N69 16106

(ACCESSION NUMBER) (THRU)

71 1

(PAGES) (CODE)

CR# 99234 13

(NASA CR OR TMX OR AD NUMBER) (CATEGORY)

FACILITY FORM 602

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

Interagency Report
NASA-99
January 1969

Mr. Robert Porter
Acting Program Chief,
Earth Resources Survey
Code SAR - NASA Headquarters
Washington, D.C. 20546

Dear Bob:

Transmitted herewith are two copies of:

INTERAGENCY REPORT NASA-99

INFRARED SURVEY OF THE PISGAH CRATER AREA,

SAN BERNARDINO COUNTY, CALIFORNIA*

A GEOLOGIC INTERPRETATION

by

Stephen J. Gawarecki**

The U.S. Geological Survey has released this report in open files. Copies are available for consultation in the Geological Survey Libraries, 1033 GSA Building, Washington, D.C. 20242; Building 25, Federal Center, Denver, Colorado 80225; 345 Middlefield Road, Menlo Park, California 94025; and 601 E. Cedar Avenue, Flagstaff, Arizona 86001.

Sincerely yours,

William A. Fischer
Research Coordinator
EROS Program

*Work performed under NASA Contract No. R-09-020-011, Task 160-75-01-44-10
**U.S. Geological Survey, Washington, D.C. 20242

UNITED STATES

DEPARTMENT OF INTERIOR

GEOLOGICAL SURVEY

INTERAGENCY REPORT NASA-99

INFRARED SURVEY OF THE PISGAH CRATER AREA, SAN BERNARDINO COUNTY, CALIFORNIA*: A GEOLOGIC INTERPRETATION

by

Stephen J. Gawarecki**

January 1969

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

*Work performed under NASA Contract No. R-09-020-011, Task 160-75-01-44-10
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A GEOLOGIC INTERPRETATION

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ABSTRACT

Infrared imagery in the 8-14μ band of the Pisgah Crater area has provided useful geologic information to complement data obtained from ground studies and from aerial photography.

Thermal contrasts representative of those found through the diurnal cycle were acquired during three of six flight periods: at about 2000 (post-sunset), 0400 (pre-sunrise), and 1200 (midday). The largest amount of information on geologic thermal parameters from a single imaging period was obtained from the imagery flown shortly after sunset.

Among the geologic features shown on imagery of one or more flight periods were basalt flow contacts where the adjacent flows differed in surface character, distribution of pyroclastics and their alluvial derivatives on the flows, collapsed lava tubes, fissured areas, detail of the Pisgah fault, zonation within Lavic dry lake, active drainage on an alluvial fan, and moist areas suggestive of ground water conditions. Most of these features are either unique in infrared imagery or are superior in their infrared presentation to images obtained from other remote sensing systems.

The integration of data from infrared scanning systems with that acquired simultaneously with other sensors should greatly expand the interpreter's capability by providing many unique physical property combinations for the identification of geologic features.

PREFACE

The following report includes the specific geologic results obtained from an infrared scanning survey of the Pisgah Crater area, California as presented September 16, 1968, during the NASA Earth Resources Program review meeting at the Manned Spacecraft Center, Houston, Texas. Emphasis is placed, as requested, on the relationship between these geologic results and their utilization in geologic mapping.

A later report will dwell on the ground measurements and their relationship to the infrared imagery and the problems involved with measurements of terrain temperatures.

INTRODUCTION

General Statement

The infrared survey of the Pisgah Crater Area, San Bernardino County, California was primarily undertaken to establish parameters by which rock types, structures, and textures peculiar to this locale could be recognized or differentiated. A secondary purpose was to provide an adequate evaluation and calibration of airborne and ground-based instruments used in the survey.

Pisgah Crater and its vicinity was chosen as one of the fundamental test sites for the NASA remote sensing program because of its relatively fresh basaltic flows and pyroclastics. Its typical exposure of basalt also made it a possible lunar analogue. A fundamental test site for the purpose of the program is defined as a readily accessible area for which the topography, geology, hydrology, soils, vegetation and other features are relatively well known. All remote sensor instrument teams, i.e. infrared, radar, microwave, and photography, were obligated to use the fundamental test sites for instrument evaluation and to establish terrain identification procedures.

Pisgah Crater, nearby Sunshine Cone, and their associated lava flows are in the southern Mojave Desert about 40 miles east-southeast of Barstow, California. (See fig. 1.) U. S. Highway 66 skirts the northern part of the area and provides access via asphalt-paved and dirt roads to the Crater and to the perimeters of the flows.

Scale in miles

Fig. 1 Index map showing location of Pisgah Crater area

Pisgah Crater, which is a pumiceous cone. is owned and occasionally quarried by the Atchison, Topeka and Santa Fe Railroad. The remaining part of the area to the south is within the boundary of the Marine Corps Base, Twentynine Palms, California and is currently being used as a gunnery and bombing range. The proximate area to east, west, and north of Pisgah Crater is public domain.

Originally, an area totaling 10 square miles was outlined for detailed study. (See plate 1.) This included an 8 mile long strip extending southeast from and including Pisgah Crater to Lavic Dry Lake, and a 2 mile strip aligned to include a portion of the Sunshine lava flow and the dry lake. Additional aerial infrared imagery of the Sunshine and Pisgah flows along the Pisgah fault proved so interesting and informative that this area is included in the discussion.

Infrared surveys were flown February 11 through 13, 1965 and August 5 and 9, 1966. The initial survey was flown by the NASA personnel aboard the NASA 926 Convair 240 aircraft. Because of technical problems with the infrared scanners (4.5-5.5 and 8-14 micron bands) and with certain ground instruments, most of the imagery and ground temperature data obtained during the initial survey period was of little value. However, excellent infrared imagery in the 8-14 micron (μ) region of the spectrum was acquired by the Geological Survey during the August 1966 survey. The scanner was mounted in a Beech D-18 aircraft provided by the Survey's Water Resources Division. Likewise, more reliable ground data was obtained at this time owing to improved instrumentation and technique.

Ground data were taken by Geological Survey personnel including W. A. Fischer, J. D. Friedman, W. R. Hemphill, D. L. Daniels, G. R. Boynton, P. W. Philbin and the author. C. R. Fross operated the infrared scanner during the August, 1966 survey and R. M. Turner was responsible for photo processing of the infrared imagery. Their assistance is gratefully acknowledged.

Previous Studies

The geology of the Pisgah Crater area has been previously mapped in whole or part by several geologists. Highly generalized reconnaissance maps were made by Darton (1915, sheet 23), Gardner (1940), and Kupfer and Bassett (1962) at the respective scales of 1:500,000, 1:250,000, and 1:125,000. Dibblee (1966) and Dibblee and Bassett (1966) mapped the Lavic and Cady Mountains quadrangles respectively at a scale of 1:62,500, covering the area of the present study. In conjunction with the present study, W. S. Wise (1966) mapped the Pisgah and Sunshine Cone lava fields in detail. Plate 2 is a compilation of these sources, of personal observations in the field, and of geology taken from large scale aerial photographs of the area. The author assumes responsibility for the resulting geological interpretation of the mappable units as presented in this report.

Several NASA technical letters on the Pisgah Crater area were distributed by the Geological Survey. These included reports and/or preliminary maps by Gawarecki (1964), Dibblee (1965), Fischer and others (1965), Altenhofen (1965), Daniels (1966), and Friedman (1966).

GEOLOGY

Geomorphic Setting

The Pisgah test site area is within the Basin and Range physiographic province and is one of the many centers of recent volcanic activity which lie on broadly alluviated valleys and playas across the central part of San Bernardino County. The area also lies within the southern Mojave Desert, a part of the Mojave structural block, which is characterized by generally northwest-trending fault block mountains and intermontane basins.

Elevations in the Pisgah area range from 1,886 feet above sea level at Lavic Dry Lake in sec. 27, T. 7 N., R. 6 E. to 4,421 feet at Sunshine Peak, which is 4 miles distant in NW 1/4, sec. 1 T. 6 N., R. 5 E. The maximum elevation in the area of detailed study is 3,121 feet above sea level at Sunshine Cone, but the average is close to 2,100 feet.

The drainage is internal, to Lavic Lake playa on the south, and to Troy Dry Lake on the northwest. The two areas are believed to have been connected by northward drainage during Pleistocene time (Kerr and Langer, 1965), prior to damming by the flood of Pisgah basalt and subsequent development of the playas during the pluvial stages. The lake beds have been augered to a depth of 160 feet in the northeast part of Lavic Lake without reaching lava (Dellwig and others, 1966), indicating that a considerable amount of deposition that has taken place. A dry 10-foot deep bomb crater observed in the lake bed shows that the water table is not near the surface.

The surface of the playa is extremely flat and has widely developed giant desiccation polygons whose sides are outlined by moist sediments and, in many cases, by vegetation. Inside the southern and western margins of the playa, phreatophyte mounds have been formed by the aeolian deposition of sand and silt around the base of brushy vegetation. The moisture for this and other vegetation is probably derived from coarser intercalated detrital beds below the surface related to the alluvial fans bordering the playa.

Recent deposition appears to be minor. The playa may contain shallow standing water for brief periods after a rare desert cloudburst. During the August, 1966 period of investigation, only the eastern margin of the lake showed evidence of moisture. Rainfall in this part of the Mojave Desert is only 1 to 2 inches annually.

The effects of wind are especially noticeable on the north side of the area where a long fetch enables the prevailing westerlies to deposit sand and silt across the northern reach of the Pisgah flows and the area immediately north of the Pisgah cone.

Lithology

General comments

The lithologic units found in the area are shown on the geologic map (pl. 2). In addition to the sources of the geologic data described earlier, geologic units discovered on the infrared imagery are included on the map. A later section on the interpretation of the imagery will treat properties of the various units insofar as they affect their thermal behavior and contrast.

The rocks range in age from probable Mesozoic to Recent. Their exact ages are, for the most part, unknown because there is very little stratigraphic and no paleontologic control available for these units of limited lateral extent.

The following description of the lithologic units is necessary for an understanding of their thermal behavior as shown on the imagery.

Biotite quartz monzonite (bgm)

The oldest rock recognized is a biotite quartz monzonite that is found on Peter's Mountain as a few small inliers near the center and in the NW 1/4 of sec. 19, T. 7 N., R. 6 E. Dibblee (1966) describes it as a gray, massive, medium-grained, commonly porphyritic granitic rock composed of from 10 to 30 percent quartz, 35 to 50 percent plagioclase (andesine); 15 to 30 percent potassic feldspar, in many places as orthoclase phenocrysts up to 2 cm. long; 3 to 20 percent biotite, in part altered to iron oxides; 0 to 5 percent hornblendes; and a total of about 1 percent sphene, zircon, and magnetite. Field relations west of the Lavic quadrangle lead Dibblee (1966) to consider the monzonite to be of Mesozoic age.

Dacite porphyry (Tdp)

Dacite porphyry of the Lava Bed Mountains borders the western part of the study area. It is in intrusive contact with the biotite quartz monzonite and has been the primary source of the gravels on the west side of the area. It is a gray-white to light-greenish-gray massive prophyry composed of euhedral and subhedral phenocrysts as large as 4 mm. In a microcrystalline groundmass, the phenocrysts, which make up 40 to 60 percent of the rock mass, are mostly plagioclase (oligoclase-andesine) with minor amounts of biotite, hornblende, and quartz (Dibblee, 1966). The gray-white groundmass is composed of plagioclase and potassic feldspar and traces of iron oxides. Emplacement of the porphyry as a large intrusive mass probably occurred during an early stage of Tertiary volcanic activity. Dibblee (1966) suggests the dacite porphyry is most likely of Oligocene or early Miocene age or possibly older.

Andesite breccia (Tab)

In the Peter's Mountain area, a sequence of volcanic and sedimentary rocks, probably as old as middle Tertiary, overlies the eroded biotite quartz monzonite. The descriptions of rocks within this sequence are largely those of Dibblee (1966) with additional comments by the author.

The oldest rock unit in this sequence is an andesite breccia, estimated to be about 250 feet thick. Gardner (1940) tentatively correlated it with the Red Mountain andesite. The unit is a flow breccia, massive to very crudely bedded, composed of light-pinkish to very dark reddish-brown unsorted angular fragments of andesite in andesite matrix. The andesite proper has phenocrysts as large as 4 mm. which make up from 20 to 50 percent of the rock and which are set in a microcrystalline to subvitreous groundmass. Most of the phenocrysts are white plagioclase (andesine?), but some are small plates of biotite, needles of hornblende, or rarely, quartz. The groundmass is mostly plagioclase with little or no potassic feldspar, and minor specks of iron oxide.

Tuff breccia (Tt)

Unconformably overlying the andesite breccia, in the NE 1/4, sec. 19 T. 7 N., R. 6 E., is a pinkish-tan to gray-white tuff breccia composed of small white fragments of devitrified pumice and small to large angular fragments of porphyritic to felstic andesitic rocks of Tertiary age in a matrix of fine- to coarse-grained tuff. The unit also contains some intercalated beds of tuffaceous sandstone and conglomerate with andesite and dacite porphyry detritus.

Fanglomerate of granitic detritus (Tfg)

A fanglomerate of granitic detritus covers the andesite and tuff breccias on the north, in secs. 17 and 18, T. 7 N., R. 6 E. On the eastern side of Peter's Mountain, the fanglomerate is medium tannish-gray, and is composed of unsorted, subangular boulders of quartz monzonite in an arkosic matrix. Desert varnish is common. The age of this fanglomerate is believed to be Oligocene or Miocene.

Basalt (Tb)

Above the fanglomerate stratigraphically, and perhaps also intercalated with and intruded into it, is a massive to thickly-layered basalt that caps Peter's Mountain and occurs as scattered outliers as far north as sec. 7, T. 7 N., R. 6 E. Sizeable basalt outcrops found east of the Pisgah flow are similar lithologically and stratigraphically to those on Peter's Mountain. Dibblee (1966) considers the eastern basalt flow to be slightly younger than those to the west, but because of their similarities, the author believes them to be the same unit. Basalt in both are olivine-bearing dark gray to black, vesicular, with differences that are common to any large flow or sequence of related flows. They differ from the younger Sunshine and Pisgah flows in being finely crystalline rather than significantly glassy in character.

The surface of basalt is generally devoid of sharp outcroppings and is commonly mantled by large angular blocks. The outcrops east of Lavic Lake appear to support more brushy vegetation than do those on the west.

Gardner (1940) tentatively correlated this basalt unit with the Black Mountain Basalt of Pliocene (?) and Pleistocene age. Dibblee (1966) believes that the western occurrences are probably either Oligocene or Miocene. There is no definite evidence for either opinion. However, the relationships of the later basalts with the Lavic Lake beds, which may in part represent Pleistocene pluvial deposits, suggest that the so-called Black Mountain Basalt correlative is significantly older than Pleistocene, probably Pliocene in age.

Claystone (QTc)

A light-reddish-brown to greenish-gray massive to bedded claystone is described by Dibblee and Bassett (1966) as outcropping about 3 miles west-northwest of Pisgah Crater. Interbedded with the clay is a 10-foot-thick cream-white, massive limestone and associated white bentonitic tuff. Dibblee and Bassett (1966) indicate a probable lacustrine origin for the beds which grade upward into an older gravel and fanglomerate unit. The age of the claystone is believed to be late Tertiary or Pleistocene.

Older fanglomerate and gravel (Qof)

A light tannish-gray fanglomerate and gravel overlies the fanglomerate of granitic detritus (Tfg) on the north side of Peter's

Mountain and also the Tertiary basalt to the south. A similar unit is found to the north and east of the Pisgah lava-field. In both occurrences, the unit is a mostly unstratified fanglomerate of poorly sorted cobbles and boulders in a coarse sandy matrix. In the western occurrence, it differs from the underlying fanglomerate (Tfg) primarily by being lighter in color and more easily eroded. At the other occurrences to the north and east, the source was to the east and the unit contains more fragments of volcanic rocks, including felsites, also Tertiary chert and jasper and Mesozoic granitic rocks.

In all occurrences, the unit is undergoing erosion. North of Pisgah Crater sections of the surface have been stripped of the fines by wind, leaving behind boulders and cobbles whose surfaces are coated with desert varnish. The varnish causes the surface to appear darker than most of the fresh rock surfaces.

The age of this unit is considered as Pleistocene by Dibblee (1966), but may be as old as Pliocene.

Fig. 2   Sunshine lava field viewed from Lavic Lake older flow on right.

Fig. 3   Pisgah fault scarp with tumulus development. Pick is on foot wall of fault that dips 55°SW.

Sunshine basalt flows (Qbs1 Qbs2 and Qps)

The Sunshine lava field, a major unit in the southwestern part of the study area, resulted from at least two periods of eruption. Flows related to each period are distinguishable (fig. 2). An older series of flows (Qbs_1) in the north end of the field were primarily erupted from a vent represented by a now faulted and eroded pumice cone in the center of sec. 30, T. 7 N., R. 6. E. The younger flows (Qbs_2) to the south issued from at least two vents: a partially buried cone in the NW 1/4 sec. 30, T. 7 N., R. 6 E. and the other, the slightly eroded Sunshine cone, in sec. 31 of the same township. Some fissure flows from the Pisgah fault may also have occurred at this time. The younger Sunshine basalt is found as far south as sec. 21, T. 6 N., R. 6 E. Much of the intervening area of flow, as in the northeast margin, is buried deeply by recent fanglomerate. The eastern edge of the lava field is buried under the Lavic Lake beds and fanglomerate, and the western margin is covered by fanglomerate from the Lava Bed Mountains.

The older basalt, which is dark gray to black on a fresh surface, is described by Wise (1966) as a porphyritic alkali-olivine basalt. Single phenocrysts, as well glomeroporphyritic clots of plagioclase and olivine occur in a groundmass of plagioclase, titanaugite, olivine, magnetite, ilmenite, and anorthoclase. Minor, but consistently present dark brown phenocrysts of titanaugite set these lavas apart from all others in the Pisgah area. Table 1 shows the modal analysis of this flow.

The original surface of the flow has been almost entirely removed by weathering and erosion and drainage is integrated. The flow surface is rubbly and the angular blocks of basalt have developed a smooth desert varnish. A product of weathering is a ubiquitous coating of calcium carbonate on joint planes and in local minor depressions. This appears to account in part at least, for the relatively lighter tone of the unit on aerial photographs.

The younger basalt is also a dark gray to black vesicular alkali-olivine basalt. Wise (1966) states that "scattered phenocrysts (3-5 mm.) occur in a groundmass of plagioclase, titanaugite, olivine, magnetite, ilmenite, and anorthoclase." He notes that plagioclase phenocrysts are very rare to absent in the area of the test strip although they are abundant in a later flow on the southern end of the lava field. Modes are shown in Table 1.

The original surface features of the younger series of flows are only partially dulled by weathering and erosion. Numerous depressions still exist that have developed into small carbonate and silt playas as large as 100 feet across. Calcium carbonate is also prominent along joint planes as in the older Sunshine flows.

The difference in surface erosion between the two units that make up the Sunshine lava field appears to indicate that a significant amount of time had elapsed between the two major eruptive periods.

The three recognized pumice cones associated with the Sunshine flows are all similar in their character and are considered as one lithologic map unit of basalt pumice (Qps). They are described by Dibble (1966) as brownish-black scoriaceous basalt composed of basaltic glass. The faulted cone related to the earlier flow period has been noticeably dissected by erosion and its pumiceous materials has been carried downslope to form an epiclastic alluvium of pebble-cobble scoria and basaltic detritus (Qpa) in the NE 1/4 sec. 30, T. 7 N., R. 6 E. The cone to the west of the fault is partially buried by fanglomerate from the Lava Bed Mountains and by

TABLE

Table 1 - Modal Analyses of Sunshine and Pisgah basalts
by: W. S. Wise

Mineral	Sunshine Lavas		Pisgah Lavas			
	First Flows 1/	Second Flows 2/	First Flows 3/	Second Flows 3/	Second Flows 4/	Third Flows 4/
					p-2	p-1
Olivine						
Phenocrysts	5.0	4.3	7.0	6.1	3.5	1.5
Groundmass	5.7	5.4	5.7	5.2	2.2	2.8
Plagioclase						
Phenocrysts	7.2	1.1	1.5	3.0	2.8	4.4
Groundmass	17.9	22.7	22.6	16.9	11.9	12.2
Clinopyroxene						
Phenocrysts	0.3	0.0	0.1	0.0	0.0	0.2
Groundmass	19.2	14.3	20.5	15.2	3.7	0.6
Alkali feldspar	10.6	4.1	4.0	2.3	0.7	12.2
Opaques	15.0	14.3	11.7	11.6	tr	tr
Apatite	4.1	1.5	3.6	2.1	tr	tr
Glass	tr	10.1	4.6	24.0	41.9	48.4
Voids	14.7	22.2	18.6	13.3	34.0	30.0

1/ and 2/ Both samples from flows in center of test strip near shore of Lavic Lake, ne 1/4 sec. 29. Each an avg. of 7 2000 point counts.

3/ These two samples were collected in center of main test strip also near Lavic Lake, w. side of sec. 20. Each an avg. of 4 2000 point counts.

4/ These two samples are from 1/4 mi south of Pisgah cone. Each an avg. of 8 2000 point counts.

Note the importance of the degree of crystallization in comparing these modal analyses. The two samples from near the cinder cones are at least 75% glass and bubbles, while those collected from the end of the flows at Lavic Lake are more completely crystallized.

a flow that possibly emanated from its vent. The Sunshine cone is cut by drainage rills 2 to 15 feet deep, but it essentially retains its original shape. Its topography suggests that an earlier pyroclastic stage may have occurred. Gardner (1940) notes that a small playa about 80 feet in diameter occurs in the center of the crater. In this respect it is similar to most other cones that characteristically contain substantial amounts of silt and weathering products, especially calcium carbonate, sifted down just below their surface.

Dibble (1966) presumes a Pleistocene age for the Sunshine basalt eruption.

Pisgah basalt flows (Qb_1, Qb_2, Qb_3, and Qpb)

The Pisgah lava eruption, as described by Wise (1966), took place in at least three distinct phases. His thesis is based solely upon the texture of the phenocryst minerals in each phase.

The first eruptive phase of the basalt (Qb_1) is believed to have begun with the building of a cinder cone in the low hill area north of the main cone and the issuance of lava from vents near the cone. Flows extended as far as the Lavic basin, about 1/2 miles to the north, and 7 miles to the west-north west in the present vicinity of U. S. Route 66.

The flow is cut by the Pisgah fault at the highway, where small tumuli are spaced quite regularly along the fault (fig. 3). The uniformly limited development of the tumuli suggests that their source was from below a congealed lava crust that ruptured during fault movement and not from along fault conduits below the effusive. The relations indicate that the Pisgah fault was active at this time as does the topography, which controlled the movement of all the Pisgah flows.

There is a possibility that the younger Sunshine flow was nearly contemporaneous with the initial Pisgah eruption since it has the same preserved surface appearance, and its direction of flow was controlled by the fault and the developing Lavic basin. The older Sunshine flow is too eroded and weathered to be considered anything but older than the first Pisgah phase.

The lavas of the first eruptive phase are composed of blocky pahoehoe and less commonly, aa type flows (figs. 4 and 5). Wise (ibid) finds the flows to be a microporphyritic alkali-olivine basalt. Microphenocrysts of olivine (less than 2mm.) are scattered and rare. The groundmass minerals are olivine plagioclase, titanaugite, magnetite, and ilmenite. Basic glass is also a common constituent in the groundmass. (see Table 1). The surface of the flows commonly have the slight lustre of desert varnish which form a tan-colored material that is a noticeable coating on fractures and at the base of spall sheets that are common on the pahoehoe. All types of flows are highly vesicular, indicating a substantial volatile or gas content during the magmatic stage. The vesicles, which make up to one-third of the volume, now contain a mixture of weathered products such as clay, carbonate, and ferrous oxides.

The second eruptive phase (Qb_2) began after a long period of quiescence; lava issued from at least 2 separate conduits. One conduit built a cinder cone close to the present cone and a second conduit domed the earlier flow unit about 2,500 feet south-southeast of the Pisgah crater and poured forth a voluminous amount of lava from around the dome base. Several small possible conduits are found scattered to the east and south of the Pisgah cone (pl. 2). However, they may represent breaches in the solidified crust that allowed lava to be issued under a magmatostatic head from a subcrustal lava passage.

Lava from the second phase reached into the Lavic basin and again flowed northwestward toward the highway along drainage developed west of the first flow. The lava first overflowed the drainage then settled as

Fig. 4 Typical pahoehoe surface of first Pisgah basalt flow (Qb_1) flow at station 66-3 near Lavic Lake. Thermistor is attached for monitoring temperature. Note windblown silt.

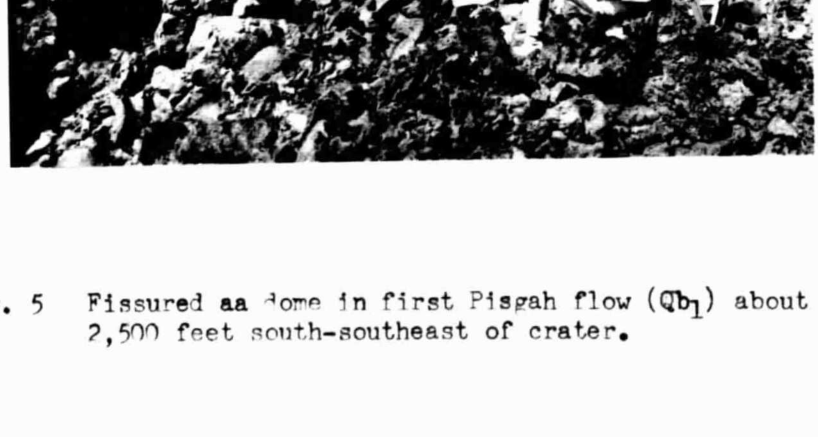

Fig. 5 Fissured aa dome in first Pisgah flow (Qb_1) about 2,500 feet south-southeast of crater.

it continued downstream, leaving prominent ridges of solidified lava crust along its margins. These and other levee-like pressure ridges formed by the pulsating flood crests of lava are accentuated by alluvial fan detrial deposited later in the troughs. A considerable part of this flow is believed to be buried by the alluvial fan in this area.

The lava of this phase is largely aa (fig. 6), but pahoehoe surfaces are found on most of the long westward part of the flow.

Lava tubes developed near the south end of the dome conduit close to the end of the flow period. Subsequent partial collapse of the roof occurred after drainage of the subcrustal lava.

The second flow is a black porphyritic alaki-olivine basalt with larger olivine (2-3mm) and plagioclase (2-5mm) phenocrysts than the first flow. The groundmass minerals whose modes are shown in table 1, are the same as those found in the earlier phase. Basic glass makes up over 40 percent of the flow near the cone and only 24 percent in the Lavic Lake area.

The third and probably final period of basalt flow (Qb_3) occurred from two separate points. The present Pisgah cinder cone in NW 1/4 sec. 32, T. 8 N., R. 6 E. formed at this time and lava issued from a vent or vents at its base on the southeast side. The lavas from the vents, restricted by the previous flows, moved westward about 4 miles, southeastward 3 miles, and northward only 2 miles.

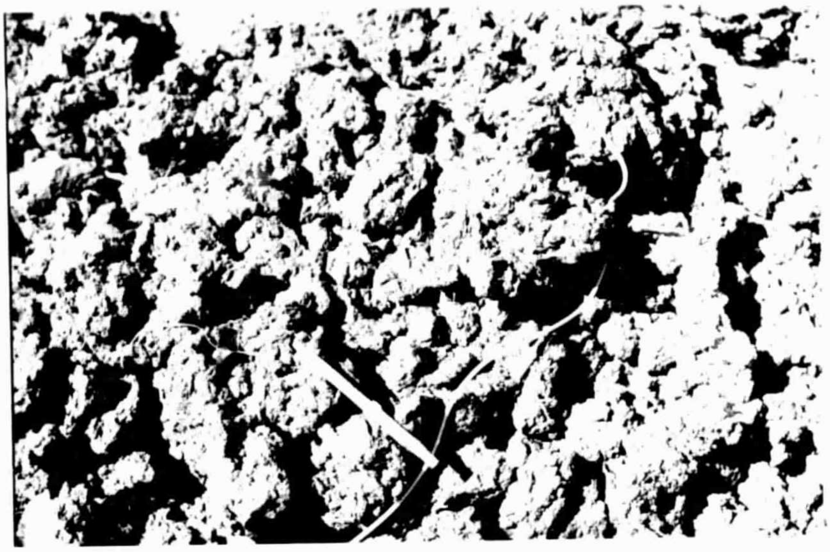

Fig. 6 Typical aa surface of second Pisgah basalt flow (Qb_2) at station 66-3 near Lavic Lake. The extremely rough surface illustrates difficulty in placing thermistors to obtain representative temperatures.

Fig. 7 View of collapsed lava tubes in pahoehoe basalt of third Pisgah flow (Qb_3). Aa of second flow in background.

Pahoehoe-type lava covers almost the entire surface of the flow, but pressure ridges and resulting blocky surfaces are quite common. The flow is cut on the west by the Pisgah fault, with tumuli again developed along the fault in the same manner as in the first flow. The southwest margin has several ridges thrust up and accentuated by fan material as in the second flow. Lava tubes developed on the margins of Pisgah Crater which subsequently collapsed over much of their lengths (fig. 7). One tube on the eastern side of the crater is over 2,000 feet long where exposed by roof collapse.

The alkali-olivine basalt has plagioclase phenocrysts generally larger than 10 mm. in length and clots of olivine crystals about 5-6 mm. across, which serve to distinguish these flows from the earlier one. However, the overall groundmass mineralogy is similar. Table 1 give modal analyses respectively, for grid samples taken 1300 feet southwest of Pisgah Crater.

All Pisgah lavas on the northern and western sides of the area are covered with substantial amounts of windblown sand and silt carried by prevailing westerlies from the alluvial fans and Troy Dry Lake to the east. The smoother pahoehoe basalts are covered by greater amounts because saltation is easier across its surface.

The Pisgah cone (Qbp), which crowns the highest part of the lava field, is built up of fragments and lapilli of brownish-black to dark reddish-gray scoriaceous basaltic glass or pumice (fig. 8). Older cinder cones, probably related to the earlier eruptions on the north side of the crater, are dark reddish gray, have been covered in greater part by the last eruption and are strongly eroded where exposed. However, the most recent cone has a

Fig. 8 Interior view of Pisgah cone. Crater is floored with typical pahoehoe basalt.

Fig. 9 Road cut in slope of Pisgah cone showing surface and buried silty horizons.

relatively fresh appearance. Road cuts in the flank of the crater expose thin silty horizons, both buried and near the surface, that may be due to windblown material and in situ weathering (fig. 9). The center of the crater is floored with typical pahoehoe-type basalt (fig. 8). There are no indications that the basalt ever reached the rim of the crater during eruption.

The top edge of the crater has loose scoria and pumice ranging in size from pebbles to small boulders. The average size is about that of small cobbles (64 mm.). The flanks of the cone are covered with larger fragments, mostly in the small boulder size (256 mm.). Volcanic bombs with the typical spindle shape are rare. The interior slope of the crater has a same size and type of material as the rim, but also has occasional small boulders and vesicular basalt.

The surface of the cone, which slopes between 25 to 30 degrees, is free of vegetation. The pahoehoe surfaces generally have scattered sage and other brushy vegetation.

The ages of the Pisgah flows and pyroclastics are believed by Dibblee (1966) to be Pleistocene and/or Recent.

<u>Alluvium of basaltic pumice and/or detritus</u> (Qpa)

Minor erosion of the pumice cones associated with the Sunshine and Pisgah flows caused the local transport and deposition of pyroclastics and other basaltic detritus. Because of their similar characteristics and continuing minor movement they are recognized as a single formation. The age of this alluvium ranges from Pleistocene to Recent.

Playa deposits (Qp)

The most extensive playa deposits are those of Lavic Dry Lake. Other deposits of limited extent are found on the surface and along the margins of the Sunshine and Pisgah flows.

The Lavic playa surface is classified as a hard, dry, compact floor type, composed essentially of densely-packed, fine-grained argillic materials, that are ordinarily only slightly penetrated by precipitation (Kerr and Langer, 1965). The same authors give the following estimates of the gross mineralogic character: 79 percent clay, 21 percent granular components, 0.2 percent accessory minerals, and a trace of saline minerals. The clays are montmorillonite and illite. The granular components are predominantly quartz and feldspar, but also include hornblende, chlorite, epidote, clinopyroxene, actinolite, biotite, muscovite, sericite, vermiculite (?), zircon, magnetite, tourmaline, and rock fragments. Saline minerals, surprisingly meager in amount, are halite, sylvite, and carbonate. Although halite is considered dominant by Kerr and Langer (ibid.) calcium carbonate is obvious by its effervescence when specimens of the lake surface are treated with dilute acid.

The lake bed has a characteristic development of giant polygonal dessication cracks over most of its surface. These cracks are measurable in hundreds of feet. Because of infilling, the cracks show very little depth and are not noticeable everywhere on the ground because of their variable degree of development. Near the margins of the lake bed brushy vegetation has taken root in the moisture afforded at depth by many of the cracks. However, a younger unvegetated set of cracks appears to have developed that are outlined by moist stripes of sediment (fig. 10). Typical mudcrack polygons are ubiquitous, but are not as permanent as the giant polygons, which owe their existence to desiccation at depth over a long period of time.

Development of small ephemeral polygons is variable over the lake bed. Adjacent to the south margin of the Pisgah flow the silty clay appears more desiccated, forming major irregular polygons averaging 10 inches across and cracks at least than 6 inches deep (fig. 11). Small subordinate polygons are developed within these major polygons. A flat mosaic of weakly developed polygons up to 6 inches across whose edges were somewhat wind eroded were found toward the center of the lake bed during one early visit to the area. Extremely flaky crust, affecting several layers and producing pottery-like shards was also found on the northwest margin of the lake bed during an early visit.

Three days prior to the August 1966 survey the eastern margin of the lake had been moistened by rainfall running off the Bullion Mountains that produced a few small puddles in vehicle tracks and softened the playa. The open water disappeared before the aerial survey was made, but the eastern margin of the playa remained moist.

Lavic Lake was, in its lower part at least, contemporaneous with the Pisgah flows. A basin toward which the lavas flowed was in existence in this area. A lava dam apparently formed at that time, which has continued through present time and provided a closed depositional basin. The age of beds in this basin probably ranges from late Pleistocene through Recent.

Fig. 10 Typical moisture stripe boundary of giant dessication polygon in Lavic Lake near center, section 27.

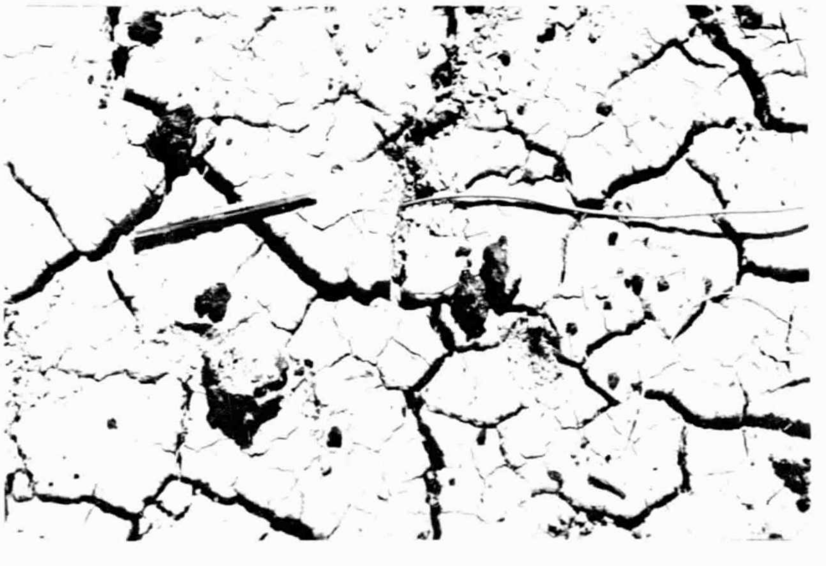

Fig. 11 Dessication cracks in Lavic playa next to Pisgah flow at station 66-2. Note surface and subsurface placement of thermistors.

Older alluvium (Qoa)

An earlier phase of Quaternary alluvium is exposed and has eroded and in some places re-covered by recent detritus. It consists mostly of massive to crudely bedded fanglomerate and gravel of unsorted fragments from pre-existing detritus and from volcanics on Peter's Mountain. It differs from other Quaternary alluvium in the vicinity by being very weakly consolidated, by having a light desert varnish that gives it a darker tone, and by supporting slightly more vegetation.

Basaltic gravel mosaic (Qbg)

At the north end of the Lavic lake bed a mosaic of angular aa and blocky basalt cobbles and pebbles is found on the lake sediments. The limited size of the fragments and their location above a buried flow suggest that they originated by vertical ice rafting during periods of winter flooding in the lake. The surface of the mosaic is quite variable in development.

The age of the mosaic is probably Recent.

Alluvium (Qa)

The most recent sediments are widespread detrital materials at lower elevations that range in size from cobble gravel through pebbly coarse sand to sand and silt. Its heterogeneity is a function of its multiple sources. However, local extremes in detrital composition result in nearly distinct alluvium sub-units.

Structure

Faults

The Pisgah fault, a major fracture zone, is the dominant structural feature of the area. It extends along the western boundary of the area and strikes N. 22° W. near Sunshine Cone, but gradually curves to about N. 40° W. near U. S. Route 66 on the northwest where it passes under alluvium (See Plate 2). It continues south-southeast from the Sunshine flows, where it is covered by a large alluvial fan and then reappears in the Bullion Mountains where it becomes an echelon with the Bullion Mountain fault before dying out. A dextral en echelon discontinuity appears also to be developed near Route 66, with a 0.2 mile offset of the fault trace.

Near the north end of the Sunshine lava field in the center of sec. 30, T. 7 N., R. 6 E., the fault was observed to be essentially vertical without any local indication of relative movement direction. To the south-southeast where it cuts the main body of lava it is splayed and highly irregular. The east wall is downdropped about 250 feet and the structure appears to be a faulted monocline. The fault at depth here is probably vertical, but the fractures in the flows tended to splay and propagate upward in the direction of the downthrown block (Hills, 1963). There is a possibility that the lava flowed over the developing fault at an early stage, but the relatively steep repose angle of the original second lava flow surface strongly suggests that deformation was primarily responsible for the present topographic situation. In this vicinity an apparent right lateral displacement of the contact between the older and younger Sunshine flows and of the drainage across the younger flow suggests that the same stresses were present as in the San Andreas fault system far to the west. A post-early Sunshine eruption dextral movement of 0.5 mile is indicated by displacement of the faulted cone. This vector is also implied by the fracture pattern on the younger flow. (See Plate 2).

At the southern end of Peter's Mountain a small graben is associated with the fault and the southwestern side of the fault becomes relatively displaced downward. Where the fault cuts the Pisgah flows to the northwest the relative displacement is reversed twice more.

The Pisgah fault was active during part of the periods of eruption, at least, of the Sunshine and Pisgah flows. This is indicated by marked faulting of a cone and associated lavas of the first sequence of Sunshine flows and by minor faulting of the first and third Pisgah flows with the development of tumuli before final cooling of both flows. The deflection of the first and second Pisgah flows around the base of Peter's Mountain on the southeastern margin of the lava field indicates that most of the deformation had occurred prior to Pisgah time.

On the east side of Peter's Mountain a topographic scarp and associated slickensides denotes a vertical generally north-trending fault, the Peter's Mountain fault, that probably extends from under the north margin of the Sunshine basalt northward to beneath the Pisgah flows. Slickensides on the fault plunge 50° due N., indicating both lateral and vertical components of displacement during last movement.

Between the Peter's Mountain fault and the Pisgah fault the Tertiary volcanics and gravels are severely cut by numerous short faults of generally high angle and limited displacement. One of these faults, which intercepts the Pisgah fault, also cuts the older Sunshine flow. Many more faults exist in this area than are shown on the map.

Two noticeable faults are found north of the Pisgah lavas. These strike about N. 10° W., appear to be relatively down-thrown on the east side, and probably dip east at a moderately steep angle. Other minor faults in this vicinity have been found in clay quarries by Dibblee (1966).

Wise (1966) has mapped a fissure-like fault, approximately one mile in length in the southern part of the youngest Pisgah flow, that strikes north-northwestward and has a downthrown southwest wall (See plate 2). Dextral en echelon offsets suggest that a weak right lateral component of strain was present. Movement along the fault, as expressed in the basalt, has been negligible, and it could represent cauldron subsidence governed in its direction by regional stress or, more likely, differential movement of lava below a solidified crust.

Folds

Aside from the monoclinal fold on the Sunshine lava described in the foregoing section there is little other folding present. Dibblee (1966) has mapped dips that suggest the presence of a gentle northwest-trending closed anticline underneath a mask of alluvium in secs. 23 and 26, T. 8 N., R. 5. E. which would be about one mile long in surface expression (See Dibblee, 1966, map). Other dips in the area suggest that other minor fold structures are present, but incomplete outcrops and scale considerations prevent their delineation on plate 2. This deformation in the older Quaternary sediments is not reflected in the Pisgah flows.

INSTRUMENTATION

Aerial infrared surveys were flown using airborne scanning radiometers which, with appropriate bandpass filters, were sensitive to the 4.5-5.5 micron (μ) and 8-14 μ regions of the electromagnetic spectrum. Both wavelength bands coincide with transmission "windows" in the atmosphere.

The latter band corresponds with the region of maximum earth emission for normal surface temperatures. Fischer and others (1964) summarize the basic infrared scanning technique as used in the Pisgah study.

An AN/AAS-5 infrared scanner was used with a dielectric filter to obtain imagery in the 4.5 to 5.5 μ band during the February 1965 survey. The detector, an InSb intrinsic photoconductor, was cooled with liquid nitrogen. The field of view of the scanner was limited to 80 degrees due to a two channel scanning mirror system configuration. The second channel recorded the visible spectrum by means of a photomultiplier.

Imagery in the 8-14 μ band was obtained with an HRB-Singer scanning radiometer during the February 1965 and the August 1966 surveys. The detector used in this instrument was a GE:Hg extrinsic photoconductor cooled by a helium-charged closed-cycle refrigeration system and filtered to receive only the 8-14 μ radiation.

Infrared imagery was acquired at 4 hour intervals to observe the changes in relative apparent temperature of the various terrain units in a diurnal cycle. Because of detector problems in both scanners and a noisy power supply during the initial February 1965 survey by the NASA aircraft the imagery from that flight for the most part was unusable. However, the 8-14 μ imagery obtained during the August 1966 mission by the Geological Survey was, in general, satisfactory. Noticeable distortion due to incorrect V/H ratio setting was insufficient to detract from the value of the imagery.

Ideally, it would have been preferable to record the detector signal on tape for later printing on film. The tape recording technique preserves a dynamic range approximately 7 times that directly printed on film. (W. A. Fischer, oral communication, 1965). Under normal terrain temperature ranges, as at Pisgah all contrasts could have been recovered through the laboratory printout of the tape signal, though the complete range may not have been within the gray scale of the film on which the imagery was printed. Further, direct recording on film is susceptible to exposure variations during the survey, and in film processing.

INTERPRETATION OF THE INFRARED IMAGERY

Infrared imagery in the 8-14μ band was flown August 4-5, 1966 over 3 flight lines (plate 1) commencing about 2000, August 4th and at approximately 4 hour intervals thereafter, covering a complete diurnal cycle. The v/h setting of the scanner was set too low for all flights, but it does not significantly affect the geological interpretation. One result is an exaggerated longitudinal scale in relation to the lateral scale. Because of this distortion, no attempt was made to provide a general scale. Geographical locations can be obtained by viewing the geologic map photomosaic (pl. 2) and/or the location map (pl. 1).

An examination of the imagery shown on plates 3, 4, and 5 shows that the midnight and pre-sunrise images are essentially the same with slightly more contrast available on the midnight image. The midday images, obtained under maximum solar heating conditions, show the most textural contrast within the basaltic flows, while the post-sunset images provide the greatest contrast between basalt bedrock and the alluvial formations. Differential heating of eastern and western slopes due to low sun angles is noticeable on the post-sunrise morning and pre-sunset afternoon images respectively.

Imagery of flight line 1 which covered the main area of study, including Pisgah crater, its flows to the south, and Lavic dry lake, is shown on plate 3. Boundaries between the different types of basalt surfaces, which correspond in places to the separately mapped flow units, are noticeable to some degree on all of the flights. Examples of the contrasts between the first, second, and third Pisgah flows are best shown on the 2010, 0827, and 1202 flight images. These flows are labeled 1, 2, and 3 respectively on plate 3. On the 2010 image, the contrast is due more to textural than to tonal (thermal) differences between the flows with small playa pockets in the third flow providing the texture. The term "texture" is used here in its photo interpretation sense, and as defined by Colwell (1952, p. 538), is "the frequency of tone change within the images." Flow 2 is slightly warmer than flow 3 at 2010, but the reverse is tone at 0827 and 1202 where thermal contrast is dominant. A probable explanation of this phenomenon is that solar radiation during the day is not reflected from the aa to the extent that it is on the pahoehoe because of its roughness and somewhat darker color, thus causing the absorption of more solar photons and consequently greater heating. The cavernous structure of the rough aa also makes it behave more like a black body, but it also causes heating of the rock to a greater depth because of its larger integral surface area. The pahoehoe, on the other hand, has a smoother, lighter, and consequently more reflective surface which would tend to absorb less radiation and restrict that heat absorbed to a shallower depth. This would account for the higher radiant temperature of the pahoehoe during periods of illumination as shown during the 0827, 1202, and 1616 flights (plate 3).

Because the aa and pahoehoe textures are not restricted entirely to individual flow units and blocky intergradations are common between the two types of textures, the units cannot be entirely delineated. Where two different flow units are adjacent and have the same surface texture it is not possible to differentiate them on the imagery. The minor differences in mineral composition and degree of crystallinity between the units is alone insufficient to produce significant variations in thermal parameters. Surface texture of the lava, which is primarily a function of the temperature of extrusion, would cause changes that would override or mask any changes brought about by differences in composition. The large scale secondary texture resulting from the presence of detrital-filled collapse structures on the dominantly pahoehoe crust of the first flow is a strong differentiating feature, especially on imagery that shows the greatest contrast between bedrock and detritus.

The Pisgah cone (p in plate 3), which is composed of scoriaceous basaltic glass and pumice, shows to advantage on the 2010 image, soon after sunset. The fragmented, porous pyroclastic material acts as an insulator and cannot conduct the solar heat input much below the immediate surface. As a consequence, the thermal input is concentrated at the surface and its radiant temperature is the highest of all the terrain units as seen in the mid-day (1202) image. As soon as the solar illumination is removed at sunset the high radiance disequilibrium between the pumice and the cold sky causes the former to cool very rapidly. The insulating property of the material and its small mass prevented it from becoming a heat sink of any consequence in comparison with the surrounding basaltic flows which have a decidedly higher thermal inertia. The diurnal radiant temperature variation relationship between the scoriaceous pumice and the pahoehoe as shown on the imagery coincides with the relationships established with ground-based radiometers. At 1202, the radiant temperature of the pumice was recorded at 61°C and the nearby pahoehoe of flow 3 was 54°C, a difference of 7°C. Prior to sunrise at 0418, the radiant temperature of the pumice was 23°C and the basalt was warmer at 26°C, a difference of only 3°C.

The thin alluvial wash of pumice immediately southeast of the Pisgah cone (Qpa on pl. 2 and a on pl. 3 images) reacts thermally in the same manner as its source material. Its presence is not readily apparent on conventional photography, but its thermal contrast is easily seen on the imagery.

The partially collapsed lava tube located immediately east of the Pisgah cone (t in pl. 3 and fig. 7) remains warm and is noticeable on the imagery flown between sunset and sunrise, (2010, 0046, and 0418). The depressions formed by the collapsed roof act somewhat as a black body cavity where radiation is exchanged between the walls, retaining the heat longer before ultimately radiating it out to the cold sky. The alignment of the partially exposed tube is easily delineated on the infrared image, whereas it is unnoticeable on conventional photography of the same scale. During the daytime flights (0827, 1202, and 1616), the collapsed portions are observable due to their cool rim shadows. The same diurnal relationships hold for the deeply fissured area about 0.5 mile south-southeast of the cone (f in pl. 3).

A roughly circular area, distorted to an oval-shape, is centered at c on the images of plate 3. Its outline is best seen on the 2010, 0827, and 1202 flights and it is characterized by a cooler rim on the first flight and a warmer rim on the latter two flights. The northwest margin is defined by several small vents and the remaining margin by pressure ridges and surface differences in the basalt. This feature, which is not noticeable on conventional photography, may represent a minor subsidence area over an abnormally thick portion of the second Pisgah flow.

The effects of wind-blown sand and silt on the basalt north of Pisgah crater is noticeable only on the nocturnal imagery (s in pl. 3; 2010, 0046, and 0418 flights). Enough wind-blown material mantled the basalt to significantly lower its albedo during the period of solar heating. As a result, the area is much cooler than the surrounding unmantled basalt. A wind-scoured area on the older fanglomerate and gravel to the northwest of this area (v on the 2010 image, pl. 3) shows up warmer on the nocturnal imagery because the residual coarser material left behind as a result of deflation has a higher thermal inertia, that is, a better capability to store solar heat. Its darker color, due to a slight desert varnish in comparison to the normal fanglomerate surface, lowered its albedo during the day which also resulted in greater heating during the day. On the midday image (v on 1202 image, pl 3), this same area is slightly cooler than the normal surface, presumably because of its ability to absorb solar heat in the coarser residual fractions of the gravel.

The tertiary basalt on the east side of the Pisgah lava field (b on 2010 image, pl. 3) reacts thermally in the same general manner as the Pisgah basalt throughout the diurnal cycle. The original surface has been eroded and the present surface is smoothed due to weathering rubble which serves to distinguish this formation from the Pisgah lavas. As with the Pisgah flows, it is best differentiated from the enclosing gravel formation and recent alluvium on the 2010 image (pl. 3).

Lavic dry lake (L in images of pl. 3) exhibits much more detail on the infrared imagery than on conventional photography, especially when the latter is optimally exposed for all terrain features. All images show evidence of crude zoning in the lake bed. There is a cool, fairly well defined margin that extends discontinuously northward along the basalt-fan contrast to the neck of the Pisgah lava field. A slightly warmer interior zone, which is restricted to the lake bed proper, includes an ill-defined area characterized by a warm reticulate pattern.

The east side of lake bed, which is especially cool, was muddy and very moist from a recent desert rainstorm. Because of the remoteness of the Pisgah area, no local data are available on the occurrence of precipitation. However, it appears that a heavy rain fell about 3 days prior to the survey to the east of the Pisgah area in the Bullion Mountains. The moist braided channels on the fan carried the run-off to the Lavic basin, and the lake bed margin, with its high silt and fine sand content, appears to have absorbed this run-off before it encroached the less permeable clay-rich interior.

The extremely cool nature of the eastern lake margin is a function of many conditions including the recency of the rainfall that provided the moisture, the high degree of saturation which results in a high heat capacity and conductivity, and the dissipation of solar heat by the latent heat of vaporization of the water. The high saturation and darker color therefrom causes the eastern margin to become a heat sink, but the latent heat of vaporization of the moisture prevents the surface from heating as much as the drier parts of the playa during the period of insolation. As a result, it remains the coolest terrain in area throughout the diurnal cycle. The other margins of the playa are only slightly warmer than the eastern margin, but generally cooler than the interior zone. This remaining portion of the perimeter zone may be thermally affected by ground water entering the playa beds from the bordering alluvial fans. The general absence of a cooler margin along the Pisgah flows appears to support this hypothesis.

The slightly warm reticulate pattern (d in pl. 3) is visible against a cooler background to a highly varying degree in all images from flight lines 1 (pl. 3) and 2 (pl. 4). The relatively warm lines that make up the net like pattern are very slightly moist stripes that form the boundaries of giant desiccation polygons (fig. 10). Their darker color due to their slight moist condition provides a lower albedo for greater heating during the day. The minor moisture, which may be in whole or part hygroscopic and/or intermolecular, is probably insufficient and/or too inefficient to reduce solar heating by vaporization. Its effect of lowering the albedo therefore appears dominant in this case. Near the southern margin (v on 1202 image, pl. 3) dry brushy vegetation and associated dry phreatophyte mounds are aligned along many of the polygon boundaries. The dark color of the vegetation and dryness of the underlying mounds combine to produce a target warmer than the background at midday (1202, pl. 3).

The cool background to the polygonal pattern appears anomalous, but the playa in this area consists primarily of tannish-white, well-compacted clay which would expect to be, from albedo and moisture considerations, cooler than the stripes. The other warmer portions of the interior zone may reflect the thermal behavior of a puffy and/or shard-like mud-cracked surface found on much of the playa bed.

It might be expected that thermal behavior of the lake sediments would change radically with a significant change in the amount and distribution of contained moisture on the surface and with depth; and with the mineralogy, grain size and distribution of the medium holding the moisture, which in turn would control its albedo, the manner the moisture is held, and its rate of release. The presence of salts concentrated by evaporation and the retention of intermolecular water in certain clay minerals would have a further modifying effect. With all of these possible physical variables it is not surprising to find complex thermal patterns on the imagery of Lavic dry lake through the diurnal cycle. It would also hold that seasonal variations in these patterns would be commonplace due to these factors and to the changes of the surface by the development of mud crack plates by extreme desiccation. The effects of moisture require further detailed study because the degree of saturation governs the heat capacity, thermal conductivity, and affects the albedo of porous terrain.

On the north side of the lake bed, the basaltic gravel mosaic (g on 0046 image, pl. 3) stands out on the nocturnal images with a warm rim surrounding a generally cooler interior. During the day, it acts thermally in same manner as the Pisgah basalt to the north. The gravel, which consists of angular to subangular cobbles and pebbles of vesicular basalt, is spread unevenly on the playa surface and appears to overlie a buried flow a few inches to several feet below the surface. The gravel is buried in or covered slightly at the margin which coincides with the thermally anomalous rim. The high temperature of the basaltic gravel is ex- cted during the day because of its low albedo, but its intimate association with the playa sediments prevents significant development of thermal inertia of the unit and like the cone material, whose thermal content is limited to the surface, it cools rapidly after sunset. The warm rim on the night images appears to be the result of a higher thermal inertia of that portion of the unit. The buried gravel at the margin presumably would give off its heat more slowly because it has to pass through a finite amount of playa sediment.

Flight line 2 imagery (pl. 4) which covers a short segment of the area originally outlined for detailed study (pl. 1), duplicates some of the area previously discussed and contains some features better viewed on flight line 3 imagery (pl. 5). However, it does offer a good comparison of the alluvial fans on the east and west sides of the Lavic playa and a reiteration of some features discussed under flight lines 1 and 3.

The alluvial fan on the east side of the Lavic playa (f on 1210, pl. 4) exhibits on all images of flight line 2 the braided channels that were active during the recent precipitation in the Bullion Mountains. The strongest contrast of the moist channels against the dry fan background is seen, as expected, on the 1210 image. While these channels are also visible on conventional photography it is believed that the contrast would remain longer on the infrared imagery as the channels slowly dried up.

The fan between the Pisgah and Sunshine flows to the west of the playa shows no evidence of recent run-off as the eastern alluvial fan does. However, on daytime images (0836, 1210, and 1624, pl. 4), there is an apparent thermal contrast between that segment of the fan that borders the Sunshine flow and that bordering the Pisgah flow. The southern segment of the fan, which appears slightly darker from the air, derives most of its detritus from the nearby outcrops of basalt, andesite, and other bedrock on the south side of Peter's Mountain (see plates 1 and 2). The remaining nothern segment of the fan has as its predominant source the older fanglomeratic gravels on the northeastern part of Peter's Mountain. These gravels provided finer detrital for the northern part of the fan than the bedrock source did for the southern part. This difference is manifested by thermal contrast on the imagery, with the slightly coarser southern segment of the fan appearing a little cooler during the day because the larger average gravel size enables it to absorb the solar heat to a slightly greater depth. That this effect is minor is shown by the lack of reverse contrast on the nighttime images. Apparently, the slightly darker color of the southern fan segment did not sufficiently lower its albedo to override the thermal effect brought about by the difference in gravel size.

Along the contact between the Pisgah lava field and the alluvial fan a cool drainage channel is visible on the daytime images (m on 1210, pl. 4). It appears to have its origin where the foot of the fan meets the lava field isthmus. This suggests that ground water may be dammed at this point and that enough moisture is present just below the surface to provide a daytime thermal contrast.

Flight line 3 is centered on the Pisgah fault, about 3 miles to the southwest and parallel to flight line 1. (See plate 1). Imagery from flight line 3, shown on plate 5, covers a small part of the area on the east flank of the Sunshine lava field that was originally chosen for detailed study. The line was flown to obtain information on the expression of the fault on the imagery and on the thermal behavior of rock types in this part of the area. Withe the exception of the last flight at 1609, which had shadows of a few scattered clouds (c on 1609, pl. 5), the imagery is free of such natural detractions. The electronic deficiencies present on the north ends of the 0815 and 1155 images (pl. 5) necessitated a shortening of the interpreted portion of the flight line.

The Sunshine lava flow sequences, shown as 1 and 2 on the flight line 3 imagery of plate 5, may be differentiated to some degree on most of the images. However, the best contrast, resulting from the differences in the degree of surface uniformity between the flows, is seen on the midday imagery (1155 on pl. 5). This effect is slightly noticeable on the 0815 image also. On the nocturnal imagery the main difference between the first and second flow sequences appears to be that a warm veining of drainage is noticeable on the former, but is somewhat obscured by background in the latter.

The basalt pumice of Sunshine cone (southernmost p on 2003 image, pl.5) and of the other cones associated with the Sunshine flows behaves thermally in the same manner as the pumice of Pisgah Crater. The alluvial pumice from these cones and other basaltic detrital (a on the images of pl. 5) is easily delineated on the nocturnal imagery as similar materials was on flight line 1 (pl. 3).

The northernmost pumice found in place in the Sunshine lava field (p on west side, 2003, pl. 5) was found to be the western half of the faulted cone found displaced one-half mile to the south on the east side of the Pisgah fault. This outcrop is very difficult to determine on aerial photographs, but is easily discerned on the nocturnal imagery.

The Pisgah fault (Pf on 2003, pl. 5) shows on the early morning imagery (0041 and 0414, pl. 5) as a relatively warm network of fine lines in detail not observable on photography. The warm nature of the fault zone appears to be due to large rubble-lined crevices and, in many places to blocky scree whose voids act much like black body cavities. Their cavity walls lose their radiant heat more slowly after sundown than the surrounding basalt because of sustained radiation interchange between the walls before ultimate cooling to the sky. This is the same effect that accounts for the warm streaks shown in collapse depressions of lava tubes and fissures near Pisgah Crater.

The best distinction between the basaltic rocks and the surrounding alluvium is on the 2003 (pl. 5), post-sunset, image, as was the case in flight line 1 (2010, pl. 3). The Tertiary basalt (b on 2003, pl. 5) on top of Peter's Mountain and along its northeast flank behaves in the same way as its eastern correlative shown on flight line 1 (b on 2010, pl.3). This older basalt has a physically weathered surface whose float hides the exact contact with the enclosing gravels. Other bedrock features on the south end of Peter's Mountain do not show well enough to be differentiated.

The warmer ill-defined gravel unit on the east side of the mountain seen in the nocturnal imagery is the fanglomerate of granitic detritus. Being older, darker, and more compact than the gravels bordering it to the west, it can absorb slightly more heat during the day (Cf with plate 2). The northwestern tip of the dissected gravel of Peter's Mountain is as warm as the older gravel unit on the east side and may be either the same material or just a facies difference in the main mass of younger gravel that makes up the mountain.

On the small bajada just west of Peter's Mountain a thin cool area is noticeable along one drainage (m on 20003 and 1155, pl. 5). It occurs at the lower end of a long drainage from the mountain and may be either the result of higher moisture in the immediate subsurface or its fresh, unvegetated nature, or both factors. It shows on older photographs of the area, but does not differ here from drainages nearby. This suggests that moisture may be the main cause.

CONCLUSIONS

The aerial infrared survey of the Pisgah Crater area resulted in 8-14μ band infrared imagery that provided useful geologic information to complement data obtained from ground studies and aerial photography.

A series of thermal contrasts representative of those found through the diurnal cycle was acquired during three of the six flight periods: at about 2000 (post-sunset), 0400 (pre-sunrise), and 1200 (midday). No single imaging period provided or can provide all of the relative thermal contrasts potentially present in the area. However, the largest amount of information on geologic thermal parameters from a single imaging period was obtained from imagery flown shortly after sunset, when optimum thermal contrast occurred between the various terrain materials. At this time thermal contrasts are best seen between bedrock and alluvium and between basalt flows and pyroclastics and their derviatives.

Midnight and pre-sunrise images are very similar and one flight period within this time period would, in most cases, satisfy the requirement for both periods. These nocturnal images show more detail of the Pisgah fault where it cuts the Sunshine flows than is normally seen on aerial photographs of the area. The discovery of a faulted outcrop of pumice on imagery of the Sunshine flow was instrumental in the determining a lateral displacement of 0.5 mile on the Pisgah fault.

Distinction of the Pisgah flows, which depends primarily on a difference in surface character between adjacent flow units, is made on the basis of thermal (tonal) contrast on the daytime images and is best seen on the late morning and midday images. The post-sunset image shows this distinction of flows to a lesser degree with a difference in image texture, that is, the frequency of tone change within the image.

Collapsed lava tubes and fissured areas in the Pisgah flows are distinguished as relatively warm streaks on the nighttime images due to a black body cavity effect, but appear as relatively cool areas during the day.

The imagery of Lavic day lake reveals crude zoning and other features in more detail than can be found with other imaging sensors. Moisture appears to be the primary factor that controls the thermal behavior of this and some of the surrounding alluvial environment. The presence of moisture outlined active drainage channels on an alluvial fan and indicated other areas of near surface drainage. The complex role of moisture in these environments is incompletely known at present and requires further detailed study because the degree of saturation governs the best capacity and thermal conductivity, and affects the albedo of porous alluvial terrain.

The empirical interpretation as presented in this report indicates that infrared imagery should prove a very useful tool in geologic field mapping. The data can bring the geologist's attention to anomalous features not readily apparent in the visible spectrum and many valid conclusions can be reached with a minimum of field verification. When the infrared scanning technique is eventually used in conjunction with other remote sensing systems the integration of the resulting data should greatly expand the interpreter's capability by providing many unique property combinations for the identification of terrain.

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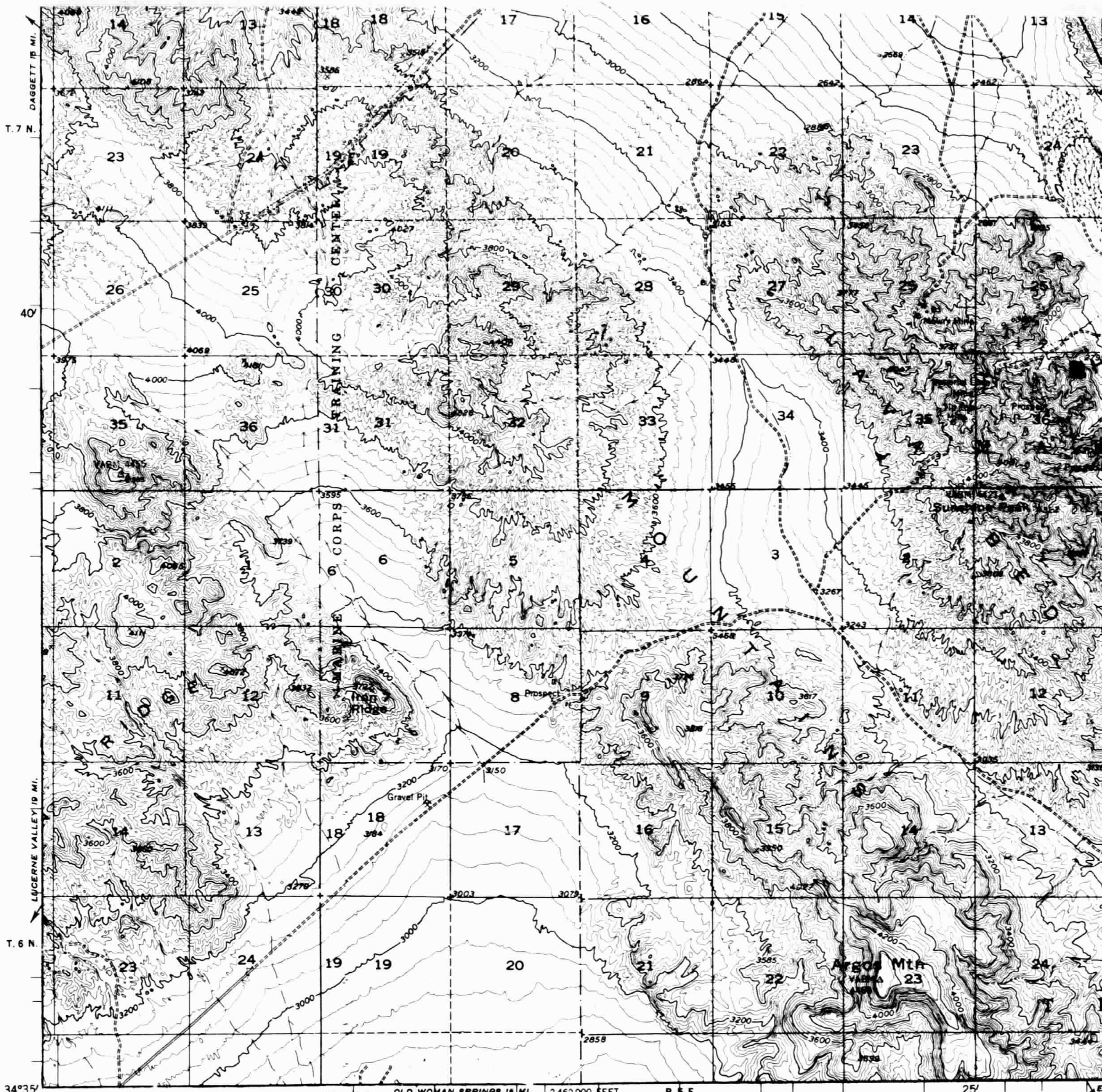
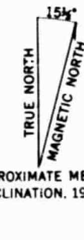


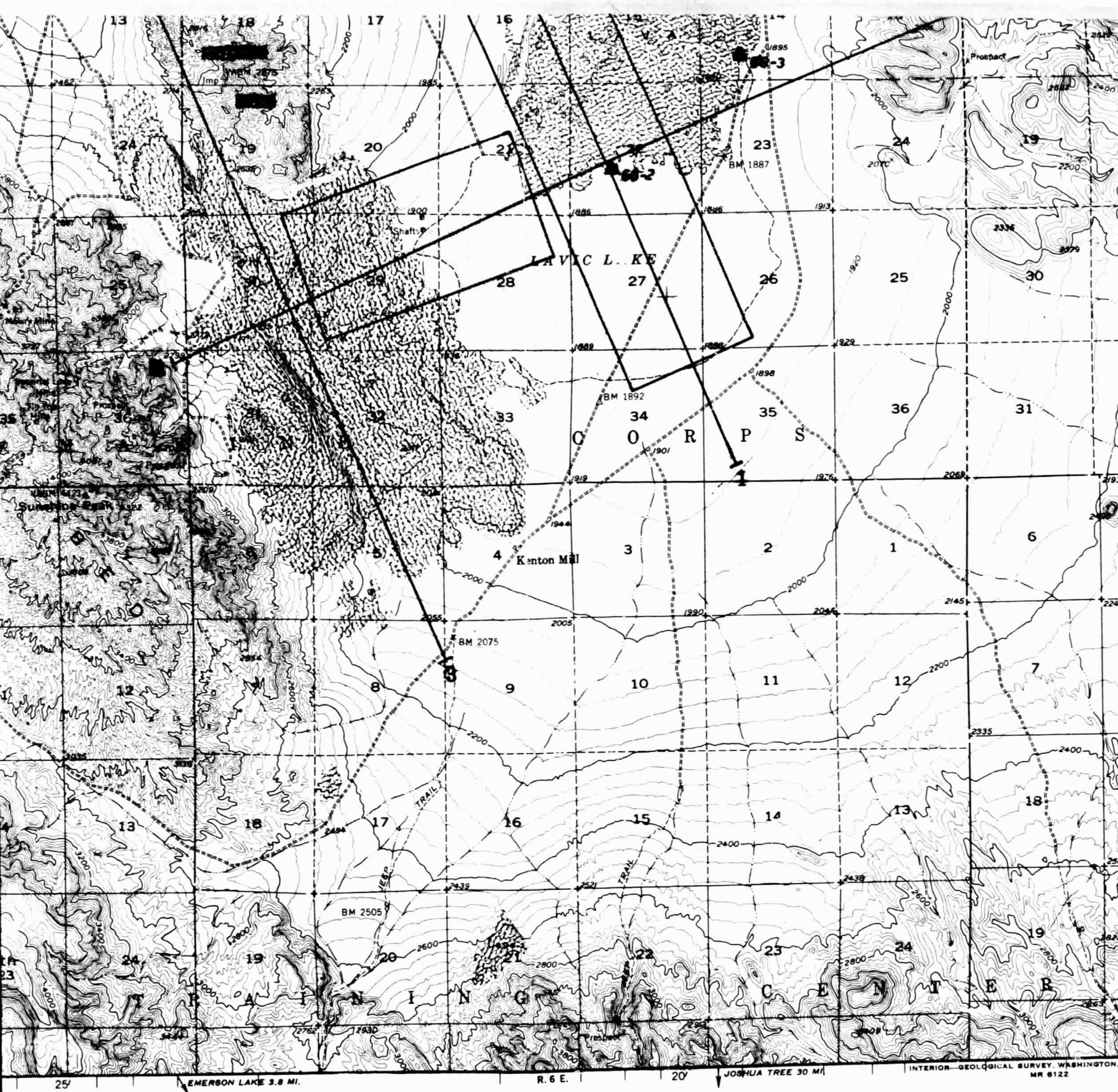
Mapped, edited, and published by the Geological Survey



APPROXIMATE MEAN DECLINATION, 1955

PLATE I-A

INDEX MAP OF PIS



SCALE 1:62500

1 ½ 0 1 2 3 4 MILES

3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 40 FEET

ROAD

Medium-duty

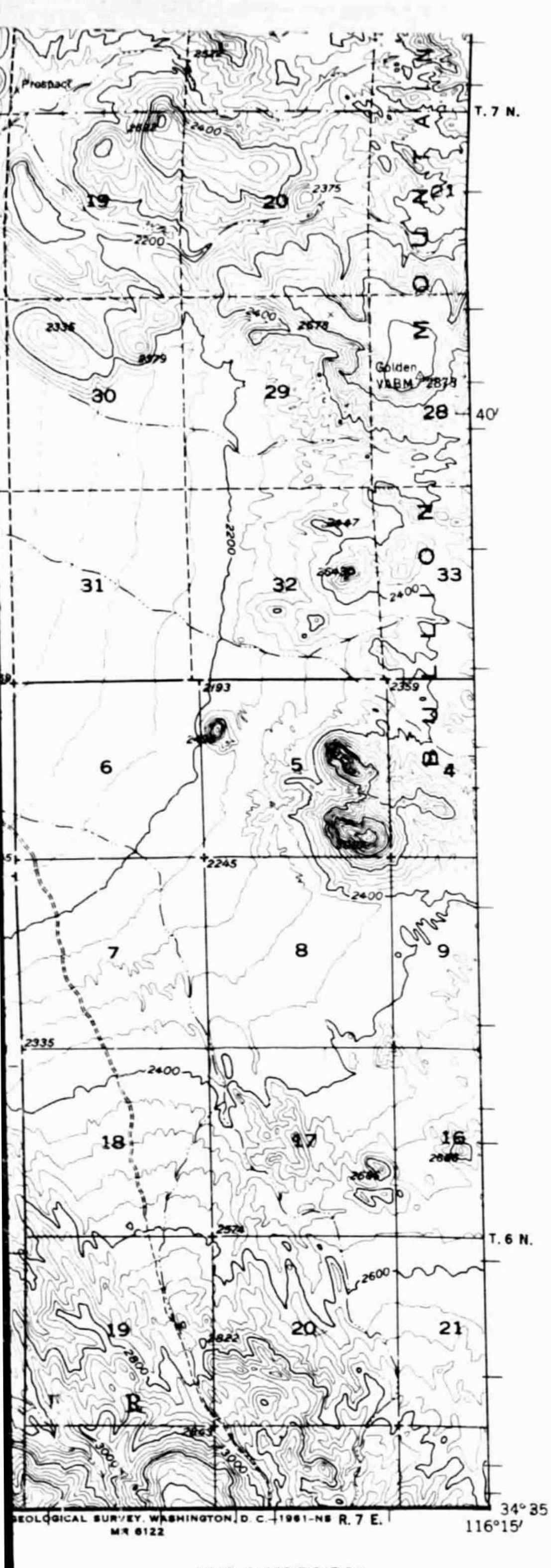
Unimpr

CALIF

QUADRANGLE LOCATION

INDEX MAP OF PISGAH CRATER AREA, SAN BERNARDINO COUNTY, CALIFORNIA

PLATE 1-B



ROAD CLASSIFICATION

Medium duty ______ Light-duty ______

Unimproved dirt ========

U. S. Route

PLATE 1-C

PLATE I-D

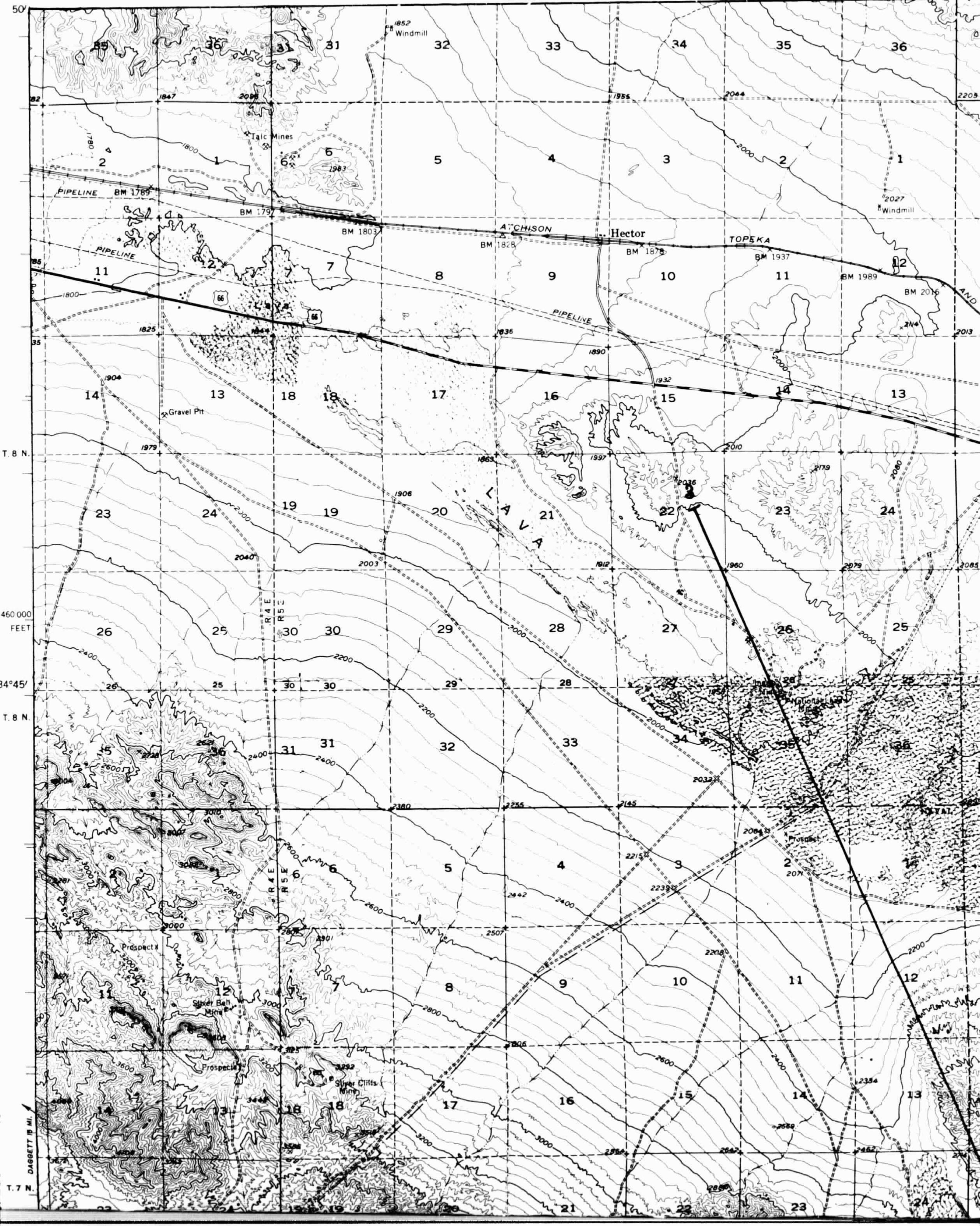
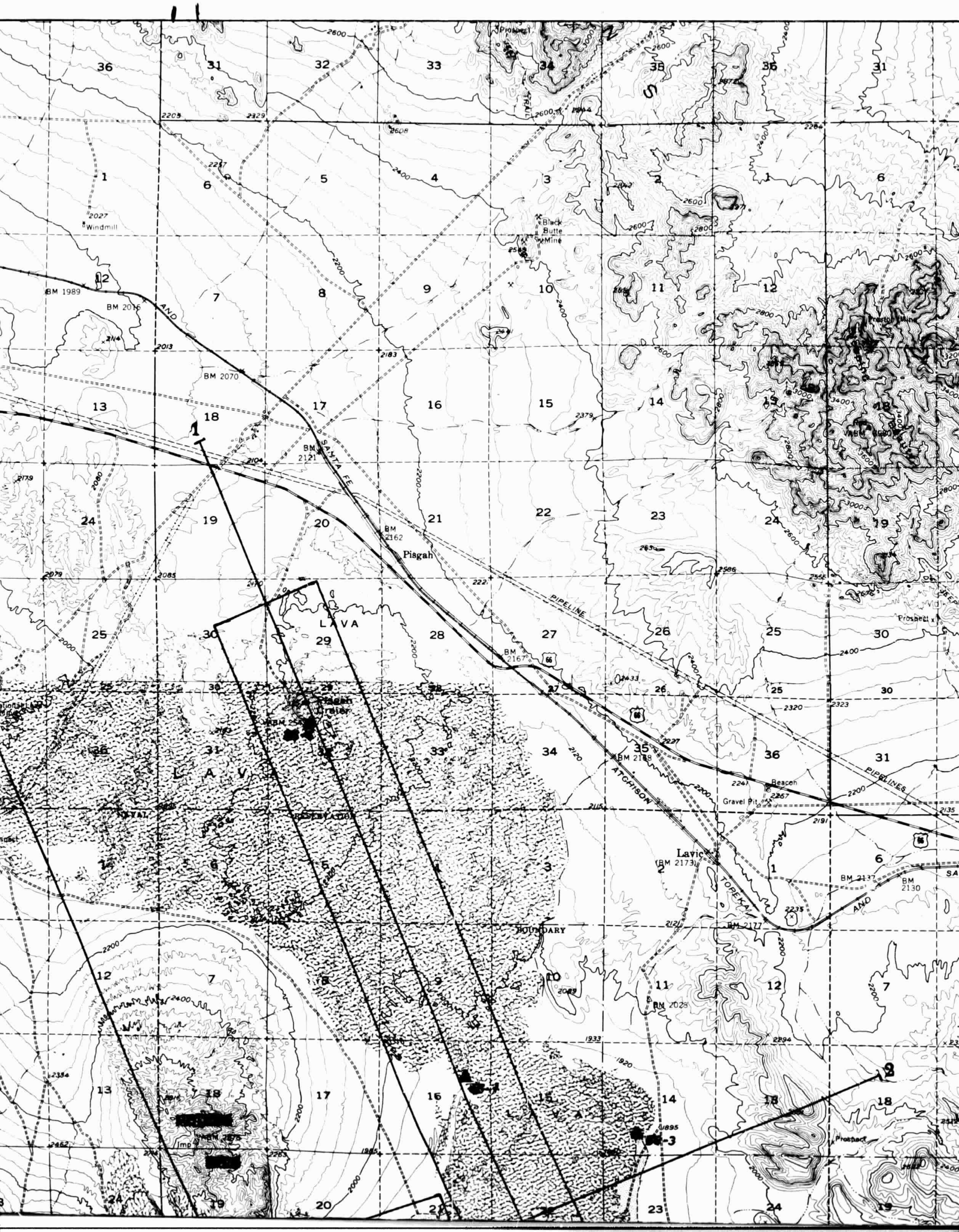
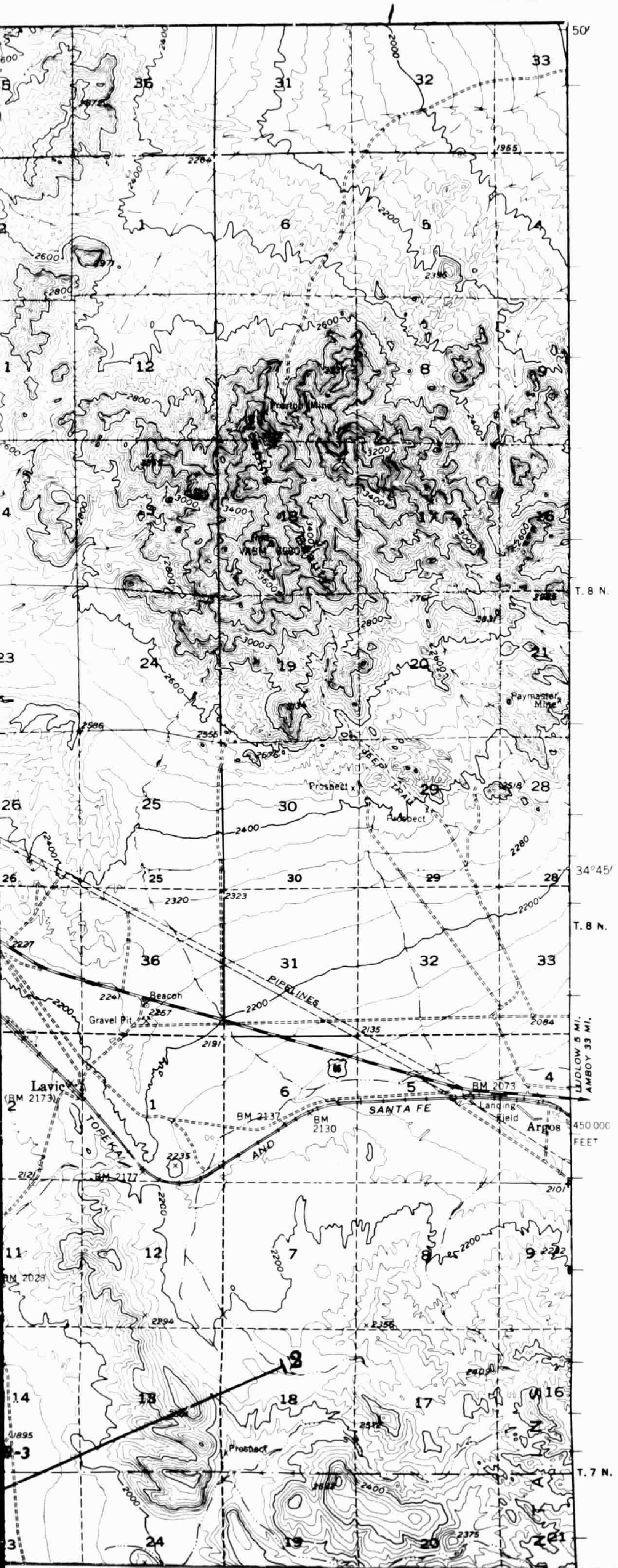

Windmill
Talc Mines
PIPELINE
BM 1789
BM 1803
ATCHISON
BM 1828
Hector
BM 1878
TOPEKA
BM 1937
BM 1989
Windmill
LAVA
Gravel Pit
T. 8 N.
LAVA
R 4 E
R 5 E
460 000 FEET
34°45′
National
Prospect
Prospect
Silver Bell Mine
Prospect
Silver Cliffs Mine
DAGGETT 15 MI.
T. 7 N.

PLATE 1-E

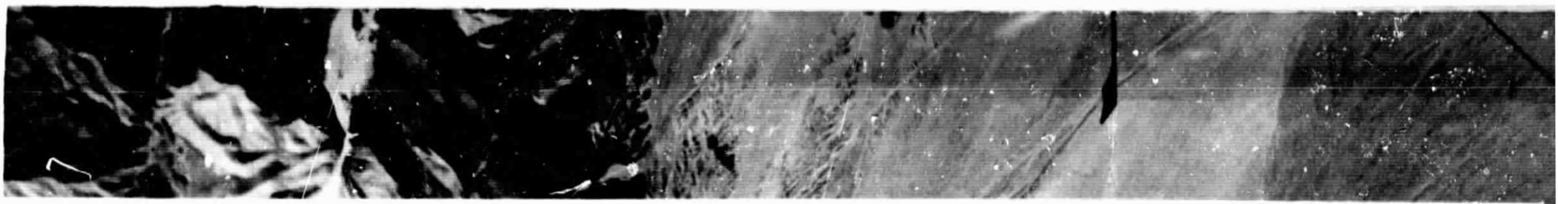


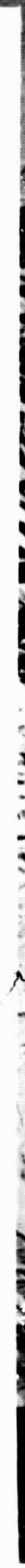
Prospect
Windmill
Black Butte Mine
BM 1989
BM 2016
BM 2070
BM 2121
BM 2162
BM 2167
BM 2188
BM 2173
BM 2177
BM 2137
BM 2130
BM 2028
Pisgah
LAVA
SANTA FE
AND
PIPELINE
PIPELINES
ATCHISON
TOPEKA
AND
Lavic
Beacon
Gravel Pit
BOUNDARY
Pisgah Crater
2600
2400
2200
2800
3000
3400
2000

PLATE 1— F



T. 8 N.
34°45′
T. 8 N.
T. 7 N.
450 000 FEET
Preston Mine
Paymaster Mine
Prospect
DEEP TRAIL
PIPELINES
Beacon
Gravel Pit
Lavic
(BM 2173)
BM 2137
BM 2130
BM 2177
BM 2073
BM 2028
SANTA FE
TOPEKA
AND
Landing Field
Argos
LUDLOW 5 MI.
AMBOY 33 MI.





GEOLOGIC MAP OF PISGAH CRATER AREA, SAN BERNARDINO COUNTY, CALIFORNIA

COMPILED AND MODIFIED BY STEPHEN J. GAWARECKI, 1968

EXPLANATION

Qa	ALLUVIUM	RECENT	
Qbg	BASALTIC GRAVEL MOSAIC	RECENT	
Qoa	OLDER ALLUVIUM	LATE PLEISTOCENE TO RECENT	
Qc	PLAYA DEPOSITS	LATE PLEISTOCENE TO RECENT	
Qpa	ALLUVIUM OF BASALTIC PUMICE AND/OR DETRITUS	PLEISTOCENE TO RECENT	
Qpb	SCORIACEOUS PISGAH BASALTIC PUMICE	LATE PLEISTOCENE AND/OR RECENT	
Qb_3	BASALT OF THIRD PISGAH FLOW	LATE PLEISTOCENE AND/OR RECENT	QUATERNARY
Qb_2	BASALT OF SECOND PISGAH FLOW	LATE PLEISTOCENE AND/OR RECENT	
Qb_1	BASALT OF FIRST PISGAH FLOW	LATE PLEISTOCENE AND/OR RECENT	
Qps	BASALTIC PUMICE OF SUNSHINE CONE	PLEISTOCENE	
Qbs_2	BASALT OF SECOND SUNSHINE FLOW	PLEISTOCENE	
Qbs_1	BASALT OF FIRST SUNSHINE FLOW	PLEISTOCENE	
Qof	OLDER FANGLOMERATE AND GRAVEL	PLIOCENE OR PLEISTOCENE	?
QTc	CLAYSTONE	PLIOCENE OR PLEISTOCENE	
Tb	BASALT OF PETER'S MTN. AND E. OF LAVIC LAKE	OLIGOCENE, MIOCENE, OR PLIOCENE	
Tfg	FANGLOMERATE OF GRANITIC DETRITUS	OLIGOCENE OR MIOCENE	
Tt	TUFF BRECCIA	OLIGOCENE OR MIOCENE	TERTIARY
Tab	ANDESITE BRECCIA	OLIGOCENE OR EARLY MIOCENE	
Tdp	DACITE PORPHYRY	OLIGOCENE, EARLY MIOCENE, OR OLDER	
bqm	BIOTITE QUARTZ MONZONITE	PROBABLY MESOZOIC	

CONTACT

DASHED WHERE GRADATIONAL OR APPROXIMATE

U D FAULT

DASHED WHERE INDEFINITE; DOTTED WHERE CONCEALED; QUERIED WHERE DOUBTFUL
U/D, RELATIVE VERTICAL COMPONENT OF MOVEMENT
DOUBLE ARROWS INDICATE RELATIVE LATERAL DISPLACEMENT

VOLCANIC VENTS   COLLAPSED LAVA TUBE

PROSPECT SHAFT   MINE OR QUARRY   INSTRUMENT STATION

PLATE 2—A

U. S. GEOL. SURVEY INTERAGENCY REPORT NASA-99

FAULT
Tab
Qoa
Tfg
Tb
Qb1
Qc
Qa
Qb3
Qpa
bqm
Qbg
Qbs2
Qps
Tdp
Q
116°25'
116°20'
0
1

PLATE 2-B

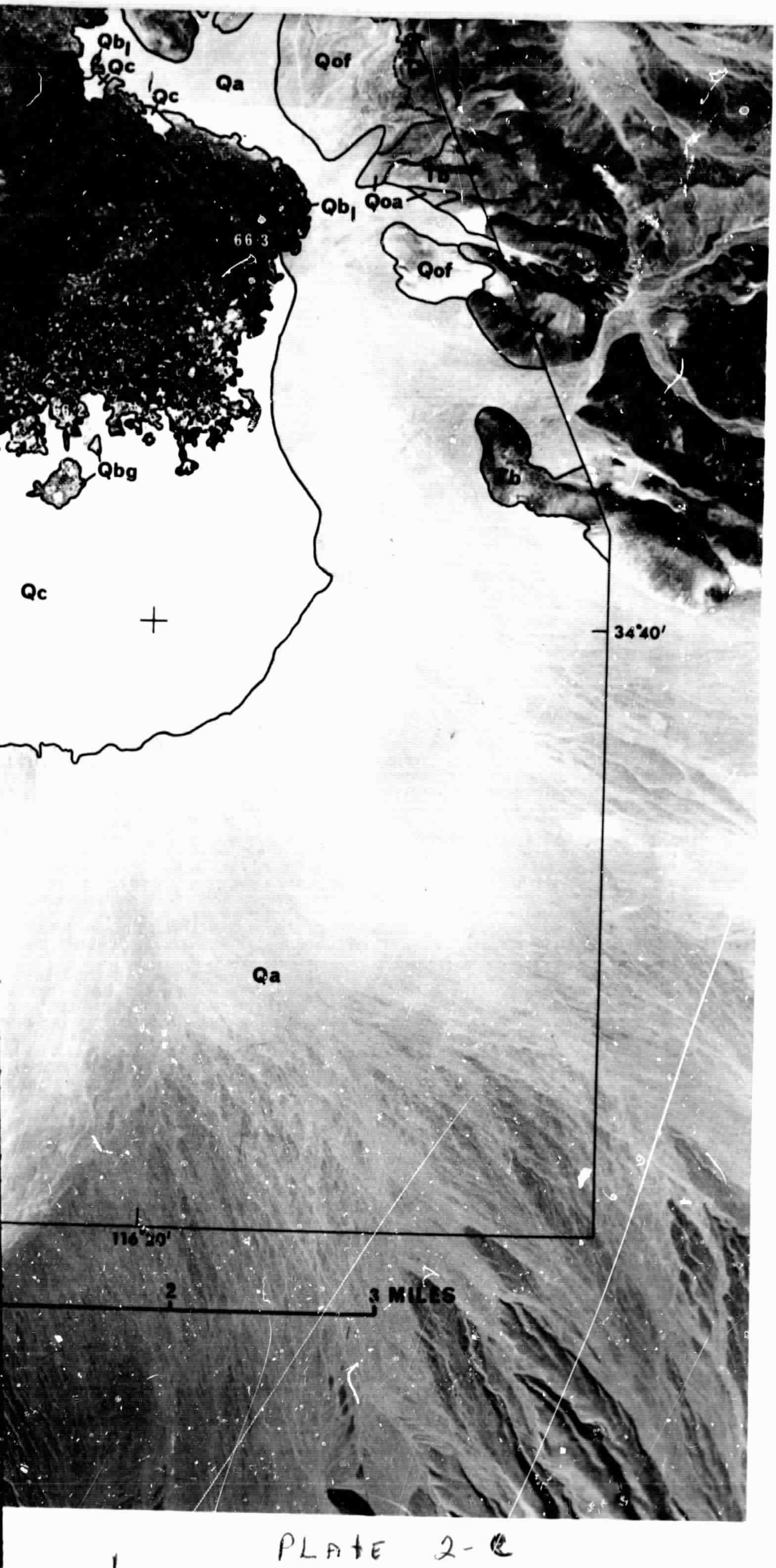
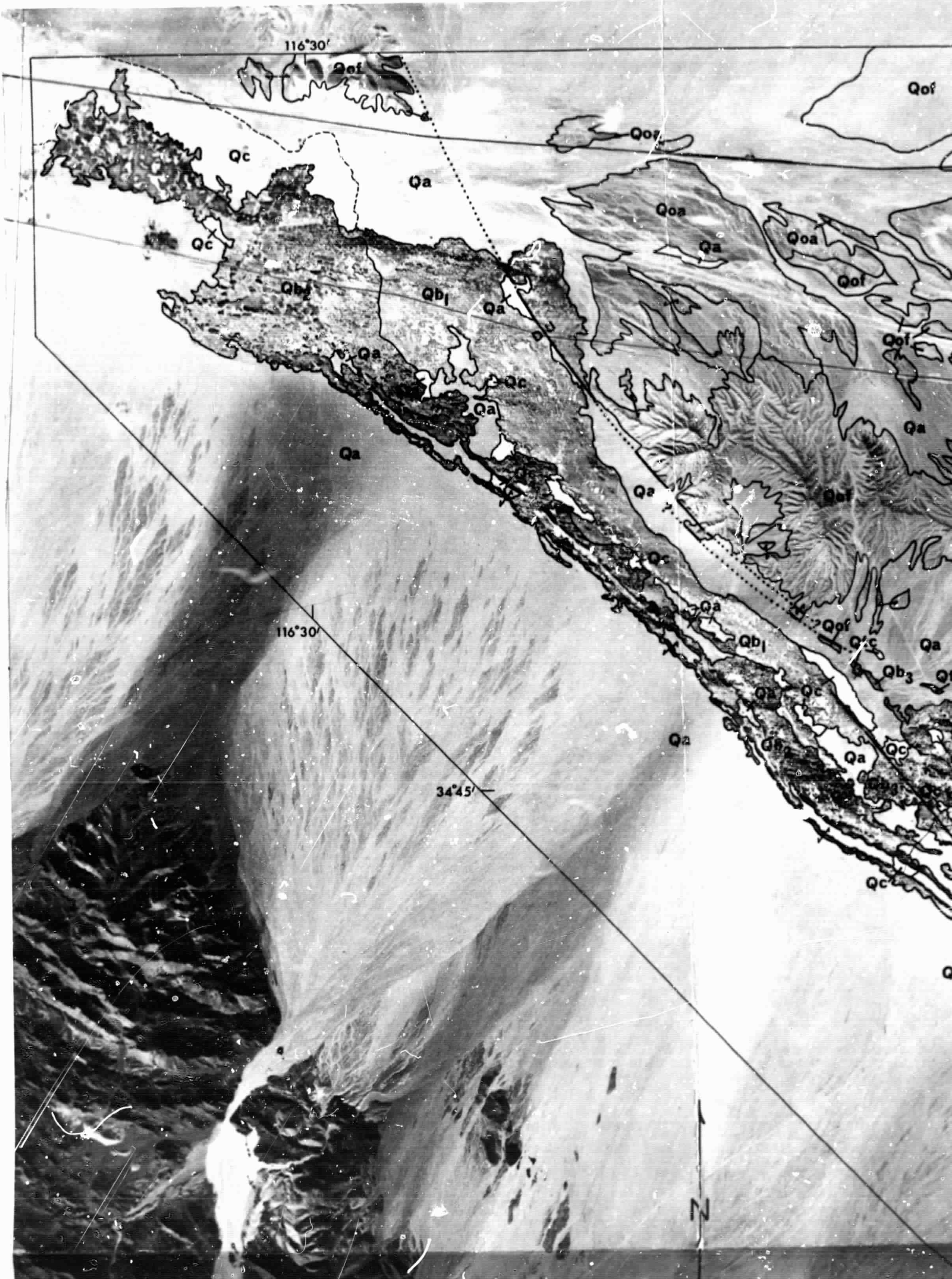

Qb1
Qc
Qc
Qa
Qof
Tb
Qb1
Qoa
66.3
Qof
Qbg
Tb
Qc
34°40'
Qa
116°20'
2
3 MILES

PLATE 2-C

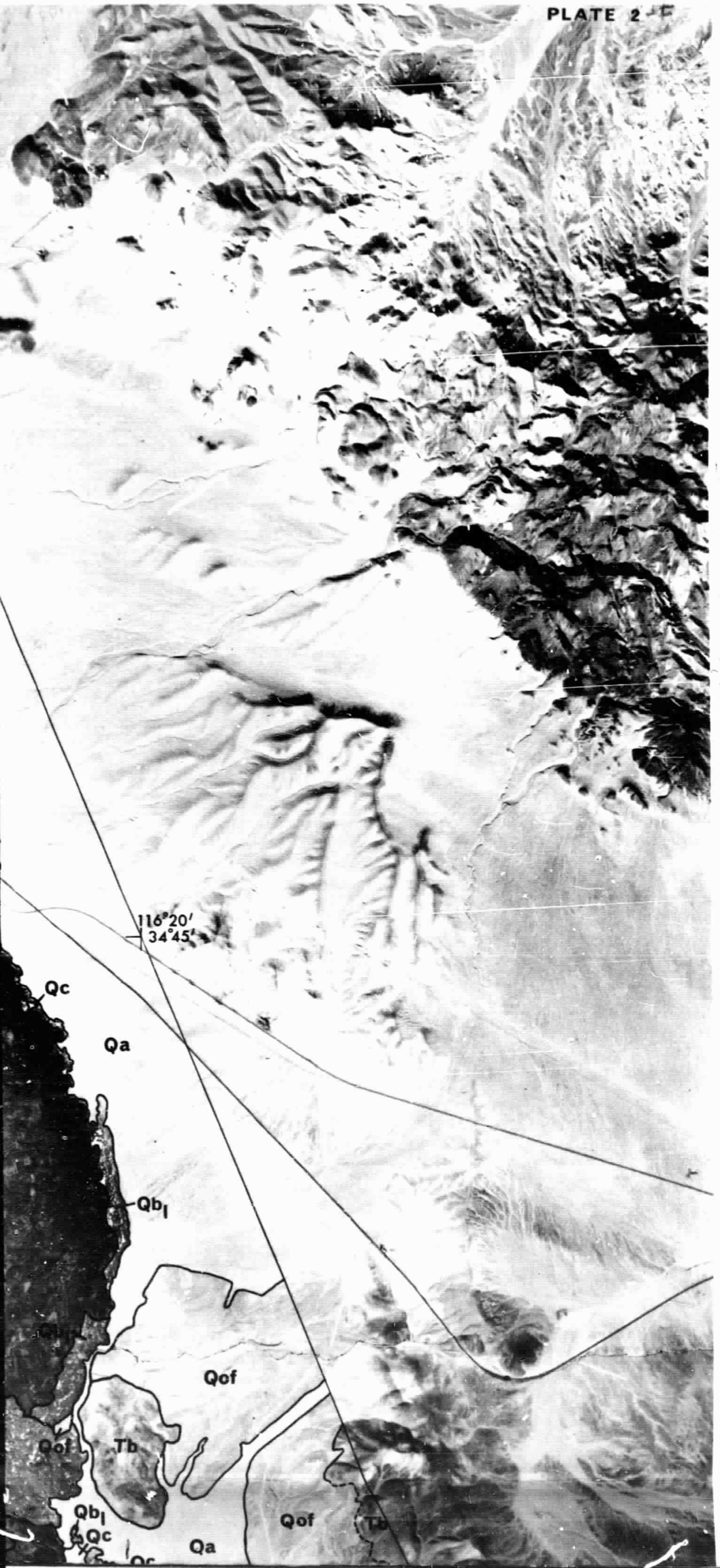


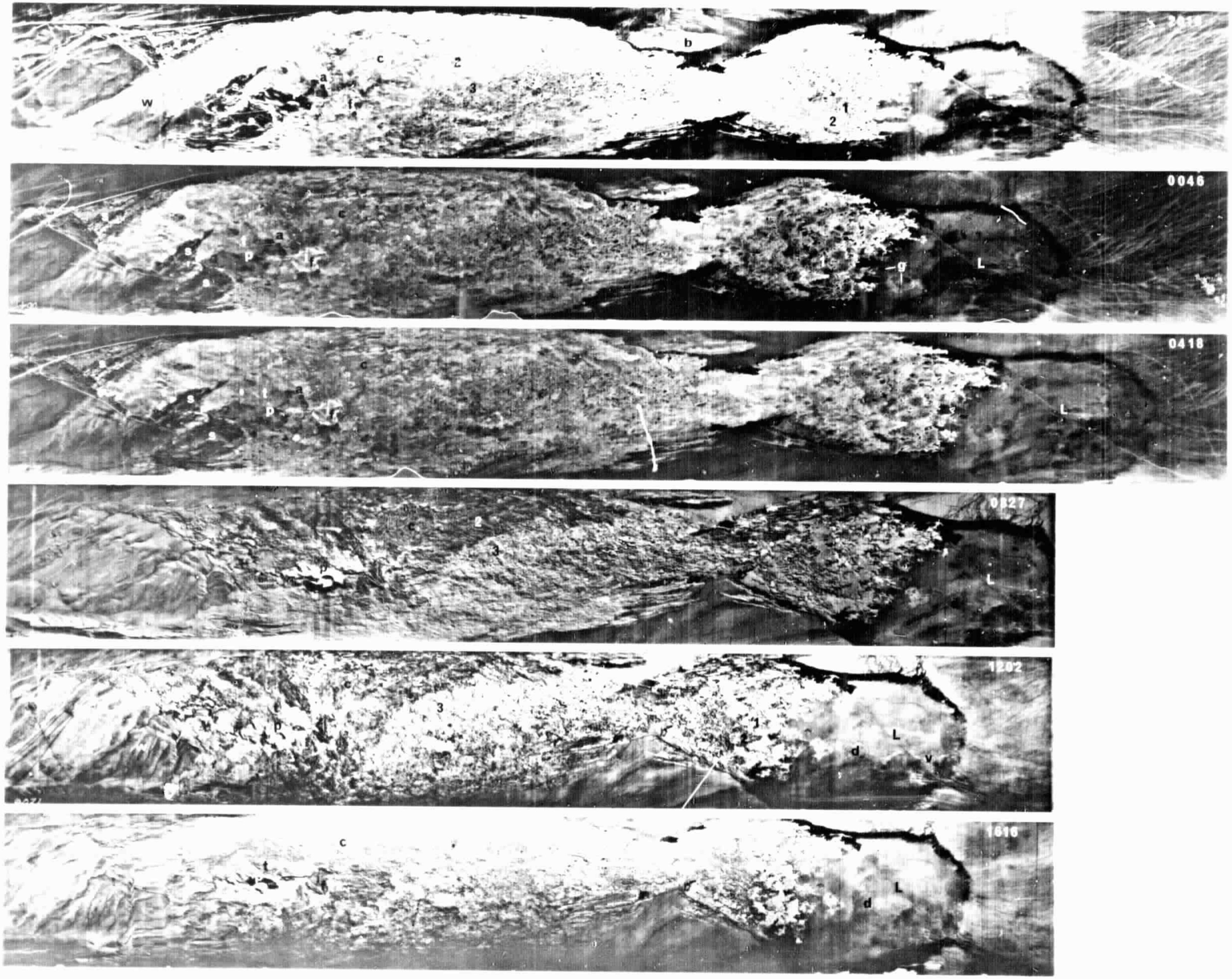
116°30′
Qof
Qof
Qc
Qa
Qoa
Qc
Qa
Qoa
Qb2
Qb1
Qa
Qof
Qof
Qa
Qc
Qa
Qa
Qa
Qof
Qc
Qa
Qb1
Qof
Qa
Qb3
Qc
116°30′
Qa
Qc
Qa
34°45′
Qc

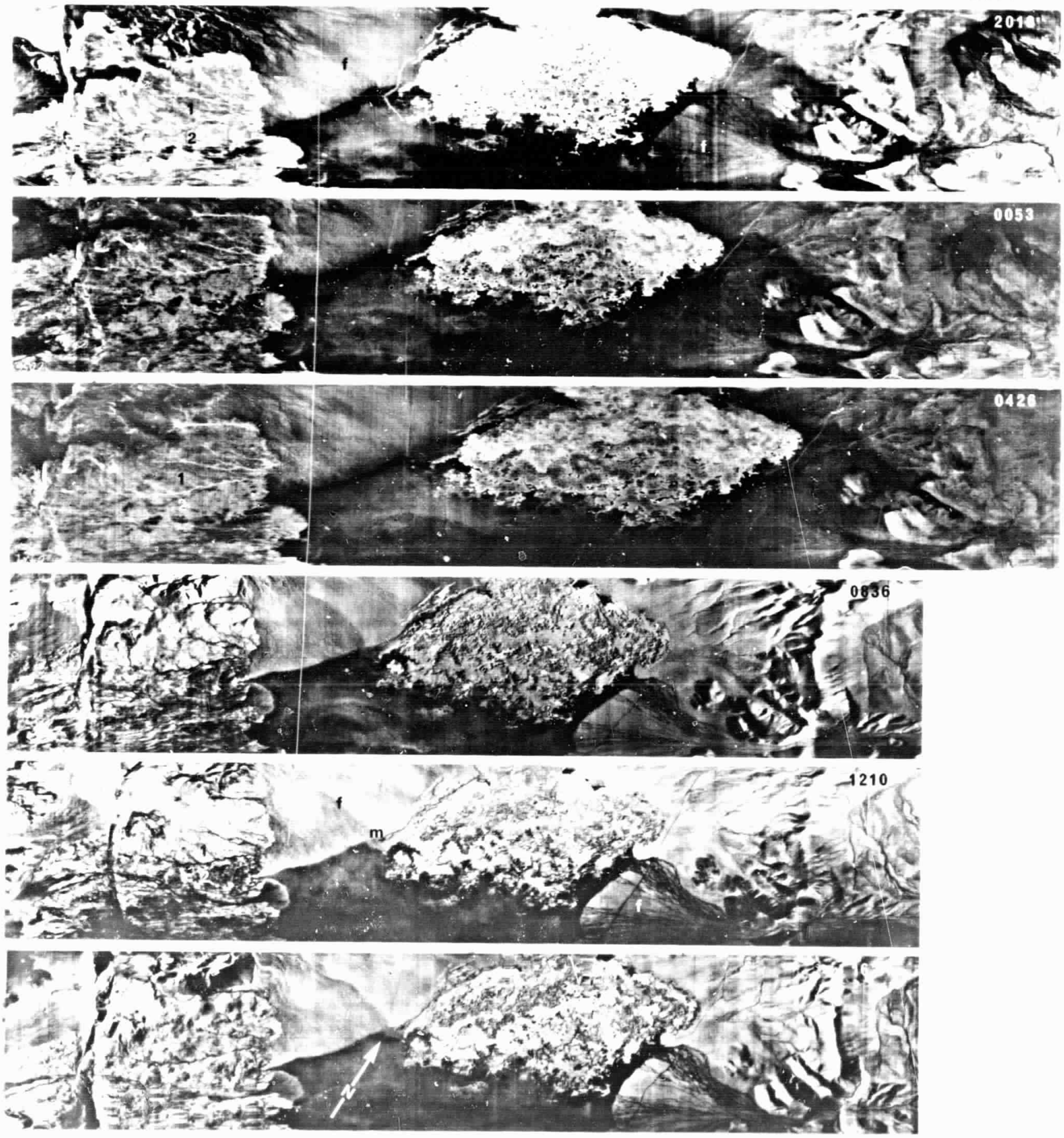
PLATE 2-E

116°25'
Qof
Qa
Qoa
UD
Qc
Qb2
Qtc
Qb3
Qb1
Qbp
Qpa
Qb2
Tb
Tfg
Qoa
PISGAH
FAULT

PLATE 2-F




0046
0418
0827
1202
1616


2010
f
1
2
f
0053
0428
1
0836
1210
f
m
f
N


c
m
a
1
2
b
p
Pt
0815
0414
0841