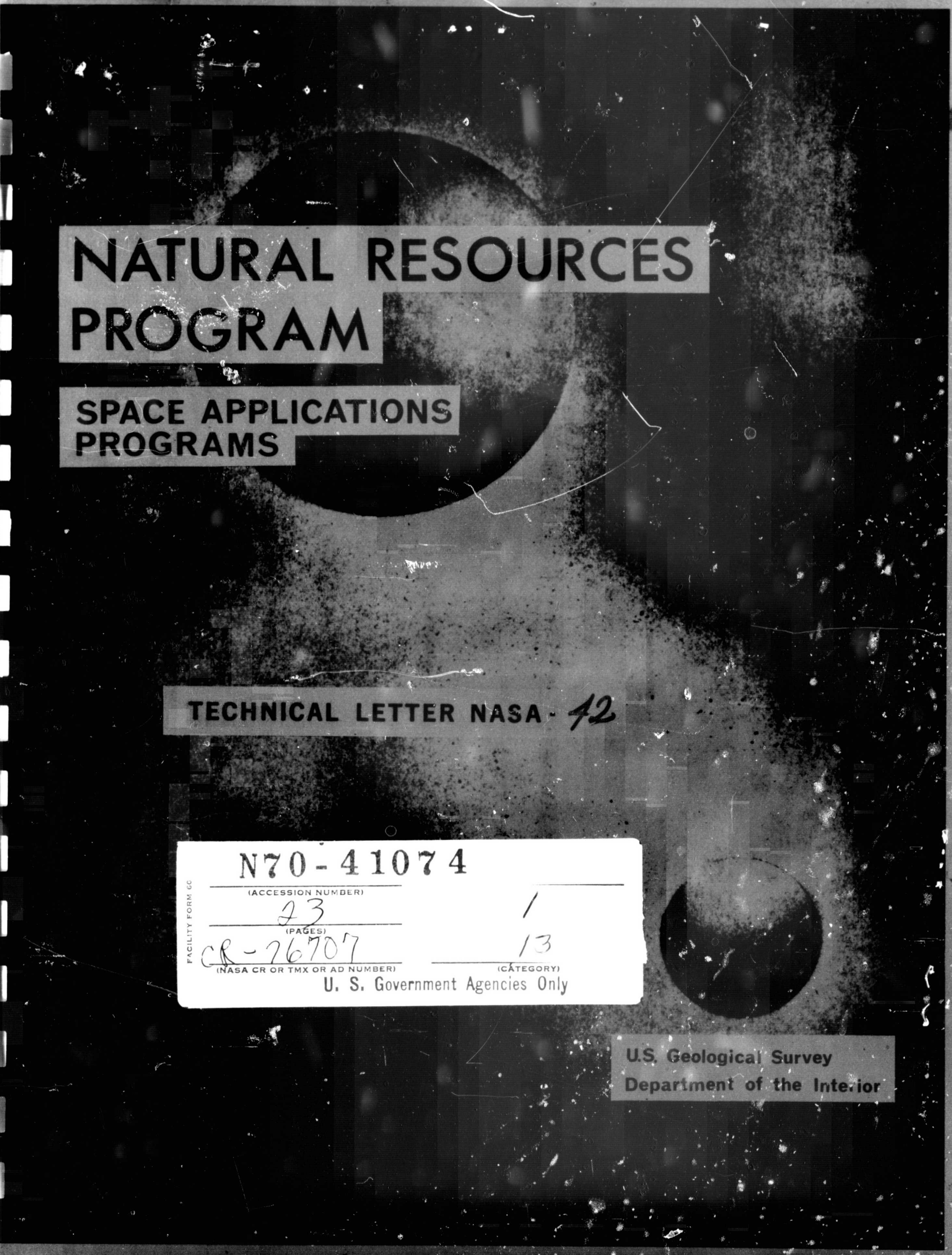

NATURAL RESOURCES PROGRAM

SPACE APPLICATIONS PROGRAMS

TECHNICAL LETTER NASA - 12

U.S. Geological Survey
Department of the Interior

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Technical Letter
NASA-42
June 1966

Dr. Peter C. Badgley
Chief, Natural Resources Program
Office of Space Science and Application
Code SAR, NASA Headquarters
Washington, D.C. 20546

Dear Peter:

Transmitted herewith are 3 copies of:

TECHNICAL LETTER NASA-42

USE OF INFRARED IMAGERY IN STUDY OF THE SAN ANDREAS FAULT SYSTEM, CALIFORNIA*

by

R. W. Wallace[1] and R. M. Moxham[2]

Sincerely yours,

William A. Fischer
Research Coordinator
Earth Orbiter Program

*Work performed under NASA Contract No. R-09-020-015
1/U.S. Geological Survey, Menlo Park, California
2/U.S. Geological Survey, Washington, D.C.

U. S. Government Agencies Only

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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by

R. W. Wallace[1] and R. M. Moxham[2]

June 1966

These data are preliminary and should
not be quoted without permission

Prepared by the Geological Survey
for the National Aeronautics and
Space Administration (NASA)

*Work performed under NASA Contract No. R-09-020-015
1/U.S. Geological Survey, Menlo Park, California
2/U.S. Geological Survey, Washington, D.C.

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Use of infrared imagery in study of the San Andreas

fault system, California*

by

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1/Menlo Park, Calif., 2/Washington, D.C.

ABSTRACT

Infrared imagery in the 8 - 13 micron band obtained from aircraft overflights in June 1965 is being used to study the San Andreas fault system in the Carrizo Plain area of California. Preliminary evaluation gives the following results:

The fault trace shows clearly over most of the approximately 200-mile length that was flown. Variations in soil moisture caused by the water-barrier characteristics of the fault zone, as well as vegetation differences related to soil moisture and microtopography are factors influencing visibility of the fault in the infrared imagery.

Other features that can be identified on the imagery, and which are useful in analyzing offset on the San Andreas fault include: offset segments of ancient stream channels disrupted by movement on the fault, landslide terrain, and numerous soil and Tertiary bedrock units. A Pliocene shale, for example, shows a relatively cool surface as compared to adjacent and nearby bodies of the Santa Margarita Formation and the upper Monterey Shale.

Imagery obtained one to two hours before sunrise is considered most useful for the fault studies.

*Published at the Fourth Symposium on Remote Sensing of Environment, April 1966, at The University of Michigan, Ann Arbor, Michigan.

INTRODUCTION

Infrared imagery in the 8 - 13 micron band obtained in June 1965 is being used to study the San Andreas fault system in the Carrizo Plain area of California.

The San Andreas fault, a fracture in the earth's crust more than 600 miles long, has been responsible for numerous earthquakes including the great earthquakes of 1857 in the Carrizo Plain-Tejon Pass area and of 1906 in the San Francisco area. A study of the amounts and frequency of historic and prehistoric displacements on the San Andreas fault is being conducted as part of a program aimed at developing earthquake prediction techniques. In the Carrizo Plain area, because of the arid climate, the effects of ancient movements on the fault are exceptionally well preserved. Channels of streams that flow across the fault were offset as much as 30 feet during the 1857 earthquake and cumulative channel offsets of as much as 3,200 feet are preserved in the Carrizo Plain area. Some geologists believe that total cumulative offset on the fault is to be measured in hundreds of miles.

Infrared detection techniques are being applied in this study in anticipation that subtle differences in soil moisture, composition, or physical characteristics that are not readily apparent in black and white aerial photographs would be apparent in the IR imagery, thus permitting the position of ancient offset segments of stream channels, alluvial fans, bedrock units or other features to be more clearly determined.

The Carrizo Plain, a broad intermontane valley lying at an altitude of about 2,000 feet between the Temblor Range on the east and the Caliente Range on the west, is approximately 40 to 45 miles west of Bakersfield, California. Annual rainfall in the Carrizo Plain area is between 3 and 8 inches.

NATURE OF STUDY

Evaluation of the IR imagery is made primarily on an empirical basis by comparing the IR images with geologic maps and with images obtained by other techniques. Geologic maps of the entire area at a scale of 1:125,000 prepared by T. Dibblee (1962) and of part of the area at a scale of 1:24,000 prepared by J. Vadder (in preparation), are important as a basis for analyzing the imagery. In addition, we made temperature measurements of selected terrane units for control during the flights, and after the imagery was obtained we made further thermal studies of selected soil and rock units in the field. Graphs (fig. 1) show representative temperature ranges measured during the time the imagery was obtained. Other types of imagery and photography have been obtained of all or parts of the area and include radar, nine-frame enhanced multiband photography, black and white photographs at scales of 1:6,000 and 1:24,000, and Aero-Ektachrome color photographs at a scale of 1:12,000. Comparison and evaluation of these different techniques is in a preliminary stage.

No data are available on the emissivity ($\overline{\varepsilon}$) of the surface materials in the report area. Descriptions below relating to relatively cool, or warm, surfaces relate to their radiation temperatures recorded by the scanning radiometer. This unknown parameter, with the nonquantitative scanning technique permits little more than qualitative discussion of the results.

INFRARED IMAGERY STUDIED

Several sets of infrared images were obtained on June 18, 1965 in an area along the San Andreas fault about 80 miles long and 20 miles wide. Some were obtained in a period of a few hours before sunrise and others were obtained within the hour after sunrise. In addition, a continuous strip was obtained on June 3 and 4 during daylight hours of an area along the fault from near San Bernardino to the vicinity of Cholama, California. All images were obtained in the 8 - 13 μ band.

The following discussions pertain entirely to the imagery obtained on June 18, because for some reason, yet undetermined, the contrast in the imagery obtained on June 3 and 4 was very low and, although the topography representing the general line of the San Andreas fault was clear, little else of geologic significance has been identified thus far.

GENERAL RESULTS

A comparison of pre-sunrise and post-sunrise imagery indicates that pre-sunrise imagery is generally more useful for discriminating rock and soil units and for determining something about their physical characteristics or composition. Post-sunrise imagery has the appearance of aerial photography in that the sun heats different facing slopes differently just as it illuminates different slopes differently. A comparison of IR imagery (fig. 2a) with photographs taken at the same time (fig. 2c) shows this similarity. The wide range in radiation temperatures resulting from topographic differences constitute noise through which it is difficult to see thermal differences related to rock characteristics.

During pre-sunrise hours the topographic influence of solar heating is at a minimum and the radiation temperatures prepresented by the imagery relate more closely to the thermal properties of the rock or soil unit. In the pre-sunrise imagery striking contrasts can be seen between: 1) plowed ground (relatively cool) and unplowed ground (relatively warm) (see fig. 3a); 2) moist ground (relatively cool) and dry ground (relatively warm) (see figs. 5a and 6a); and 3) areas covered by vegetal material both alive and dead (relatively cool) and barren areas (relatively warm) (see fig. 4a).

One marine siliceous shale unit of Pliocene age (informally termed the Bitterwater Creek shale by Dibblee) appears relatively cool in comparison to surrounding and nearby recent alluvail deposits and Pliocene sandstones and conglomerates (see fig. 7).

DISCUSSIONS OF SELECTED EXAMPLES

IR images of selected areas are discussed below and most are compared to black and white photography.

The temperature graphs (fig. 1) show the ranges of temperatures that prevailed during the time imagery was obtained.

Figures 2a, 2b and 2c.--These three images show the same area in IR post-sunrise (0645 PDST) (2a), IR pre-sunrise (0535 PDST) (2b), and panchromatic photographs (2c) taken simultaneously with the post-sunrise IR imagery. The similarity of the post-sunrise IR imagery and the photograph is apparent. The San Andreas fault which controlled the development of a valley in this frame bisects the area from left to right.

In post-sunrise IR imagery peculiar scallops appear along the boundary between the lightest area and adjacent dark areas. The cause appears to be instrumental inasmuch as each scallop appears to center on a cluster of dark scan lines. Peculiarly the scallops do not appear along every light-dark boundary. This is one type of instrumental "noise" with which a geologist must become acquainted in using IR imagery for geologic interpretations.

The pre-sunrise IR imagery appears "flat" and without contrast, but under these conditions the radiation temperatures, which are controlled in large part by the thermal inertia of the rock units, can more readily be seen. For example, recent alluvium on the floors of the meandering valleys in the upper left part of the view appears distinctly warmer than the adjacent bedrock.

Figure 3a and 3b.--These images compare pre-sunrise IR imagery (3a) (0535 PDST) and panchromatic photography (3b). The San Andreas fault bisects the view from left to right. Note that several stream channels are displaced along the fault. It is this type of feature from which, hopefully, a history of prehistoric movements on the fault can be developed.

The light wavy line in each image is a dirt road formed by grading and compaction of the local surface materials. In the IR imagery the distinct contract between light (warm) and dark (cool) areas is between unplowed and plowed ground. Both units were extremely dry. The rock or soil material throughout the area is somewhat similar except for the difference resulting from plowing, although color differences are discernible on the ground and in the panchromatic photography that cannot be discriminated in the IR imagery. For the most part the material of the area is unconsolidated alluvium composed of silt, sand, and angular pebble-sized fragments derived from siliceous shale and sandstone units of Pliocene age in the Temblor Range.

The fact that the most compacted material (the road) is warmest and the least compacted material (plowed ground) is coolest seems consistent with what might be expected of differences in the thermal inertia of the materials.

Note that although some boundaries between plowed and unplowed ground show in the photographs, discrimination between the two can be made with nowhere near the certainty possible in the IR imagery.

Figure 4a and 4b.--These images compare pre-sunrise IR imagery (4a) with panchromatic photography (4b). The San Andreas fault bisects the area from left to right, and has caused segmentation of the drainage. Note the lack of continuity of drainage through the three zones in the area top, middle and bottom of imaged areas.

To be noted is the narrow dark (cool) area uphill (top of figure) from (and immediately adjacent to) the San Andreas fault. Relatively moist ground, in part accompanied by a stand of green grass, is represented by the relatively cool areas. The fault zone seems to serve as a partial groundwater barrier although in the area of this view topographic relief also exerts a significant control. Here the light-colored (warm) band through the center of the view is a low ridge bordering the fault.

The deepest black tones in gulches and along the fault represent accumultations of tumbleweeds that have blown into hollows sheltered from the wind. The piles of tumbleweeds are excellent insulators and exhibit the properties of a material having exceptionally low thermal inertia; thus they have relatively cool radiation temperatures before sunrise. During the day radiant temperatures of the tumbleweed were measured with a Barnes IT-2 radiometer and were found to be relatively high.

Figures 5a and 5b.--These images compare pre-sunrise IR imagery (5a) and panchromatic photographs (5b). To be noted in these images are the dark areas (cool) believed to be related primarily to soil moisture. The San Andreas fault which bisects the area from left to right serves as a ground-water barrier and tends to raise the soil moisture on the uphill side (top of frame) of the fault. There is little or no topographic expression of the fault in this area. Some dead grass and a small amount of green grass were in the darker areas and help to enhance the coolness of the surface. Radiation temperatures of green grass were measured in the field during daylight hours with a Barnes IT-2 radiometer and were found to be as much as 10°C cooler than those of the surround barren soil.

Even a small growth of vegetation tends to build up a thin humus mat in these slightly more moist areas. The insulating characteristics of a quarter-inch layer of humus composed of partly decomposed grass, small twigs and sheep manure was demonstated by a 9°C temperature difference between the upper and lower surface of the humus layer.

A water-tank area shows as a set of dark (cool) spots along the fault zone about 3/4 inch left of the road that crosses the fault. The spots represent concentrations of dry cow and sheep manure which are excellent insulators.

Inasmuch as areas of slightly higher soil moisture possibly related to higher water tables can be identified in the IR imagery, the suggestion is made that IR may prove useful in searching for ground water in desert areas.

Figures 6a and 6b.--These images compare pre-sunrise IR imagery (6a) with panchromatic photography (6b). The San Andreas fault trends from left to right in the view at the base of the hills near the top of the frame.

Of primary interest in this view is the high contrast between dark (cool) and light (warm) areas in the lower half of the frame. The lobate light (warm) areas are lobe-like masses of soil and rocks that have moved as landslides (J. Vadder, oral communication, 1965) in a direction from bottom toward top of the frame. The dark areas are undrained or poorly drained zones between the landslide lobes. Ground moisture was high and considerable vegetation was growing in these poorly drained areas which presumably accounts for the relative coolness. No temperature measurements were made to determine the precise temperature difference represented.

Of interest are the relative warmth of the asphalt road (the bright line extending the width of the frame), its relative obscurity in photographs compared to unpaved roads, and the relative obscurity of unpaved roads in the IR imagery.

The clarity with which the landslide terrane can be discriminated suggests that IR imagery may be useful in preparing an inventory of landslide terrane along and near the San Andreas fault as part of the geologic hazards study related to the earthquake study program.

Figure 7.--IR imagery obtained in pre-sunrise hours has shown that some bedrock units display distinctive thermal characteristics. The two elliptical dark gray (relatively cool) areas shown in this frame represent outcrops of a siliceous shale of Pliocene age (informally termed the Bitterwater Creek shale by Dibblee). The differences in physical or chemical characteristics which cause this to be one of the most distinctive bedrock units in the IR imagery is not yet known, but studies are underway. It is of interest to note that these same outcrops also show very low back scatter in side-looking radar imagery. The shaly parting of the rock and resulting platy nature of the fragments which form the outcrop surface may be important in producing low back scatter of the radar energy and in influencing the emissivity of the surface in the 8 - 13 μ range.

CONCLUSIONS

Infrared imagery in the 8 - 13 μ band is potentially useful in the study of the San Andreas fault system, California. It is clear from the present study that certain properties such as degree of compaction, platyness of surface fragments, and soil moisture may influence greatly the thermal inertia and emissivity, and thus the surface temperature of different soil and rock units. A quantitative evaluation of the variables, however, is not yet available.

Relative radiation temperature differences between different rock and soil units are more clearly displayed in imagery obtained in pre-sunrise hours than in post-sunrise hours when irregular topography is irregularly heated by solar radiation and effects of the thermal inertia of rock units are masked.

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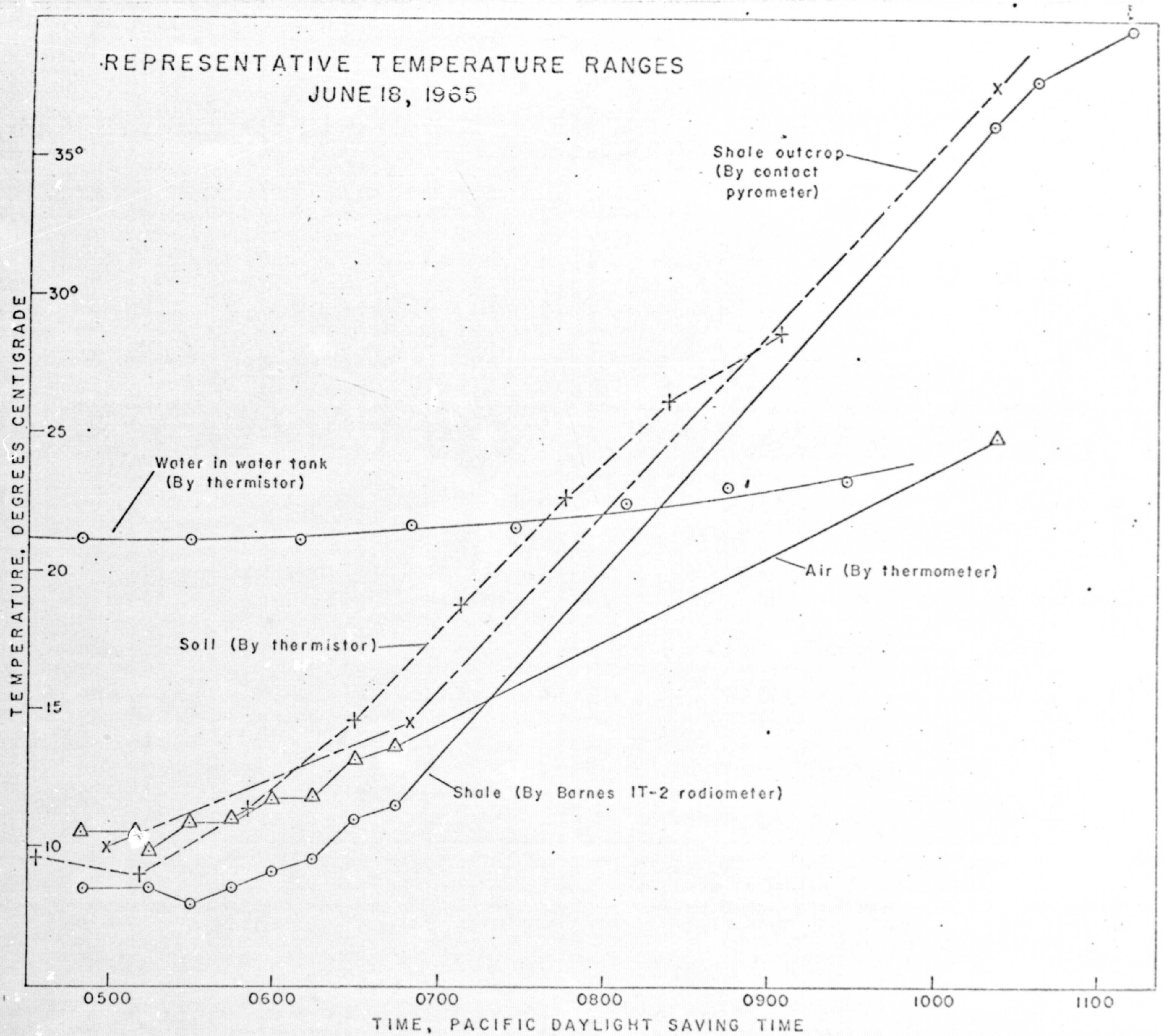

REPRESENTATIVE TEMPERATURE RANGES
JUNE 18, 1965
Shale outcrop (By contact pyrometer)
Water in water tank (By thermistor)
Air (By thermometer)
Soil (By thermistor)
Shale (By Barnes IT-2 radiometer)
TEMPERATURE, DEGREES CENTIGRADE
35°
30°
25
20
15
10
0500
0600
0700
0800
0900
1000
1100
TIME, PACIFIC DAYLIGHT SAVING TIME

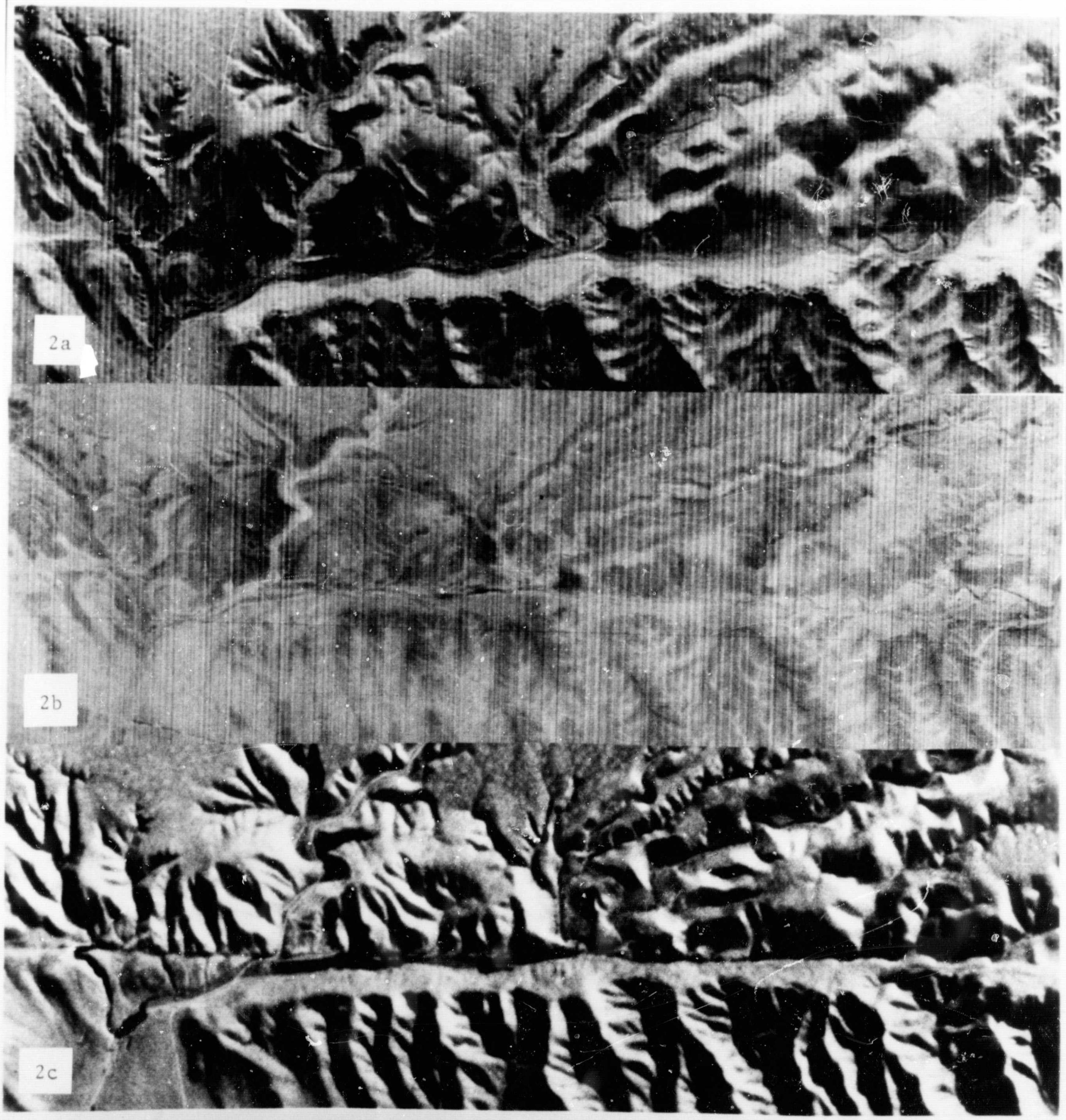


FIGURE 2. a. POST-SUNRISE IR IMAGE, b. PRE-SUNRISE IR IMAGE, c. AERIAL PHOTOGRAPH. See text for discussion.

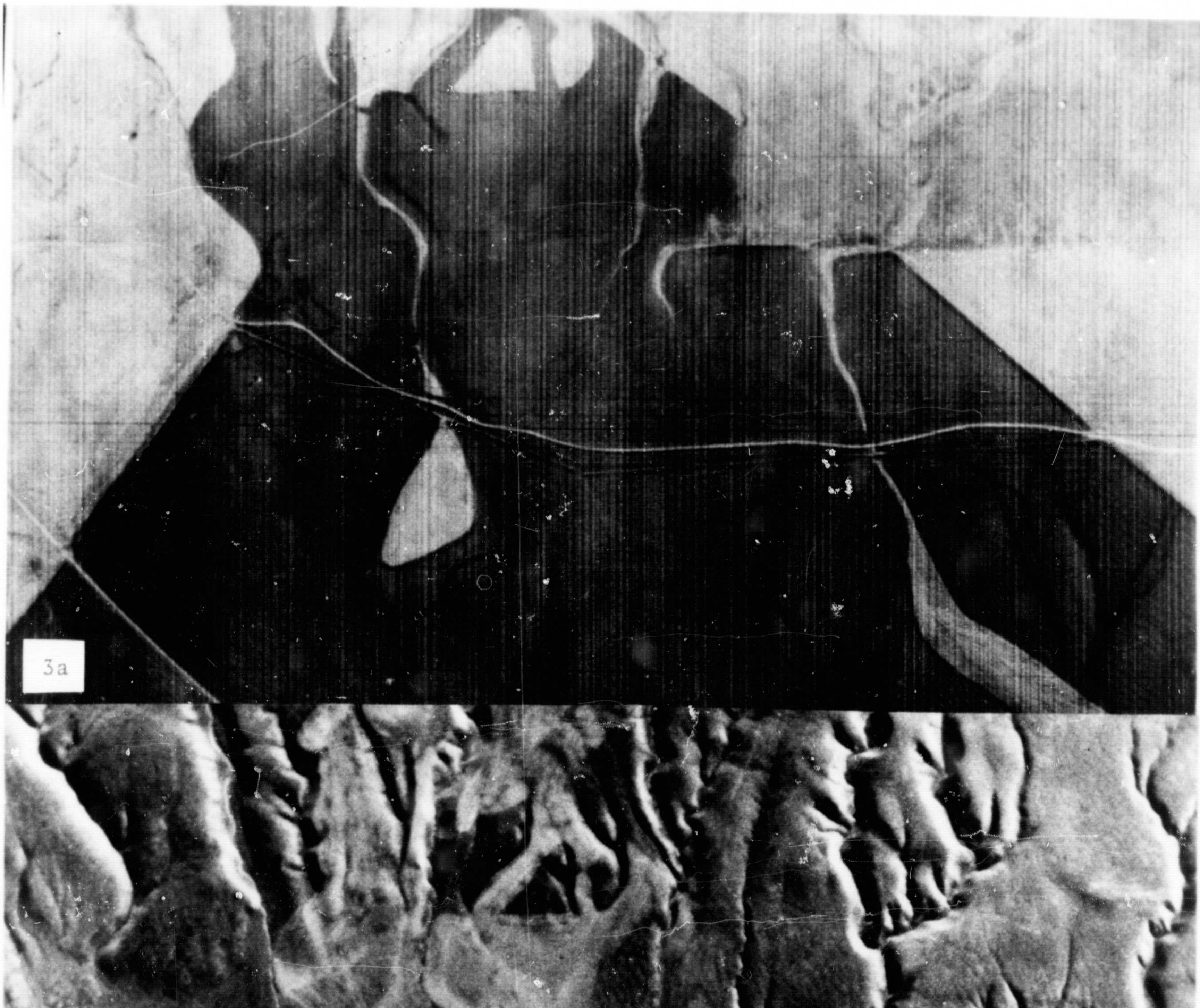
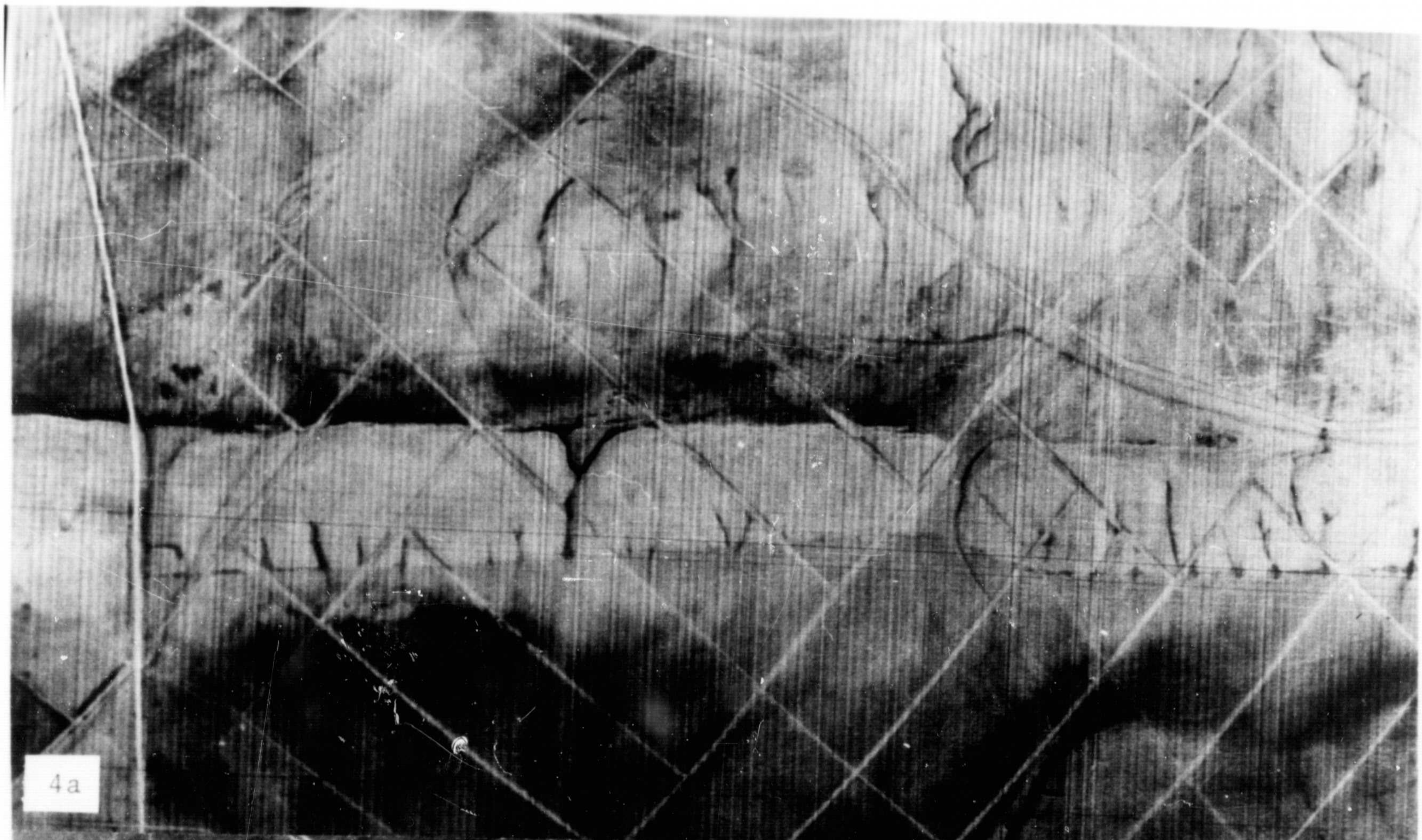


FIGURE 3. a. PRE-SUNRISE IR IMAGE, b. AERIAL PHOTOGRAPH.
See text for discussion.



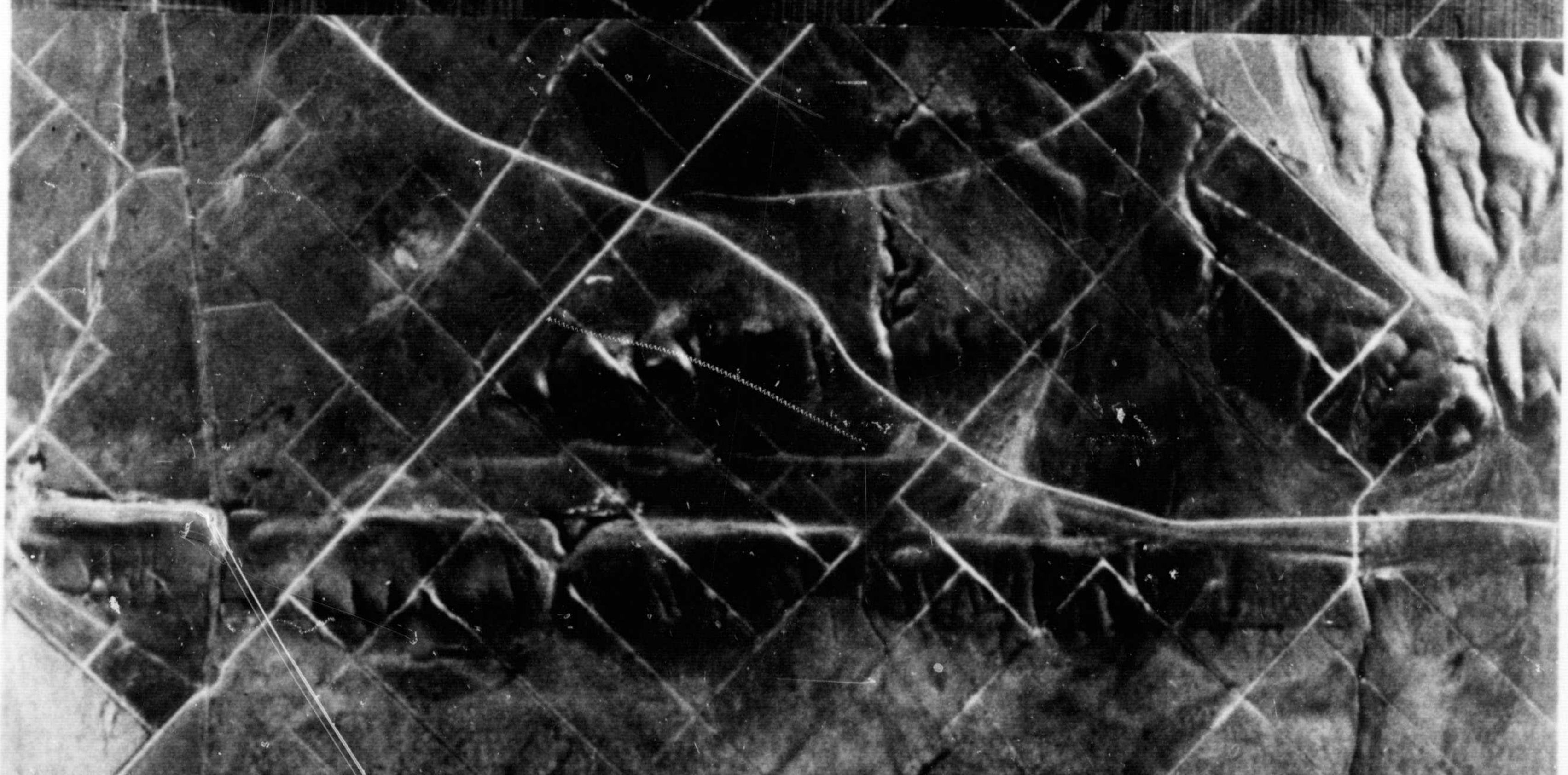


FIGURE 4. a. PRE-SUNRISE IR IMAGE, b. AERIAL PHOTOGRAPH.
See text for discussion.

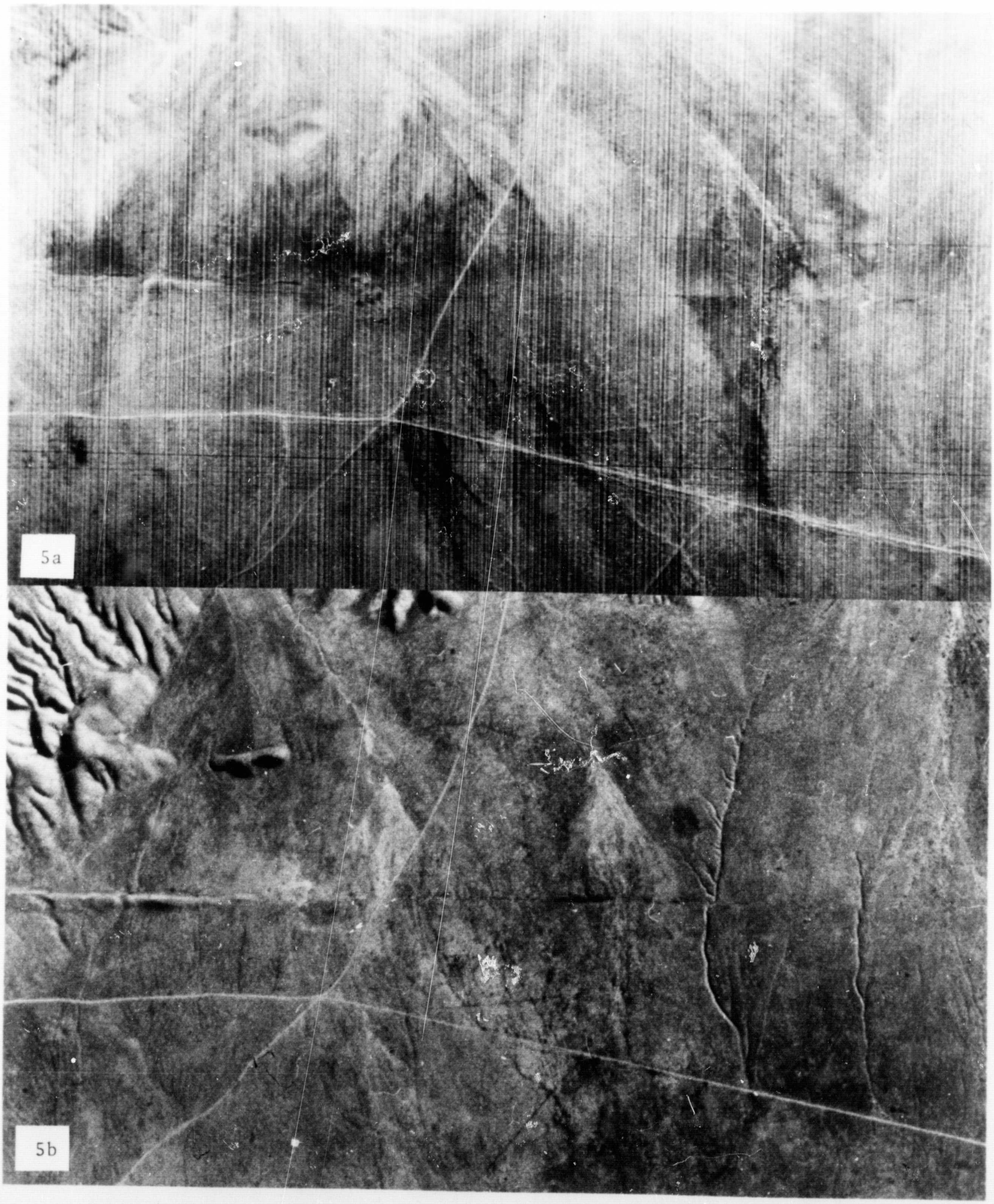


FIGURE 5. a. PRE-SUNRISE IR IMAGE, b. AERIAL PHOTOGRAPH.
See text for discussion.

FIGURE 6. a. PRE-SUNRISE IMAGE, b. AERIAL PHOTOGRAPH.
See text for discussion.

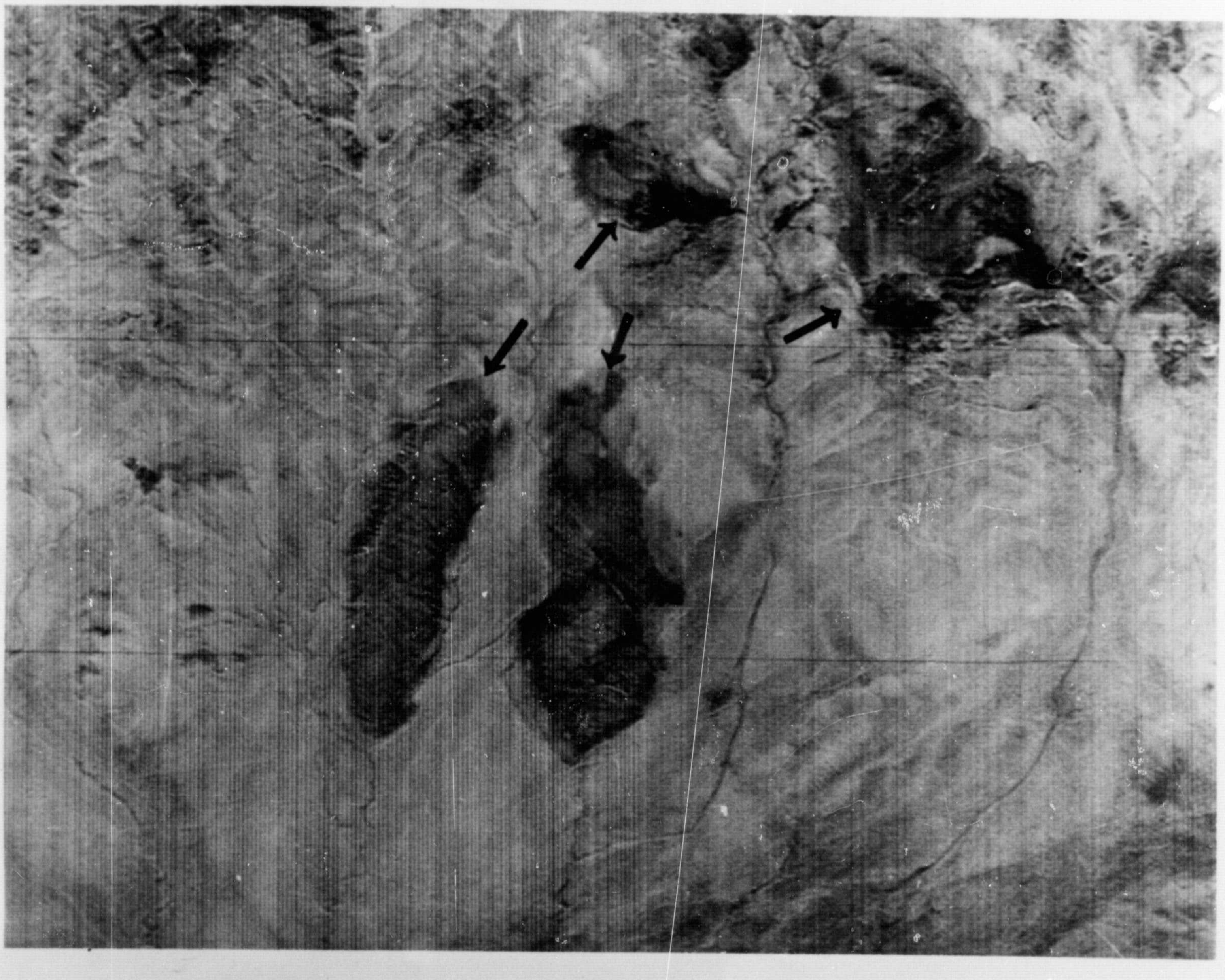


FIGURE 7. PRE-DAWN IR IMAGE. See text for discussion. Arrows point to outcrops of Bitterwater Creek Shale.