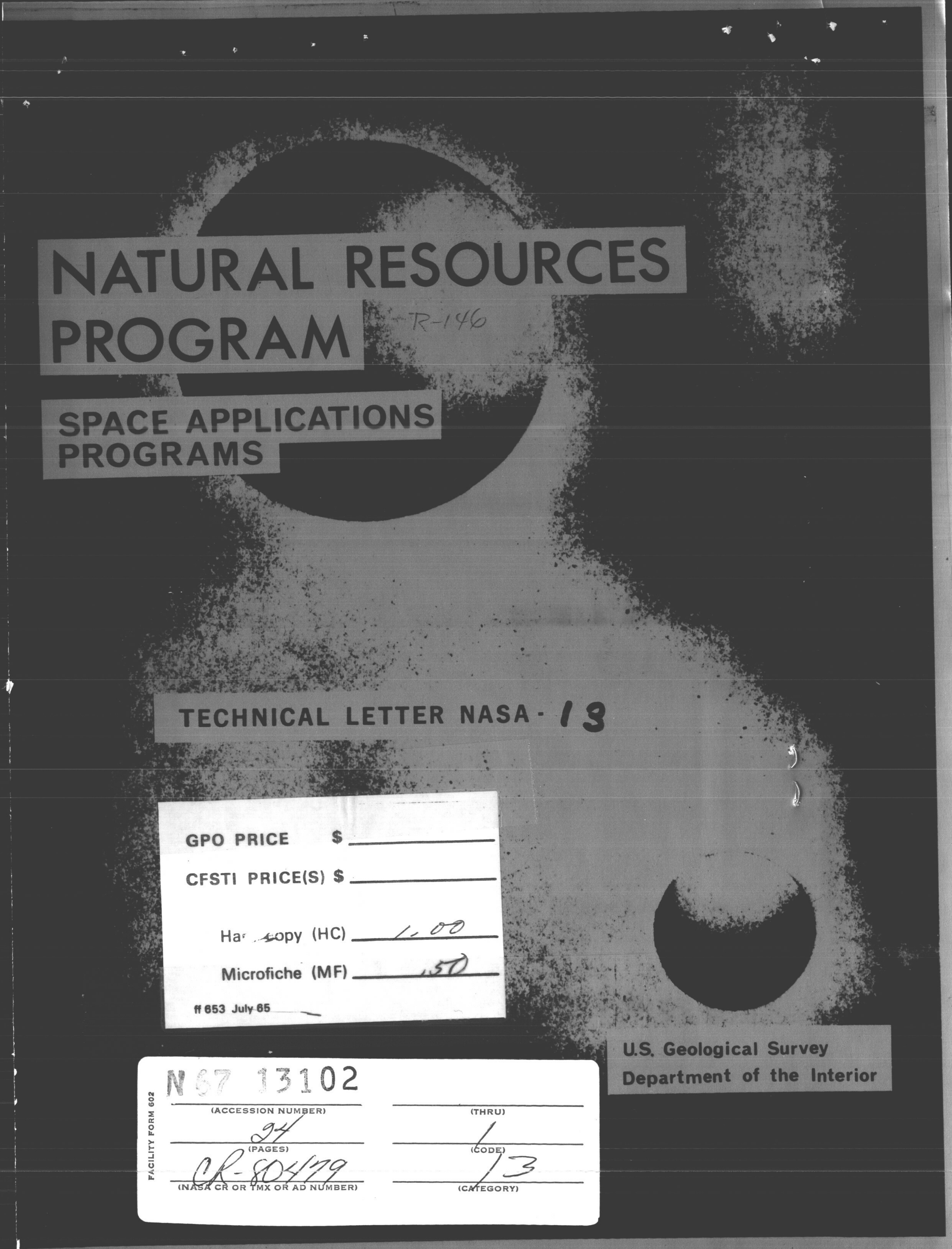

NATURAL RESOURCES PROGRAM

R-146

SPACE APPLICATIONS PROGRAMS

TECHNICAL LETTER NASA-13

U.S. Geological Survey
Department of the Interior

March 3, 1849

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

Technical Letter
NASA-13
November 1966

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

Dear Peter:

Transmitted herewith are 3 copies of:

TECHNICAL LETTER NASA-13

INFRARED SPECTRAL EMITTANCE OF ROCKS FROM THE PISGAH CRATER AND MONO CRATERS AREAS, CALIFORNIA*

by

David L. Daniels**

Sincerely yours,

William A. Fischer
Research Coordinator
Earth Orbiter Program

---

*Work performed under NASA Contract No. R-146-09-020-006
**U.S. Geological Survey, Washington, D.C.

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INFRARED SPECTRAL EMITTANCE OF ROCKS FROM THE PISGAH CRATER AND MONO CRATERS AREAS, CALIFORNIA

by

David L. Daniels

ABSTRACT

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A Block Engineering Inc. Model I-4T interferometer-type spectrometer was used to measure the spectral emittance, in the 8 to 14 micron wavelength band, of various rock types from the Pisgah Crater and Mono Craters areas in California. The emittance spectra of acidic igneous rocks (rhyolite obsidian and pumice, Bishop Tuff, quartz monzonite) are very similar and are spectrometrically difficult to distinguish one from the other. Their spectra, however, do differ from the spectra of basalt from both localities.

Author

INTRODUCTION

The principal objective of this investigation is to measure the infrared spectral emittance of natural rock surfaces from two NASA test sites. Samples examined came from the Mono Craters area near Lee Vining, California and from Pisgah Crater, 40 miles east of Barstow, California. Spectral emittance data is needed before remote sensing identification schemes based upon spectral emission differences can be formulated. The spectral region concerned is the 8-14 micron atmospheric window.

Weathering, like surface roughness and granulation, alters the emittance spectra of rocks, effectively reducing the differences in spectra among different rocks. The aim of this work was to determine if enough of the spectral signature is retained to be recognizable for typical samples of weathered rocks.

The infrared spectral emittance of a wide variety of rocks is well known largely due to the work of Lyon (7,8,9,10). Considerable spectral emittance data for rough-surfaced rocks is available (7, 8, 9); the effect of granulation on the spectra of rocks has also been investigated (7, 8, 11). Lyon and Patterson have measured the spectral emittance of natural rock surfaces in place using a mobile spectrophotometer (10).

EXPERIMENTAL TECHNIQUES

Samples

The location of the samples from the Mono Craters area is shown in figure 5. The geology of the same region may be seen in previous reports; Technical Letters 9 (ref. 5) and 12 (ref. 4). Figure 6 shows the geology and sample locations of the Pisgah Crater area. Sample descriptions are listed in tables 1, 2 and 3. At the sampling localities a wide variation in weathering and surface roughness was observed. Samples collected, however, were estimated to be average in these variations. Slabs about 3 x 3 x 1/2 inches were cut from the samples, retaining one large natural surface.

Instrumentation

The flat, reverse side of the cut sample is placed on a temperature-regulated hot plate and heated to 345°K (72°C) by conduction. The hot plate and sample are enclosed in an aluminium box measuring 7 x 7 x 7 inches with 1/2 inch walls blackened on the inner surface (3M Velvet Black Enamel) (fig. 1). The upper surface of the sample radiates into the spectrometer optics which receives the radiation through a hole in the top of the box.

The purpose of enclosing the sample in a black box is to control the radiation environment so that emittance calculations will be simplified. The spectrometer detector produces a signal proportional to the difference in spectral radiance between the sample and detector. Therefore, the zero line on the spectral chart represents not zero radiance but the radiance of the detector.

To obtain emittance values as a simple ratio of the sample signal to a blackbody signal, it is necessary to balance the detector radiance with the black box enclosure radiance. This is done by keeping them at the same temperature (30-31°C). The spectral emittance equation is developed in the appendix.

The basic instrument used is the Model I-4T Interferometer Spectrometer made by Block Engineering Inc. of Cambridge, Mass. The general characteristics have been described elsewhere (1, 2). The characteristics are: Detector-ambient temperature thermistor bolometer; wavelength limits 2 to 16 microns; field of view 15°; resolution about 35 cm^{-1} (0.3 micron at 10 microns) for 1/2 second, 500 micron mirror sweep.

The spectrometer output is processed by a General Radio recording wave analyzer which performs the partial Fourier transform and plots the spectrum on chart paper in the form of voltage versus frequency, representing spectral radiance versus wavenumber. These voltages are read off as divisions on the chart paper at about 30 points across the 8 to 14 micron band. The values are tabulated and then divided by the equivalent values for a blackbody at the same temperature. The wavelength calibration is obtained from an absorption spectrum of polystyrene film. The resulting emittance spectra are shown in figures 2-4.

Temperature Measurement

The accurate measurement of sample surface temperature was the chief experimental difficulty. Small thermistor probes (3/16" diam., 1/16" thick disks) were pressed against the rock surface with a springloaded piston.

The thermal continuity was increased between probe and surface with the use of silicone grease (transistor heat sink grease). Under best circumstances (polished sample of high thermal conductivity) the thermistor probe will register the correct temperature as judged by its spectrum in comparison with the blackbody spectrum. However, with the rough samples used in this work, the measured temperature using the surface thermistors had little meaning and was therfore not used. In practice, the sample temperature was increased stepwise until the sample radiance curve just fit under the blackbody curve at 345°K. The thermistor probe then generally indicated a temperature 7-15° too low. The result of this practice is that one point (ϵ_ν) on the resulting emittance curve will have a value that approaches or equals 1. This is not an unreasonable result. In the work of Coblentz (3) the reflectance of most silicates approaches zero at about 7.5 microns. In this work (ϵ_ν) is usually .97-1.00 at 7.5-7.7 microns. However, if no point on the emittance curve is actually nearly unity, then the absolute emittance values will be in error.

Blackbody Reference

A blackened cone (45°) set in one face of a sheet copper cube filled with water (Leslie Cube) was the blackbody standard used. Two other standards were tried and rejected; 1) an aluminium block 3 x 3 x 1/2 inches with one face painted with 3M brand Velvet Coating (black enamel 101-C10); this had a 9% emittance dip at 9 microns,

2) a block of injector type razor blades bolted together (Lyon, 1965, p. 721); the emittance was found to extremely dependent on the angle of view.

Error

1) The largest potential error in the emittance data results from the uncertainty of sample surface temperature. This uncertainty is present in the absolute level of the emittance curve. The accuracy of relative values between any two wavelengths should not be affected.

2) To estimate the amplitude precision of the spectrometer and data processing system, six emission spectra of the blackbody were recorded, keeping conditions constant. The range in values around the average value for each spectral point from 7.41 to 14.86 microns was determined. The precision ranged from ± 1.4% to ± 6.3% with an average value of ± 2.5%. The percent error in emittance values could be somewhat larger. Another measure of repeatibility is shown in the comparison of spectra #86 and #89 which are repeats of sample #369.

3) Drift in the temperature of the detector and optical components will a) shift the wavelength calibration and, b) change the magnitude of the signal. These errors were kept small by monitoring the instrument temperature. Data were taken only when the temperature had stabilized.

4) The emittance equation given in the appendix requires the temperature of the detector and the enclosure to be identical. It is estimated that they differed less than 2°C.

CONCLUSION

The emittance spectra of weathered surfaces, while they may vary considerably from sample to sample, in general are still recognizable as the spectra of the underlying rock.

The spectra of the acidic igneous rocks from the Mono Craters area are very similar and would be difficult to spectrometrically distinguish one from the other even without the problem of weathering. It should be possible however, to distinguish them from the basalts of the area.

There are no significant spectral differences between the two textural varieties of basalt, pahoehoe and aa, from the Pisgah Crater area.

FUTURE WORK

Future work will be concentrated on evaluating the limits of variation of the spectra of weathered surfaces. New techniques will be tried to improve accuracy and signal to noise ratio.

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APPENDIX

Spectral Emittance Equation

The output of the I-4T spectrometer is a voltage, which is a function of the difference in radiance between rock surface and detector.

$$(1) \qquad V_{\nu S} = R_\nu \Delta N_\nu = R_\nu \left| N_{\nu S} - N_{\nu D} \right|$$

Where

$V_{\nu S}$ is the spectral output voltage of the spectrometer for the sample

R_ν is the spectral responsivity of the spectrometer

$N_{\nu S}$ is the spectral radiance of the sample

$N_{\nu D}$ is the spectral radiance of the detector

$N_{\nu S}$ is, however, the sum of the radiation emitted and reflected from the rock surface. In this work the sample is enclosed in a box which approximates a blackbody cavity at the temperature of the detector. The radiation reflected from the sample is a function of the radiance of the enclosure and the reflectance of the sample.

$$(2) \qquad N_{\nu S} = \epsilon_\nu N_{\nu \underset{T_1}{BB}} + (1 - \epsilon_\nu) N_{\nu E}$$

Where

ϵ_ν is the spectral emittance of the rock surface

$(1 - \epsilon_\nu)$ is the spectral reflectance of the rock surface

$N_{\nu \underset{T_1}{BB}}$ is the spectral radiance of a blackbody at T_1

$N_{\nu E}$ is the spectral radiance of sample enclosure

combine (1) and (2)

$$(3) \qquad V_{\nu S} = R_\nu \left| \epsilon_\nu N_{\nu \underset{T_1}{BB}} + (1 - \epsilon_\nu) N_{\nu E} - N_{\nu D} \right|$$

If one assumes that the detector and enclosure have an emittance of 1 and if their temperatures are equal at T_2, then $N_{\nu E} = N_{\nu D} = N_{\nu BB_{T_2}}$

Equation (3) will then reduce to:

$$(4) \qquad V_{\nu S} = R_\nu \epsilon_\nu \left| N_{\nu BB_{T_1}} - N_{\nu BB_{T_2}} \right|$$

If the sample were replaced by a blackbody at T1, ϵ_ν would be unity, therefore

$$(5) \qquad V_{\nu BB} = R_\nu \left| N_{\nu BB_{T_1}} - N_{\nu BB_{T_2}} \right|$$

The ration of equations (4):(5) gives

$$(6) \qquad \frac{V_{\nu S}}{V_{\nu BB}} = \epsilon_\nu$$

The spectral emittance of a rock, therefore, is the ratio of voltages produced by rock and blackbody respectively.

TABLE I - ROCK SAMPLES - MONO CRATERS QUADRANGLE, CALIF.

Spectrum #	Sample #	Sample Description	Location*	Surface
73	325	Obsidian - gray glass with flow banding	North Crater SW 1/4, Sec. 19, T1N, R27E	smooth, glassy fracture
74	324	Obsidian - black glass with flow banding	UTM zone 11** ^{3}21600 m E 41 97300 m N	smooth, glassy, fracture
85	332	Rhyolite Pumice - gray fine vesicules, glassy matrix, flow banding	North Crater SW 1/4, Sec. 19, T1N, R27E	weathered, rough
75	330	Rhyolite Pumice - gray fine vesicules, glassy matrix	UTM zone 11 ^{3}23650 m E ^{41}90400 m N	weathered, rough
79	334	Crystal-Lithic-Tuff - (upper Bishop Tuff) - tan color, low density, small crystal and large lithic fragments.	Aeolian Buttes - NE 1/4; Sec. 14, T1S, R26E	weathered, rough
80	331	Welded Tuff - (lower Bishop Tuff) - gray dense, compacted Crystal-lithic tuff.	Aeolian Buttes - NE 1/4, Sec. 14, T1S, R26E	weathered, rough
78	333	Biotite Quartz Monzonite medium grained, friable	Aeolian Buttes - NE 1/4, Sec. 14, T1S, R26E	weathered, rough

* See Figure 5.

** 1000-meter Universal Transverse Mercator grid system used on most USGS topographic maps. Used here where section markings are absent.

TABLE 2 - ROCK SAMPLES - MONO CRATERS QUADRANGLE, CALIF.

Spectrum #	Sample #	Sample Description	Location**	Surface
62	330	Rhyolite Pumice - gray, fine vesicules, glassy matrix.	UTM zone 11 323650 m. E 4197400 m. N	sawed
77	329	Rhyolite - older flow from a formation that is largely andesite* Gray, banded with plagioclase and sanidine (?) phenocrysts, groundmass is glass.	NE 1/4, Sec. 31, T1N, R27E	weathered, rough
64	329	Rhyolite - (see above)	NE 1/4, Sec. 31, T1N, R27E	sawed
82	335	Beach Sand - rhyolitic glass fragments	South shore Mono Lake, SE 1/4, Sec. 16, T1N, R27E	loose sand
84	328	Basalt Pumice - red, oxidized, vesicular, basalt cinder - small plagioclase phenocrysts	Small splatter cone NE 1/4, Sec. 36, T1S, R26E	weathered, very rough

*Kistler, R.W., 1966, Geologic Map of the Mono Craters Quadrangle, Mono and Tuolomne Counties, California: U.S. Geol. Survey Geological Quadrangle Map GQ-462.

**See Fig. 5

TABLE 3 - VESICULAR OLIVINE BASALTS - PISGAH CRATER, CALIF.

(all samples from Lavic Lake Quad., Calif. - Sec. 32, T8N, R16E)

Spectrum #	Sample #	Flow type	Sample Locality*	Surface condition
71	368	pahoehoe	P-1	weathered, very rough
72	368	pahoehoe	P-1	Sawed
89	369	aa	P-2	weathered, very rough
86	369	aa	P-2	weathered, very rough
91	371	aa	P-2	weathered, very rough
90	370	aa	P-2	rough, broken

* See Figure 6.

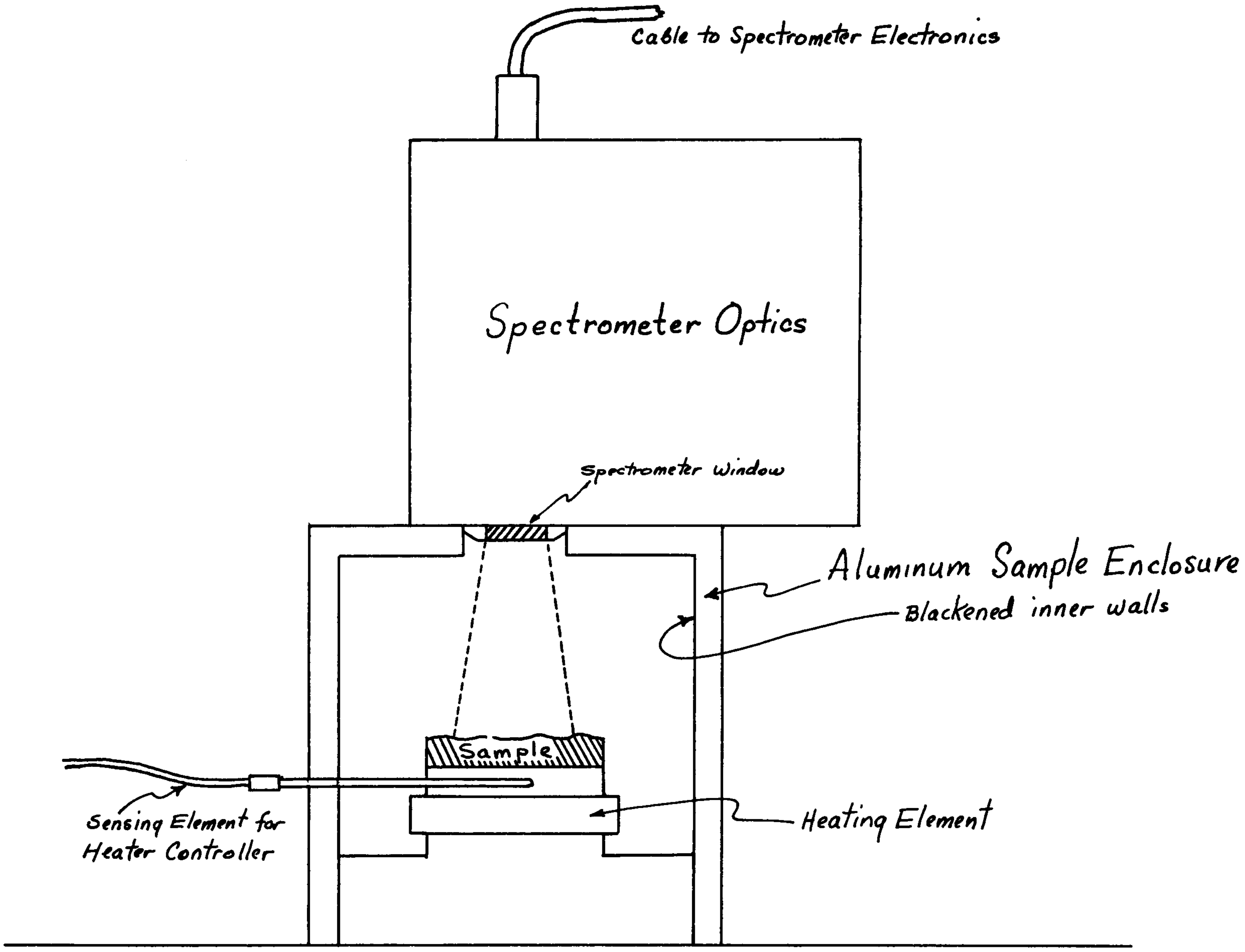


Figure 1 - Section Through Sample Enclosure - X 0.4

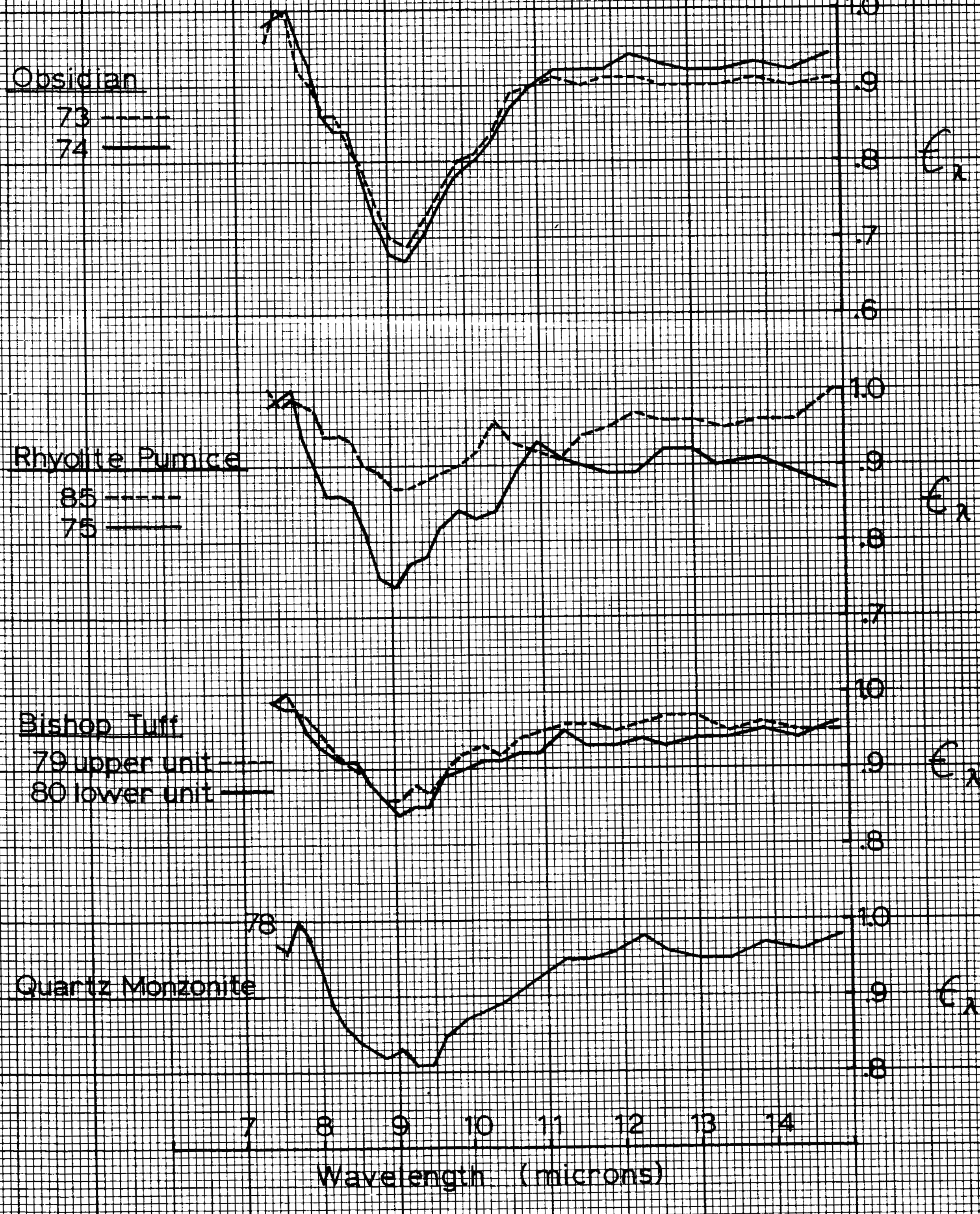


Fig. 2 Emittance Spectra of weathered samples - Mono Craters Area

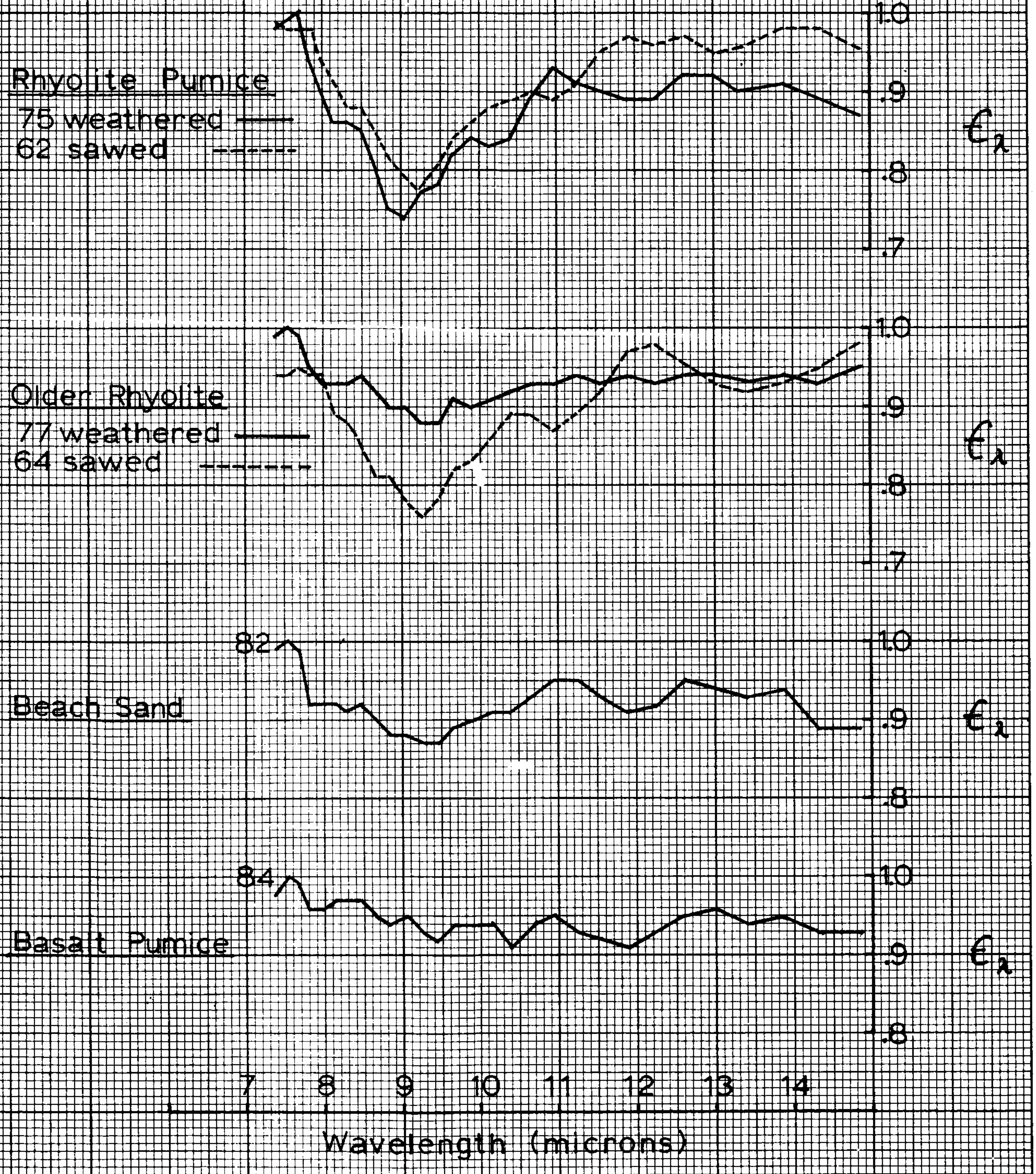


Fig 3 Emittance Spectra of samples from the Mono Craters Area

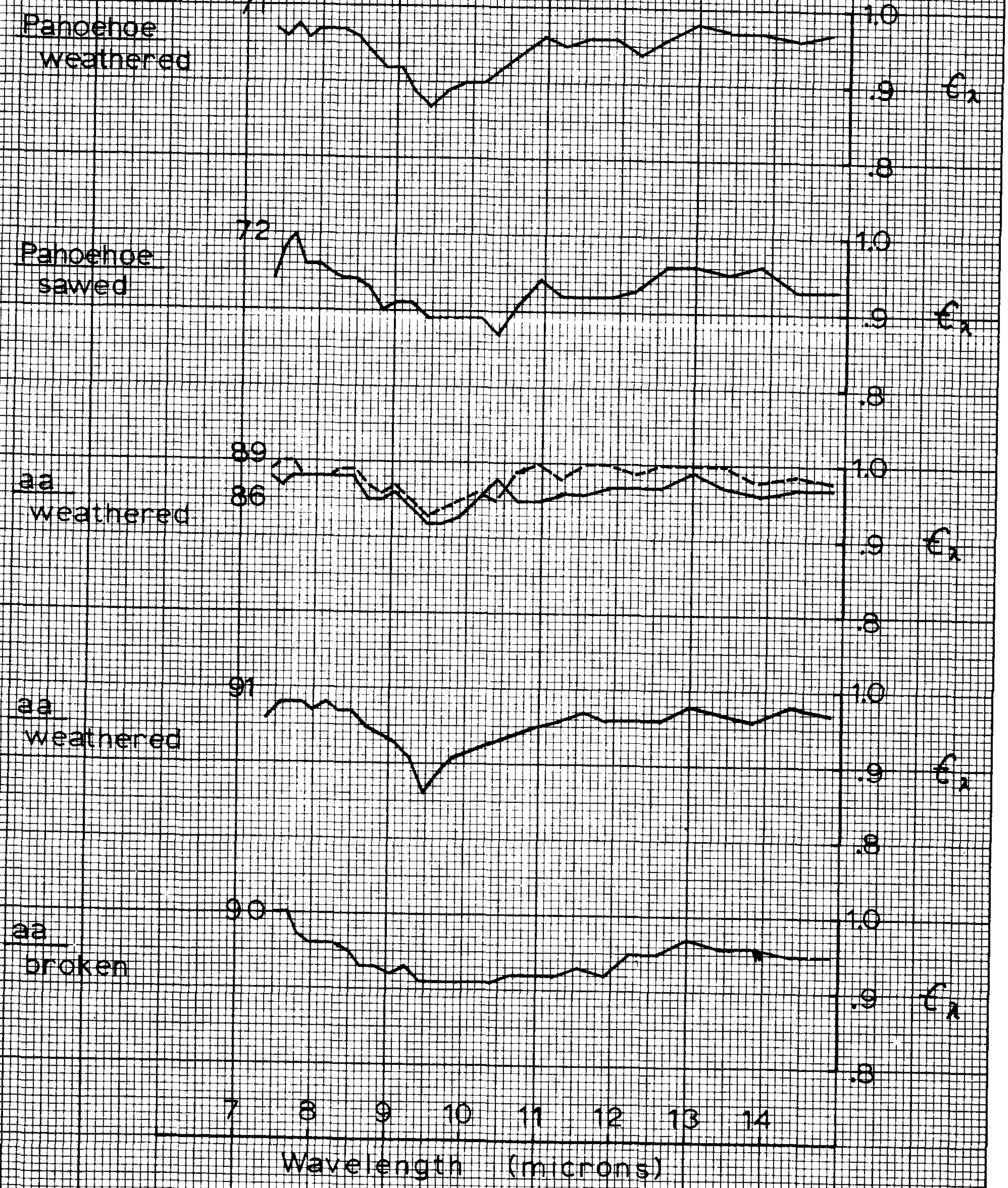


Fig. 4 Emittance Spectra - Vesicular Olivine Basalts
Pisgah Crater Area

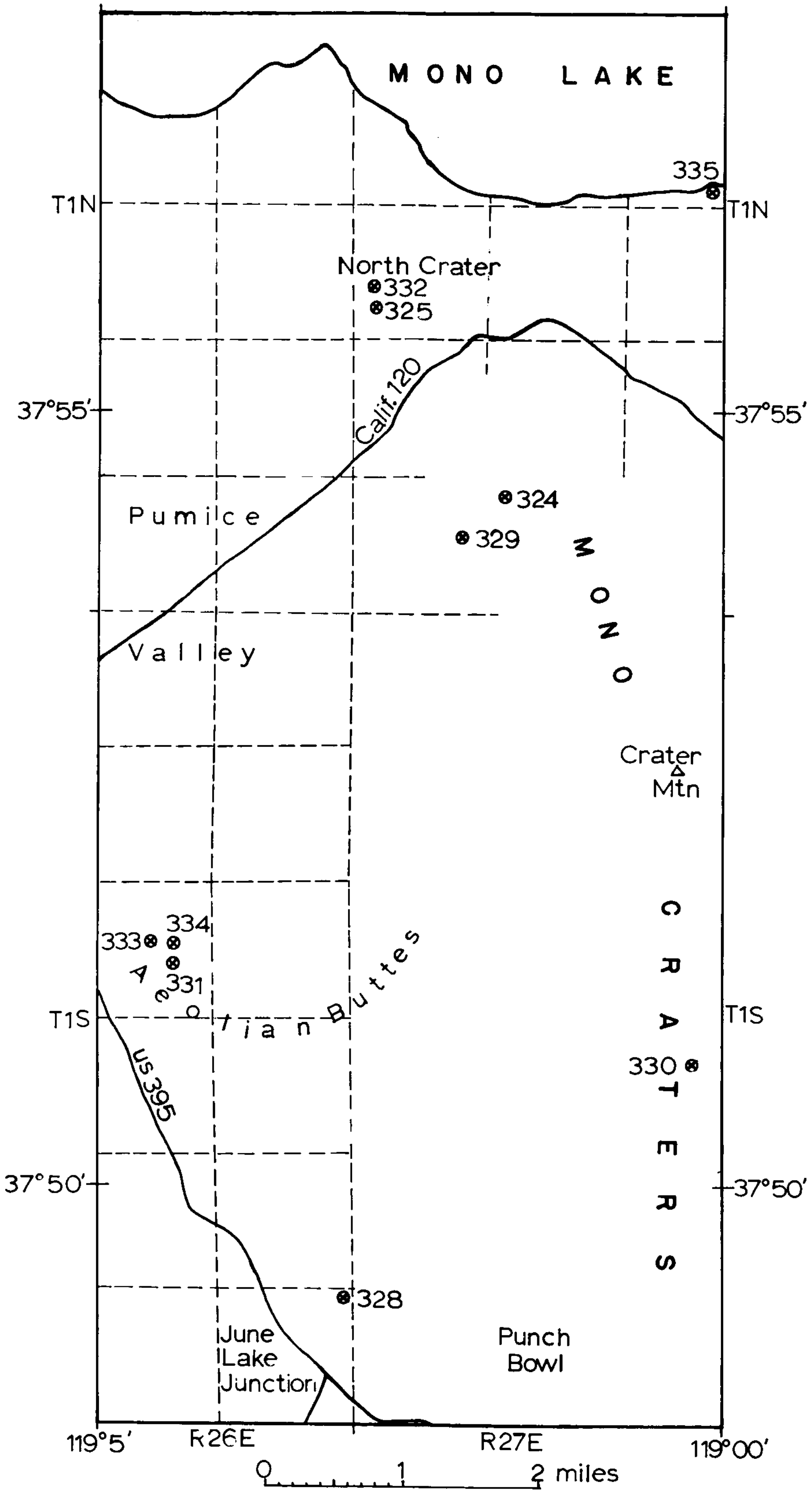


Fig. 5 Sample location map - Mono Craters area, Calif.

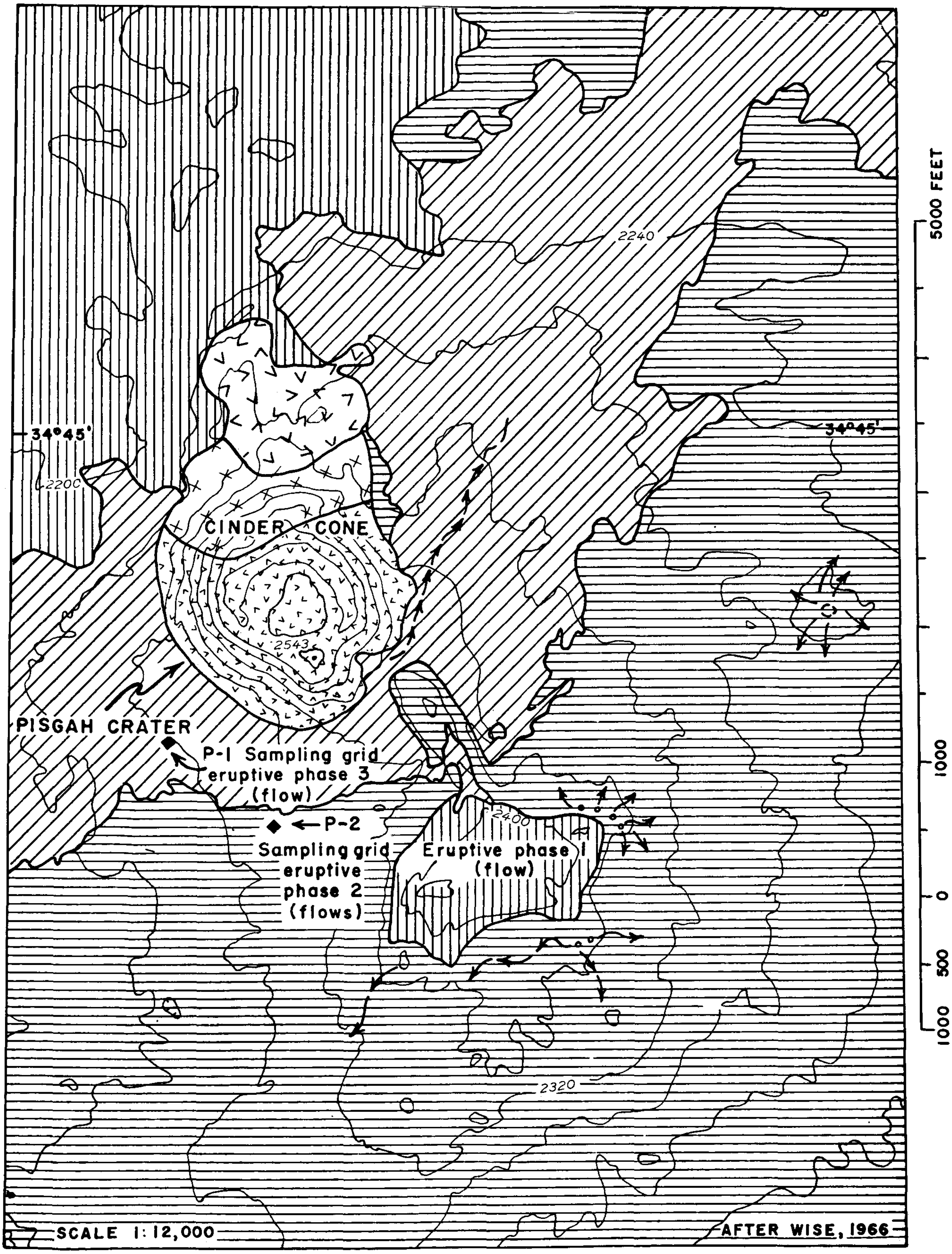
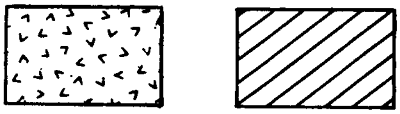


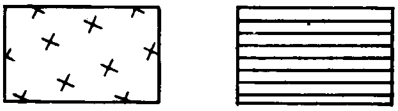
Fig. 6 Geologic Map of the Pisgah Crater Area, California: showing sampling locations.

EXPLANATION FOR GEOLOGIC MAP OF THE PISGAH LAVAS, SAN BERNARDINO COUNTY, CALIFORNIA

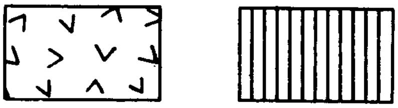
Pisgah Lavas



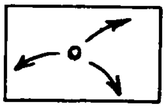
Porphyritic olivine basalt of eruptive phase three



Porphyritic olivine basalt of eruptive phase two



Microporphyritic olivine basalt of eruptive phase one



Lava vent, with flow directions of last flow on surface