To Measure Is To Know—Or Is It?

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"To MEASURE IS TO KNOW." It matters little who first uttered this oft-quoted saying, or whether *photo* measurements were within his purview. But it does matter greatly that many photogrammetrists believe implicitly in the truth of this saying, even when they are by no means certain of what it is they are measuring. It matters equally that many photo interpreters, in their reluctance to make photo measurements, deprive themselves of whatever knowledge photo measurements can provide.

The primary objective of this paper is to demonstrate why all users of aerial photos, be they mensurationists or interpretationists, should think more critically about the uses and limitations of photo measurements; for by so doing, they may be able to avoid serious errors they currently are making, either in measuring or in abstaining from measuring. As a consequence they may greatly improve their ability to extract useful information from aerial photographs.

The most convincing way to present this topic is through the consideration of specific examples. Consequently this paper will be illustrated with several aerial photographs, so chosen as to be (1) representative of a wide variety of military and civil applications of aerial photography, and (2) illustrative of the extent to which photo measurements can be relied upon to increase our knowledge of the area photographed.

Among the many kinds of measurements which photo users commonly make on aerial photographs are those designed to provide a more accurate knowledge of the heights, depths, shapes, sizes, volumes, tones, and rates of motion of the various objects which are imaged on the photographs. This listing serves to govern the organization of the remainder of this paper. Under each of the headings which follow, examples will first be given of the genuine value to be found in photograph measurements, properly made; then examples will be given of the erroneous conclusions which can be reached when the photo measurements are either improperly made, or made in ignorance of important associated facts.

Relief Measurements

Figure 1 illustrates the great value of photo measurements to a military commander who wishes to make an amphibious landing within an enemy-held area, as shown here. From this stereo photography, flown under combat conditions, it was possible to measure water depths, in the lower right portion of the stereogram, and to obtain valuable information on the configuration and gradient of the ocean bottom. Predictions were then made of the distance offshore at which various types of vessels, each of known draft, would run aground during an amphibious landing. Measurements also were made *above* the waterline shown in this stereogram. From these measurements the width and gradient of the beach were determined, and the roughness of the uplifted coral reef was estimated; in addition, measurements were made to determine the height of each bluff that would have to be scaled by our landing forces when seeking an exit from the beach. The steepness of slope and height of vegetation atop the bluffs also were estimated. Each of these determinations was made with the aid of accurate *measurements* of stereoscopic parallax.

Later, an amphibious landing was successfully made on the beach, part of which is shown in Figure 1. Subsequent ground checking by the writer established that, for water depths up to thirty feet (the maximum depth at which underwater detail could be discerned), the average error of depth estimates based on photo measurements was less than one foot, and the maximum error, less than two feet. Comparable errors resulting from photo measurements made *above* the water line were six inches and one foot, respectively. Clearly, in this example "to measure was to know" to a far greater order of accuracy than if the photos had merely been interpreted instead of measured.

Even in this straightforward example, however, the danger of placing too much confidence in mere measurements existed. For example, had the photo measurer failed to correct his underwater parallax readings for the refraction of light rays at the water-air interface, the average error in his answers

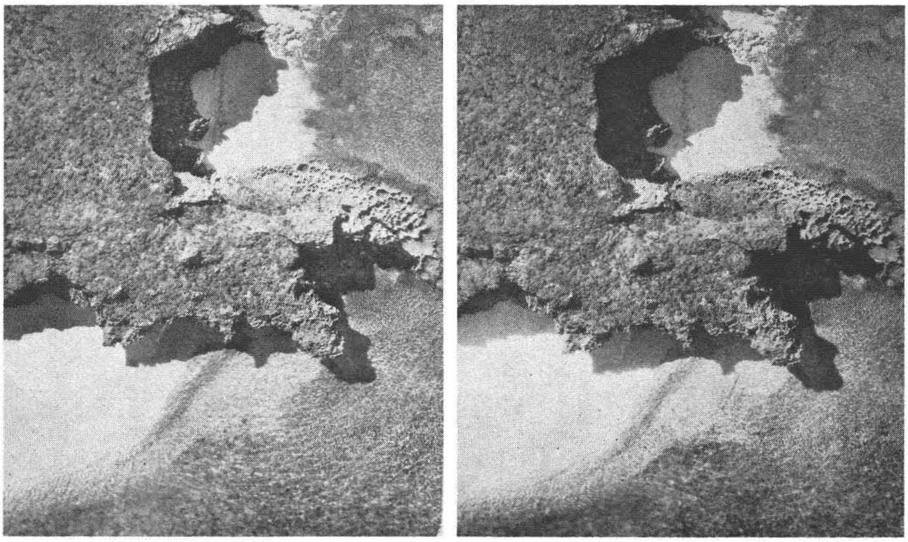

FIG. 1. For a discussion of the value to a military commander of photo measurements that might be made of this area where an amphibious landing is contemplated, see text. (Department of Defense photo.)

would have been increased by a disastrous thirty-three per cent. In a similar way if the photo measurer had failed to report height of the tide at the time the photos were taken, his depth measurements, however accurate, might have been dangerously misleading to personnel planning for making an assault landing here at some other stage of the tide. In this instance, then, the photo measurements were clearly essential, but it was equally important to know exactly what each such measurement signified.

Figure 2 shows an area representative of those in which foresters commonly measure tree heights as a step in the determination of timber volumes. After measuring accurately the stereoscopic parallax for Tree "*A*" (on the original photos, which are shown in Figure 2 at reduced scale) a forester computed the height of the tree to be 138 feet. A second forester measured the height of the same tree from its relief displacement on the left photo only,—an equally legitimate method in this instance. He obtained an astounding value of 583 feet, even though he made no significant errors in either his measurements or his calculations. A third forester, by measuring the shadow lengths cast by the tree, and by a telephone pole of known height imaged elsewhere on the photo, obtained a height of only 42 feet for the tree. Finally a fourth forester measured the relief displacement of Tree "*A*" on one of the photos of an adjacent flight line, on which the tree was equally well imaged. He arrived at an incredible height of *minus* 112 feet for this tree! A ground check made by the writer revealed the true stem length of this tree to be 161 feet.

An examination of Figure 3 shows that the error made by each of these photo users was not in his *photogrammetry* but in his *interpretation;* each assumed the tree to be vertical, when actually it was leaning. This is a far more common type of difficulty than is generally realized. Few trees are truly vertical, and they certainly need not have as much lean as Tree "*A*" to introduce significant errors in photogrammetric determinations of tree height.

When working with aerial photographs, it is rarely recognized, except through the most careful photo interpretation, that a tree or some other "normally vertical" object is leaning. We expect objects to appear somewhat distorted on an aerial photo, particularly when imaged near the edge of the photo. (See also Figure 7.) This example, then, shows that unless we correctly *interpret* photo images, we do not know the true meaning of our photo measurements, once we have made them.

Corollary to what has just been said, an equally serious error can arise when the photogrammetrist, in attempting to determine the true horizontal ground distance between two points, measures the apparent distance between them very precisely on aerial photos. If, because of an error in photo interpretation, he has misidentified either of the points on the photographs, a commensurate error will, of course, appear in the calculated ground distance, despite the high precision of his photo measurement.

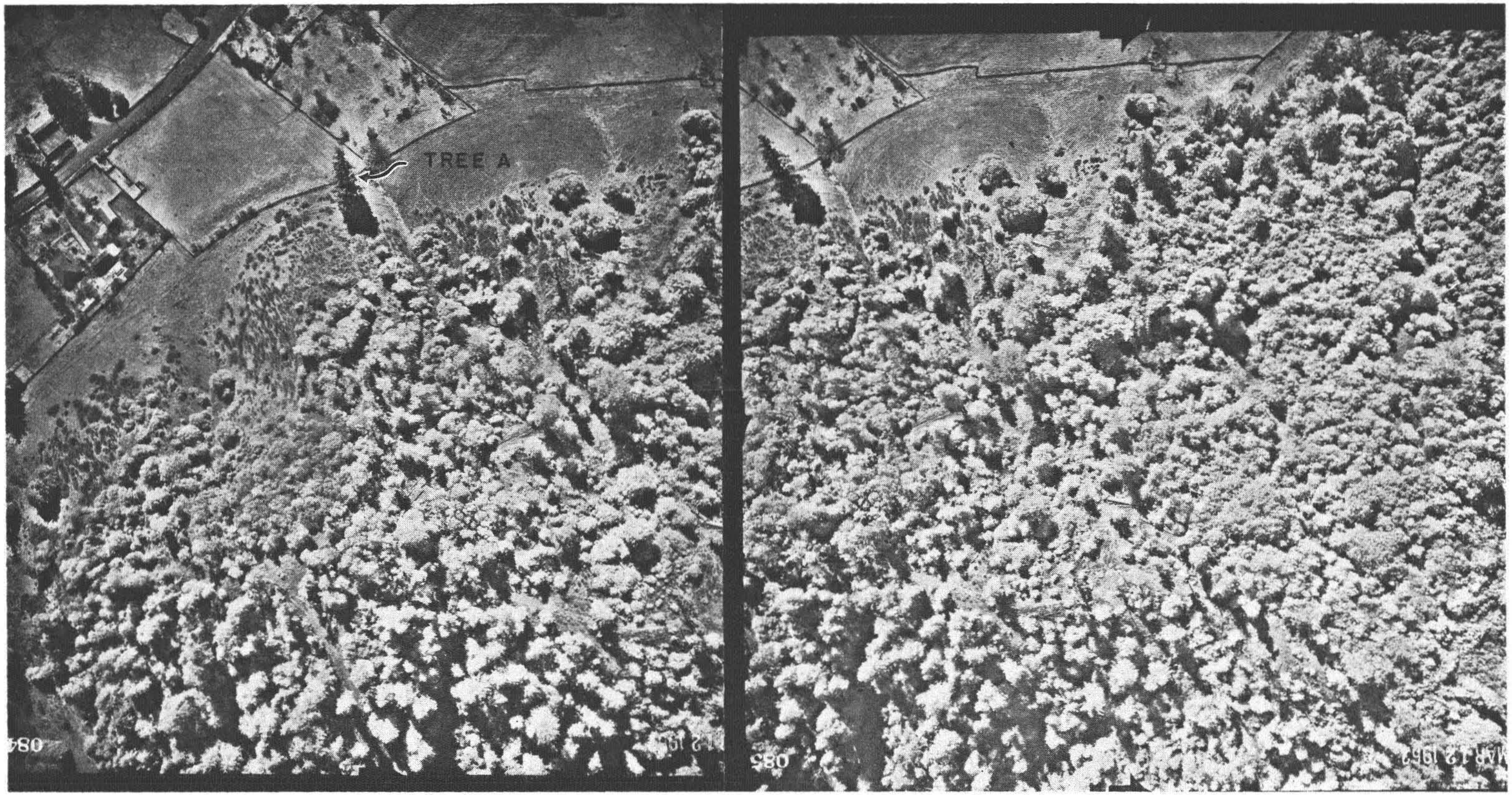

FIG. 2. Two overlapping vertical aerial photographs of an area in which most tree heights can be accurately measured photogrammetrically. Very sizable errors result when attempting to measure the height of tree *A*, however. Compare with Figure 3.

FIG. 3. Ground view showing the amount of lean in Tree "A" of Figure 2. Even if this tree had much less lean, very significant errors might result from attempting to measure its height photogrammetrically, while assuming it to be truly vertical.

SHAPE AND SIZE MEASUREMENTS

Figure 4 illustrates the value of making accurate measurements of an unidentified object and thus of facilitating its identification. This stereo-pair of photographs, taken over enemy-held territory, reveals peculiarly-shaped objects of a type that had never before been seen by our military photo interpreters. The images were merely "interpreted" rather than measured (a common failing among photo interpreters) and the objects were not correctly identified. If accurate photo measurements of these objects had been made in the x, y and z directions their true size and three-dimensional shape would have been more fully appreciated. It then would have been apparent that each of these objects has a deep V-notch at one end and only a shallow V-notch at the other. This is a common design feature of the "cradles" used for transporting small boats. Such a shape for objects of this size, is rarely, if ever, encountered elsewhere in the physical universe. The boat keel, which slopes downward from fore to aft, fits snuggly into the V-notches which, because of their differing heights, permit the boat to be transported in a horizontal position.

In the instance shown in Figure 4, the

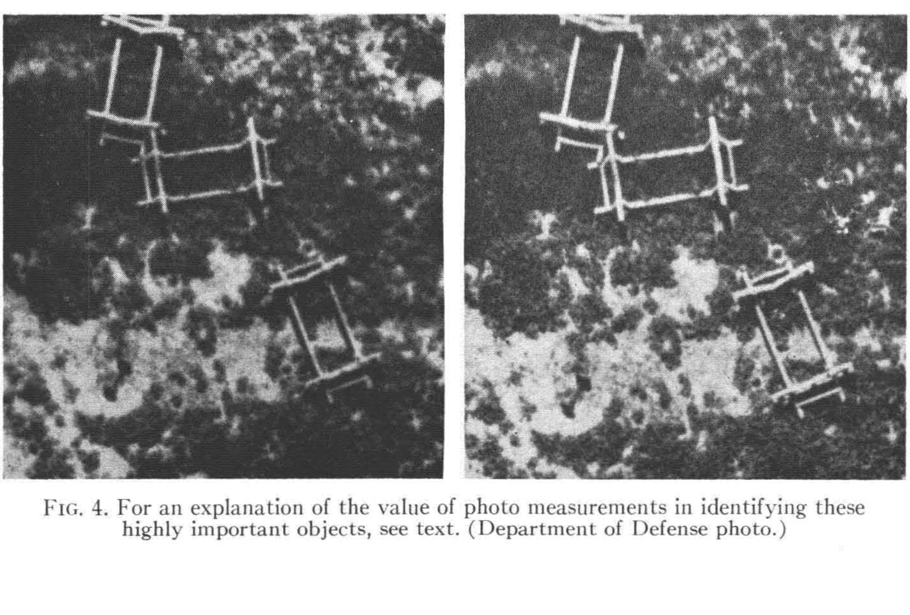

FIG. 4. For an explanation of the value of photo measurements in identifying these highly important objects, see text. (Department of Defense photo.)

FIG. 5. Two "suicide boats" after removal from the caves in which they had been hidden. Only by identification of the objects shown in Figure 4 might the presence of these important weapons of war have been detected. Each carried a "warhead" containing 640 pounds of high explosive. (Department of Defense photo.)

enemy's clever plan was to keep his total supply of 400 of these secret weapons, known as "suicide boats," hidden in caves on a small, insignificant island, a few miles offshore from the main island on which we were about to land 100,000 troops. Then, under cover of darkness, the boats were to be transported on these cradles to the nearest beaches for launching. During high speed runs at night they were to ram their high explosive warheads directly into our supply ships, thus sinking them and leaving our troops stranded ashore, at the mercy of a numerically superior enemy ground force. Historically, it has been well-documented that failure of our entire military operation might well have resulted from the inadequate extraction of information from the photos shown in Figure 4, had it not been for a most fortunate compensating factor that worked to the advantage of our forces.

It is difficult to make an unbiased judgment when viewing this photo interpretation problem in retrospect. It is the author's opinion, however, that had he and his colleagues *measured* these images instead of merely *interpreting* them, the objects would have been correctly identified prior to the landing and thus the entire enemy plan for their use would have been deduced.

Figure 6 provides an illustration in which hasty photo interpretation procedures might lead to the conclusion that there is a train proceeding from right to left near the center of the stereogram, while in the top portion, automobiles are busily threading their way along a freeway system. The photo interpreter has ready access to information on the flight altitude and focal-length of photography. Nevertheless, either his laziness or his reluctance to calculate scale, make photo measurements, and determine the actual dimensions of the objects he is examining, is about to lead him into making a ridiculous mistake. For if he were to practice the most elementary photogrammetry, he would note that the entire train, including its engine and seven cars, is little more than 150 feet long, and the automobiles on the freeway in the top of the stereogram are only six to seven feet

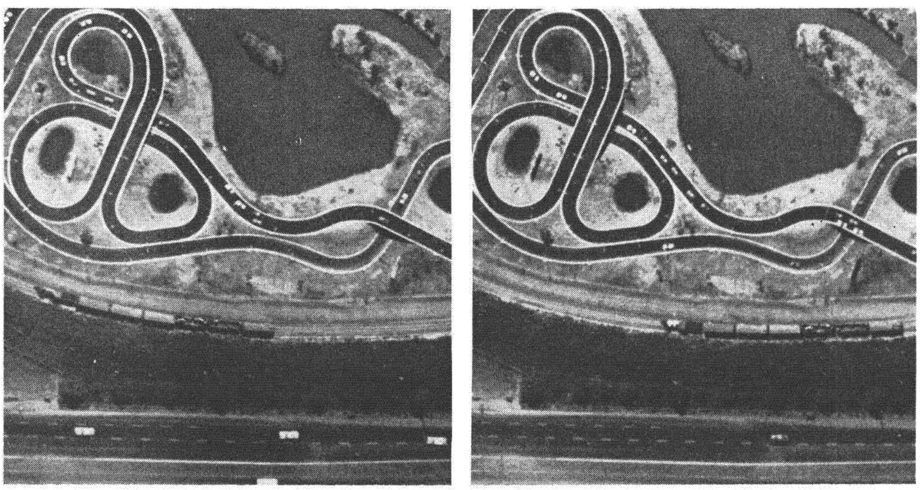

FIG. 6. Objects shown in this photo might readily be misinterpreted unless careful photo measurements were made of them, as explained in the text.

long. In this instance, then, "to measure is to know" that the area shown here is only a land of make-believe, (actually a portion of Disneyland in Southern California) in which the trains and automobiles are merely small scale models used strictly for play purposes.

It should not be inferred from this example, however, that the only way for the photo interpreter to have avoided the error he was about to make would have been through photo measurement. More careful interpretation often will serve to accomplish the same objective. For instance, with a bit more care he might have noted the full-scale automobiles and freeway lanes in the bottom of the stereogram, and rectified his hasty interpretation of the upper portions of the stereogram without having made any actual photo measurements.

The top stereogram of Figure 7 is included, lest too much credence be placed in photo measurement as the cure-all to identifying uninterpretable objects. Countless measurements might be made with great precision on the stereogram shown here, without leading to correct identification of this object as a dirigible mast. The difficulty resides in the simple fact that few photogrammetrists have had prior experience with this type of object, even on the ground. The solution to this problem is not to be found through more numerous and precise measurements. It probably is best found through (1) the "team approach," wherein a group of photo interpreters, each drawn from a different type of background, meets to exchange ideas as to what various unidentified objects might be, and (2) reference to photo interpretation keys which illustrate and identify various kinds of objects (including dirigible masts) and which also set forth in some systematic fashion a word description of their photo recognition features.

The stereogram in the middle of Figure 7 shows the ease with which we might erroneously conclude that the water tower has only four peripheral legs instead of six, if we were given only the right photo of the stereo-pair. In this instance, proper photo measurements, even if only the right hand photo had been available, would have obviated the error. The bottom two photos of Figure 7 show "dummy" objects whose lack of fidelity, in shape and size, to the objects they simulate, is best established by photo measurement when only small scale aerial photos are available. However, it does not follow that "to measure," in this instance is "to know" the *ultimate* significance of that which is measured. In some instances dummies such as these are cleverly constructed in the hopes of luring the enemy into wasting his efforts by bombing and strafing the dummies. But in other instances the dummies are made obviously asymmetrical in the hope that the enemy will be certain to recognize them as dummies, and will thereupon carefully avoid bombing and strafing the area. Beneath such dummies vital supplies of ammunition and fuel may then be stored, unmolested by aerial attack until such time as the double deception is deduced.

Tone Measurement

Figure 8 illustrates the potential value of tone measurement on various film-filter combinations as an aid to knowing water depths, vegetation types, and kinds of ground surface material. As this example suggests, there frequently is a need to detect and identify various objects and conditions in the physical universe solely from "tone signatures" obtained by cameras or other sensors that are remotely situated with respect to the area being investigated. The energy that is either emitted or reflected from objects in the area is recorded by the sensors, usually in photographic form. Quite commonly, as illustrated in Figure 8, one portion of the desired information is best obtained when sensing the energy returns in one part of the electromagnetic spectrum, while another portion requires sensing in a different part of the spectrum.

These considerations have given rise to a reconnaissance method known as "multiband spectral reconnaissance," by means of which two or more remotely-situated cameras or other sensing devices, each specially suited for the sensing of energy in its own spectral band, can be used in concert to provide information that no single sensor could have provided (Colwell, 1961). Frequently, for such a data-gathering process to be of maximum value the tone values must be *measured*, not merely interpreted, so that truly quantitative tone signatures can be relied upon (Fischer, 1961).

Microdensitometers have recently been perfected with the aid of which tone densities can be accurately measured, either on the original negatives, or on opaque positive prints. Similarly useful instruments some of which are known as "densichrometers" or "densichrons," are currently being used to quantify measurements of hue, value and chroma on color photography. Such instruments have demonstrated the validity of the concept, "to measure is to know," for a large

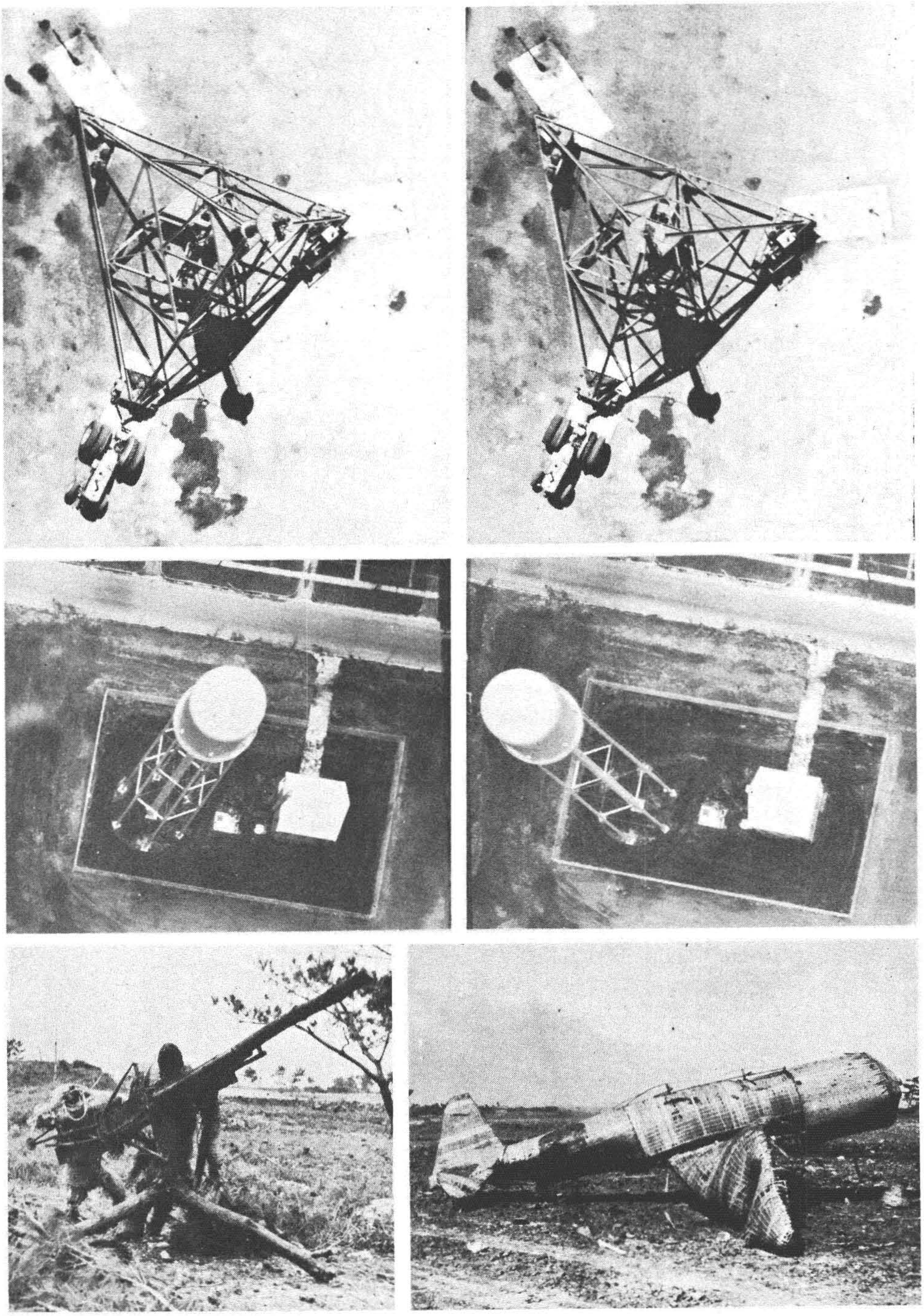

FIG. 7. "To measure is not necessarily to know," as illustrated by the photographs in this figure. For explanation, see text.

variety of data-gathering problems which rely on the use of aerial photgraphy.

Figure 9 demonstrates the need for exercising precaution when relying on photographic tone to identify various objects and conditions. Figure 10, by way of further precaution, shows an instance wherein the most precise measurements of tone may be of little

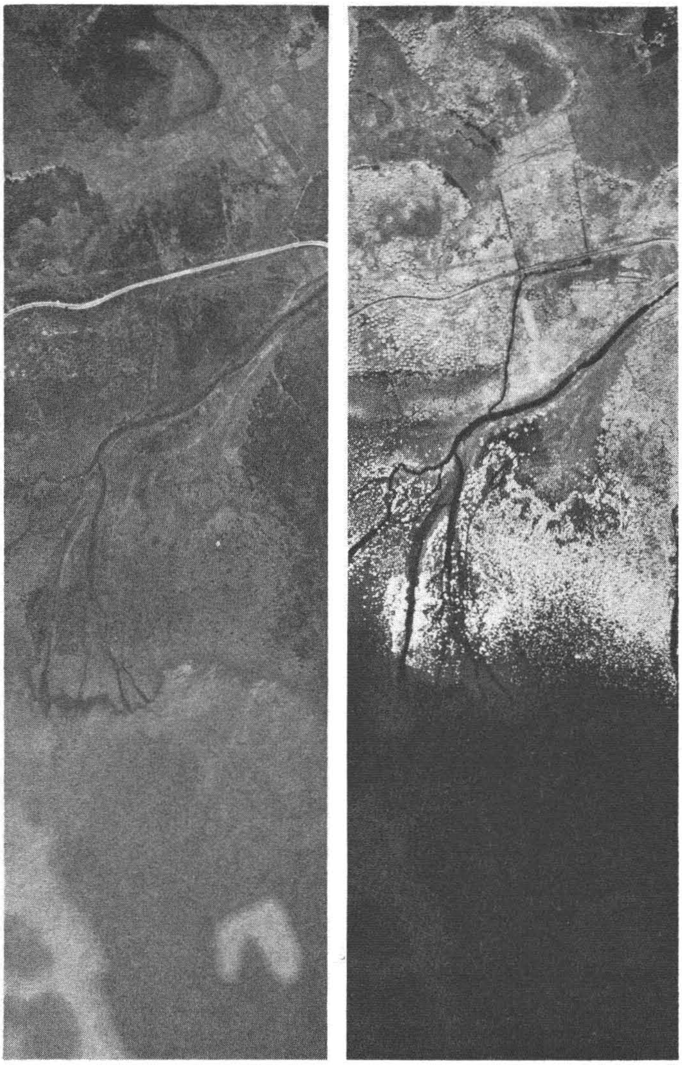

FIG. 8. An example of the value of tone measurement on multiband aerial photography. The film-filter combination used in taking the left photo reveals underwater detail to a depth of nearly twenty feet, readily reveals the presence of a road, and provides unique photographic tones for certain important plant species not identifiable on the right photo. On the other hand, the *right* photo reveals underwater detail only to a depth of about 5 feet, accentuates water courses rather than roads, and provides unique photographic tones for certain important species not identifiable on the left photo. It follows that much more complete information is obtainable from both photos interpreted in concert, than from either one alone, particularly if the tones of certain of the objects are actually *measured* rather than merely *interpreted*.

or no value in helping us to know exactly what is imaged.

Motion Measurement

Figure 11 is a graphic illustration of the possibility of making measurements on "discrete-frame" aerial photos to determine the velocity of flow in various parts of a stream. The photogrammetrist must know the time interval between exposures. He then can calculate the rate of stream flow merely from stereo parallax measurement of floating objects (in this instance, chunks of ice) on the two overlapping photos. Both the direction of flight of the aircraft and the direction of flow of the stream must be considered in making the calculations. In Figure 11 the portions of the stream having the highest velocity are those in which the ice appears to be floating at the highest level when the stream is viewed

FIG. 9. The danger of relying on photographic tone measurements without due regard to seasonal state is illustrated by these two photos of an area in the central Netherlands. That which is light-toned on the left view is dark-toned on the right view, and vice-versa, even though both photos were taken with the same film-filter combination. The left photo was taken on November 29 at a time when drainage conditions in this area were very poor because drainage pumps were not working and the shallow depressions were almost flooded. The right photo was taken on the following January 5 after a heavy frost. In this photo the depressions are white, but on the low ridges the ice or snow has melted; consequently the ridges are wet and appear in dark tones. (Photos courtesy Dr. P. Buringh.)

stereoscopically. It will be noted, when this figure is studied stereoscopically, that the islands in the stream appear to be embedded far below the surface of the stream, itself. This is because the chunks of ice in the stream exhibit a false parallax, because of their motion, thus making them appear nearer to the camera than they actually are.

Figure 12 illustrates the difficulty of making accurate motion measurements on "continuous strip" photography. The elongation of the images of automobiles when they are mov-

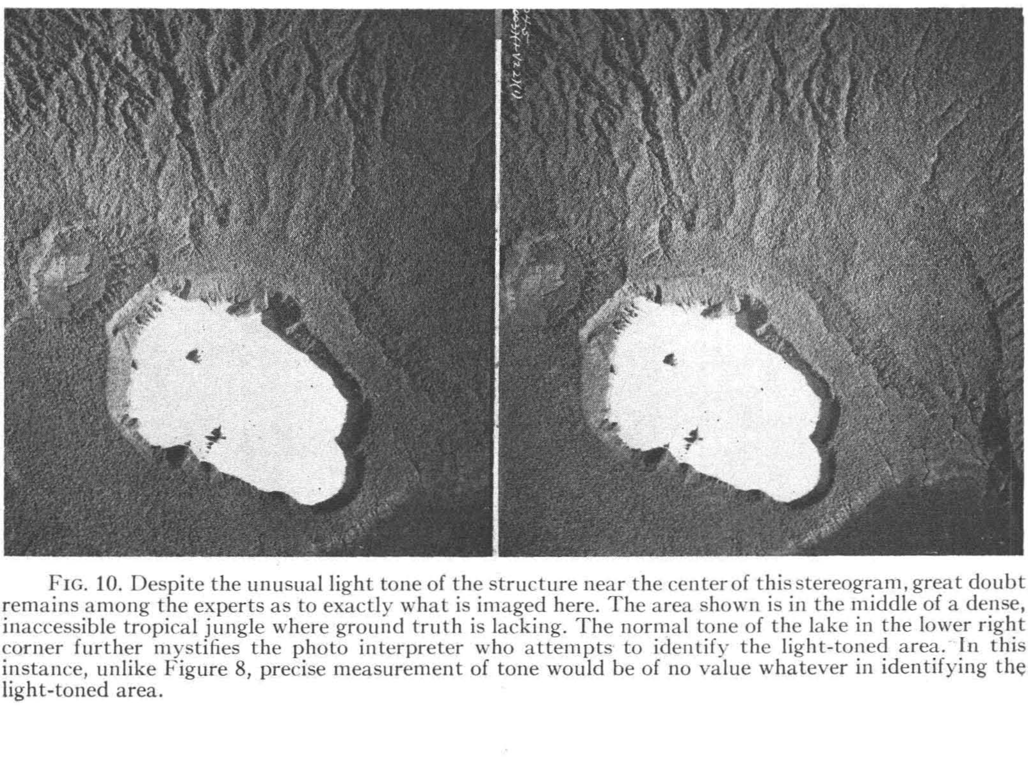

FIG. 10. Despite the unusual light tone of the structure near the center of this stereogram, great doubt remains among the experts as to exactly what is imaged here. The area shown is in the middle of a dense, inaccessible tropical jungle where ground truth is lacking. The normal tone of the lake in the lower right corner further mystifies the photo interpreter who attempts to identify the light-toned area. In this instance, unlike Figure 8, precise measurement of tone would be of no value whatever in identifying the light-toned area.

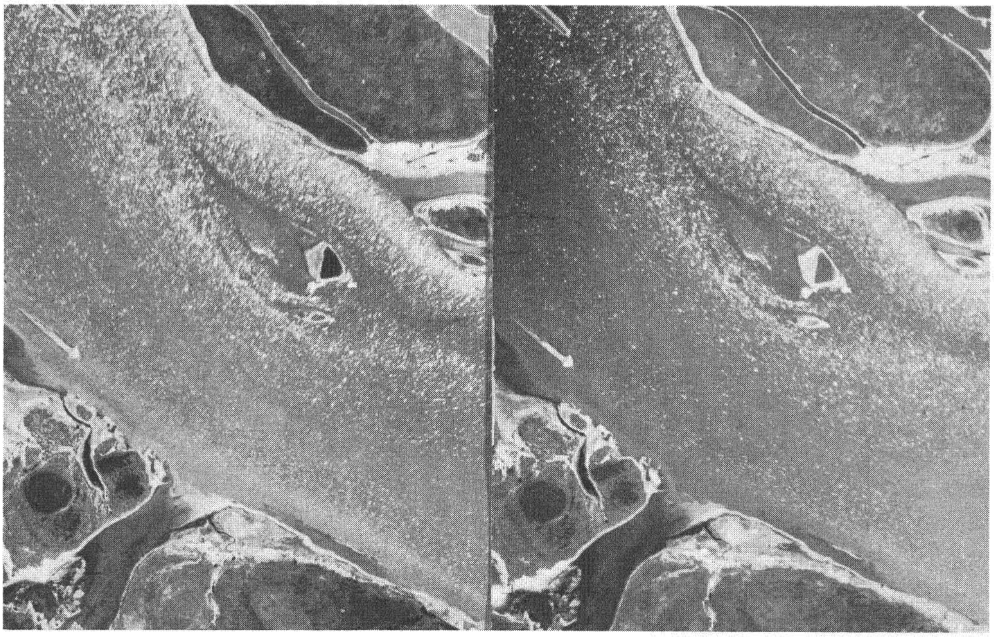

FIG. 11. Stereogram showing many chunks of ice floating in a Canadian stream. The motion of the ice provides an artificial parallax which, when accurately measured, permits a precise determination of stream velocity in various parts of the stream, as explained in the text. (Photos courtesy of Royal Canadian Air Force and Dominion Forest Surveys of Canada.)

ing in one direction, and their foreshortening when they are moving in the opposite direction, is well illustrated in this figure. If the true dimensions of each car were known, the velocity of each could be measured on such photography, from the amount by which each appeared to be foreshortened or elongated. In doing this it would be necessary to take into consideration the velocity of the photographic aircraft and the amount of image motion compensation introduced into the film drive mechanism, but photogrammetrically the problem would be quite straightforward. Since the dimensions of the automobiles are not known in this instance, photo measurements on this single strip photography do not permit us to know the velocities at which the automobiles are travelling.

VOLUME MEASUREMENT

Figure 13 shows several objects whose volumes we may wish to determine through aerial photo measurement. The volume of wood chips in each of the piles on the left side of this stereogram is readily determined by contouring the piles photogrammetrically at a known vertical interval and determining, from area and height measurements, the volume of each layer delineated by adjacent contours. Determinations as to the volume of each cylindrical tank (near the top of the stereogram) and of the centrally-located pile of logs likewise are straightforward problems in

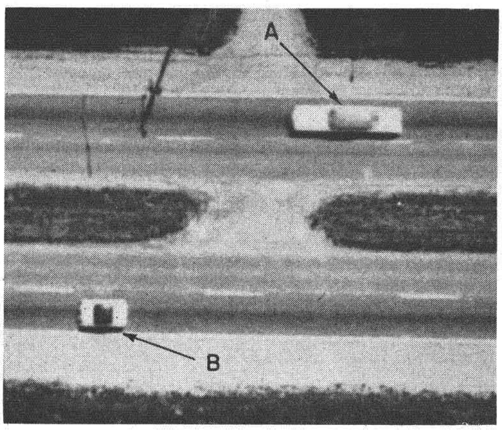

FIG. 12. Portion of a Sonne continuous strip photograph in which image motion compensation causes the ground to be registered in sharp detail, but in which automobiles moving in one direction are elongated (see *A*) and those moving in the opposite direction are foreshortened (see *B*). If the true length of each vehicle is known, it is possible through accurate photo measurement, to determine its velocity. (Photo courtesy of Chicago Aerial Survey.)

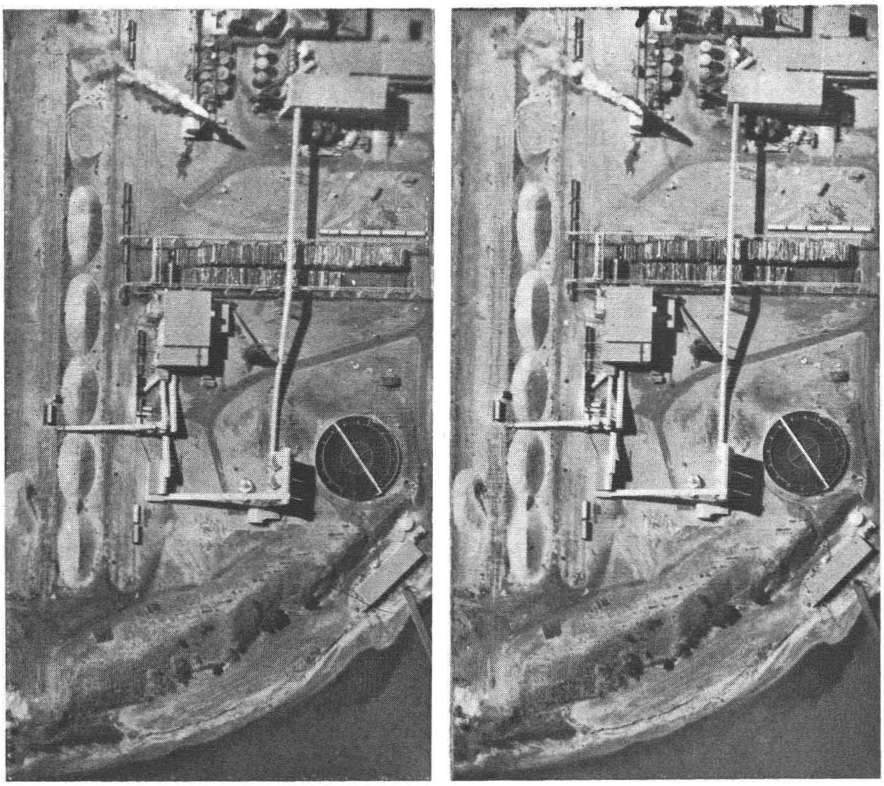

FIG. 13. For a discussion of the value of photo measurements in determining the volumes of various features shown in this stereogram, see text.

photogrammetry. Highway engineers concerned with cut and fill calculations have long since discovered the advantages of using aerial photo measurements to obtain this information.

A more complicated problem in volume determination is illustrated in Figure 14. The vertical aerial photo shown here was taken from an altitude of approximately 8,000 feet above the floor of Yosemite Valley in which Stand "A" is growing. The forest photo interpreter having only a rudimentary knowledge of photogrammetry can make measurements on this photo and its stereo mates, from which he can determine the volume of timber in Stand "A" quite accurately. To do so, he most likely:

(1) will calculate the scale, S, of the photography from the relation

$$S = \frac{f}{H};$$

(2) will measure, with a floating dot instrument or parallax wedge, the average height, h, of the dominant and codominant trees in Stand "A," using the relation,

$$h = \frac{H \times dP}{P + dP}$$

(3) will measure the average crown diameter of these same trees from the relation,

$$\text{Actual Crown Diameter} = \frac{\text{Photo Measurement of Crown Diameter}}{\text{Photo Scale}}$$

(4) will measure or estimate the crown closure of the stand with the aid of acetate template overlays on which crown closures of varying densities have been simulated so that the apparent crown closure of Stand "A" can be compared with this guide.

(5) will measure the acreage occupied by Stand "A," with the aid of an acetate template overlay on which dots have been drafted at such a spacing that each dot represents, say, one acre at the scale of the photography. The forester will then consult a previously-prepared aerial photo volume-table which relates actual timber volumes-per-acre (as previously established from ground survey) to tree-height, crown-closure and stand-

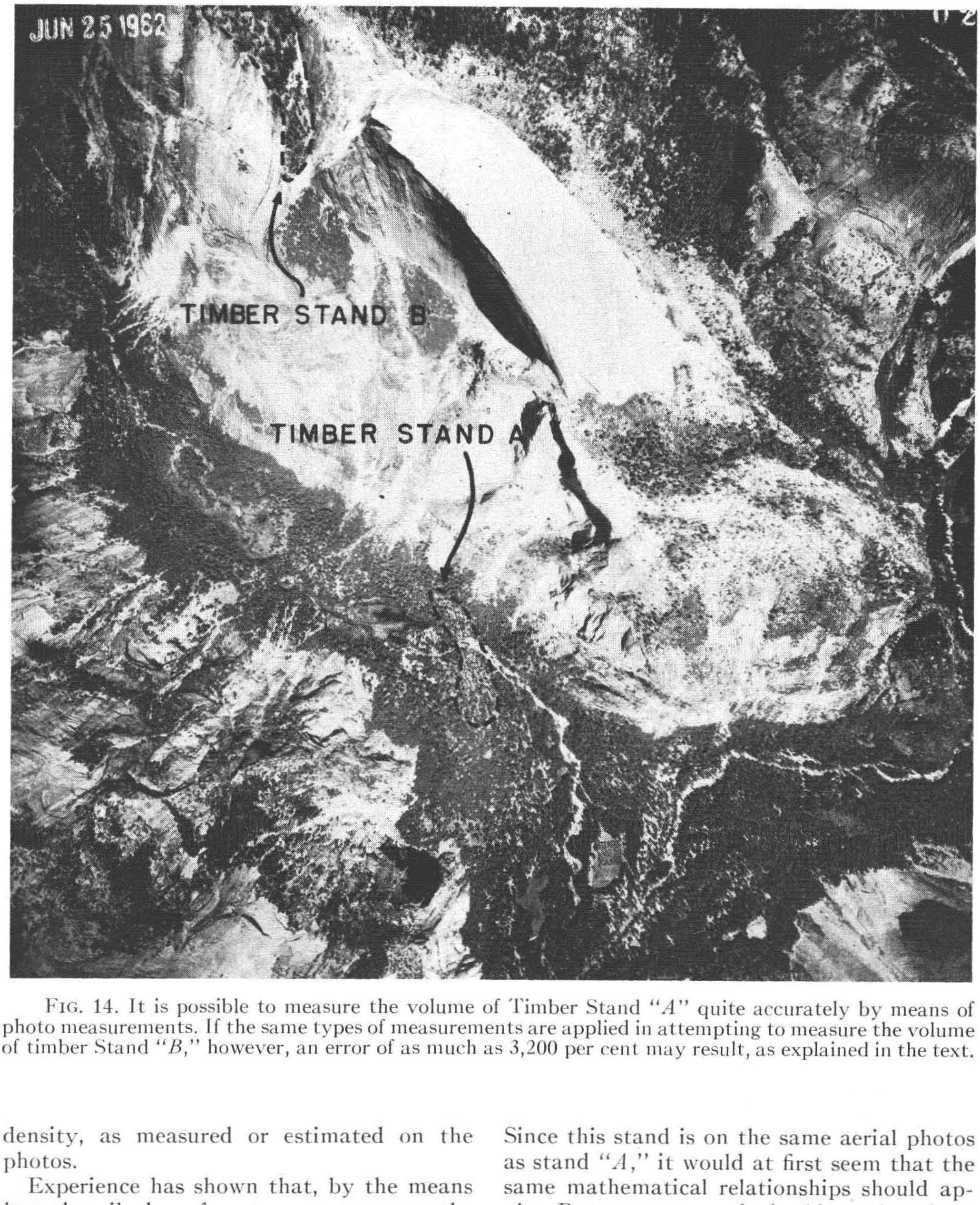

FIG. 14. It is possible to measure the volume of Timber Stand "*A*" quite accurately by means of photo measurements. If the same types of measurements are applied in attempting to measure the volume of timber Stand "*B*," however, an error of as much as 3,200 per cent may result, as explained in the text.

density, as measured or estimated on the photos.

Experience has shown that, by the means just described, a forester can measure the volume of timber, stand by stand, throughout a sizable area, such as the entire floor of Yosemite Valley, to an average error of considerably less than 10 per cent. This compares very favorably with the accuracy likely to be obtained by conventional methods of "timber cruising" on the ground.

Thus encouraged, the photo user might next attempt to use the same types of measurement and the same mathematical factors in determining the timber volume of stand "*B*." Since this stand is on the same aerial photos as stand "*A*," it would at first seem that the same mathematical relationships should apply. But upon ground checking, the photo user probably would find to his consternation that he had overestimated the volume of stand "*B*" by a staggering 3,200 per cent! A little reflection on how this could be possible will show that most of his difficulties stem from the fact that his camera was only 4,000 feet above stand "*B*" while it was 8,000 feet above stand "*A*"; consequently he probably has overestimated the *acreage* of stand "*B*" by 4-fold, its *tree-heights* and *crown-diameters*, each, by about two-fold, and its apparent *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