*Photogeological Interpretation of Areas of Regional Metamorphism**

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ABSTRACT: *The process of photogeological interpretation is considered and the use of photogeological "keys" deprecated. Emphasis is laid on the importance of developing a legend specifically adapted to photogeological work.*

Several stereopairs of aerial photographs are discussed with special reference to that geological information which can be obtained reliably, and in some cases only, from the photographs. It is claimed that aerial photographs should be regarded as geological research instruments in their own right, and not merely as aids to other geological work; that geological information from aerial photographs has a right to be treated as geological knowledge; and that geological field mapping must be consistent with photographic evidence, or must show positively where and why that evidence may be disregarded.

Eight principles of interpretation (not all of them original), developed from the discussion, are stated explicitly.

PROBABLY the earliest reference to the use of aerial photographs for geological interpretation is a lecture delivered by Thomas (1920, *c*), on 5th November, 1919, of which only the abstract is freely available. In the course of this lecture (the quotations are from the abstract itself and not from the lecture) Thomas noted that: " . . . a perfectly new method of illustrating and investigating some branches of physical geology is afforded by aeroplane photography. It seems first to illustrate in a very striking and convincing form many geological phenomena, such as the structure of a volcano or the land-forms resulting from erosion, and may be of value in the teaching of the science. In the second place it may, in certain circumstances, become a valuable means of research, especially in connexion with river-development or denudation in a region which is somewhat inaccessible, or where the surface of the ground is very complicated and the main features are obscured by a mass of less important detail." Later in the lecture, Thomas stated that in arid country, where the underlying rock is laid bare, the aeroplane camera often shows the general geological structure of the district, and, referring to the depression of the Dead Sea, he remarked that some evidence of faulting at different periods can be distinguished.

Another important paper by the same writer (Thomas, 1920, *a*) described an investigation into the possibility of using aeroplane photographs for the production of maps in Egypt during the war. He stated that it was there that the strip system of aerial photography was developed, as distinct from the old system of photographing a number of adjacent points in no regular order, known as pin-pointing. He was much ahead of his time in his valuation of the stereoscopic view, and he wrote (p. 357): "Form lines were added to all the later maps, and these were based on the stereoscopic examination of adjacent prints."

At this very early stage in the development of photogeology, Thomas had an astonish-

* A slightly abridged version of a paper published in the *Transactions of the Institution of Mining and Metallurgy*, vol. 70, 1960–61, Part 9, pages 521–543 (Bulletin 655, June 1961). Illustrations in the original publication were printed by the Collotype process, and the author apologizes in advance if any details referred to are not in fact visible on the illustrations reproduced here by the half-tone process and using a 133 line screen.

ingly clear understanding of the potentialities of aerial photography for the purposes of geology, geography, botany, archaeology and meterology (Thomas, 1920, *b*) and, so far as photogeology is concerned, he has a strong claim to be regarded as the principal originator of the subject. Unfortunately he has not been given due credit in the voluminous literature on photogeology which has subsequently been written.

The author of this paper has been employed by the Directorate of Overseas Geological Surveys, Photogeological Division, since January, 1954, on the photogeological study of areas of regional metamorphism in Africa. During this period three prolonged field visits were made at the request of the Geological Survey of Nigeria to check the photogeological interpretations with the field evidence and also to provide bases for further interpretations.

All except one of the photographs reproduced with this paper were taken by the Royal Air Force, the majority in 1948 and 1949. The flying height was about 17,000 ft. and the camera lens had a focal-length of 6 in. Thus, after allowing for a ground height of 1,000 ft., it will be seen that the average scale of the photography is 1:32,000.[1] The photographs used for the field work and photogeological interpretation were 9-in by 9-in contact prints on waterproof bromide paper.

INTERPRETATION—GENERAL

The factors which determine the appearance of a rock on aerial photographs are: (i) climate, (ii) vegetation cover, (iii) soil cover, (iv) absolute rate of erosion, (v) relative rate of erosion of the rock compared with that of the surrounding country rock, (vi) colour and reflectivity, (vii) mineral constituents, (viii) physical characteristics, (ix) depth of weathering, (x) structure, (xi) texture and (xii) factors inherent in the type of photography and the conditions under which the photography was obtained.

It is not proposed to discuss the effect of each of these factors separately but rather to draw attention both to their large number and to the fact that many of them are interrelated. The vegetation cover affects the soil cover, the rate of erosion, and the depth of weathering; it is itself affected by climate, soil cover, the absolute rate of erosion of the rock, and by various characteristics of the rock, such as its mineral constituents, physical characteristics, depth of weathering, structures, and textures. The rate of erosion affects vegetation cover, soil cover, depth of weathering; it is itself affected by climate, vegetation cover, soil cover, mineral constituents, phyical characteristics, depth of weathering and structures within the rock. This interrelation of the factors produces an immense number of variations in the possible photographic appearance of a particular rock type.

Considerable attention has fairly recently been given to the production of "systems" or "keys" to aid in photogeological interpretation. A good example of a "key" is that by Liang and others (1951). This publication contains a large number of excellent photographs of different rocks taken under different climatic conditions. It is of value in the early stages of photogeological tuition and it might help inexperienced personnel to search on photographs for particular rocks. A student, studying aerial photographs with the assistance of the "key," might find a particular photographic image which corresponded to one in the "key." In the process, however, he might well have seen many other photographic images of the same rock which did not correspond to the "key" and which he would thus be unable to interpret.

Such a "key" therefore is not of great value in the photogeological interpretation of areas of regional metamorphism because it is frequently impossible to find in the "key" a photographic image similar to the one observed on the aerial photograph. This is to be expected because of the great variability in the photographic appearance of the rocks mentioned above. Thus it is possible sometimes to go successfully from the "key" to the aerial photograph, but seldom vice versa.

The two granites, represented in Figures 1 and 2,[2] which occur within 8 miles of one another, and which differ widely in photographic appearance, support the above contention. From the stereopair Figure 1, the following facts about the rock are obtained: (1) it is light toned; (2) it has practically no cover of vegetation; (3) it has no soil cover; (4) it erodes less quickly than the country rock (metasediments); (5) it weathers by exfoliation, forming domes; (6) it has a clearly defined joint system; (7) it shows no bedding features; (8) it shows few textural features; (9) it is sensibly homogeneous. On the basis

[1] This scale refers to the original negatives and contact prints and not to the scale or reproduction in this paper.

[2] Field confirmation of the granites in Figures 2 and 13 was provided by Dr. J. Truswell of the Nigerian Geological Survey.

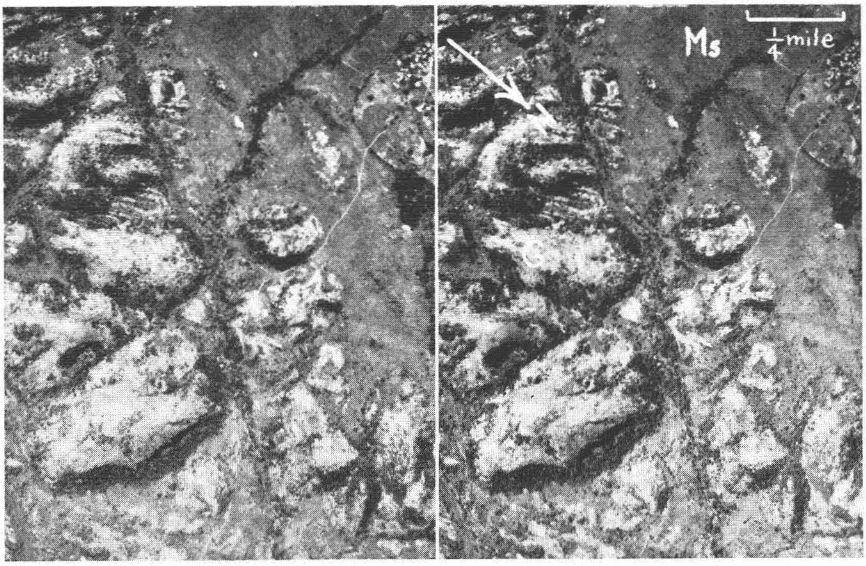

FIG. 1. Stereopair—Granite (G) and metasediments (Ms), Tegina Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

of these facts all geologists, whether experienced or not in photogeology, would interpret this rock correctly as granitic.

From the stereopair Figure 2, the following different set of facts about the rock occupying the centre of the figure are obtained: (a) it is light-toned; (b) it has a cover of vegetation; (c) it is covered with light-toned soil; (d) it erodes rather more quickly than the country rock; (e) it contains few, poorly developed, joints (point 1); (f) it shows no textural features; (g) it shows no bedding features; (h) it is sensibly homogeneous; (i) it is emplaced within the nose of a fold in metasediments. On the basis of these facts, most geologists would again correctly interpret the rock as granitic, although the facts obtained from Figure 2 differ considerably from those from Figure 1.

The reason that the geologist can produce

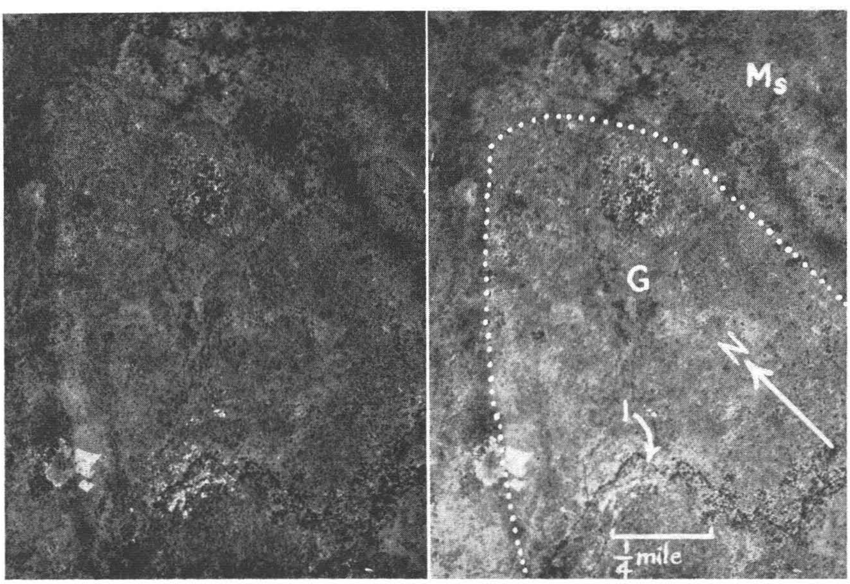

FIG. 2. Stereopair—Granite (G) and metasediments (Ms), Zungeru Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

the same correct interpretation from a dissimilar set of facts is because he takes into consideration the interrelation of the factors which affect the photographic appearance of rocks. He evaluates and synthesizes the geological information supplied by the aerial photographs, instead of interpreting it automatically according to some "key." His process of interpretation of aerial photographs is analogous to his interpretation of rocks in the field; in both cases he obtains a certain number of facts about the rock, and in the light of all these facts considered simultaneously, he decides what the rock is. This is the reason why a photogeologist must be primarily a geologist, and why a photogeological "key" cannot be used by a non-geologist to produce a useful photogeological map.

Stringer (1953) suggested that photogeology should take its place along with petrology and paleontology as an equal and vital tool of the geologist. Perhaps a more apt comparison is, however, between an aerial photograph and a petrological microscope. This comparison is useful because it leads to an understanding of both the value and the limitations of photogeology. The petrographer, using his microscope, studies a very small piece of rock very closely, and all those characteristics of the rock which require an area larger than that of a thin section to become apparent, are unseen by him. The field geologist has not the the advantage of seeing the microscopic characteristics of the rock, but he sees all the macroscopic characteristics which are able to express themselves in the area of a single outcrop. The photogeologist, however, is in effect even further away from the rock than the field geologist. Many of the macroscopic characteristics expressed in single outcrops are lost to him, but in partial compensation for this he sees those rock characteristics which require great areas for their expression.

As the geologist retreats further and further from his rocks, in order to get a wider and wider view, so must his rock division become progressively more generalized. It has long been accepted that the field geologist, working without the valuable aid of a petrological microscope, must perforce use more generalized rock divisions than the petrographer in his fully equipped laboratory. In a precisely analogous way, it is necessary for the photogeologist to use more generalized rock divisions than the field geologist.

The necessity for the photogeologist to work according to a generalized legend adapted specifically to his needs has been largely overlooked in the past, and no reference to it will be found in the literature. This oversight has probably retarded the development of photogeology, because geologists studying aerial photographs for the first time have been disappointed by their inability to determine rock types seen on the photographs with the same precision as those seen in the field; this has led them to underestimate the value of the data which they have in fact obtained from the photographs.

THE GENERALIZED PHOTOGEOLOGICAL LEGEND

A photogeological legend should be self-explanatory, be not more specific than the photogeological evidence justifies, and should enable all the geological information obtained from the photographs to be recorded.

For a particular body of rock, some or all of the following data may be obtained from aerial photographs:

(a) the photographic tone of the rock body relative to that of the adjacent rocks,
(b) the resistance to erosion of the rock body relative to that of the adjacent rocks,
(c) the boundary of the whole rock body,
(d) the topographical expression of the whole rock body,
(e) the boundaries of the individual outcrops,
(f) the joint pattern,
(g) the fault pattern,
(h) the drainage pattern,
(i) the vegetation cover,
(j) the bedding or the relic bedding lineaments,
(k) the schistosity or "gneissosity" lineaments,
(l) the regional geological environment.

These data form the basis for the subdivision of rocks by the photogeologist and thus for his generalized legend. They should, under favourable conditions, enable him to decide, among other things, whether a particular rock is sedimentary, metamorphic, or igneous, and whether the igneous rock is extrusive or intrusive, acid or basic in character. If the rock is sedimentary, the data may enable it to be given a specific name, but for igneous and metamorphic rocks this is frequently not possible. The photographic data often give little indication of the mineral constituents of the metamorphic rocks, and mineralogical prefixes to the names of the metamorphic rocks are usually unsuitable for a photogeological legend.

Although a satisfactory "key" showing all the possible photographic appearances of particular metamorphic rocks cannot be produced, dissimilar metamorphic rocks will in general appear dissimilar on the photographs; they can frequently be differentiated on photographic evidence alone although no specific rock names can be given to them. It is therefore true to say that a photogeologist can sometimes sub-divide the metamorphic rocks into their respective groups without being able to decide of what the groups consist. It is one of the purposes of the generalized legend to enable these sub-divisions to be recorded without using specific petrological names which are not justified by the photographic data. The generalized photogeological legend should therefore indicate the type of rock rather than the petrological name of the rock; and the various groups of metasediments are better differentiated by numbers rather than by names of doubtful accuracy.

As an example of a generalized photogeological legend which is of value in areas of regional metamorphism in savannah-like country in Africa, the following is suggested:

- (i) Metasediments—Group (1)[3]
- (ii) Metasediments—Group (2), etc.
- (iii) Quartzites (these can frequently be recognized specifically from aerial photographs alone)
- (iv) Metasediments—undifferentiated
- (v) Permeation gneiss and migmatite
- (vi) Granitic rocks—autochthonous, mostly granites and granodiorites
- (vii) Granitic rocks—intrusive
- (viii) Granitic rocks—general, may be autochthonous or intrusive
- (ix) Acid igneous rocks—extrusive
- (x) Basic igneous rocks—intrusive
- (xi) Basic igneous rocks—extrusive
- (xii) Dyke—acid
- (xiii) Dyke—basic
- (xiv) Dyke—general (may be acid or basic)
- (xv) Superficial cover—residual
- (xvi) Superficial cover—transported.

(The unmetamorphosed sediments have been ignored in this legend because they are outside the scope of this paper; they can frequently be named specifically from the study of aerial photographs.)

Probably in no single area would such a legend be used in its entirety, because each area has its own special problems of photogeological interpretation. The use of group numbers for distinguishing between rocks of dissimilar photographic appearance, but falling into the same main divisions can be extended to all the main divisions in the legend, instead of being confined to the metasediments as in the legend above. The flexibility of this legend is of great value in the photogeological interpretation of areas of regional metamorphism allowing continuous modification and enlargement as the work progresses.

[3] Metasediments are defined as metamorphosed sediments, of all grades of metamorphism up to, but excluding, that represented by permeation gneiss.

INTERPRETATION TECHNIQUE

In areas of regional metamorphism the photogeological interpretation of a single stereopair is occasionally a matter of uncertainty. Features of undoubted geological origin are sometimes observed on a particular stereopair without that stereopair providing sufficient data to indicate what the features represent. Such features may be of considerable length and extend across several stereopairs, any part of any one of which may provide the data necessary for their interpretation. It is therefore very desirable that the photogeologist be able to study each stereopair individually, then in relation to the immediately adjacent stereopairs, and finally in relation to the area as a whole.

The photogeologist working in areas of regional metamorphism must also be able to postulate on the photographs the existence of structures and boundaries, etc., and then modify them as he obtains further data from the adjacent photographs.

Finally, it is desirable that the photogeologist keep constantly in his mind the relationship between the geological structures on the stereopair he is studying and those of the area as a whole. For this purpose, he should be able to form a rough uncontrolled print "laydown" of the photography of the whole area in a few minutes.

In order to satisfy all the above requirements a special technique is necessary for the interpretation and handling of the aerial photographs. The technique described in this paper was developed by the author for his work in Nigeria.

All the edges of the photographs are trimmed off with a guillotine, with the exception of the titling strip. By the simple process of matching edge detail, the alternate photographs are arranged into strips and stuck with cellulose tape; their conjugate pairs are kept separately in numerical order. The strips are then put together in their correct relative position to form a rough uncontrolled print laydown, and then numbered in numerical order from north to south. A strip near the centre of the area, on which the geology is shown most clearly, is selected as the one on which to begin interpretation. The other strips are piled upon one another in numerical order, to save space.

If a very detailed interpretation is required, the photograph in the selected strip on which the geology is shown most clearly is removed from the strip, and interpreted stereoscopically with its conjugate pair, under a high-power (6 ×) binocular mirror stereoscope. Frequently, however, the required map does not justify such detailed work, and in that case the photograph is not removed from the strip but is interpreted stereoscopically, with its conjugate pair, under a pocket stereoscope. After completion of this interpretation, the next photograph along the strip is interpreted, and so on, to the end of the strip. With the strip completed, it is then considered as a whole to see whether the interpretation is consistent from one photograph to the next. The advantage of studying each photograph on its merits before considering it in relation to the other photographs is that in this way attention is drawn to those areas where the interpretation is doubtful, thus reducing the danger of making an incorrect interpretation based on insufficient evidence and then transferring it from photograph to photograph. When all the strips have been similarly interpreted, they are re-interpreted in relation to one another in the following way:

(a) The "side-lap" between strip numbers (1) and (2) is studied stereoscopically with a pocket stereoscope and the interpretations are compared and finally equated for both strips. Strip number (1) is then studied again with a pocket stereoscope, and the new information from the adjacent strip (2) is incorporated in its interpretation.

(b) The "side-lap" between strips (2) and (3) is next studied stereoscopically as described in (a) above, and strip (2) is re-interpreted with the incorporation of the data from strips (1) and (3). In this way all strips are eventually re-interpreted with the incorporation of the data from their adjacent strips, and the geological interpretation of all strips is made consistent.

When this procedure has been completed, all photographs have been interpreted twice; once individually, and once in relation to all the surrounding photographs.

ANNOTATIONS

When making a photogeological interpretation in an area of regional metamorphism, it is advisable not to use an overlay but to work directly on the photographs with grease pencils; the advantages are that: (i) no damage is caused to the emulsion of the photograph; (ii) the annotations may be removed in a few seconds with a rag moistened with methylated spirits, thus enabling the photogeologist to revise his interpretation when fresh data are obtained; (iii) there is no overlay to obscure the photograph during interpretation; and (iv) much time is saved which would otherwise be spent in cutting, filing, and handling the overlays, etc. The disadvantages however, are that: (i) the annotations are not really permanent and are liable to smudge; (ii) once an annotation covers a particular feature, that feature cannot be seen stereoscopically; (iii) fine detail cannot readily be traced with a grease pencil.

Because of disadvantage (iii), Desjardins (1950) advised that photographs should be annotated with water colour and a mapping pen. This system is useful when dealing with sediments in which the interpretation is not in doubt, when precision is of great importance, and when the annotations are to form a basis for contouring individual horizons. In areas of regional metamorphism, however, the interpretation often contains an element of doubt, the dips of the metasediments are frequently very steep, and the metasediments themselves are usually entirely unsuitable for structure contouring. The ease with which grease pencil annotations may be removed from photographs has the advantage of allowing the photogeologist to "think aloud" on his interpretation.

AERIAL PHOTOGRAPHS AS INSTRUMENTS OF RESEARCH IN AREAS OF REGIONAL METAMORPHISM

BEDDING AND FOLIATION[4]

In areas of regional metamorphism, aerial photographs frequently provide the most reliable as distinct from the quickest way of ascertaining the strike of metasediments. One of the principles in photogeological interpretation now considered is that, in areas of metasediments, aerial photographs indicate the bedding rather than the foliation direction, and that where only one direction of lineaments is observed, that direction represents the bedding.

Much can be learned by comparing the photographic appearance to be expected of an

[4] Foliation is defined as the ability of rocks to break along approximately parallel surfaces. (Billings, M. P. *Structural Geology* (New York: Prentice-Hall, 1942), 213.)

area of rock in which the rock foliation controls the lineaments, with that of an area consisting of a series of dissimilar metasediments in which the bedding controls the lineaments. The two types of lineaments, in the author's opinion, are fundamentally different.

In areas of foliated but otherwise homogeneous rock, the lineaments should be controlled by the foliation. Such lineaments can be expected to show some or all of the following characteristics:

(i) They should be parallel to one another. Because the foliation results from regional stress, the foliation planes should be parallel to one another over a large area.

(ii) They should be very numerous. Because there is an almost infinite number of foliation planes in the rock, there is no limit to the number of lineaments one could expect to find on the photographs.

(iii) They should be short. Because one foliation plane is similar to another, there is no property which can ensure the continuation of a particular lineament. For example, if a stream bed is parallel to the foliation, and if it reaches a line of greater weakness, such as a transverse joint, it will continue in the transverse direction to the end of the joint and then take up its original direction parallel to the foliation; its final course, although parallel to its original course, will not be in the direct prolongation of it, and there will thus be two short, parallel, separate, linear features. In contrast to this, if the stream had been in a bed of metasediments noticeably more easy to erode than the surrounding rocks, it would tend always to return to the soft bed, or alternatively a new stream would develop in the soft bed; whichever event occurred, the soft bed would form a long, single, and almost continuous feature.

(iv) They should never consist of long continuous ridges or valleys for the reasons given under (iii) above.

An example of the kind of lineaments which result when the controlling factor is foliation is seen on the top of the outcrop of autochthonous granite in Figure 9. In the field this granite showed an indistinct "gneissosity," but no trace of relic bedding.

In areas of heterogeneous metasediments, where the lineaments are controlled by the bedding, they can be expected to show some or all of the following characteristics:

(a) They should be long compared with the foliation lineaments. Although they may intermittently be covered by superficial deposits, they should reappear again and again throughout the length of the controlling bed.

(b) They should tend to be more evenly spaced, and limited in number, as compared with the lineaments resulting from foliation.

(c) They may sometimes consist of long, continuous, parallel ridges or valleys, because beds which differ in their mineralogical composition will also differ in their resistance to erosion. Resistant beds will thus tend to form ridges along their full length, whereas the more easily eroded beds will form valley bottoms.

(d) They may sometimes show bedding structures.

A soil-covered area of metasediments is shown in Figure 3. The precise area there shown has not been visited by the author, but field work south of the area has indicated that these metasediments consist of quartz-mica schists and schistose arkoses.[5]

The lineaments in Figure 3 are typical of those controlled by the bedding. Study of the stereopair in this figure gives the following data concerning the lineaments: (i) they are continuous over considerable distances; (ii) they consist of long, subdued, parallel ridges, (see points (1) and (2)), and (iii) they are unidirectional.

In country such as that depicted in Figure 3 outcrops are often small and sparsely distributed and the bedding planes are difficult to determine from the individual outcrops. If the geologist, working without aerial photographs, in country of this type, finds the evidence of his small rare outcrops inconclusive, he is compelled to use the ridges as a general guide to the strike direction of the metasediments, thus using the same criteria as the photogeologist; but his observations are more laborious and less conclusive.

One of the reasons why the observations of the field geologist may sometimes be less dependable than those of the photogeologist is that the field geologist lacks the advantage of vertical exaggeration when he observes topographic forms. He is compelled to estimate the crests of the ridges, which may be indistinct, and then to judge their direction. He sees only a short length of the ridge at a time, and must either extrapolate on his map or walk the length of the ridge.

Aerial photographs are almost invariably

[5] The areas actually visited in the field do not always provide the best photographic illustrations for the subjects under discussion. Unless otherwise stated, therefore, the discussion of the illustrations can be assumed to have the support of field work, but the precise points referred to on the illustrations cannot always be assumed to have been visited in the field.

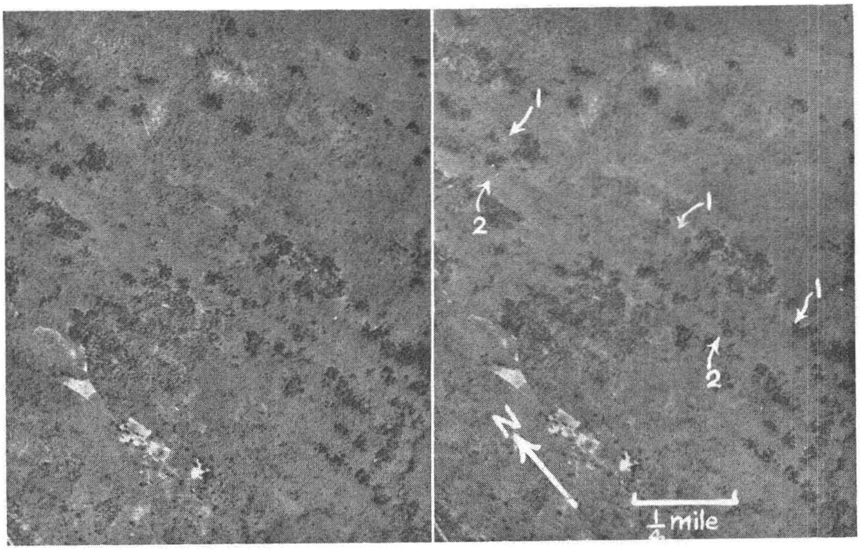

FIG. 3. Stereopair—Metasediments, Tegina Sheet, Nigeria.
(R.A.F. photographs, Crown copyright reserved.)

taken in such a way as to produce vertical exaggeration in the resulting photographic stereomodel, and, as a result of this exaggeration, low, rounded, subdued and indistinct ridges appear relatively sharp on the stereomodel and can be followed with precision. Very subdued ridges which are imperceptible on the ground become visible on the stereomodel. When it is recalled that these subdued ridges are the surface expression of the strike of the underlying metasediments, it will be agreed that aerial photographs sometimes provide the most reliable, as distinct from the quickest, means of determining the strike of

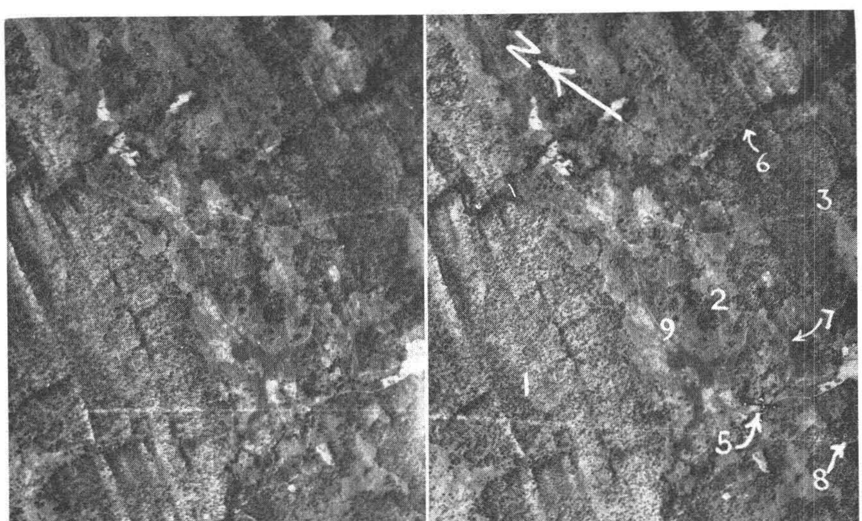

FIG. 4. Stereopair—Metasediments, Tegina Sheet, Nigeria.
(R.A.F. photographs, Crown copyright reserved.)

the metasediments, and that sometimes they provide geological data unobtainable by normal field methods.

Difficulties in determining the strike of metasediments from photographs are largely confined to the following two conditions: when two or more different sets of lineaments show on the photographs, and when there are no distinct lineaments.

The doubt sometimes expressed as to whether photographs show bedding or foliation is largely due to the fact that these directions so frequently parallel each other. On aerial photographs the bedding direction will be emphasized, but in field outcrops the foliation direction usually will be the more prominent. As these two directions are often parallel in strike, it is not surprising that the field geologist frequently suspects incorrectly that the photographs reveal foliation rather than the bedding.

Another example in which aerial photographs provide geological data which can be obtained only with difficulty from field work is given in Figure 4. Field work showed that the rocks there depicted consisted of phyllite, the foliation planes of which were parallel to the ridges. The major ridge (1) and the ridges (2) and (3) obviously represent bands of rock relatively resistant to erosion. Their characteristics agree with those listed above for lineaments controlled by the bedding. The question, however, arises: Could these ridges (1), (2) and (3) be controlled by the foliation?

If they were controlled by foliation then they would not be expected to persist on each side of the transverse streams as they do—see points (4), (5) and (6). Similarly, the fact that the stream beds marked (7) and (8) form a single straight line crossing the major transverse stream indicates that they occupy the same definite line of weakness. If they were merely following foliation planes they would be parallel, but it would be a coincidence if they were co-linear. On the opposite side of ridge (2), the wide "U"-shaped valleys marked (9) and (10), north and south of the transverse stream, are also co-linear. There is therefore no doubt that ridge (2) is controlled by the bedding and thus indicates the true strike of the metasediments. The same arguments apply to ridge (3) and show that this ridge also indicates the strike direction.

The strike of these metasediments was determined in the field and it was confirmed that the ridges were parallel to the bedding, and hence that they indicated the true strike direction of the metasediments.

The problem of finding the strike direction of metasediments in the field can be an arduous one. Aerial photographs, however, sometimes provide the information immediately and reliably as in Figures 3 and 4. This is one of the reasons why aerial photographs are of so much value in research on areas of regional metamorphism.

The problem of the interpretation of the dip of metasediments from aerial photographs is more difficult than, and not strictly analagous to the interpretation of strike, for the following reasons:

(i) The metasediments are characteristically tightly folded and steeply dipping.

(ii) Because the metasediments are usually steeply dipping, the trace of the strike on the surface of the ground is but little affected by variation in topography and tends therefore to give only the minimal evidence of the direction of dip.

(iii) True indisputable dip slopes are seldom observed.

(iv) Although, in tightly folded metasediments, the strike of the foliation is usually parallel to the strike of the bedding, it is less certain that the dip of the foliation is parallel to the dip of the bedding.

(v) As only one type of slope can be recorded on the photographs, it is not possible to generalize and to postulate by analogy with the strike discussed above that, if only one slope is indicated, that slope represents the dip of the bedding.

(vi) Whether or not an apparent dip slope is that of bedding or foliation depends upon the relative effect the forces of erosion have on these different types of discontinuity.

The reliable criteria for the recognition of dip on metasediments on aerial photographs are:

(a) the "V"-like traces produced by clearly defined lithological boundaries as they cross river valleys or other topographical features;

(b) the occurrence of apparent dip slopes associated with indisputable bedding structures.

FOLDS

Because aerial photographs frequently supply the clearest and most reliable indication of the bedding direction in metasediments, they also frequently supply the clearest and most reliable evidence of folds and faults within the metasediments. In the discussion of Figure 4, it was stated that the determination of the strike of the metasediments from field work might be an arduous task. If complete fold structures in the metasediments had to be elucidated by the multiple determinations of strike in the field, it could indeed be a mammoth task, and many important structures would inevitably be overlooked altogether. Fortunately, however, aerial photographs greatly simplify the structural investigation of areas of metasediments.

The structure in Figure 5 (not investigated in the field) is not readily elucidated, because of soil cover. If a single photograph of the stereopair is observed with the unaided eyes, the distribution of the vegetation will be seen to indicate the existence of a nose of a fold. When the stereopair is studied under a stereoscope, the ridges near points (1) and (2) confirm the presence of a fold. If the trace of the bedding is followed with care in Figure 5, it will be found that at point (3), where the bedding is cut by a stream, it forms an obtuse-angled "V" with the angle pointing towards the west, i.e. downstream. The beds near point (3) are therefore dipping due west. No other dips can be determined with any confidence, but as the bed at point (3) dips west and forms an eastern limb of the fold, there is some evidence that the fold is synclinal.

Another fold, depicted in Figure 7, has been traversed by the author approximately along the line of the path shown on the figure. The rocks seen were quartzites, quartz schists and biotite schists. The great majority of the area is soil covered and outcrops are very sparsely distributed.

The bedding beneath the soil cover in Figure 7 is indicated by the dark lines of vegetation which occur on the crests of low ridges—see points (1) and (2). In the field, the ridges and vegetation lines can be seen only with difficulty even when attention has been directed to their presence by the aerial photography. They would not normally be observed by a geologist without aerial photographs and if he did notice them he would have great difficulty in following them across country. The ridges and vegetation lines, can however, be traced on the stereopair Figure 7 in paths such as point (2) via point (3) to point (4), to form the nose of a fold. As a result of studying the aerial photographs, the geologist is able to know that he is about to traverse a fold before he even starts his field work.

Field work in the area shown in Figure 7 revealed that the beds forming the eastern limb of the fold dip 40° to the east, and those forming the western limb dip 35° to the west. Thus the combination of a single field traverse and a few minutes inspection of a stereopair of aerial photographs indicates that the structure is an almost symmetrical anticline.

Without aerial photographs the field observations on the eastern and western limbs of the fold would perhaps enable the field geologist to foresee the possibility of the presence of an anticline, but as he would have no reason to believe that the rocks observed in the west were of the same series as those of the east, he would not be justified in mapping the anticline. Before he could map an anticline, he would have to "walk" the beds round the nose of the fold—a time-consuming task in this area of sparse outcrops and thick soil cover. Thus Figure 7 shows an example of an important fold in metasediments, which can be mapped with great confidence from aerial

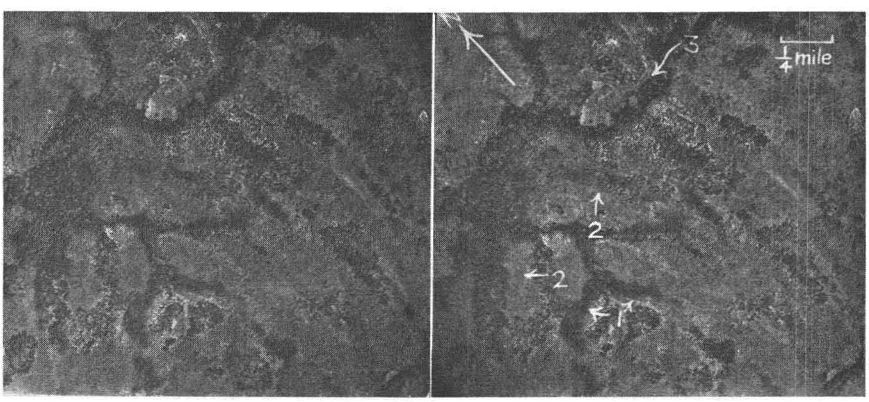

Fig. 5. Stereopair—Fold in metasediments, Zungeru Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

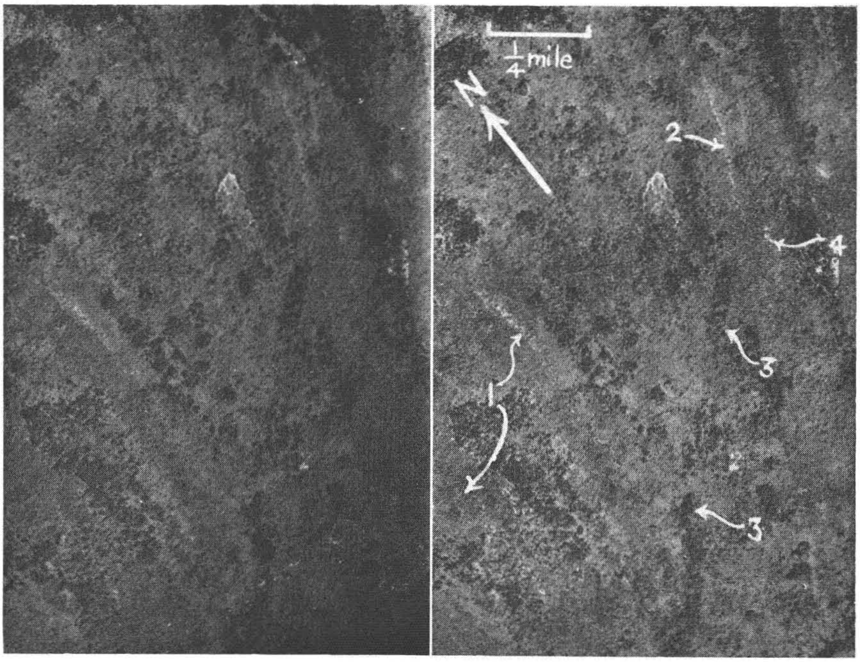

FIG. 6. Stereopair—Fault in metasediments, Zungeru Sheet, Nigeria. (R. A. F. photographs, Crown copyright reserved.)

photographs but which would be in danger of being completely overlooked by the field geologist who is working without aerial photographs.

FAULTS

Because aerial photographs sometimes provide the most reliable evidence of the strike of rocks in soil-covered areas, they also sometimes provide the most reliable evidence of faults in such areas.

The stereopair in Figure 10 shows an area of Karroo sediments. It has been chosen because it illustrates the author's contention that aerial photographs should be treated as research tools in their own right and not merely as a

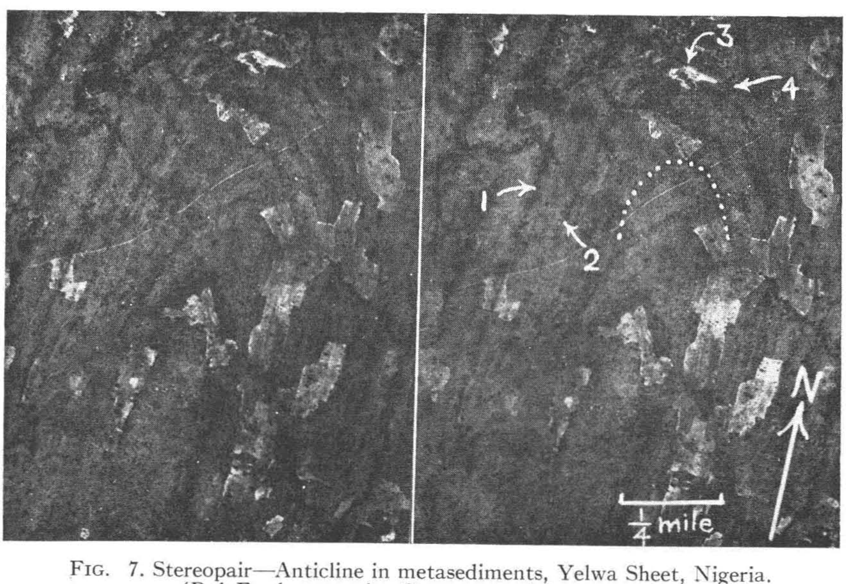

FIG. 7. Stereopair—Anticline in metasediments, Yelwa Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

means of doing work more quickly. (The area in Figure 10 has not been visited by the writer.) The faults marked (1) and (2) in that figure are soil-covered, yet their presence is indisputable; the apparent displacement of the sediments caused by the faulting can be clearly seen. The recognition of the direction and amount of apparent displacement depends upon the recognition of particular geological horizons, which in their turn, in this example, depend upon the recognition of particular vegetational characteristics. If doubt were felt whether the treeless zones marked (3) were one and the same horizon, it would be dispelled by the relative positions of the bush-covered zones marked (4).

Much structural information can be obtained from the stereopair in Figure 10, and the example is worth discussing in order to distinguish between the structures which do not need checking in the field—in which case the aerial photographs are being used as a research tool in their own right—and those structures which can be postulated, but not proved, from the photographic data and which require the support of field evidence.

The existence of faults (1) and (2) and the apparent horizontal displacement of the beds by these faults do not require checking in the field. Similarly the existence of the fault (5) is not in doubt, and the direction of movement along this fault is shown conclusively by the change in strike of the beds at point (6).

It can be seen that fault (1) is cut off by fault (5), and thus that fault (5) is later than fault (1). This does not require field confirmation. By analogy one would expect to find fault (5) later than fault (2), but the photographic evidence is here inconclusive because both fault (2) and fault (5) appear to end at the same place and field work is necessary to solve this problem.

At point (9), fault (5) bifurcates into faults (7) and (8). As fault (5) is known to be sinistral from photographic evidence, it is tempting to assume that faults (7) and (8) are also sinistral, but the photographic evidence is inconclusive and field work is necessary. The photographs do indicate, however, what field work is required and where it should be done.

The stereopair in Figure 10 has shown that aerial photographs sometimes provide such conclusive evidence as to the presence of faults that no confirmatory field work is necessary. The question now arises as to what should be the geologist's attitude if, owing to paucity of outcrops or some other reason, his field work produces no evidence either for or against the existence of the fault indicated by the photographs. In this case, in the author's opinion, the evidence from the aerial photographs should be given the same status as that from any other source; if the photographs show the presence of a fault, then a fault should be mapped; if the photographs indicate a probable fault, then a probable fault should be mapped, and this should be done even though no confirmatory field evidence is found. If positive field evidence is found that the postulated fault does not exist, then of course, the geologist must expunge the fault and try to find out why his photogeological interpretation was in error.

This example, concerning faulting in Karroo sediments, although representing a deviation from the main theme of the paper, has demonstrated how aerial photographs can be used as a research tool in the study of faulting, and has served as an introduction to the examples, in areas of metasediments, which are less easy to demonstrate and thus less easy to comprehend.

In Figure 6 (not investigated in the field), the ridges indicate the strike of the metasediments, and it can be seen that the rocks forming the ridges (1) are converging with those forming the ridge (2), towards the south. As there is insufficient room for the ridges (1) and (2) to continue in a southerly direction, evidence of folding or faulting can be expected. In the southern half of Figure 6, a lineament (3) can in fact be seen which is transverse to the ridges (1) and (2). This lineament (3) represents a shallow negative morphological feature (see particularly the southwest end), and its presence is emphasized by the vegetation.

If the lineament is traced to the northeast, it will be seen to cut the ridge (2), which again undoubtedly represents the bedding of metasediments, and displaces it to the east to point (4). The lineament (3) is therefore a sinistral fault, with an apparent displacement of about 640 ft., which can be measured on the photographs.

THE ORIGIN OF CERTAIN QUARTZ SCHISTS

Aerial photographs sometimes give evidence as to the origin of certain rocks when field evidence is equivocal, non-existent or difficult to obtain.

De Swardt successfully mapped the area covered by Ilesha Sheet 243 in Western Region of Nigeria without the assistance of aerial photographs—a very considerable achievement—and in his discussion of the quartz schists (de Swardt, 1953), he wrote (p. 35): "The schists may represent a younger

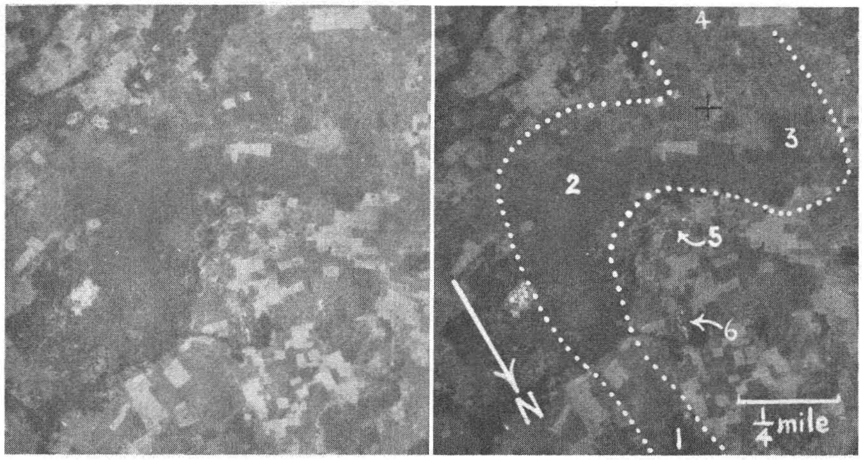

FIG. 8. Stereopair—Quartz schists, Iwo Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

sedimentary formation, metamorphosed and infolded in the Basement Complex, but it is also possible that they were formed by silicification along major planes of dislocation."

In 1957 the author of this paper mapped photogeologically the Iwo Sheet 242, which is west of, and adjacent to, the Ilesha Sheet. He had the advantages of the use of aerial photographs and some reconnaissance field work and agreed with de Swardt that "the quartz schists range from massive, granular, glassy rocks to schistose varieties with closely spaced sericite partings. . . ." The author's photogeological studies, however, have prompted the conclusion that the quartz schists were definitely not formed by silicification along major planes of dislocation, and probably did not represent a younger sedimentary formation metamorphosed and infolded in the Basement Complex; that, instead, they represented original sediments which resisted those processes of granitization responsible for the production of the permeation gneiss and the migmatite forming the country rock.

Much of the evidence for this conclusion is illustrated by the quartz schist from the Iwo Sheet in Figure 8. (Although the author visited the area in Figure 8 in the course of his rapid reconnaissance field work, he did not find any true outcrop on the soil-covered ridge, and the assumption that the ridge consists of quartz schist is based on the float material observed on the top of the ridge.)

In Figure 8 the following significant observations should be noted:

(i) The ridge is continuous from point (1) via points (2) and (3) to point (4).

(ii) The "folds" at points (2) and (3) are typical of tight folding in areas of metasediments.

(iii) The relic bedding lineaments of the permeation gneiss which forms the country rock are consistently parallel to the ridge—see points (5) and (6).

The contorted nature of the ridge of quartz schist in Figure 8 is evidence against the hypothesis that it was emplaced along a major plane of dislocation, unless of course it is assumed that the plane of dislocation was itself folded after the emplacement of the quartz schist. The contorted ridge in Figure 8 is typical of that which results from the

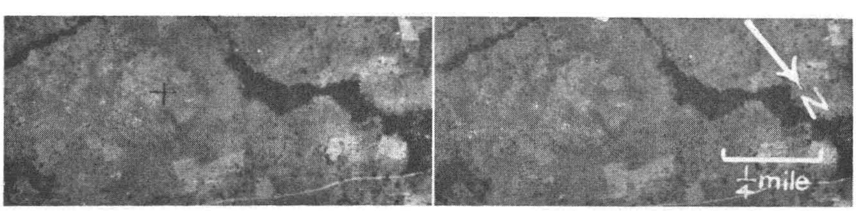

FIG. 9. Stereopair—Autochthonous granite, Iwo Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

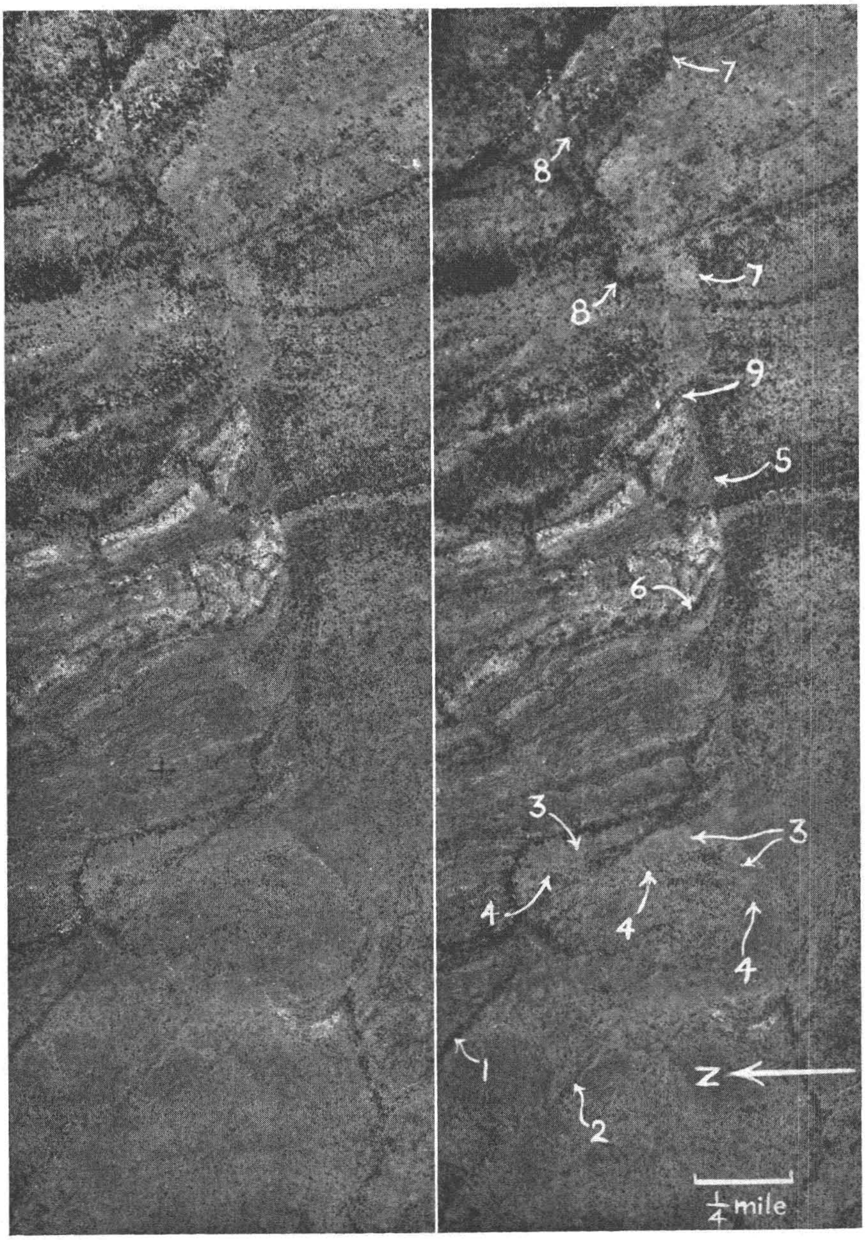

FIG. 10. Stereopair—Faulting in Karroo sediments, near Rufiji River, Uluguru Sheet, Tanganyika. (R.A.F. photographs, Crown copyright reserved.)

folding of metasediments in the plastic state in areas of regional metamorphism.

The important question is therefore whether the quartz schist represents a younger sedimentary formation infolded in the Basement Complex after the processes of granitization were completed, or whether it represents sediments which were in place before granitization began and which were capable of resisting the processes of granitization. This question is difficult to settle conclusively, but considerable evidence can be obtained from the aerial photographs.

It was noticed in Figure 8 that the relic bedding lineaments in the permeation gneiss which forms the country rock are consistently parallel to the trend of the ridge, and follow the contortions of the ridge accurately. See points (5) and (6). (Only a short length of ridge has been illustrated in Figure 8, but on the original aerial photographs the ridge and its contortions can be followed for several miles.) This parallelism of the strike of the quartz schist and that of the relic bedding of the adjacent permeation gneiss suggests that they were folded together in a plastic state. If the quartz schist was infolded after the formation of the permeation gneiss, the relic bedding of the permeation gneiss would be expected to be sometimes not parallel with the ridge of quartz schist; furthermore the quartz schist would be expected to be represented by rather simpler geological structures, such as synclines, instead of by long contorted ridges.

Further evidence comes from the fact that the only ungranitized sediments in the vicinity are the quartz schists; the absence of any other ungranitized sediments supports the hypothesis that the quartz schists represent the original sediments which resisted granitization, rather than the hypothesis that they represent a younger sedimentary formation infolded in the Basement Complex. If they were infolded in the Basement Complex after the process of granitization had been finished, one would expect to find other ungranitized sediments associated with them of a mineral constitution capable of being granitized.

In Figure 11, quartz schists from the Ilesha Sheet itself are illustrated. This example does not require a detailed discussion because the contortions of the quartz schist at points (1), (2) and (3) provide evidence that these rocks do not represent silicification along major planes of dislocation. Such contortions are typical of the folding of rocks in the plastic state.

If the quartz schists represented later sedimentary beds infolded into the already granitized Basement Complex, structures simpler than the contorted folds of Figures 8 and 11 would be expected. Also one would expect to find associated with the quartz schists other rocks, such as mica schists, which are not so resistant to granitization. The fact that only those rocks resistant to granitization are found suggests that they were in situ before the process of granitization took place, and that all those rocks not resistant to granitization were in fact granitized.

As a result of the photogeological study, the following is suggested as the origin of the quartz schists:

(i) They were derived from the more siliceous beds of a series of sediments.

(ii) These sediments were tightly folded together.

(iii) The agencies of metamorphism and granitization affected the whole series of metasediments, creating quartz schists from the resistant siliceous beds but permeation gneiss from the other sediments.

In the examples given above, field work would probably eventually have produced the same evidence as to the origin of the quartz schists as that actually obtained from the aerial photographs. Under the conditions of the Western Region of Nigeria, however, such field work would be very prolonged. It would entail "walking" the whole length of the ridges through dense and tangled undergrowth. In practice, such field work is not usually possible, and evidence as to the origin of certain rocks may thus be overlooked.

The significance of features seen in the field is not always so apparent as that of lineaments seen on the aerial photographs of the same area, the reason being that a much greater area can be inspected simultaneously on aerial

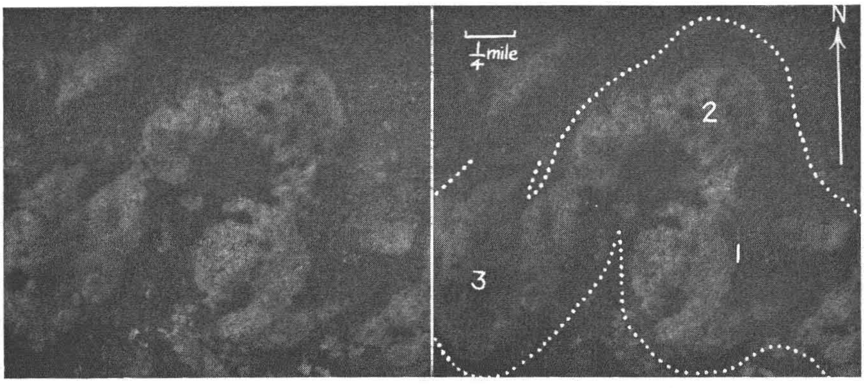

FIG. 11. Stereopair—Quartz schists near Apa, Ilesha Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

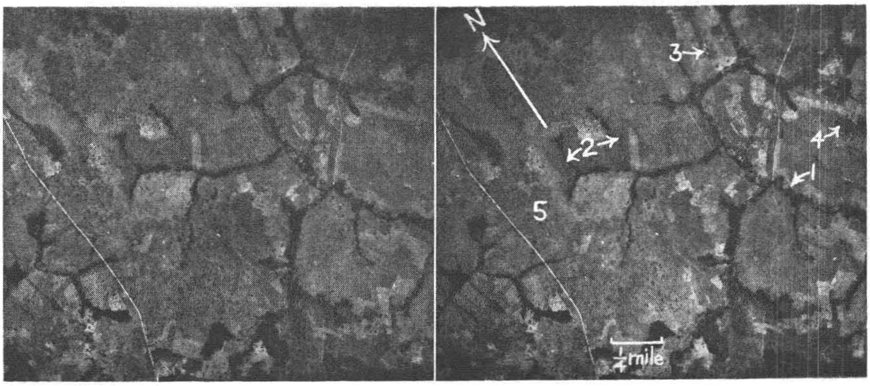

FIG. 12. Stereopair—Soil covered permeation gneiss, near Inisa, Iwo Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

photographs than in the field, and the genetic significance of lineaments may become apparent only when they are viewed over a large area.

On the Ilesha Sheet, de Swardt mapped the "closely spaced sericite partings" in the quartz schist as foliation. On the basis of evidence from individual outcrops, and lacking photographs, this is all he is entitled to do. On aerial photographs, however, lineaments are seen which are parallel to the trace of the foliation mapped in the field, but the wider view presented by the aerial photographs makes it apparent that these photographic lineaments represent the trace of the relic bedding of the quartz schist. The photographs show in fact that the foliation planes are controlled by, and represent, the relic bedding, and could in fact be used to map the relic bedding in the field. Thus genetic information concerning the quartz schist can be obtained from aerial photographs which is absent from individual field outcrops.

PERMEATION GNEISSES

Aerial photographs often record the relic bedding of permeation gneisses. A ground-level photograph of permeation gneiss is given in Figure 15. This rock consists mainly of quartz, orthoclase feldspar and biotite, and the dark bands differ from the lighter bands because they contain a higher proportion of biotite. In this paper the bands are referred to as relic bedding, and it is assumed, but not proved, that they owe their existence to the pre-granitization relic bedding and foliation planes within the original metasediments.

Permeation gneiss similar to that shown in Figure 15 but not from the same outcrop is shown in the stereopair Figure 13. This rock was studied in the field and the field outcrop was compared with the photographic image. It was found that the photographic lineaments, such as those covering the surfaces of the rock outcrops, are parallel to the trace of the relic bedding seen on the ground; it was also noted that the foliation of the permeation gneiss seen in the field is almost invariably parallel to the relic bedding. Thus the photographic lineaments are parallel to both the trace of the relic bedding and to the foliation. It is probable that permeation gneiss is intermediate between that type of rock in which the relic bedding controls the lineaments and that in which the lineaments are controlled by foliation (see section on "Bedding and Foliation").

The bands of the permeation gneiss, such as those in Figure 15, are, of course, usually too small to be recorded individually on an aerial photograph taken at a scale of, say, 1:32,000. The relic bedding bands and the foliation which is parallel to them, however, control the minor drainage channels, the distribution of vegetation and the direction of the long dimension of the individual outcrops. Thus the whole body of permeation gneiss in Figure 13 is covered with lineaments which are parallel to the relic bedding, and which are big enough to be recorded on aerial photographs. This observation is important because it means that aerial photographs can be used with confidence to trace the strike of the relic bedding of permeation gneiss over large areas.

In Figure 13 the relic bedding of the metasediments is indicated by very subdued ridges and by rows of small trees (4) and it will be noticed that this relic bedding is consistently parallel to that of the adjacent permeation gneiss. This is evidence in favour of the hypothesis that the metasediments pre-dated

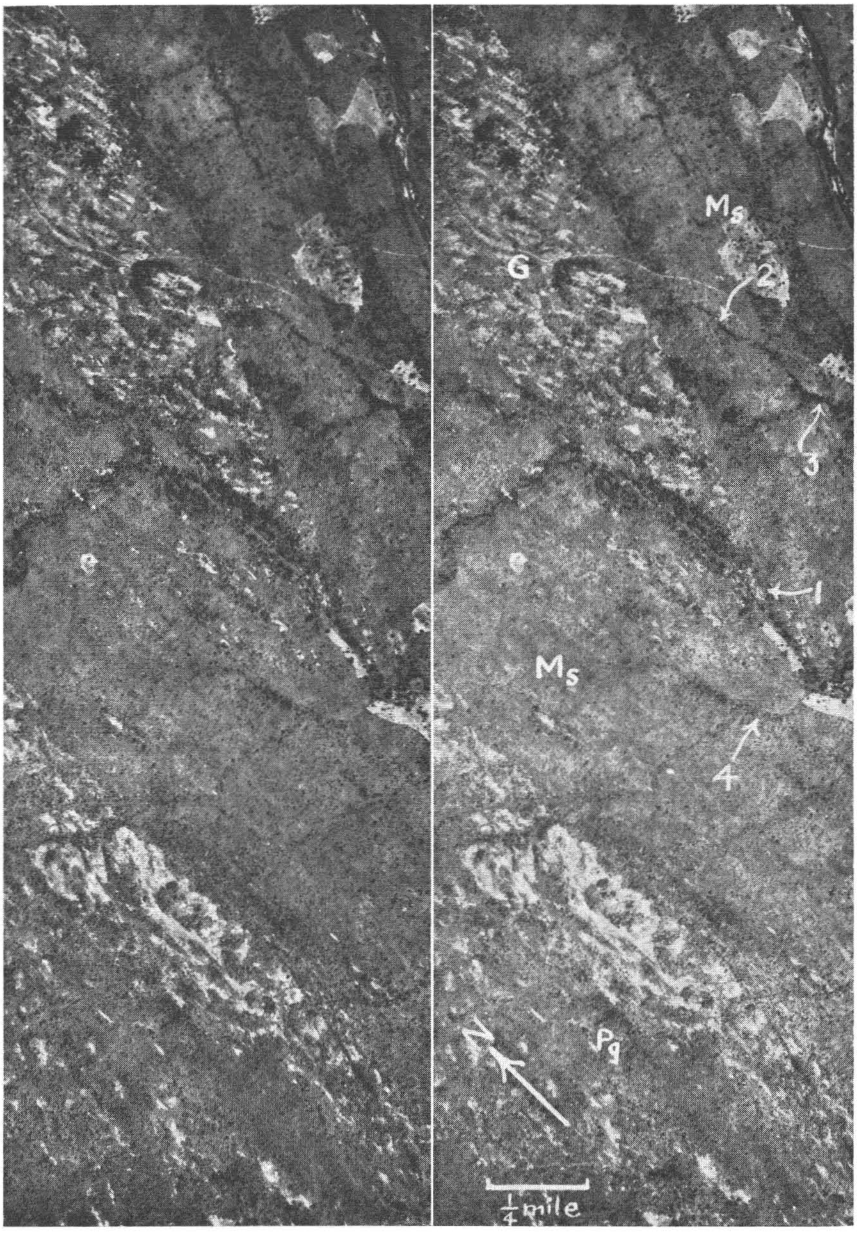

FIG. 13. Stereopair—Granite (G), permeation gneiss (Pg), and metasediments (Ms), Zungeru Sheet, Nigeria. (R.A.F. photographs, Crown copyright reserved.)

the formation of the permeation gneiss, and that the permeation gneiss was formed by granitization of the pre-existing sediments. It is evidence against the hypothesis that the sediments were deposited on pre-existing permeation gneiss and subsequently folded and metamorphosed.

Aerial photographs frequently record the traces of the relic bedding of the permeation gneisses even when they are soil covered. The area in Figure 12 has been visited by the author in the field, and is known to consist of permeation gneiss almost completely covered by soil. If a single photograph of Figure 12 is inspected with the naked eye, a "flowing" appearance will be noticed from the northern corner to the southeastern corner of the photograph. This appearance of "flowing" is typical of areas of soil-covered permeation gneiss, and results from the presence of a very large number of individually insignificant parallel lineaments. Field work within the area of Figure 12 proved that these numerous lineaments were in fact parallel to the relic bedding bands and foliation within the permeation gneiss.

It is noteworthy that the appearance of "flowing," which indicates the direction of relic bedding in the permeation gneiss, shows with much greater clarity on a single photograph of a large area than it does on a magnified stereoscopic model of a smaller one. This is therefore an example in which smaller-scale photography results in a clearer and more reliable interpretation than larger scale (see Hemphill, 1958).

If Figure 12 is studied with a magnifying stereoscope, it will be found that the relic bedding lineaments are of the following kinds: (a) The main river (1), (b) the second-order tributaries (2), (c) the direction of the long dimension of the small outcrops (3), (d) the alignment of small trees (4) and (e) the crests of subdued ridges (5). The lineaments, perpendicular to the relic bedding lineaments, represent joints.

None of the lineaments in Figure 12 listed above, considered individually, gives convincing evidence of the strike of the relic bedding, but seen collectively on a photograph of a large area they produce the "flowing" appearance which is characteristic of the soil-covered permeation gneiss.

The area in Figure 12 is another example in which aerial photographs are able to supply geological data more reliably, as well as more quickly, than field work alone. Once the geologist has satisfied himself by field work that the "flowing" appearance is characteristic of soil-covered permeation gneiss, and that the "flowing" lineaments represent the relic bedding of the permeation gneiss, then he is able to map the permeation gneiss and the relic bedding structures within it, both quickly and with confidence over large areas.

The geologist unassisted by aerial photographs is forced to rely on finding outcrops for his geological data. These outcrops may be small, sparsely distributed, and indeed difficult to find without the aid of aerial photographs. (The area in Figure 12 is exceptional in that it was chosen partly because if contained the location of field observations, and thus it has more outcrops than is usual in this type of country.) Away from the outcrops, the geologist has little information from which to deduce the underlying rock, and none at all on which he can map the strike of the relic bedding.

The criteria which the photogeologist can use to determine the strike of the relic bedding in the soil-covered areas are not available to the field geologist lacking aerial photographs. The parallelism between the second order tributaries and the main river in Figure 12 might well go unnoticed by a field geologist working without either a good base map or aerial photographs. The trend of the very subdued ridges would not be observed in the field; they become apparent on aerial photographs because of the great exaggeration of the vertical scale in the photographic stereoscopic model. The alignment of small trees and bushes is usually unnoticed at ground level, and even if, in a particular case, the alignment is noted, its significance is not normally apparent. It is the parallelism of the alignment of the trees, the ridges, the tributaries, and the main rivers which indicates their significance in Figure 12; it is this parallelism which the field geologist cannot see.

This property of aerial photographs of indicating the presence of permeation gneiss, and showing the strike of the relic bedding through the superficial soil cover, makes them valuable instruments of research in areas of regional metamorphism. It sometimes gives evidence of the pre-granitization structure of the area, and of the origin of the gneisses.

GRANITES OF DIFFERING ORIGIN

It is sometimes possible, from the evidence provided by aerial photographs, to distinguish between bodies of granitic rocks of differing origin. The wedge-shaped body of rock, marked (G), in Figure 13 bears a superficial resemblance to the permeation gneiss (Pg) in the same figure. After careful inspection, however, the following significant observations can be made:

(i) The rock (G) has displaced the adjacent metasediments. In the vicinity of point (1) the metasediments bifurcate as though the rock (G) had been wedged between them.

(ii) The lineaments in the rock (G) are more clearly defined than those in the permeation gneiss.

(iii) The lineaments in the rock (G) are not parallel to the relic bedding of the adjacent metasediments.

(iv) At points (2) and (3) there are lineaments within the metasediments parallel to those within the rock (G), but transverse to the relic bedding of the metasediments.

The fact that the lineaments in the rock (G) are not parallel to the bedding of the adjacent metasediments suggests that the rock is not another outcrop of permeation gneiss. This is confirmed by observation (iv). The lineaments (2) and (3) in the metasediments are parallel to and thus probably genetically related to the lineaments in the rock (G); they are not parallel to the relic bedding lineaments of the metasediments, and do not displace them; they are therefore joints and not faults. Since the lineaments (2) and (3) are joints, the probability is that the parallel lineaments in rock (G) are also joints and not faults. This conclusion is supported by the large number of lineaments in the rock (G).

The fact that the bedding lineaments of the metasediments diverge at the rock (G)—see point (4)—is evidence that the rock (G) has been forced between the bedding planes of the metasediments. The photographic evidence is thus very strong that the rock (G) is an intruded rock, and this, considered in conjunction with the light tone, jointing, resistance to erosion, and general photographic appearance, enables a photogeologist to interpret rock (G) as an intruded granite.

In Figure 14, another stereopair of the granite in Figure 13 is given. If Figure 14 is studied stereoscopically it will be seen that there is an area within it (G_2) which differs from the rest (G_1), in that it is free from jointing. Field work is necessary to determine the significance of the difference, although aerial photographs not only draw attention to its existence but also enable the area to be delineated accurately. The field geologist is thus able to start his work forewarned of the existence of the subdivision of the intruded granite, and can direct his attention to the mineralogical and textural differences within the granite which he would possibly not have noticed had he been unassisted by aerial photographs.

Aerial photographs may therefore be regarded as useful instruments of research in areas of intruded rocks in that they may reveal significant subdivisions of apparently simple intrusions (see also Stringer, 1953). They sometimes enable a geologist to decide whether a particular granite is autochthonous or intruded, even when the evidence of a single outcrop is equivocal. The outcrop in Figure 9 was visited by the author in the field and was found to be a gneissose "granite" with no trace of permeation gneiss banding or relic bedding, such as that in Figure 15. In the absence of further evidence, this rock would have been mapped as a gneissose granite and its mode of origin would have been unknown.

Inspection of the stereopair Figure 9 shows lineaments very reminiscent of some of those of the permeation gneiss (Pg) in Figure 13. Comparison of the field outcrop with the stereopair in Figure 9 showed that the lineaments on the photographs were parallel to, and presumably caused by, the "gneissosity" seen in the field.

This similarity in photographic appearance between the granite shown in Figure 9 and the permeation gneiss in Figure 13 suggested that the granite might be autochthonous. The author therefore inspected the outcrops between the area shown in Figure 9 and the permeation gneiss which was known to form the country rock, and found that as the permeation gneiss was approached ghost-like banding parallel to the "gneissosity" of the granite became visible and then grew progressively more distinct until it became similar to the typical permeation gneiss banding in Figure 15.

Thus the granite in Figure 9 is seen to have a gradational contact with the permeation gneiss and can be presumed to have been formed by a continuation of the same processes of granitization, which produced the

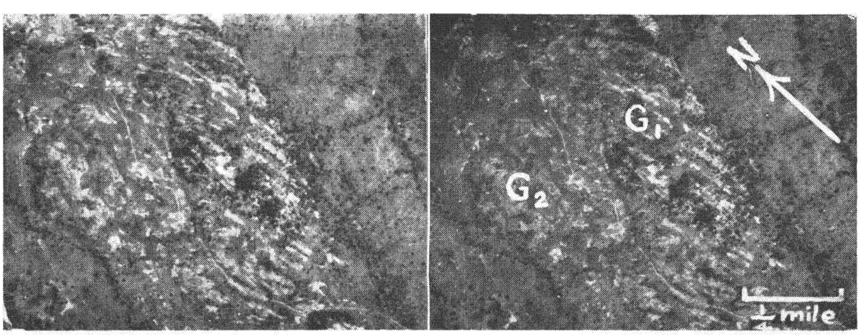

FIG. 14. Stereopair—Granite (G_1 and G_2), Zungeru Sheet, Nigeria.
(R.A.F. photographs, Crown copyright reserved.)

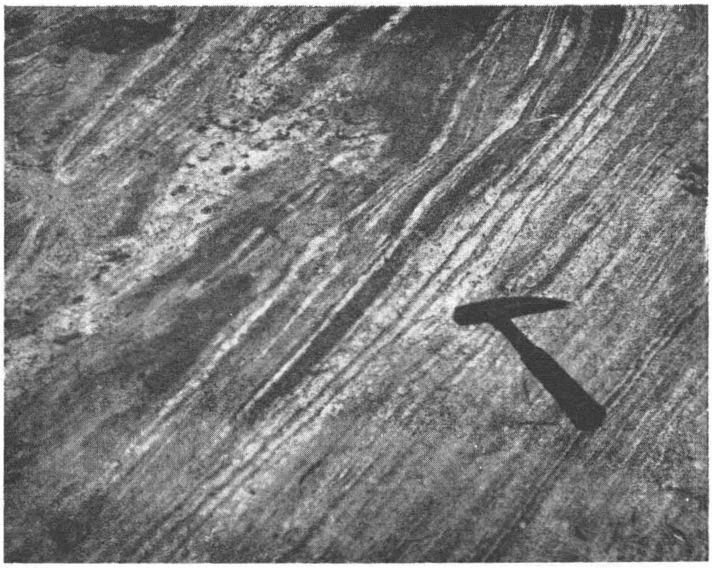

FIG. 15. Permeation gneiss near Ogbagba, Iwo Sheet, Nigeria.

permeation gneiss from the original sediments. The "gneissosity" in the granite of Figure 9 represents the last traces of the relic bedding of the permeation gneiss.

The important observation is, however, that the aerial photographs continue to indicate the autochthonous origin of the granite even when the processes of granitization have advanced to such a stage that the evidence of the field outcrops is equivocal. The "gneissosity" lineaments on the photographs are more apparent than the corresponding "gneissosity" texture on the surface of the granite outcrop; furthermore, as the photographic lineaments can be seen simultaneously over a large area, the parallelism between the "gneissosity" lineaments of the granite and the relic bedding lineaments of the permeation gneiss is obvious.

The field geologist may sometimes be in danger of mistaking an autochthonous granite for a gneissose intruded granite, but the photogeologist is in greater danger of mistaking an autochthonous granite for a permeation gneiss.

CONCLUSIONS

Geological information, which, in practice, is unobtainable in any other way, can sometimes be obtained from aerial photographs. The geologist has no right to ignore structures "seen" on aerial photographs merely on the grounds that he has found no positive evidence for them in the field; if he does so, he is rejecting much of the most valuable assistance which aerial photographs can offer to him. It is in those soil-covered areas, where field observations are sometimes inconclusive, that the geologist should pay increased attention to the evidence provided by the aerial photographs.

Absolute proof of the contentions contained in this paper is precluded by the very nature of the subject. What has been attempted, however, is the statement and demonstration of certain principles (not all original) of which the most important are:

(1) It is necessary to take into consideration, during photogeological interpretation, the interrelation of the factors which affect the photographic appearance of rocks.

(2) Photogeological interpretation should be according to a generalized photogeological legend developed specifically for the area concerned.

(3) Aerial photographs of metamorphic areas should be interpreted in conjunction with the photographs of the surrounding country.

(4) The geological data obtained from aerial photographs should be accepted as having a status, value and reliability, in their own spheres, fully equal to those obtained from other geological sources. If therefore the photogeologist, after considering the geological data obtained from the aerial photographs, postulates the existence of certain geological structures, such structures should be plotted with suitable qualifications on the geological map, unless positive field evidence

is found which proves that the postulated structures are inaccurate or non-existent.

(5) In areas of regional metamorphism, aerial photographs frequently provide the most reliable, as well as the quickest, way of ascertaining the strike of metasediments.

(6) In metasedimentary areas, the aerial photographs indicate the bedding, rather than the foliation, direction; and where only one direction of lineaments is observed, that direction represents the bedding.

(7) Because aerial photographs sometimes provide the most reliable evidence of the strike of metasediments, they also sometimes provide the most reliable evidence of faults and folds.

(8) Aerial photographs sometimes indicate the origin of certain rocks even when the field evidence obtained from individual outcrops is equivocal.

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Airborne Geoscience Research

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(*Abstract is on next page*)

DR. ABRAMS* has been very honest in his appraisal of the present status of aerial photography, its interpretation and applications. We heartily concur with his major thesis and find it quite difficult to conceive of other individuals unwilling or unable to accept the fact that we are indeed at the crossroads of a new era in photogrammetry.

As evidence of our concurrence, we are outlining here our own feelings on a subject which we feel has virtually unlimited application in many different fields of endeavor. "Airborne Geoscience," for convenience, may be defined as methods used for obtaining terrestrial information through airborne means.

BACKGROUND

Military specialists in electromagnetic radiation have seldom considered the problem of sensing the geophysical environment of the earth's surface. Instead, their interests have

* Abrams, Dr. Talbert, "Aerial Photographs are Obsolete," PHOTOGRAMMETRIC ENGINEERING, December, 1961, Vol. XXVII, no. 5, pp. 691–694.