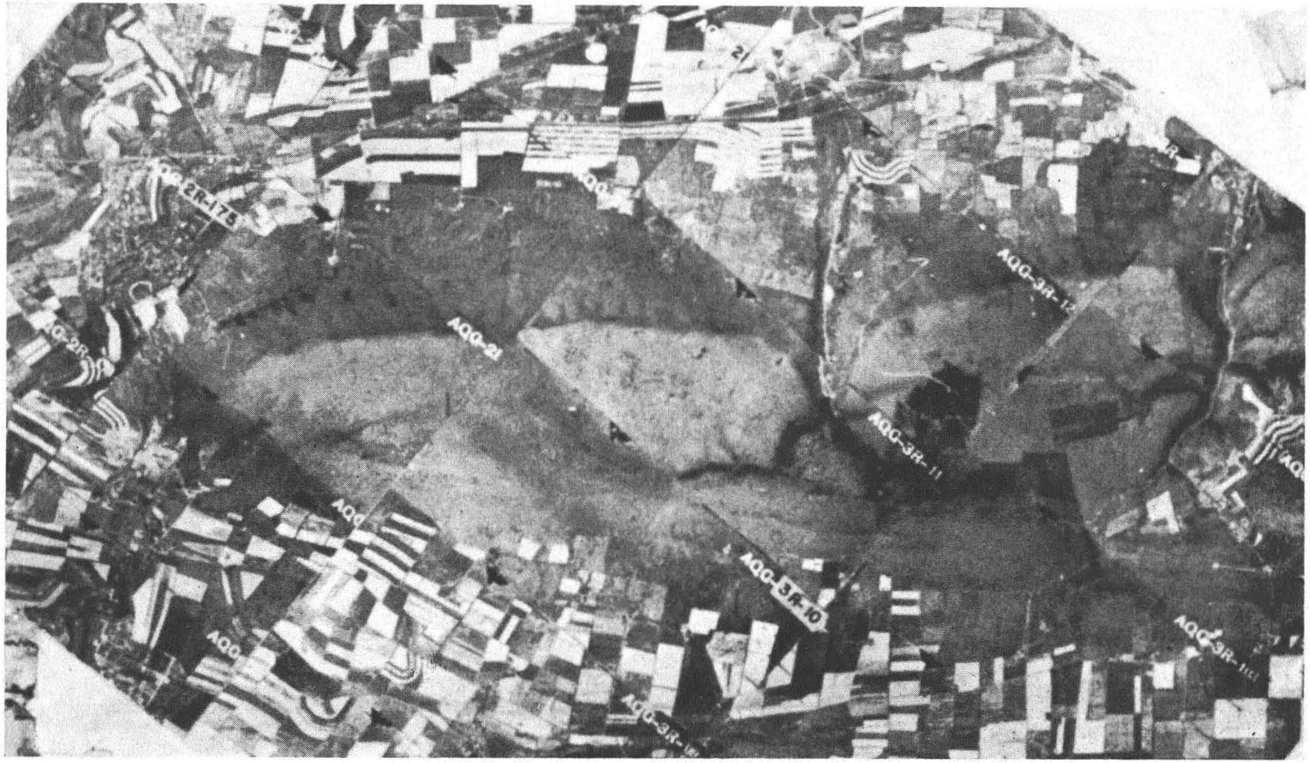

FIG. 3. PHOTO INDEX SHEET OF MT. NITTANY, PENNSYLVANIA. This is approximately the same area as shown on Figure 2. The photo index sheet is compiled from conventional aerial photography. (Photo index sheet by Commodity Stabilization Service.)

temperature than the northern side. Although heat is being radiated from the ridge during the night (when the IR image was obtained) the southern side is still at a higher temperature than the northern side, and emits more IR radiation hence presenting a lighter tone on the final photographic image.

Open field areas are warmer than wooded areas and are clearly shown by a lighter tone. The valleys (Figure 2, point 1) exhibit quite a dark tone; hence they are cooler than the uplands. This may be due to their having been more in shade during the day and therefore having received less solar radiation. In addition, cool air probably flows down the valleys at night and evaporative cooling may occur in them. The vegetation in the valleys also contributes to the dark tone.

The asphalt road (Figure 2, point 2) absorbed considerable solar radiation during the day and hence produces a light (warm) tone on the image.

GEOLOGIC FEATURES

The Oswego-Reedsville contact is delineated on Figure 2. The tonal difference between the two formations makes them very easy to map on the IR image. Figure 3 also shows that the formations can be readily differentiated on conventional aerial photography but the tonal difference is not nearly as marked as on Figure 2.

The tonal difference between the Oswego sandstone and the Reedsville shale exhibited on the IR image may be caused by several factors. Due to different specific heats and conductivities of the rocks and soils derived from them, the two formations were probably heated to different temperatures by solar radiation during the preceding day and were therefore at different temperatures when the IR image was obtained. The Oswego sandstone supports a coniferous vegetation whereas the Reedsville shale supports a more deciduous vegetation. In April the deciduous vegetation is not fully leafed. Therefore the Oswego had more vegetation in leaf when the image was made and the tonal difference on Figure 2 is probably due primarily to vegetation.

At two points marked 3 on Figure 2 may be seen light-toned areas along the valley sides. These areas are springs. Apparently the groundwater was warmer than the ground at night and hence produced a lighter tone on the IR image. The triangular area just south of the westernmost point 3 exhibits a mottled pattern. This area is swampy and the water here was apparently warmer than the ground. It is this water which flows northward into the valley to make the springs at point 3. The swamp also appears on conventional aerial photography (Figure 3) but the springs are not obvious. Certainly several springs along the sides of the valleys are obvious on the IR image and not on conventional aerial photography.

The trend of carbonate rocks in the lowlands may be clearly seen on the IR image (Figure 2) east of point 2. The same trends are visible on stereo aerial photographs but not on the mosaic. Notice that the disturbing "patchwork" field pattern on Figure 3, annoying to much photogeologic work, is very subdued on Figure 2.

CONCLUSIONS

Experience in the geologic interpretation of IR imagery is limited. Within these limits however, it appears that much valuable geologic information not visible, or difficult to see, on conventional aerial photography may be displayed on IR images. The photogeologist cannot afford to pass up this potential source of information.

ACKNOWLEDGMENT

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EDITOR'S NOTE

Advance announcements of the SPECIAL ISSUE promised inclusion of selected technical papers written by leaders in photogrammetry. Early in August the Publications Committee Chairman solicited my aid in obtaining a sufficient number of the desired papers, since at that time he had been able to "line up" only one paper. On August 15 I wrote to "leaders in photogrammetry" known to me to be fully qualified. The response was heart-warming. One was not in the U. S. All others responded promptly. All expressed complete willingness but delay by some was necessary. From the others a fully ample number was promptly received. They are on pages 64 to 126. I greatly appreciate this evidence of cooperation and of interest in the Society and photogrammetry.

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