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---GEOLOGIC UTILITY OF SMALL-SCALE AIRPHOTOS*

by

Malcolm M. Clark**

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**U. S. Geological Survey, Menlo Park, Calif.

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GEOLOGIC UTILITY OF SMALL-SCALE AIRPHOTOS

By Malcolm M. Clark, Menlo Park, Calif.

ABSTRACT.--This report emphasizes the geologic value of small-scale airphotos by describing the application of high-altitude oblique and 1:120,000 to 1:145,000 scale vertical airphotos to several geologic problems in California. These examples show that small-scale airphotos can be of use to geologists in the following ways:

1. High-altitude, high-oblique airphotos show vast areas in one view, introducing a geologist or his audience to the salient geographic and topographic attributes and many geologic features of an area.
2. Vertical airphotos
 - a. Offer the most efficient method of discovering the major topographic features and commonly, important structural and lithologic characteristics of new or unfamiliar terrain.
 - b. In stereo, show a broad region in one 3-dimensional view that may reveal relations or suggest geologic hypotheses not otherwise apparent.
 - c. May reveal features of such extent, subtlety, or discontinuity that a broad view is necessary to recognize them.
 - d. Instantaneously record rapidly changing conditions over large areas, such as tidal flow and surface wind patterns.

Small-scale airphotos do not replace large-scale airphotos or field investigations. They make the geologist more effective by saving time or revealing relations he might otherwise miss because of lack of experience or astuteness. Geologists would be helped in most projects by using airphotos at several scales that are smaller by successive factors of 3 than the largest scale used.

Color and black and white airphotos at scales as small as 1:175,000 are within the capability of present commercial airphoto aircraft using cameras equipped with short focal length lenses. Small-scale airphotos also have potential use now in cartography, forestry, agriculture and geography, both in current programs and those contemplated for earth resource satellites. Moreover, several years, if not decades, are likely to pass before photos from orbit replace small-scale airphotos.

INTRODUCTION

Small-scale vertical air photographs covering large areas of the earth will become available in the immediate future, both from imminent earth resources satellites (Report for the Committee on NASA Oversight, 1968) and from increased use of high altitude aircraft (e.g., Bock, 1968) and short focal length cameras in aerial photography. To take full advantage of these photos, geologists should become aware of their potential usefulness in solving geologic problems.

Hemphill (1958), using 1:60,000 scale airphotos, pointed out that the chief benefit from such photos is that they permit continuity of observation over large areas. This broad view leads to easier recognition of geologic features such as rock strata, tectonic lineaments or lithologic units characterized by subtle but persistent topographic or tonal differences. The purpose of this report is to support and add to Hemphill's work by illustrating the geologic utility of airphotos that range in scale from 1:120,000 to 1:145,000. These airphotos are of significantly smaller scale and contain information that is not obvious on present "small-scale" airphotos, either the widely available 1:60,000 USGS photos or photos taken for special projects, such as a series of 1:90,000 photos that cover the western portion of California. Furthermore, the scales of the photos in this report are attainable by present commercial aircraft and cameras.

The photos to be described were taken in 1967 and 1968 for this investigation of geologic uses of small-scale airphotos by U.S. Air Force aircraft flying between 60,000 and 70,000 feet. Cameras were equipped with 6" focal length lenses and used 9½" black and white roll film. Flight lines covered geologic features of interest in the Far West, principally active faults in California. The project thus far has yielded about 1300 overlapping vertical photographs, covering many swaths 16 to 18 miles wide and up to several hundred miles long. Figure 1 shows locations and approximate ground coverage of the airphotos of Figures and Plates.

EXAMPLES OF GEOLOGIC USE OF 1:120,000-1:145,000 SCALE AIRPHOTOS

Garlock fault

Figure 2 is a high oblique airphoto looking east across the northern boundary of the Mojave Desert from about 60,000 feet. In a single view this photo shows much of the geographic and geologic character of an immense region. Such photos afford an excellent and often spectacular way to introduce, display or summarize the geologic relations of a large region. They can be very useful to a geologist in the first steps or the reconnaissance part of a field study or in areas which lack vertical airphotos. Moreover, they can serve the geologist later when he communicates his findings to an audience.

Some of the small-scale vertical photographs described in this report are being used in a project to locate the most recent breaks along the Garlock fault throughout its 150-mile length. Figure 3 (scale 1:120,000) shows part of the fault (A-A') near Searles Valley. The linear aspect of the fault, expressed mainly by scarps, valleys, and ridges shows clearly in this photo, as well as on large scale (1:20,000) photos, which have been the primary tool for locating and recording the position of recently active traces of the fault. However, in places where surface evidence of the fault is missing for several miles, the large-scale photos are much less useful than small-scale photos, which reveal the continuity of the fault throughout its length.

Plate 1 (scale 1:120,000) shows the course of the Garlock fault at Koehn Lake, a playa about 40 miles west-southwest of the area shown in Figure 3. Here most of the surface continuity of the fault disappears as it changes trend by two poorly defined en echelon steps. Large-scale photos are of little use at Koehn Lake, for the features that mark the location of the surface traces are scarps 5 or more miles apart or a few subtle tonal lineaments among many tonal boundaries not necessarily of tectonic origin. In this area the value of the small-scale airphoto becomes clear. From an inspection of Plate 1, one can discover features that line up with existing scarps or that are aligned with projections of the fault from either side of this area. For example, scarp A and lineament B on Plate 1 are aligned with the prominent scarp C. C, in turn, is almost continuous with the trace shown in Figure 1. A scarp at D (obvious in stereo) and lineaments at E, about 10 miles apart, line up with the projected trace from the southwest (Pl. 2).

Subsequent field checks showed the lineament at B to be a drainage channel across the playa and the one at E to be the southern boundary of a zone of light-colored modern channels. In both places the channels, and hence the resulting lineaments, appear to be controlled by subtle topographic trends of probable tectonic origin, in view of their position in line with prominent fault scarps.

Squares on Plate 1 represent the size of available photos at scales of 1:20,000 and 1:32,000 in the same area. Presumably these photos could be used to locate the traces shown in Plate 1 by assembling them into a mosaic or by using them to locate many linear features, transferring the features to a map and then looking for alignments. Inspecting a single photo is obviously easier and probably more accurate.

A photo scale of 1:250,000 would perhaps be even better for working on the problem at Koehn Lake. The 1:120,000 photo shown in Plate 1 had to be joined to the overlapping photos on either side in order to project the prominent traces from the northeast and southwest on to Plate 1. One photo at a smaller scale would eliminate this extra step, provided the lineaments were still visible.

It could be argued that a high oblique photo similar to Figure 1, but with Koehn Lake somewhere in the foreground and with a direction of view within about 10° of the bearing of the fault traces, would also reveal the location of the faults in the vicinity of the playa. Such a photo, however, would require careful positioning of the aircraft and some foreknowledge of the features of interest. One vertical airphoto, in contrast, can be inspected from any direction, in a sense simulating

many oblique photos. Vertical photos, in further contrast to obliques, present the geometric relations of surface features in a form that is more easily studied and understood. In my experience with high oblique and vertical photos taken from low, high, and even orbital altitudes, I have yet to see a high oblique that was more useful for general geologic interpretation than a vertical photo, at suitable scale, of the same area.

Although the use of 1:120,000 scale airphotos described above was part of an investigation to locate the most recent breaks along the Garlock fault, the general position of the fault had earlier been known throughout its length (Jennings et al., 1962; Smith, 1965; Dibblee, 1967). Had the Garlock fault and the geology of its surroundings been completely unknown, a geologist would have been able to easily discover it and determine most of its extent from a cursory inspection of a few 1:120,000-scale photos, if not from orbital photos at 1:600,000 scale or so.

Anza-Borrego Desert area

Coyote Creek Fault

Plate 3 (scale 1:145,000) shows an area along the eastern edge of the Peninsular Ranges of southern California about 50 miles north of the Mexican border. Traversing the photo from right to left (A-A') is the surface rupture along the Coyote Creek fault that accompanied the Borrego Mountain earthquake of April 8, 1968. This earthquake, which was of Richter Magnitude 6.5, was the strongest to occur in California since 1952. The 1968 break extended the known position of the fault roughly 12 miles beyond its previously mapped southeastern end near

Highway 78 (B), at the lower right corner of Plate 3 (Rogers, 1965). However, a casual inspection of these photos when they were received in December 1967, 4 months before the earthquake, revealed the fault at C and its probable extension along the faint lineament out to D. Thus, study of a few photographs that were obtained for the purpose of investigating the San Jacinto fault system (of which the Coyote Creek fault is a branch) quickly suggested an extension of the fault beyond its recorded location, an inference dramatically verified a few months later by the earthquake.

Without the photos shown on Plates 3 and 4, the search for extensions of the fault beyond its mapped extent at this location would involve use of existing airphotos: those of the California Division of Highways at 1:90,000 scale, U.S. Geological Survey at 1:25,000, or U.S. Department of Agriculture at 1:20,000. Assuming the search to be restricted to a zone 5 miles wide, extending for 17 miles beyond the then known end of the fault (roughly the width of Pl. 3), stereo coverage of that area by the three available types of photos would require, respectively, 5, 20 and 33 photos. Obviously at least the first part of such a search is most efficient using three 1:145,000 scale photos.

During the subsequent investigation and mapping of the new break formed April 8, all these other photos were used, but only after reconnaissance by aircraft, with the help of the 1:90,000 and 1:145,000 scale photos (which showed the traces resulting from previous earthquakes), revealed the general extent and location of new breakage. The surface ruptures were plotted on 1:20,000 and 1:25,000 photos, but the smaller scale

photos were indispensable for establishing continuity of breaks, indicating locations that should be investigated for breaks, and organizing such logistic problems as access to different parts of the break.

Small-scale stereo

The advantage of small-scale airphotos are greatly extended by stereo use, which yields a 3-dimensional view of a very large area. Although topographically expressed features such as lineaments are generally obvious on a single photo, particularly if illumination is favorable, the addition of stereo may reveal otherwise obscure topographic lineaments or topographically expressed differences between lithologic units.

Moreover, problems dealing with the analyses of surfaces and their relations to each other and surrounding terrain may be more quickly and easily recognized and analyzed with stereo photos than with a topographic map. Plate 4 forms a stereo pair with Plate 3. The strikingly dissected region of folded sediments in the vicinity of Fish Creek Wash 5 to 10 miles west of the Coyote Creek fault preserves fragments of several levels of older alluviated surfaces, as at E, F, and G. These different levels may represent episodes in the tectonic history of these mountains and the adjacent Imperial Trough. Analogous surfaces exist in many other drainages of the region. Any attempt to understand the history of the older surfaces requires, among other efforts, correlation of the existing fragments, visualization of their probably former extent, and identification of sources and direction of distributary channels on those alluvial

surfaces. A single stereo view of the entire drainage containing the surfaces makes such tasks much easier, and may reveal relations or lead to hypotheses that could not be gained by other methods.

For example, the stereo view leads directly to such questions as the following: What is the relation of surfaces H, I, and J (Pl. 3) to the two major surfaces E and F? When during the history of these surfaces did the canyon at K become part of the drainage system? Do the different surfaces represent distinct episodes of equilibrium throughout the drainage during its erosional history, or do they represent preserved remnants of local equilibrium during a continuing process of erosion whose intensity switches from place to place throughout the basin as the major channels move laterally across the basin?

The single stereo view at small scale helps the investigator form the questions that must be asked and helps him organize the task of answering them by presenting a single, detailed three-dimensional view of a large part of the system being studied.

A problem commonly arises whenever airphotos must provide a single stereo view of a specific region. As ordinarily obtained, airphotos of a region yield individual stereo models that overlap each other by about 10 to 30 percent, in contrast to roughly 60 percent overlap of the individual photographs. Thus a geologic feature of interest such as a basin might not coincide with a single stereo view, even though its dimensions are small enough, because the photo centers fall in the wrong places.

The most practical way to overcome this problem is to use photos at a scale sufficiently small that the region of interest is small compared to the area covered in a single stereo model. The smaller the target area with respect to the coverage of the stereo model, the lower the probability that it will be split between two stereo models. If necessary, the feature can be enlarged for study in stereo, and photos of larger scale can be used for investigating details of critical parts of the basin.

Study of the dissected surfaces shown by Plates 3 and 4 would probably be further helped if areas outside of the stereo model shown here, but still in the same immediate drainage basin, could be included in a single view. Photos at 1:200,000 to 1:400,000 scale would probably cover the necessary area; moreover, photos at even smaller scales would show relations between several adjoining basins, if they retained the necessary detail.

In the above example, the use of small-scale stereo models broadly illustrates the general relations between photos of different scales and indicates how a problem in a relatively small area might benefit from the availability of both high altitude and orbital photographs, in addition to ordinary large-scale photos.

Sierra Nevada

Glacial deposits

Another type of geologic study in which a single stereo view of a large region is valuable, is illustrated by Plates 5 and 6 (1:125,000), which show the abundant Pleistocene glacial deposits near Virginia and

Green Creeks on the east slope of the Sierra Nevada just north of Mono Lake. Figure 4 is a geologic map of part of this area. These two drainages contain prominent lateral and terminal moraines of the Tahoe and Tioga Glaciations (early and late Wisconsin, respectively) and large areas of older till (Sharp, 1965, p. 75; Blackwelder, 1931, p. 898) and moraines that may represent deposits of more than one pre-Tahoe glaciation (Clark, 1967, p. 57).

A single stereo view reveals a possible relation between some of the older till masses (moraines?) that lie beyond the Tahoe moraines of Virginia Creek. The bodies of till at A and B on Plate 5 are evidently remnants of a pre-Tahoe right-lateral moraine from Virginia Creek. From the photo, the till body at C appears to be a remnant of the same lateral moraine. This relation was not obvious to me or several others, even after spending several days in the field equipped with 1:16,000 and 1:60,000 airphotos. We considered it as a possibility, yet it did not seem mechanically likely. In particular, the canyon immediately west of the till, leading south to Mono Lake, would appear to complicate the flow of any glacier in Virginia Canyon, if not divert it away from the till at C. Yet the small-scale stereo view reveals a degree of continuity between the till masses at A, B, and C that strongly suggests they are remnants of the same lateral moraine. By this explanation the canyon west of the till at C would have been shallower when the till was deposited, and was presumably filled with till of the lateral moraine, subsequently eroded out. This hypothesis receives strong support from the broad stereo view afforded by the small-scale photographs.

In Green Creek, the next drainage north, the small-scale stereo view reveals what appear to be remnants of lateral and terminal moraines (D) left by a large pre-Tahoe glacier. These presumed moraines were first detected on a 1:60,000 photo (Plate 7) (Clark, 1967, p. 57), and, if interpreted correctly, represent the best example yet known in the Sierra Nevada of the preservation of moraines of a glaciation older and more extensive than Tahoe. As far as I know, the possible morainal nature of the till at D was not earlier recognized on the ground or on large-scale air photographs.

Additional information, not obvious on photos of larger scale, can be seen on Plates 5 and 6. The crests of the older assumed moraines (D) are distinctly lower than the enclosed Tahoe-Tioga crests, implying relative down-faulting of the older till with respect to the mountain front and subsequent alluviation east of the resulting scarp. This caused the later Tahoe glacier to emerge from the mountain front relatively higher than the older, more extensive moraines, as evidently happened also in Mono Basin, 20 miles to the south (Clark, 1967, p. 41-42). In both areas this relation was not recognized until a single stereo view on small-scale airphotos became available of the entire morainal assemblage of each drainage.

Faults

Plate 5 reveals faults heretofore unrecognized in this area. Two gently curving discontinuous tonal and topographic lineations, probably related to faults bounding the eastern margin of the Sierra Nevada, are quite noticeable between E and E' on Plate 5. The upper lineation is

distinctly less apparent on 1:60,000 airphotos. Both are difficult to recognize on large-scale airphotos, and their continuity is not evident on the ground. Their position is proper for range front faults, and they are aligned with the major range front scarps to the north and south. The lower, more prominent of the two lineations at E-E' is composed of vegetation contrasts (presumably in part controlled by ground water), a few subdued and short topographic scarps, and irregularities in the otherwise continuous moraine crests above Robinson Creek at the northern end of the lineament. Considered individually, such features are of little note. Vegetation contrasts and small scarps abound in this area, created by lithologic boundaries, joints, and minor structural irregularities. Indeed, in the field, the interrupted crests of the moraines (representing three different ages; Sharp, 1965, p. 74-76) appear to be a result of local sliding. However, the remarkable alignment of so many features along E-E' strongly suggests a fault. A parallel, more continuous lineament, almost certainly a fault, is at F-F'. This feature is also prominent on 1:60,000 scale photos (see Plate 7). None of these features, however, were detected during geologic mapping of this area until the small-scale airphotos became available.

Advantages of using several photo scales in a single area

During a reconnaissance field check of the glacial deposits, three scales of vertical airphotos were used: 1:16,000 (Plate 8), 1:60,000 (Plate 7), and 1:105,000 (flown by USAF, but not shown). The photos of Plates 5 and 6 (1:125,000) were obtained after field work was finished. The 1:16,000 photos were the base for recording field information and

investigating differences between adjacent lateral moraines of the same drainage. Plate 8 shows the Tioga terminal moraine (latest Wisconsin) of Green Creek and surrounding older moraines. 1:60,000 photos (Plate 7) proved valuable for comparing some of the moraines of adjacent canyons; for example, the Tahoe and Tioga moraines of Virginia Creek to those of Green Creek. They were also valuable for discovering some of the faults (e.g., F, Plate 7) and checking detail of structures seen on the smaller scale photos. However, the 1:60,000 photos did not extend far enough to show obviously the continuity of the main range-front fault system, or permit convenient comparisons between the moraines of Green Creek and those of the next drainage north, Robinson Creek. These regional structures and relations show best on the 1:125,000 photos (Plates 5 and 6) (The 1:105,000-scale photos mentioned above divided the moraines of both Virginia and Green Creeks between two adjacent flight lines, hence were much less satisfactory than the 1:125,000 photos). Photos at scales of 1:200,000 to 1:400,000 would be very valuable to any study of the structural setting of the Virginia-Green-Robinson Creek area. Such photos would show the orientation and continuity of faults and joints of this region in relation to the structure of adjoining parts of the Sierra Nevada and the ranges immediately to the east.

San Andreas fault

Carrizo Plain

Small-scale airphotos have proven useful in the study of the tectonic settings along faults. R. E. Wallace (1968, written commun.) has evaluated small-scale photos of the San Andreas fault where it traverses the Carrizo

Plain in central California (A-A', Plates 9 and 10, 1:133,000 scale). He had previously made a detailed study of the fault in this region, aided by airphotos at scales of 1:6,000 and 1:24,000. Subsequently, using the small-scale photos, Wallace discovered several lineaments (parallel to B-B', Plate 9) that he had not earlier recognized near the fault; although once located, he could identify them on the larger scale photos. He also noted that features more than one mile long were more easily identified on the small-scale photos than on large-scale photos and suggested that a distinctive feature is enhanced by a certain amount of nondistinctive or random background pattern. For example, a lineament becomes more apparent when it is obviously longer than the randomly oriented linear elements of the local terrain. Such recognition requires a single view significantly larger than the size of the random elements. Thus, Wallace was more easily able to recognize landslide scars 1 to 1½ miles across at (C) and vague but persistent folds at (D) on the 1:133,000-scale photos than at larger scales.

The detailed field studies completed by Wallace prior to receiving the small-scale photos included examination of stream channels offset at the fault (1968). He determined that offsets of 300 to 500 feet were obvious during a rapid scan of contact prints of the small-scale photos, and offsets as small as 50 feet were apparent with 2 to 3X magnification. On the photo, these distances are roughly 0.03" to 0.05" and 0.005", respectively. Hence, at this location, the practical limit of resolution on a contact print for an offset linear topographic feature is about .005" (roughly 0.1 mm), or 50 feet on the ground. Somewhat smaller offsets are

probably evident on the film negative. Significantly better resolution is presumably attainable with other cameras and films.

Moreover, for the recognition of linear patterns, 9" contact prints at a scale of about 1:130,000, offer a minimum length of 11 miles of terrain in stereo and 18 miles in a single photo. Whether a geologist can recognize a given feature in these distances depends on the characteristics of the feature and the surrounding terrain and the skill and experience of the user.

Cholame Valley

Plates 11 and 12 (scale 1:133,000) show the San Andreas fault in Cholame Valley, about 50 miles northwest of the Carrizo Plain shown on Plates 9 and 10. This segment of the fault ruptured with several inches of right-lateral offset at the surface during the earthquakes of June-August, 1966 (Brown et al., 1967); however, the part of the fault on the right half of Plate 12 is difficult or impossible to detect at this scale. (Plates 11 and 12 were taken in November 1967, after the earthquake.) The recently active traces are evident on large-scale photos, on which they were located by both Dickinson (1966) and Brown before the 1966 movement. The active traces were mapped in more detail after the earthquake, again using large-scale photos (Brown et al., 1967, p. 10).

R. D. Brown, Jr. (written communication, 1968) has inspected Plates 11 and 12. He pointed out that scarps and mounds 1 to 2 feet high, small contrasts in vegetation and depressions mark the active trace in the places where it is not visible on these Plates. Apparently these features or their linear nature are too small to be evident at 1:133,000

scale. Thus, although the San Andreas fault is a through-going linear feature in this region, plainly visible on large-scale airphotos, it does not show locally on the high altitude photos if the elements that mark its position are too small to be resolved or recognized.

However, Brown found other characteristics of the high altitude airphotos that made them valuable to a study of the fault in the Cholame Valley area. One feature the photos show, as a result of their broad but relatively detailed view, is the systematic deflection of many northeast-trending channels at B (Plate 12). The deflection is apparently the result of right-lateral deformation of downstream reaches of the channels. This relationship was not obvious either on the limited coverage of large-scale airphotos or the generalized topography of a 1:62,500-scale map.

Another characteristic Brown noted is that the large stereo view of the high altitude photos reveals a broad but discontinuous alluvial surface northeast of the fault (C) that is now being dissected, apparently as a result of recent fault movement. As has been pointed out elsewhere in this report, this relation can be gleaned from topographic maps or a mosaic of larger scale airphotos, but not nearly as easily nor are the relations as obvious as on small-scale stereo airphotos.

Flow patterns in water

Small-scale photos have proven useful in the study of patterns of tidal currents. Cameron (1961) described the use of 1:80,000 photos in such studies near New Brunswick. The U. S. Geological Survey has employed the small-scale photos

described in this report to record the distribution and flow patterns of suspended particles in San Francisco Bay. Plate 13 (1:140,000) shows the southern part of the bay. Three such pictures, taken within about 5 minutes of each other, cover the entire bay, effectively recording flow patterns and relative sediment distribution during that time interval. A series of these pictures, taken at different times during a tidal cycle, at different seasons and during periods of unusual runoff, would record a wide range of current and sediment conditions.

If it had sufficient resolution, a single photo at a scale of about 1:400,000, covering the entire bay, would be the most efficient way of making this particular study. Perhaps suitable photos will be available in a few years from satellites. However, at present, high altitude photos offer the best way of accomplishing this work.

Moreover, an instantaneous view of a large area might be useful in studies of the waxing and waning of floods, wave patterns, eolian transport, or any other phenomenon characterized by rapid changes over a large area.

Summary of geologic usefulness

The foregoing examples of geologic uses of small-scale airphotos are limited in scope and application; yet, hopefully, they illustrate the general utility of these photos in work on geologic problems. Unfortunately, none show clearly an important attribute of small-scale photos illustrated and emphasized by Hemphill (1958, fig. 6); that a broad view may reveal subtle but pervasive regional differences between lithologic units in topography, reflectivity or vegetation (expressed as photographic texture or tone).

Summarizing the uses illustrated above:

1. High-altitude, high-oblique airphotos show vast areas in one view, introducing a geologist or his audience to the salient geographic and topographic attributes and many geologic features of an area.
2. Small-scale vertical airphotos
 - a. offer the most efficient method of discovering the major topographic features and, commonly, important structural and lithologic characteristics of new or unfamiliar terrain.
 - b. show a broad region in one 3-dimensional view that may reveal relations or suggest geologic hypotheses not otherwise apparent.
 - c. may reveal features of such extent, subtlety, or discontinuity that a broad view is necessary to recognize them.
 - d. instantaneously record rapidly changing conditions over large areas, such as tidal flow and surface wind patterns.

Anyone can correctly argue that nearly any feature displayed by or "discovered" on small-scale airphotos, can be recognized by an experienced and astute geologist using a topographic map and large-scale photos or field investigation. The major claim made in this report is that small-scale photographs furnish the geologist with another tool, that helps make geologic features evident to him and thereby makes him more effective, either by saving time or by revealing relations he might otherwise miss because of lack of experience or astuteness.

RESOLUTION AND SCALE

High resolution appears to be an important aspect of the usefulness of small-scale photos, particularly if a feature is expressed by small, discontinuous elements that require such resolution for detection. Furthermore, an observer nearly always wants a closer look at any feature of interest. Magnifying a high resolution, small-scale image is nearly always more convenient than switching to another air photograph taken at larger scale.

Conceivably, in a few situations the detail resulting from high resolution of small features might obscure more subtle, larger elements of a photograph. It is always possible to degrade resolution or change tonal contrast of prints in order to search for things thus hidden, rather than to specify or accept inferior resolution in the original photos.

Thus, the most versatile airphoto would be one taken at the smallest useful scale and capable of magnification to the largest practical scale for a given project. Such an ideal is most closely approached by using very fine-grain films that yield transparencies, which in turn are analyzed on light tables equipped with high magnification stereoscopes. A far more practical solution for most geologists, however, is to translate this ideal into terms compatible with his equipment and methods.

For most geologists a major advantage of airphotos is their ease of use in the office and in the field. Convenient use of the information on airphotos in such locations virtually demands prints rather than transparencies and light tables, and simple 2X to 4X magnifying stereoscopes

rather than bulkier stereoscopes of higher magnification. Prints and simple stereoscopes can be and are used almost anywhere by geologists. Faced with the option of using high resolution transparencies plus a high magnification stereoscope as opposed to prints at two scales yielding the same information with a low magnification stereoscope, I suspect most geologists would pick the latter as being more convenient for their type of use.. Such an attitude will prevail until transparencies become as easy to view, annotate, and carry, along with the necessary stereoscopes, as are prints and common stereoscopes.

The useful limit of magnification for ordinary paper prints of most airphotos is about 3X, based on my comparisons between magnified small-scale photos and unmagnified photos of larger scale (e.g., Plates 5, 7 and 8). Hence, the most effective use of small-scale photographs for geologic field work dictates that they be available in scales differing by roughly a factor of 3. The geologist should pick the large-scale photos best suited to his project and then attempt to secure smaller scale photos according to the above guide. Thus, in the project described earlier at Green Creek, photo scales of 1:16,000, 1:60,000 and 1:125,000 are reasonably close to the 1:16,000-1:50,000-1:150,000-1:450,000 scales suggested as most suitable. Hopefully, such a spread in scales permits the most efficient transition from one scale to the next larger and allows small-scale views of features of a wide range of sizes.

With scale ratios of 3:1, each photo of one scale covers 9 times as much area as those of the next larger scale. Once coverage is obtained of an area at the largest, "working", scale, additional coverage at 1/3,

1/9, and 1/27 of that scale means an increase in the total number of photos for the project of 11%, 1.2%, and .14%, respectively. These are quite small increases in view of the potential benefits to be gained, assuming the small-scale photos already exist, and do not have to be flown for the project.

MOSAICS

Various types of assembled large-scale photos, from photo indexes to carefully matched and controlled mosaics, yield a single view of large areas, and are commonly reduced to scales of 1:100,000 or smaller. Such mosaics may be very useful in the absence of single small-scale photos, but in comparison to the latter, mosaics have two major disadvantages:

1. Line and tone discontinuities between adjacent photos greatly reduce the usefulness of assembled photos. Minimizing or eliminating these discontinuities is difficult and expensive.

2. A mosaic of photos cannot be viewed stereoscopically. Most of the applications of small-scale photos described in this report would have been more difficult, and some would have been impossible without stereo. Hence, mosaics would have been a poor substitute in these applications.

Of course, mosaics of small-scale photos will be valuable in certain regions until orbital photos that cover the same area become available. Once aircraft and satellite photos at all scales become available for the entire earth, mosaics will likely become obsolete except for such uses as world photomaps or cloud-free images of an entire hemisphere.

AVAILABILITY OF SMALL-SCALE AIRPHOTOS

1:60,000-scale airphotos cover most of the U.S. They were flown in the 1950's with 6" lenses and are sold by the Map Information Office of the U.S. Geological Survey in Washington, D. C. Airphotos of smaller scale, such as the California 1:90,000 photos, are available for a few areas. As far as I know, all are larger than 1:100,000 scale. The series of 1:125,000 to 1:145,000-scale vertical and corresponding high obliques described in this report are available for research purposes from the U.S. Geological Survey in Menlo Park, California.

Although present nonmilitary jet aircraft cannot attain the altitudes from which the photos in this report were taken (ca. 70,000 feet), operational commercial jet photographic aircraft equipped with "superwide-angle" cameras will yield comparable scales. These aircraft can operate near 50,000 feet (Bock, 1968). "Superwide-angle" lenses have a focal length of about $3\frac{1}{2}$ inches that produces a 9-inch image, and have been used for years: the 1:90,000 California photos were made with such a camera in 1964. At 50,000 feet above the surface a superwide angle lens yields an image scale near 1:175,000. Thus, operational commercial air photographic equipment can presently produce scales smaller than those of the photos in this report.

Such a system, in essence, has been in use since mid-1968 by the Phoenix Research Unit of Water Resources Division of the U.S. Geological Survey. Members of that group modified a T-33 jet trainer to accept a KA-50A superwide-angle camera loaned by the U.S. Navy. The camera uses 5" roll film and has a $1\frac{3}{4}$ " focal length lens, yielding the same ground

coverage as does a 3-1/2" lens on 9½" roll film from the same altitude.

The camera was obtained from the Navy specifically for this evaluation of small-scale airphotos and a related study of small-scale, low sun angle airphotos. However, the Phoenix Research Unit has since used the camera and aircraft for many other projects involving collection of hydrologic and geologic data. Virtually all the photos are taken from about 35,000 feet, yielding scales of roughly 1:120,000 on 9" x 9" enlargements. The Phoenix Unit finds that the small-scale photos commonly offer the best way of studying such hydrologic phenomena as water flow, wave patterns, flooding and pollution.

Plate 14 shows a 2X enlargement of a portion of the Garlock fault taken with this camera from about 32,000 feet. The picture was one of a series obtained in early morning to study small-scale photos taken with a low sun angle. Plate 15 shows the same terrain taken with a 6" lens ("normal" wide-angle) on 9½" film from roughly twice the altitude. The flight lines and ground coverage were nearly the same for the two flights, but the sun angle is quite different.

The purpose of Plates 14 and 15 is to compare the effectiveness, for geologic purposes, of the photographs taken by cameras with superwide- and wide-angle lenses. Unfortunately, the great difference in illumination between the pairs prevents any meaningful comparisons of tonal differences. However, there is little reason to believe that focal length should significantly affect the rendition of tone contrasts. Furthermore, a careful comparison of sharpness is difficult, because no control existed

over such factors as type of film, camera vibration, film processing and printing. Resolution should, however, deteriorate more rapidly towards the sides of the image of the shorter focal length camera, other things being equal (Gruner and others in Thompson, 1966, p. 86).

As far as geologic interpretation is concerned, the primary difference between the images is the greater parallax in those made with the shorter focal length lens. Greater parallax leads to greater apparent stereo relief and increased relief distortion (Ray, 1964, p. 14). In most of the examples cited in this report, exaggerated relief would make interpretation easier. Certainly this is so when the problem includes identification of geologic features that are expressed topographically. Exaggeration also helps in the study of old erosion surfaces by more clearly separating those at different elevations. On the other hand, exaggeration and distortion of relief would be detrimental when features marked on airphotos are transferred to maps with a reflecting projector rather than by inspection or with a plotter.

A potential disadvantage of short focal length lenses arises in areas of rugged topography because some parts of the surface may be hidden from the camera. With respect to a 9" square image size, a camera with 6" lens has a 90° field of view between opposite corners and about 74° between opposite sides, whereas a 3½" lens (or 1-3/4" lens with a 4½" image) includes about 120° between corners and 104° between sides (Fig. 5). This means that a camera with 3½" lens will not "see" slopes steeper than 38° that are facing away from the camera along the sides of the flight path, whereas a camera with 6" lens will miss only those slopes steeper than

53° along the edges of the flight path. Of course, the amount of terrain thus hidden from the camera will be reduced if there are adjacent, overlapping flight lines. Thus, in general, the amount of terrain hidden from a 3½" lens is small except in very steep terrain.

Some of the remarks about relief and hidden slopes are illustrated by Plates 14 and 15. Tops and bottoms of both pairs of images extend fully to the edges of the original photos. The increased relief and relief distortion and poorer resolution in 14 is obvious. But also notice that little information is missing in Plate 14 from the slopes along the edges as compared to Plate 15, because of the low angle of view.

Thus, a camera with a short focal length lens appears to be generally suitable for geologic interpretation except in areas of particularly steep terrain or for problems in which relief distortion must be minimized. Even then, however, such disadvantages can be removed, by using sufficient side lap between adjacent flight lines to eliminate the need to use the edges of the photos.

Although all of the photographs evaluated for this report were taken in black and white, color should be entirely suitable for small-scale airphotos, either from high altitude (ca. 70,000 feet) or from medium altitude with superwide-angle lenses. Certainly the excellent quality of color pictures from Gemini and Apollo spacecraft indicates that high altitude does not significantly diminish the usefulness of color photographs for the study of the surface of the earth. Moreover, given proper

anti-vignetting filters, superwide angle lenses should also be able to produce good color pictures (e.g., Duddek, 1968, p. 158-160). Indeed, the Phoenix Research Unit of the U.S. Geological Survey has routinely and successfully used Eastman type 2448 Ektachrome and 8443 Infrared Ektachrome with the superwide angle camera described above, at altitudes up to 35,000 feet.

Hence, airphotos in both black and white and color, at scales as small as 1:175,000, are within the present capability of commercial aerial photographers. Smaller scales from aircraft await the routine and unclassified use of superwide angle cameras in high-altitude military aircraft, or the availability of this type of aircraft to private firms. At 70,000 feet a superwide angle camera with a 9" square image yields a scale of 1:240,000. Such photos could be useful in many projects today, if they were available.

OTHER USES OF SMALL-SCALE AIRPHOTOS

Disciplines other than geology may find small-scale airphotos useful. Surveys of large regions for cartography, forestry, agriculture, land and resource management, and urban planning could use small-scale airphotos if resolution is sufficient to the task. For example,

the U.S. Geological Survey selected the 1:140,000 high-altitude photos described in this report as the most rapid, economical and accurate method of revising 1:250,000 scale maps in the San Francisco Bay area to show shorelines changed by landfill operations, and new highways. The high-altitude photos were chosen because they contained the necessary information in the smallest number of photos, and offered a more efficient

source of the information than alternatives such as large-scale maps or other types of records.

Moreover, it is likely that many of the photographic projects contemplated for earth resources satellites (e.g., Badgley and others, 1967), could be effectively carried out now by the systems described in this report. Certainly if small-scale orbital photos are claimed to be a more effective or efficient way to do some tasks presently accomplished by large-scale airphotos, then currently available small-scale airphotos will also be more effective and efficient for such tasks. Moreover, projects of a regional nature which are contemplated or proposed for satellites because they cannot be reasonably or practically carried out now by large-scale air photographs, might effectively be done now by airphotos of the scale described in this report.

The first earth resources satellites will probably secure photos at small scales, perhaps 1:500,000 to 1:1,000,000 (for a 9-inch image size) and televise them to earth (Report for the committee on NASA oversight, 1968, p. 24-25). As explained elsewhere in this report, these photos will be most useful if studied along with photos at 3 to 4 times their scales. Presumably, earth satellites will eventually be able to produce vertical photos which range in scales from a single view of an entire hemisphere to the larger scales commonly used now in aerial photography. Furthermore, increases in resolution of the image transmission system or the use of film recovery will likely make photos from orbit as good as those obtainable from aircraft.

Eventually a resources satellite will probably be capable of producing all the photographs necessary for detailed geologic studies of any region. However, this does not mean that a satellite will be the most economical or efficient way of obtaining all the necessary photographs. Certainly, during the development of orbiting photographic systems there will always be a scale larger than which aircraft systems are most economical. This "boundary scale", separating practical aircraft and orbital photographic systems, will doubtless become larger as satellite photographic systems develop. However, it will probably be at some value large enough to require general use of aircraft-mounted cameras for at least a decade or several decades, assuming we employ aircraft and satellite camera systems as they are presently conceived.

The small-scale photographic systems described in this report are not in immediate danger of being replaced for earth resource studies, by cameras in orbit. Earth resource satellites are not yet operating, and when they do, early models are not likely to produce images with the scales or resolution of the photos described in this report.

Thus, the small-scale airphotos have a definite use now and perhaps for years to come in earth resource work. Hopefully, this report will stimulate users to either obtain and use available small-scale aerial photos or order such photos flown for their projects, using available aircraft and cameras.

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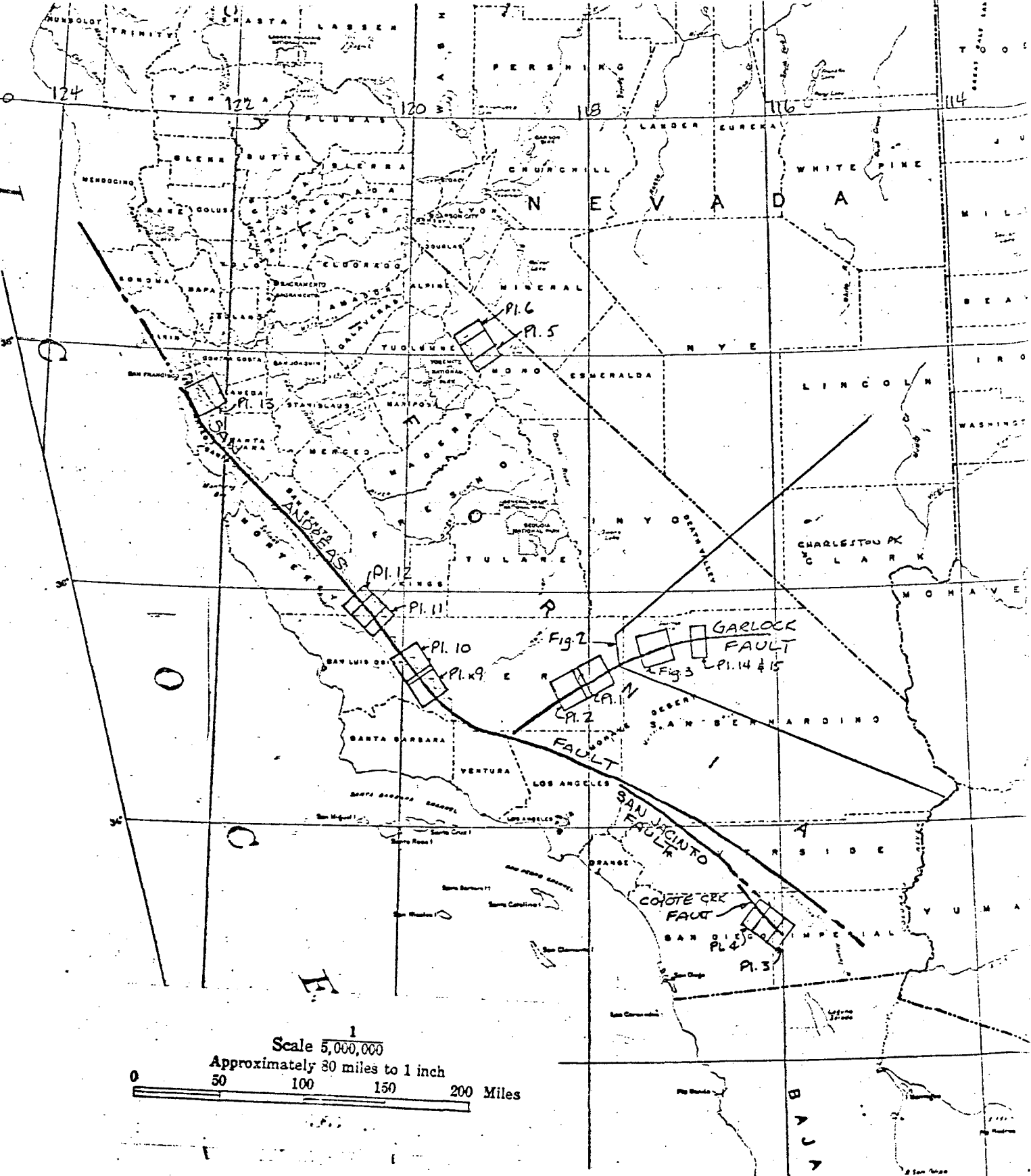


Figure 1.--Locations and approximate coverage of high altitude photographs shown in Figures and Plates.

Figure 2.--Oblique photo taken from 60,000 feet. View is eastward along the Garlock fault (A-A'), which separates the Mojave Desert to the south from the Great Basin region to the north (see also Fig. 3). Although not active in historic time, the Garlock fault exhibits many of the same surface features as the active San Andreas fault, including offset stream channels and aligned scarps, valleys, trenches and depressions, all of which make it conspicuous in Figures 2 and 3. Over this large area the photo shows the positions and varied relations between eroded hills and mountains, their surrounding alluvial aprons and the playas at the lowest points of many closed drainage systems. Details of tone and erosional texture permit discrimination and tentative identification of lithologic units such as the dark volcanic rocks at B. (Locations of Figures and Plates are shown in Fig. 1.)

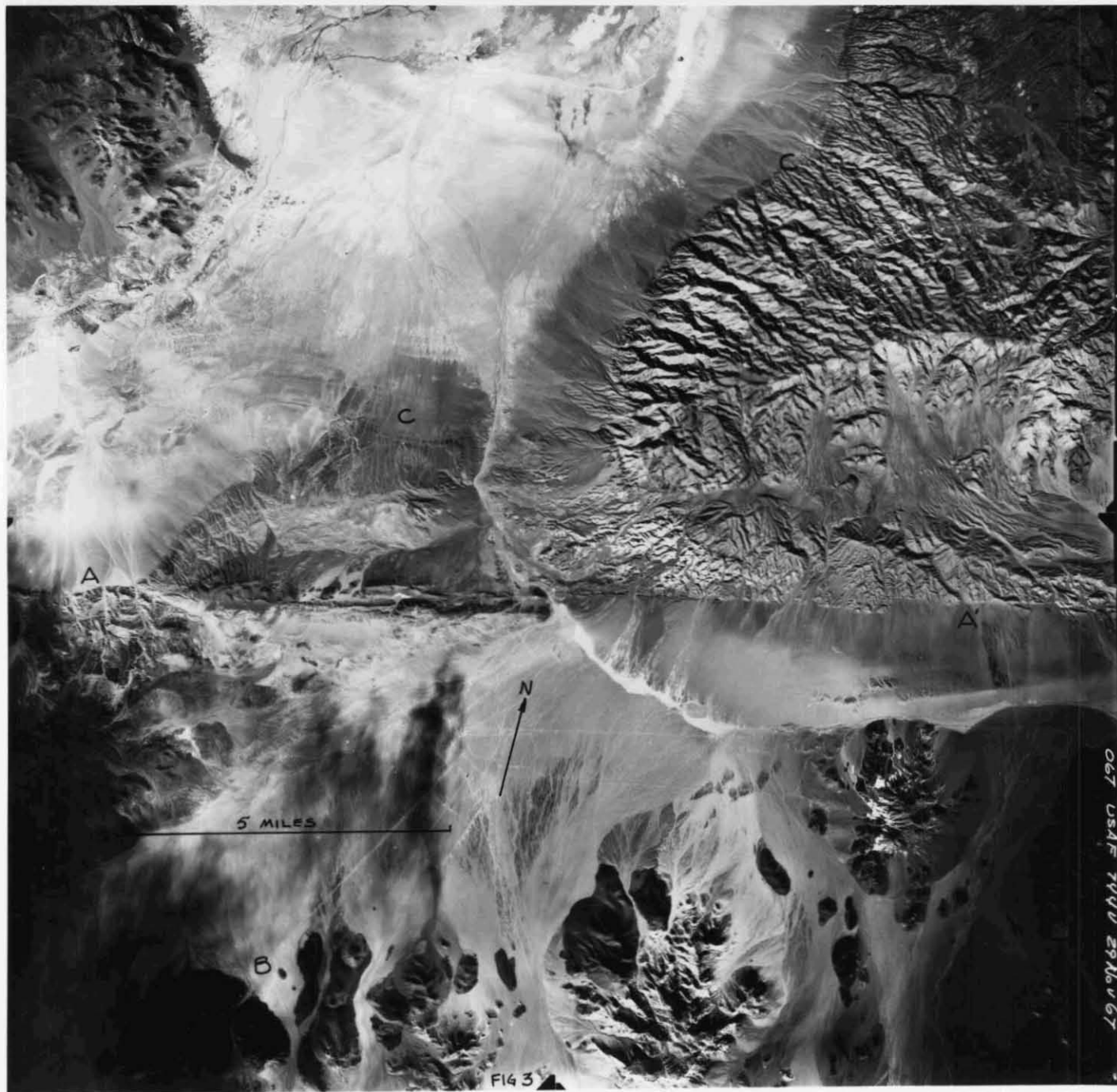
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Figure 3.--(1:120,000). Small-scale view of the Garlock fault (A-A') near Searles Valley. Cloud shadows obscure detail of volcanic rocks in the southwest corner at B. Shorelines of Pleistocene Lake Searles are evident at C; the modern playa is just beyond the north edge of the photo.



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Figure 4.--Geologic sketch map of bedrock and surficial deposits in part of the Bridgeport Basin, California. Based on unpublished map of Stanford Geological Survey, 1968, under direction of W. R. Dickinson; R. P. Sharp, 1965, Figure 8-2; and field investigations by the author in 1967 and 1968. Base from U.S. Geological Survey topographic map, Yosemite National Park and vicinity, California, 1:125,000, 1958.

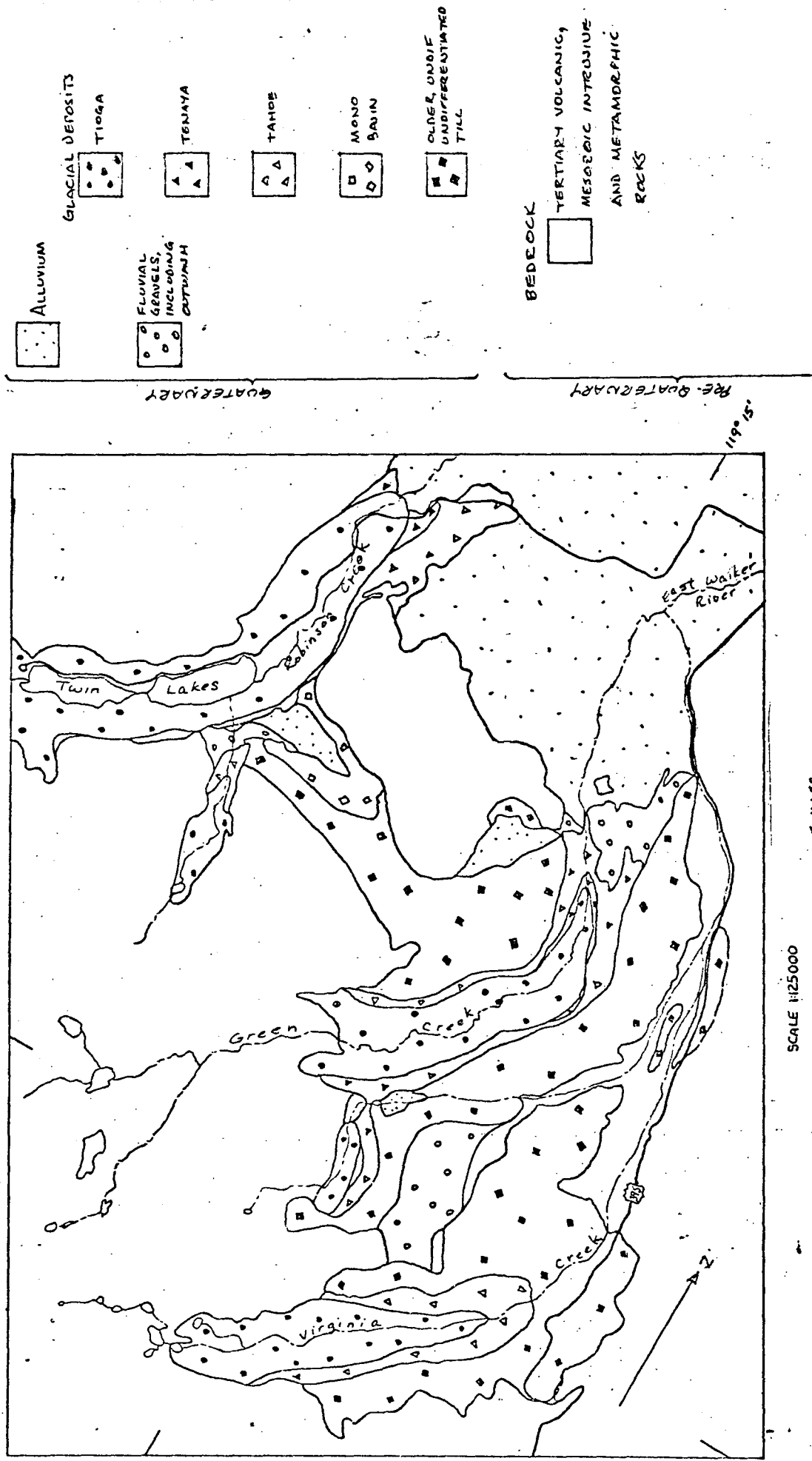


Figure 4.

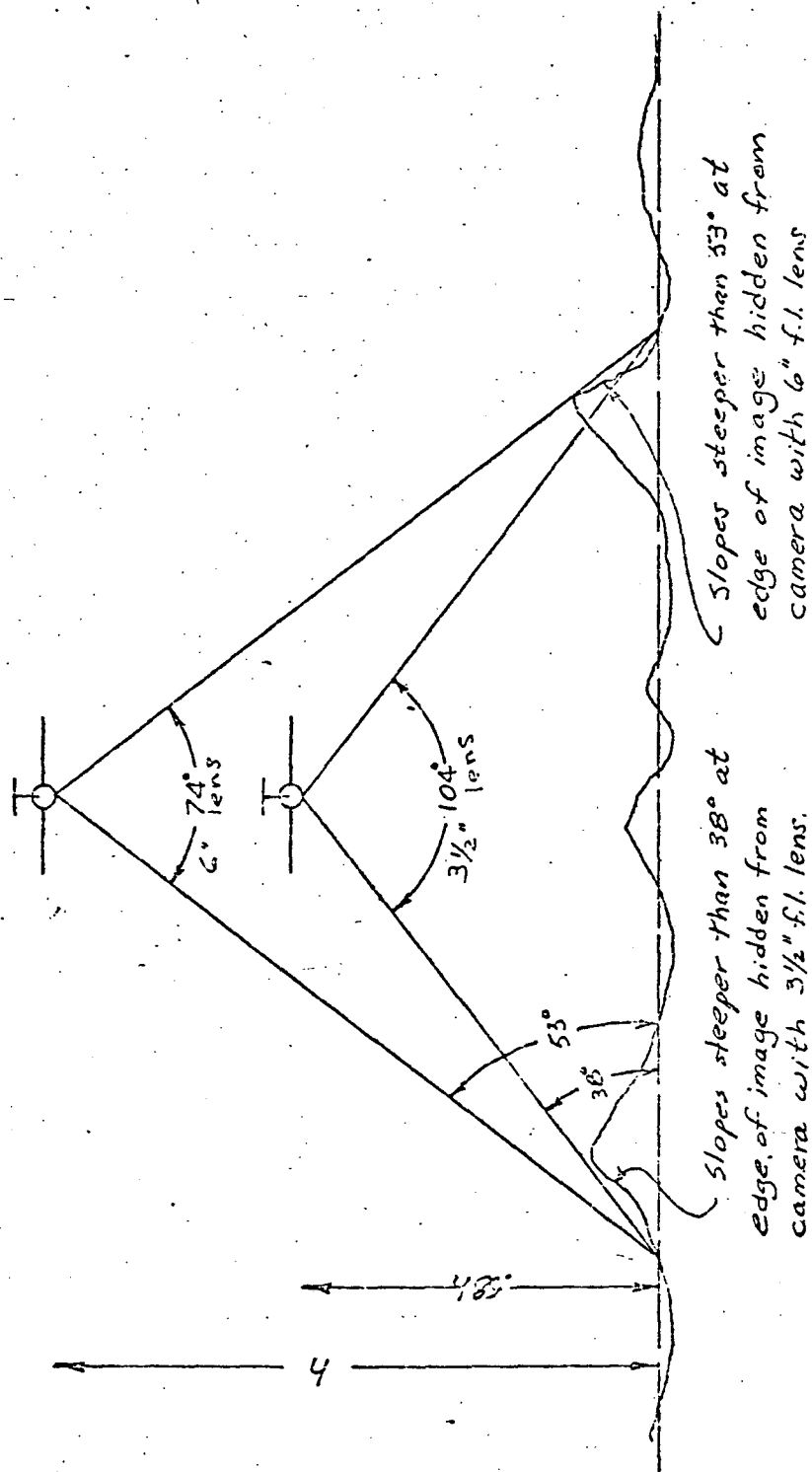


Figure 5.--Relations between flying height, h , angular field of view and terrain hidden from view of aerial cameras equipped with 6-inch and $3\frac{1}{2}$ " focal length lenses and $9\frac{1}{2}$ -inch roll film.

Plate 1.--(scale 1:120,000). Koehn Lake, a playa crossed by the Garlock fault. Scarp A and lineament B are aligned with the prominent scarp of the fault at C. Scarp at D and tonal lineament at E are aligned with the portion of the fault that extends to the southwest beyond the photo (see Plate 2). Squares show coverage of existing 1:32,000 and 1:20,000 photos.

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Plate 2.--(1:120,000). Portion of the Garlock fault (A-A') southwest of
that shown in Plate-1.

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Plate 3.--(1:145,000). Southeast end of Coyote Creek fault. Southeast part of the surface rupture of April 9, 1968 earthquake is at A-A' (northwest portion of the rupture is on Plate 4). Previously known southeast extent of fault is at B. Lineations at C and D were identified on this photograph as probable extensions of the fault before the earthquake. E through J are old erosion surfaces. K is the canyon of Fish Creek Wash.

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Plate 4.--(1:145,000). Southeast portion of Coyote Creek fault.

Plate 4 forms a stereo pair with Plate 3. Line L-L' is the northwest branch of the main surface rupture of the Borrego Mountain earthquake of April 9, 1968.



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Plate 5.--(1:125,000. See Figure 4 for map of this location.) Mono Lake and drainages of Virginia and Green Creeks. A, B and C are remnants of a postulated pre-Tahoe moraine of Virginia Creek. Curved ridges at D appear to be lateral and terminal moraines of an extensive pre-Tahoe glacier. Lineations at E-E' and F-F' are probably part of the range-front fault system of the Sierra Nevada.



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Plate 6.--(1:125,000). Bridgeport Basin. Plate 6 forms stereo pair
with Plate 5.



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PLATE 6

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Plate 7.--(1:60,000). Green and Virginia Creeks. Location shown on
Plate 5. Lineaments at E-E' and F-F' may be part of the Sierra
Nevada range-front fault system.

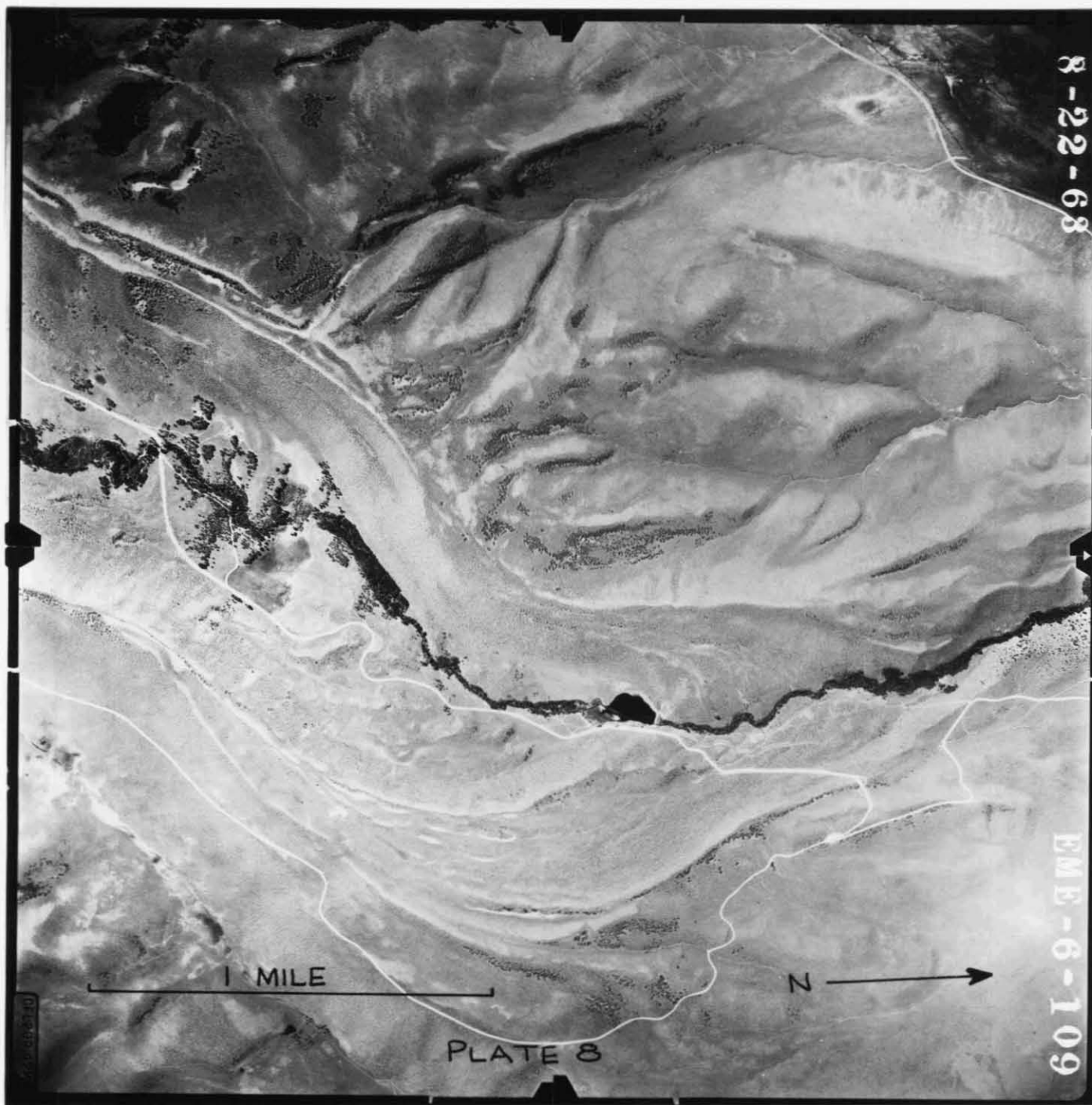
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Plate 8.--(1:16,000). Wisconsin moraines near Green Creek. Location
shown on Plate 5. -



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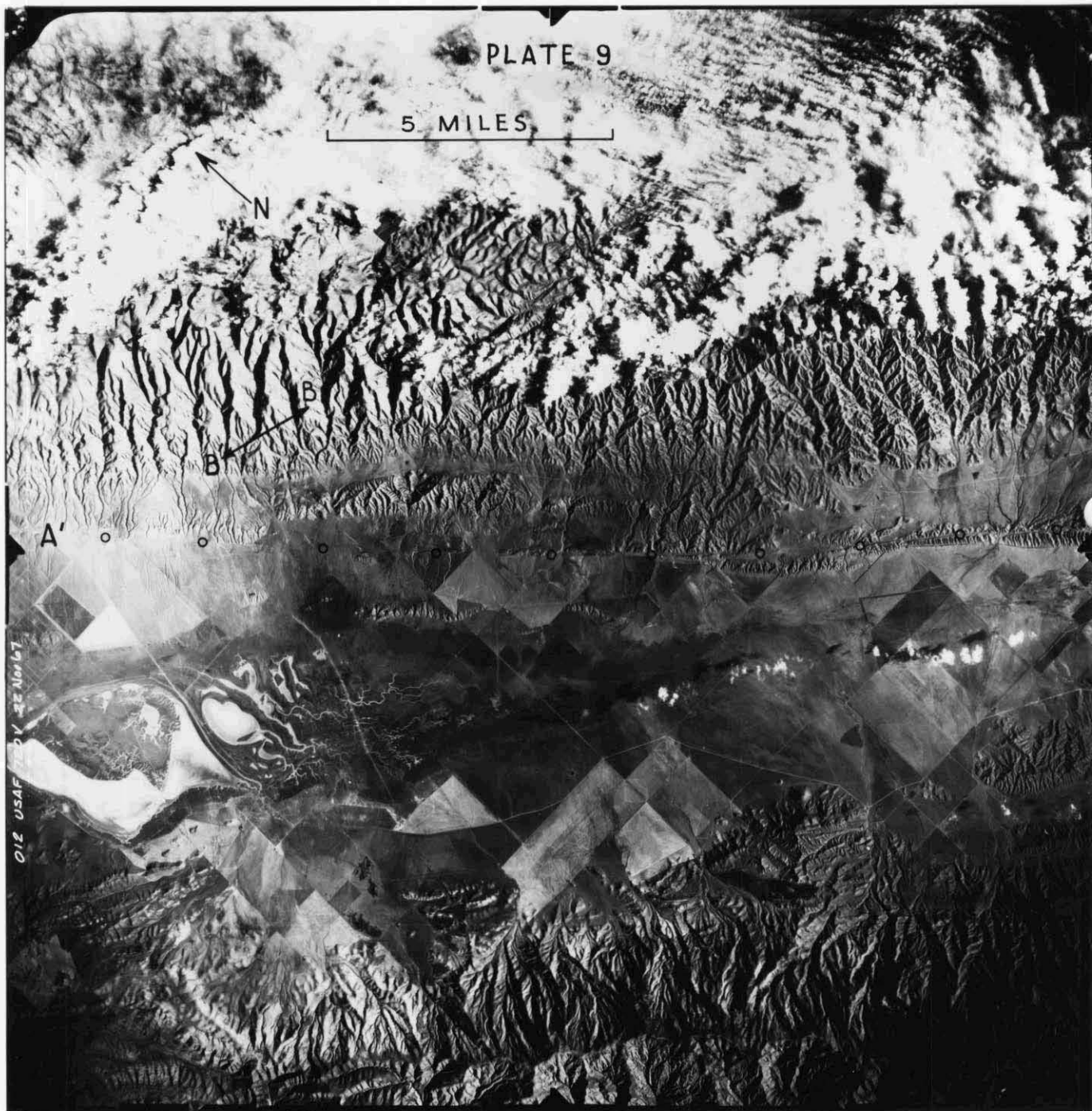


Plates 9 and 10.--(1:133,000). San Andreas fault (A) at Carrizo Plain.

Both plates show several stream channels offset by the fault.

Subtle lineaments, either tectonic or stratigraphic, parallel B-B'.

C marks landslide scars not easily evident on large-scale photos,
and subtle folds are at D.



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Plates 11 and 12.--(1:133,000). San Andreas fault (A-A') at Cholame Valley. A group of deflected stream courses is at B. C is an old erosion surface, now being dissected.



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Plate 13.--(1:140,000). Southern part of San Francisco Bay. San Mateo

Bridge is at left center, and San Francisco Airport at top right.

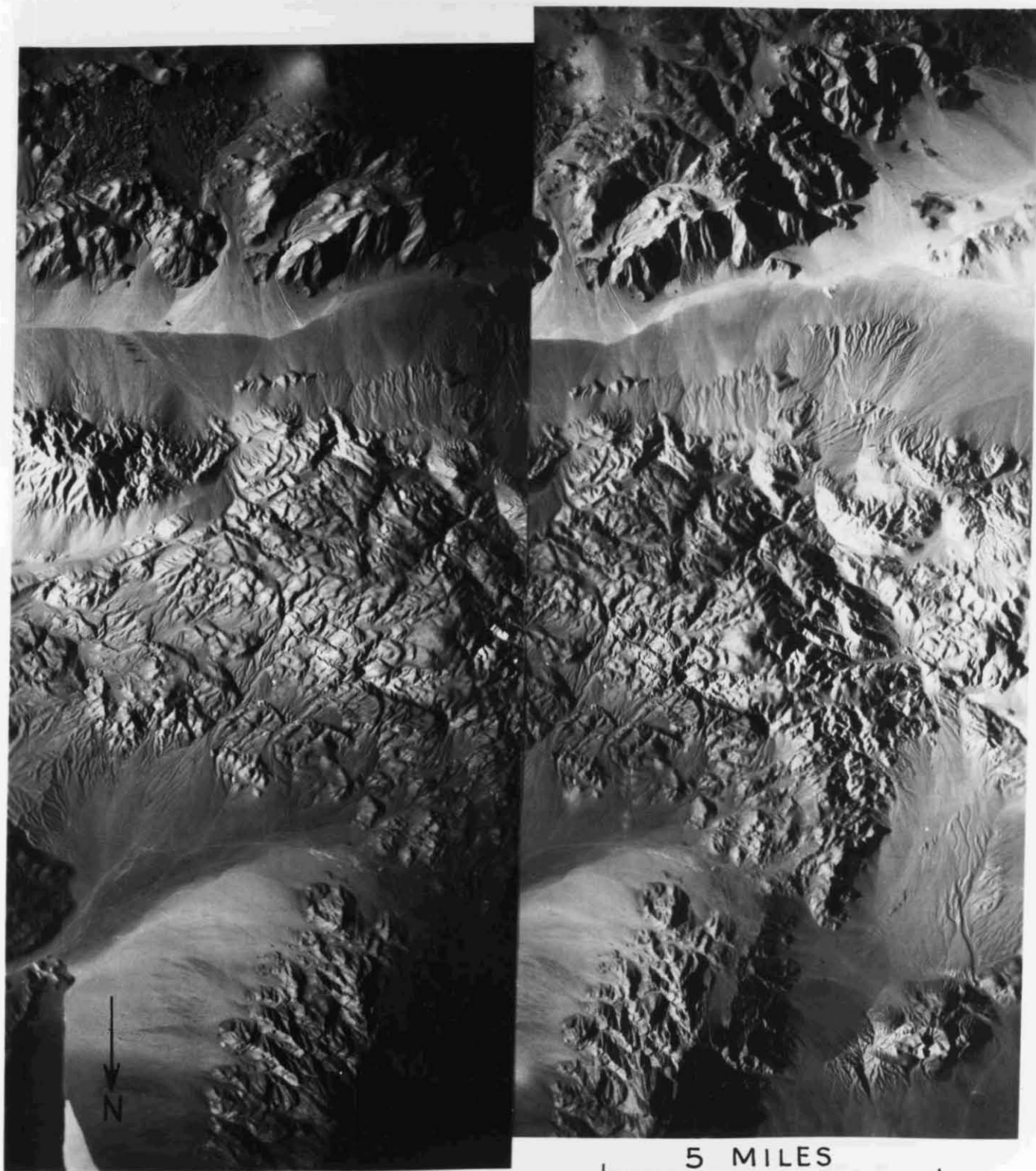
Three photos of this series record major surface water flow patterns of the entire bay.



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Plate 14.--(1:120,000). Stereo pair of Garlock fault zone taken with
superwide-angle lens (1-3/4" focal length on 5" film; enlarged X2)
from 35,000 feet.



5 MILES

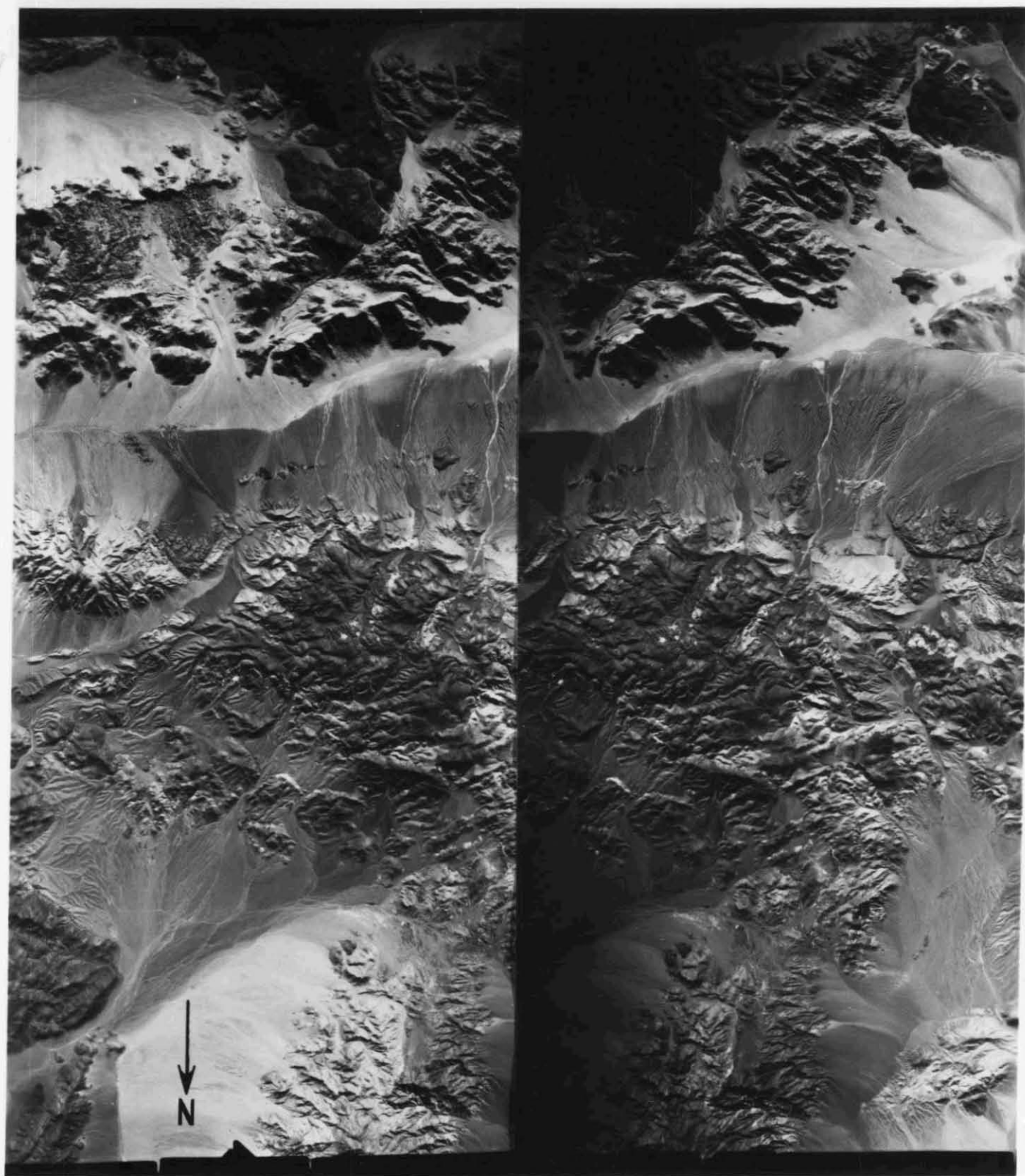
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PLATE 14

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Plate 15.--(1:120,000). Stereo pair of Garlock fault zone taken with normal wide-angle lens (6" focal length on $9\frac{1}{2}$ " film) from 60,000 feet.



5 MILES

PLATE 15

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