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Photogeologic Interpretation In Antarctica

A promising field for photogeologic studies; the difficulties of conventional methods place a high premium on the results.

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INTRODUCTION

PHOTOGEOLOGY IS THE SCIENCE and art of extracting geologic information from aerial photos. It has become a standard method of geologic investigation, supplanting, to various degrees, work previously done more slowly and more laboriously on the ground, and substantially increasing the efficiency of that part of the ground study which always remains essential. Under optimum conditions, the time required on the ground may be cut by 80 per cent or more from that formerly necessary. Under less favorable conditions, the reduction may be only 10 to 20 per cent. But in virtually all cases, significant economies are effected, and frequently accuracy is greatly increased also. This has been demonstrated in many types of terrain in many parts of the world, but can it apply also to the distinctive conditions of Antarctica, with its extensive cover of snow and ice, and other natural obstacles? Certainly any saving of time and effort, however modest, would be extremely helpful, for working conditions are particularly rigorous, the field season is limited in time, logistic problems are exceptional, and the status of geologic mapping is at least 50 years behind that in the United States. It is therefore of interest to analyze the various limiting factors on photogeologic work in general, and to consider their applicability to Antarctica in particular.

LIMITING FACTORS

The limitations on photogeologic studies are primarily three, of which the first is absolute, while the others are conditional: (1) the nature of the terrain, (2) the characteristics of the photography, and (3) the background of the interpreter. In considering the nature of the terrain, it is assumed, at this point, that bedrock geology is the objective of the study. The limitations then are those related to the nature of the geology and to the nature of the exposures. The former has to do with the distinctiveness of the various rock units, and the regularity or predictability of their structural trends, or relations in space. Distinctiveness depends on contrasts in visible characteristics (particularly color and/or relief due to differential resistance to weathering and erosion), on the scale of those contrasts, and on the arrangement of contrasting units in natural assemblages having group contrasts. Color contrasts are particularly helpful, but to be usable they must be such as to register clearly on the photographic media employed. And any contrasts to be of value must be on a sufficiently large scale to be easily recognizable at the scale of the available photography. To varying degrees these

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conditions are fulfilled in the area to be discussed.

The factor of structural regularity has to do with the simplicity or complexity of rock geometry—whether changes in the position and attitude of rock units from place to place are gradual or abrupt, systematic or unsystematic, continuous or discontinuous. Where the structures are comparatively regular and simple, interpolations between and extrapolations beyond particular localities can be made over considerable distances with confidence. Where the opposite is true, however, continuous or nearly continuous tracing of the rock bodies from place to place may be required for dependable results. In Antarctica structural regularity, in general, is favorable in the younger rocks but relatively unfavorable in the older rocks.

Closely tied to the above factor is that of the nature of the exposures—their shape, size, spacing, and disposition. In most regions more or less of the bedrock surface is concealed from view by a cover of soil and surficial deposits accumulated by the action of weathering, gravity, water, wind, and glacial ice; and to these is added the ice itself in Antarctica. The study of these deposits may be a specific objective for the surficial geologist, as noted later, but for the bedrock geologist they represent only an interference. In general, the simpler the geologic relations, the fewer and smaller the exposures needed for their interpretation, and the more complicated the geology, the greater the need for larger, more numerous, and more favorably situated exposures if photogeologic studies are to be effective. In that part of Antarctica under consideration, the availability of exposures differs greatly in different places—from minimal to excellent.

The second main limiting factor comprises the characteristic of the photography—the types and scales of the photos, types of film and filters used, the location of flight lines in relation to outcrop areas, ground conditions at time of photography, quality of the negative, and quality of the resulting print that the geologist receives for his work. For most areas of Antarctica, available photography is of the Tri-metrogon type, made with panchromatic film, and intended primarily for reconnaissance topographic mapping. The scale is comparatively small. Flight lines were not planned to show geologic features to the best advantage. Because of logistic conditions, flights could not always be timed for optimum lighting and weather conditions, with the result that surface detail may be adversely affected by long shadows, haze, overcast, or recent snow. The quality of the resulting negative varies with extremes of contrast which may be too low when lighting is poor, or too high were dark-colored rock is close to sunlit snow. And on the final positive print that reaches the geologist, these deviations may be accentuated if the printing is not carried out on an individualized basis with his particular requirements in mind. The photogeologist thus has a limited range of choice in his materials as compared to that which he might expect closer to home.

The third limiting factor is the knowledge which the interpreter brings to his task. As in all similar situations the best results are obtained only by the man who is most familiar both with the type of geology concerned and with the individual peculiarities of the terrain under study, a familiarity best gained from ground observations on representative areas, or, if that is not possible, by second-hand assimilation of the observations reported by others. With the foregoing generalities in mind, we may turn now to a more particularized consideration of what can be done, first with respect to bedrock geology, and then in

ABSTRACT: *The effectiveness of photogeologic interpretation under Antarctic conditions depends on the characteristics of the available photography and on the nature of the terrain itself. Trimetrogon photos made primarily for cartographic purposes provide a good starting point, but for best results they must be supplemented by vertical and/or oblique photographs at larger scales, along more favorable flight lines, at more suitable angles, and in both color and black-and-white. The terrain factors involve size, shape, and spacing of snow-free and ice-free areas; amount of cover by surficial deposits; distinctiveness of lithologic units and of their sequence; and degree of structural complexity. In general, the sedimentary rock of the Beacon group,* together with associated intrusives, *are readily interpreted, while the more complicated basement rocks are more difficult. This research was conducted under NSF grant GA-21.*

regard to geomorphology and surficial geology, and finally to the special field of ice tectonics.

Bedrock Geology

The total area of exposed bedrock in Antarctica is very small, and is confined mainly to the various scattered mountain ranges projecting through the ice. Our understanding of the geology of one major continent, however, and of its relations to other continental areas and its bearing on important questions of world geologic history, rests largely on the study of those small and scattered outcrop areas. Of these, the best and most available for study is the ice-free valley system and associated mountains and nunataks bordering McMurdo Sound. Geology is diversified and relatively well exposed, and there is a background of geologic study dating back to the time of Scott's historic expeditions in the early part of the century. Weather is relatively favorable, and the area has been photographed repeatedly at different scales and under different conditions. Helicopter support is available for field inspection and for supplemental photography. A favorable starting point for photogeologic studies is thus provided.

In general, the most basic distinction which can be made on photos is between layered and non-layered rocks, and this commonly can be done even well out on the Tri-metrogon obliques; this provides two generalized mapping units (Figure 1). The most distinctively layered rocks are the younger ones, the sandstones and associated shales of Devonian to Jurassic age, generally referred to as the Beacon sandstone or Beacon group. Intercalated with and lying beneath these are thick sills of dolerite, conspicuous for their darker color and more prominent relief. These rocks together show only minor deformation with some tilting and faulting. Their general relations can be mapped from available photography without difficulty, and if this photography had been available at the time, judicious use of it could have greatly expedited the reconnaissance geologic mapping already done (Gunn and Warren, 1962); as it is, the main use of photos has been to illustrate reports based on conventional ground methods, with the exception of one study by Hamilton (1965).

Detailed stratigraphic subdivisions, however, are another matter. Distinctive horizon markers are lacking, and appearances throughout the succession, in black-and-white photos, are much the same. Recent work by a colleague, however, has led to the recognition of color differences between Devonian and younger strata (Matz and Hayes, 1966), and there seems to be a good probability that this might be distinguishable on color photography of suitable quality and scale.

The non-layered to sporadically-layered rocks comprise the basement complex, of pre-Devonian age, together with some thick sills and thinner dikes of a later age. The basement rocks include both plutonic intrusives and strongly-deformed metamorphic rocks. The intrusives are of relatively uniform surface expression, and their general character is easily recognizable where exposures are adequate, as along the sides of Wright and Victoria valleys. Distinctions between them, however, are made on the basis of petrographic characteristics which can be ascertained only by field inspection and laboratory studies (cf. McKelvey and Webb, 1962). The associated metamorphic rocks locally show banding (Figure 2) but owing to structural complexity individual units generally cannot be traced very far, and the "homogenization" of physical characteristics produced by the metamorphic process has largely erased any distinctions in surface expression due to differential erodibility. Except in a few localities, as in middle Taylor Valley, available photography holds little promise for photogeologic studies, except as a guide to places for field examination.

It is possible, however, that color photography could be more helpful, both for the metamorphic and the igneous rocks. Some trials were made, but the Metrogon lens used proved unsuitable for color work, producing marked inequalities of exposure from center to edge of the photos. If uniform exposure could be attained by use of a compensating filter, or a more suitable lens, the value of color photography could be better appraised, and experiments with 35-millimeter cameras suggest that the potential is there.

The dikes intruding the basement complex generally have good surface expression, owing both to color contrasts and to relief resulting from differential erodibility. They are comparatively small, however, and are best studied on photos of comparatively large scale. On steep valley sides they may be delineated effectively on low-altitude oblique photos. Distinctions between different sets of dikes having different petrographic characteristics, although suggested in places by tonal contrasts, generally can be made only to a decidedly limited extent on available photography; here again color photography might be

FIG. 1. Tri-Metrogon oblique photo of upper Wright Valley, illustration surface expression of rocks units in the McMurdo region. The rock within the valley belongs to the basement complex, of pre-Devonian age, and is intruded by a dike complex represented by the striped pattern to the left of the frozen lake. The thick dark band of rock rimming the valley is a dolerite sill, and there is also a lower sill within the basement complex, here obscuring by detritus, but well exposed farther downvalley. The lighter banded rocks in the right foreground are sediments of the Beacon group, and toward the background these are seen to be capped or intercalated with a higher sill. Geomorphic features included are raised beaches just to the right of the lake, wind-eroded rock basins in the dike complex (not directly identifiable on photography at this scale), morainal and mass-movement detritus along the valley bottoms and sides, and an area of "scabland" topography at the head of the valley, believed formed by torrential flood erosion. (This and following illustrations are from photos made by U. S. Navy for U. S. Geological Survey.)

more useful. Dikes and associated minor intrusives occur also in the younger sedimentary rocks, and are particularly well shown on oblique photos of some valley sides, suggesting interesting research problems in structural geometry of the intrusive process.

A third general category of rocks in the McMurdo region, locally important, comprises the recent volcanics. These are most readily recognized from their topographic form. Details of form, however, tend to be obscured by the low contrast and very dark color of the rock, unless microrelief is accentuated by snow patches left after partial melting. New snow tends to add confusion.

Away from the McMurdo region, some photo coverage of ice-free areas is available (Whitmore and Southard, 1966), but at present the geologist generally is much more limited in his choice of photos. Scale generally is small, and features of geologic significance may lie well toward the background of oblique photos, permitting observation only of some gross characterististics. Snow cover also may be more extensive. Along the Trans-Antarctic ranges at least as far as the Beardmore Glacier, however, the same general divisions of rock bodies may be observed from the air, and their study could be facilitated by use of appropriate photography.

Supplemental photography made by the geologist himself, from helicopters or other aircraft, can be particularly useful for this purpose. These would be mainly hand-held obliques, made at selected altitudes, distances, angles, and lighting conditions, and may be in stereo pairs where desired. A 35-mm. camera of high quality gives good results, and a 70-mm. camera might be better. Some trials of two models of the latter have been made, but mechanical malfunctions caused difficulty. Panoramic views with a 16-mm. movie camera have been tried also, and although showing less detail, are useful for general orientation. If taken well before completion of field work, supplemental photography can contribute to maximum effectiveness of time spent on the ground.

One problem sometimes encountered with supplemental photography is that of locating particular photo areas. There are various ways of recording this at the time of photography, but one of the more helpful, particularly in strange or unmapped areas, is to include some prominent landmark in each overlapping group of photos, if not on each photo.

Another means of obtaining supplemental photography, although less flexible and requiring special arrangements not yet in effect, would involve the use of additional cameras on the aircraft employed for standard cartographic photo missions, now limited to Tri-Metrogon equipment. The auxiliary cameras might be fixed or hand-held, or both. Lenses of longer than the standard 6-inch focal length, properly aimed, should be useful for giving greater detail, and the use of color film for significant areas should be most helpful. Such photography, of course, could be of maximum value only if made by an operator thoroughly conversant with the geologist's needs.

The foregoing discussion is limited to geologic interpretation as such, with annotated photos as the product. The making of geologic maps from those photos involves additional procedures. If adequate base maps already prepared from photos are available, data may be transferred from photos to maps by controlled sketching, with the guidance of

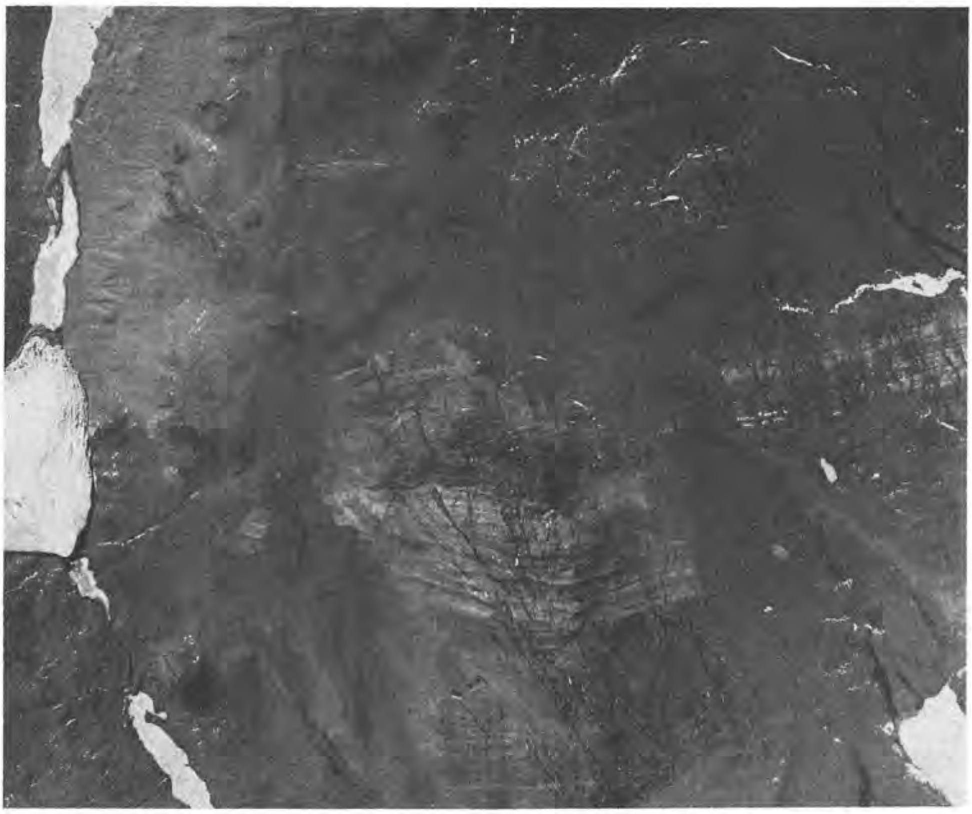

FIG. 2. Locally well-banded and strongly-deformed metamorphic rocks of the basement complex in middle Taylor Valley, on and near Mt. Nussbaum. The lower areas are partly covered by debris. The dark lines are dikes.

well-defined points identifiable on both map and photo, a method analogous to that widely used by geologists on the ground. This process is facilitated if nadir points of cartographic photos are marked on the map. For base maps that include contours, no special problems are involved, but if only planimetric detail is shown, auxiliary photogrammetric methods may be required, and if the geologist is not familiar with these, the assistance of a specialist is desirable. If base maps are of inadequate quality, or are lacking entirely, the problem is more involved, and photogrammetric techniques play a much larger role in the production of the required geologic map. Unless the geologist has had more than average experience with those techniques, teamwork with a photogrammetrist is needed.

Geomorphology and Surficial Geology

The more recent geologic events of a region are recorded in its landforms and surficial deposits. In Antarctica these have to do mainly with the work of glaciers and frost, but include also the work of wind, waves, and running water. The work of glaciers, past and present, has been a subject of widespread study (Nichols, 1964) with the main result that the problems have been outlined. Some of the grosser glacial features, such as moraines and cirques, are recognizable on air photos of available scales, and these have been used in their study. Other significant features, however, involving microrelief features and color distinctions, require photography of larger scale, under more carefully selected conditions, and with the use of color.

The work of frost is displayed primarily in the widespread occurrence of polygonal structures. On the largest scales of available photography, these are so minute that detailed characteristics are unrecognizable. On low-altitude photography made for the purpose, however, varietal differences can be distinguished, and it may be seen that they occur on bedrock as well as on unconsolidated deposits, a fact not previously reported in the literature.

Little has been written previously about the work of running water in Antarctica. In the present project, however, features which seemed best explained by that process were noted on photos prior to entering the field, and subsequent studies utilizing aerial and ground observations, together with low-altitude photography, pointed to flood erosion under catastrophic conditions (Smith, 1965a), a phenomenon known from very few other places in the world. A research problem was suggested and its execution was facilitated by photogeologic study.

The geologic effects of wind action have been variously and casually referred to in Antarctic literature. Some of these effects, such as sand dunes, are clearly displayed on air photos of standard scale. Others, however, are too small for this, but during the present project were spotted by aerial observation on helicopter flights and were recorded by low-altitude photography. These comprise wind-eroded rock basins (Smith, 1965b) and wind-formed pebble ripples (Smith, 1966), features not previously reported, and features giving new insight into the effectiveness of eolian processes in polar deserts.

In the study of surficial geology it thus appears that aerial observation, together with supplemental photography made for specific purposes, constitute an important research procedure. Photography for more generalized purposes may suggest some problems and provide some data, but leaves much undetected.

Ice Tectonics

One special type of feature of geologic interest which is shown with particular clarity on photos involves the deformation of ice. On land ice, this is represented by crevasse patterns. Although crevasses have long been known as a hazard to travellers, comparatively little has been done on the physics of their development. Air photos provide important data on their localization, spacing, pattern, etc., (Figure 3) and can provide a record also of changes with time. Infrared sensors, under favorable conditions, can give additional information on snow-covered crevasses (McLerran, 1965). Correlation of this information with surface topography of the ice, subsurface configuration of the bedrock floor as determined by geophysical methods, and rate and direction of ice movement, should contribute substantially to an understanding of the development of crevasses, and of their value as indicators of what lies beneath, and perhaps also of the prediction of their occurrence where concealed by snow cover.

On shelf ice, the pressures of ice movement against topographic buttresses, result in folds such as islands, and faults (Zumberge, et al, 1960) believed by some geologists to be more or less analogous with much larger features of the same type produced in rocks by lateral displacement. These ice structures are vividly shown on air photos (Figure 4), and photography at successive points in time may be used to study their gradual changes as pressure continues. This, hopefully, might lead to additional data for speculations on the larger questions of rock deformation.

Conclusions

Antarctica is a very promising field for photogeologic studies, and the difficulties of conducting conventional field studies place a particular premium on results therefrom. In some geographic areas and in some types of terrain, the limitations are greater than others, but in virtually all cases judicious use of photos can make for "streamlining" of the field program, effecting significant economies of time, effort, and materials, and allowing coverage of more territory. Under favorable conditions, the major geologic units may be blocked out in advance, permitting field studies to be concentrated on preselected places having maximum promise for detailed investigation, and reducing the time required for the more routine phases of geologic mapping. In some cases, photogeologic studies may direct attention to special research problems otherwise unrecognized. Any geologic project which fails to make full use of air photos both before and during the field work is likely to labor under serious and unnecessary handicaps.

Available cartographic photography provides a starting point, but supplemental special-purpose photography, which need not meet cartographic standards, is an invaluable supplement, particularly if made or directed by the geologist concerned. Further experimentation with color photography should be particularly helpful. The use of auxiliary cameras for this purpose on photographic missions could contribute in this connection, and the use of compact, hand-held cameras

FIG. 3. Crevasse patterns on undulating ice surface.

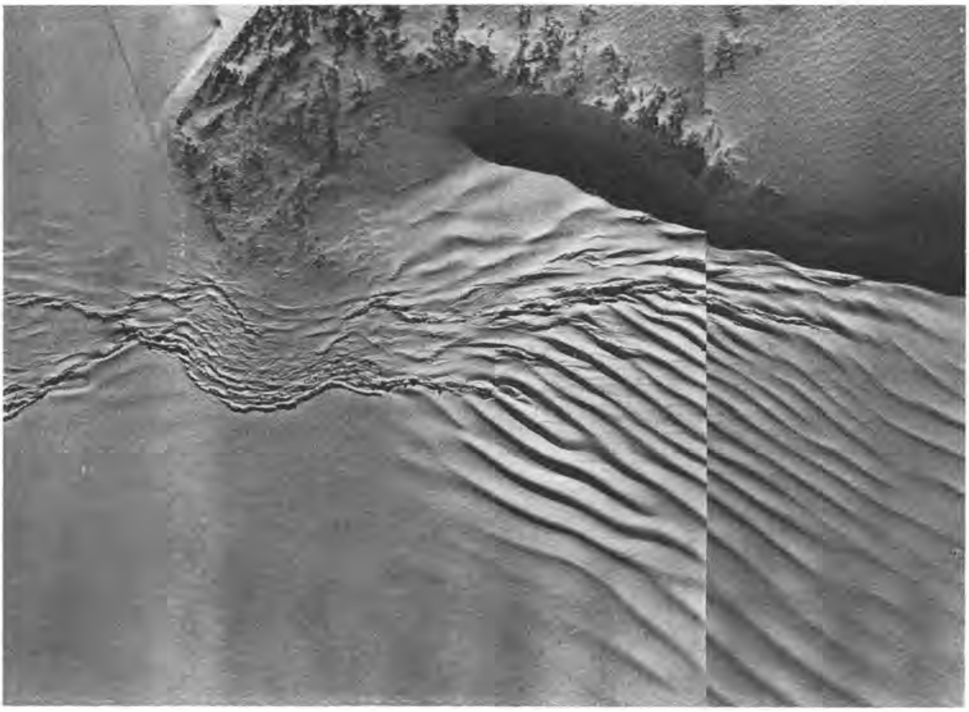

FIG. 4. Fold and fault patterns in shelf ice at south tip of Ross Island.

by geologists on flights to, from, and in field areas should be particularly advantageous. The use of remote sensing devices along with photography, furthermore, might provide additional information aiding in photo interpretation. And finally, photography from satellites in polar orbit (cf. Simonett and Brown, 1965) could contribute to a broader perspective on geographic and geologic relationships, and thus provide a better background for photogeologic work.

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