data derived in the manner just described, if control shots are obtained to indicate dip of the beds.

The plane-table-and-alidade method in conjunction with air photographs is applicable equally to measurement of more or less steeply inclined strata. Horizontal measurement should be scaled at right angles to the strike of the beds and elevations of hogback crests should be located along the same selected line. It is necessary in addition to make dip readings, by Brunton compass or by alidade measurement of two or more points on the same stratum. The data are then used for construction of a graphic section and thicknesses of formational units may be scaled from the section. The aerial photograph aids in obtaining a more detailed and accurate section than can be made otherwise without surveying work on the ground, which is likely to be slow and difficult.

CONCLUSION

Aerial photography is a new tool having value to stratigraphic geology in approximately the manner and almost the degree that a telescope serves astronomy. Although geologists studied, described, classified, measured, and mapped rock formations before the airplane was invented, just as astronomers studied heavenly bodies before the days of Galileo, few geologists or astronomers today would care to dispense with the modern equipment at their command.

AERIAL PHOTOGRAPHS IN GEOLOGY

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AERIAL photographs have been used for field mapping in this country only since the late '20's, and their utilization by geologists has continued down to the present. The aerial photograph as a base map has largely supplanted the topographic map and doubtless will continue to be one of the most effective tools available to the field geologist. Advantages of ease of location, wealth of detail, up-to-dateness of cultural features and representation of soil and lithologic differences by differences in shading far outweigh disadvantages of distortion and the handling of large numbers of prints in the field and office.

Several papers and books have appeared recently that are concerned with the interpretation of geologic features shown on aerial photographs (see references 1–16). Very few of these articles discuss the use of aerial photographs in the field; most of them describe photo-interpretation, or photogeology (Rea, 14), as a means to an end by itself.

To my mind this is putting the cart before the horse. It seems to me the fundamental use of aerial photographs is a base for field mapping. For this purpose they are unexcelled; used by themselves in the office as a substitute for field work their use can sometimes lead to serious errors in interpretation almost as well as to the truth.

AERIAL PHOTOGRAPHS IN FIELD MAPPING

When aerial photographs are used in the field as a base map for plotting dips, strikes, attitudes of joints, faults and contacts, their utilization involves few problems additional to those encountered in using a topographic or planimetric base. In fact, it has been my experience in the war and in teaching students in field geology that most people have less difficulty in visualizing terrain from an aerial photograph than they do from a conventional map.

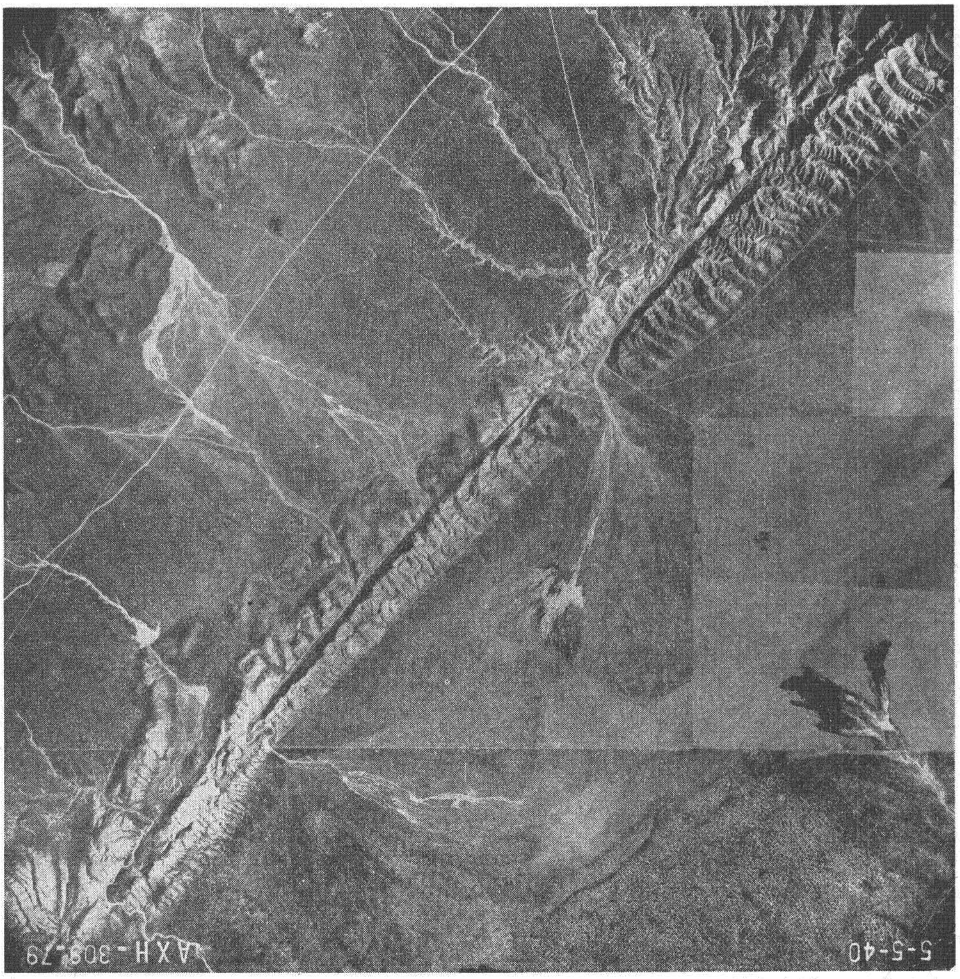
Spence Air Photos

FIG. 1. San Adreas fault near Indio, California. An oblique photograph is ideal for illustrating the topographic expression of this type of fault for students.

Our practice at the University of California is to have men do detailed mapping of small areas both on contour maps and aerial photographs. The standards of accuracy they can attain are much greater on the aerial photographs and the students feel that they get a better picture of field relationships. By using photographs at an early stage in their professional career they learn by themselves something of the relationship of rock resistance and topographic expression, of structure and landforms, and of the control of soil and bedrock on the vegetation pattern.

The effectiveness of aerial photographs is greatly increased if a stereoscope is used in the field. The magnifying pocket stereoscope developed during the war is a nearly ideal instrument. It is compact, light, easy to use in field mapping and provides magnification as well as stereoscopic relief. With practice most people can learn to view two prints simultaneously without an instrument, but the magnification provided by the stereoscope is a marked advantage, especially when many notations are to be made on the photograph.

When several types of information have to be entered on the map, as, for example, in a detailed soil survey, a series of acetate overlay sheets can be used, each sheet to carry a different set of data. These sheets have the advantage of high transparency as well as the ability to hold true scale. Various types of ink



Fairchild Aerial Surveys, Inc.

FIG. 2. San Andreas fault zone adjacent to the Carrizo Plains, California. This vertical photograph demonstrates the control the rift exercises over the drainage pattern.

are available, both permanent and removable, and these can be used in the field for mapping directly on the overlay sheet.

PHOTOGEOLOGY

The use of aerial photographs by themselves in place of a ground reconnaissance is a comparatively recent development. Rea (14) is perhaps the first to describe the method. More elaborate discussions are given by Brundall (2) in general terms and by Joliffe (6) for applications in a specific area.

These authors are careful to point out the limitations of the method. The rewards in time and low cost are great, but pitfalls for the unwary are many and deep. The method rarely can be a substitute for field work, but there are occasions where field work may be impracticable or even impossible. The method is unexcelled for reconnaissance of an inaccessible region, or for blocking out areas that need detailed study.

A background knowledge of the topographic expression of rock types and

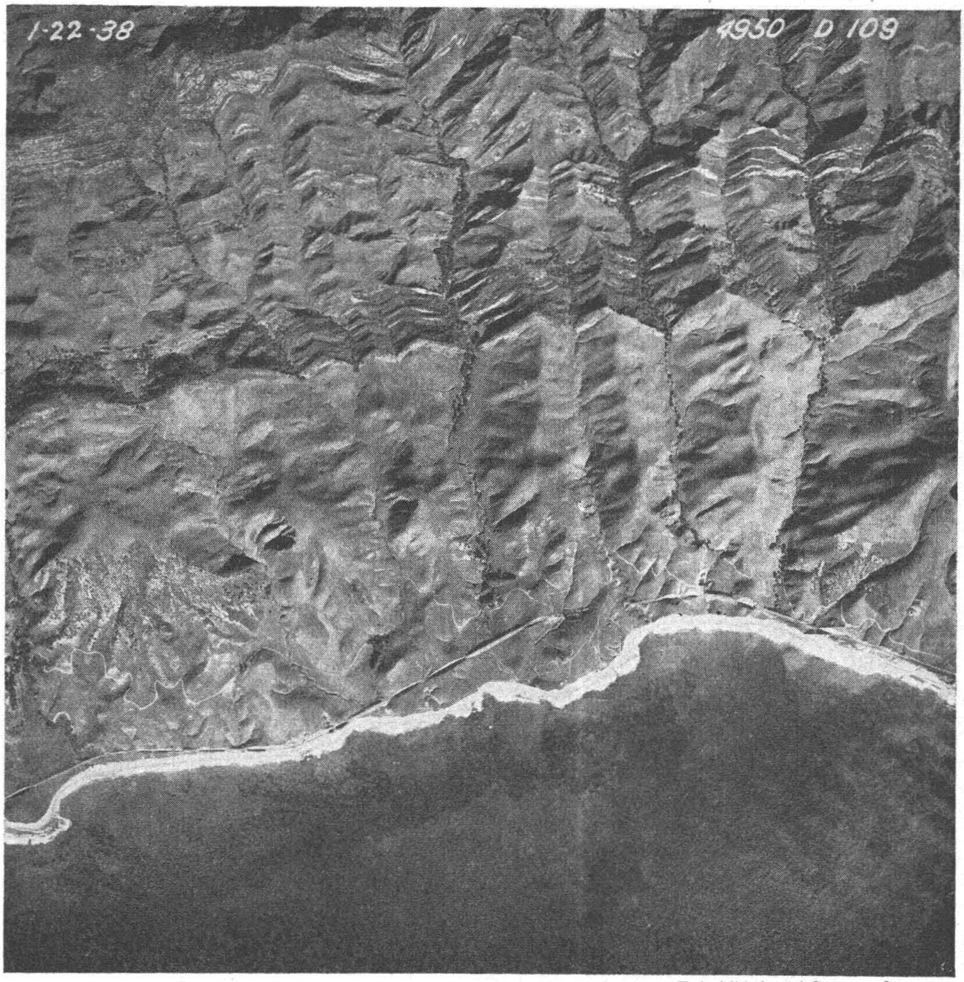


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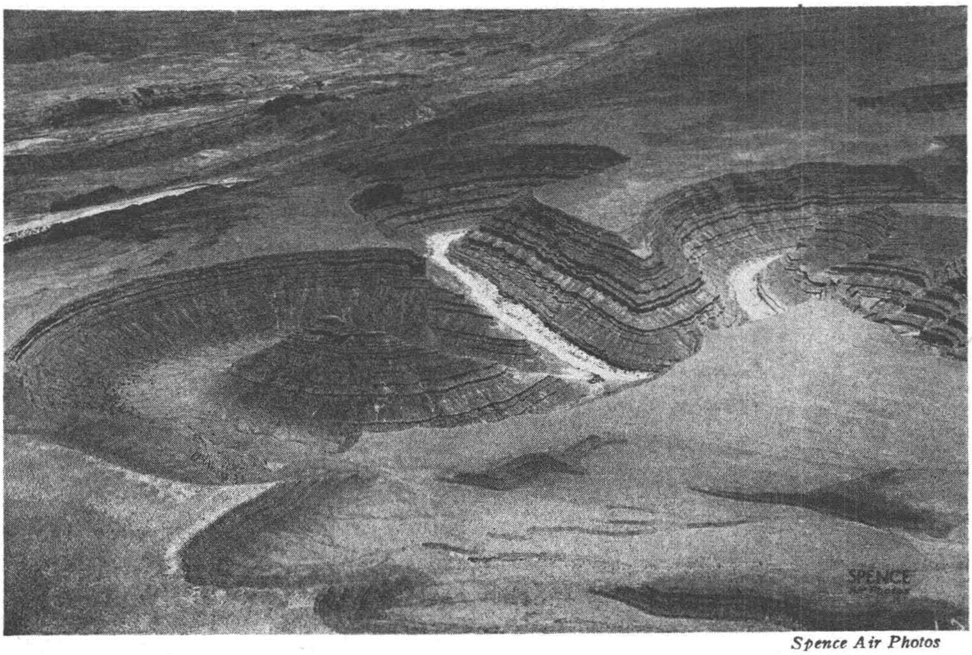
FIG. 3. California coast west of Santa Barbara. The relative permeability of these seaward-dipping strata is reflected in the vegetation pattern. Grassy slopes are shale; wooded ones are sandstone. Note how sandstone ledges on the sea floor control the distribution of seaweed (dark patches offshore).

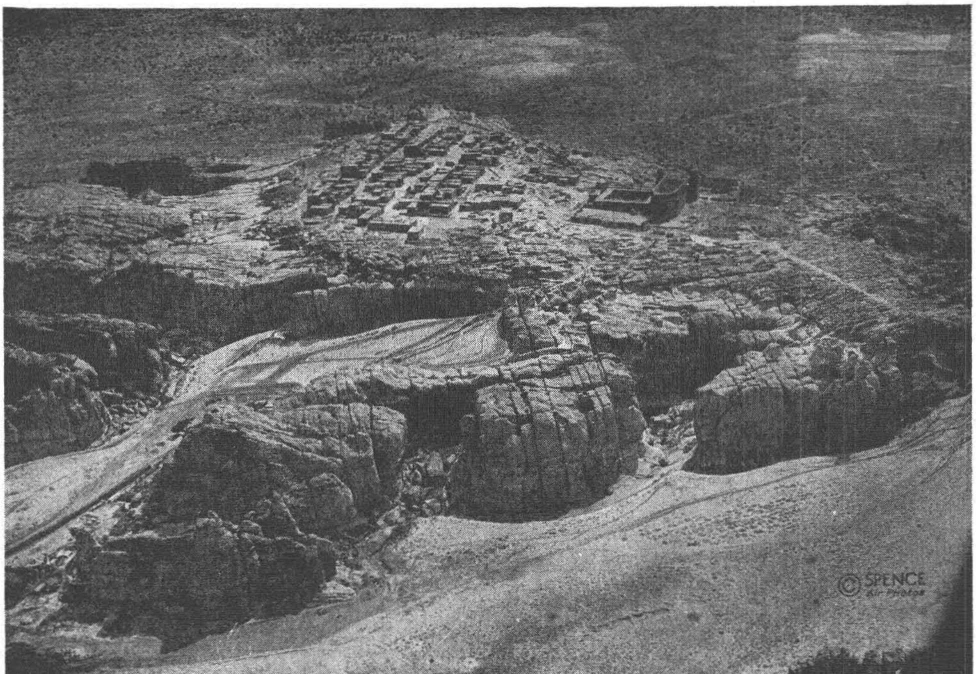
structure, of soil types that form in various climates and on different kinds of parent material, and an understanding of controls that affect the distribution of vegetation are all necessary for successful photogeology. In addition to a store of basic knowledge drawn from geology, climatology, soil and plant geography a photo-geologist must have real ability to weight various types of evidence—most of it indirect—to select significant details from a great mass of irrelevant data, and to decide what is the most likely rock or structure represented on the photograph, often from very inadequate information.

Sometimes geologic features are strikingly apparent on aerial photographs, but they are frequently very obscure. They tend to be more recognizable where strong differences exist in the erosional resistance of adjacent rocks. Thus, sedimentary rocks, as sandstone, shale, and limestone, are likely to be more apparent than relatively homogeneous rocks like granite, especially if the sedimentary



Spence Air Photos

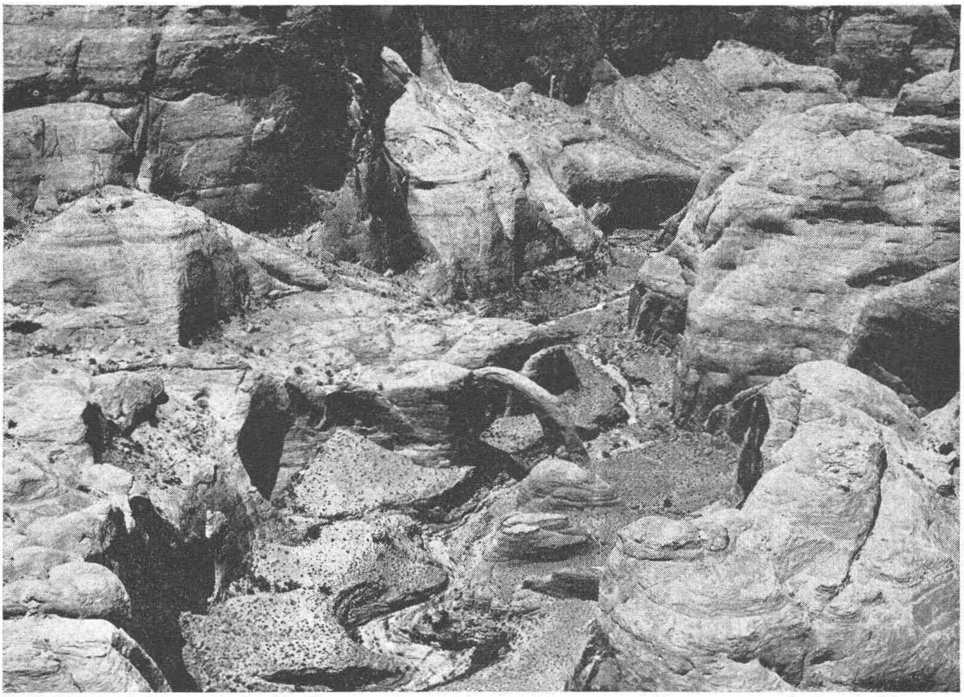
FIG. 4. Goose-necks of the San Juan River, southern Utah. This oblique illustrates the relationship between the structure of nearly flat-lying strata and the resulting landforms in a dry climate. Note the cut-off meander.



Spence Air Photos

FIG. 5. Acoma Pueblo, New Mexico. Widely-spaced joints in thick-bedded sandstone.

rocks have a moderate dip. Differences in the relative permeability of rocks can be reflected in the vegetational pattern; for example, in semi-arid regions, shale, because of its relative impermeability, will support grass, while outcrops of sandstone with a relatively higher content of ground water can be identified by their cover of bushes and trees. This same factor of relative impermeability frequently controls the drainage pattern as well; a closely-spaced network of drainage channels will be cut in impermeable material like clay and silt because



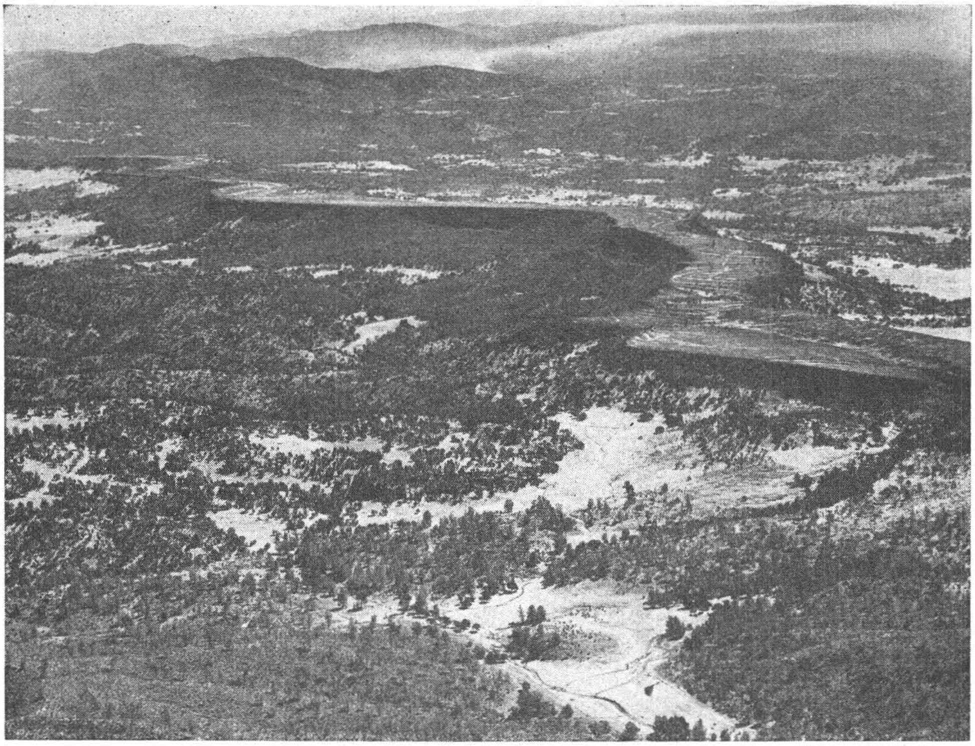
Spence Air Photos

FIG. 6. Rainbow Natural Bridge, southern Utah. This oblique is superior to a ground view for showing the setting of the bridge in helping to explain to students its origin as a cut-through entrenched meander.

a greater part of the precipitation runs off than is absorbed in more pervious sediment like sand and gravel.

Faults, joints, and dikes sometimes can be identified in pictures. These lineaments may be less resistant than the bordering rocks, in which case they will probably be etched out by a linear pattern of subsequent streams. If dikes are more resistant, they may stand up as elongate ridges. Faults can sometimes be recognized because they are less permeable than the rocks they cut, and thus make a relatively impermeable membrane. In this case the fault trace is marked by spring zones with characteristic vegetation, or in a forest is indicated by aligned trees.

Surficial features commonly are more apparent than bed-rock structures. In this category are such landforms as: sand dunes, natural levees, beach ridges, strand lines of former lakes, marine and river terraces, glacial deposits, volcanic forms, and coral reefs. For many of these the aerial photograph commonly can give more information on mutual relationships, pattern, and distribution than a ground survey.



Spence Air Photos

FIG. 7. Table Mountain near Sonora, California. This unusual mountain is a former stream channel that stands above its surroundings because of the greater resistance of the lava flow that solidified in the stream course. Mountains that once bordered the stream have been eroded away.

Spence Air Photos

FIG. 8. Ship Rock, New Mexico. An eroded volcanic neck with two radial dikes. The dikes and the neck stand out in relief because they are more resistant to erosion than the surrounding rocks.

MILITARY GEOLOGY

Many times during World War II aerial photographs were the only source of intelligence regarding ground conditions in enemy-held territory. This was especially true in the Southwest Pacific where much of the war was fought in unexplored or little known regions. An accurate appraisal of the terrain was essential in many operations because such large-scale facilities as airfields, supply dumps, and harbor installations had to be built. In addition to preparing the way for these engineering activities, aerial photographs often were the only means available for estimating wave conditions and depth of water at landing beaches, for determining the possibility of crossing coral reefs, and estimating the nature of the ground as it affected the movement of men and vehicles.

To cite but one of many examples where this method proved successful: it was possible to select airfield sites on Mindoro in the Philippine Islands in advance of the landing on 15 December 1944, and to have ground conditions turn out about as anticipated. These airfields were needed to provide air cover for the assault on Luzon, and they were completed by the target date assigned.

That aerial photographs are not infallible was shown at the landing on Morotai in the Netherlands Indies on 15 September 1944. Here, part of the encircling reef was interpreted as solid coral; instead it proved to be finely-comminuted coralline mud, about the consistency of flour. Most of the vehicles that attempted to cross this section of beach sank from sight. The error in this case may not have been entirely the fault of the photo-interpreters, for higher echelons were unconvinced of the need for studying coral reefs in the field in order to provide a sound basis for recognizing their characteristic features on aerial photographs.

The war in the Pacific abundantly demonstrated the need for continuing and active research in the identification of landforms on aerial photographs and the estimation of their effect on tactics, in comparing ground conditions in known areas with ones likely to be encountered elsewhere, and in testing equipment and vehicles on types of terrain that may be found in future theaters of operation.

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GEOLOGICAL APPLICATIONS OF OBLIQUE PHOTOGRAPHY

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MUCH has been written about the geological interpretation of aerial photographs, but most of it has referred to verticals, used either singly or combined as mosaics, or to overlapping verticals which can be studied under the stereoscope. Not so much attention has been given to oblique photographs and the geological uses to which they may be put.

The oblique photograph for the portrayal of landscapes has been much employed, and for that purpose it has many advantages as compared with the vertical picture—particularly a greater areal coverage and a more natural appearance of the terrain, and hence easy interpretation by the layman.

Nothing further need be said about such obliques. They are very useful to the geologist as records and for study, but such use is well known.

STEREOSCOPIC OBLIQUES

Stereoscopic obliques have not received as much attention as they deserve from geologists. They combine the advantages of stereoscopic vision with those of broad coverage of the terrain and of the possibility of seeing and assessing its relief features to even better advantage than can be done with overlapping verticals.

For geomorphic studies, stereoscopic obliques are especially advantageous as can be well demonstrated by the stereo-pair reproduced as Figure 1. This picture was taken with a miniature camera in the course of a flight on a regular passenger liner. A single picture of this pair gives no suggestion of the fact that the land of low relief in the foreground lies at the summit of a mountain mass and records a strongly-uplifted very old-age surface.

The possibility of seeing in one view the salient features of the geology as well as of the topography, and the relations between the two, is one of the great advantages of stereoscopic aerial obliques as a tool in geomorphic studies.

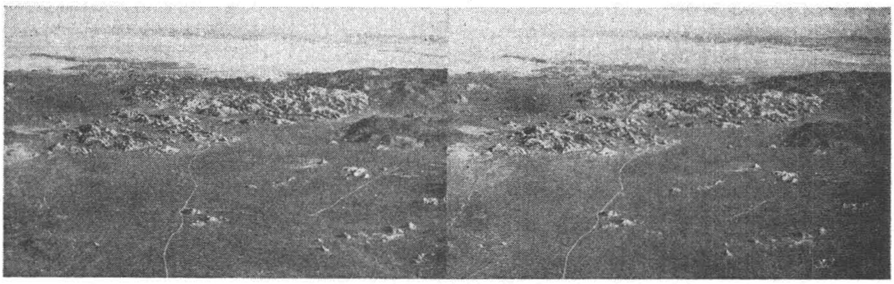

FIG. 1. Stereo pair illustrating advantages of stereoscopic obliques for geomorphic studies. Looking north over northwest end of Little San Bernardino Mts., Calif.