UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

AERIAL INFRARED RECONNAISSANCE OF THE STEAMBOAT SPRINGS AREA, NEVADA

by

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1968

69-176
OPEN FILE REPORT

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INTRODUCTION

The Steamboat Springs area is in southern Washoe County, Nevada, about eight miles SSE of Reno (fig. 1). Intense hydrothermal activity has taken place here, through most or all of Quaternary time (White and others, 1964). The thermal springs have been known for more than a century and the waters have long been used for health purposes. Exploration drilling has been undertaken for geothermal steam and prospecting for antimony, mercury and other metals has been done.

At present the hot springs are confined mainly to an elongate N-S area (the Main and Low Terraces) generally bounded by flight lines 0, 2, 5 and 6, shown on figure 1.

It was our purpose to map the infrared (IR) radiance of the terrain and to make a preliminary assessment of its relation to the thermal activity.

AERIAL SURVEYS

The area surveyed is indicated by the flight lines on figure 1. The pattern was designed to give regional coverage supplemented by more detailed imagery over the presently-active spring area. To obtain regional coverage in the pre-dawn hours it was necessary to navigate rather precisely owing to the mountain ranges that flank the area on the east and west. This was accomplished by flying lines 4-8 each at a constant distance from the Reno Vortac, a navigation transmitter station whose signal provides range and azimuth to the aircraft. In this instance, the pilot simply sets his course to maintain a constant predetermined DME range between the appropriate azimuths at the ends of the flight lines. To achieve the navigational precision and safety by this system, however one must accept curved flight lines. In surveys elsewhere, we have been able to select Vortac stations at sufficient distance so that the flight line curvature was negligible. At Steamboat Springs unfortunately, we had no choice but to use the nearby Reno Vortac as all more distant stations were blocked by intervening topography.

The shorter lines, 0-3, were flown with the aid of portable light beacons on the ground, supplemented by ground-air radio guidance for the pilot.

The scanner was carried in a D-18 Twin Beechcraft, operated by the USGS Water Resources Division.

Aerial surveys were made as follows:

Date	Lines	Hour	Date recorded
Oct. 18, 1967	1	0600 - 0604	IR (8-14μm)
Oct. 19, 1967	0-8	0455 - 0638	IR (8-14μm)
Oct. 19, 1967	Covers about western 2/3 of the area	1236 - 1347	Ektachrome 70mm photography
Oct. 20, 1967	0-3	0543 - 0624	IR (8-14μm)
Oct. 20, 1967	1	1450	IR (8-14μm)

The hours given above are local time.

The IR instrument used in this study was an HRB-Singer Co., Reconofax IV, equipped with an electrically-cooled Ge:Hg detector. An 8-14μm filter was used at all times.

Tri-X Aerecon film was employed for the IR imagery. Images reproduced in this report are positive prints so that the polarity is white=hot.

Isodensity maps were made of both original negatives and enlarged film positives. On a negative, density values increase with higher terrain radiance and vice versa for a film positive. In order to facilitate comparison of isodensity maps made from the two different media, densities of negatives are given in positive values; those of film positives are given in reciprocal densities.

GEOLOGIC SETTING

The geology, hydrology and geothermal activity of the Steamboat Springs area has been studied in great detail by D. E. White and his colleagues whose work has led to a series of papers, only a few of which are cited here. The geologic map accompanying this report (fig. 2) has been taken from Thompson and White (1964, plates 1 and 2); other mention made below of geological data and geothermal activity is based extensively on White (1968) and White and others (1964).

The lithology of the rock units which occur in the Steamboat Springs area is designated in the explanation accompanying figure 2; the geology will not be amplified here except with respect to the thermal activity.

The thermal springs are presently confined to the Main Terrace and the Low Terrace (figs. 3 and 4) (in the sinter area traversed by U.S. 395, fig. 2), though past hot spring discharge is indicated by the High Terrace and other sinter deposits north and west of the Main Terrace. Abnormal sub-surface temperatures have also been observed at Sinter Hill, an old eroded sinter terrace; the silica pit area, and in the clay quarry - Pine Basin area, where four geothermal exploration boreholes have been drilled.

The principal thermal spring activity is on the Main Terrace where water temperatures range from 51°C to boiling (near 95°C at this altitude). More than 70% of the springs are hotter than 90°C, however. Most of the higher temperature discharge is from a series of N to NNW trending fissures near the crest of the terrace, while the lower temperature springs generally issue from the terrace margins.

In many places in the fissured area the water table does not intersect the surface so that no spring discharge takes place, though steam escapes through openings and the surface is thus heated by convective as well as conductive heat flow.

White (1968) has shown that the fissure system dips steeply to the east and provides the major pathways for thermal water rising to the surface or near-surface in this part of the Steamboat Springs system.

The Low Terrace, on which Steamboat Resort is located, is relatively smaller in extent than the Main Terrace and the number of active springs are fewer. Near the central and northern axial crest of the Low Terrace, temperatures are near boiling and most of the active vents discharge as geysers or boiling springs. Most of the natural discharge from the Low Terrace is from springs of moderate temperature on the eastern flank of the terrace and from unseen vents in the bed of Steamboat Creek.

TEMPERATURE MEASUREMENTS

Temperature measurements at seven localities (fig. 10) on the main terrace were made during the period of the aerial surveys. Yellow Springs Instrument Co., Series 400 thermistors were used. They had a maximum diameter of 3/16", and for surface temperatures were implanted at a depth of ∿3mm. One thermistor was used to obtain air temperature about 1 foot above the ground. The thermistors were connected to a digital thermometer that printed out the temperature of each probe, to the nearest 0.1°C, at 10 minute intervals. A very high-precision (low temperature coefficient) resistor was used for calibration and its equivalent temperature was recorded on each print-out cycle. The maximum calibration drift during the observation period was ±0.1°C. Additional details on the digital system are given elsewhere (Moxham and others, 1968).

One thermistor (curve A fig. 11) was placed in sinter that locally bridged a 3 inch-wide fissure (the westernmost open fissure, closest to the Explosives Engineering Co., buildings). In both directions along the fissure from the sinter bridge, the fissure was open and steaming. The temperature remained relatively constant at ∿92°C. Evidently the steam flow here was relatively constant and little affected by ambient air circulation. Another thermistor (curve B) was in a similar sinter bridge but here the surface winds either periodically diverted the steam flow or affected the thermistor, or both.

Curve C is from a thermistor in fragmental sinter on the terrace surface about 50 feet west of the westernmost open steaming fissure. The temperature here has dropped drastically from those previously described, but is very slightly higher (~2°) than the probes still further west from the open fissure.

Other spot temperature observations were made at Reno Resort:

Date and time		Location	Temperature
Oct. 20, 1967,	0530	Reno Resort swimming pool	14.5°C
"	"	Sand strip bordering pool on the north	5°
"	1445	Reno Resort swimming pool	15°
"	"	Sand strip bordering pool on the north	30°-30.7°
"	"	Asphalt parking lot	28.5°-30°

RESULTS

The scanner's electronic limitations primarily, and atmospheric absorption to a lesser degree, both militate against quantitative evaluation of IR image density in terms of terrain temperature (Lowe, 1968; Moxham, 1968). Though quantitative analyses of the IR negatives (and enlarged film positives) were made with a Joyce-Loebl isodensitracer, their evaluation is largely in qualitative terms and is useful only for comparing relative terrain radiance.

A regional IR image of Steamboat Springs and vicinity, made along flight line 6 (figure 5) clearly shows the Main Terrace to contain the points of greatest radiance. The thermal features on the Low Terrace are barely perceptible by contrast. The Pine Basin area shows a light-toned mottling at Sinter Hill and the quarries to the southwest, but there are many other places on the image of similar tonal intensity. Other high-radiance features relate to agricultural developments and to irrigation water.

An isodensity map (fig. 6) of this image was made with a 400μm aperture on the densitometer. This relatively large aperture does not resolve small thermal features, consequently, at the Main Terrace, only the anomalies at Reno Resort are delineated. From a regional standpoint the largest areas of highest radiance are associated with the Kate Peak formation in the northeast part of the region. An isodensity map of the central part of figure 5 was made using a 100μm aperture and an enlargement factor of 5 (figure 7). The smaller aperture (compared to figure 6) brings out more of the radiance details. But the maximum values associated with the main terrace (by inspection of figure 5) evidently have been reduced by spatial integration so that they are given the same values as other somewhat lower (by inspection) but larger radiance features. The most extensive high radiance zone includes the Main Terrace and extends southwestward, following in a general way the higher elevations of the Steamboat Hills, occupied by the basalts and basaltic andesite of the Lousetown formation.

The lowest radiance is in Steamboat Valley and the valley of Steamboat Creek. In the predawn hours the alluvial material here would tend to be cooler than the adjacent bedrock, due to lower thermal inertia $(k\rho C)^{\frac{1}{2}}$, but cooler air draining into the topographic lows may also be involved.

For the greatest part of figure 7, there is no clearcut relation between lithology and terrain radiance.

Figure 8 shows the area from the Reno Resort to the Low Terrace, and includes the Main Terrace. In this view, a few of the natural springs at the Low Terrace as well as the Steamboat Wells, can be seen. On the Main Terrace the high radiance zones conform well to the fissure system that generally follows the terrace crest, though there are two spring clusters probably including White and others (1964, pl. 2) springs 8 and 9 east of the crest, and whose discharge can be seen flowing to Steamboat Creek.

An enlarged film positive was made from the negative of figure 8 and an isodensity map of the enlargement is shown in figure 9.

It has been previously pointed out, that owing to instrument characteristics and atmospheric absorption, terrain radiance cannot be derived in any very precise quantitative way from the image density. But some rough estimates were made with respect to figure 9. It was assumed that the temperature on October 19 at the Reno Resort swimming pool was about the same as 14.5° observed on the following day. This suggests the solid areas on figure 9 probably represent terrain radiant temperatures of >14°C. The sinter at probes 4, 10 and 20 (fig. 11) were at ∿3°C, suggesting the lowest density^{-1} contour corresponds to ∿2°C. These numbers can only be rough estimates and apply only to large targets along the central swath of the isodensity map. It is quite evident that the high temperatures along the steaming fissures are not resolved on the isodensity map.

An enlarged film positive of the Main Terrace was made from the negative of figure 8, and an isodensity map of the enlargement is shown in figure 10. The contours rise very steeply around the fissures and other vents, and in some places the spacing had to be exaggerated to preserve the contour continuity. This suggests that the surface temperature anomalies detectable with our equipment are rather closely confined to the vents associated with the principal structural system along which the heated water is rising. The lowest density^{-1} contour, west of the terrace crest, trends NE and seems to follow a small drainage that heads nearby in the Steamboat Hills. On the east, the contour generally lies along the terrace slope in an irregular configuration, but is locally influenced by hot spring drainage and the berm along U.S. 395.

SUMMARY

The results show that the IR technique can quickly and efficiently delineate the high temperatures associated with the first order phenomena of convective heat transfer in major geothermal systems. In reconnaissance geophysical exploration for such geothermal systems, such observations can be of great value. The more subtle surface effects of lower-temperature conductive and convective heat transfer related to subsurface occurrence of geothermal steam are much more difficult to perceive with the present generation of IR scanners. The difficulty lies in the combined effect of lack of radiometric capability and the obscuration of anomalous surface temperatures by extraneous effects of meteorology, surface moisture and emissivity.

The advent of quantitative scanners combined with tape recording and playback will doubtless afford greatly improved analytical techniques in the future.

ACKNOWLEDGMENTS

The authors are grateful for the assistance rendered in the field by George R. Boynton, R. M. Turner and C. R. Fross.

Cooperation extended by Mr. Byers of the Explosives Engineering Co., and by the management of Steamboat Springs and Reno resorts is also greatly appreciated.

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Figure 1. Location map showing IR flight lines.

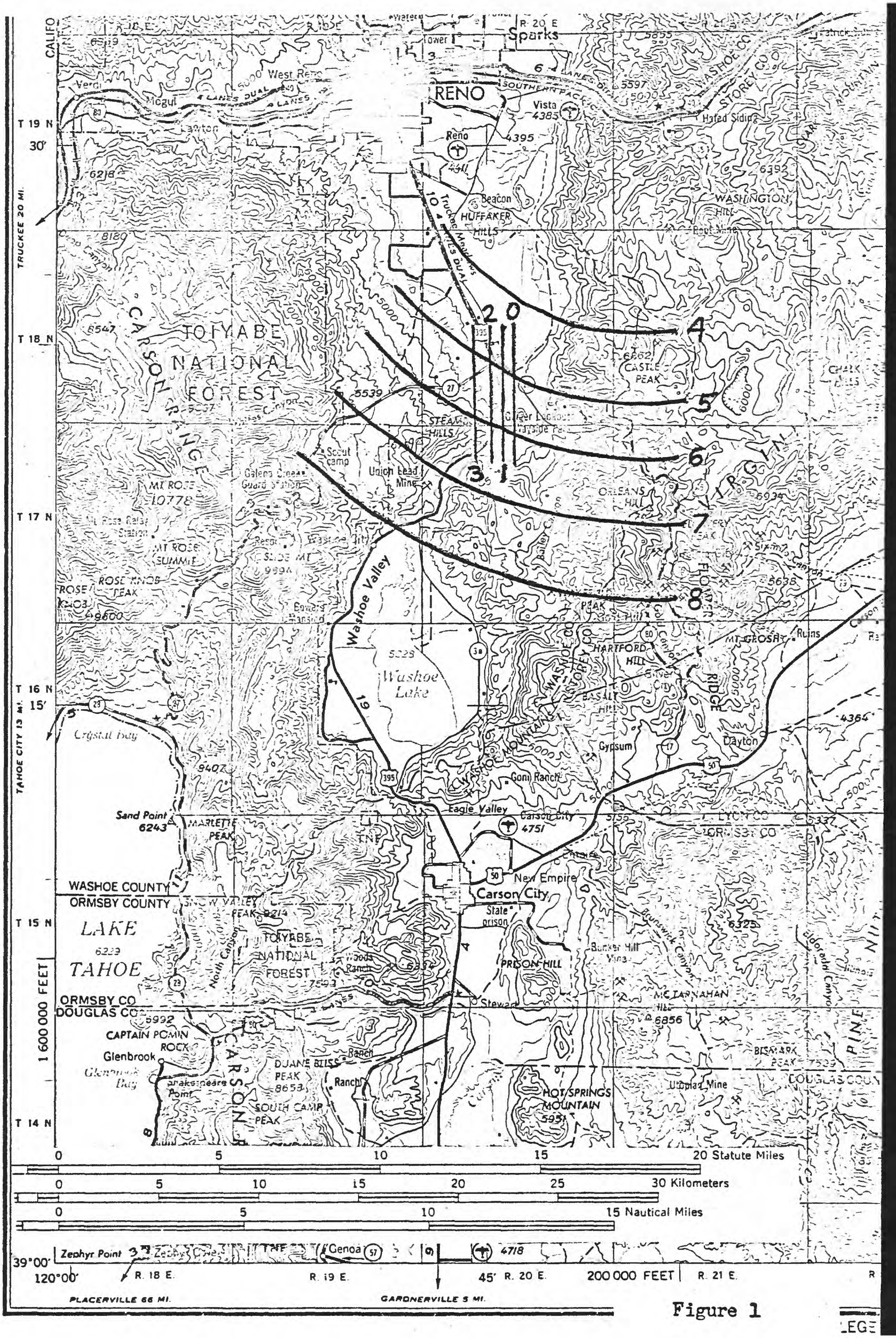


Figure 1

Figure 2. Regional geologic map of the Steamboat Springs area. From Thompson and White (1964, pl. 1 and 2) A=U.S. Hwy. 395; B=St. Hwy. 27; C=Steamboat Creek; D=Steamboat Ditch; E=Crane Ditch; F=Chandler Ditch; S=Steamboat Resort.

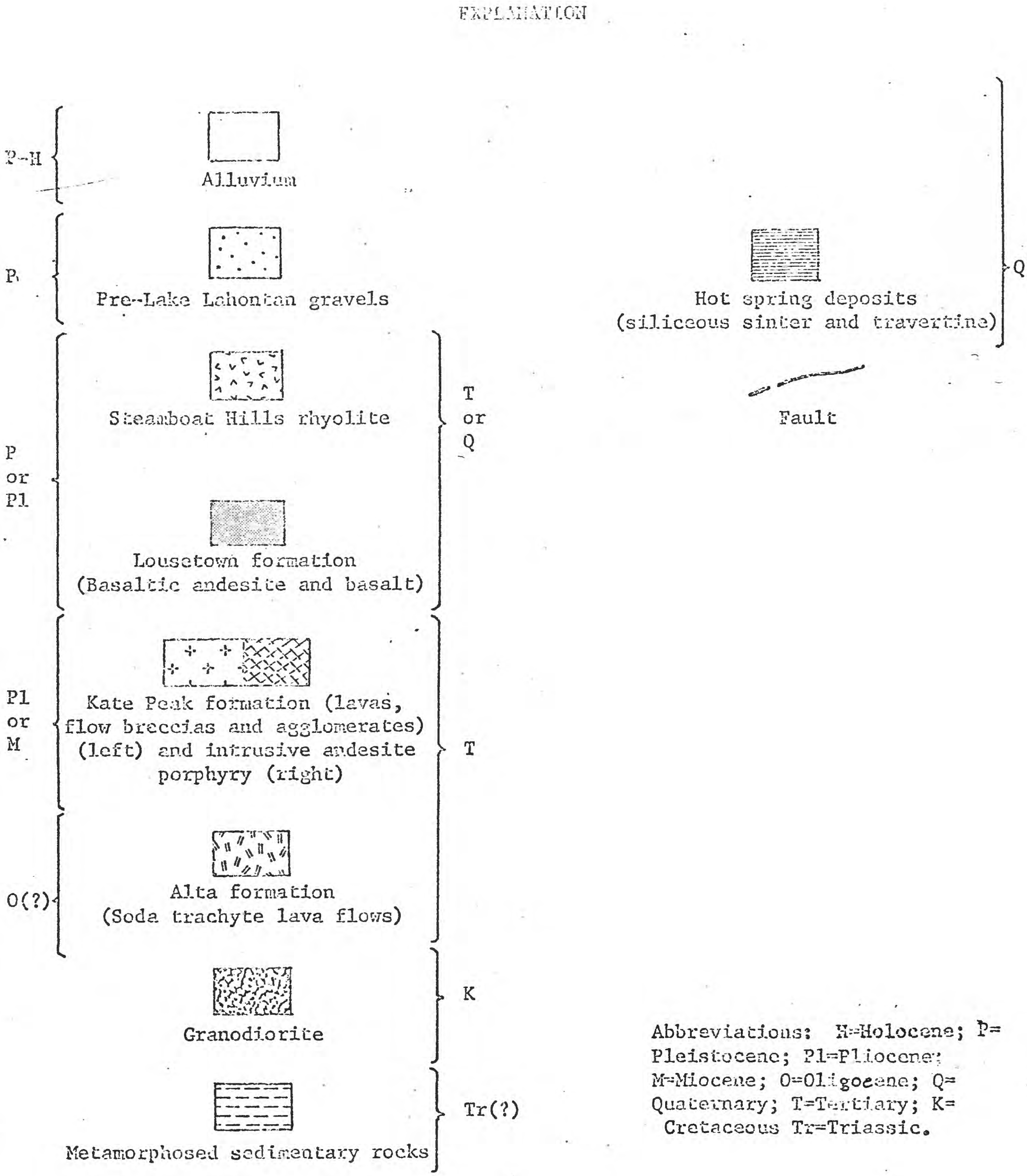

EXPLANATION
P-H
Alluvium
P
Pre-Lake Lahontan gravels
Hot spring deposits (siliceous sinter and travertine)
Q
Steamboat Hills rhyolite
T or Q
Fault
P or Pl
Lousetown formation (Basaltic andesite and basalt)
Pl or M
Kate Peak formation (lavas, flow breccias and agglomerates) (left) and intrusive andesite porphyry (right)
T
O(?)
Alta formation (Soda trachyte lava flows)
Granodiorite
K
Metamorphosed sedimentary rocks
Tr(?)
Abbreviations: H=Holocene; P=Pleistocene; Pl=Pliocene; M=Miocene; O=Oligocene; Q=Quaternary; T=Tertiary; K=Cretaceous Tr=Triassic.

Figure 2

Figure 3. Aerial photo of the Steamboat Springs area, October, 1967. A=U.S. Hwy. 395; B=State Hwy. 27; C=Reno Resort; D=Main Terrace; E=High Terrace; F=Low Terrace; G=Sinter Hill; arrow shows location of fissure at station 1.

Figure 3

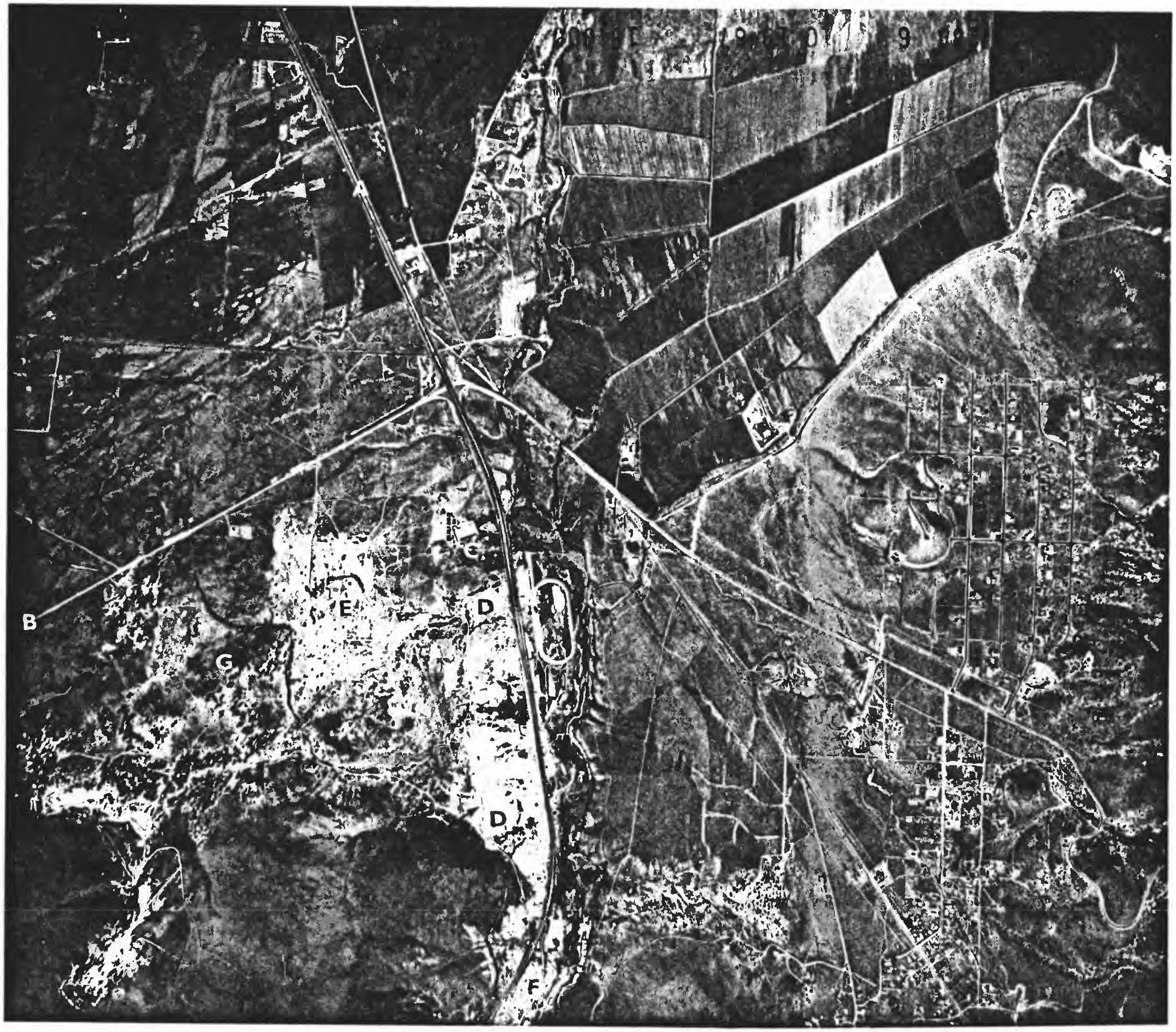


Figure 4. Aerial photo of the Steamboat Springs area, October 1967. A=U.S. Hwy. 395; B=Low Terrace; C=Steamboat Valley; D= Steamboat Creek.

Figure 4

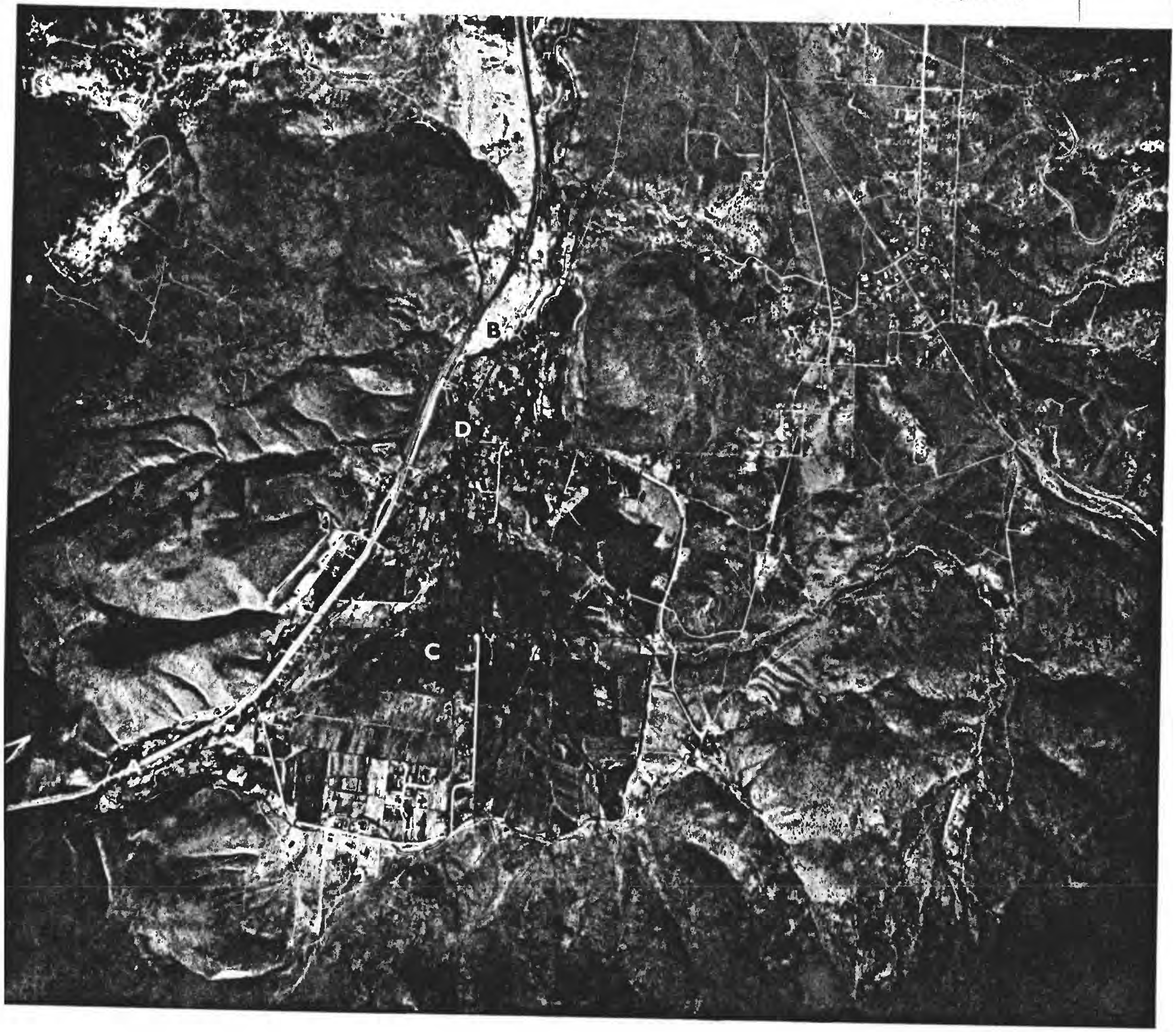


Figure 5. IR image along flight line 6, October 19, 1967. A=U.S. Hwy. 395; B=State Hwy. 27; C=Main Terrace; D=High Terrace; E=Low Terrace; F=Reno Resort; G=Steamboat Ditch; H=Steamboat Hills; J=Sinter Hill.

Figure 6. Isodensity map of figure 5. Aperture=400μm. A=U.S. Hwy. 395; B=State Hwy. 27; C=Main Terrace; D=High Terrace; E=Low Terrace; F=Reno Resort; G=Sinter Hill. Density contours: stipple ≥0.36; long dash=0.32; short dash=0.28; dot=0.25.

FIG. 6

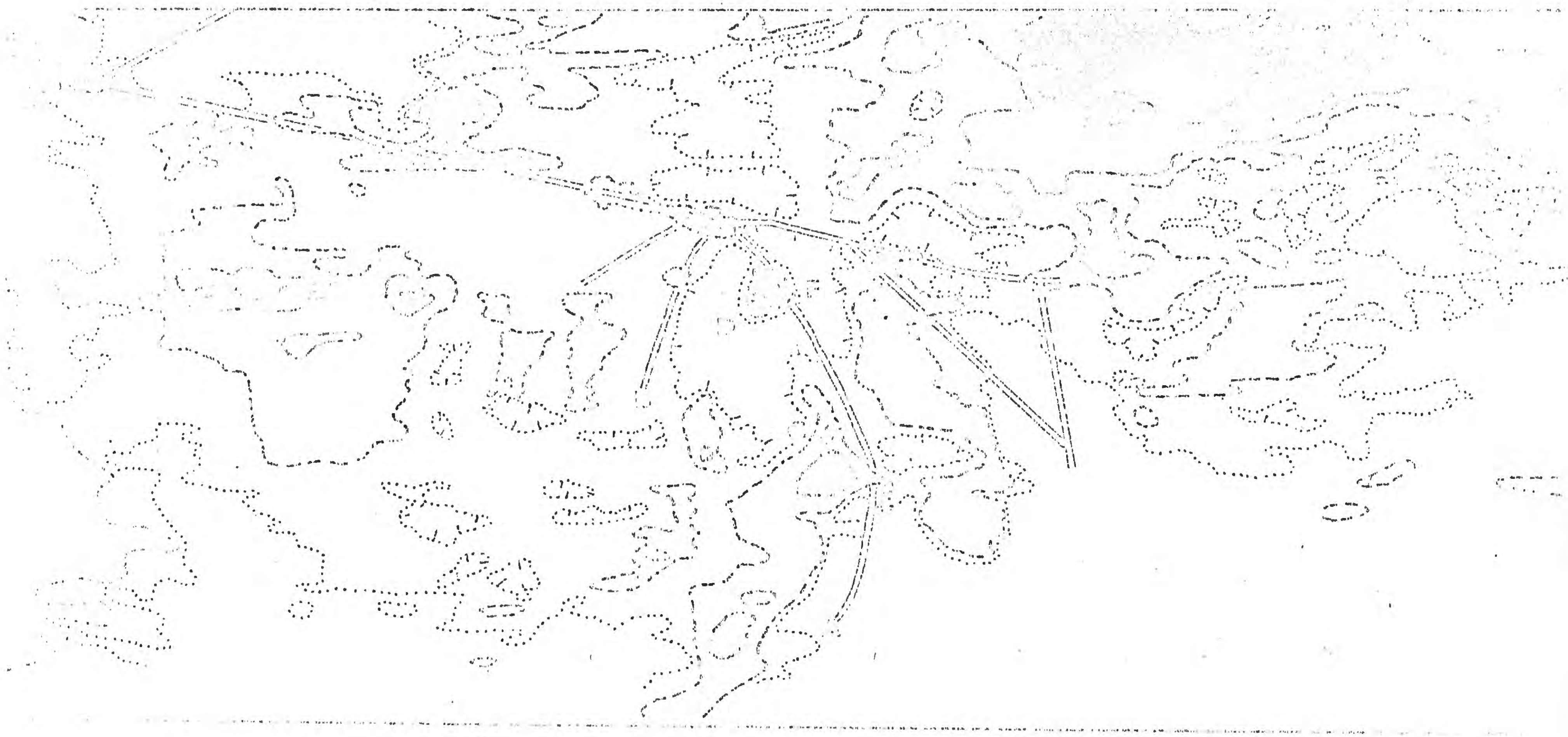
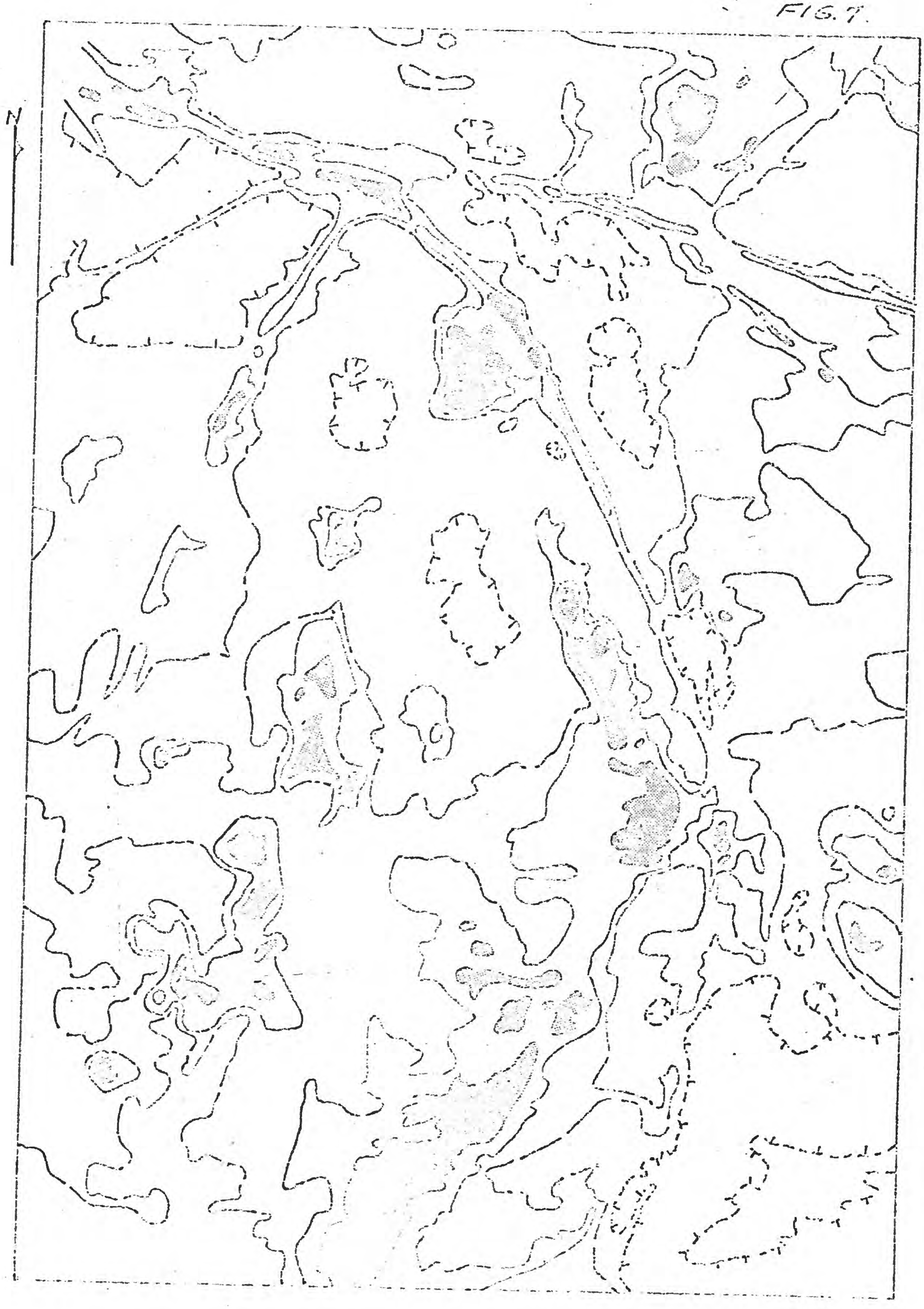


Figure 7. Isodensity map of the central part of figure 5. Letters correspond to features identified on figure 5. Density contours: Solid ≥ 0.38; stipple=0.33; solid line=0.28; long dash=0.23; short dash=0.19.

FIG. 7.



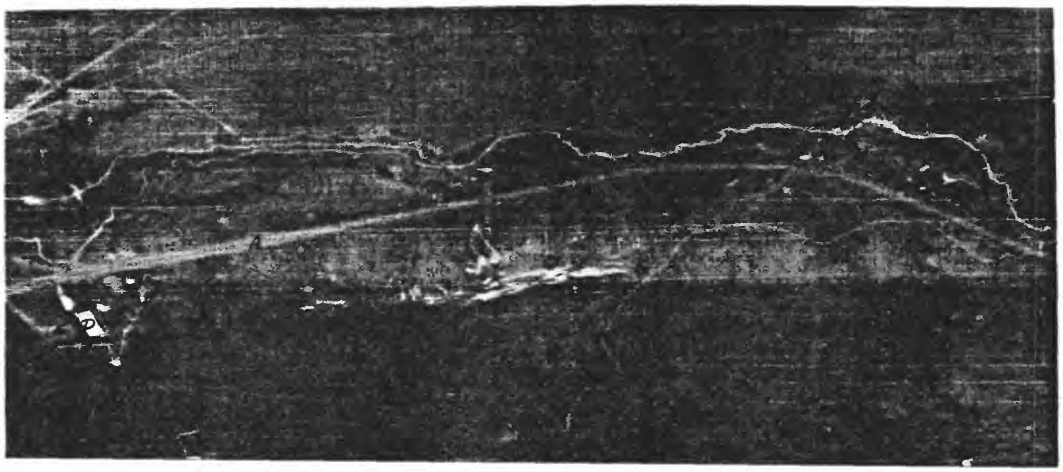


Figure 8. IR image of the Reno Resort - Low Terrace area, October 19, 1967, 06:15. A=U.S. Hwy. 395; B=Steamboat Resort; C=Steamboat Wells; D=Reno Resort swimming pool; E=Reno Resort parking lot; F=Steamboat Creek; G=Main Terrace; H=drainage ditch(?); K=Steamboat Ditch; L=temperature monitoring station 1.

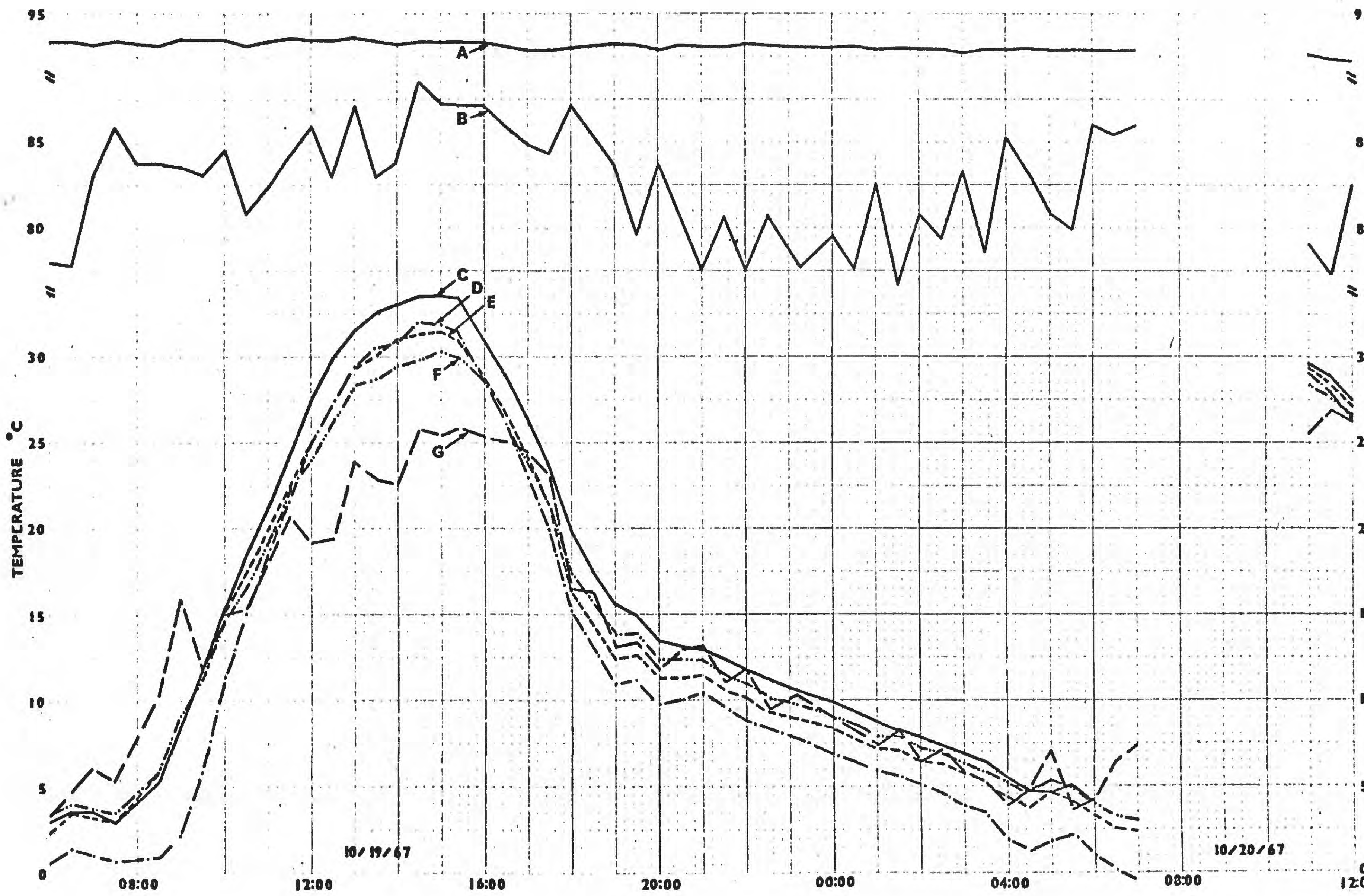
Figure 9. Isodensity map of figure 8. Map made from an enlarged file positive. Densitometer aperture=150μm. Letters correspond to features identified on figure 8. Density^{-1} contours: Solid $\geq$1.96; solid line=1.70; long dash=1.50; short dash (shaded toward higher d^{-1})=1.32. Scale is approximate.

Figure 10. Isodensity map of the central part of figure 8. Map made from an enlarged film positive. Aperture=150μm. A=U.S. Hwy. 395; B=Bldgs. of Explosive Engineering Co.; C=Steamboat Ditch. Numbers correspond to temperature probes identified in figure 11. Density^{-1} contours: Solid ≥3.70; gray=3.02; stipple=2.42; solid line=2.00; dash=1.75; dot=1.49.

Figure 11. Temperature measurements at station 1 near the south end of the Main Terrace.

Thermistor no.	Material tested	Curve, fig. 11
12	Sinter bridging 3" steaming fissure	A
18	Sinter bridging 6" steaming fissure	B
8	Fragmental sinter	C
20	Fragmental sinter	D
4	Partially cemented sinter	E
10	Partially cemented sinter	F
1	Air, 1 foot above surface	G

FIG. 11



95
85
80
30
25
20
15
10
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TEMPERATURE °C
A
B
C
D
E
F
G
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