UNITED STATES

DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

TECHNICAL LETTER NASA-32

REFLECTANCE OF ROCKS AND MINERALS TO VISIBLE AND ULTRAVIOLET RADIATION*

by

H. V. Watts**

July 1966

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

*Work performed under NASA Contract No. R146-09-020-006
**IIT Research Institute, Chicago, Illinois

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

Technical Letter
NASA-32
July 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 2 copies of:

TECHNICAL LETTER NASA-32

REFLECTANCE OF ROCKS AND MINERALS TO

VISIBLE AND ULTRAVIOLET RADIATION*

by

H. V. Watts**

Sincerely yours,

William A. Fischer
Research Coordinator
Earth Orbiter Program

*Work performed under NASA Contract No. R146-09-020-006
**IIT Research Institute, Chicago, Illinois

Technical Memorandum W6137-1

REFLECTANCE OF ROCKS AND MINERALS TO VISIBLE AND ULTRAVIOLET RADIATION

by

H. V. Watts
Astro Sciences Center
of
IIT Research Institute
Chicago, Illinois

for

William A. Fischer
U. S. Geological Survey
18th & F Street, GSA Bldg.
Washington, D. C.

APPROVED:

C. A. Stone, Director
Astro Sciences Center

April, 1966

TABLE OF CONTENTS

	Page
I. INTRODUCTION AND SUMMARY	1
II. EXPERIMENTAL TECHNIQUES	3
A. Sample Surface Preparation	3
B. Reflectance Measurement	3
III. DATA AND DISCUSSION	6
IV. CONCLUSIONS AND FUTURE WORK	17
REFERENCES	18
Appendix: SPECTRAL REFLECTANCE DATA CURVES	19
Table 1 - Reflectance Samples	8
Figure 1 - Spectral Dependence of Total Diffuse Reflectance from the Ground Surfaces of a Selected Set of Rock Samples	16

REFLECTANCE OF ROCKS AND MINERALS TO VISIBLE AND ULTRAVIOLET RADIATION

I. Introduction and Summary

The reflectances of 38 different samples of rocks and minerals were measured throughout the visible and ultraviolet spectral range of 7000A down to 2300A. Reflectances were measured for both a flat ground surface and a polished surface of each material except for the samples of pumice and mica whose surfaces were measured as received. The diffuse reflectance was detected both with and without the inclusion of the specularly reflected component.

None of the reflectance curves showed any characteristic peaks or bands. The shapes of the reflectance curves are generally the same for both the ground and the polished surfaces with the total reflectance from the ground surface greater than that from the polished surface. For most samples the reflectance increases as the wavelength increases.

Of major interest is the fact that the relative reflectance from sample to sample does not remain the same throughout the spectral range. Thus, the contrast in imaging an array of different rocks could vary appreciably between a visible sensitive imager and an ultraviolet sensitive imager. For example, pumice has a diffuse reflectance of 32 percent at 5000A (one of the higher observed reflectivities) and only a 3 percent reflectance at 2500A (the lowest reflectance recorded), monzonite has reflectance values of 16 percent and 18 percent at 5000A and 2500A, respectively. Pumice would appear about twice as bright as monzonite at 5000A, but monzonite would be about five times brighter than pumice at 2500A. Many other examples of contrast changes with wavelength can be shown from the data reported herein.

Also of interest is the observation that several of the samples exhibited an apparent increase in reflectance as the wavelength decreased below 2500A. These increases in detected light could be due to the onset of photoluminescence. Additional measurements extending the wavelength range below 2300A and into the vacuum ultraviolet will be performed and, in so doing, any photoluminescence from these samples will be determined.

One correlation with rock composition was noted. That is, the rocks with high quartz content showed a marked increase in reflectance with increasing wavelength. On the other hand the rocks low in quartz showed no appreciable change in reflectance with wavelength.

II. Experimental Techniques

A. Sample Surface Preparation

Each sample was cut to form a one-quarter inch thick slab. One surface of the slab was then ground with 320 silicon carbide (30 micron particle size). This surface is designated as the "ground" surface for the reflectance measurements.

The other surface was ground with W8 aluminum oxide (8 micron size) and then polished with Linde "B" (0.05 micron) on one-quarter inch felt. This surface is designated as the "polished" surface for the reflection measurements. The samples of pumice and mica were not ground or polished.

Immediately after grinding or polishing, the surfaces were washed under running water to remove all abrasive. The sample surfaces were than rinsed in absolute alcohol. Care was taken in subsequent handling of the samples to insure that the surfaces were not touched or contaminated.

B. Reflectance Measurement

A Cary* Model 14 MR recording spectrophotometer with a model 1411 diffuse reflectance accessory was used for all reflectance measurements. The instrument was used in the

---

*Applied Physics Corporation, Monrovia, California

Type I illumination mode, i.e., a dispersed (monochromatic) collimated light beam is incident upon the sample surface, and the total diffuse reflectance is collected by an integrating sphere and detected by a DuMont type 7664 multiplier phototube. The sample reflectance was measured relative to a magnesium carbonate block which in turn was periodically calibrated against freshly prepared magnesium oxide surfaces.

The incident beam size at the sample surface has a constant height of 15 mm and a width of from 1 to 2 mm, proportional to the slit width of the spectrophotometer, throughout most of the spectral range studied. At wavelengths below 2500A the beam width increases continuously to about 5mm at 2300A. The spectral resolution varies from 10A to 20A throughout the visible and near ultraviolet, and then the spectral band opens up at wavelengths below 2500A to about 45A at 2300A. All data were recorded at a spectral scan rate of 10A/sec.

Two detection modes are possible with this instrument. In one mode the specularly reflected component is trapped or masked off from the integrating sphere. In the data which follow we designate this mode as (D), diffuse reflectance only. The other mode includes the specularly reflected component and is designated as (S), specular plus diffuse.

The absolute values of reflectance used for the magnesium oxide standard reference are listed below. These values

λ(A)	% Refl. of MgO
7000 to 4000	97.0
3500	96.5
3250	96.0
3000	95.5
2750	94.8
2500	94.0
2400	93.0
2300	92.0

are selected from several references (1,2,3). There are still uncertainties of the absolute values of reflectance in the ultraviolet spectral range. However, differences of a few percent in the absolute values of magnesium oxide reflectance would not change the reported data significantly.

III. Data and Discussion

The samples studied are listed in Table 1. These are grouped first as Rocks, Minerals, and Meteorites. The rocks are then grouped roughly as to their composition and texture. For example, Granite is the coarse-grained equivalent of Rhyolite (both have about the same composition), and Gabbro is the coarse-grained equivalent of Basalt. Diabase is approximately the same composition as both Gabbro and Basalt, but it has an intermediate texture.

The data curves are given in the Appendix in the same order as the Table 1 listing. The notations for the four curves for each sample are the following:

Ground (D) = ground surface, diffuse reflectance only;

Ground (S) = ground surface, diffuse plus specular reflectance;

Polish (D) = polished surface, diffuse reflectance only;

Polish (S) = polished surface, diffuse plus specular reflectance.

Since the incident beam size is 1 to 2 mm in width, one could expect differences in reflectance for the coarse grained samples which are dependent upon the sample position. This was tested on several of the coarse grained samples and it was found that the reflectance curves obtained for different positions of the sample surfaces had the same shape with a constant reflectance value difference of one or two percent. The absolute reflectance values of these data are considered, therefore, to be good to within plus or minus two percent, i.e. a plotted value of 10 percent is 10$\pm$ 2 percent. The instrument stability and reproducibility are far better than that quoted above. Thus the curve shapes and relative values are accurate as shown.

Table 1

REFLECTANCE SAMPLES

Code No.	Type	Source Locality
		ROCKS
Li 2617	Biotite Granite	Pike's Peak, Colorado
Li 3823	Granite	Moose-a-bec, Maine
Li 4582	Granite	Newark, Vermont
	- - - -	
Li 2730	Rhyolite	West flank of Black Range, Grant Co., New Mexico
Li 3760	Rhyolite	Nathrop, Colorado
324	Obsidian (banded) Rhyolitic	Mono Craters, Lee Vining, California
Li 1832	Obsidian	Regla Falls, Aidalgo, Mexico
326	Rhyolite Pumice	Mono Craters, Lee Vining, California
Li 1221	Pumice	Latacunga, Ecuador
Li 2213	Nepheline Syenite	Cripple Creek, Colorado
Li 3946	Nepheline Syenite	Magnet Cove, Arkansas

Table 1 (continued)

Code No.	Type	Source Locality
	- - - -	
Li 3765	Quartz Monzonite Porphyny	Garfield, Colorado
Li 3905	Monzonite	Tintie, Utah
312	Quartz Monzonite	June Lake, California
	- - - -	
Li 2816	Diorite	Bar Harbor, Maine
Li 3770	Diorite	Timichi Creek, Gunnison, Colorado
Li 3662	Hornblende Andesite	Larch Mountain, Oregon
	- - - -	
Li 3676	Gabbro	Tahawas, New York
G-1	Gabbro	Near Clearwater Lake, Gunflint Trail, Minnesota
Li 4238	Gabbro	Everton, New York
258	Anorthosite-Pyroxene Gabbro	Grass Valley, California
Li 2288	Basalt	Whatcomb Co., Washington

Table 1 (continued)

Code No.	Type	Source Locality
101	Basalt	Jack Green-IR Standard sample
G 3161	Basaltic Lava	El Paricutin, Mexico
Li 4156	Volcanic Bomb (probably Basalt)	Near Needles, California
	- - - -	
Li 2811	Diabase	Hall Quarry, Mount Desert Island, Maine
222	Diabase (Triassic)	________________
	- - - -	
El 8086	Dunite	Buck Creek Dist., Macon Co., North Carolina
289	Olivine (Dunite) polycrystalline	Jackson Co., North Carolina
	- - - -	
Li 2402	Kimberlite	Elliot Co., Kentucky

Table 1 (continued)

Code No.	Type	Source Locality
	MINERALS	
Li 3675	Anorthosite	7 miles N.E. of North Hudson, New York
260	Potash Feldspar	Keystone, South Dakota
	Microcline	
251	Plagioclase Feldspar-Albite	Bancroft, Ontario
292	Mica - Biotite	Bancroft, Ontario
288	Amphibole-Hornblende	Faraday Twp., Ontario
44	Dolomite (fine-grained)	Wise Co., Virginia
	METEORITIES	
ME 1990	Hypersthene Chondrite	Colby, Clark Co., Wisconsin
ME 1252	Coarse Octahedrite (iron-nickel)	Canon Diablo, Cononime Co., Arizona

At 4000A the instrument's light source is changed from a tungsten filament lamp for the visible to a hydrogen lamp for the ultraviolet. There are related changes in slit width (beam width) and slight changes in beam position due to this light source change. Thus, the reflectance values of these inhomogeneous samples are not precisely the same at 4000A for the different light sources. Again it is noted from the data that, in all curves but one, the differencein reflectance values is no more than two percent at the 4000A change-over point. Sample No. 258 (Anorthosite - Pyroxene Gabbro) has an abnormally high gap of five percent at 4000A. Unfortunately, this sample was returned to the sponsor and has not been rechecked.

None of the reflectance curves showed any characteristic peak or bands. In general, the shapes of the reflectance curves for all samples are the same for both the ground and polished surfaces, and the total reflectance from the ground surface is greater than that from the polished surface. Also, in general, the reflectance increases as the wavelength increases. In the few cases where these general observations are not true, the exceptions occur primarily in the ultraviolet wavelength region. The inclusion of the specularly reflected component is significantly noticeable only for the polished surfaces where the total reflectance increases appreciably but the reflectance curve shape remains the same.

In the ultraviolet region, at 2500A, for example, the vast majority of the rocks and minerals examined have reflectance values which lie in the range of 5 to 15 percent while, in the visible region, at 6000 - 7000A for example, these same materials have reflectance values ranging from 10 to 50 percent. The relative reflectance from sample to sample, however, does not remain the same throughout the spectral range. Thus, the contrast in imaging an array of different rocks could vary appreciably between a visible sensitive imager and an ultraviolet sensitive imager. For example, pumice has a diffuse reflectance of 32 percent at 5000A (one of the higher observed reflectivities) and only a 3 percent reflectance at 2500A (the lowest reflectance recorded), monzonite has reflectance values of 16 percent and 18 percent at 5000A and 2500A, respectively. Pumice would appear about twice as bright as monzonite at 5000A, but monzonite would be about five times brighter than pumice at 2500A. Many other examples of contrast changes with wavelength can be shown from the data reported herein.

Several of the samples exhibited an apparent increase in reflectance as the wavelength decreased below 2500A. These increases in detected light could be due to the onset of photoluminescence. Additional measurements extending the wavelength range below 2300A and into the vacuum ultraviolet will be performed and, in so doing, any photoluminescence from these samples will be determined.

The rocks with high quartz content (>10%) show a marked increase in reflectance with wavelength. These are granites and rhyolites. On the other hand, the rocks low in quartz (about 0%) show no appreciable change in reflectance with wavelength (e.g., gabbros and basalts). So the presence of quartz seems to cause the reflectance to increase with increasing wavelength. This is shown very nicely by comparing the quartz monzonites with the monzonite: the reflectance of the quartz monzonites increases with increasing wavelength whereas the reflectance of the monzonite decreases with increasing wavelength.

Notice also that the reflectance of both the potash and plagioclase feldspar increases with increasing wavelength. In general, the total feldspar content of common rocks is constant, say 85% for a number. In the granite type rocks most of the feldspar is of the potash variety whereas in the basaltic type rocks most of the feldspar is the plagioclase variety. Since the reflectance vs. wavelength characteristics of both are vary similar, it appears doubtful that the feldspars (either potash or plagioclase) will provide a diagnostic means for determining rock types by ultraviolet spectral data (as does the quartz content as pointed out above).

The effect of texture on reflectance may be indicated by a comparison of obsidian or mica, very smooth glassy like surface, and pumice, a very rough and porous surface. Obsidians reflectance is nearly independent of wavelength while the reflectance of pumice increases markedly with wavelength.

The above mentioned dependence on the reflectance curve shape with the quartz content of the rock is illustrated in Figure 1, where the spectral curves of the total diffuse reflectance from the ground surfaces of a selected set of eight different rocks are shown. It must be understood that the actual quartz content of these particular samples is not known; however, the ordering of increasing quartz content as given in the figure is one which could generally be expected geologically and is used to indicate a possible trend in reflectance versus rock composition. The monzonite sample (Li 3905) exhibits an anomalous behavior below 4500A compared to the other samples of this set, i.e. its reflectance continues to increase with decreasing wavelength. At this time there is no suggested explanation for this fact.

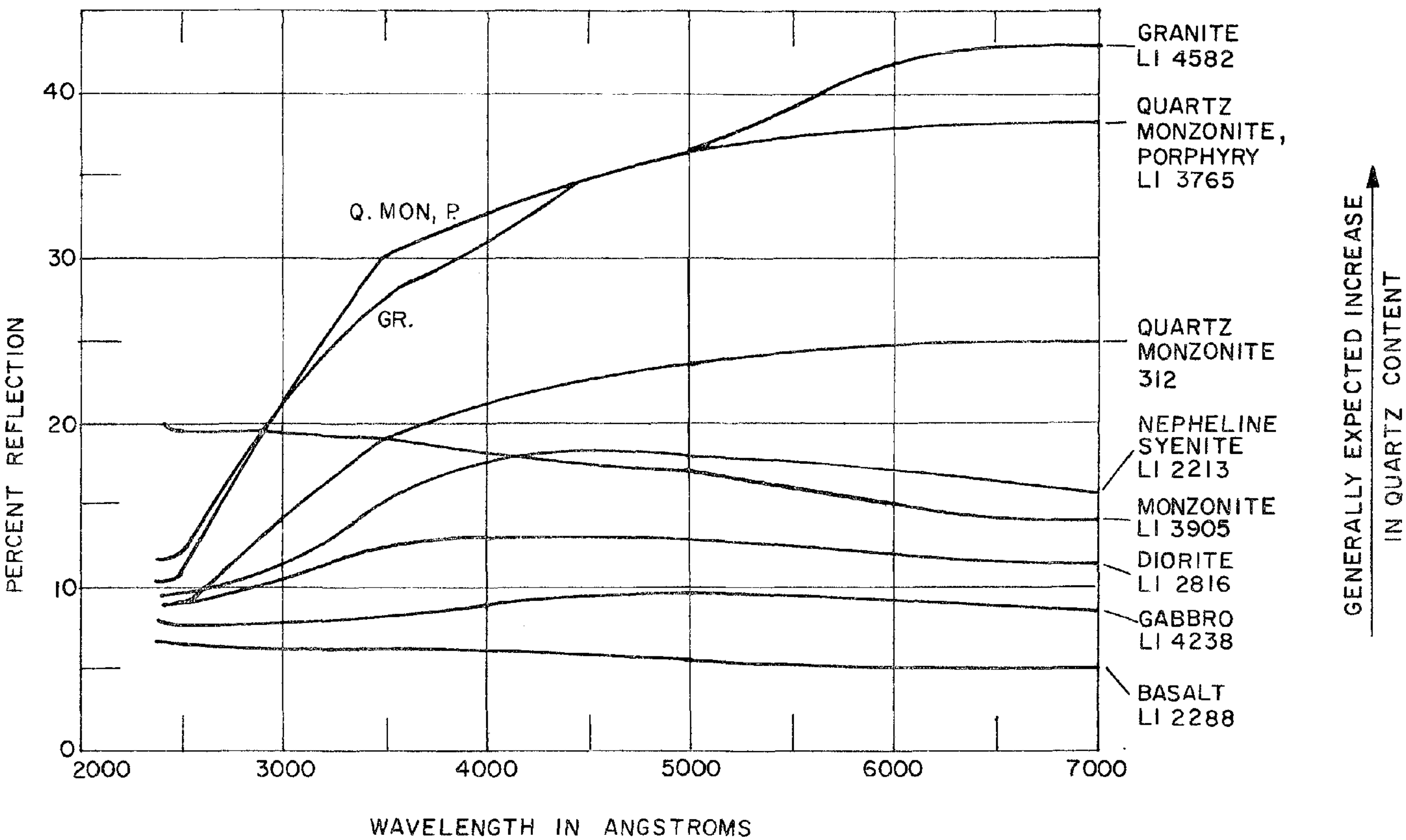


FIGURE I. SPECTRAL DEPENDENCE OF TOTAL DIFFUSE REFLECTANCE FROM THE GROUND SURFACES OF A SELECTED SET OF ROCK SAMPLES. THE DATA CURVES ARE CHOSEN TO ILLUSTRATE THE POSSIBLE TREND IN REFLECTANCE CURVE SHAPE WITH THE QUARTZ CONTENT OF THE ROCKS.

IV. Conclusions and Future Work

In general, the reflectance from rocks and minerals increases as the wavelength increases from 2300A to 7000A, and the shapes of the reflectance curves are the same for both the ground and the polished surfaces.

Rocks with a high quartz content showed a larger increase in reflectance with wavelength than those with a low quartz content.

Since the relative reflectance from sample to sample does not remain the same throughout the spectral range, the contrast in imaging a rock pattern would vary appreciably between a visible sensitive imager and an ultraviolet sensitive imager.

Future work will be conducted extending the wavelength range below 2300A and into the vacuum Ultraviolet to about 1000A. This work will utilize a scanning vacuum grating monochromator of the Seya - Namioka Type. A special sample and detector housing for this instrument has been designed and is now being constructed. The study will look for both reflectance and photoluminescence from the samples. Also, the data to be obtained with this instrument will overlap that reported herein up to 3000A. This overlap in data should indicate whether there are differences in reflectance from a rock surface in vacuum versus that in air.

REFERENCES

1. W. E. K. Middleton and C. L. Sanders, J. Opt. Soc. Am. 41, 419 (1951).

2. Gene A. Zerlaut and A. C. Krupnick, "An Integrating Sphere Reflectometer for the Determination of Absolute Hemispherical Spectral Reflectance," presented at 1st AIAA Annual Meeting, Washington, D. C., June 29 - July 2, 1964.

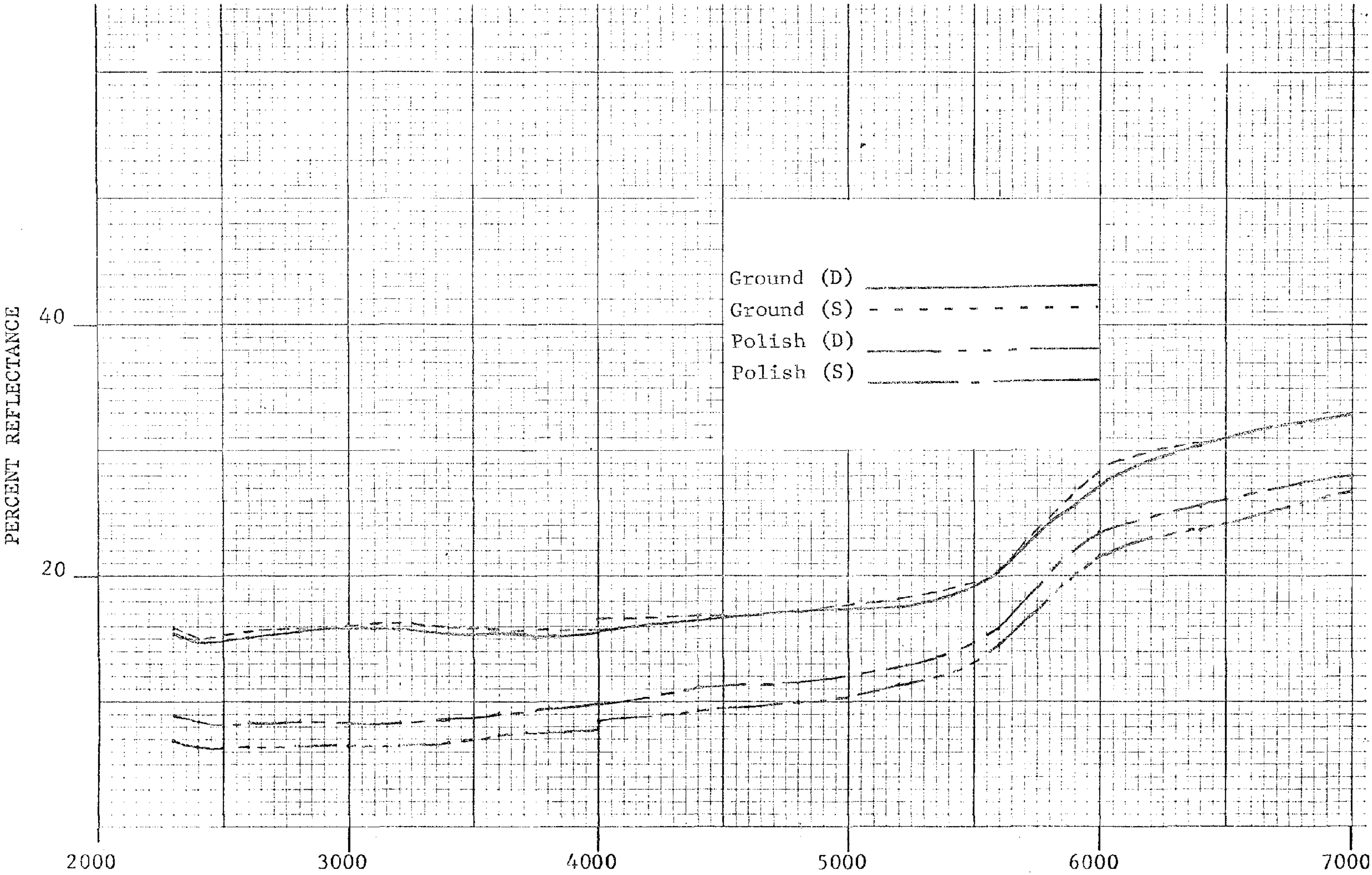
3. Gene A. Zerlaut, (private communication of unpublished work).

APPENDIX

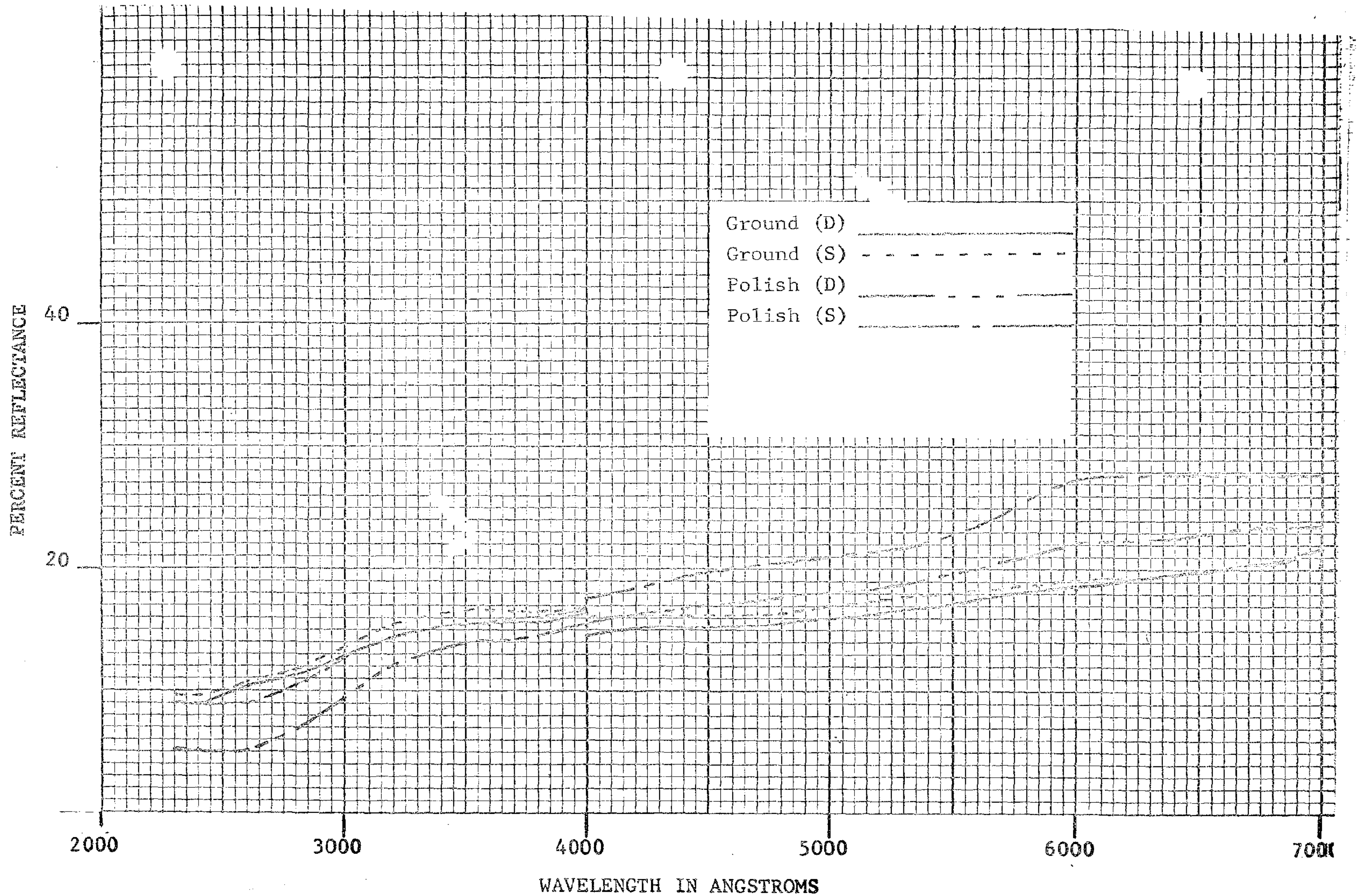
SPECTRAL REFLECTANCE DATA CURVES

Rocks	pp. 20 - 49
Minerals	pp. 50 - 55
Meteorites	pp. 56 - 57

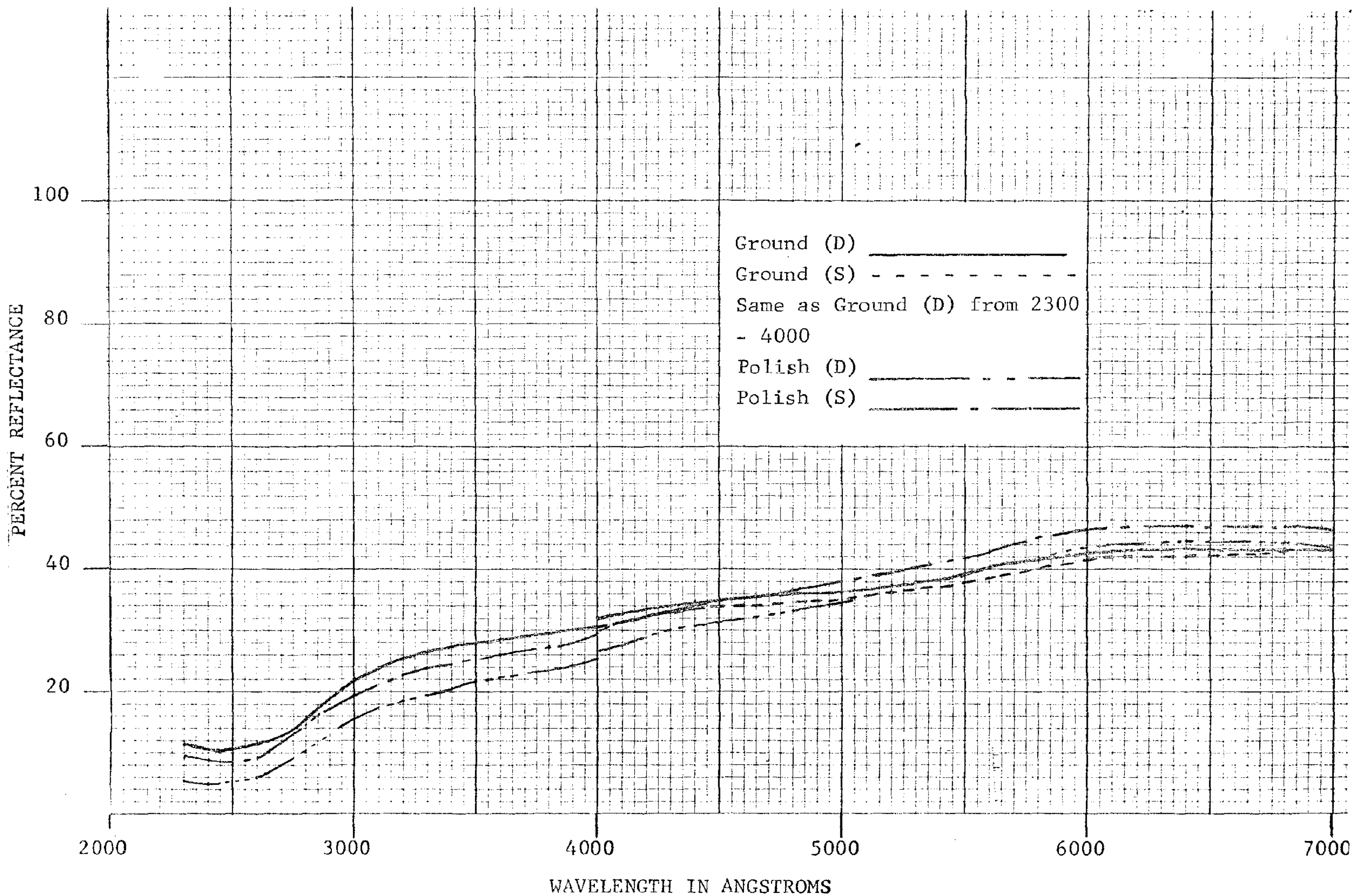
Note: The data curves are presented in the same order as listed in Table 1.



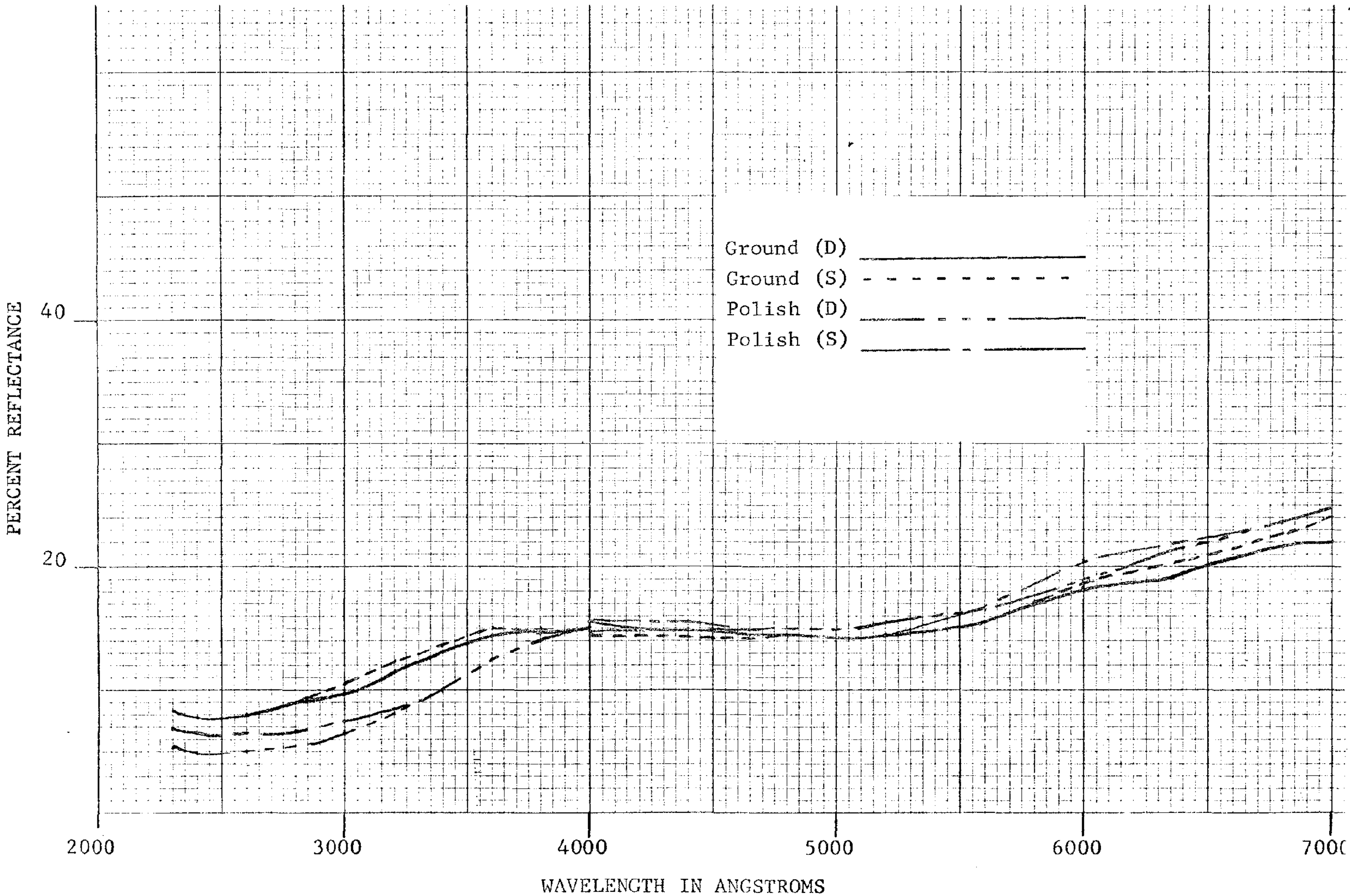
Li 2617 Biotite Granite



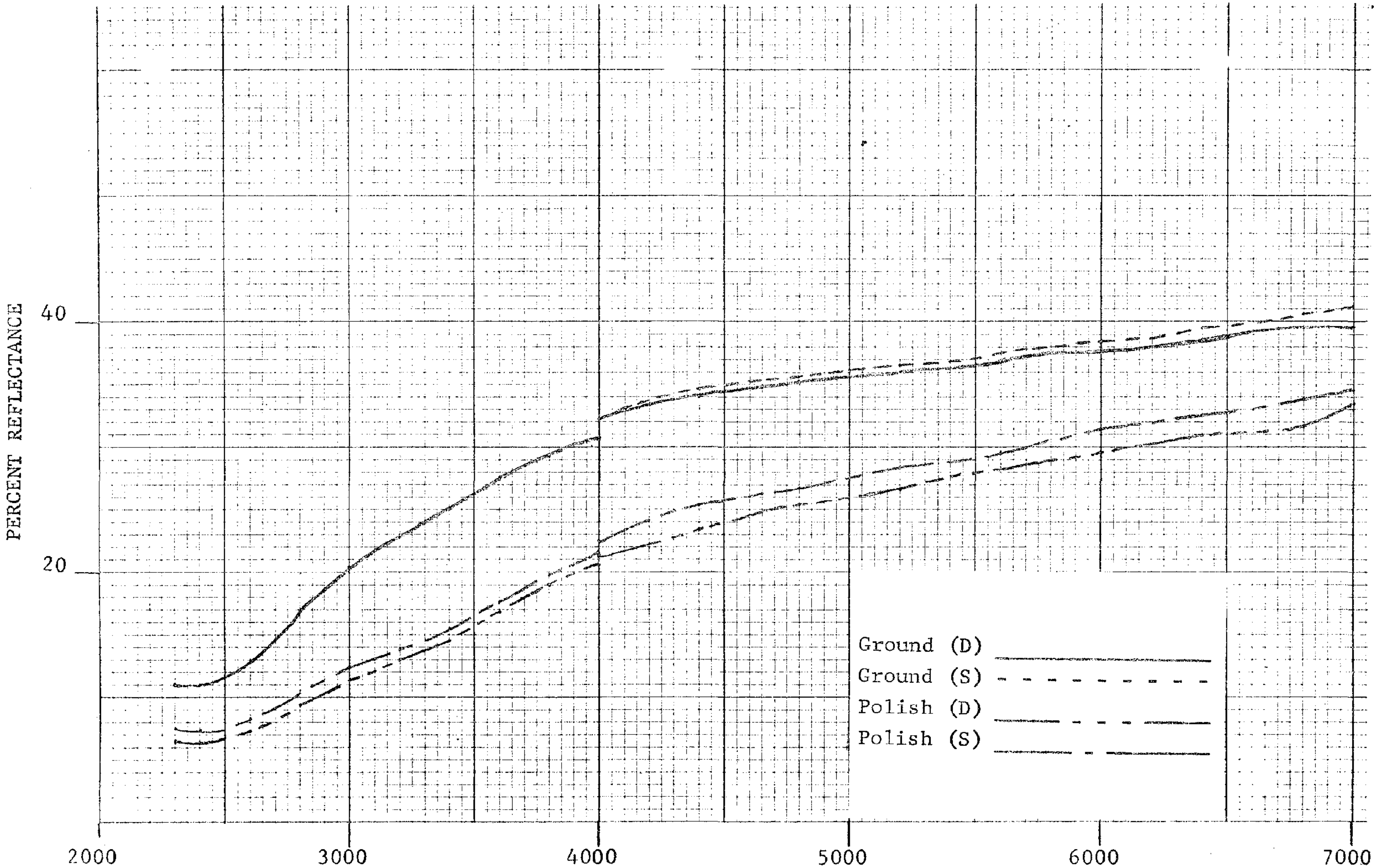
Li 3823 Granite



Li 4582   Granite

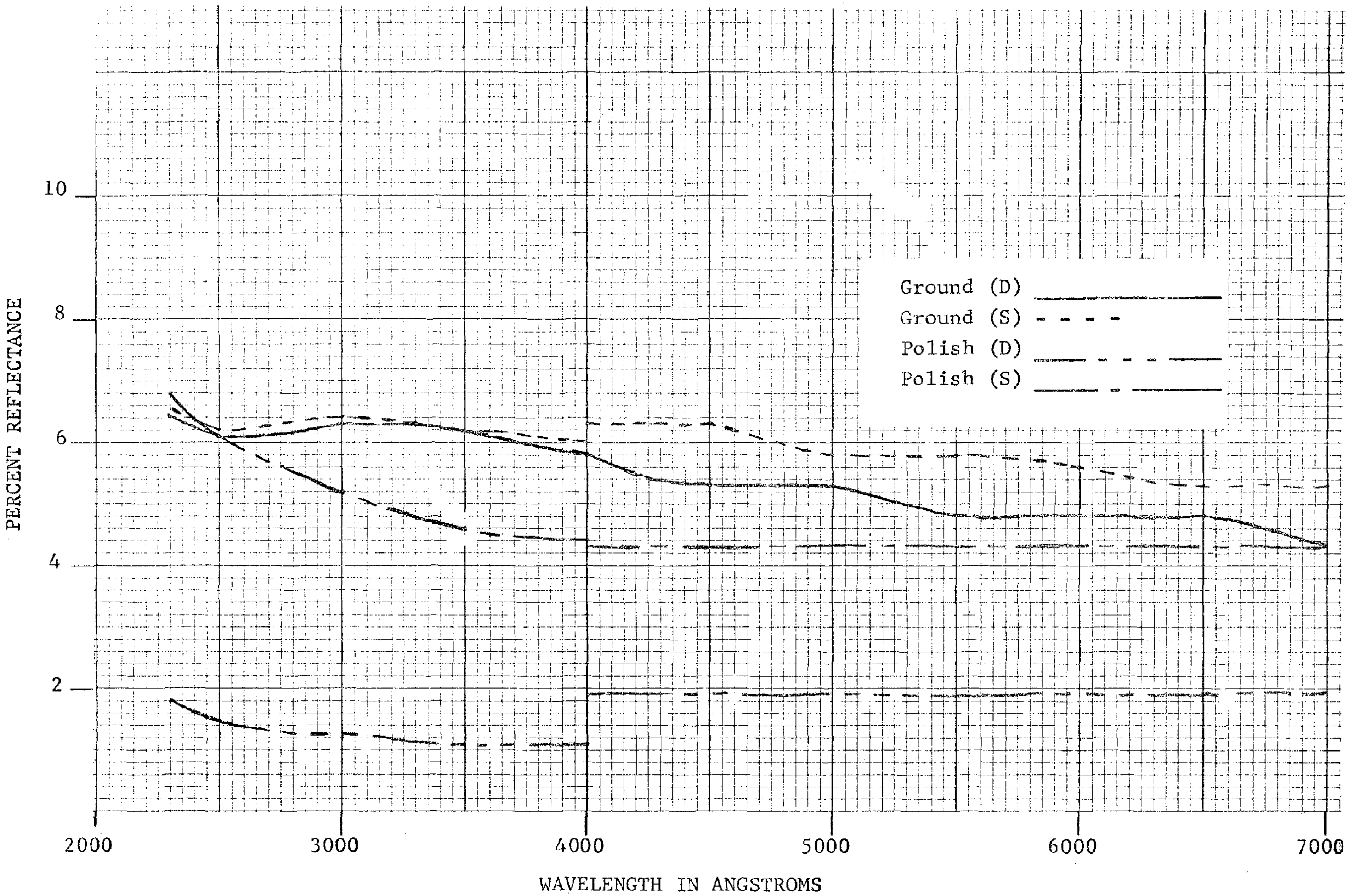


Li 2730 Rhyolite

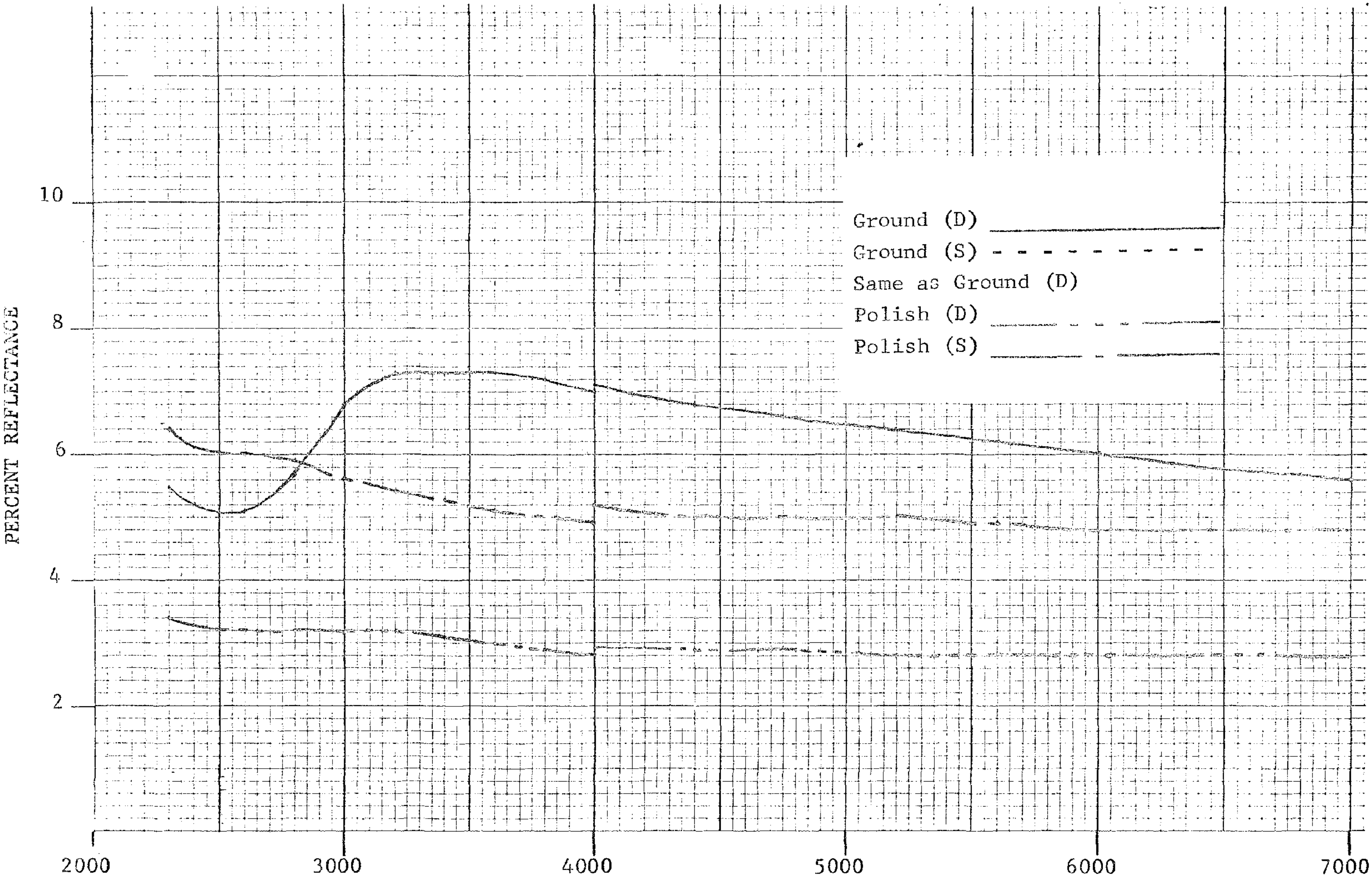


WAVELENGTH IN ANGSTROMS

Li 3760 Rhyolite

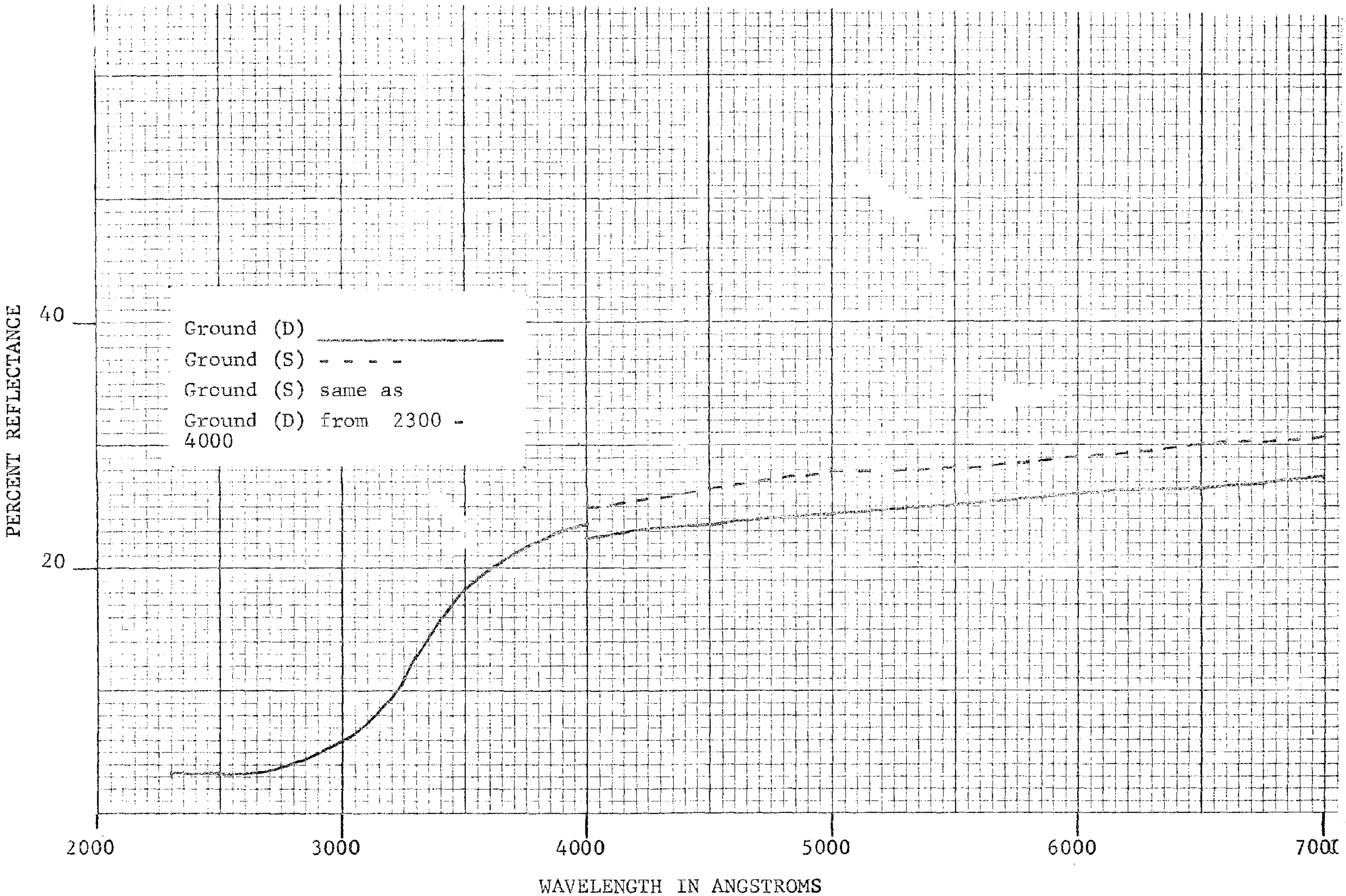


324 Obsidian (banded) rhyolitic

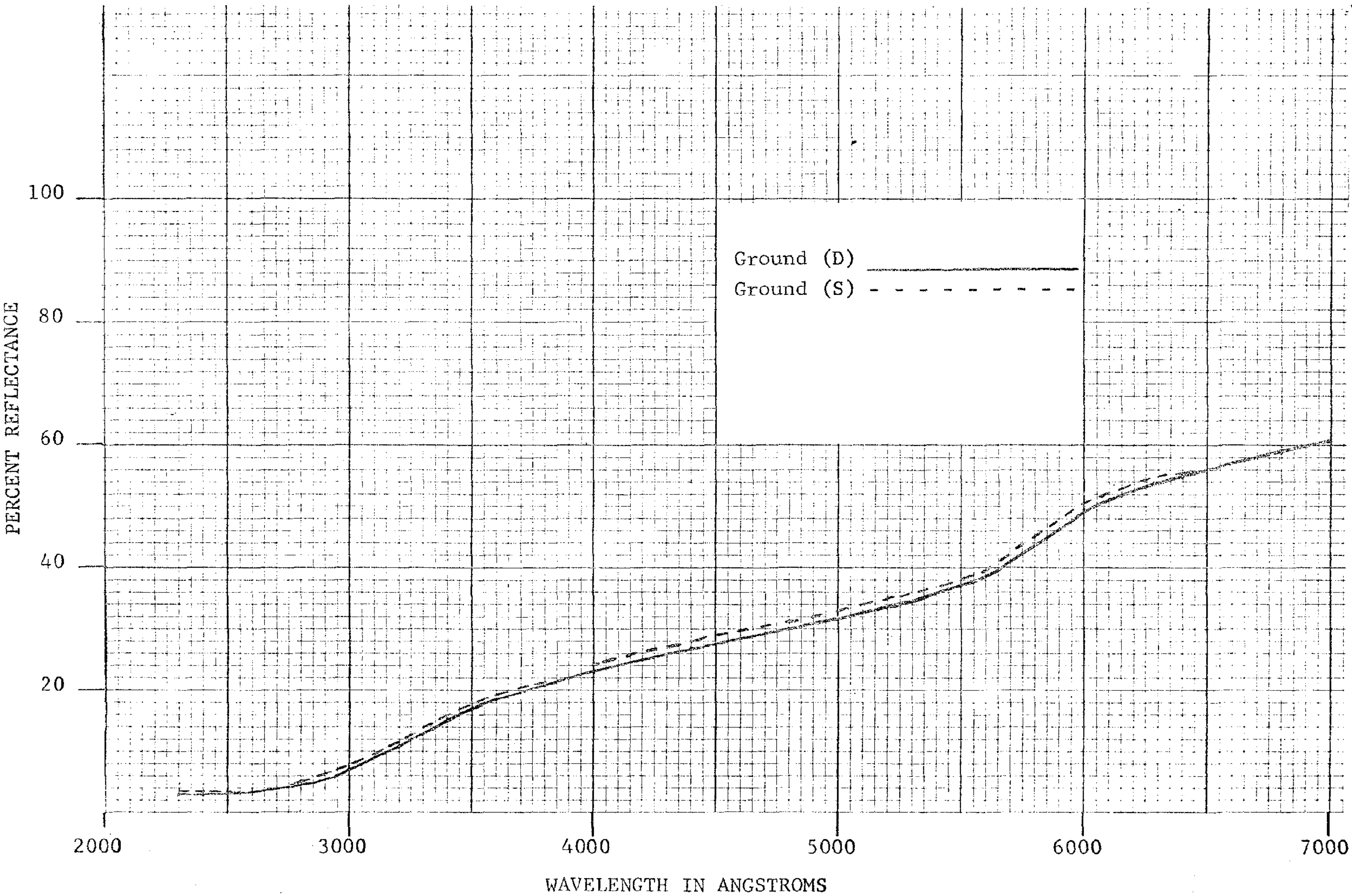


WAVELENGTH IN ANGSTROMS

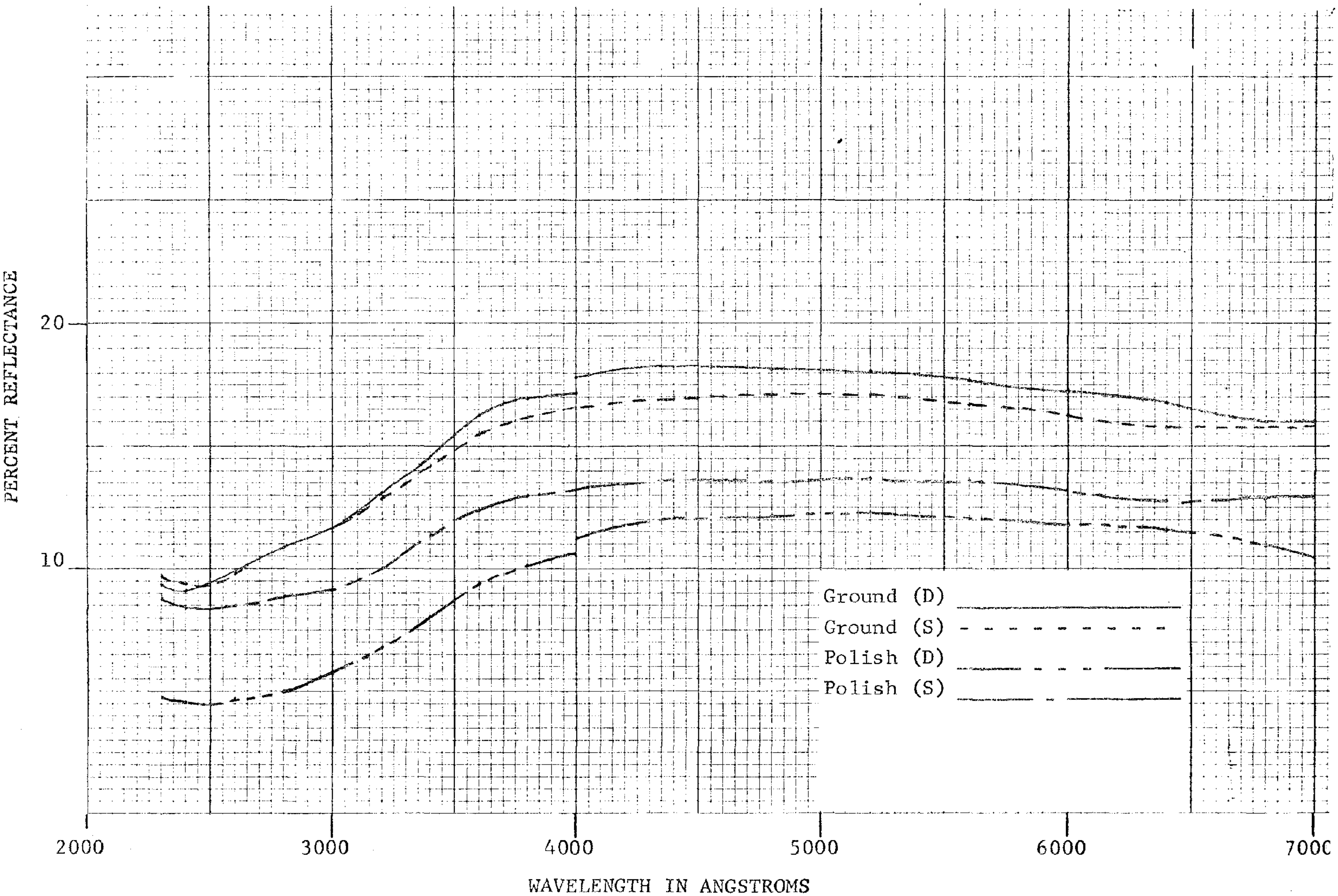
Li 1832 Obsidian



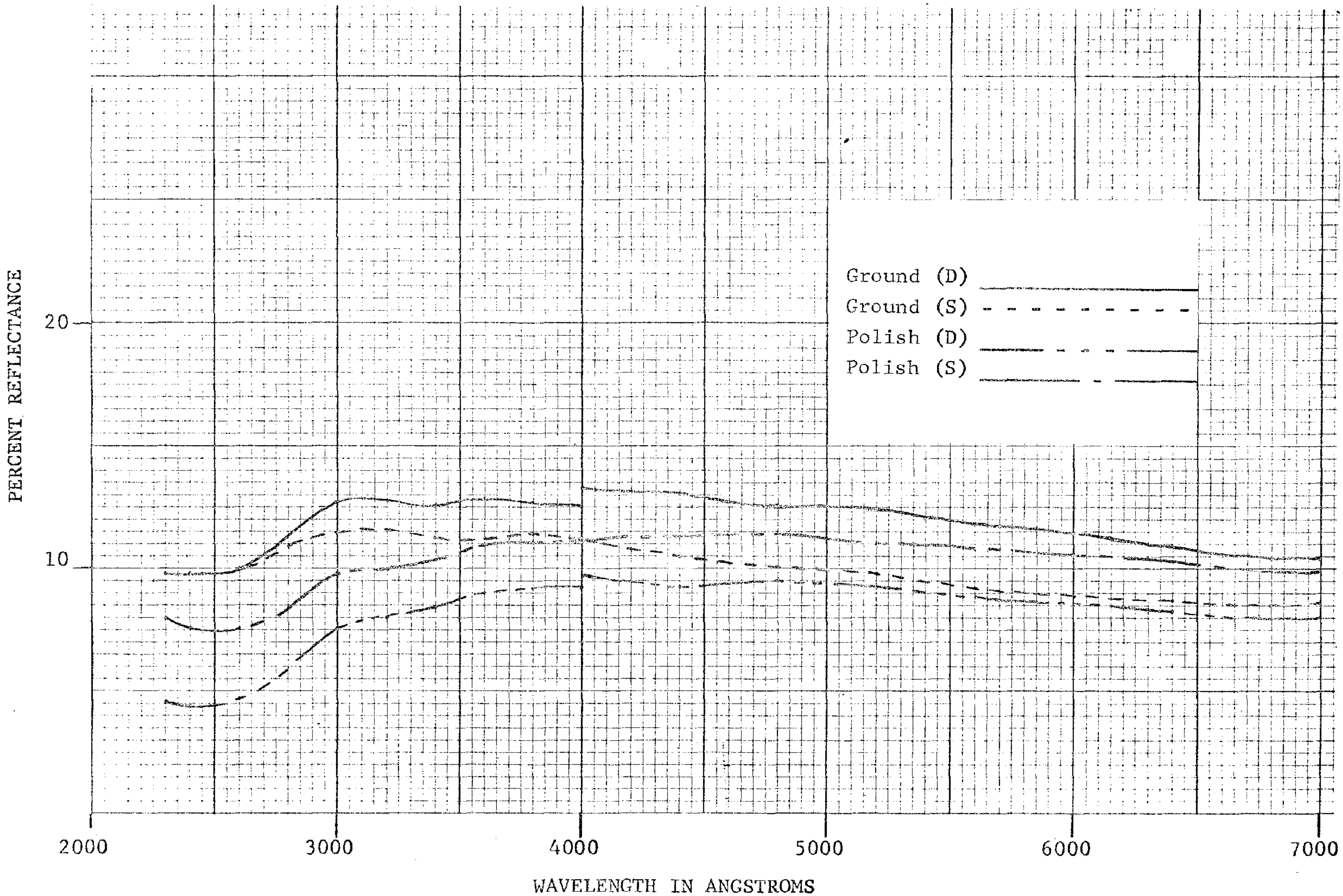
326 Rhyolite pumice



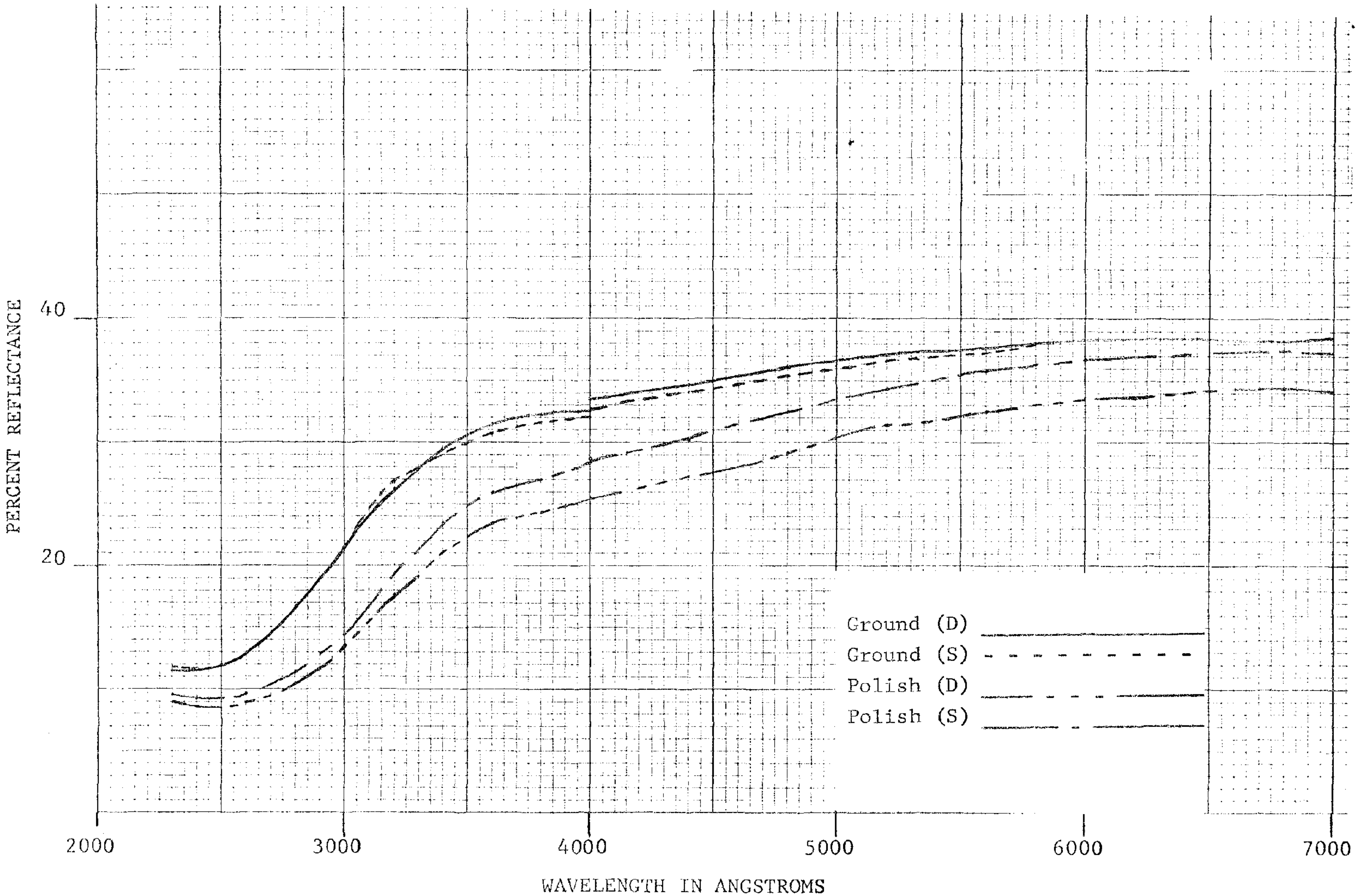
Li 1221 Pumice



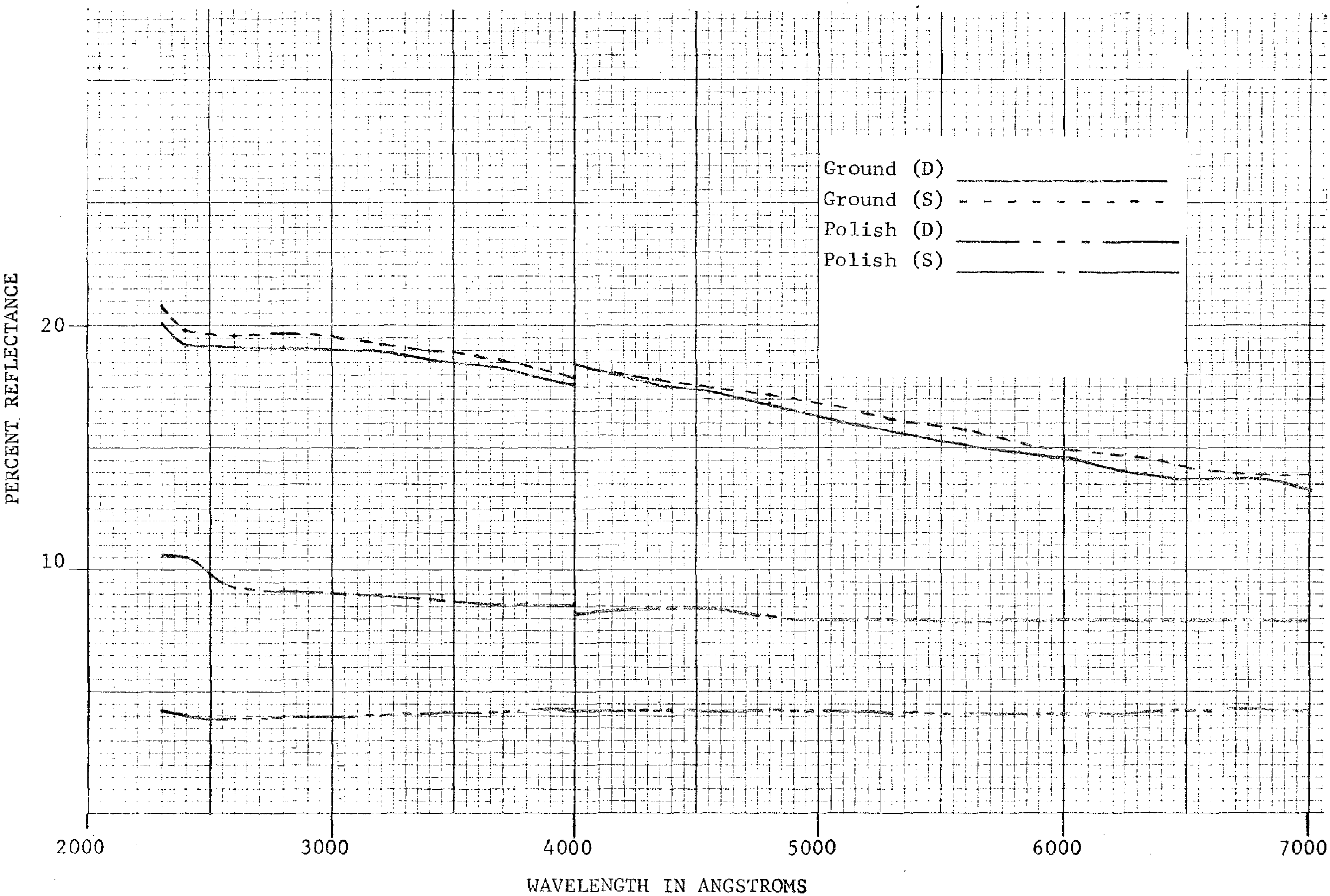
Li 2213 Nepheline Syenite



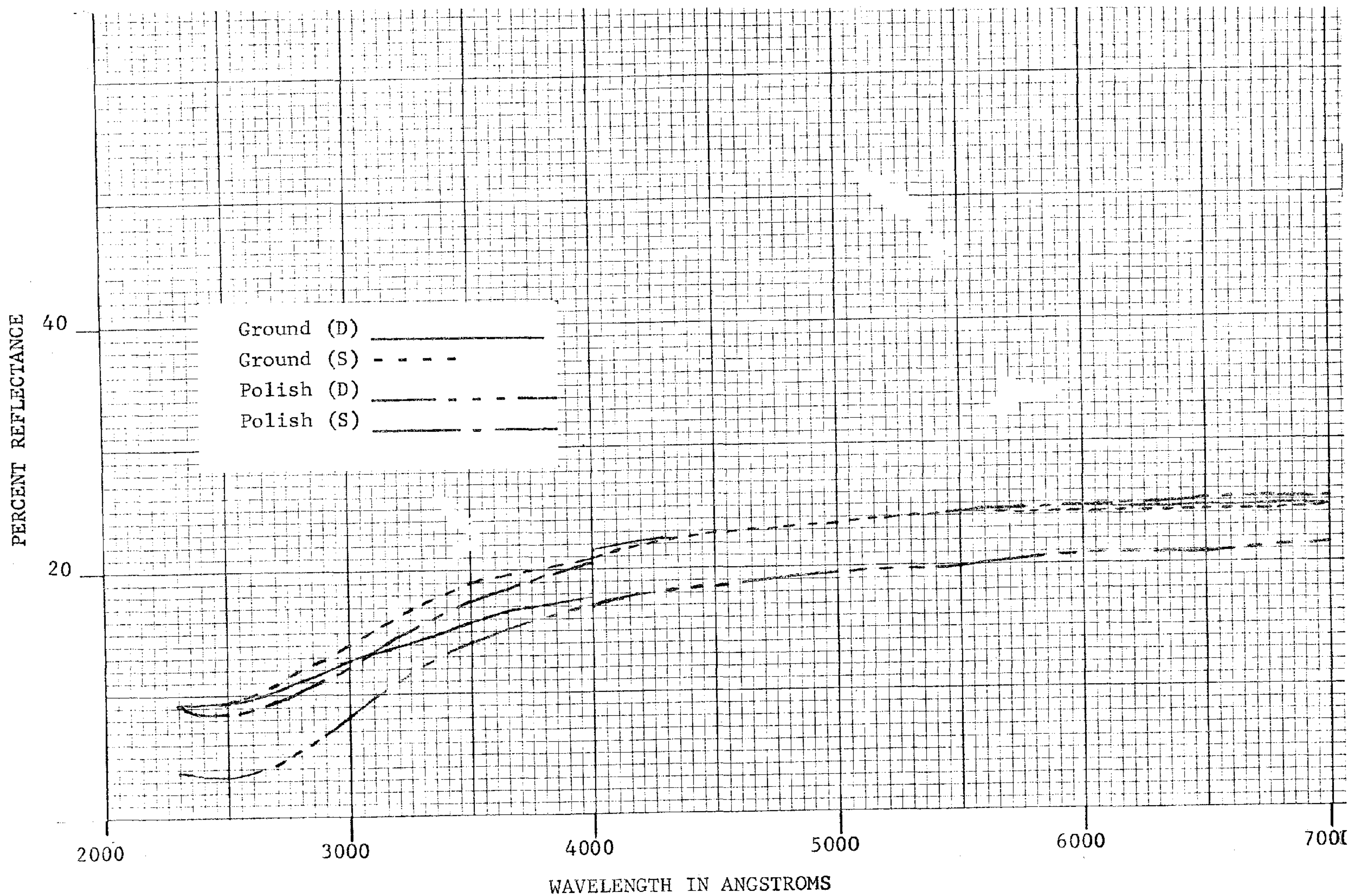
Li 3946   Nepheline Syenite



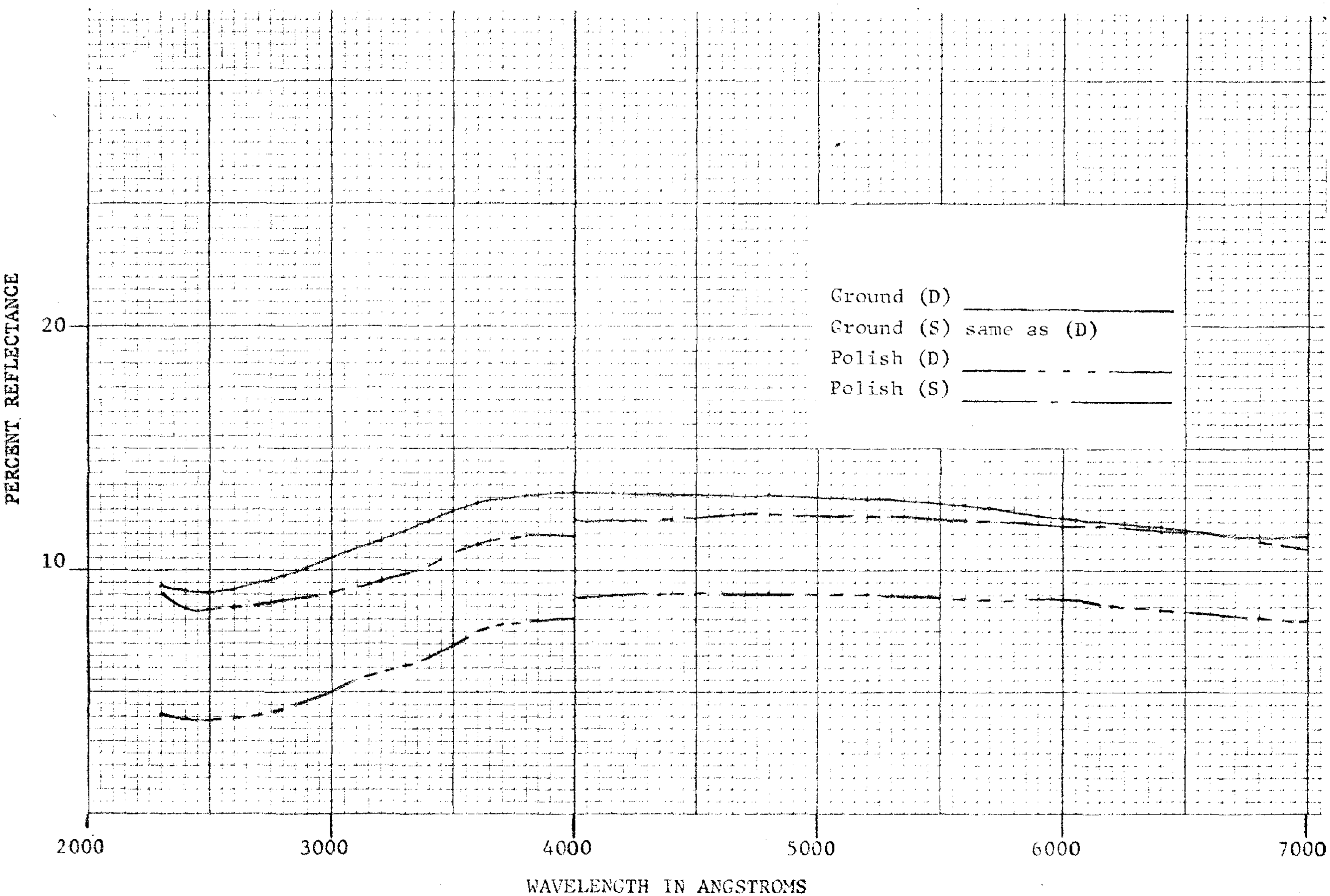
Li 3765 Quartz Monzonite, Porphyry



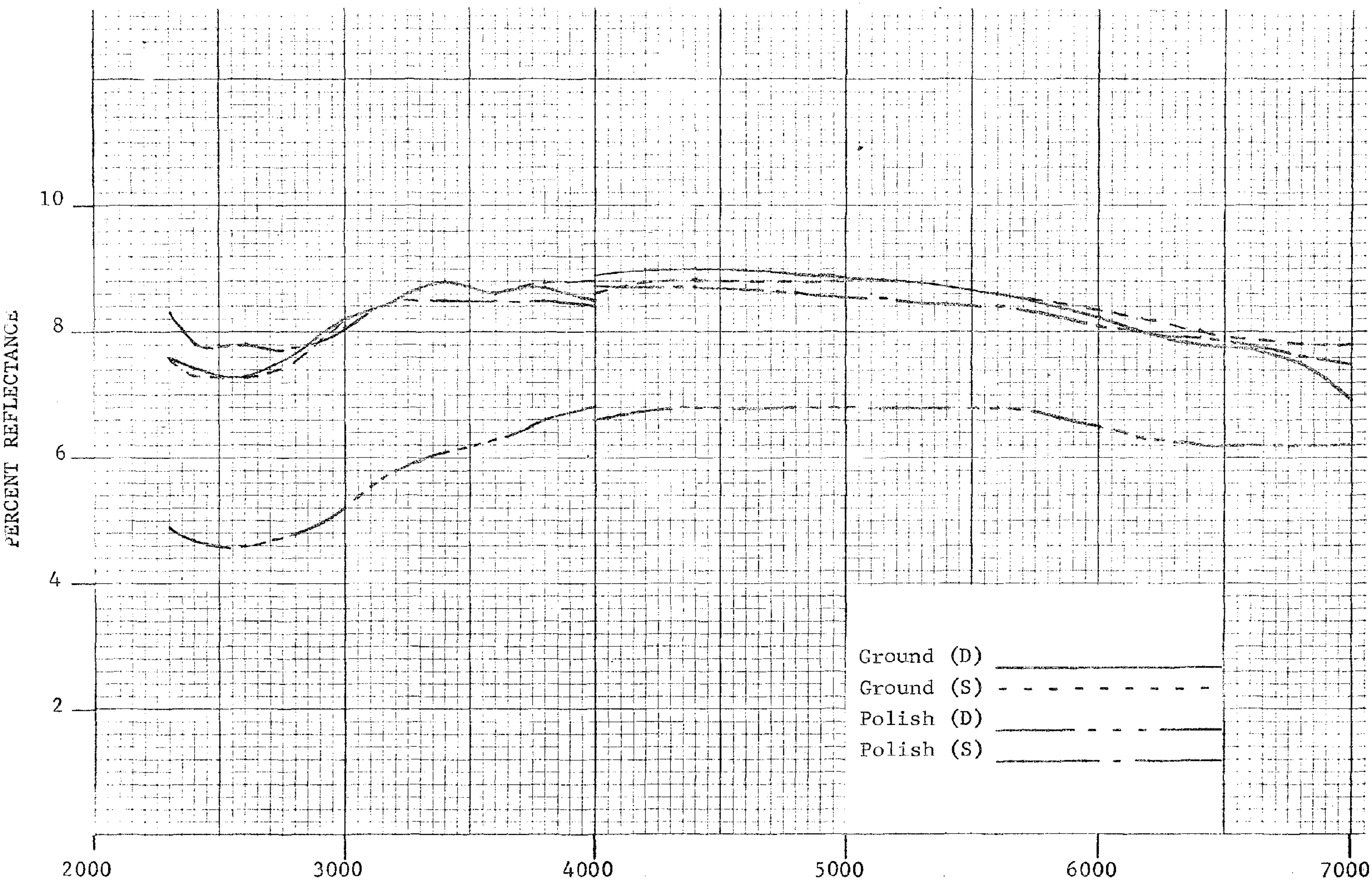
Li 3905 Monzonite



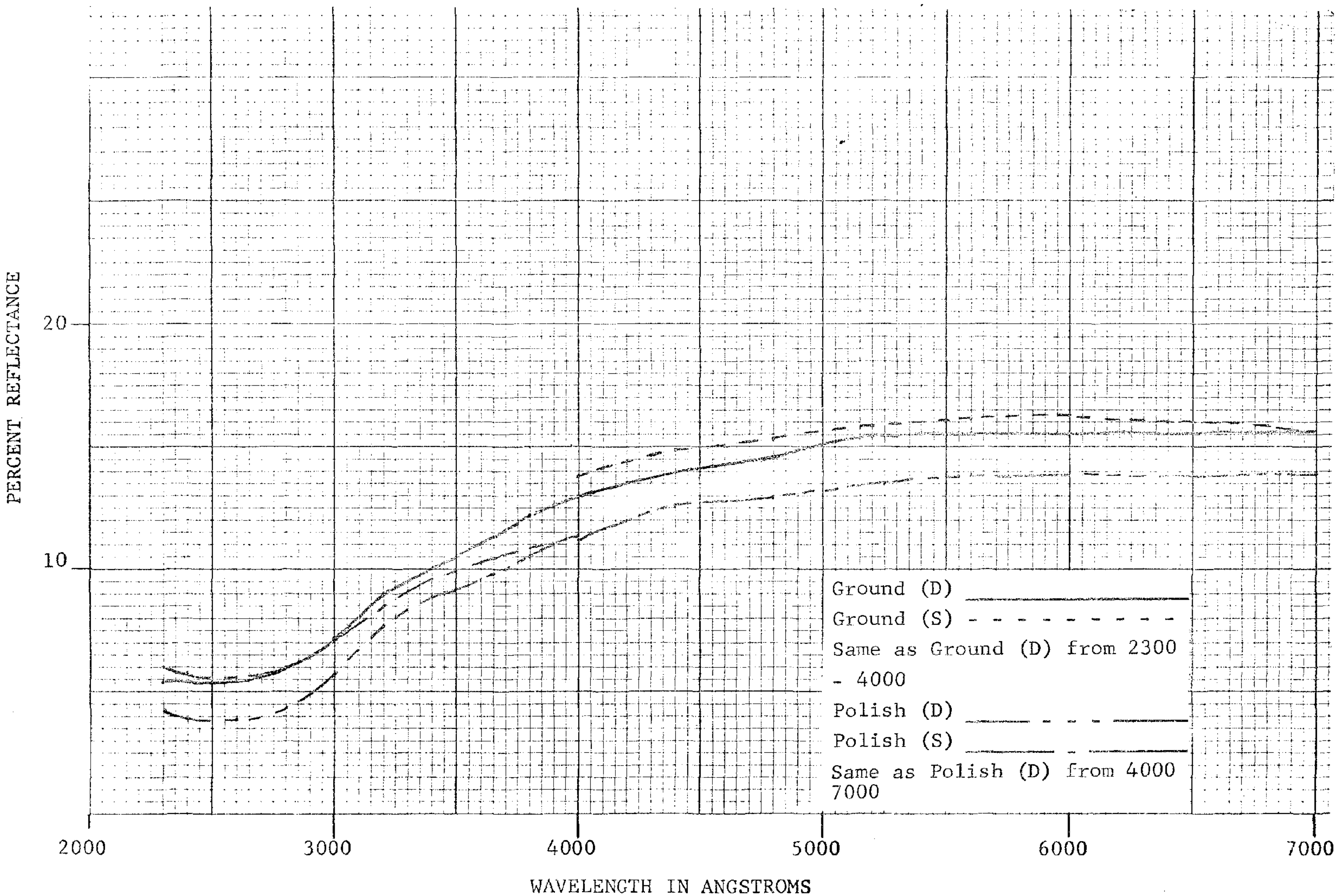
312 Quartz Monzonite



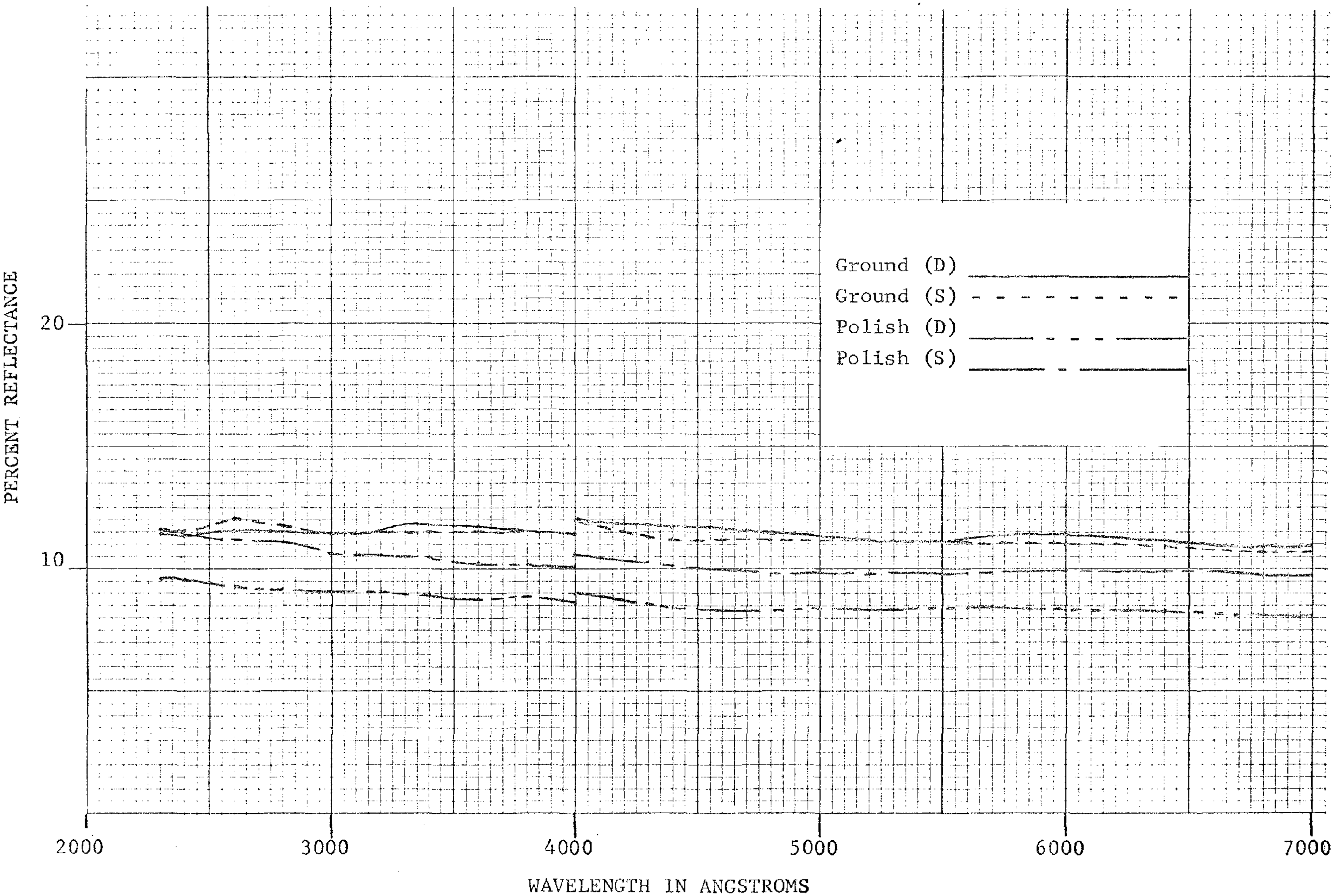
Li 2816 Diorite



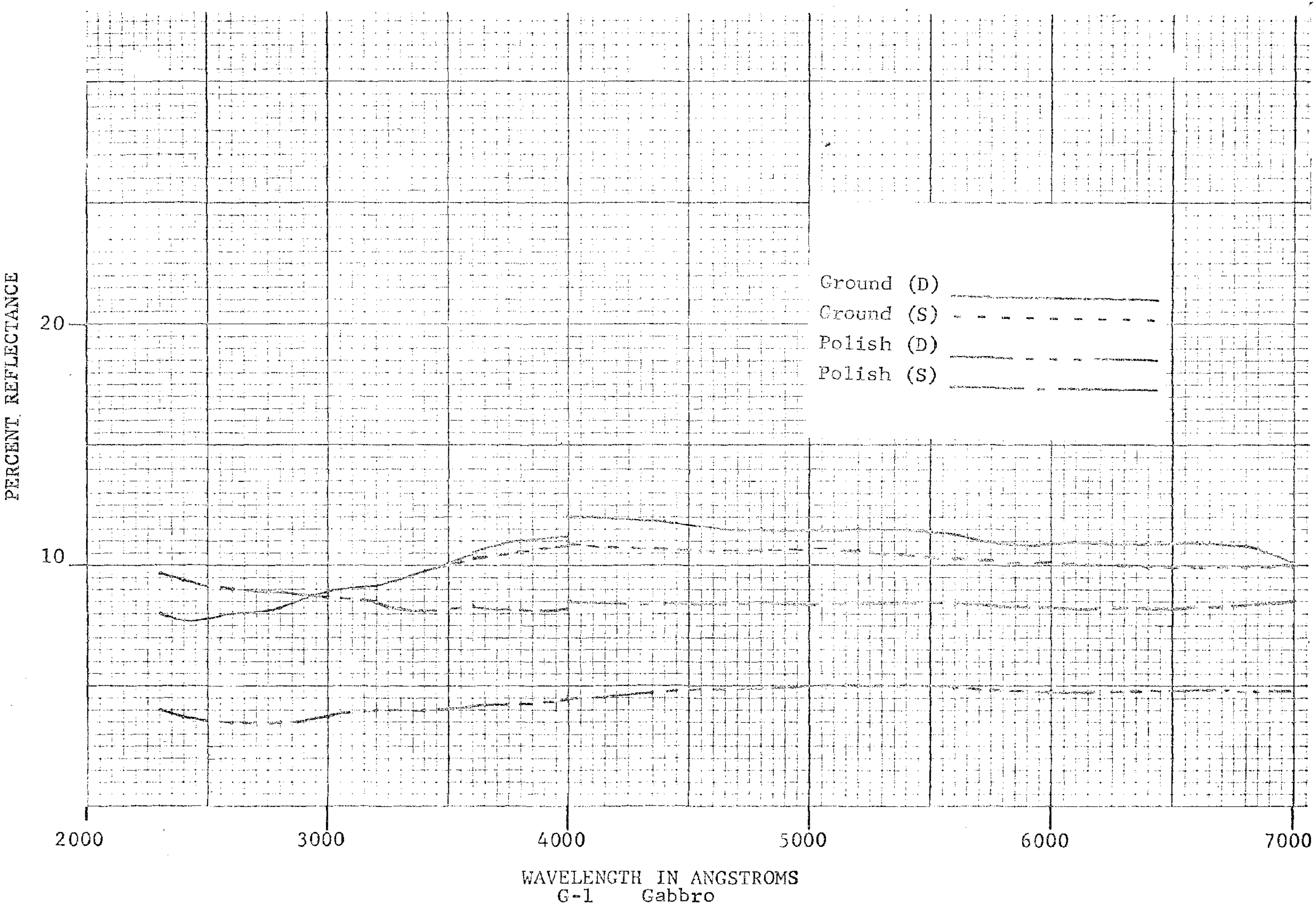
Li 3770 Diorite



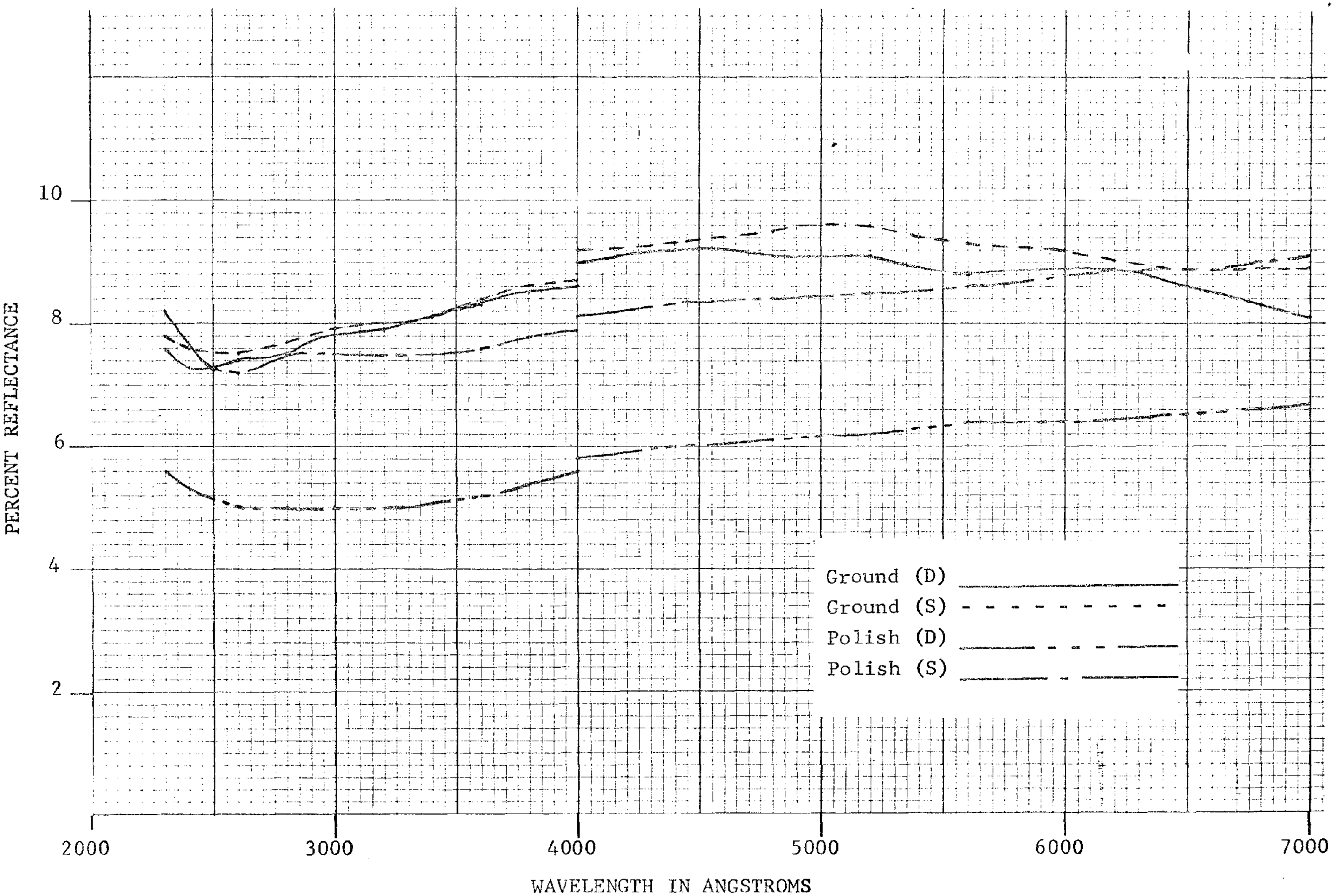
Li 3662 Hornblende Andesite



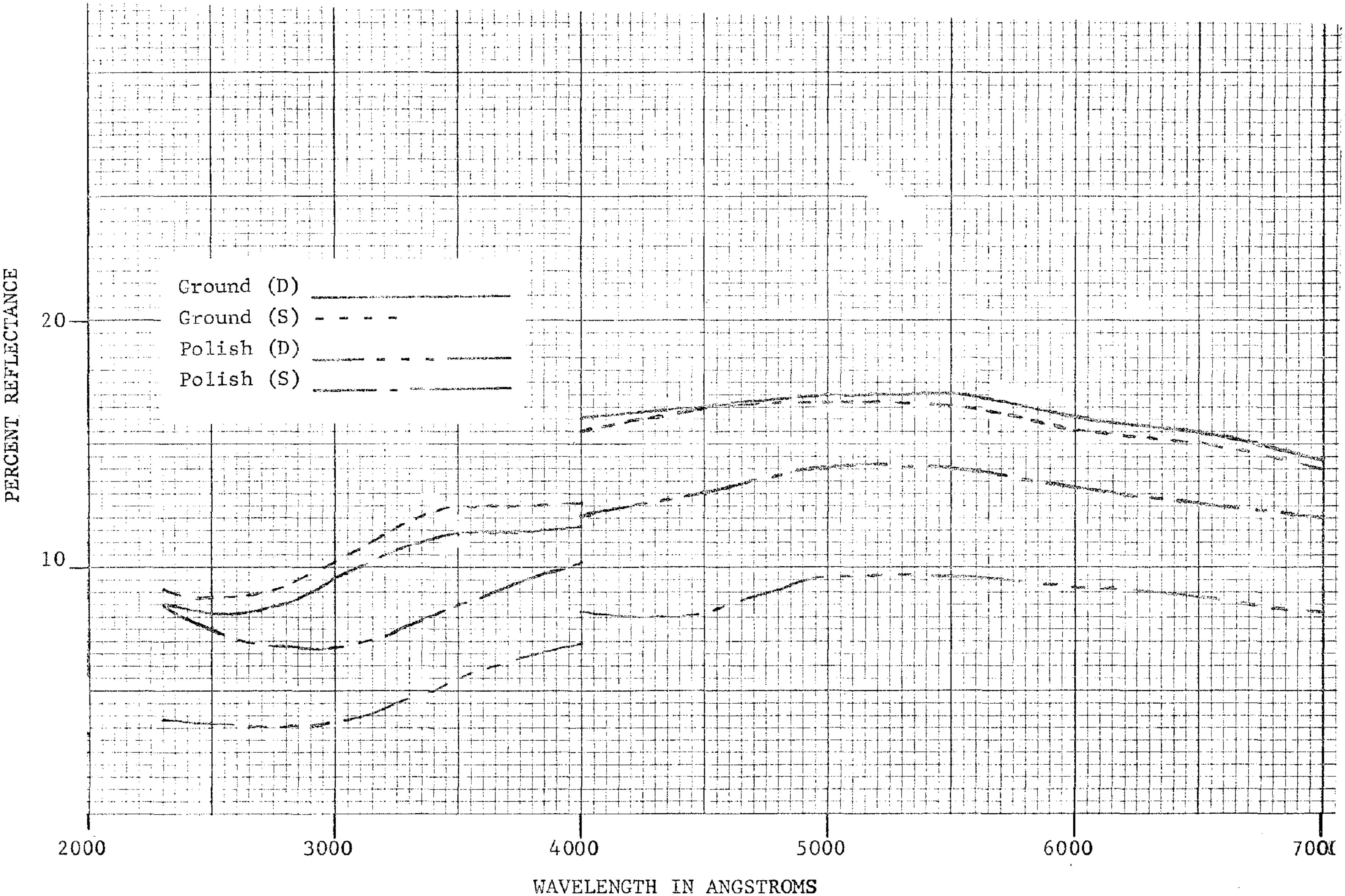
Li 3676 Gabbro


PERCENT REFLECTANCE
20
10
Ground (D)
Ground (S)
Polish (D)
Polish (S)
2000
3000
4000
5000
6000
7000
WAVELENGTH IN ANGSTROMS

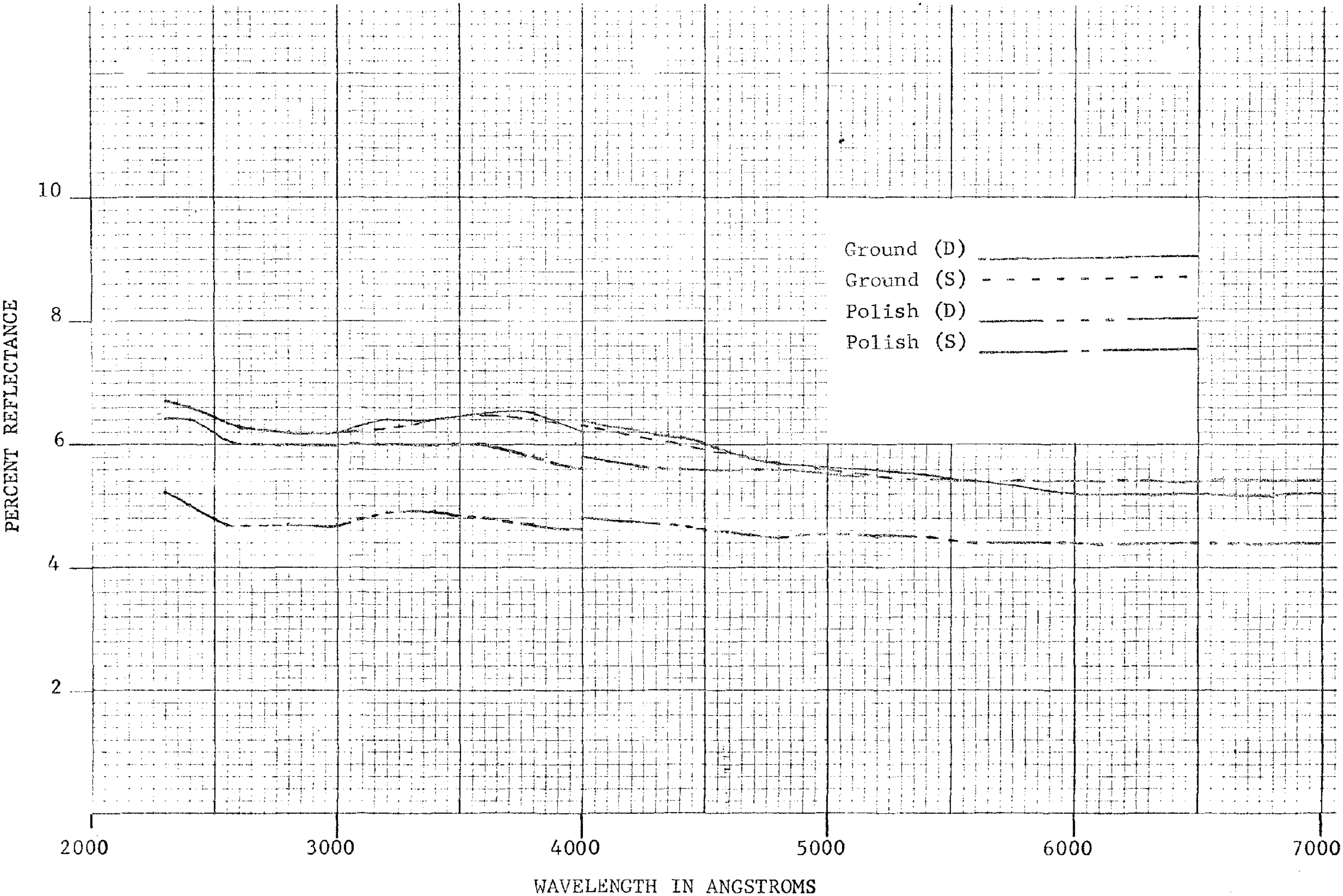
G-1 Gabbro



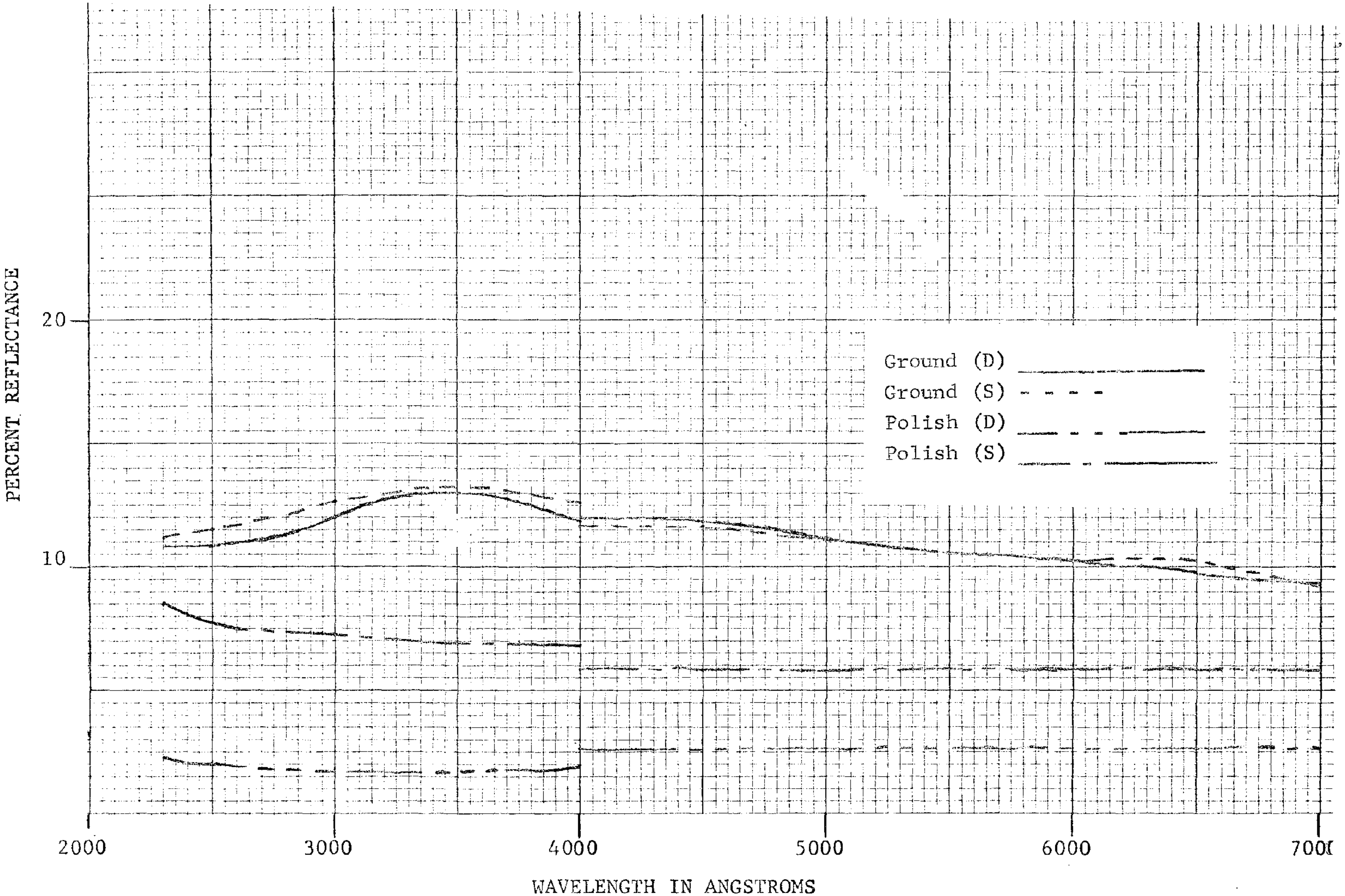
Li 4238 Gabbro



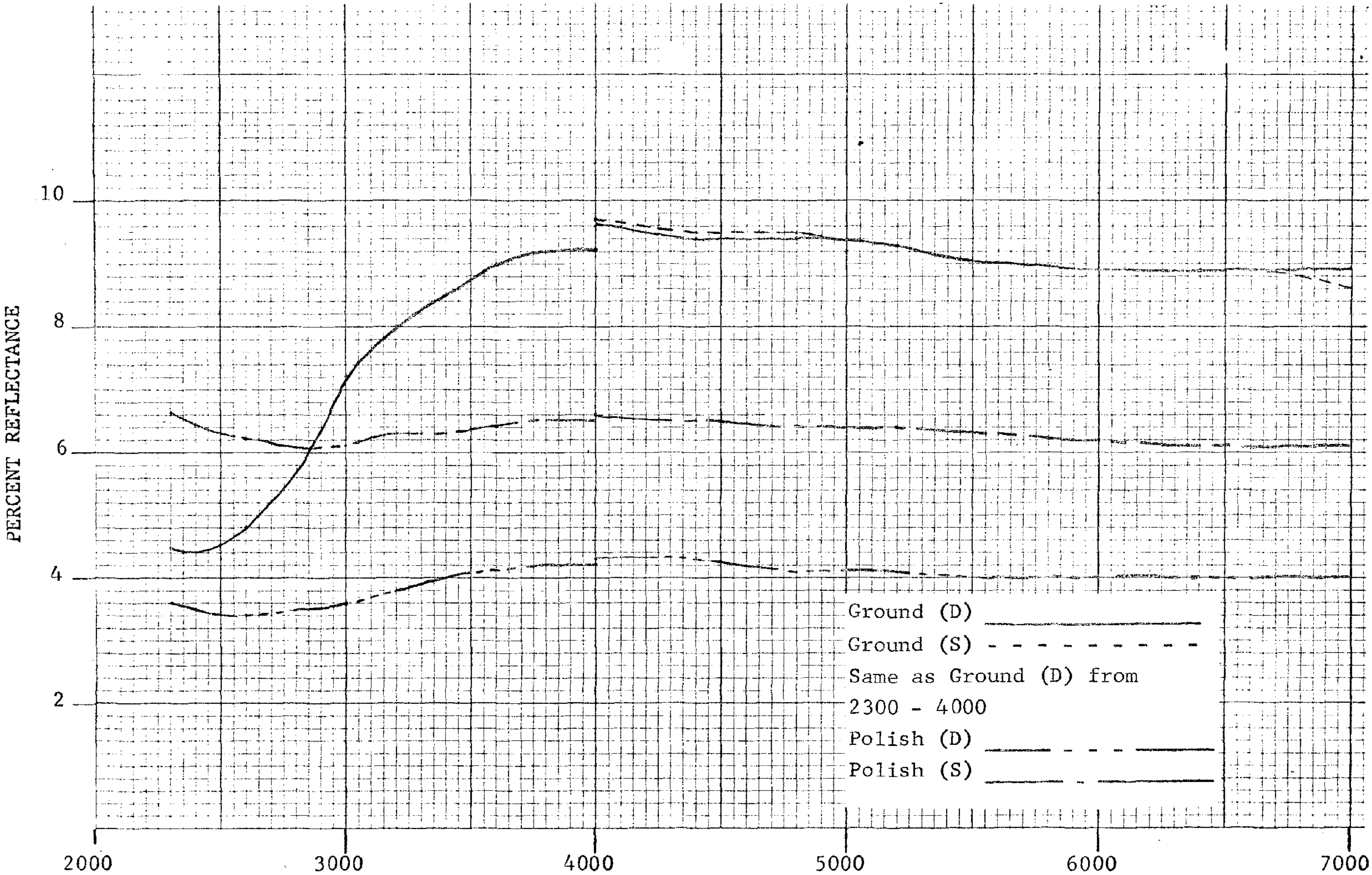
258 Anorthite-pyroxene gabbro



Li 2288 Basalt

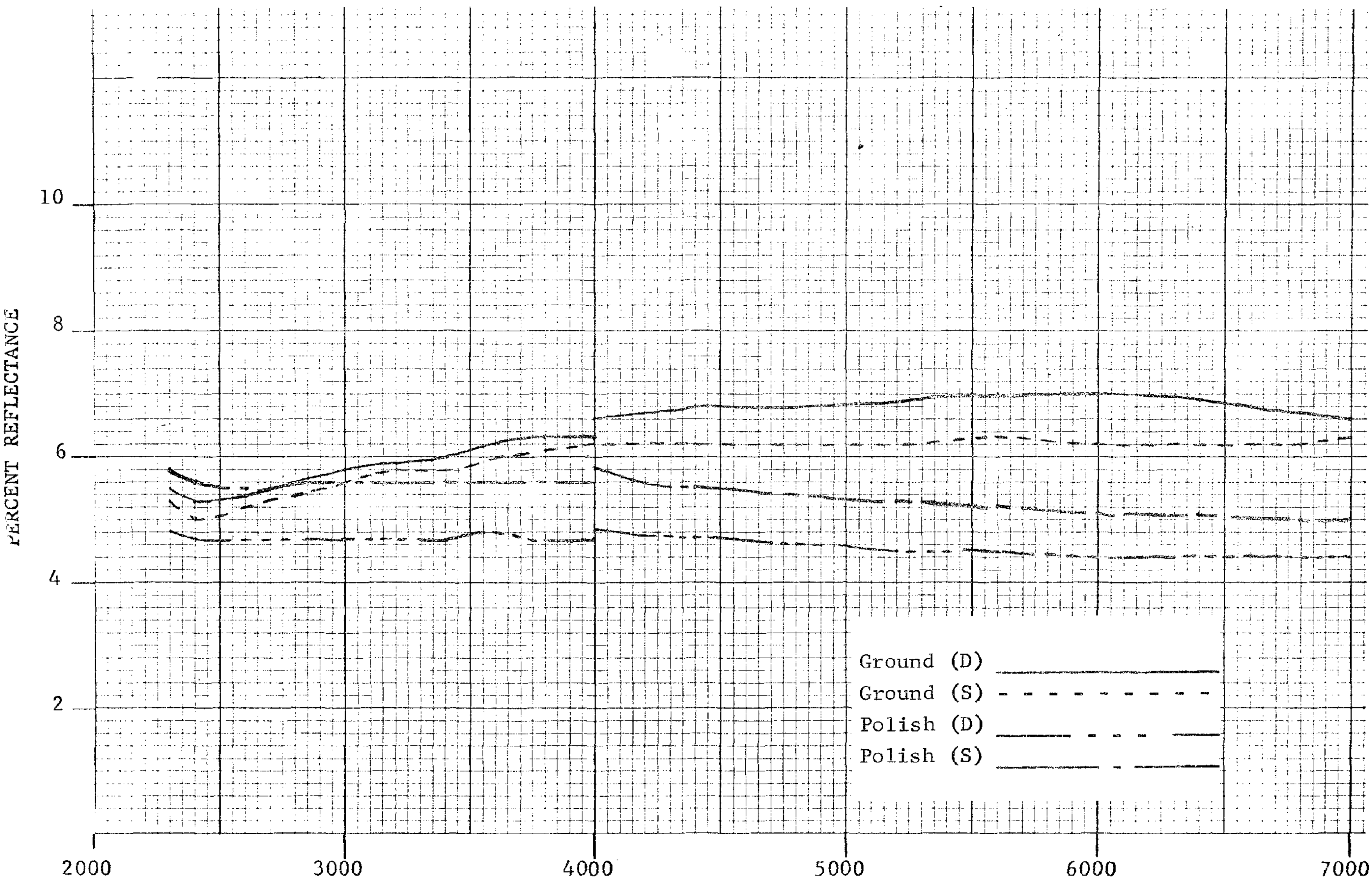

PERCENT REFLECTANCE
20
10
2000
3000
4000
5000
6000
7000
WAVELENGTH IN ANGSTROMS
Ground (D)
Ground (S)
Polish (D)
Polish (S)

101 Basalt

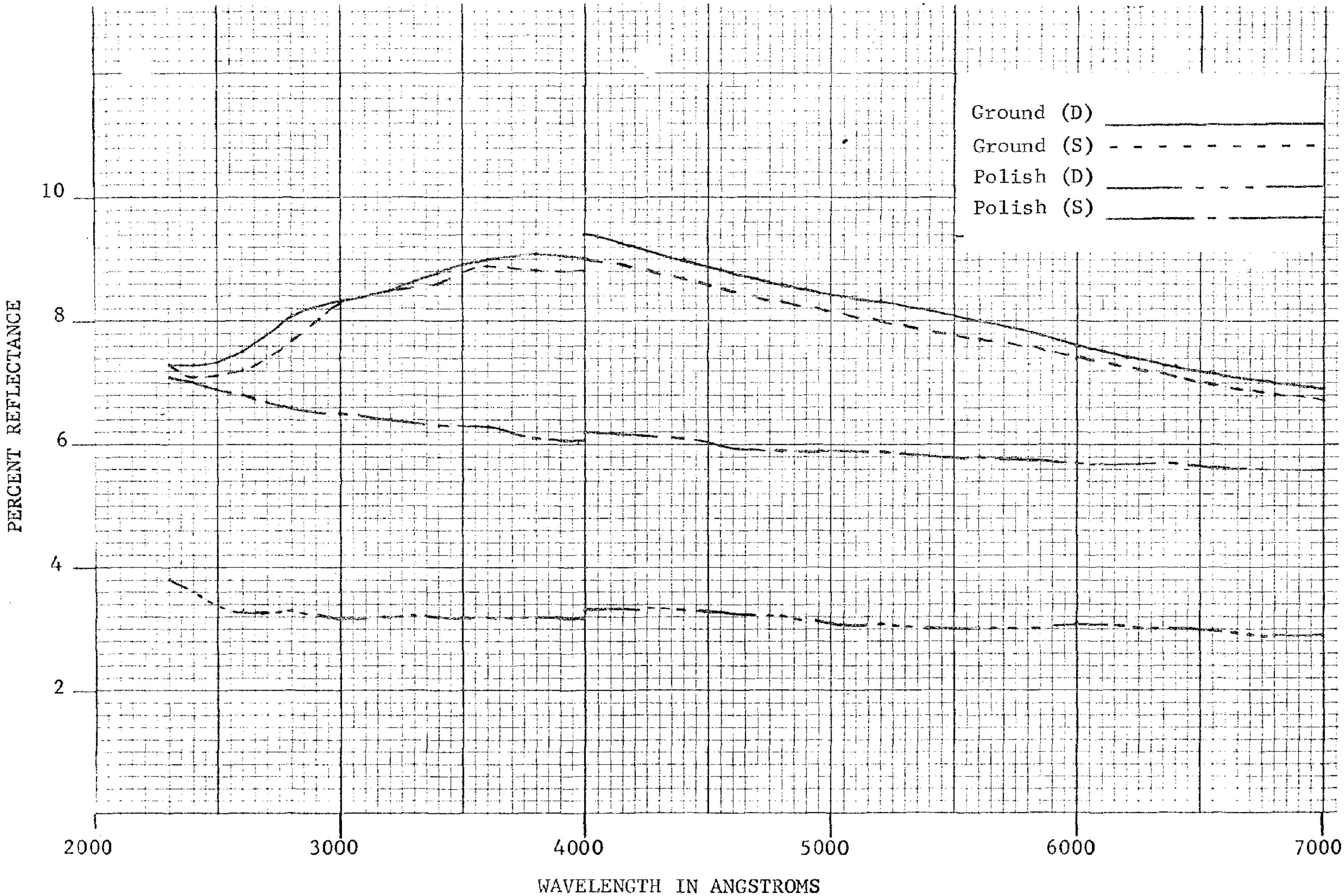


WAVELENGTH IN ANGSTROMS

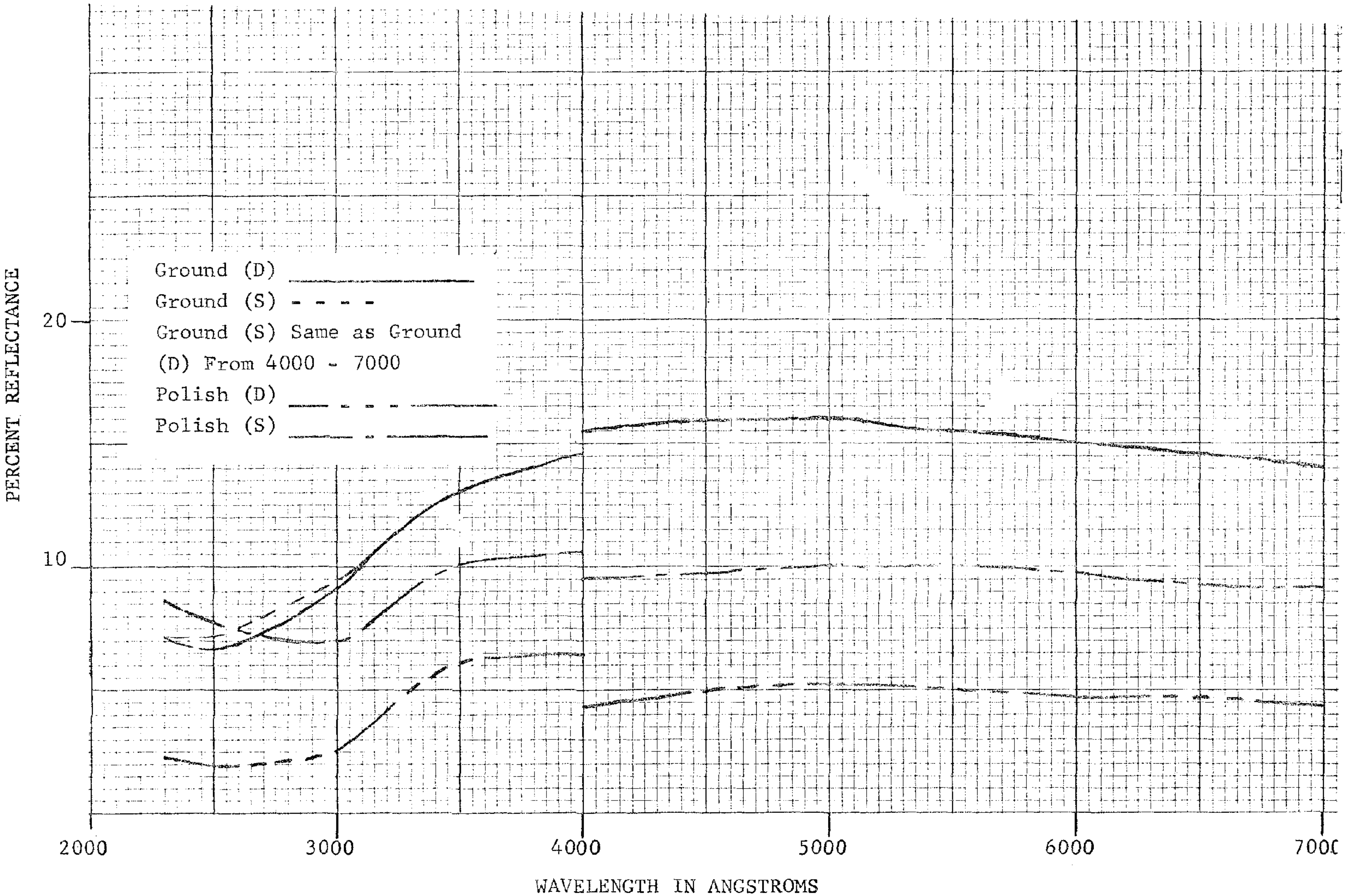
G 3161 Basaltic Lava



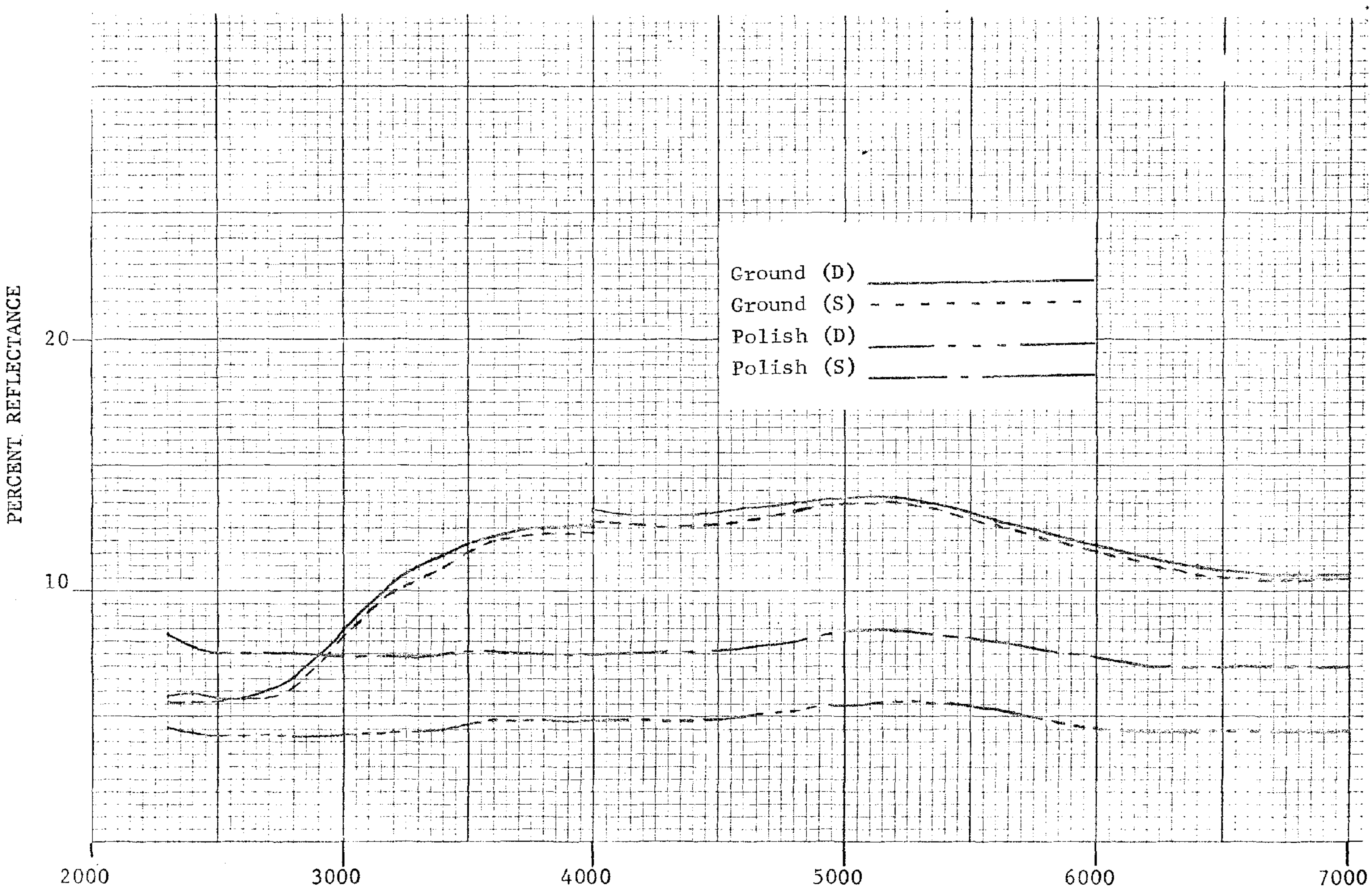
WAVELENGTH IN ANGSTROMS
Li 4156 Volcanic Bomb



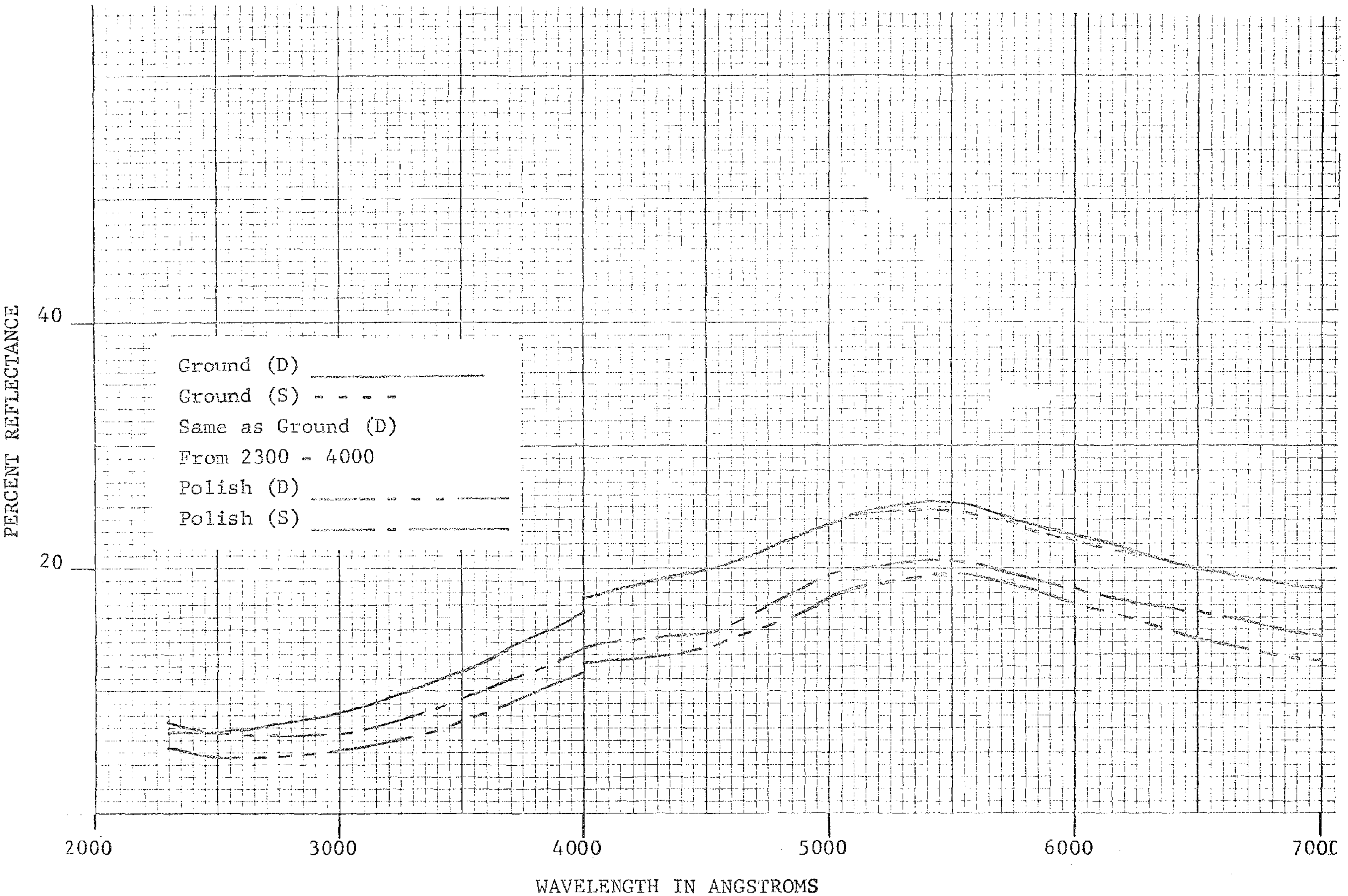
Li 2811 Diabase



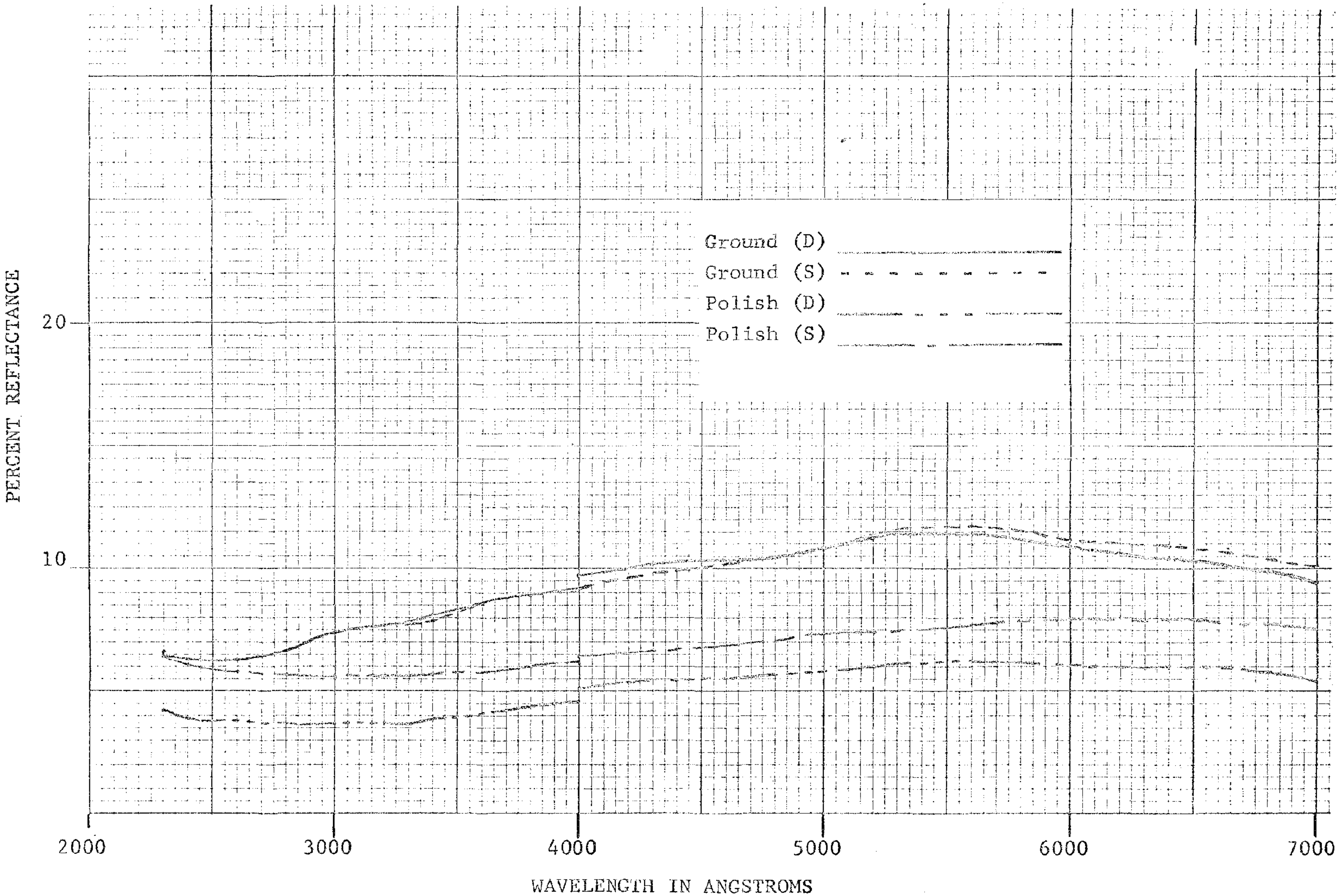
222 Diabase (Triassic)



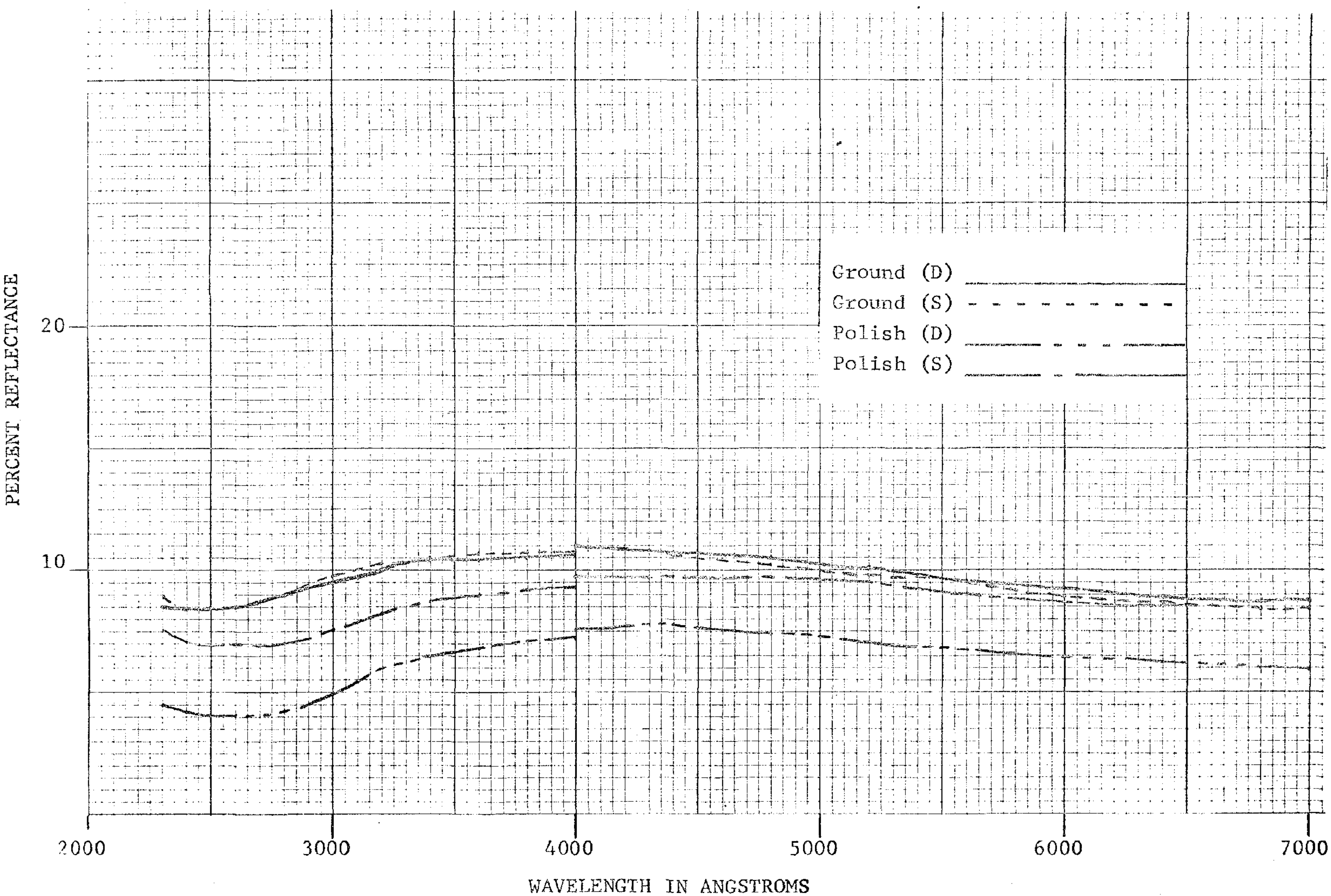
WAVELENGTH IN ANGSTROMS
E 18086 Dunite



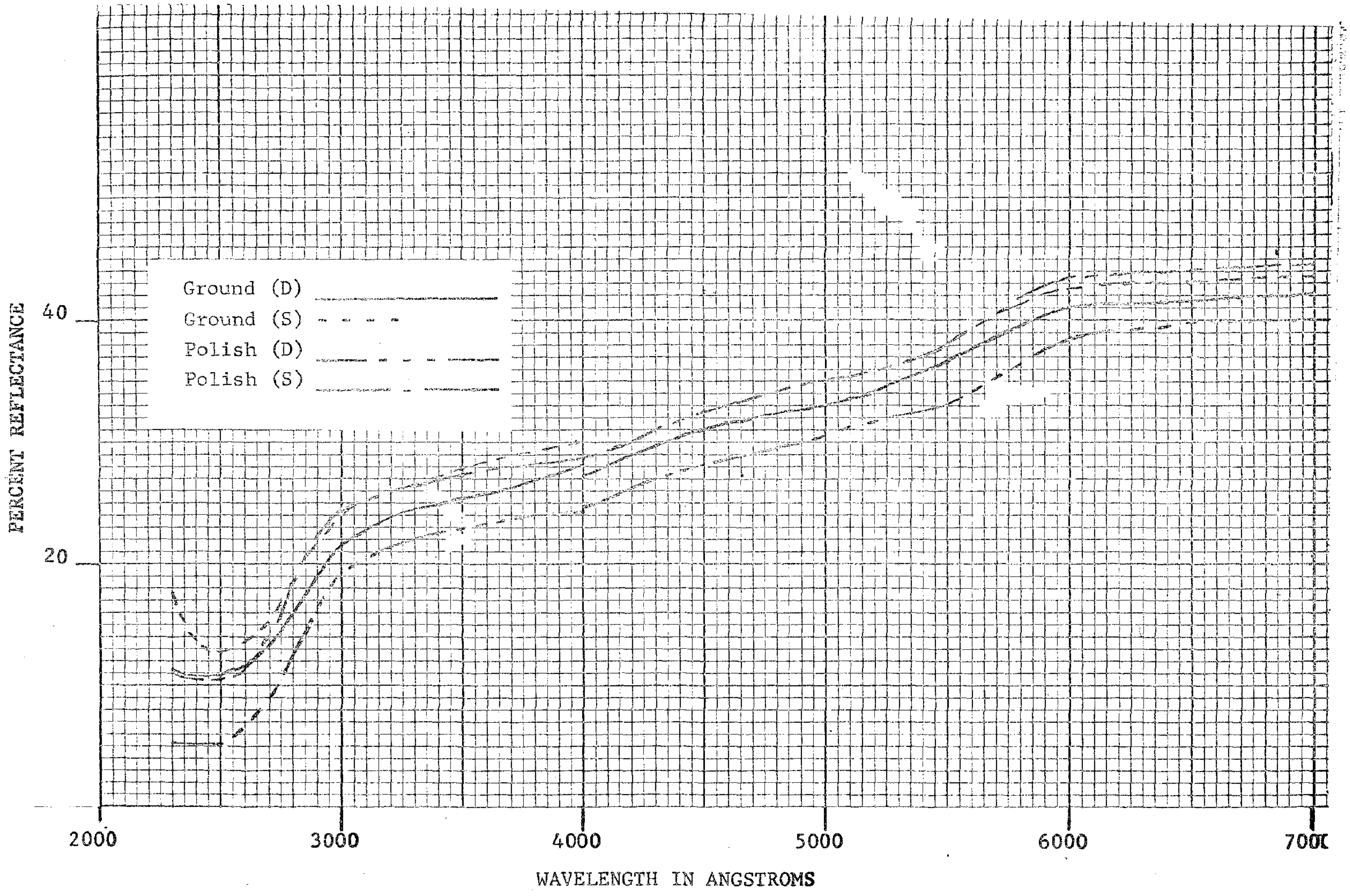
289 Olivine (dunite) ploycrystalline



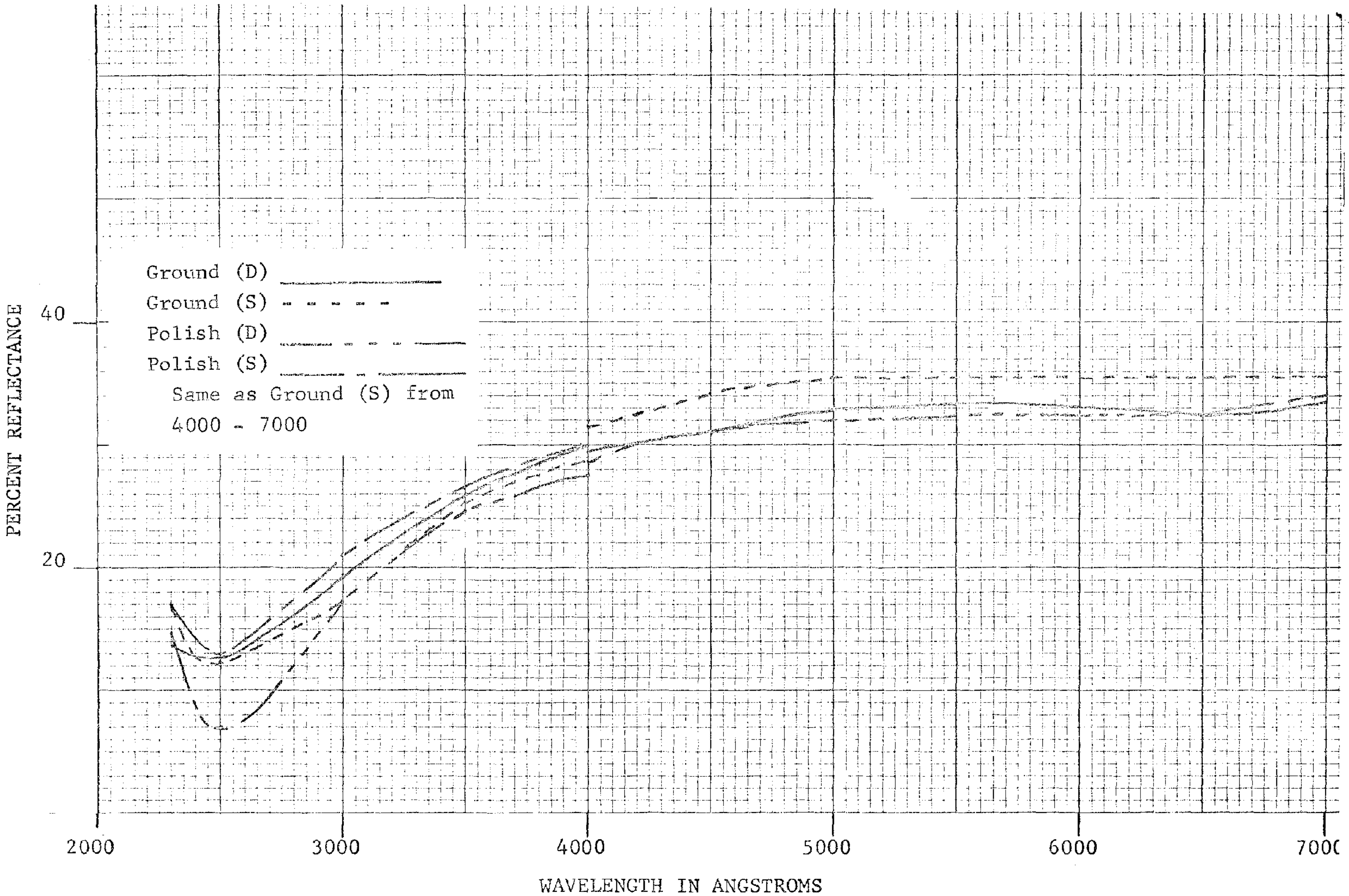
Li 2402 Kimberlite



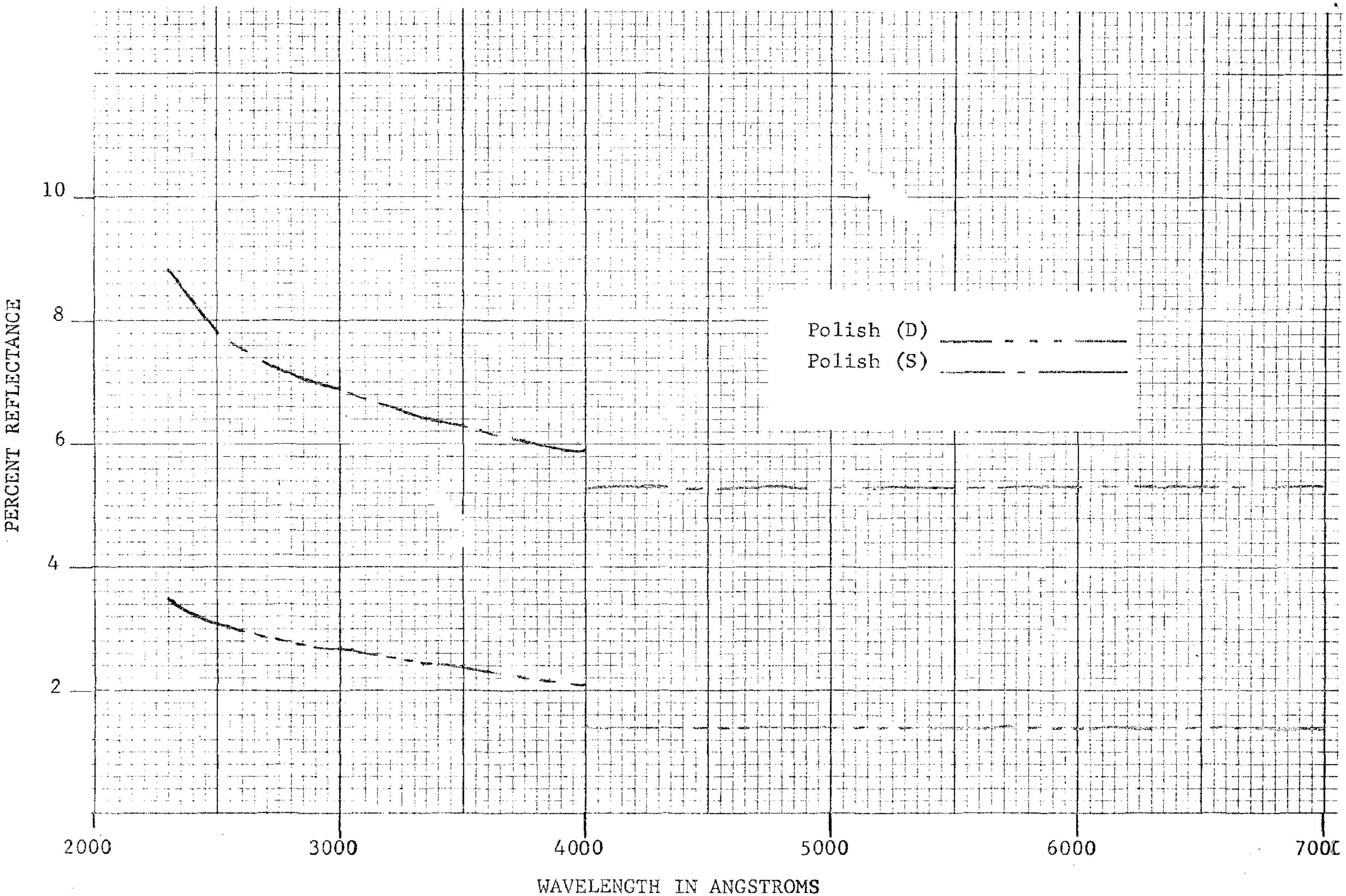
Li 3675 Anorthosite



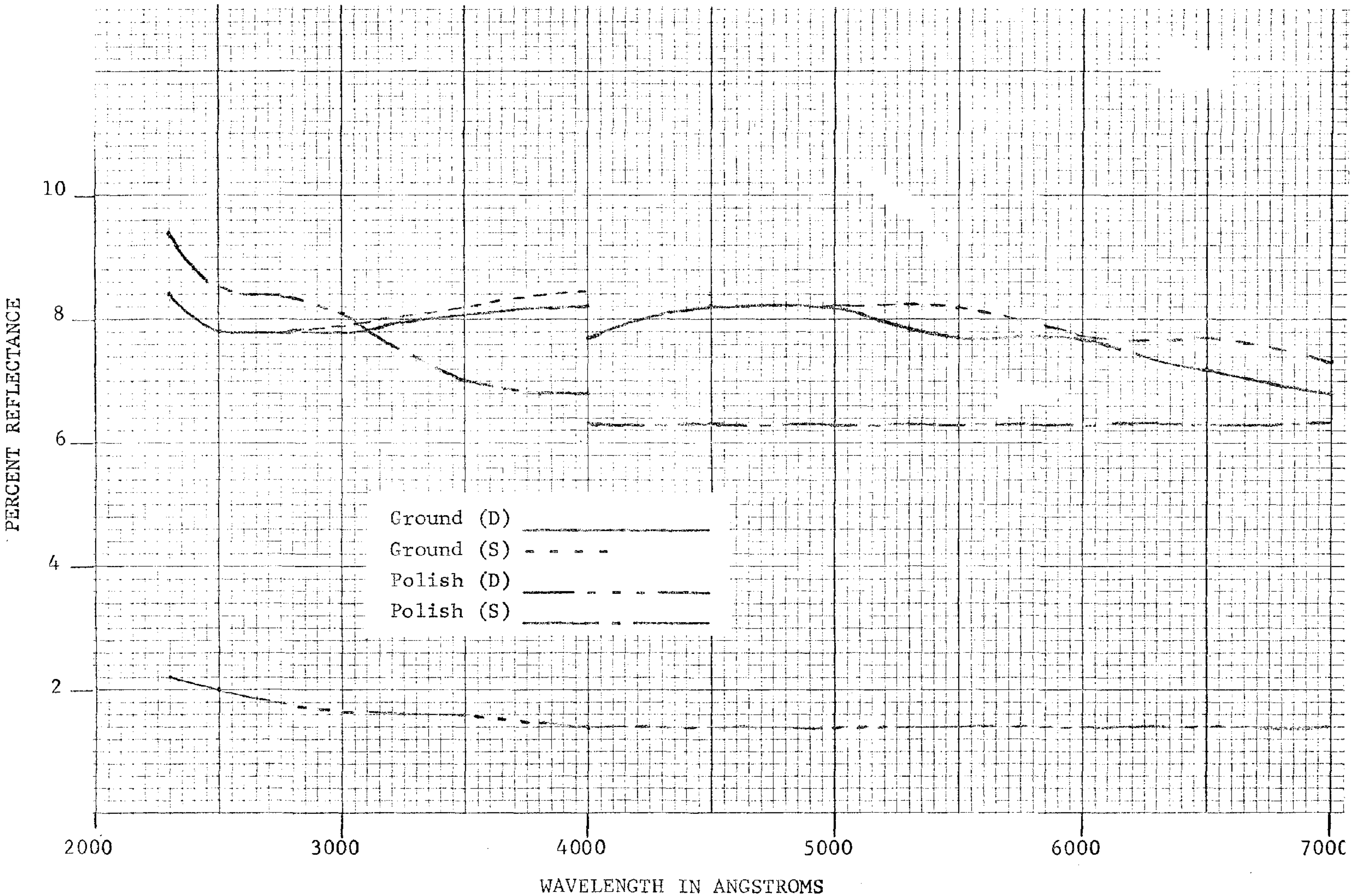
260 Potash feldspar-microcline



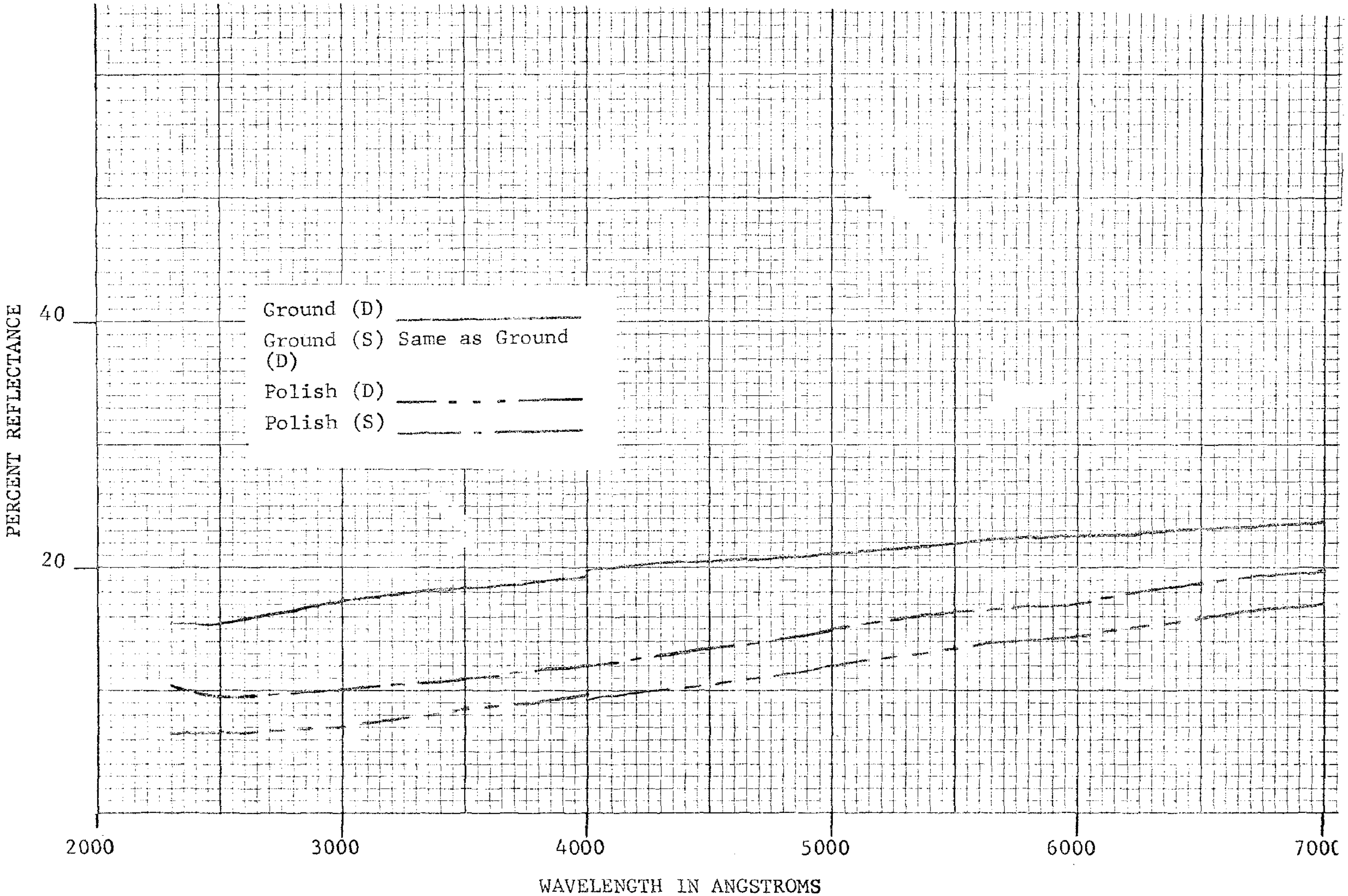
251 Plagioclase feldspar-albite



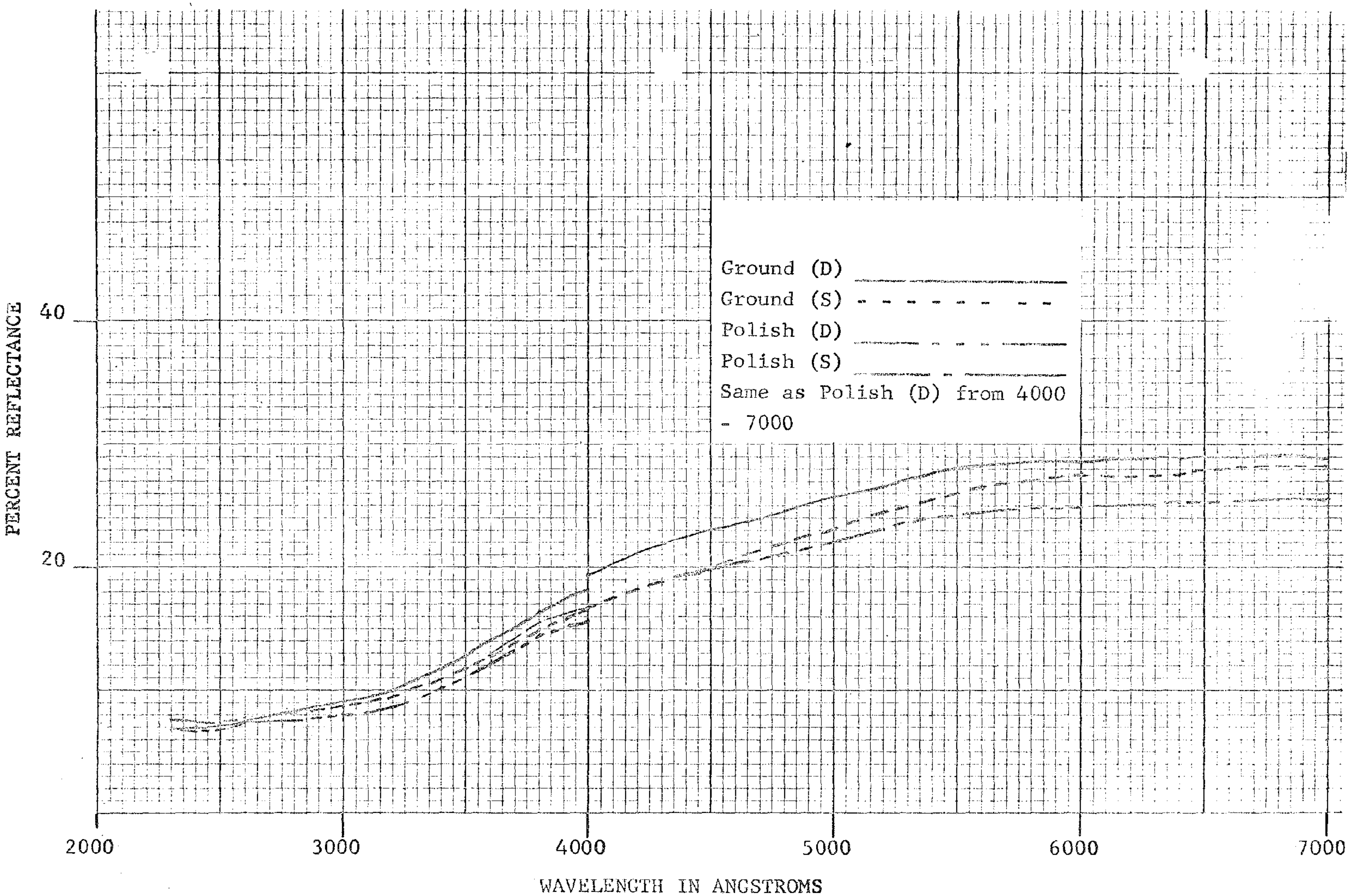
292 Mica-biotite



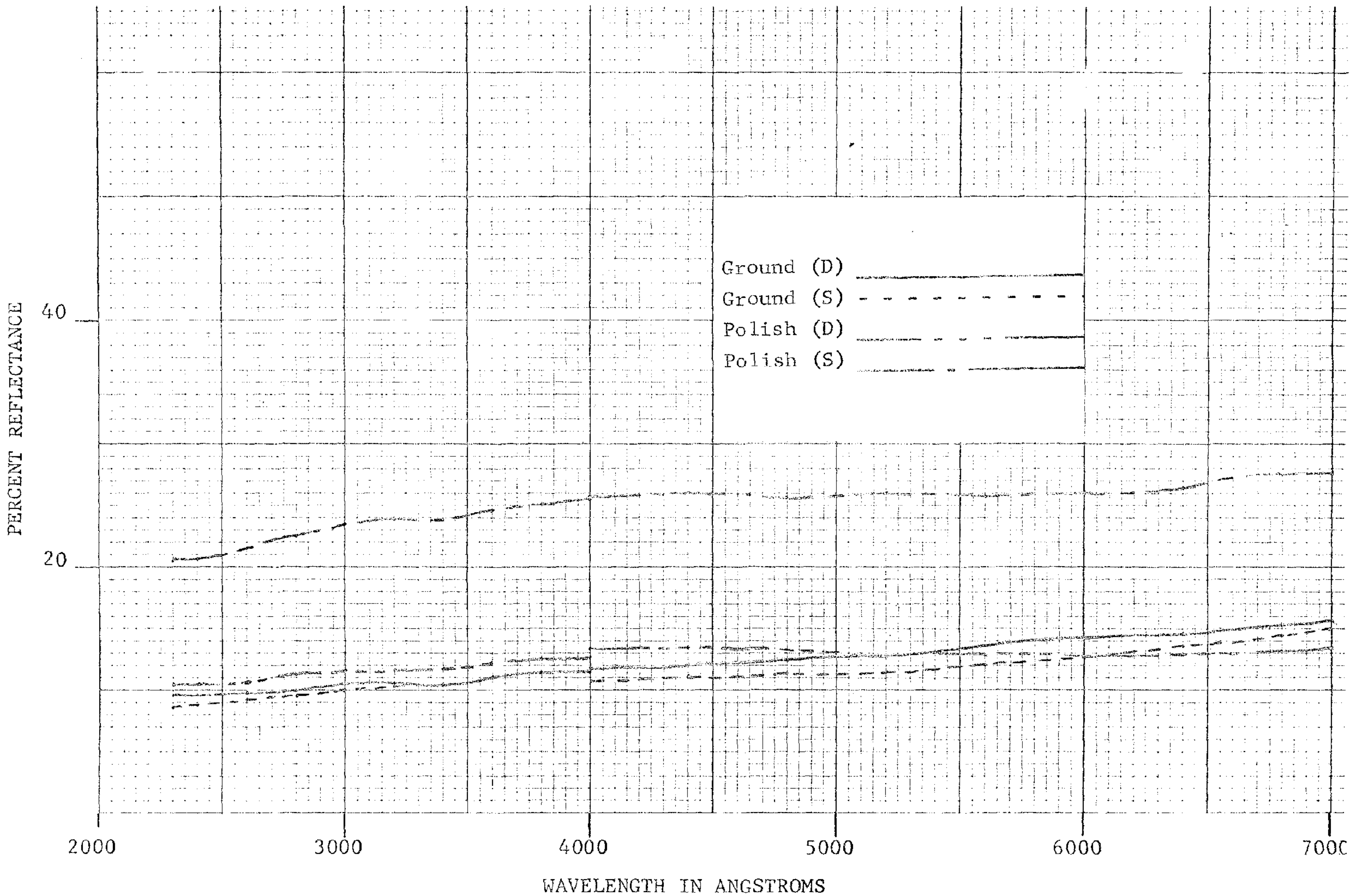
288 Amphibole - hornblende



44 Dolomite (fine - grained)



Me 1990 Colby (Wisconsin), Hypersthene chondrite



Me 1252   Canon Diablo, Coarse octahedrite