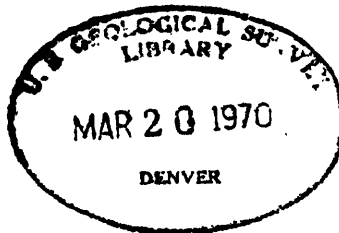


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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



EVALUATION OF COLOR AND COLOR INFRARED PHOTOGRAPHY FROM THE
GOLDFIELD MINING DISTRICT, ESMERALDA AND NYE COUNTIES, NEVADA

by

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U. S. Geological Survey
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This report is preliminary and has
not been edited or reviewed for
conformity with Geological Survey
standards or nomenclature.

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Sources of remote sensing data.--Kodak Ektachrome Aero Film, Type 8442, and Kodak Ektachrome Infrared Aero Film, Type 8443, (false color) were exposed simultaneously by the NASA-MSC Earth Resources Program aircraft on the Mission 76 midday flight, July 16, 1968. The Mission 76 photographic log for Site 75 is reproduced here as Figure 1. The two films were exposed in Wild RC-8 Universal Avilogon 6-inch focal length cameras. Solar altitude ranged from 67 to 70 degrees.^{1/} The flight lines intended for Site 75 are shown in Figure 2. The images obtained on low-level flight lines 3, 4, and 5 have a scale of 1:14,000, and those for the high-level flight line, number 6, have a scale of 1:21,000. Low-level lines 1 and 2 were not flown because of insufficient fuel.

Two sets of duplicates of the original color and false color transparencies, one set printed on color-reversal print film, the other set printed on color-reversal print paper, were supplied for this study. The color duplicates are nearly identical with the originals,^{2/} although the paper prints for line 6 retain a little more range of density than do the corresponding film prints. The film copies show sharper detail than the paper prints. The Ektachrome Type 8442 used for these images was exposed at 1/400 at f/5.6, which for desert terrain at midday resulted in overexposure of about one stop. Consequently, the color photos display very low density and have a pale yellow-brown cast, with a small range of

^{1/}Determined by D. B. Tatlock, September 1968.

^{2/}S. J. Gawarecki, written communication, September 1968.

EVALUATION OF COLOR AND COLOR INFRARED PHOTOGRAPHY FROM THE
GOLDFIELD MINING DISTRICT, ESMERALDA AND NYE COUNTIES, NEVADA

Site 75, Mission 76

NASA-MSC Earth Resources Aircraft Program and

U.S. Geological Survey

Introduction

General.---The Goldfield mining district is in the western part of the Basin and Range Province in desert terrain of relatively low relief. Altitudes range from about 5500 to 6900 feet. The district is underlain predominantly by volcanic rocks of intermediate to silicic composition and of middle Tertiary age. Recorded production is valued at \$89,000,000, most of it gold at \$20.17 per ounce, and the bulk of this production took place between 1905 and 1919. The deposits were of epithermal bonanza type.

The objective of this study is to determine what geological features characteristic of the Goldfield epithermal ore deposits can be identified from color and color infrared aerial photography. Hopefully, techniques developed here can be applied to aerial reconnaissance and eventually orbital reconnaissance of lesser known areas. Of greatest importance in recognizing a Goldfield-type deposit are features visible on the photography that allow the interpreter to locate volcanic centers and hydrothermally altered portions of these centers, including potentially mineralized veins formed along faults and fractures.

Recognition of volcanic centers depends upon the ability of the photography to reveal varied assemblages of volcanic rocks, and concentric or radial structural patterns. Hydrothermally altered areas must contrast with surrounding unaltered rocks, and structural features associated with alteration, such as veins or fracture zones, must be resolved. It is helpful to the interpreter, furthermore, if the photography has the resolution and the response necessary to show prospects and mine workings, including cuts, shafts, waste dumps, and mill tailings.

To thoroughly test the capabilities of the photography, results of detailed surface geologic mapping the petrographic examination are considered basic information, and the imagery is systematically examined to see what part of this basic information is recorded. Geochemical investigations have also been performed, but are not considered because most geochemical variations are easily related to petrographic differences between rocks, or can be explained by behavior of elements with weathering and oxidation in a desert climate. Anomalous minor element concentrations occur only in the vicinity of previously mined areas. Although most features seen on the photographs will be explained in the course of the discussion, no attempt is made to explain all details visible on the photography. This report demonstrates that color photography in particular, if properly obtained and processed, contains a wealth of information pertinent to recognizing hydrothermally-altered volcanic centers.

FIGURE 1

PHOTOGRAPHIC LOG																												
MISSION NUMBER		SITE		DATE																								
76		75		7-16-68																								
PHOTOGRAPHERS																												
MONCRIEF																												
POSITION 1 INSTRUMENT RECORD		POSITION 2 EKTACHROME		POSITION 3 EKTACHROME IR		NOTES: WEATHER: CLEAR WITH SLIGHT HAZE. FLIGHT LOGS CORRECTED FROM FILM, NIKON NOT CORRECTED, 19 JULY 1968.																						
CAMERA NO. NIKON		CAMERA NO. RC-8 (300)		CAMERA NO. RC-8 (307)																								
FILM PLUS-X		FILM 8442-78-2		FILM 8443-115-3																								
FILTER --		FILTER HF-3		FILTER WRATTEN 12																								
SPEED F STOP 1/60 5		SPEED F STOP 1/400 5.6		SPEED F STOP 1/275 5.6																								
ROLL NO. 1		ROLL NO. 1 of 1		ROLL NO. 1 of 2																								
FRAME No. MX 76		FRAME No. RC-8 (300)		FRAME No. RC-8 (307)																								
START STOP		START STOP		START STOP											LINE		RUN		TIME		ABSOLUTE ALTITUDE		DRIFT		GROUND SPEED		MAGNETIC HEADING	
1 9		1340 1348		1464 1479											3936 3944		6 1		20:05:50 20:08:15		9000		3°R		195		339°	
113 125		1452 1464		1479 1492											4048 4060		5 1		20:49:50 20:52:00		6000		2°L		210		076°	
126 140		1465 1479		1479 1492		4061 4075		4 1		20:55:40 20:58:20		6000		0°		191		255°										
141 153		1480 1492		1492 1500		4076 4088		3 1		21:01:20 21:03:25		6000		2°L		211		074°										

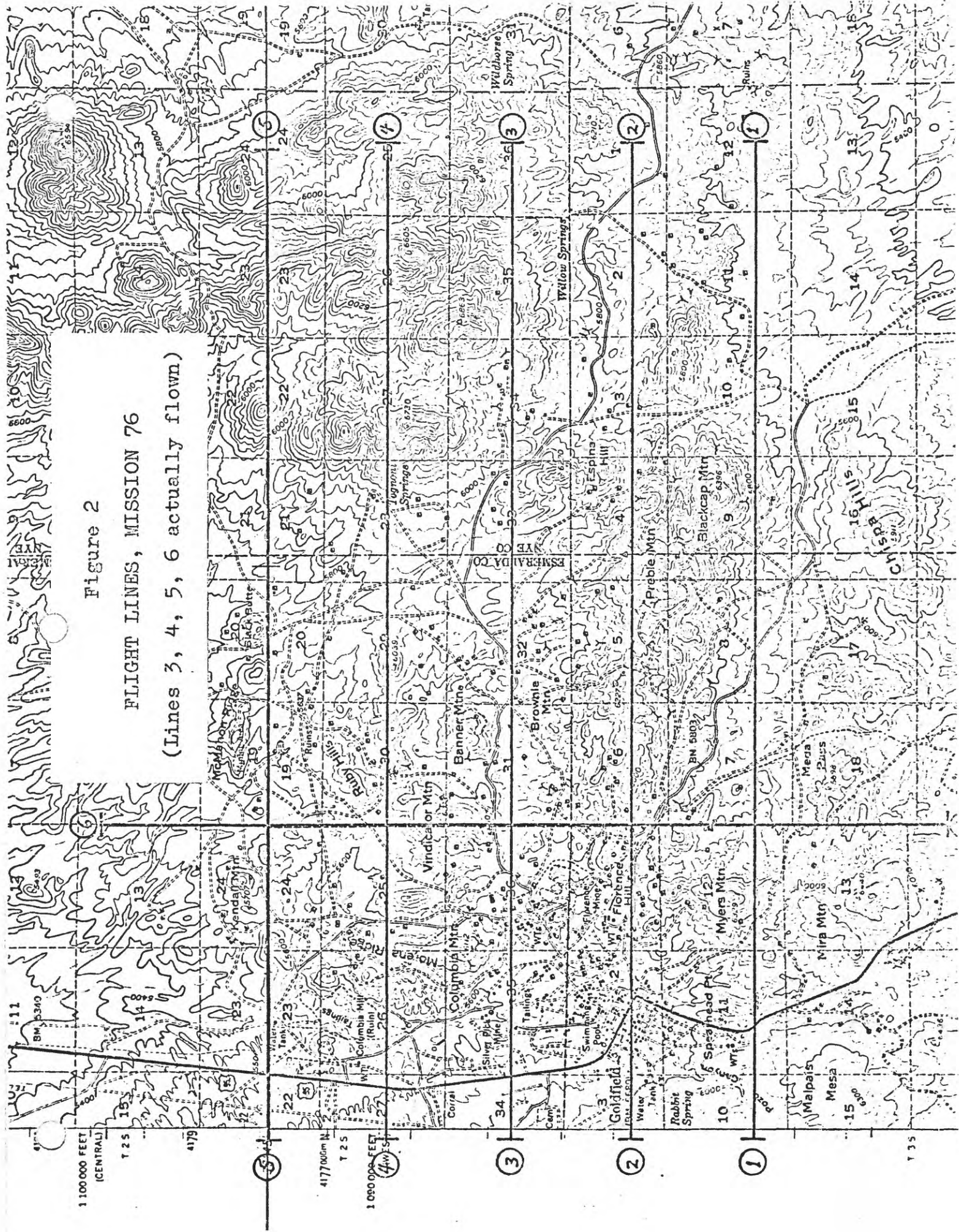


Figure 2
FLIGHT LINES, MISSION 76
(Lines 3, 4, 5, 6 actually flown)

color saturation.

All the false-color images show a conspicuous hot spot at the point of maximum solar specular reflection, and pronounced vignetting. The false-color infrared paper prints are probably nearly the same as the originals, but the film prints are notably different. The film prints have a violet-gray cast near their centers, whereas the originals and paper prints are bluish-gray. Vignetting causes the film prints to go to a dark bluish-green at their margins, instead of yellowish-green as seen on the paper prints and originals. The solar specular hot spot has equally low density in both the film and paper prints, but away from the hot spot the film prints show a greater range of density, giving better contrast. As usual, the film prints show sharper detail than the paper prints. Healthy vegetation, normally bright red in the false color rendition, is somewhat subdued on all copies relative to the originals. The Ektachrome Infrared Aero Film, Type 8443 was exposed at 1/275 at f/5.6, which resulted in about one-half stop overexposure over most of each image, with even greater overexposure at the solar specular hot spot. On the other hand, the yellow antivignetting filter provided by Wild for color infrared did not compensate well for the naturally lower exposure produced on the margins of the images relative to the centers: even though the centers are overexposed, the margins are underexposed.^{1/} The very small exposure latitude of Ektachrome Type 8443, $\pm 1/2$ stop according to Fritz (1967, p. 1132), makes uniform exposure difficult to achieve.

^{1/} Comparison of false-color infrared film prints with originals and evaluation of exposure from S. J. Gawarecki, written communication, September 1968.

Rather than attempt interpretation of the low-density natural color images, color negative photography at a scale of 1:23,000, previously purchased from private contractors by the Branch of Heavy Metals of the Geological Survey, was substituted for the Site 75 photography. Ektachrome MS Aerographic Film (Estar base), Type 2448 was exposed in a Wild RC-8 Universal Aviogon like those used in NASA-MSC Mission 76, with a 2.2X graded density filter, and was processed to a negative.^{1/} Both color and black-and-white paper prints were made for field use, and Ektacolor print film transparencies were made for office use. Printing was by electronic scanning. Both the color prints and transparencies display excellent color saturation and a broad range of densities. Although solar altitude during exposure ranged from about 55 to 65 degrees, the solar specular hot spot is inconspicuous, having been markedly reduced by the favorable range of density coupled with electronic printing. This photography also shows no appreciable vignetting.

In comparison to color reversal films such as Type 8442 and Type 8443, color negative film has greater exposure latitude ($\pm 1 \frac{1}{2}$ stops versus ± 1 stop) and a less critical developing procedure. Furthermore, color balance can be adjusted in the laboratory by appropriate filtering when prints are made, rather than during exposure.^{1/}

^{1/}Information from D. E. Tatlock, oral communication, September 1968.

Sources of geologic data.--Recent surface geologic mapping at Goldfield by Albers and Cornwall (1966) and Ashley (in progress) provides the geological background for this investigation. This mapping is part of an ongoing investigation of the geology, geochemistry, and hydrothermal alteration at Goldfield by the Geological Survey. This investigation was initiated by J. P. Albers and is being continued by R. P. Ashley.

Since the mine workings are now almost entirely inaccessible, older descriptions of the Goldfield district by Ransome (1909), Locke (1912a, b), and Searls (1948) are relied upon for the brief description of ore occurrences.

Geologic setting

The Goldfield district is underlain by andesitic, dacitic, latitic, and rhyolitic flows, tuffs, volcanic breccias, and tuffaceous sedimentary rocks of middle Tertiary age. Cherts and siliceous shales of the Ordovician Palmetto Formation and intrusive Mesozoic quartz monzonite crop out in scattered inliers. Remnants of late Tertiary welded tuff and basalt locally cap the middle Tertiary rocks.

The oldest volcanic unit is a rhyolitic welded tuff found in the vicinity of Vindicator Mountain (Pl. 1), here designated Tvr. It is overlain by a sequence of latitic materials found in the central part of the area: a latite flow (Tl), latitic tuffs (Tlt), and a welded quartz latitic lapilli tuff (Tlat). An unconformity truncates the rhyolitic welded tuff and latitic units. Channel gravels appear locally on this unconformity throughout the central and northwestern

parts of the area. The gravels are covered by rhyolitic tuffs, lapilli tuffs, and laharic breccias bearing some rounded pebbles from the gravels. These tuffaceous units are followed by a rhyolitic welded tuff and a rhyolite flow that appear mainly near the western edge of the area. Only the rhyolitic tuffs and laharic breccias with small patches of gravels (all designated Sandstorm Formation, Tst) are found in areas to be considered in detail in this report. Flows of the Milltown Andesite (Tma) blanket all previous units unconformably, forming the most extensive pre-alteration stratigraphic unit. Many flows of diverse petrographic character are included. Dacite domes and flows (Td) locally intrude and cover the andesite. Relatively large dacite bodies are located east of the town of Goldfield, east of the Ruby Hills, at Preble Mountain, and at Black Butte (Pl. 1). The largest body is east of Tognoni Springs, mostly outside the area considered in this report. Related dacitic welded tuff occurs on the south side of the area, in a belt from Myers Mountain to the Chispa Hills. Hydrothermal alteration and ore deposition followed the dacitic volcanism. All pre-ore units, with the possible exception of the Vindicator welded tuff, are unique to the Goldfield area, indicating that it is a volcanic center.

To the east and south of the area shown on Plate 1, post-ore rhyolite, welded tuff, and andesite cover the altered volcanic units unconformably. To the north and west, tuffaceous sediments of the middle Miocene Siebert Formation (Ts) cover the altered units, again unconformably. Malpais Mesa, which caps the non-resistant Siebert sediments west and southwest of Goldfield, is composed of two distinct cliff-forming units; the lower one is the Spearhead Member of the Thirsty Canyon

Tuff, a rhyolitic tuff of lower Pliocene age, and the upper one is the Malpais basalt.

Rock alteration at Goldfield is of two different types. The older, which may be termed deuteric or propylitic, actually encompasses several alterations, each of which characterizes a single volcanic unit and therefore probably occurred shortly after extrusion. The younger and more conspicuous one is intense hydrothermal alteration having nearly the same character in all rock types. Jagged outcrops of silicified rock dot the landscape within large areas of soft-weathering sericitized and argillized rocks having a "bleached" appearance due to destruction of ferromagnesian and calcium-bearing minerals by the hydrothermal fluids, and production of such minerals as quartz, K-mica, kaolinite, pyrophyllite, and montmorillonite. The silicified bodies, composed mainly of microcrystalline quartz, are crudely tabular. They represent zones of intense alteration adjacent to fractures which conducted the hydrothermal solutions. In all hydrothermally altered rocks much iron is retained as pyrite which partly replaces former mafic minerals. Subsequent oxidation to hematite and limonite above the water table gives the bleached areas variable red to yellow pastel colors. Locally hematite is abundant, giving a deep red color. Both deuteric and hydrothermal alterations will be described in greater detail in the next section.

The tabular silicified zones serve to delineate fault and fracture systems in the Goldfield district. Many subparallel ledges form a belt one-half to one mile wide which trends eastward from Goldfield

through Preble Mountain. Other ledges form an ellipse about 5 miles east-west by 3 1/2 miles north-south. The ellipse is centered north of the east-west belt and is tangential to the belt near its western end. The ellipse is partly open to the east, past Tognoni Springs, and arcuate east-dipping faults concave to the east traverse the Vindicator Mountain-Banner Mountain-Ruby Hills area. Bedding and flow layering within the ellipse dip at low to moderate angles to the west, and are successively offset downward to the east along the arcuate faults, suggesting partial collapse of the block bounded by the ellipse. Dips outside the ellipse to the north, west, and south are away from the center of the ellipse.

At Goldfield the hydrothermally altered rocks crop out over a 17-square-mile area, some of it outside the area of this report, but nearly the entire gold and silver production of the district came from ore shoots in several large silicified zones (veins) located immediately east-northeast of the townsite of Goldfield. All mining was subsurface, at depths of as much as 1000 feet, but a few lodes apexed within tens of feet of the surface and several were covered by only a few feet of post-ore Tertiary Siebert sediments or Quaternary alluvium. "Glory holes", or stopes that break through to the surface, now occupy such localities. The boundaries of this highly productive ground, projected to the surface, describe an oval area about one mile north-south by 0.6 mile east-west (Pl. 2). Outside this main part of the district, smaller concentrations of ore occurred locally in silicified zones along the arcuate fault system that forms the western and northern margins

of the elliptical fracture zone. This fault system, known as the Columbia Mountain Fault (Searls, 1948, p. 14-15) extends north from Goldfield along the east flank of Columbia Mountain-Morena Ridge, and turns east to pass through McMahon Ridge and Black Butte. Ore bodies along this trend were stope to the surface at several localities. All ore bodies, regardless of grade, volume, or location, were associated with silicified rocks, which in turn are always enclosed in sericitized and argillized rocks. The known deposits are worked out. All silicified zones in the extensive altered areas are potential targets for gold exploration, but the many surface exposures of these silicified zones appear to be barren or subeconomic, judging from negative results of a recent geochemical reconnaissance by Ashley and Keith (report in preparation), and decades of unsuccessful prospecting by many individuals.

Data analysis, natural color photography

Introduction.--Detailed analysis is limited to three areas (Pl. 1), each displaying features critical for recognizing altered volcanic centers. Area 1 (1.5 square miles) includes McMahon Ridge: here silicified zones, some productive and others barren, with associated K-mica and clay alteration, are well shown as they appear in a single type of host rock. Area 2 (3.2 square miles) includes Banner Mountain and a section of the Kawich Road, a major secondary road leading east from Goldfield to the northern part of the Nellis Air Force Base Bombing and Gunnery Range. This area includes relatively large patches of rock that have not been hydrothermally altered. Distinct color differences between and within various flows and tuffaceous units are primarily

due to distinctive deuteric alterations. Area 3 (1.3 square miles) covers the main mining district at Goldfield. The discussion of this area centers on problems encountered in interpreting geology from imagery with the surface conditions prevailing in an old mining district. a synthesis of structural and alteration information from these three areas would complete the process of interpreting the Goldfield district as an altered volcanic center, but is not within the scope of this study. Such a synthesis will be included in a future Geological Survey report.

One color paper print (Geological Survey photography) is included for each of the above three areas (Pls. 3, 4, and 5) with overlays showing distribution of rock units and hydrothermal alteration. One false-color infrared paper print from NASA-MSC flight line 3 or flight line 5 (scale 1:14,000) is also included for each of the areas (Pls. 6, 7, and 8), but overlays were not constructed. Plate 1 shows locations of photo centers and flight lines for all aerial photography related to this report.

Naming colors and making color comparisons must be qualitative because variations in color rendition are unavoidable: the effective lighting on a subject varies as the viewing angle changes along a flight line, and conditions vary during film developing and printing. The paper prints of Geological Survey photography included in this report were produced in a single processing batch, and have an overall greenish aspect, with black areas tending toward dark reddish hues.

Descriptions of colors, however, refer to these prints, and no attempt is made to compensate for the apparent color bias. The Rock-color Chart^{1/} is used as a guide for terminology.

Area 1.--Area 1 covers McMahon Ridge and the low hills to the north and south of it. Resistant silicified zones, most of which strike approximately east-west and dip steeply south, top the ridge over its entire length of about 0.8 mile. Maximum topographic relief is about 200 feet. Several different flows of the Milltown Andesite form most of the bedrock in the area (see geology overlay, Pl. 3). Most of the area is underlain by at least two, and possibly as many as three or four, flows of porphyritic andesite with 20 percent plagioclase phenocrysts 0.5 to 1 mm in diameter and 5 percent hornblende phenocrysts of the same size. These andesites show propylitic alteration, with the plagioclase saussuritized, hornblende partly converted to chlorite, and the groundmass altered to aggregates of calcite, epidote, chlorite, albite, and quartz. It is recorded on the color image as grayish green and locally dark greenish gray where propylitization is relatively weak. In the southeast corner of the area is an andesite with 10 percent flow-aligned hornblende needles as much as 5 mm long and 15 percent plagioclase laths as much as 2 mm long. It is also propylitized, and is indistinguishable on the color images from the above-described flows. The low ridge immediately south of McMahon Ridge is composed of microporphyritic

^{1/} Rock-color Chart prepared by the Rock Color Chart Committee, distributed by the Geological Society of America.

andesite with abundant plagioclase laths less than 0.5 mm long and a few scattered hornblende phenocrysts as much as 3 mm in diameter. The northwestern corner of the area is underlain by another flow which is similar except that it has minor disseminated hematite as a result of deuteric oxidation. Both flows produce dark red hues on the image: the flow south of McMahon Ridge, with no notable deuteric oxidation, is blackish red, whereas the flow in the northwest corner, distinctly lighter, is a grayish red. These two flows are locally more or less strongly propylitized, with the same alteration products as described above, and in the propylitized areas their color is also grayish green to dark greenish gray, approaching grayish red or brownish gray where propylitization is weak.

Hydrothermal alteration produces several zones recognizable in the field. These zones form envelopes concentric around the fracture zones that were the passageways for hydrothermal fluids. Silicified zones, inches to tens of feet wide, represent the metasomatized wall-rocks that were immediately adjacent to the fractures. They are predominantly quartz with some alunite and minor kaolinite, diaspore, or pyrophyllite. Silicified zones represent rocks that have undergone extreme leaching and removal of Na, Mg, Ca, and in some cases, even Al. Remaining zones show progressively less leaching of base cations and assemblages typical of lower temperatures. An envelope of advanced argillic alteration surrounds many of the silicified zones: the mineral assemblage is nearly the same as it is in silicified rocks, with quartz, alunite, kaolinite, pyrophyllite, allophane or opal, and diaspore, but quartz is much less abundant

than it is in silicified rocks, yielding soft rather than hard material. These zones, although often as wide as adjacent silicified zones, are poorly exposed because the resistant silicified zones shed blocky debris over them. The advanced argillic alteration grades outward into a zone of argillic and potassic alteration with quartz, kaolinite, and K-mica, and locally adularia. This zone is several times as thick as the nearest silicified zone. Kaolinite-K-mica rocks are moderately hard, forming low, rounded exposures. They grade outward into montmorillonite- and kaolinite-bearing argillized rocks with much relict plagioclase. These rocks react to weathering as do any materials containing swelling clay, forming soil that is powdery with shrinkage cracks when dry, and sticky when wet.

Below the zone of oxidation, all alteration zones have pyrite, both disseminated and partly or completely replacing former mafic minerals. During oxidation it is converted to red or black hematite in silicified zones, and to finely disseminated purple to red hematite in advanced argillic and K-mica-bearing argillic zones. Although yellow-brown or brown limonite (mostly amorphous goethite) is abundant in these higher-grade zones at only a few localities, limonite or jarosite are the most common iron-bearing minerals in oxidized montmorillonite-bearing rocks. Thus silicified zones are black or dark red, higher-grade argillized rocks are pale pink or purple, and montmorillonite-bearing argillized rocks are shades of yellow or brown. Iron-bearing minerals are more abundant in silicified zones than in other zones, probably reflecting some enrichment in iron, as pyrite, in silicified zones during alteration.

On the alteration overlay for Plate 3, all three types of argillized rocks are grouped together and shown by the stippled pattern. Silicified zones are best seen on the crest of McMahon Ridge, the hill at the western edge of the area, and in the low-lying terrain at the northeast corner of the area. Clean outcrops are black, but the debris immediately surrounding and locally covering the outcrops is dark reddish brown. Black hematite coats many closely spaced joints and fractures that cut the silicified zones, producing the black color, whereas red hematite is disseminated throughout; broken debris exposes some of the red disseminated hematite and releases some of the black hematite to disintegrate to red powder. Advanced argillic zones are not distinguishable anywhere in Area 1; silicified rock debris covers them, changing from dark reddish brown to grayish red away from the silicified zones as hematite-rich debris is diluted by fine-grained debris from pastel-colored argillized rocks. The only good exposures of K-mica-bearing argillized rocks are a few trenches and prospect pits on the south side of McMahon Ridge and a few patches on the north side of the ridge near the west end. Some K-mica-bearing argillized rock is poorly exposed around the silicified zones in the northeast corner of the area and at the western boundary of the area. In debris from workings, these rocks appear white. Natural exposures range from nearly white through light greenish gray to grayish yellow green. The pale purples and pinks seen in hand specimens are not recorded.

Montmorillonite-bearing argillized rocks are better exposed in Area 1 because they have spotty occurrence over large areas away from McMahon Ridge, with no nearby silicified zones at the present level of exposure. Where the montmorillonite-bearing rocks contain limonite they are grayish orange pink to light brown on the images. Patches in the northeast and southwest corners of the area show these colors well. Where finely divided jarosite gives a pale lemon-yellow color as seen on the ground, the image shows yellowish gray: see particularly the areas about 500 to 1,000 feet north of the west end of McMahon Ridge and 500 to 1,000 feet on either side of the hill at the western edge of the area. In many places, however, the color value of these rocks is very low, yielding white to light greenish gray, indistinguishable from K-mica-bearing argillized rocks.

Distribution of altered rocks is obviously controlled in many places by faults and fractures (compare alteration and geology overlays for Plate 3). The fact that silicified zones are fracture-controlled is easily recognized. The andesites on either side of McMahon Ridge are cut by many narrow argillized zones also located along fractures. The low northerly dips of the flow units cannot be seen on the images. Flow contacts locally can be traced on the ground, yielding information on the attitudes of the flows, but flow contacts are not visible on the photographs.

Information on underground workings adds the third dimension to the distribution of hydrothermally altered rocks. Most of the ore produced in this area was extracted before 1909, so Ransome's Professional Paper (1909, p. 247-251) adequately describes the extent of underground

exploration of the McMahon Ridge veins, the Belmont vein, which trends northeast from the east end of McMahon Ridge, and the veins of the Vernal claim, in the northeast corner of the area.

The ore was found at depths to 400 feet in small veins which belong to the vein system seen at the surface, but only a few of the veins mined actually crop out at the surface. Most veins dip steeply to the south, indicating an overall dip of the McMahon Ridge vein system of about 70 degrees south. Complete oxidation extended to between 70 and 100 feet, but partly oxidized material was found as deep as 370 feet. Values were in gold and silver, with gold contents generally greater than two ounces per ton. Total production from all the veins in the area is poorly known but is probably about \$100,000.

Color aerial photographs yield no details on underground workings, but some general information can be obtained from them. Small prospect pits, trenches, and shafts, easily identified with magnifications of x4 or more, help outline the total areal extent of altered rocks even where surficial debris obscures the bedrock. Open stopes appear at three locations along McMahon Ridge and at two locations at the southwest and northeast ends of the Belmont vein. The McMahon Ridge stopes are not large and therefore are not distinguishable from prospect pits without supplementary information. The Belmont stopes might be recognized by the fact that individual depressions are elongate, are aligned on a single trend, and although they are very deep they are not immediately surrounded by much waste rock. Large waste dumps at the sites of major shafts or tunnels

display the same colors as rocks seen at the surface if the workings penetrate only oxidized rocks. Many workings, however, are deep enough to penetrate unoxidized altered rocks bearing pyrite. The pyrite oxidizes on the surface of waste dumps to produce sulfates which give the dumps colors ranging from pale greenish yellow to greenish yellow or pale olive. The nearly black material seen on one or more arms of five large dumps distributed throughout the area is unaltered and propylitized andesite. Overall, however, material not hydrothermally altered is scarce on the dumps, suggesting that little unaltered material was encountered between veins in the deeper parts of the workings, and therefore pervasive alteration extends to depths greater than the depth of oxidation. Details of Ransome's account substantiate this conclusion.

Other cultural features, less important than mine workings, include old buildings, headframes remaining on major shafts, and the orange-pink mill tailings on the slope and in the wash on the south side of McMahon Ridge near its western end.

One other stratigraphic unit besides Milltown Andesite, the Sandstorm Formation (Tst), crops out at two localities in the southern and southeastern parts of Area 1. Most is white silicic tuff, probably of laharic origin, with scattered clasts of black Ordovician Palmetto Formation chert and siliceous shale, pale-gray silicic volcanic rocks, and a few white granitic rocks. The tuffaceous matrix is everywhere argillized or silicified. Much of the exposure area is soft montmorillonite-bearing argillized rock which erodes rapidly, leaving the clasts behind to form a lag gravel.

Although the altered tuff itself has very low iron content and is therefore a brilliant white color, the lag gravel that always forms over it decreases its reflectance, and it is rendered light greenish gray on the images. Patches of tuffaceous shale within both the Sandstorm Formation areas are easily distinguished by their pale brown to light brownish gray or brownish gray color. During oxidation thin coatings of limonite are deposited along minute bedding-plane fractures in the shale; the weathered shale forms a pavement of platy chips covering the surface, so the coatings of limonite on the plates give these areas their brownish hues.

Alluvium is generally greenish gray with streaks of pale red to pale brown or light brownish gray. Some active channels which head in areas of altered and silicified rocks are light brown to pale yellowish brown or yellowish gray, easily distinguished from the older, presently inactive and more heavily vegetated alluvium. Colluvium thick enough to obscure bedrock does not cover large areas in Area 1, where low topographic relief prevails. Where colluvium is thick enough to obscure bedrock, as it is on McMahon Ridge, it is easily traced to its nearby source (see p. 15).

Area 2.--Area 2 is a rectangle two miles east-west by 1.6 miles north-south, dominated topographically by Banner Mountain, located in the north central part, and Vindicator Mountain, in the northwest corner. This area includes several of the many Tertiary volcanic units found in the vicinity of Goldfield, and two pre-Tertiary rock units as well. More than half the area shows effects of hydrothermal alteration, but the large unaltered patches south and southeast of Banner Mountain are particularly suitable for examining color differences between various

types of deuteric alteration as they are registered on natural color aerial photographs. This low-relief terrain has many large barren-rock outcrops, and elsewhere thin soil and little colluvial rock debris.

The description of hydrothermal alteration zones given for Area 1 (p. 13-16) applies to hydrothermal alteration as it affects all the units in Area 2. Altered rocks have the same appearance on the aerial photographs as they do in Area 1 except that silicified rocks along several north- and northeast-trending faults located south and southeast of Banner Mountain contain much red and red-orange hematite, but no black hematite coating fractures, given a moderate reddish orange to moderate reddish brown color. The distribution of hydrothermal alteration makes the arcuate north-northwest to north-northeast fault trends in Area 2 easily visible. Bedding, eutaxitic structure, and flow banding in the volcanic units dip west at low to moderate angles, but these features can be seen at only a few spots on the images, and certain identification is impossible without field information.

The most extensive volcanic unit in Area 2 is a latite flow (T1) which is porphyritic and locally flow banded. Although the original rock was probably a vitrophyre, hand specimens have a stony appearance because the originally glassy groundmass was deuterically altered to fine-grained mineral aggregates. In outcrop the latite may either appear pale blue to pale green or pale purple. In the bluish to greenish material, the groundmass is an aggregate of K-mica, nontronite, quartz, chlorite, minor epidote, minor K-feldspar(?), and minor hematite; andesine phenocrysts are partly altered to aggregates of K-mica and calcite, some with quartz or epidote; former biotite

and hornblende phenocrysts are composed of K-mica, leucoxene, chlorite, and in some cases nontronite and epidote. The mafics have rims of opaque granules, and sites of hornblende crystals sometimes bear hematite in addition to the minerals mentioned above. Scattered magnetite grains are usually only slightly altered to hematite at their margins, but several percent fine-grained hematite is distributed throughout. Variations in the proportions of nontronite, hematite, chlorite, and epidote give the rocks their various shades of blue and green. The most important of these are nontronite and hematite. The name "nontronite" here designates a pleochroic olive-green to grass-green iron-bearing montmorillonite with $d_{(001)}$ ranging from 14 to 16Å in a single specimen. When treated with ethylene glycol this mineral expands to $d_{(001)}$ spacings of 17.0 to 17.3Å, and temperatures of 280° to 300°C are required to collapse the structure. The chlorite in these rocks is pleochroic green Fe-Mg chlorite with very low birefringence (<0.004), and shows anomalous blue interference tints. It has a basal spacing, $d_{(001)}$, of 14.2Å. The epidote contains more than 10 percent $\text{Ca}_2\text{FeAl}_2\text{Si}_3\text{O}_{12}(\text{OH})$ molecule, but is too fine-grained to be separated easily for accurate determination. Apparently the amount of nontronite, chlorite, and epidote present versus the amount of hematite controls whether the rock has a dominantly green or blue hue. Pale purple latite has almost the same mineral assemblage as pale bluish or greenish latite, except that it has little or no nontronite and no epidote, but does have kaolinite in the groundmass and replacing plagioclase phenocrysts, more abundant K-feldspar, and more hematite, especially replacing biotite and hornblende. The abundance of hematite and scarcity of

nontronite apparently produce the purple hue. On the aerial color images the pale bluish and greenish latite is very pale blue or very pale blue green to pale blue or light bluish gray, whereas the pale purple latite is grayish red purple of constant hue with only slight variations in lightness from place to place. The images show that blue and red-purple latite areas grade into each other over distances of a few tens of feet. Small spots of blue are scattered through dominantly red purple areas, and red-purple spots are scattered through the blue areas. Most of the dominantly blue latite forms an irregular belt several hundred feet wide at the contact with younger flows (Tma and Td), which suggests that blue areas are located near the upper part of the latite flow. The mineral assemblage characteristic of blue latite probably represents a lower grade of deuteric alteration than the assemblage characteristic of the red-purple latite. If so, it is reasonable that it should occur at the upper edge of the flow.

The latite is overlain by latitic and quartz latitic tuffs (Tlt), which appear east-northeast of Banner Mountain, and by a welded crystal-rich quartz latitic lapilli tuff (Tlat) which covers a relatively large area in the vicinity of Banner Mountain. These tuffs have been subjected to deuteric alteration very similar to the alteration that affected the bluish and greenish latite. The alteration mineral assemblage is the same as that for bluish to greenish latite, including nontronite and chlorite with precisely the same characteristics, except that hematite is scarce or absent, and kaolinite is a common alteration product of plagioclase. In these

rocks nontronite or chlorite or both are always abundant, replacing the formerly vitric groundmass and lapilli. The lapilli, notably squashed due to compaction, are visible on bedding surfaces as green, relatively crystal-poor blobs as much as two or three inches in diameter within a relatively crystal-rich green-brown matrix. The latitic tuff (Tlt) is very pale green to various shades of pale green and pale yellowish green on the color images. Outcrops of the quartz latitic lapilli tuff are grayish brown, but debris surrounding them grades through brownish gray to pale greens with increasing distance from the outcrop. The fine-grained latitic tuffs are very poorly exposed, weathering to a powdery soil filled with platy rock chips, so apparently disintegration and weathering to produce nontronite and chlorite-bearing soil is necessary to register distinctly green hues on the aerial imagery, even though bedding-plane surfaces of outcrops appear green on the ground.

Both Milltown Andesite (Tma) and "Goldfield dacite" (Td) flows overlie the latitic materials, the dacite being younger than the Milltown Andesite. The Milltown Andesite includes flows of pyroxene andesite, hornblende andesite, and one flow of olivine-bearing basalt, whereas the dacite is a relatively uniform porphyritic quartz-bearing biotite-hornblende-hypersthene rock with plagioclase phenocrysts commonly as much as 5 mm diameter and locally larger. Where free from hydrothermal alteration, both the andesites and the dacite, like the andesites of Area 1, have experienced propylitic alteration, with calcite, chlorite, albite, K-mica, epidote, quartz, and leucoxene as alteration products. Calcite, albite, K-mica, and

epidote partly replace plagioclase (saussurite), whereas chlorite and leucoxene are the chief alteration products of mafic minerals. Almost all these alteration minerals in various amounts also replace originally glassy or aphanitic groundmass materials. These units crop out in the southern and west central parts of Area 2; colors shown on the aerial images are grayish brown to brownish gray, and olive gray. Field examination shows that the andesite and dacite are propylitized almost everywhere; apparently the brown-colored areas do not have a content of green mineral large enough to produce a detectable component of green hue on aerial photography. In areas tending toward a dark olive hue apparently have just enough chlorite and epidote to draw the color away from brown (essentially a yellow-red hue) toward yellow-green. Locally, however, intense propylitization results in a greenish-gray color (see particularly 1500 to 2500 feet west to southwest of Banner Mountain). Relatively intense propylitization and associated greenish-gray hues are much more common in the andesites of Area 1 (see p. 12, 13). The mineral chiefly responsible for the color is chlorite, an Fe-Mg variety essentially the same as that found in the latite, with very low birefringence (≤ 0.005), anomalous blue interference tints, and $d_{(001)}$ of 14.2 to 14.3 Å. Again, epidote is too fine-grained and not abundant enough to easily obtain a reliable estimate of iron content.

Quartz monzonite (Kqm) of Mesozoic age and a silicic welded tuff (Tvr), the basal Tertiary unit, are hydrothermally altered throughout Area 2, and show the pastel colors typical of argillized rocks and the dark reddish-browns and grayish-reds typical of silicified rocks. Cherts, siliceous shales, and argillites of the

Ordovician Palmetto Formation, forming part of the pre-Tertiary inlier of Vindicator Mountain, come into Area 2 at its western margin. These materials are black in outcrop, with no trace of hue. The aerial image shows these rocks as essentially medium dark gray, but with a definite element of brown or yellow-brown. Although these rocks could not be specifically identified without field information, they are easily distinguished from even the darkest-colored volcanic rocks.

Area 2 shows that natural color photography has considerable potential for distinguishing volcanic flows with different mineralogic compositions. The local patches of greenish gray in the andesites and the rather striking blue, blue-green, yellowish-green, and red-purple hues of the latitic and quartz latitic flows and tuffs can easily be recognized as various types of deuteric alteration affecting volcanic rocks. Since the rocks of volcanic centers bearing mineral deposits often show alterations such as this as well as hydrothermal alteration associated more directly with ore deposits, recognition of deuterically-altered volcanic rocks provides important supplementary information.

Area 3.--Area 3 covers the Goldfield main district. Almost the entire production came from the ground bounded by the major roads on the north, west, and south sides of the area, and the railroad grade on the east. The main vein system apexes on the west side of the area, trending generally north with steep dips to the east. Moving eastward, as depth of the vein system increases, dips decrease, so that at the eastern edge of the area, where the vein system pinches out at depths of 1100 to 1200 feet, dips are only 15° east (Locke, 1912a,

p. 801-802, Searls, 1948, Pl. 1). Subsidiary veins, including a major one through the center of the area, dip at moderate to steep angles to the east and join the main vein at depth. The veins themselves are large silicified zones; the ore bodies were irregular pipelike and tabular bodies mostly within silicified zones, but locally extending into adjacent advanced argillic alteration zones. High-grade ores were found in "stope streaks" or narrow breccia zones which cut silicified zones approximately parallel to their contacts. These high-grade ores were open-cavity fillings and coatings on breccia fragments; the coatings and fillings consisted of layers of pyrite, famatinite, and bismuthinite, tellurides, and native gold. The bodies of average-grade ore surrounding these breccia zones had relatively small amounts of disseminated native gold (averaging about one ounce per ton) and minor pyrite, famatinite, and bismuthinite.

Within the productive area about 25 percent of the ground surface is covered with waste dumps or tailings, or disturbed by cave-ins or man-made cuts. The dominantly north to northeast trend of silicified zones can be seen where they are exposed on the crests of hills, although many of these zones when examined in the field are found to dip west rather than east. The main district has little topographic relief, but the resistant silicified zones shed colluvial debris over most of the slopes. Furthermore, erosion of dumps has spread debris over low-lying areas (see particularly northeast of center of the area). Thus additional details on alteration are obscured. An open stope immediately north of the center of Area 3 shows that ore occurred on the northerly-trending silicified zones, and one can

deduce from the distribution of waste dumps and presence of both large and small open cuts that an important northerly-trending vein system apexes in this vicinity. One linear segment of the main vein, about 600 feet long, striking northwest and dipping 86 degrees northeast, is the only sizeable exposed element of this vein system, but it could not easily be recognized as such without supplementary information.

The large open cuts on the west side of the area show that oxidation extends to depths of at least 50 or 60 feet, but the yellow-green hues of the dumps, including pale greenish yellow, grayish yellow green, grayish green, greenish gray, pale olive, and locally olive brown, show that almost all vertical workings encountered unoxidized rock. Indeed, according to Ransome (1909, p. 188), oxidation extends only to 150 feet. The decrease in size of single waste dumps from west to east reflects mainly the decrease in volume of productive ground; the accompanying increase in average depth of workings has only minor effect on the amount of waste.

Post-ore sedimentary rocks of the Siebert Formation (Ts) are easily visible on the west side of the area; their color is nearly the same as that of recent alluvium: pale green and greenish gray, locally brownish gray. In fact, the Siebert here consists of conglomerates and fanglomerates having almost the same composition as present alluvium. The Siebert Formation covers only a small part of the productive area.

The foregoing study of Area 3 indicates that the information available from aerial color photographs for the main mining district at Goldfield is somewhat limited. It is likely that the same situation will prevail with other vein deposits that occupied small blocks of ground, reached the surface at few localities, and have been subjected to intensive underground rather than open-pit mining. So much man-made and natural debris covers the surface in the Goldfield main district that one cannot determine whether the apex area of the main vein has unique features that would permit it to be distinguished from barren silicified zones. The short vein segment visible that is part of the main vein system, however, does not look different from barren silicified zones elsewhere.

Data analysis, color infrared photography

Introduction.--Kodak Ektachrome Infrared Aero Film, Type 8443, is specifically designed for applications involving vegetation (Fritz, 1967, p. 1130-1132), and in order to balance the film for the large reflectance of healthy vegetation in the range 750 to 850 nanometers, the infrared-sensitive cyan-forming dye layer has been made slower in speed than the green- and red-sensitive yellow-forming and magenta-forming layers. In this way, the exposure of each dye-forming layer is kept well above the toe of its respective sensitometric curve.

Limited ground photography with a 35 mm camera using Type 8443 film in combination with Wratten 15, 21 and 25 filters^{1/} indicates

Wratten 15 used in lieu of recommended Wratten 12. Wratten 12 cuts off all visible light below about 500 nm, Wratten 15, below about 515 nm. Wratten 21 and Wratten 25 cut off all visible light below 535 nm and 580 nm, respectively.

that no rock type at Goldfield reflects enough light of wavelength greater than 700 nm to produce a red rendition, or even an orange rendition on this film. However, argillized rocks that appear white or pastel in the field are pale blue-green to white on Type 8443 with a Wratten 15 or 21 filter, indicating that here significant reflectance persists above 700 nm. How strong the 700 to 850 nm radiation is relative to that between 510 and 700 nm is impossible to determine because the cyan-forming layer is so much slower than the yellow and magenta-forming layers. Using a Wratten 15 or 21 filter, optimum exposures giving the largest density ranges produced an overall yellowish-green rendition. A ground infrared exposure and accompanying Kodachrome print are included (Fig. 3) to illustrate the appearance of an optimum exposure.

An examination of all the false-color aerial imagery available for the Goldfield area indicates that visibly dark colored rocks are generally black with more or less dark-green hue, depending on degree of film exposure. The black Palmetto Formation chert and siliceous shale, however, is black regardless of film exposure. Visibly pastel rocks are generally pale purple to white, depending on amount of film exposure and density of low-growing vegetation. Visibly red hematite-rich silicified and argillized areas are pale yellow in parts of the images that are correctly exposed to underexposed, due to the strong reflectances of iron oxides in the range 600 to 700 nm. Capping basalt flows and most silicified zones are black, but locally enough red hematite occurs in oxidized parts of the flows and on fractures in the silicified rocks to produce a discernible yellow cast. Just as the ground photography with a 35 mm camera indicates,

iron oxides apparently have little reflectance above 700 nm. Indeed, hematite has an absorption band at 850 nm, and "limonite" (a mixture of iron oxides) at above 870 nm (Adams, 1968, p. 1453).^{1/} Specific examples and further discussion of these observations are given in the next three sections.

Joshua trees are the only native plants large enough to be resolved individually; the tufts of green spikes that form the crowns are recorded red. The few springs in the vicinity of Goldfield are easily visible as red patches, due to abundant grass, brush, and locally deciduous trees. Most of the species of desert shrubs have relatively little infrared reflectance. Apparently grass and low-growing broad-leaved plants produce the red-purple hue seen in many areas; red-purple content is directly proportional to the abundance of these plants if the images are obtained early in the summer before the plants dry out (before August at the latest).

Problems of exposure encountered with near-visible infrared, including solar specular hot-spotting and vignetting were discussed in the section on sources of remote sensing data (p. 3). Hopefully, these problems can be reduced by better filtering and more accurate exposure, but as pointed out on page 3, the small exposure latitude of the film ($\pm 1/2$ stop) will make the task difficult. More serious, the slow speed of the cyan-forming layer in the present film combined with the apparently low near-visible infrared reflectance of rocks limit the potential utility of the film for geologic information.

^{1/}The cyan-forming layer is near maximum sensitivity at 850 nm, but tails off sharply from there to 900 nm (Fritz, 1967, p. 1130).

Area 1.--Silicified zones are easily recognized as dark gray to black spots. Lighter areas within them take on the purple hue that dominates most of every image. Using stereoscopic pairs their morphology is distinctive, just as it is with any other stereoscopic photography. Only locally, however, do the silicified zones and their surrounding debris have enough red hematite to produce weak yellow hue. Exposed argillized areas are pale red purple to pinkish gray. Strongly propylitized areas are generally somewhat darker: pale red purple to grayish red purple. Weakly propylitized areas, which are dark on the natural color image, are darker shades of grayish red purple and grayish purple (dusky red purple and dusky purple), tending toward grayish to dusky blue.

The natural-color yellow-green hues of mine waste dumps have strong enough reflectance in the region from 540 to 560 nm to register a distinct bluish hue on the false-color images: light bluish gray to pale blue of moderately variable lightness and hue.

Distinctions that are difficult with natural-color photography, such as distinguishing rocks having different types of argillization, are not made easier with the false color images. Indeed, some distinctions are lost: colluvial debris on McMahon Ridge, derived from silicified zones, is readily distinguished on natural color images, but in false-color it is indistinguishable from altered and propylitized rocks elsewhere in Area 1. Aside from the incorrect exposure, poor color balance, and other technical deficiencies of the images, detrimental terrain and vegetation conditions exist in the nearly arid environment of Goldfield: grasses and broad-leaved plants achieve

greater density in areas where soft soil capable of holding moisture is rapidly formed, with little response to soil composition. Soft soil exists in argillized and intensely propylitized bedrock areas, alluvial areas and colluvial areas. As indicated above (p. 30) grasses and broad-leaved plants seem to be the most important source of red-purple hue. Although rock type in the argillized and intensely propylitized bedrock areas is partly responsible for variations in lightness (degree of exposure is more important), pale yellow, red, brown, green, and blue-green hues seen both north and south of McMahon Ridge on the natural color images are indistinguishable on the false color images. Thus soil conditions, which are nearly the same over many different geologic units, are more important than the differences between rock compositions that are sought.

Area 2.--The false-color photography here shows the same responses that it does in Area 1. Silicified zones are nearly black; these and light-colored altered zones delineate fault trends. Red hematite is abundant enough to produce discernable yellow hues in only a few places, particularly on the south side of the area. Due to overexposure, even the north- and northeast-trending faults south and southeast of Banner Mountain which show striking reddish-orange to reddish-brown altered areas on the natural color images are only barely distinguishable, by presence of pale-yellow hue, from other altered areas which are visibly pastel.

Dark propylitized andesite and dacite can be distinguished from the lighter latite flow and quartz latitic tuffs, but within the latitic and quartz latitic rocks the blue, bluish-green, green, and red-purple hues of the natural color image which are correlated with

differences in deuteric alteration are lost. The most important source of variation again seems to be density of vegetation, responding to favorable soil conditions. The darkest spots with the smallest component of red hue are barren-rock areas with very sparse vegetation. Area 3.--As is the case with Areas 1 and 2, the false color photographs provide no geologic information not obtained more easily from the natural color photographs. Due to the false-color infrared film's sensitivity to vegetation, however, it can provide supplementary information on some of the man-made features common in Area 3. The false-color images show that major waste dumps always have blue, never red-purple hues, and therefore support no vegetation. This supports the conclusion (confirmed in this study by ground observation and information in published literature) that most or all rock removed beneath the zone of oxidation bore sulfide minerals. Similarly, mill tailings are white to very pale blue, indicating that they support no vegetation and therefore bear sulfides. Debris from the large open cuts in the northwestern part of the area, on the other hand, consists of oxidized rock. This loose debris with abundant fine-grained particles supports considerable low-growing vegetation, producing a pale-red to pale-red-purple color.

Conclusions

Natural color aerial photography provides ample information of the kind necessary for recognizing hydrothermally altered volcanic centers: volcanic flows and pyroclastic rocks with different

compositions and deuteric alterations can be distinguished by color variations and geomorphology; structural trends can be deduced from alteration patterns, and in some cases structures are directly resolved; prospects and mine workings are visible, and colors of waste rock allow a few generalizations about the rocks encountered in the workings. Several important features are generally not discernible: differences between various types of argillic alteration within hydrothermally altered areas; bedding, flow-banding, or eutaxitic structures within individual volcanic units, fresh or altered; dips of structures where dips are moderate to high and topographic relief is low.

False-color near-visible infrared photography shows many, but not all, of the features distinguished on natural color photographs. The several important features not visible on natural color photographs are also not visible on false color. Interpretation is very much more difficult because the photographs have low color contrast, and most parts of a single photograph show essentially a one or two-color rendition. Furthermore, variations in rock type in many cases compete unfavorably with variations in soil conditions which control density of vegetation. Since in a near-arid environment physical soil conditions are generally more important than chemistry of the soil, vegetation density is poorly correlated with rock type. The primary usefulness of false color infrared is to detect subtle differences in abundance and vitality of vegetation, and in a few instances such information is useful for desert terrain such as that at Goldfield, but the film has much greater potential for more humid areas with a variety of vegetation that responds to rock type.

Of all the photography examined for this study, Ektachrome MS Aerographic Film, Type 2448, yielded the best results. The aero-negative system has the following inherent advantages over Aero Ektachrome Type 8442: increased exposure latitude, which minimizes loss of data due to under- or over-exposure; flexibility of process, with proper color balance determined during printing; flexibility of product, with black and white, color paper prints, and color positive transparencies obtainable from the same negative.

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Figure 3

Optimum exposure of Kodak Ektachrome Aero Film, Type 8443, with accompanying Kodachrome II exposure, for an oxidized vein (silicified zone) in the main district at Goldfield, Nevada. Viewing direction is east-southeast, illumination is bright sun, time 1:00 PM (PST), August 17, 1967, elevation 5,700 feet. The vein is at center, bounded by two vertical light-colored streaks. Above the vein is a waste dump composed of unoxidized sulfide-bearing rock, with a weathered surface shell containing iron sulfates.

Fig. 3a--Ektachrome Infrared Aero Film, exposure 1/250 second at f/16, with Kodak Wratten 21 filter.

Fig. 3b--Kodachrome II, exposure 1/250 second at half-stop between f/5.6 and f/8, unfiltered.

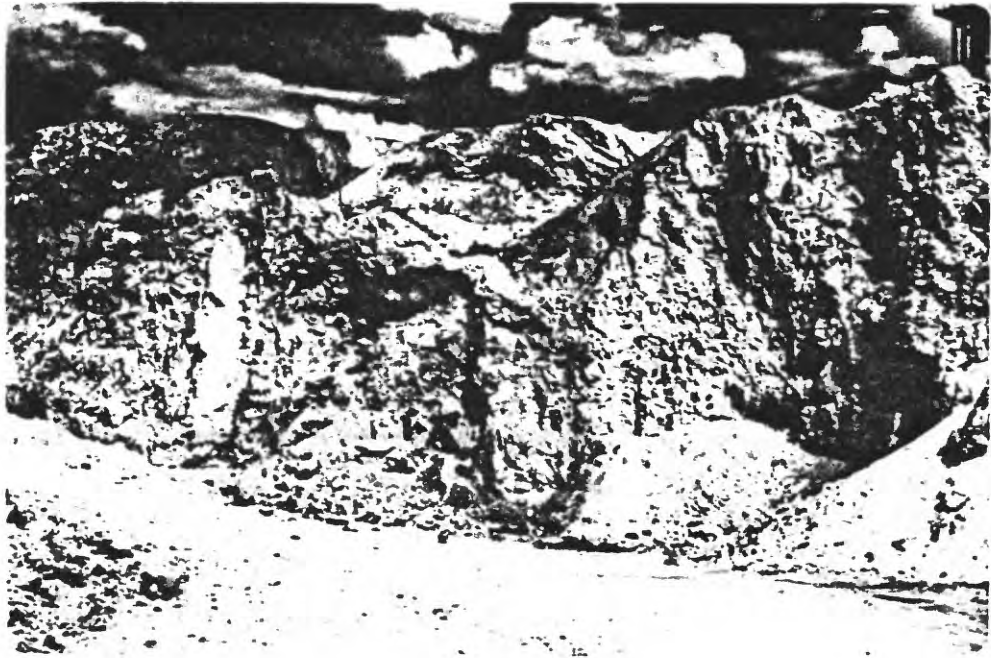


Figure 3A



Figure 3B



PLATE 3. COLOR PRINT AND OVERLAYS, AREA 1.



PLATE 5. COLOR PRINT AND OVERLAY, AREA 3.

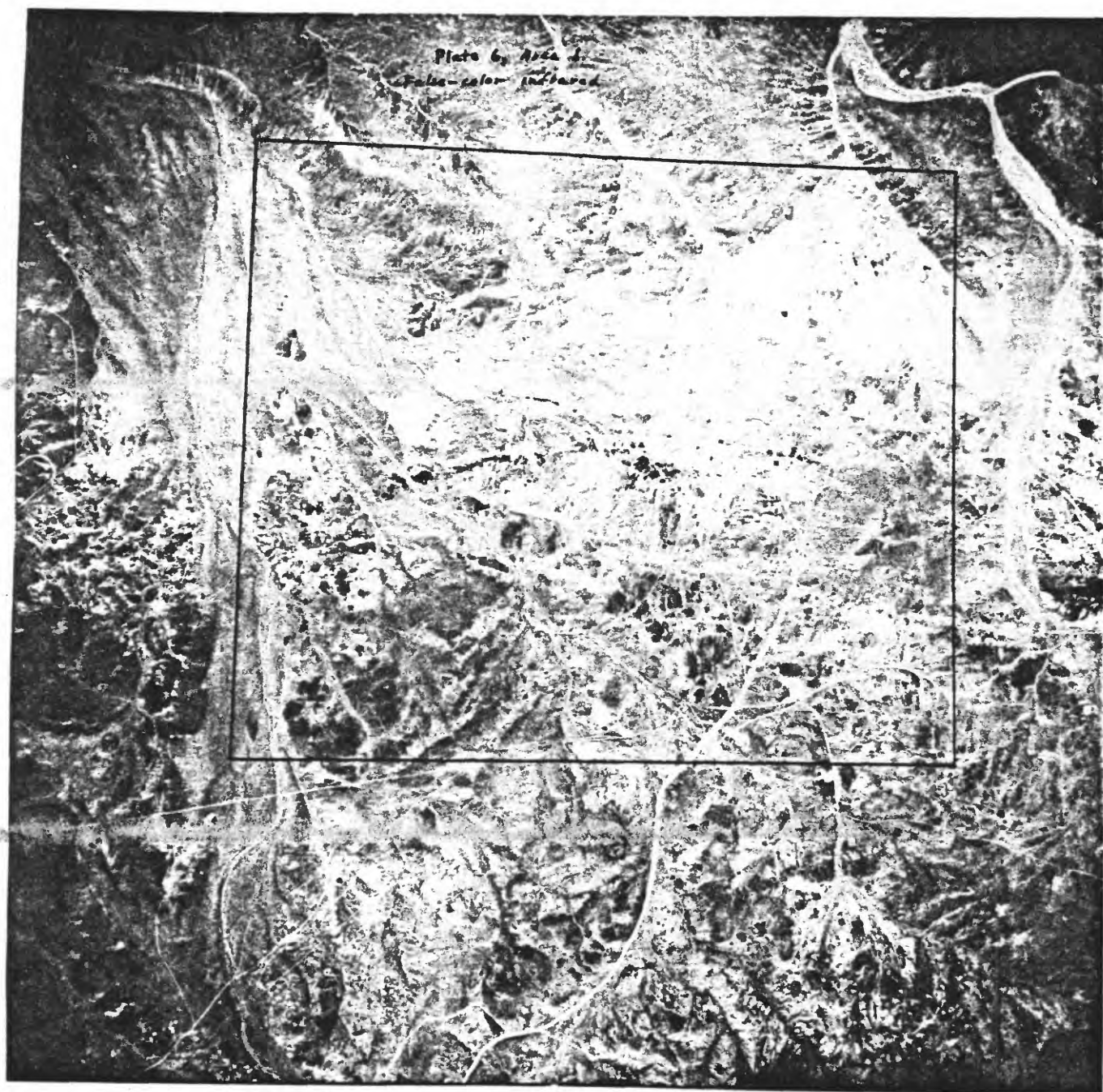


PLATE 6. FALSE-COLOR INFRARED PRINT, AREA 1.

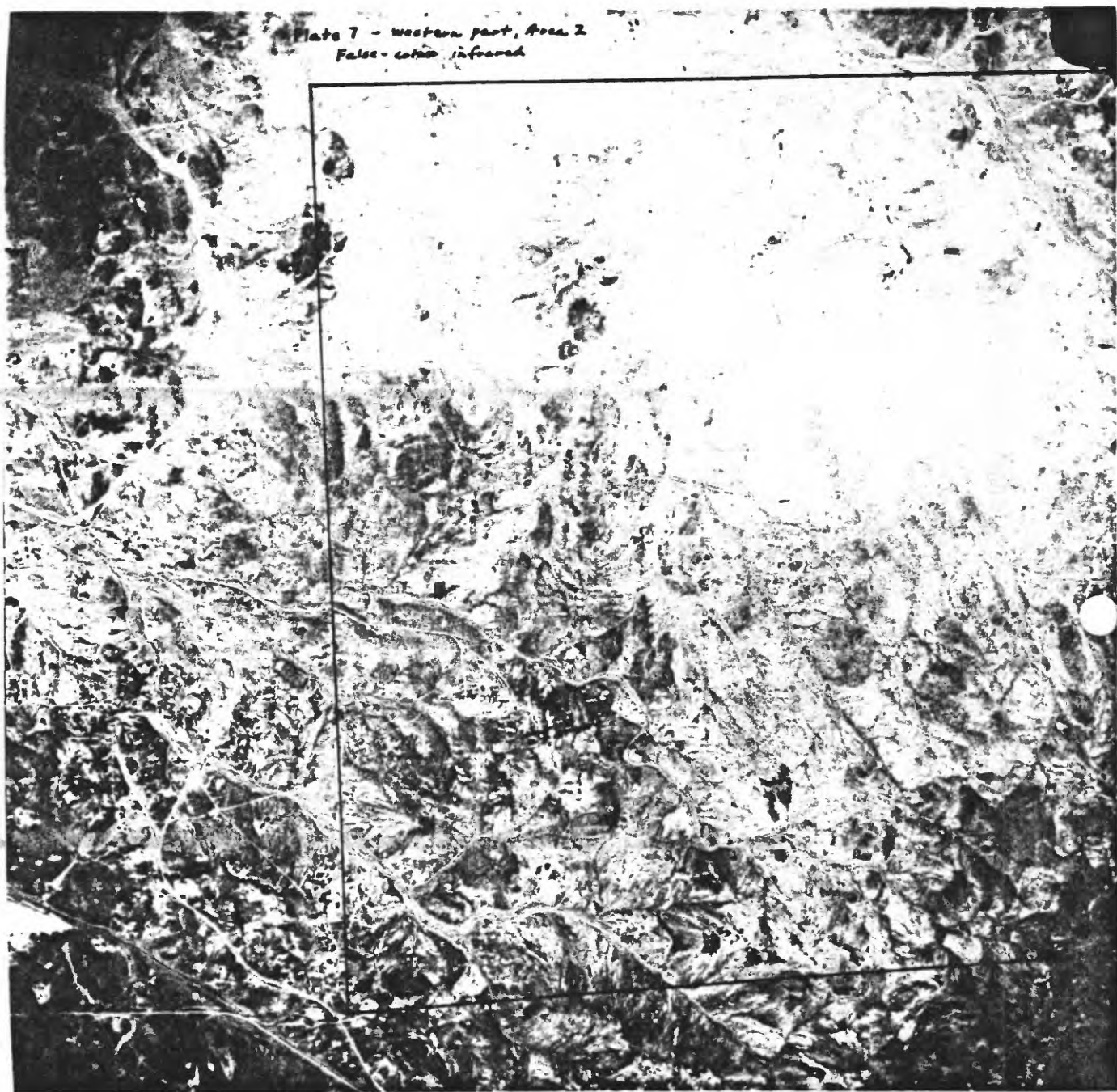


PLATE 7. WESTERN PART, AREA 2.

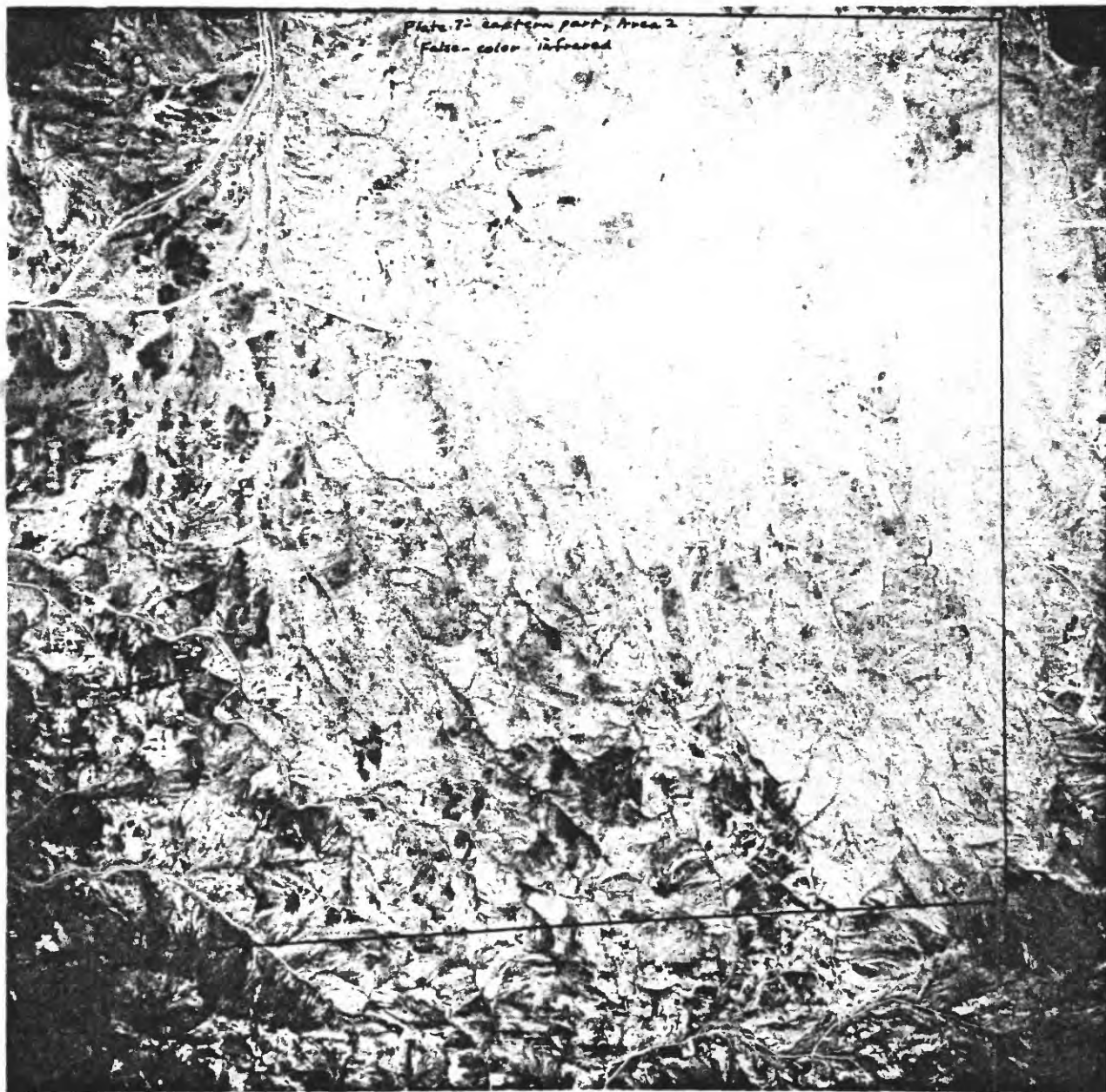


PLATE 7. FALSE-COLOR INFRARED PRINTS, EASTERN PART, AREA 2.

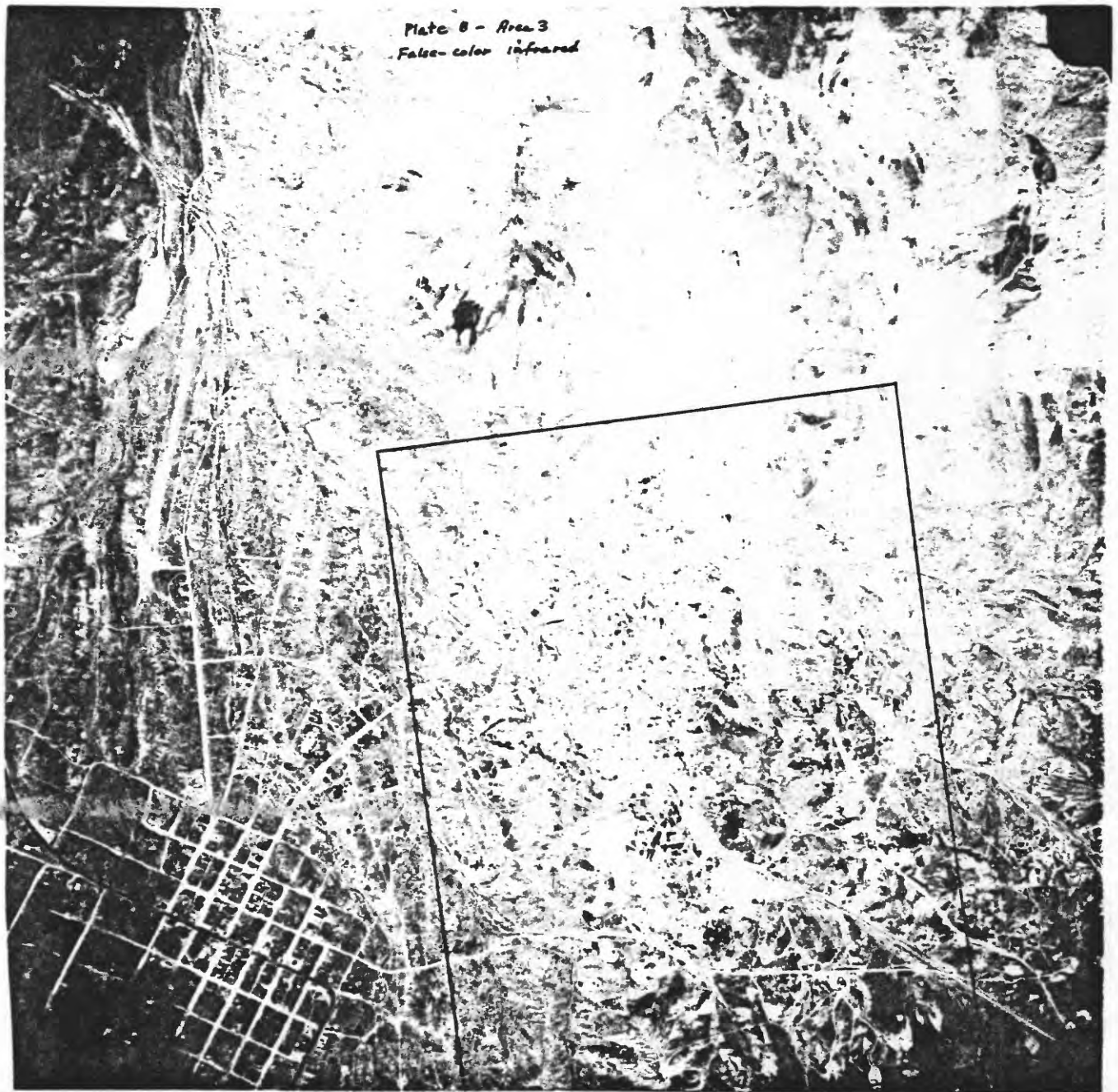


PLATE 9. FALSE-COLOR INFRARED PRINT, AREA 3.