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PHOTOMETRIC MEASUREMENTS OF
SIMULATED LUNAR SURFACES

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PHOTOMETRIC MEASUREMENTS OF
SIMULATED LUNAR SURFACES

by

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Geo-Astrophysics Section

January 1965

Second Interim Report on NASA Contract No. NAS 9-3182

Approved by:

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Director of Research

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SUMMARY

This report presents the results of experiments performed in the second interim period of Contract No. NAS 9-3182 consisting of "Photometric Measurements of Simulated Lunar Surfaces."

Phase I experiments, consisting of the photometric investigation of twenty-two natural specimens at 0° , 30° , and 60° viewing angles, have been completed. The major portion of Phase IIa experiments consisting of the photometric investigation of geometric solids covered by a backscattering powder has also been completed. Work on Phase IIb, the final phase of this investigation, has been initiated and is currently in progress.

The results of most Phase I experiments performed in this period essentially confirm the conclusions reached in the previous progress report; namely, that specimens other than fine dust reproduce the lunar photometric data and that the consistency or competence of the lunar surface material is not a property that can be uniquely inferred from the photometry of the surface.

In Phase IIa, the photometric properties of elongated prisms have been measured under both transverse and parallel modes of sun-source motion with regard to the prism ridges. The experimental results are not yet very revealing regarding the extent of micro or macro roughness needed by a surface in order to backscatter light like the moon. However, a useful analytical technique has been developed to check and confirm the test results. This technique, if developed further, promises to yield the desired quantitative relationship between the geometrical and photometric properties of a surface. For a number of reasons it is recommended that this approach be pursued.

INTRODUCTION

This is the second of two interim reports on the "Photometric Measurements of Simulated Lunar Surfaces" performed under Contract No. NAS 9-3182. This report covers the remainder of Phase I and parts of Phase II.

Essentially, the contractual work as originally planned is proceeding on schedule and, barring unforeseen difficulties, will be terminated on time.

The photometric set-up, the test samples, the experimental procedure and some test results were presented in the previous progress report (1). A brief and tentative evaluation of the results of tests performed in the interim period is submitted pending a more complete analysis to be given after the completion of Phase II.

WORK ACCOMPLISHED TO DATE

Phase I

This phase is now completed. Albedo and photometric measurements at 0° , 30° , and 60° viewing angles on a total of twenty-two natural specimens have been made. The first eight specimens were presented in the previous report and the remaining fourteen are presented in this report. Except for the "dendritic copper," all the eighteen specimens that were originally proposed have been investigated. Five new

specimens have been added in order to make up for the missing dendritic copper specimen which, unfortunately, was lost. The new specimens are: 1) Carborundum (fine powder); 2) Metallic Meteorite (Krasnojarsk No. 897, borrowed from the American Museum of Natural History in New York); 3) "NASA Slag" No. 1 (level, rough side); 4) Scoria No. 1; and 5) Scoria No. 2. The last three of these specimens were presented in the last report. The fourteen specimens that are reported here are as follows:

NASA Slag No. 1 (smooth side)	Figure 4
NASA Slag No. 1 (rough side)	Figure 5
CuO on NASA Slag No. 1 (smooth side)	Figure 6
CuO on Scoria No. 2	Figure 7
Volcanic Ash No. 1	Figure 8
Volcanic Ash No. 2	Figure 9
Coral No. 1	Figure 10
Coral No. 3	Figure 11
Coral No. 4	Figure 12
Metallic Meteorite (Krasnojarsk No. 896)	Figure 13
Metallic Meteorite (Krasnojarsk No. 897)	Figure 14
Foam	Figure 15
AgCl on Foam	Figure 16
Carborundum (fine powder)	Figure 17

Phase II

This phase has two parts, both of which, unlike Phase I, deal with artificial or controlled models in an attempt to develop an intuitive and, if possible, an analytical grasp of how the geometrical properties of the lunar surface, or of any surface, emerge from its photometric properties. The effects of surface roughness and albedo are investigated in Phase IIa, the effects of grain size and porosity (or bulk density of the material) are investigated in Phase IIb.

Phase IIa

The specimens in this phase consist of wooden or metallic geometrical figures of varying dimension (prisms, as shown in Figure 18, pyramids, spheres, etc.), covered by a veneer of sprinkled CuO powder of known photometric quality. To date, the specimens in the third column and fifth row of Figure 18 have been examined at normal viewing angle with the sun-source moving in a direction parallel and perpendicular to the ridges. The results are shown in Figures 19 to 22. An analytical investigation of these models under both conditions of illumination is presented in Appendix A of this report.

Phase IIb

The models in this phase are prepared by crushing and screening into seven gradations of particle size the volcanic ash and the NASA slag that were successfully investigated in Phase I.

Since the original specimens were insufficient for the needs of this operation, new batches were ordered from the same sources. Six different specimens of the volcanic ash from the Haleakala volcano in Hawaii were received. All six specimens were investigated in an "as-received" condition at all three viewing angles in order to select the most suitable one for crushing and screening. The results are

shown in Figures 23 to 28. Two of the most promising specimens of the furnace slag received from the NASA Manned Spacecraft Center were investigated for the same purpose. The results are shown in Figures 30 and 31.

DATA PRESENTATION

A slightly different format is used in this report in presenting the standard lunation curves at 0° , 30° , and 60° viewing angles. These curves, unlike the ones appearing in the previous report, are represented by a shaded band rather than a line. The band represents the scatter of the available observational data for the entire lunar disc. It is enclosed by three sets of curves, one of which is reported by Van Diggelen (2) and the two others are reported by Orlova (3) as averages for the maria and the highlands. The actual curves that delimit the band were shown in Figures 1a, 1b, and 1c for the 0° , 30° , and 60° viewing positions respectively. For the sake of clarity, the lines have been omitted in the figures containing the test curves where the standard lunar curve is represented by a shaded band only. The new format will be adhered to in the final report.

For reasons explained in the previous report, all the test curves have been normalized at about 4° phase.

DISCUSSION OF TEST RESULTS

Phase I

The results of the photometric measurements of the fourteen specimens are shown in Figures 4 to 17. All the specimens show a sharp peak at zero phase angle except the carborundum which, as expected, is more lambertian due to its relatively high albedo and more particularly to its "non-fairy-castle" (i.e. denser) packing.

The volcanic ash No. 1 and all the variations of the NASA slag (rough side, smooth side, with and without CuO cover) show as good a match with the lunar curves at 30° and 60° viewing angles as they do at 0° . Notice that the signature of the NASA slag is steeper for the rough than for the smooth side, as expected, and is steepest (surpassing the lunar backscatter) when the smooth side is covered with CuO powder. This indicates that the superposition of fine dust or of a "fairy castle" microstructure on top of a sufficiently macrorough structure unnecessarily steepens the sample curve beyond the lunar curve and that the macrorough structure could reproduce the lunar curve equally well provided it has the proper geometry. What this geometry consists of in terms of actual size, shape, and porosity is not yet very clear; all that can be said about it at this time is that the solid, shadow casting elements are arranged in an "underdense" pattern separated by a complex array of cavities which appear in most cases to be interconnected.

The volcanic ash No. 2, Figure 9, does not follow the lunar standard curves as closely as the volcanic ash No. 1, Figure 8, particularly at large phase and viewing angles. The "bulge" or increase in brightness at these angles has a curious similarity to the photometric properties of individual lunar craters (Albategnius, Plato, Grimaldi and Schikhard) as shown in Figure 2. It is hoped that an explanation for this anomaly could be found in the succeeding phase of this investigation.

The coral specimens Nos. 1, 3, and 4 shown in Figures 10, 11, and 12, are also interesting in so far as they all exhibit a sharper backscatter than the moon at most viewing angles despite their relatively high albedo. This is most probably

due to their extreme macroroughness, dendritic structure, and an equally complex microstructure as exemplified by the CuO-covered NASA slag. The anomalous, rough outline of coral No. 4 curve, Figure 12, is consistent with its high degree of large scale roughness and is indicative of poor integration by the photometer of the changing shadow and light areas. This is due to the large size of shadow-casting irregularities relative to the area seen by the photometer. These irregularities are of the order of inches whereas the area seen by the photometer has a diameter of 3 inches only.

Phase IIa

Although the direction in which the sun-source ought to travel over the specimen was not originally specified in the proposal, both directions of travel, i.e. parallel and perpendicular to shadow-casting ridges, have been investigated analytically as well as experimentally. The discussion of the test results in this phase is presented in terms of model combinations and lighting conditions as described below:

Condition No. 1: One to five prisms, constant 45° base angle (column 3, in Figure 18); sun-source moving parallel to the prism ridges.

The photometric properties of the CuO covered 45° prisms at normal viewing angle are shown in Figures 19a and 19b for one to five prisms. The test curves are all nearly identical indicating that the number of prisms does not affect the photometry of the surface under this particular set of conditions which is, in effect, equivalent to a flat surface inclined to the horizontal at the same angle as the base angle of the prism. This equivalence is confirmed by analysis and actual measurement. The analysis is presented in Appendix A and the measurement of a CuO-covered flat plane at 45° is shown in Figure 19c. The test curve in this figure does not differ noticeably from the curve obtained from the CuO powder on a horizontal surface as shown in Figure 6a of the previous report (1). Thus, it is not necessary to measure the photometric properties of the other prisms in Figure 18 under this particular condition of illumination.

Condition No. 2: Same as Condition No. 1 except that sun-source moves perpendicular to the prism ridges.

The photometric properties of the CuO-covered 45° prisms at normal viewing angle are shown in Figures 20a to 20e for one to five prisms respectively. In general the test curves have a slightly sharper backscatter than measured in the previous condition because under transverse lighting the prism ridges are in a position to cast shadows. The test curves differ from one another only to the extent that the "bend" at 45° phase shown by the single-prism curve, Figure 20a, becomes gradually smoother with each additional prism, Figures 20b to 20e. A typical analysis of the one-prism and three-prism configuration is presented in Appendix A. This analysis confirms the experimental curves, as indicated by the plotted points in Figures 20a and 20c, and shows that the subsequent blending of the "bend" in the one-prism curve is due to the presence of shadows in the trough of the prisms at phase angles larger than 45° . Since the single-prism configuration does not have any troughs, the entire face remains exposed to light beyond 45° phase and, consequently, registers a brighter signature.

The close fit between the analytical and test curves indicated that in general it is possible to predict the photometric behavior of a surface of known

geometry, like that of the prisms shown in Figure 18, if the photometric function of an individual element, such as the face of a prism, is known. It is thus possible to derive analytically the photometric curve of the other models in Figure 18, on the basis of a single measurement consisting of a flat surface of the same composition and inclined to the horizontal at the same angle as the base angle of the prisms. Conversely, it should be possible to reconstruct a surface or surfaces to correspond to a known photometric function. The analytical technique developed for the purpose of verifying the prism curves might be used to build a physical photometric model which will obey the peculiar reflection laws of the moon. Past attempts (2) to build such a model have not been very successful.

Condition No. 3: Five prisms, base angle 0° , 30° , 45° and 60° , (row 5 in Figure 18); sun-source travels parallel to the ridges.

In this and the following condition the number of prisms under observation remains constant but the base angle of the prisms varies from 0° (a horizontal plane) to 60° . Under this condition the sun-source travels parallel to the prism ridges. In lunar terms, this particular combination of model and lighting is equivalent to increasing the latitude of the observed lunar areas at a given longitude. The lunar observational data (2) shown in Figure 3 indicates that the photometric properties of individual areas on the lunar surface are nearly independent of latitude. The test results shown in Figure 21 confirm the lunar data. Both sets of curves show only a slight increase in backscatter with increasing latitude or base angle. It is believed that no useful additional knowledge will be gained by investigating the other models in Figure 18 under this condition of illumination.

Condition No. 4: Same as Condition No. 3, except that sun-source moves in a direction perpendicular to the prism ridges.

The photometric properties of the set of five prisms with varying base angles are shown in Figure 22. The test curves reveal a progressive sharpening of the backscatter with increasing base angle or decreasing ridge angle of the prisms. The overall increase in backscatter is more pronounced under the transverse than under the parallel mode of illumination. Since the albedo and the surface composition of these models remain constant, the sharper backscatter could be attributed mostly to the shadows cast by the large scale features (i. e. prism ridges) at large phase angles under the transverse mode of illumination. It should be noted that the prisms by themselves cannot reproduce the lunar curve without the help of the CuO cover. However, these experiments indicate that it may be possible to achieve a match with the lunar curve with lambertian, centimeter-size elements alone provided these elements have sharp edges and are arranged in the proper order which is, as yet, unknown. It is apparent that the investigation of prisms alone will not lead to this pattern, but sufficient knowledge has been gained from these experiments to explore other, less conventional geometries. An analytical and experimental investigation is now being made to discover this pattern or set of patterns.

Phase IIb

The test curves at 0° , 30° and 60° viewing angles on the six volcanic ash specimens recently received from Hawaii are shown in Figures 23 to 28. They all show a reasonably good fit with the lunar data particularly when the data on the individual lunar craters shown in Figure 2 are also taken into consideration. Volcanic ash No. 4 was selected for further investigation because it shows the best fit with the

lunar curves. The specimen was ground and sieved into seven assorted grain sizes as shown in Figure 29; their albedo and photometry are currently being measured.

The test curves at 0° , 30° , and 60° viewing angles of the two best furnace slag specimens recently received from NASA Manned Spacecraft Center are shown in Figure 30 and 31. The new specimens do not match the lunar curves as closely as the original investigated in Phase I, Figure 4. They have a higher albedo and relatively fewer interconnected cavities. It is possible and desirable for a trained observer to select more suitable specimens at the source of supply.

CONCLUSIONS

Phase I

Essentially, this phase of the "Photometric Measurements of Simulated Lunar Surfaces" has successfully met its objectives insofar as twenty-two natural specimens (about four more than originally proposed) were examined at 0° , 30° , and 60° viewing angles under a viewing area about an order of magnitude larger than previously achieved. These specimens consist of loose particles ranging in size from microns to centimeters and of massive substances such as furnace slags (NASA supplied), volcanic scorias, sea corals, metallic meteorites, foams etc. Most of them reproduce the lunation curves reasonably well and confirm the major conclusions reached in the previous report; namely, that it is no longer necessary to postulate a layer of dust on the moon in order to account for the lunar photometric data, nor is it justifiable to rule out the presence of dust on the moon on the basis of these data alone.

The high porosity that is common to all the good models permits one to infer only that the uppermost layer of the lunar surface is covered with an underdense material of unknown depth, composition, grain or pore size, cohesiveness and structure. The latter properties cannot be uniquely inferred from the photometric data but a quantitative estimate of a range of porosities and relative roughness appear to be theoretically possible and eventually useful in estimates of bearing strength of the lunar surface when this knowledge is used in conjunction with the lunar radiothermal data. Phases IIa and IIb of this work were conceived primarily as an attempt to acquire this knowledge.

Phase IIa

This phase is oriented toward the study of large scale surface roughness effects on the photometric function. Although this study is not yet complete, certain preliminary conclusions emerge.

The photometric signatures of the elongated prisms depend upon the direction in which the sun-source travels with respect to the prism ridges. This is obviously due to the fact that in the "parallel" mode of illumination the ridges do not cast shadows; whereas, in the "transverse" mode they do.

Analysis and tests show that in the former mode, increasing the number of the prisms or steepening their side slopes has no or little effect on the photometric function. The latter case, i.e., steepening the side slopes, is equivalent in lunar terms to increasing the latitude of the observed area. The test results in this case agree with the lunar data.

When the sun-source travels in a direction perpendicular to the prism ridges, the test results do show a tendency towards a sharper backscatter primarily because the prisms are in a position to cast shadows. (The test curves show an excellent agreement with the analytical curves). This tendency is particularly noticeable when the side slopes of the prisms are progressively steepened indicating a predominance of steep slopes or sharp edges in the microstructure of the lunar surface. These experiments have not yet yielded the desired quantitative relationship between the geometric and photometric functions of a surface, but they have shown the conditions of illumination under which such a relationship may exist and the eventual possibility of reproducing the lunar photometric curves by means of controlled macrorough features alone without the benefit of a backscattering type powder veneer, provided the right combination of horizontal and vertical shadow casting elements is found.

Phase IIb

This phase, consisting of the study of porosity effects on the photometric function, is currently under investigation.

RECOMMENDATION

It is desirable to pursue the analytical approach initiated in Phase IIa in order to arrive at a quantitative formulation of the photometric function of a surface in terms of its geometry.

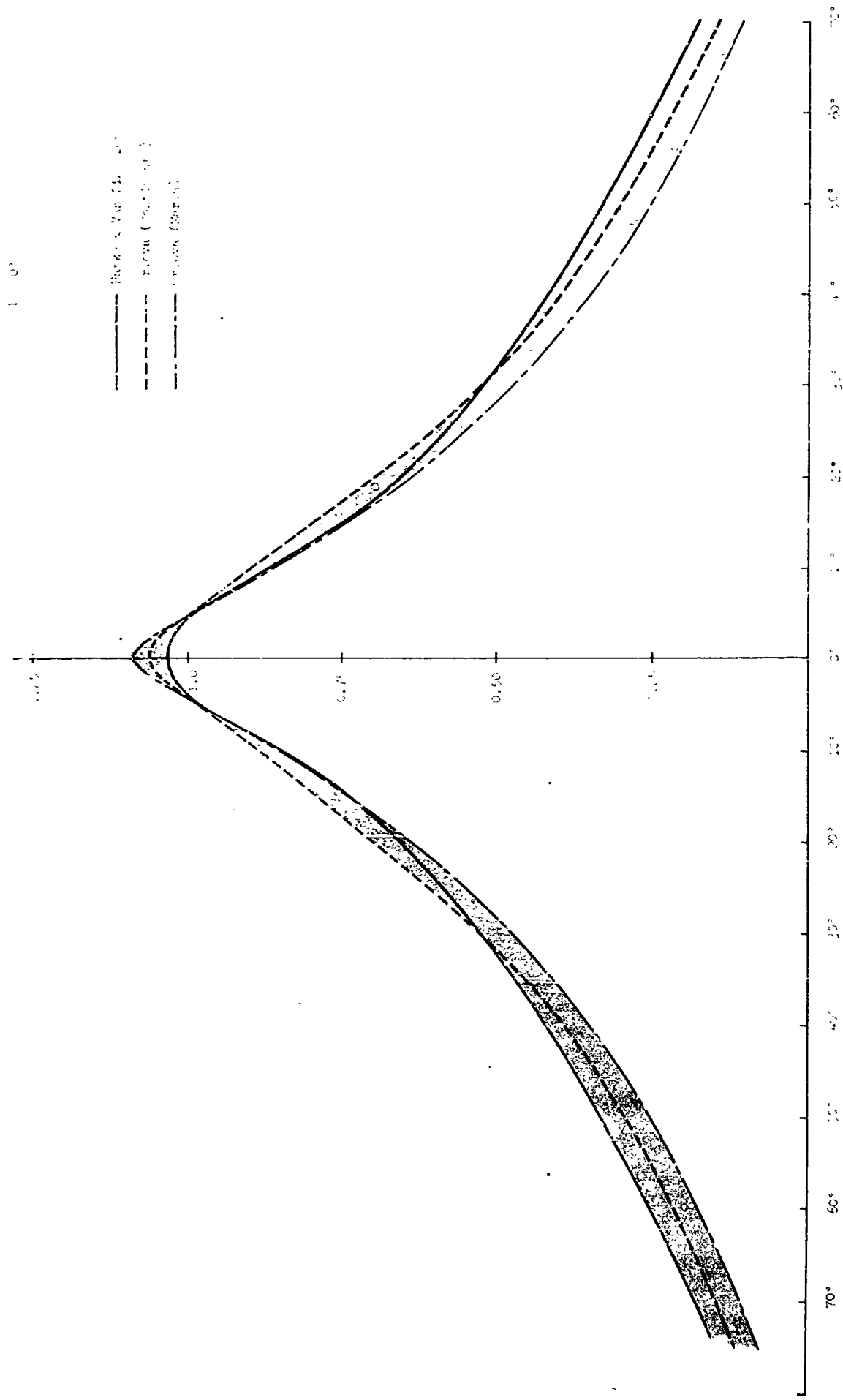
The estimate of the relative surface roughness and porosity of the lunar surface could be made more conveniently from such a geometry, contrived as it may be, than from the natural specimens discovered in Phase I of this work or elsewhere.

One of the benefits of this investigation would be to acquire the knowledge necessary to interpret the lunar radiothermal data and arrive at an estimate of the bearing strength of the lunar surface (4).

ACKNOWLEDGMENT: It is a pleasure to thank again Mr. H. B. Hallock and his assistants Mr. T. Grausaukas and Mr. D. Lamberty for their diligence and care in making the photometric measurements.

REFERENCES

- (1) Halajian, J. D., "Photometric Measurements of Simulated Lunar Surfaces," First Interim Report on NASA Contract No. NAS 9-3182, Grumman Research Department Memorandum RM-250, Nov. 1964.
- (2) Van Diggelen, J., "Photometric Properties of Lunar Crater Floors," Recherche Astronomiques de l'observatoire d'Utrecht Vol. XIV, 2. 1959.
- (3) Orlava, N. S., "Photometric Relief of the Lunar Surface," Acad. Sci. of the USSR, Astronomical J., Vol. 33, Nov. 1, 1956, NASA T-T-F-75, 1962.
- (4) Halajian, J. D., "The Case for a Cohesive Lunar Surface Model", presented at the N. Y. Academy of Sciences meeting on "Geological Problems in Lunar Research" May 1964. Grumman Report AD-04-04-64.2



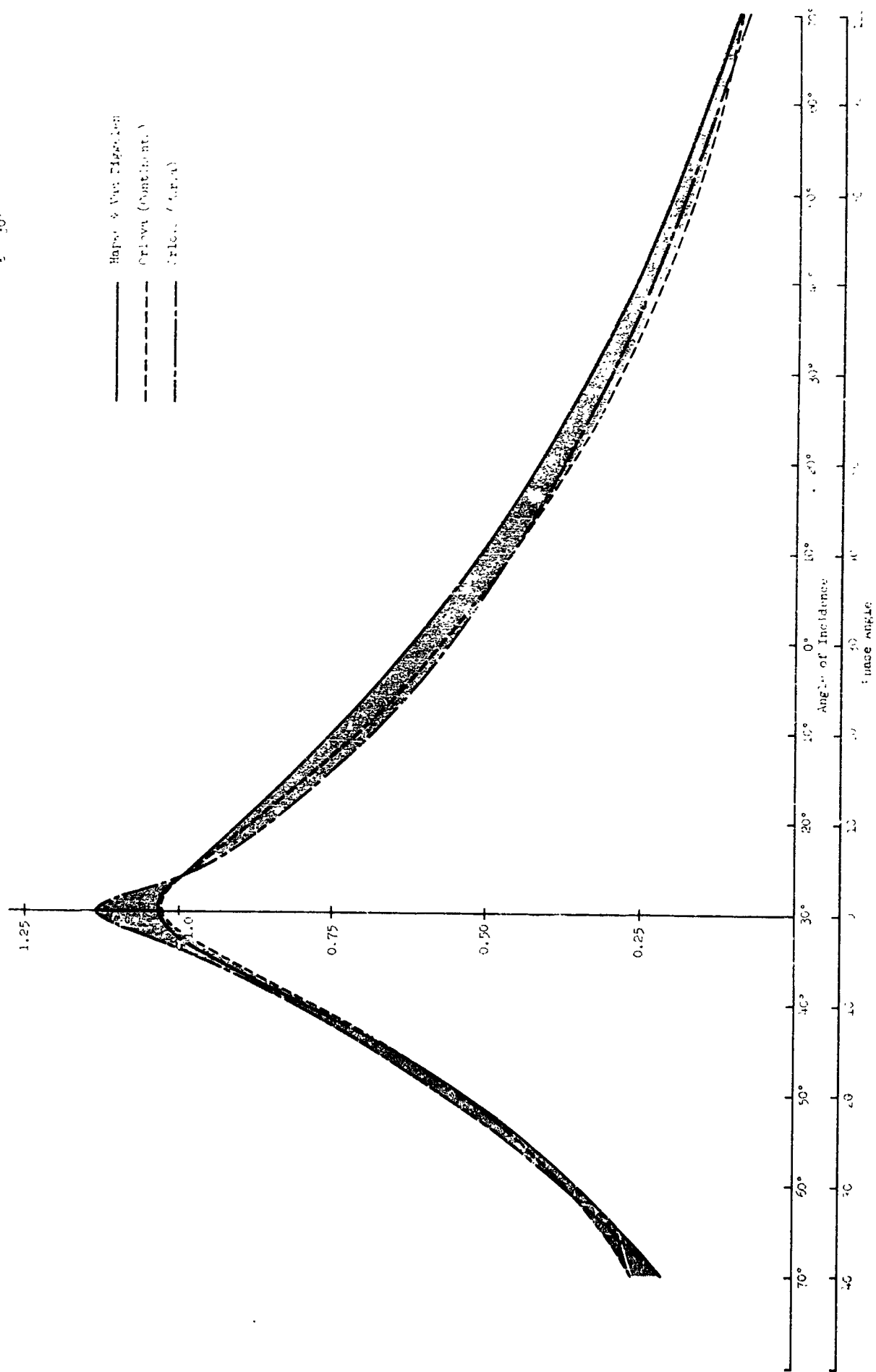


Figure 1b. Standard Lunar Photometric Curve

1. 10°

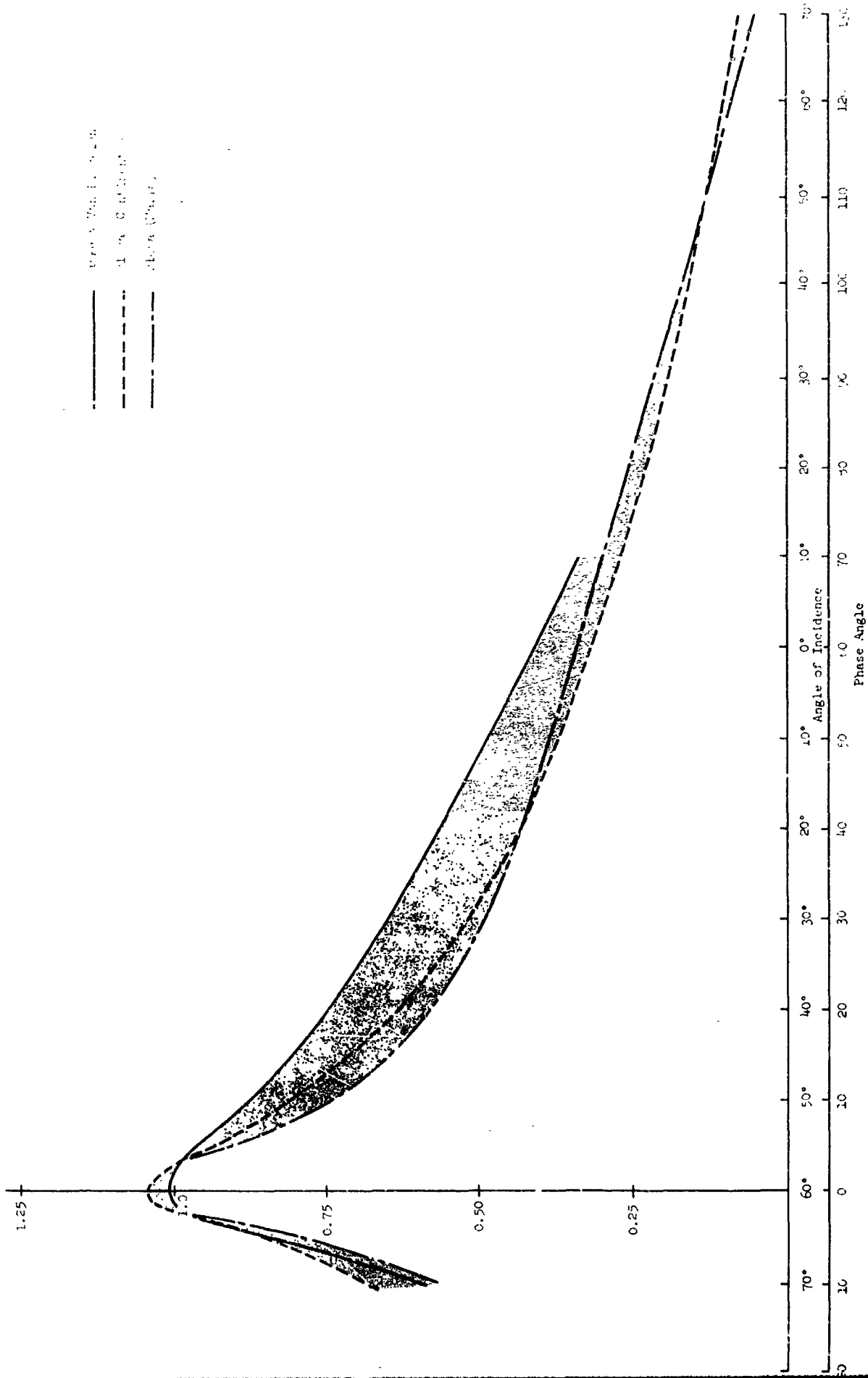


Figure 1c. Standard Lunar Photometric Curve

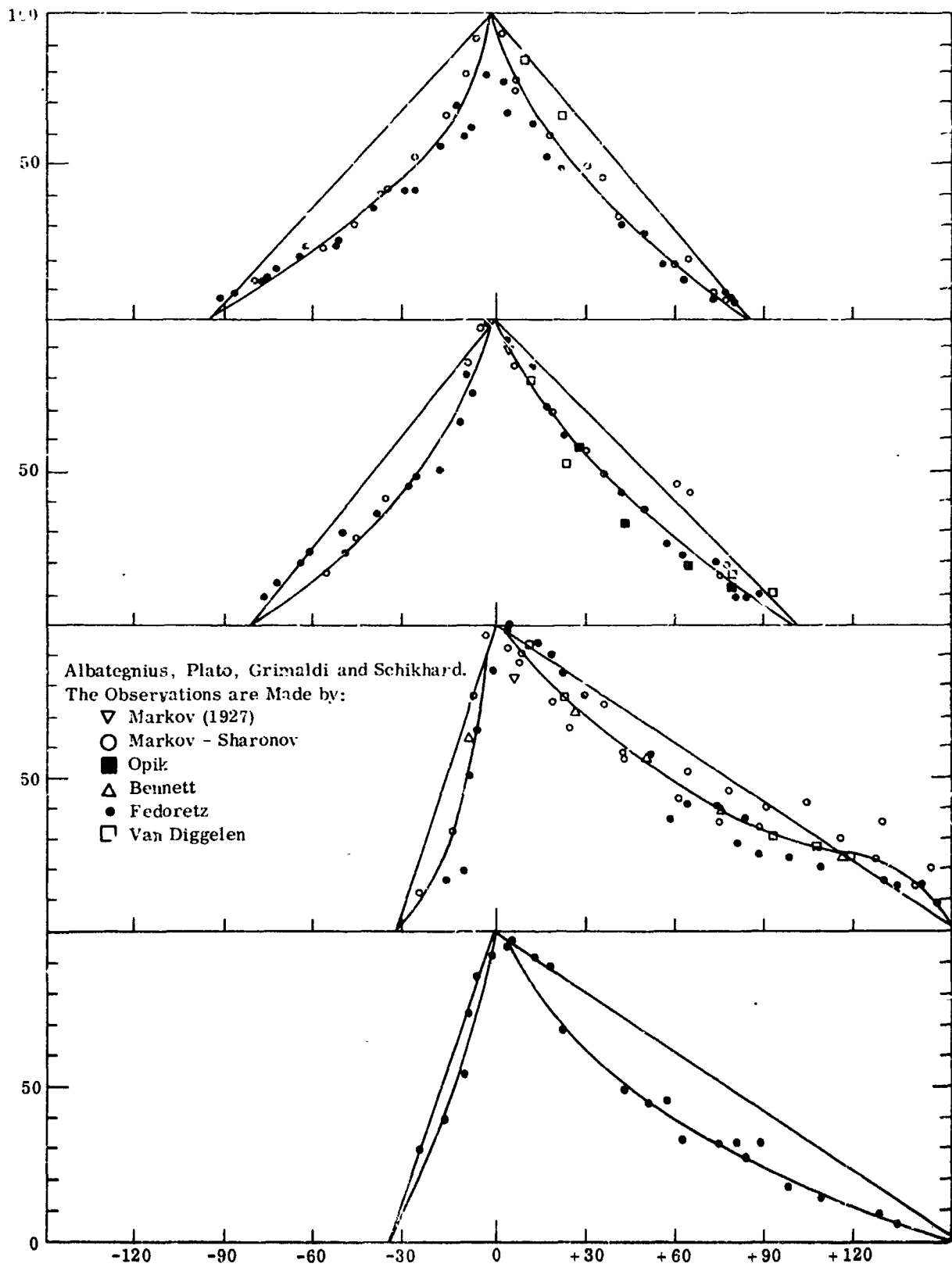


Figure 2. Lutation Curves of Four Craters Near the Van Diggelen Standard Points (Ref. 2)

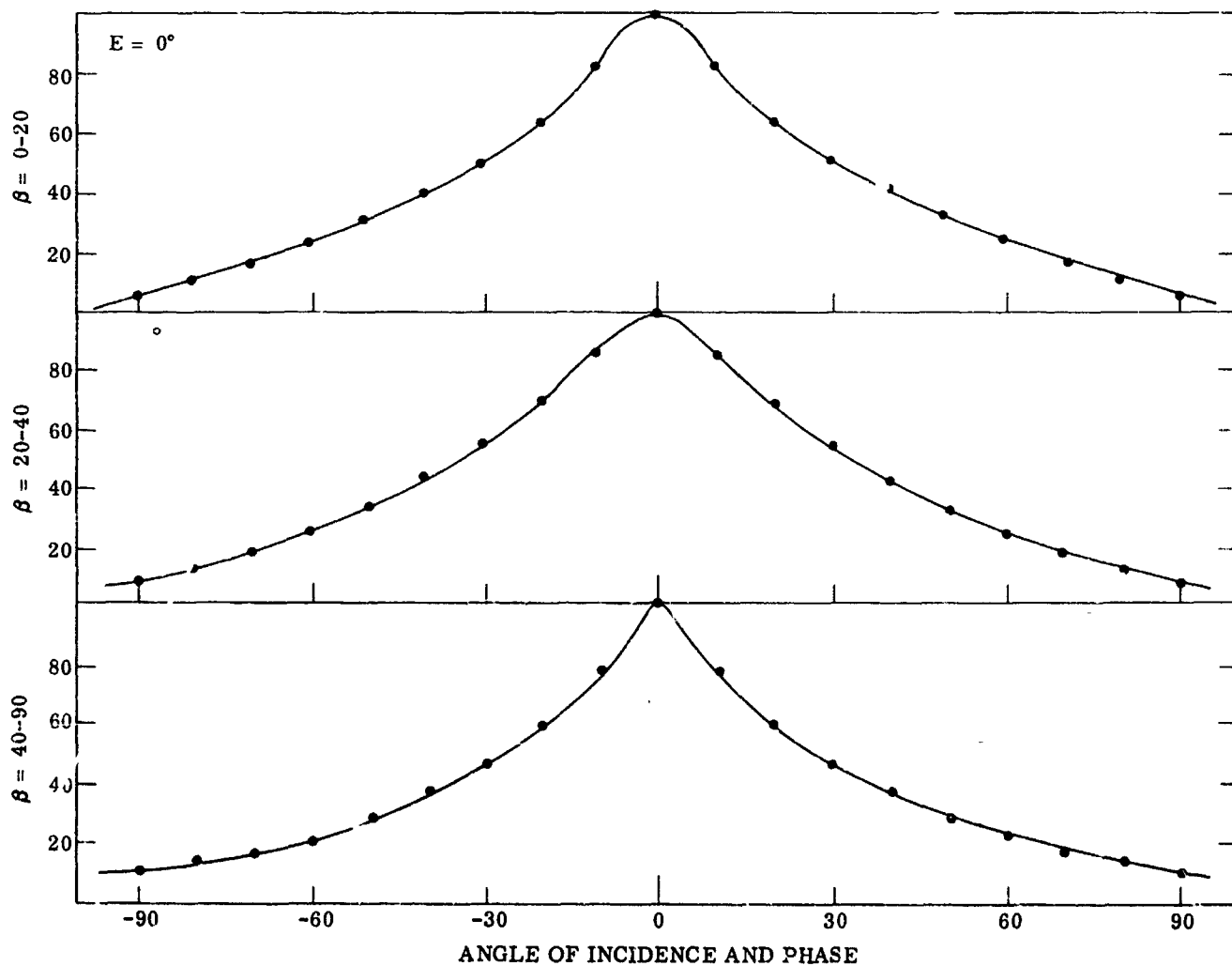


Figure 3. Lutation Curves of 0° to 10° Longitude Crescent; β = Latitude (Ref. 2)

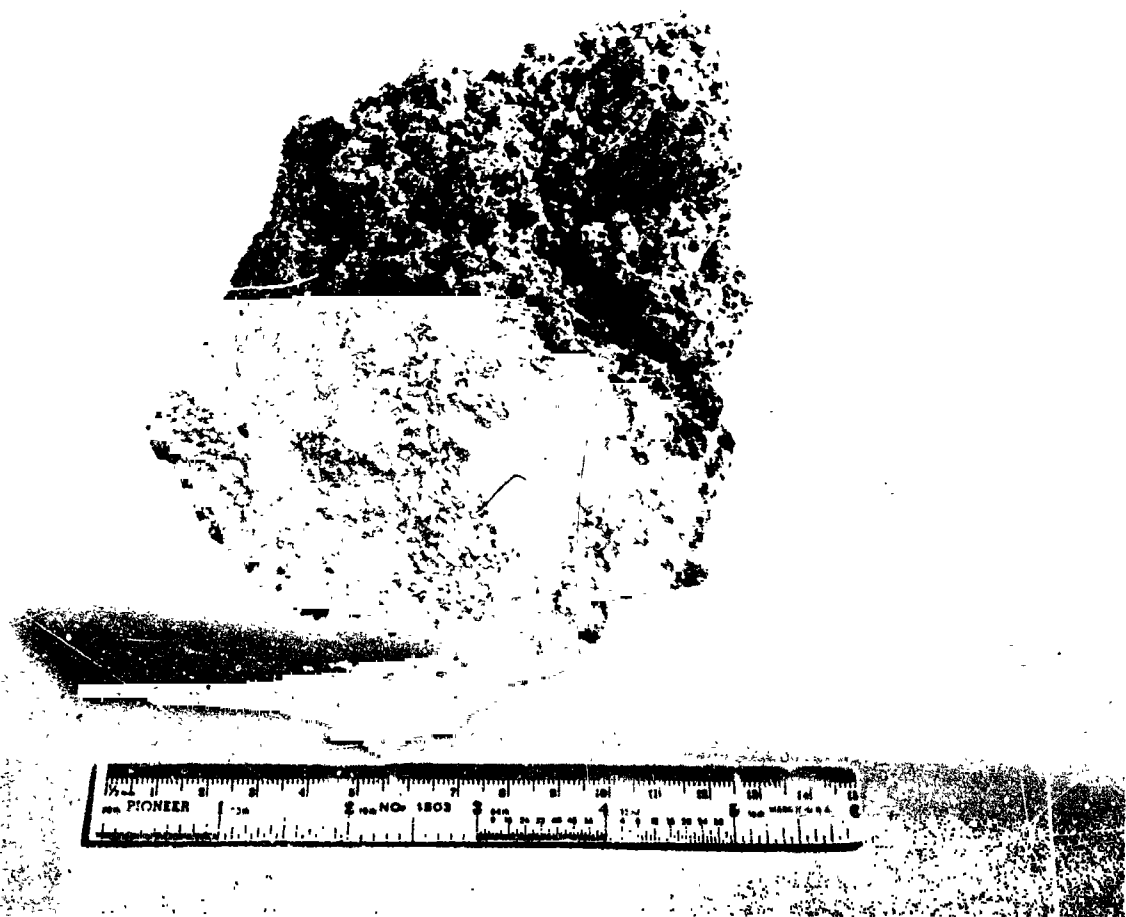
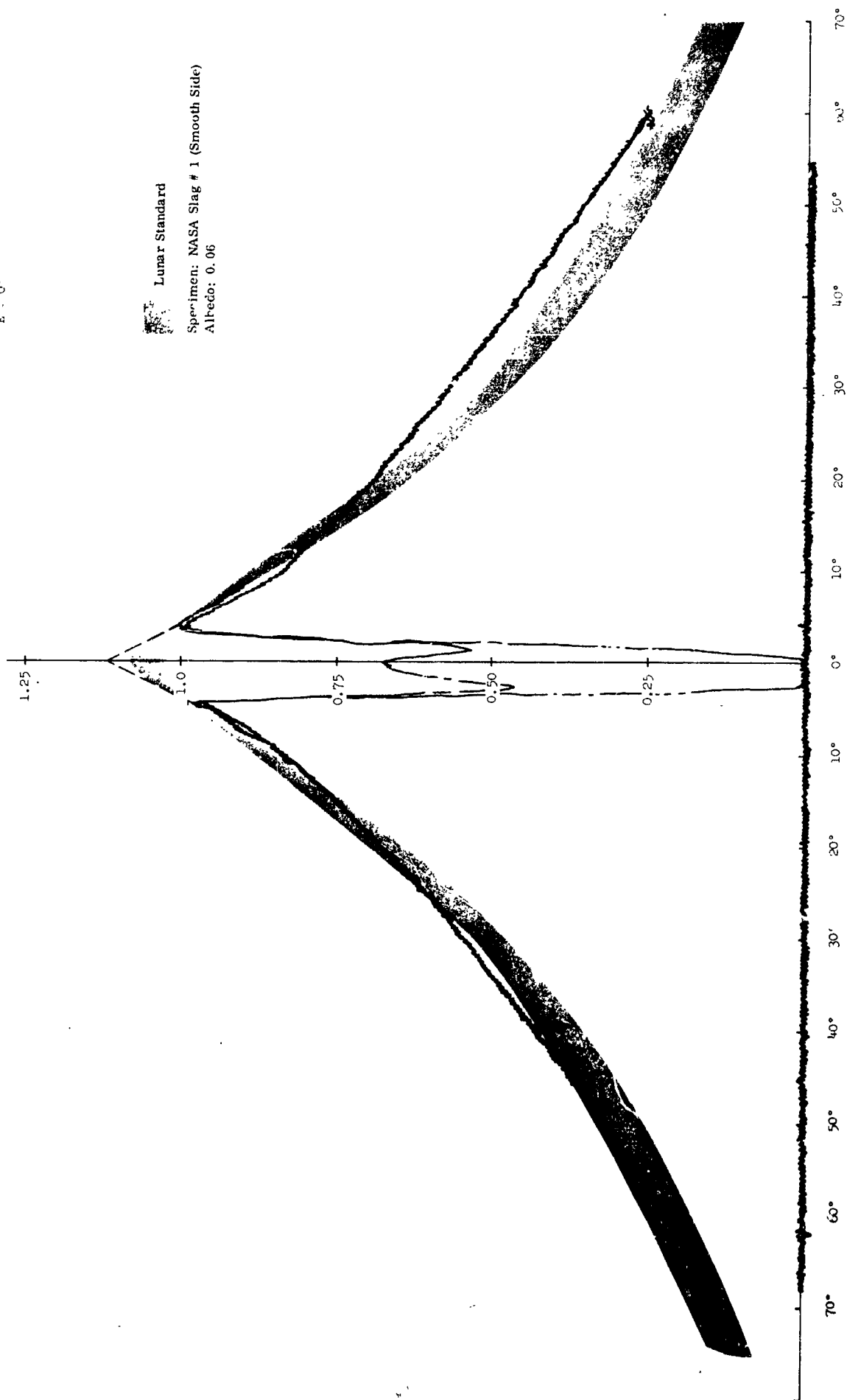


Figure 4a. NASA Slag # 1 (Smooth Side)

E = 0°

Lunar Standard
Specimen: NASA Slag # 1 (Smooth Side)
Albedo: 0.06



Angle of Incidence and Phase

Figure 4b. NASA Slag # 1 (Smooth Side)

$\theta = 30^\circ$

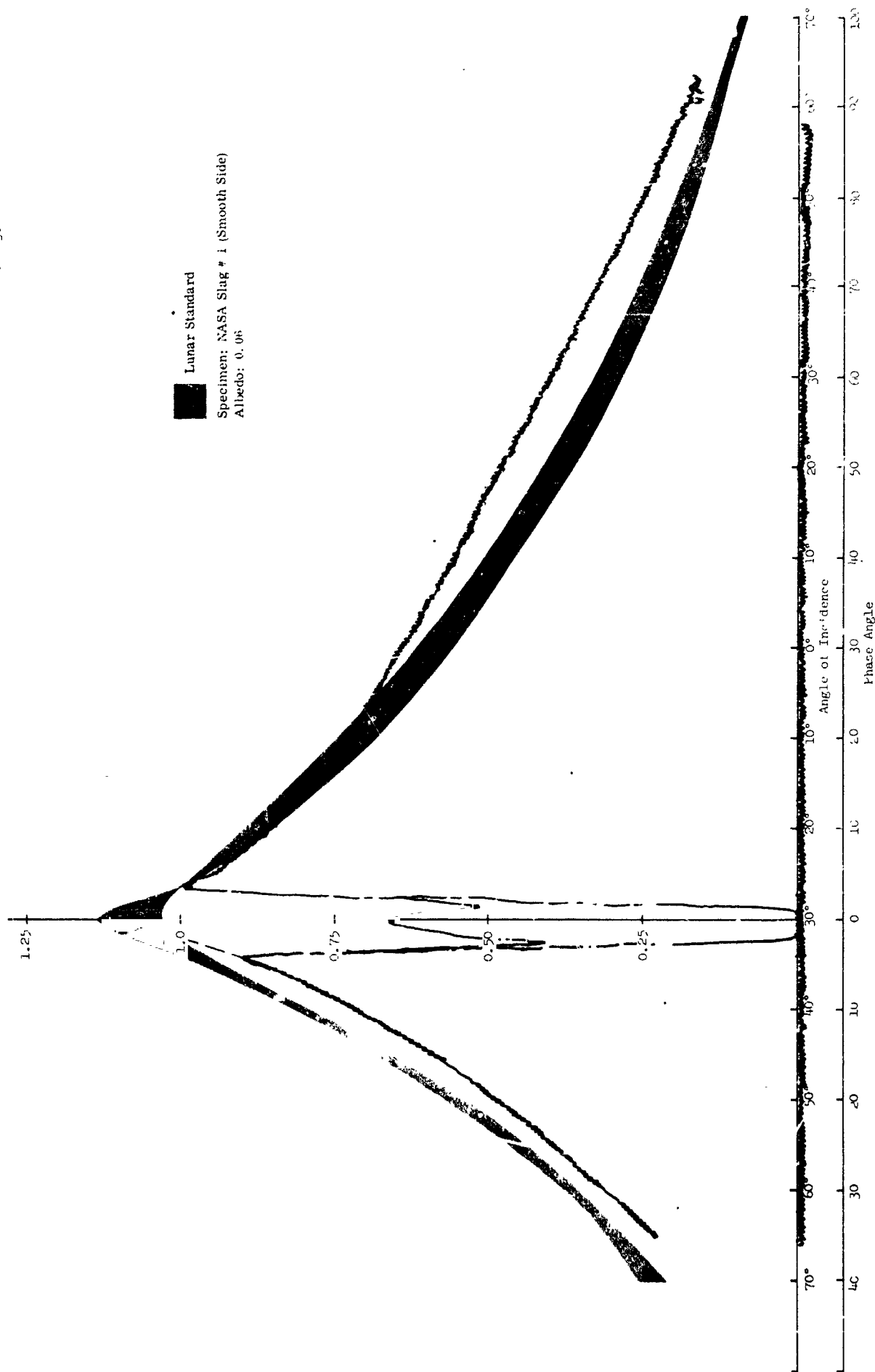


Figure 4c. NASA Slag # 1 (Smooth Side)

$E = 60^\circ$

Lunar Standard
Specimen: NASA Slag # 1 (Smooth Side)
Albedo: 0.06

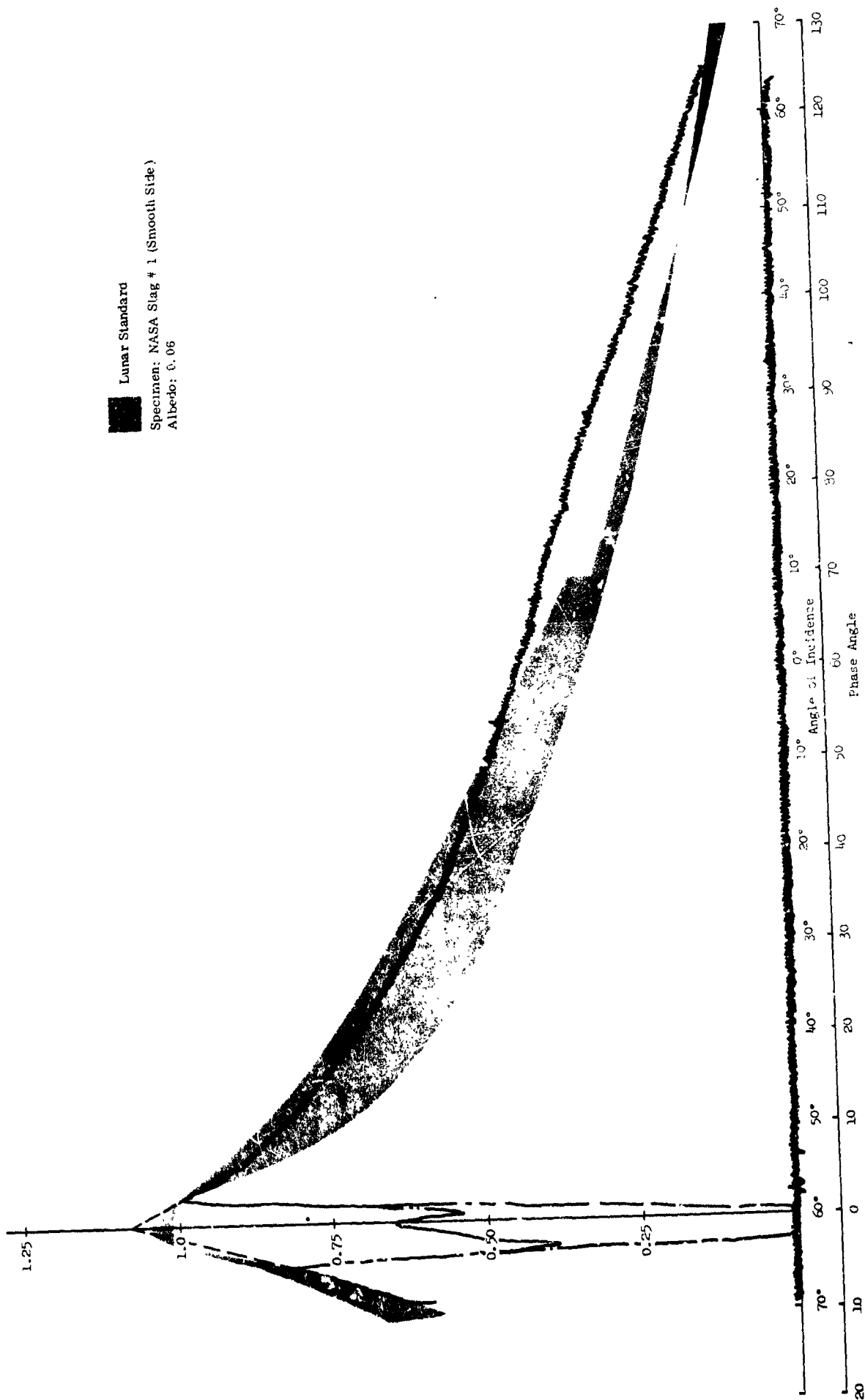
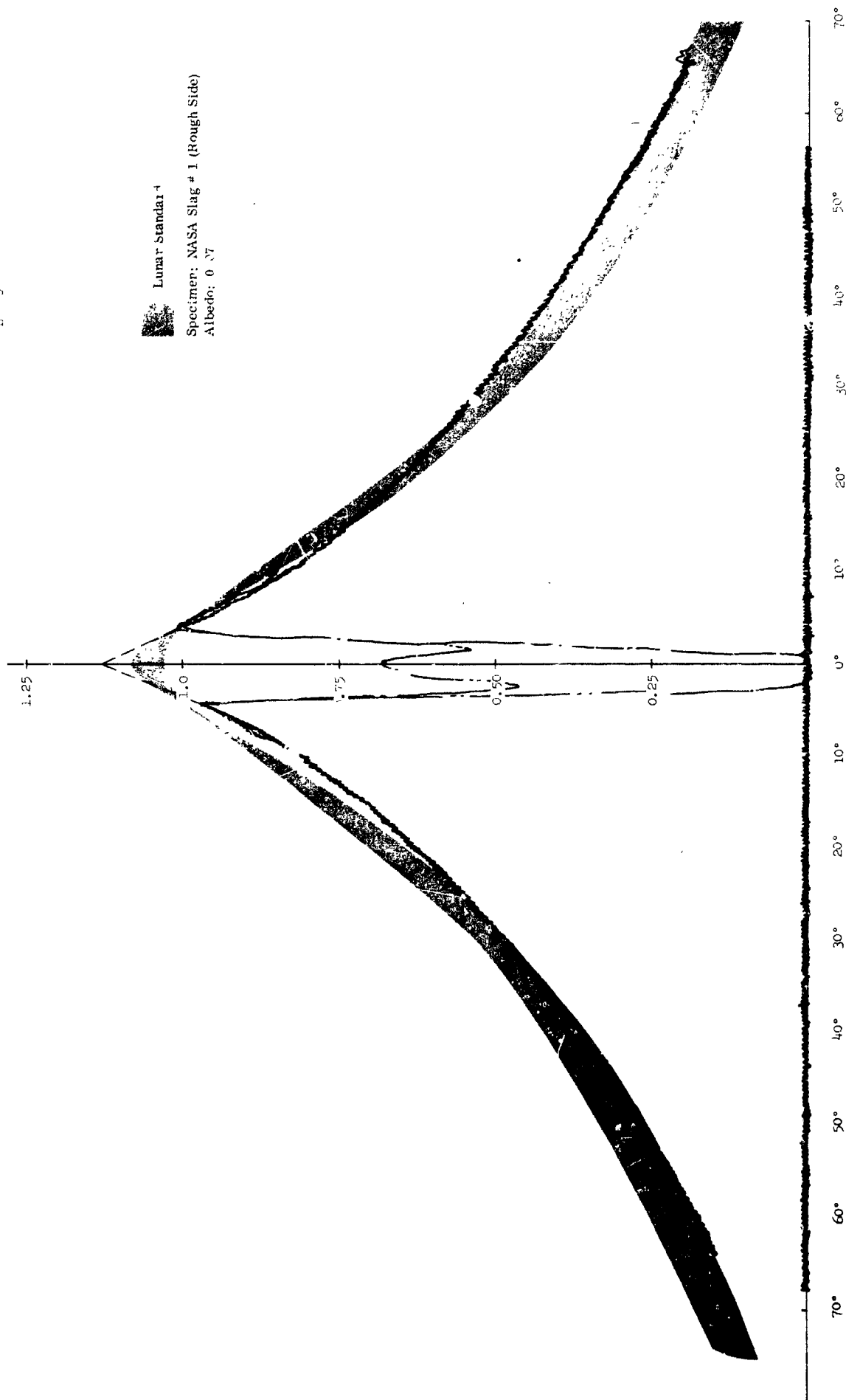


Figure 4d. NASA Slag # 1 (Smooth Side)

E 0°



Lunar Standard
Specimen: NASA Slag # 1 (Rough Side)
Albedo: 0.07

Angle of Incidence and Phase

Figure 5a. NASA Slag # 1 (Rough Side)

$\lambda = 50^\circ$

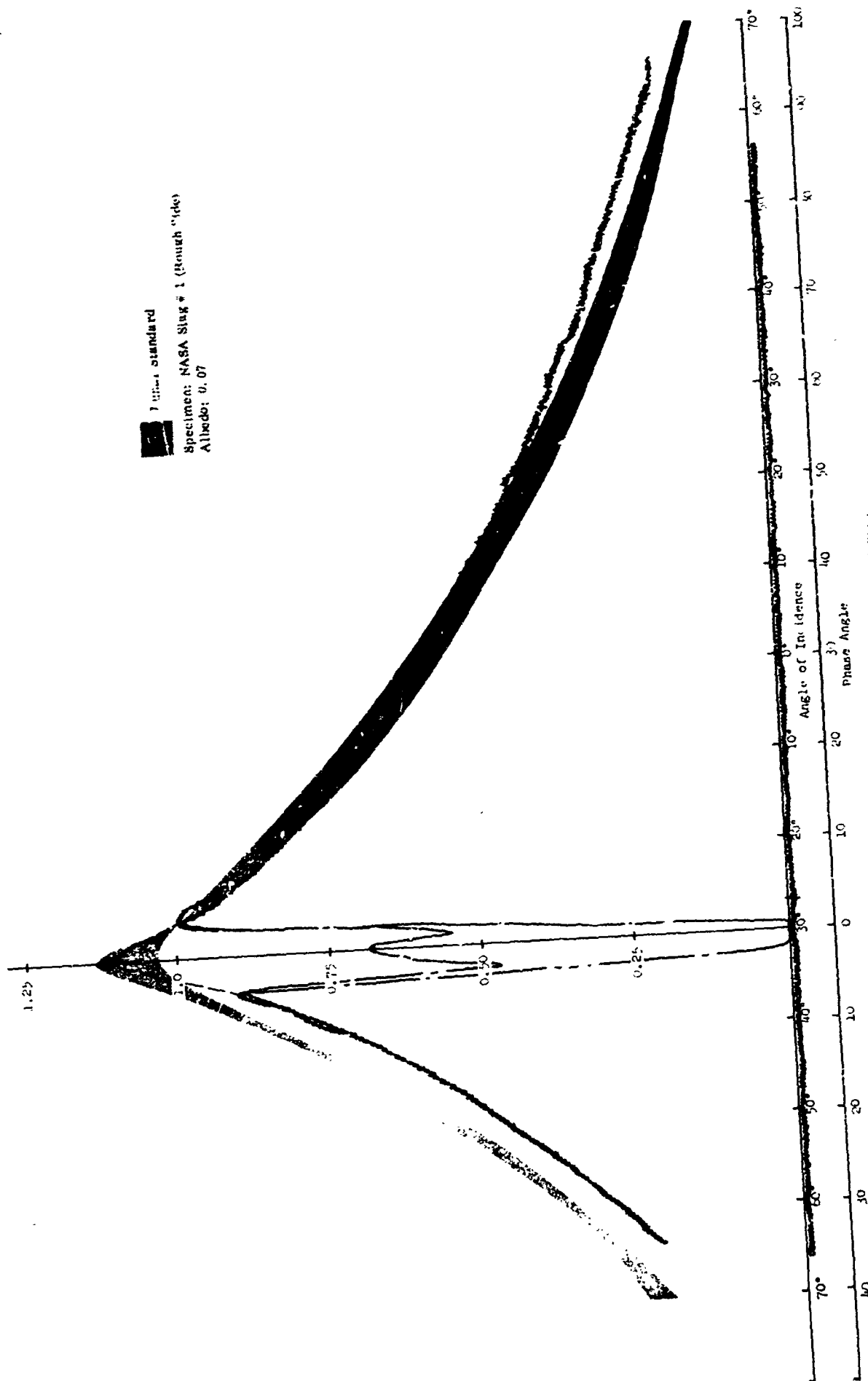


Figure 5b. NASA Slag # 1 (Rough Side)

$\lambda = 60^\circ$

Lunar Standard
 Specimen: NASA Slug # 1 (Rough Side)
 Albedo: 0.07

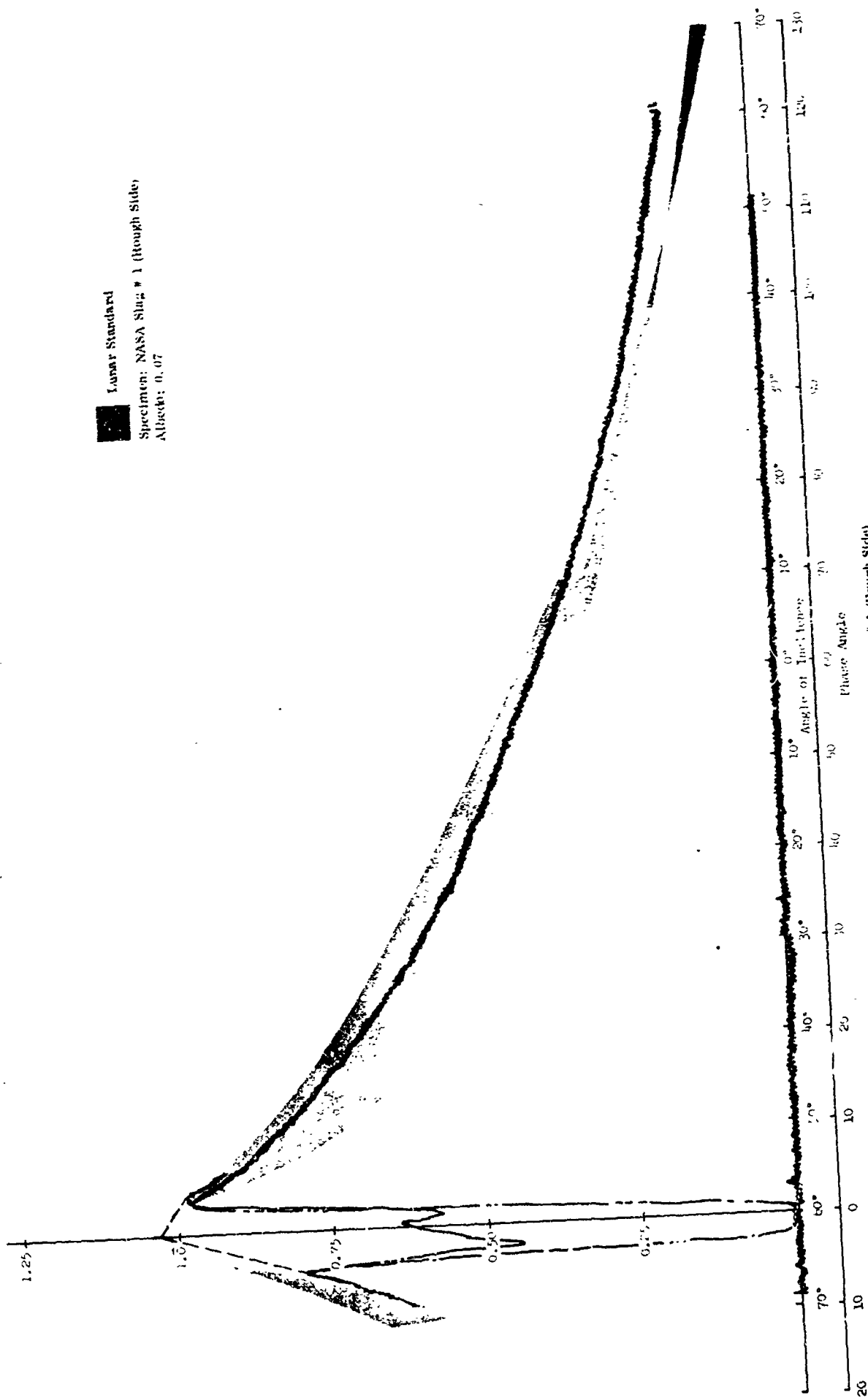


Figure 5c. NASA Slug # 1 (Rough Side)

$k = 0.5$

Lunar Standard

Specimen: CuO on NASA Slag # 1 (Smooth Side)

Albedo: 0.06

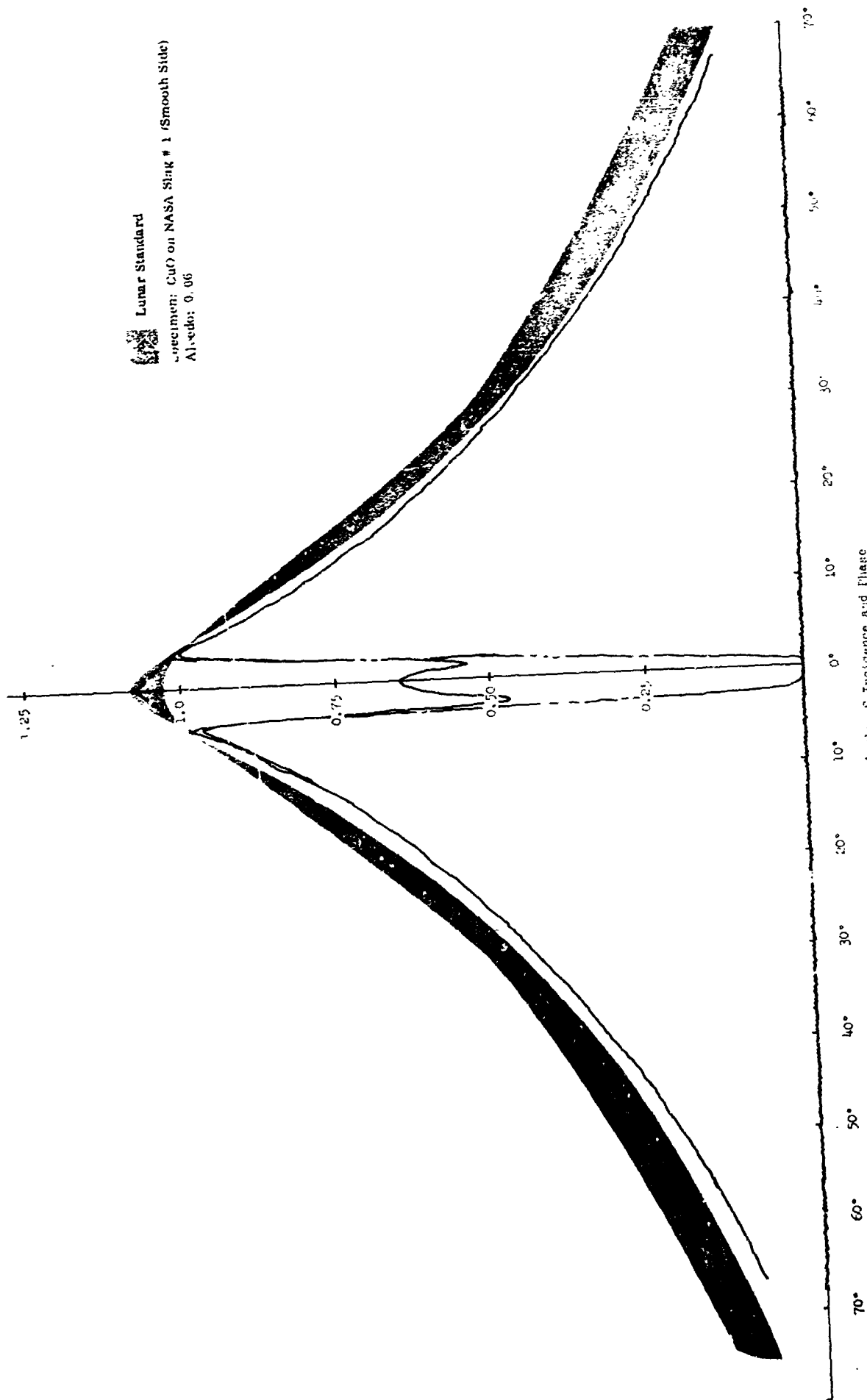
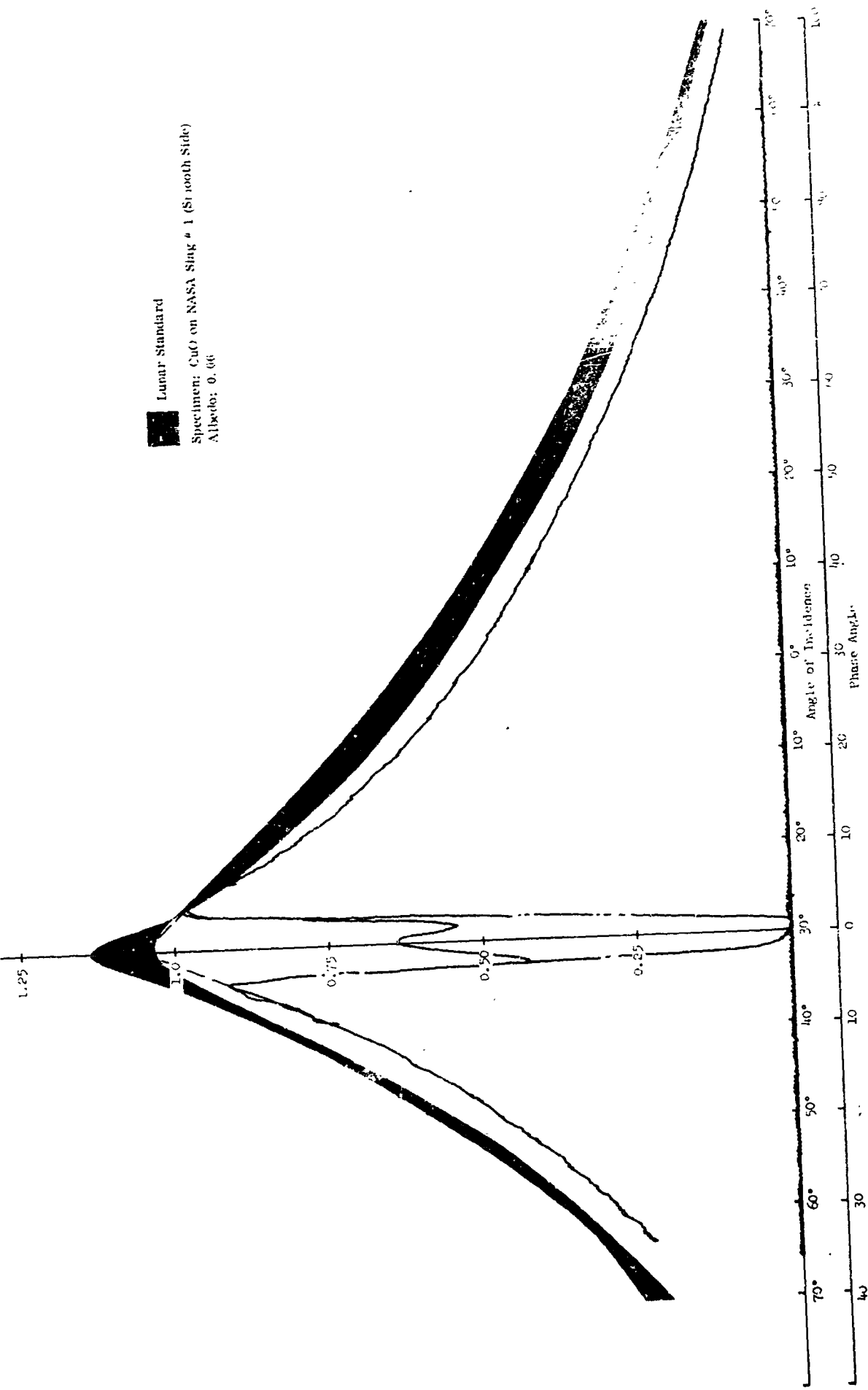


Figure 6a. CuO on NASA Slag # 1 (Smooth Side)



Lunar Standard
 Specimen: CuO on NASA Slag # 1 (Smooth Side)
 Albedo: 0.06

Figure 6b. CuO on NASA Slag # 1 (Smooth Side)

E - 10°

Lunar Standard

Specimen: CuO on NASA Slag # 1 (Smooth Side)
Albedo: 0.06

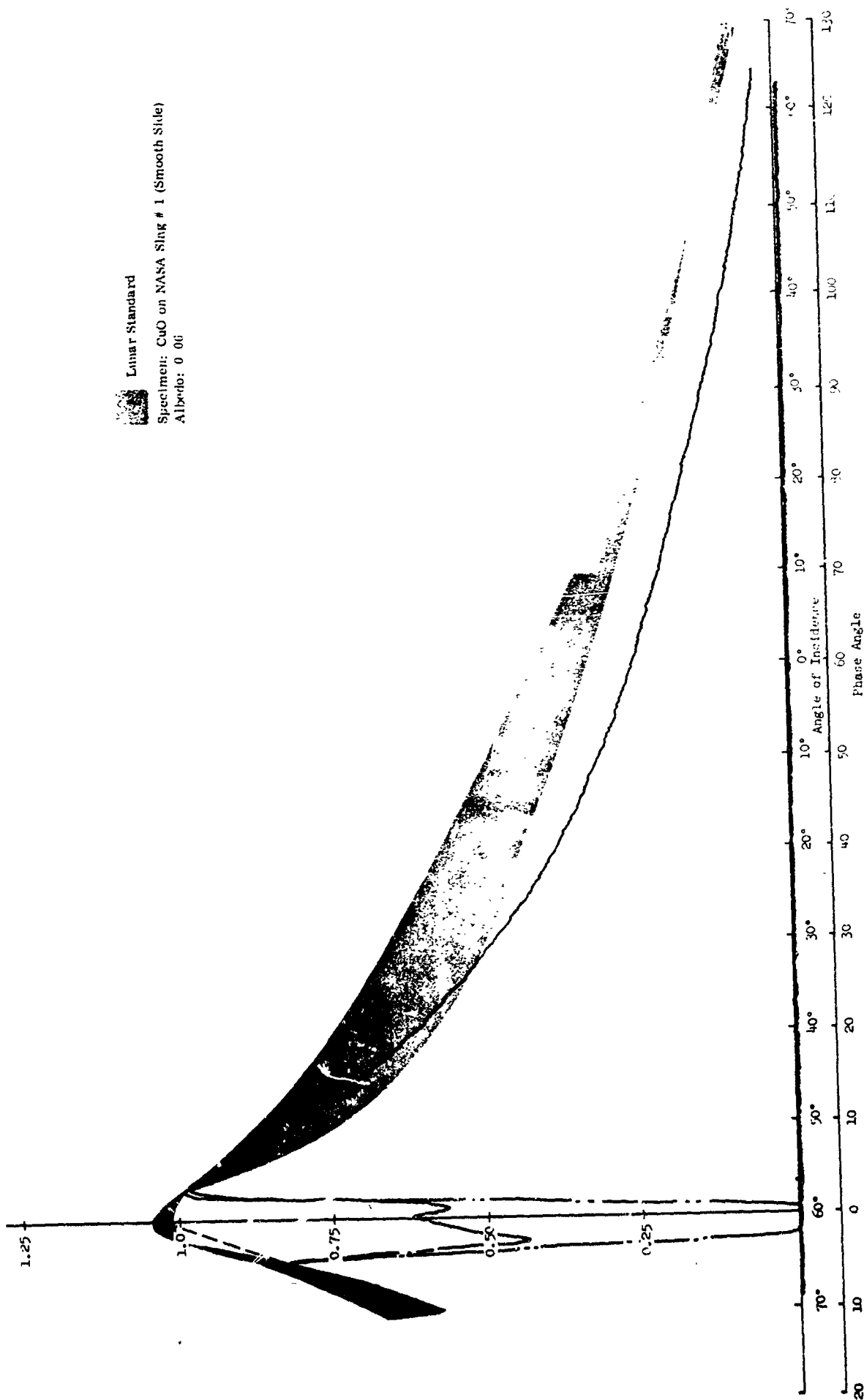


Figure 6c. CuO on NASA Slag # 1 (Smooth Side)

F. 0°

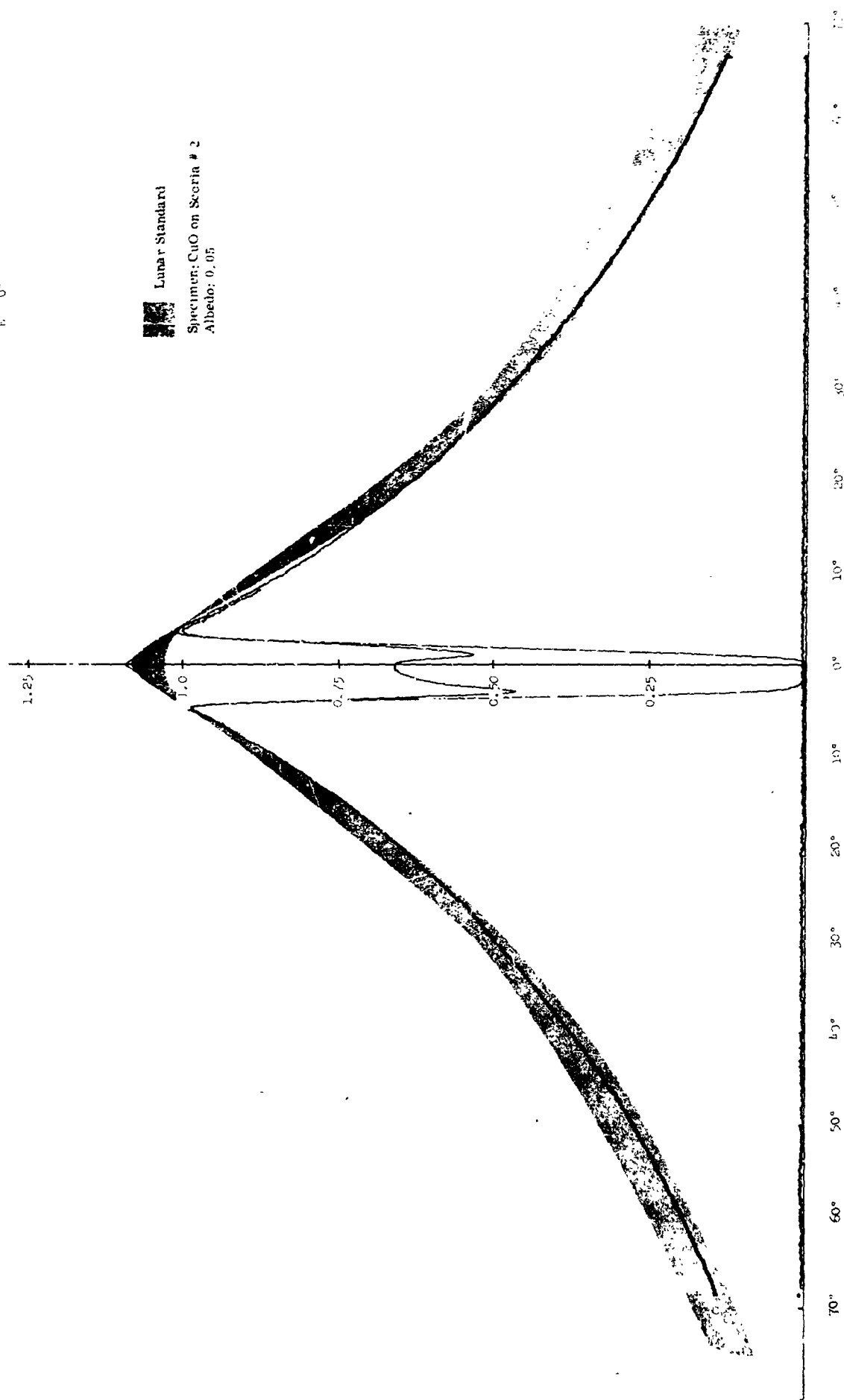


Figure 7a. CuO on Scoria # 2

$E = 30^\circ$

Lunar Standard
 Specimen: CuO on Scoria # 2
 Albedo: 0.05

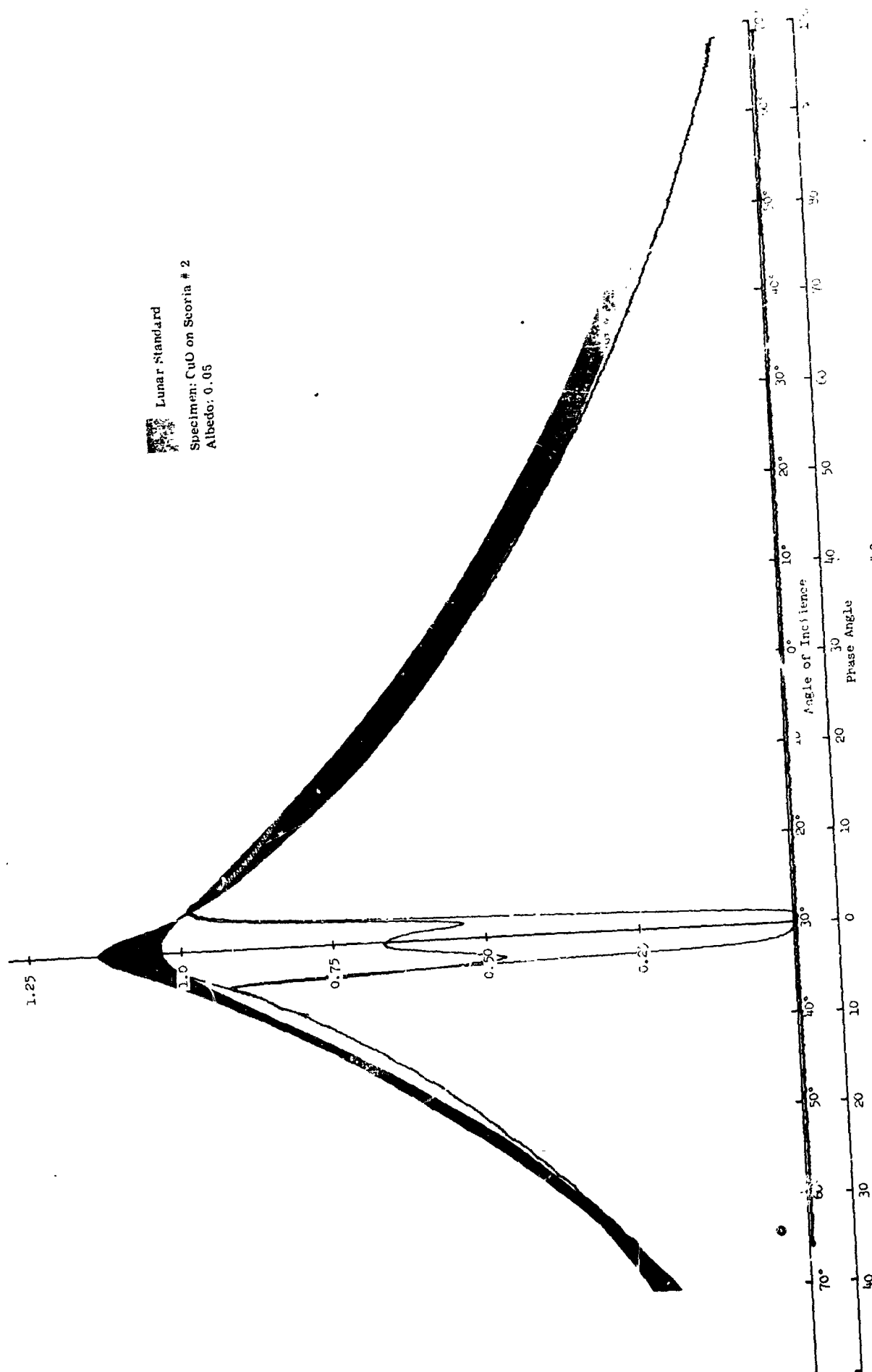


Figure 7b. CuO on Scoria # 2

$E = 60^\circ$

Lunar Standard
 Specimen: CuO on Scoria # 2
 Albedo: 0.05

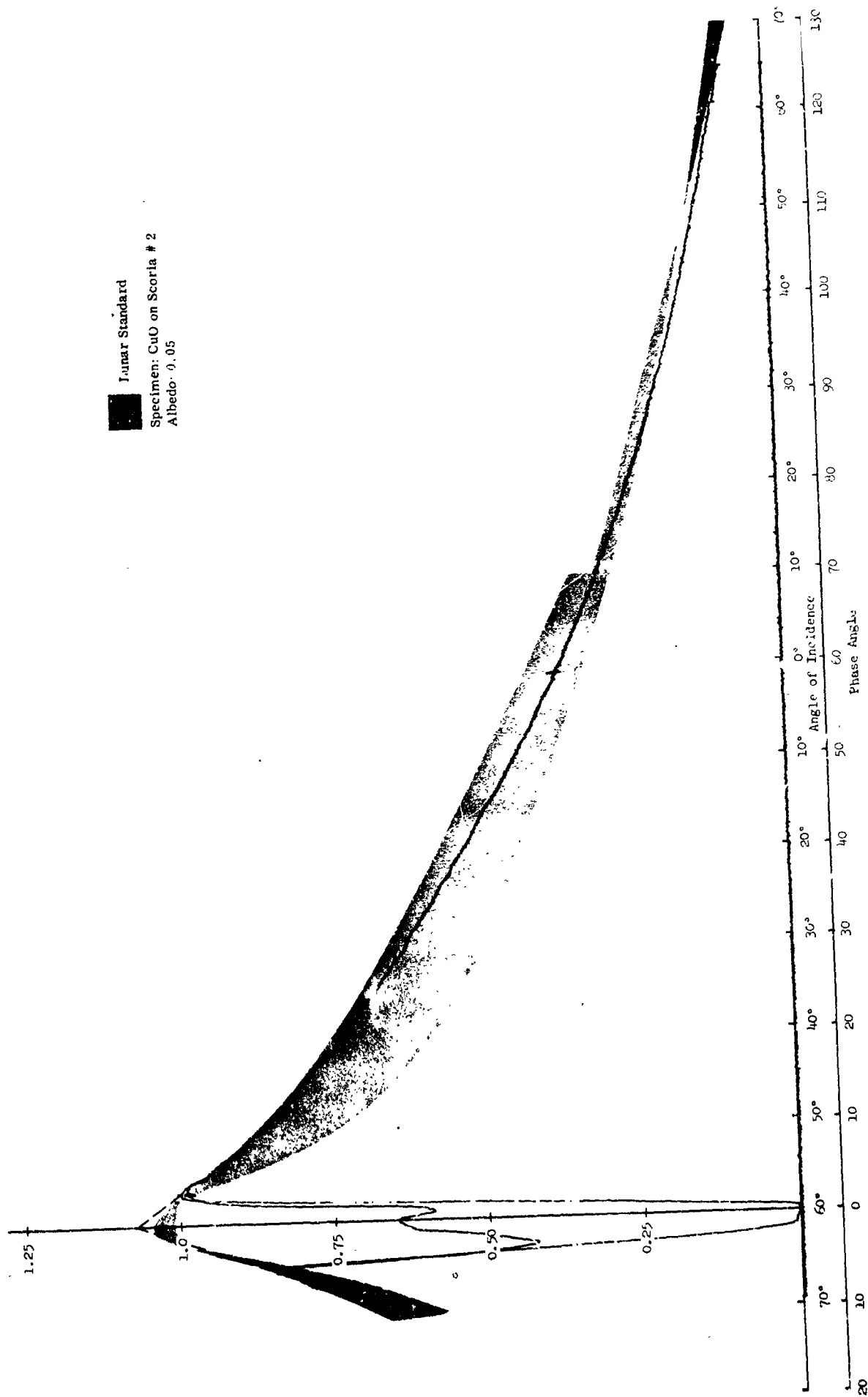


Figure 7c. CuO on Scoria # 2

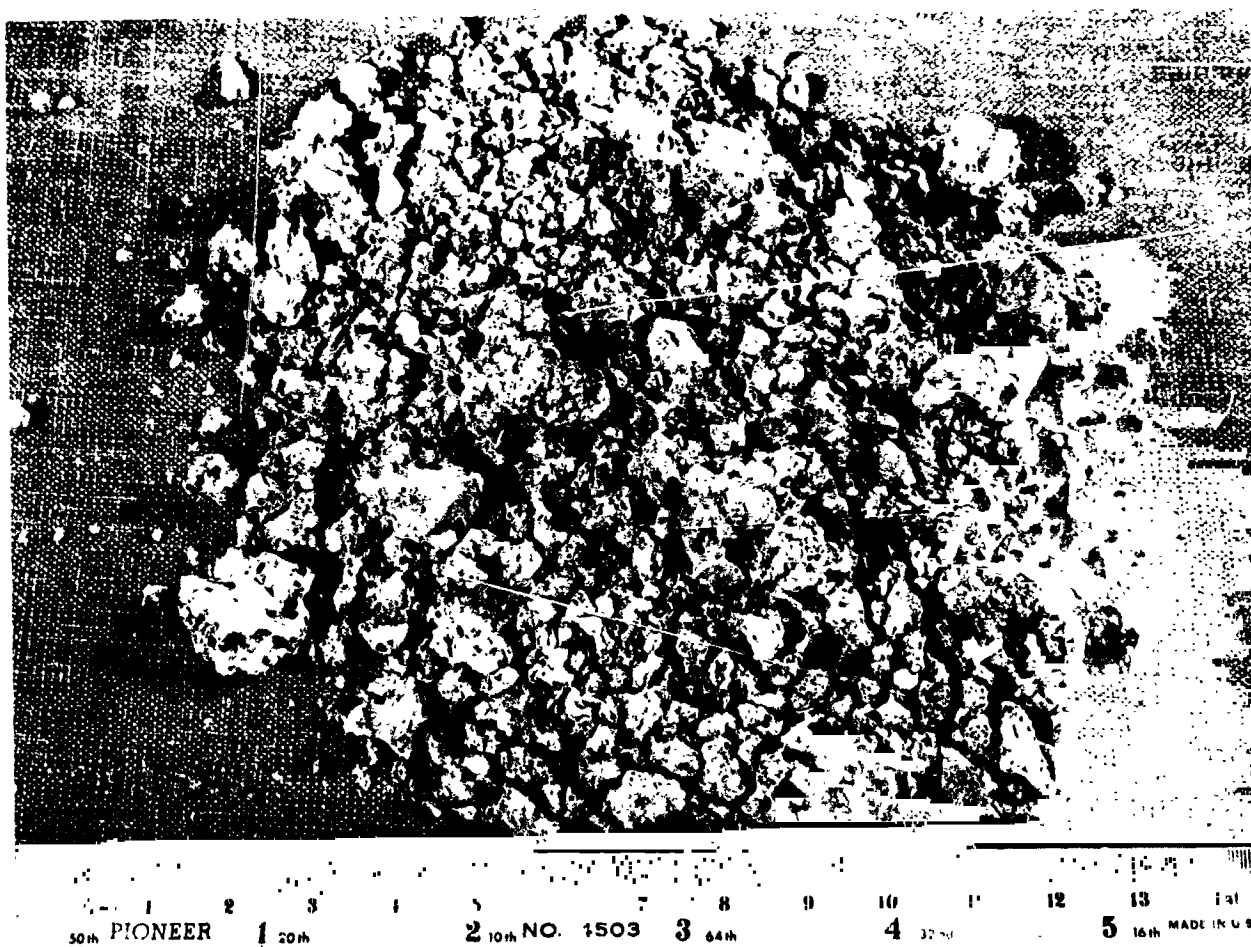


Figure 8a. Volcanic Ash # 1

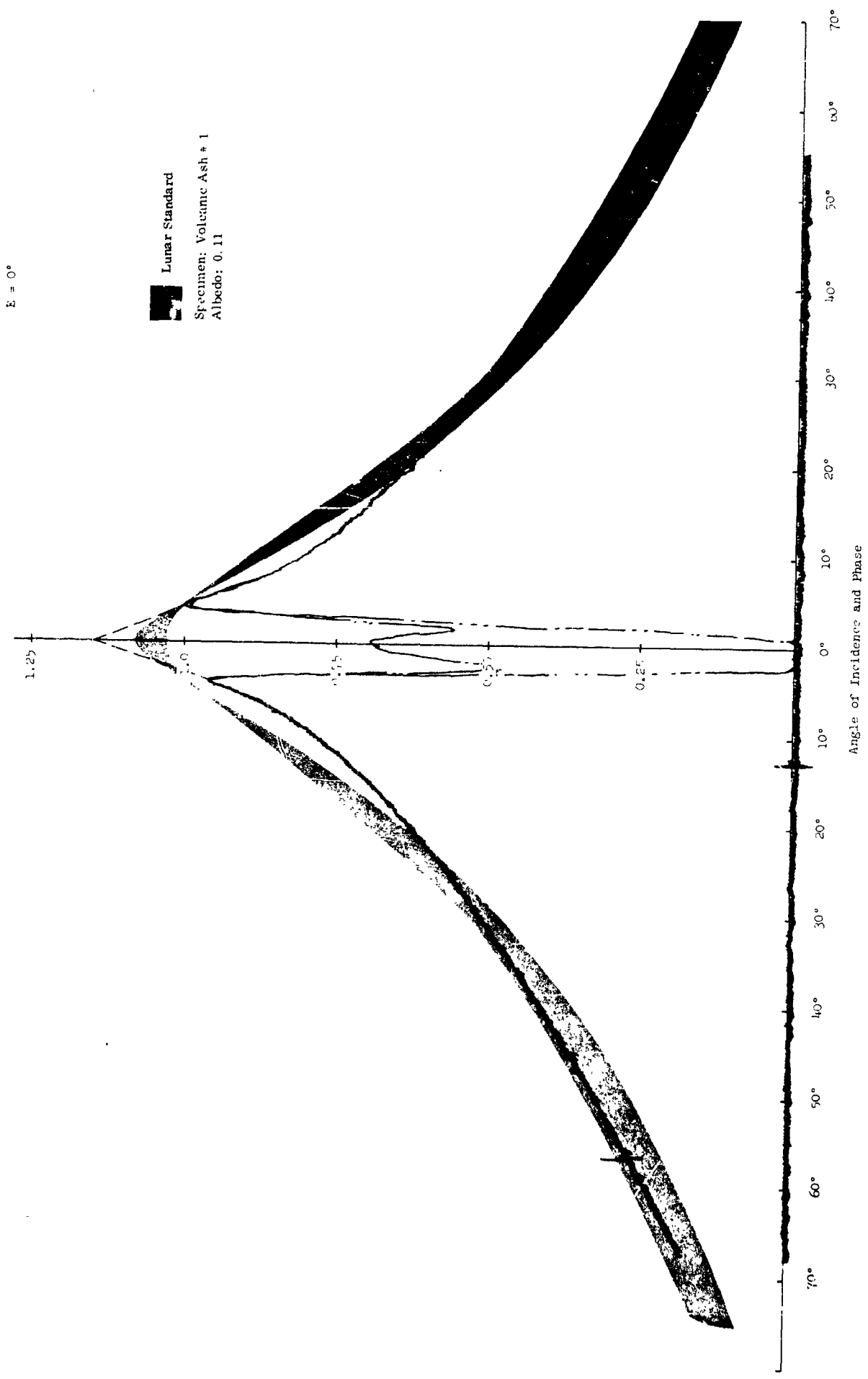
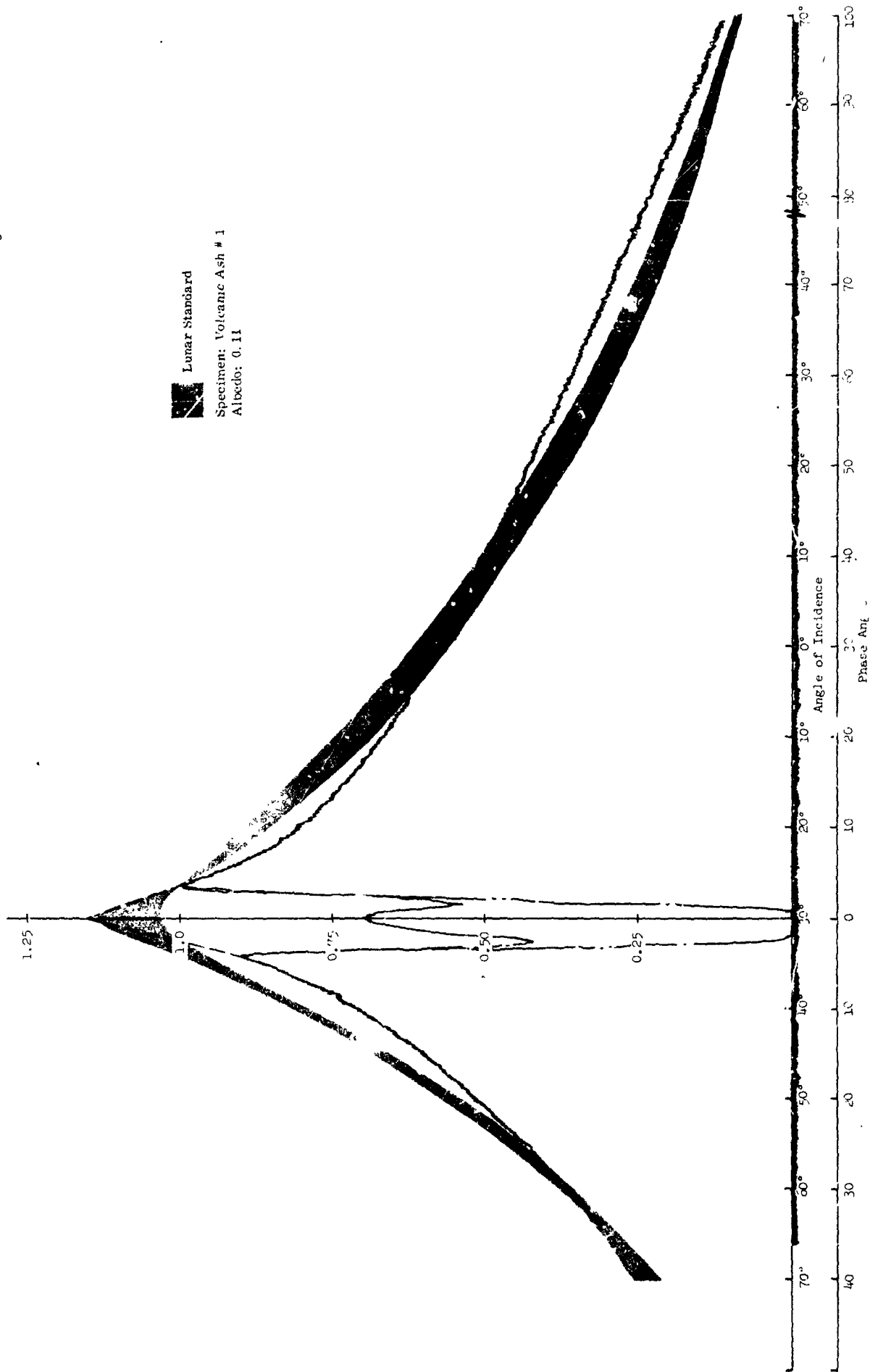


Figure 8b. Volcanic Ash # 1

E = 30°



Lunar Standard
Specimen: Volcanic Ash # 1
Albedo: 0.11

Figure 8c. Volcanic Ash # 1

$E = 60^\circ$

Lunar Standard
Specimen: Volcanic Ash # 1
Albedo: 0.11

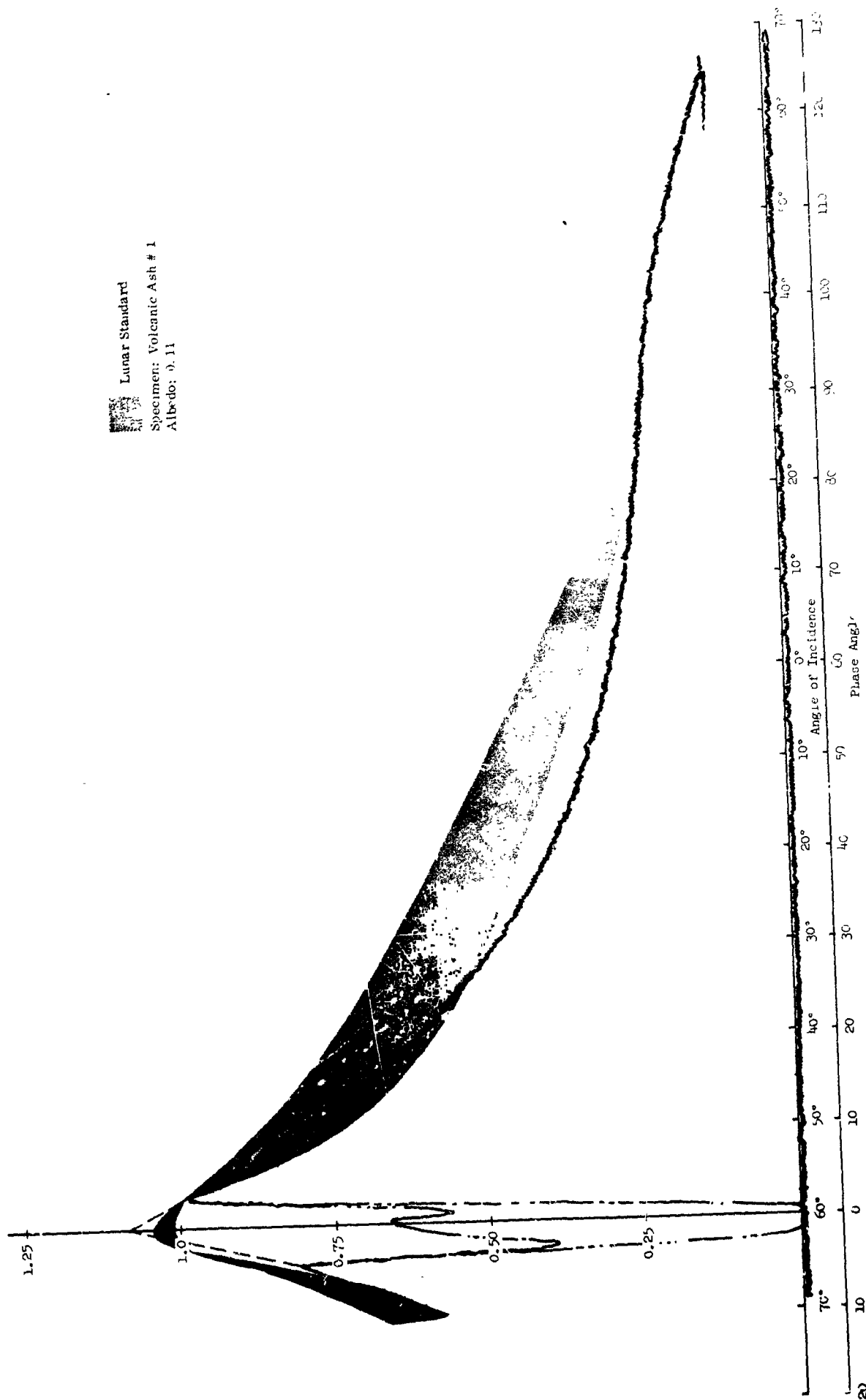


Figure 8d. Volcanic Ash # 1

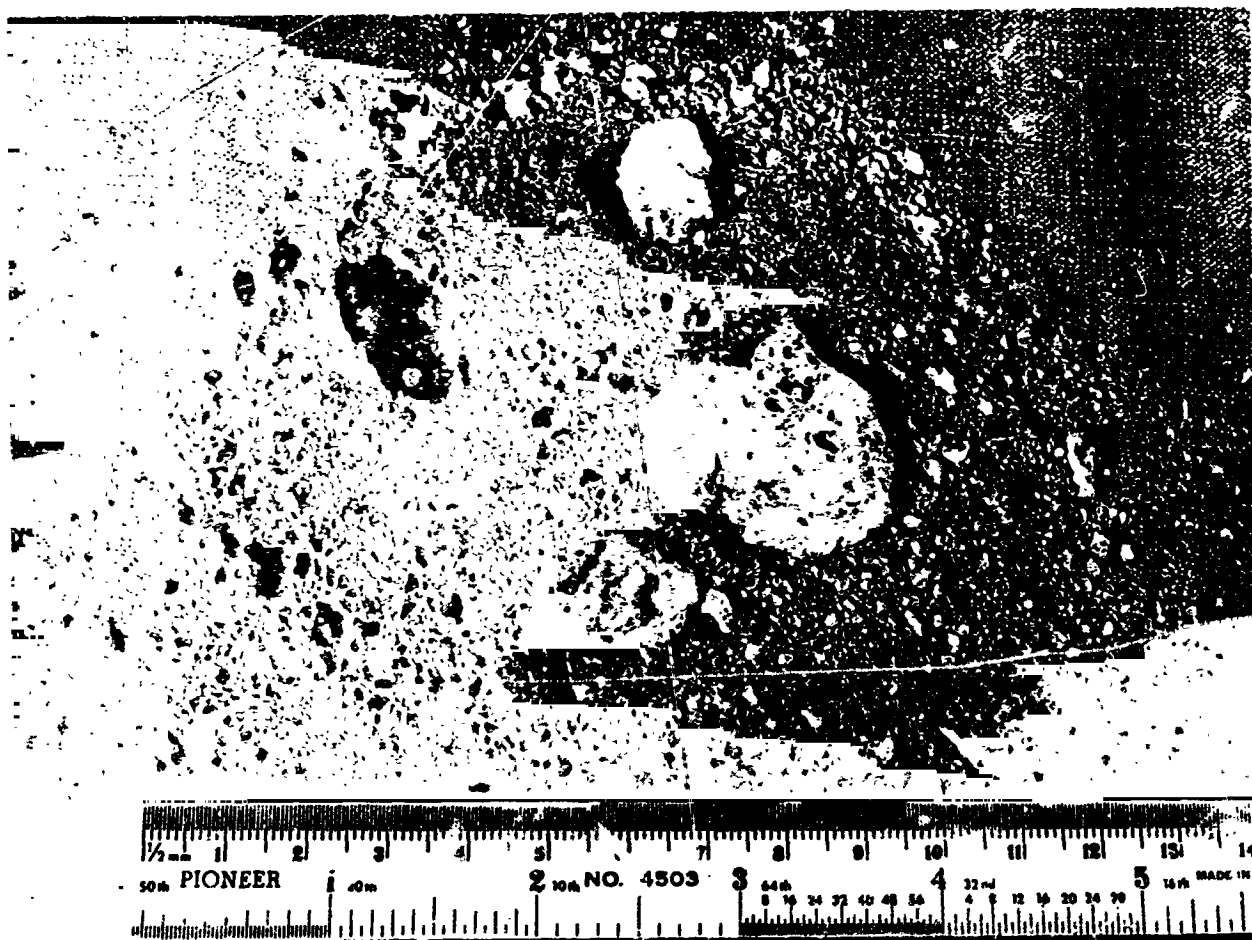


Figure 9a. Volcanic Ash # 2

1.0°

Lunar Standard

Specimen: Vol. and Ash # 2
Albedo: 0.12

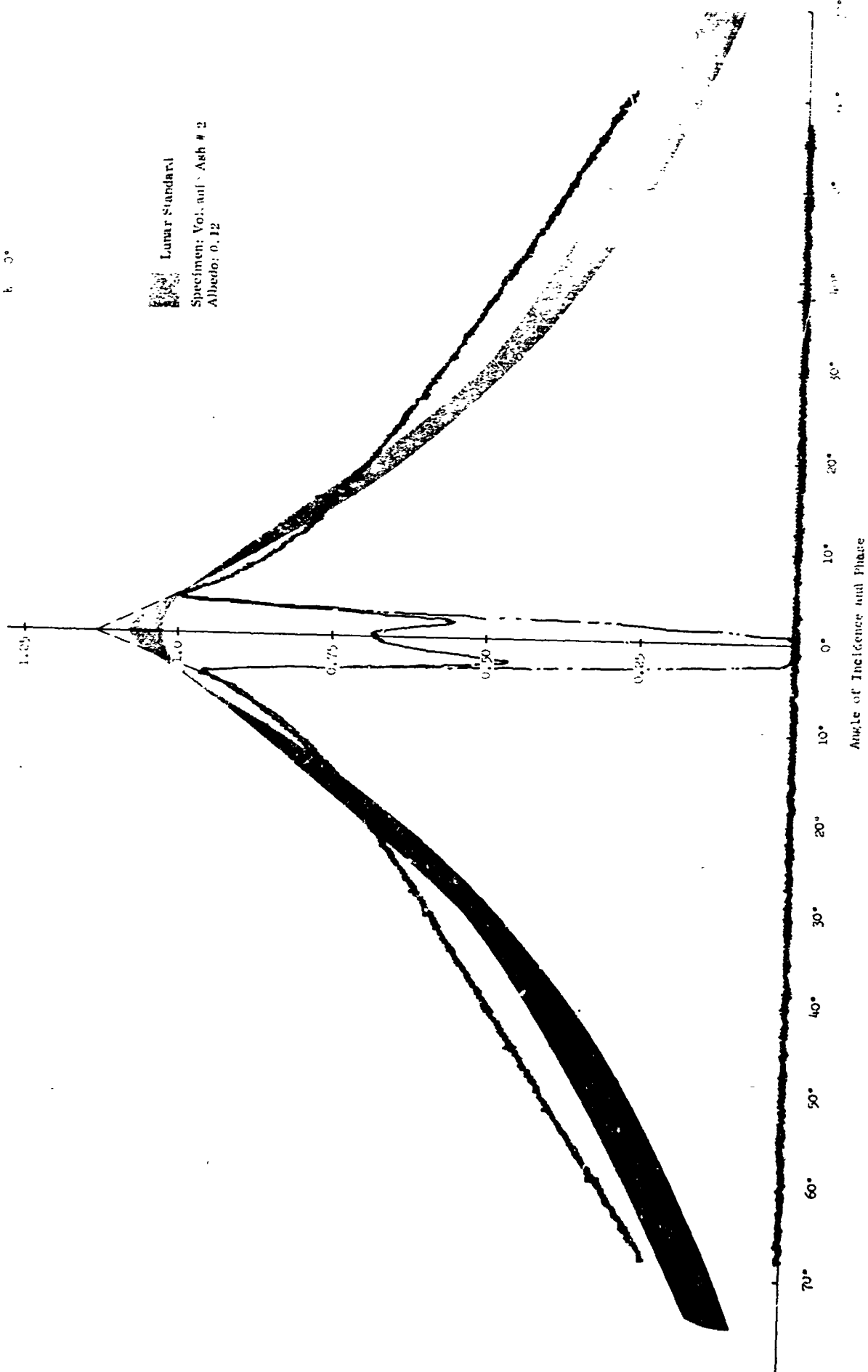
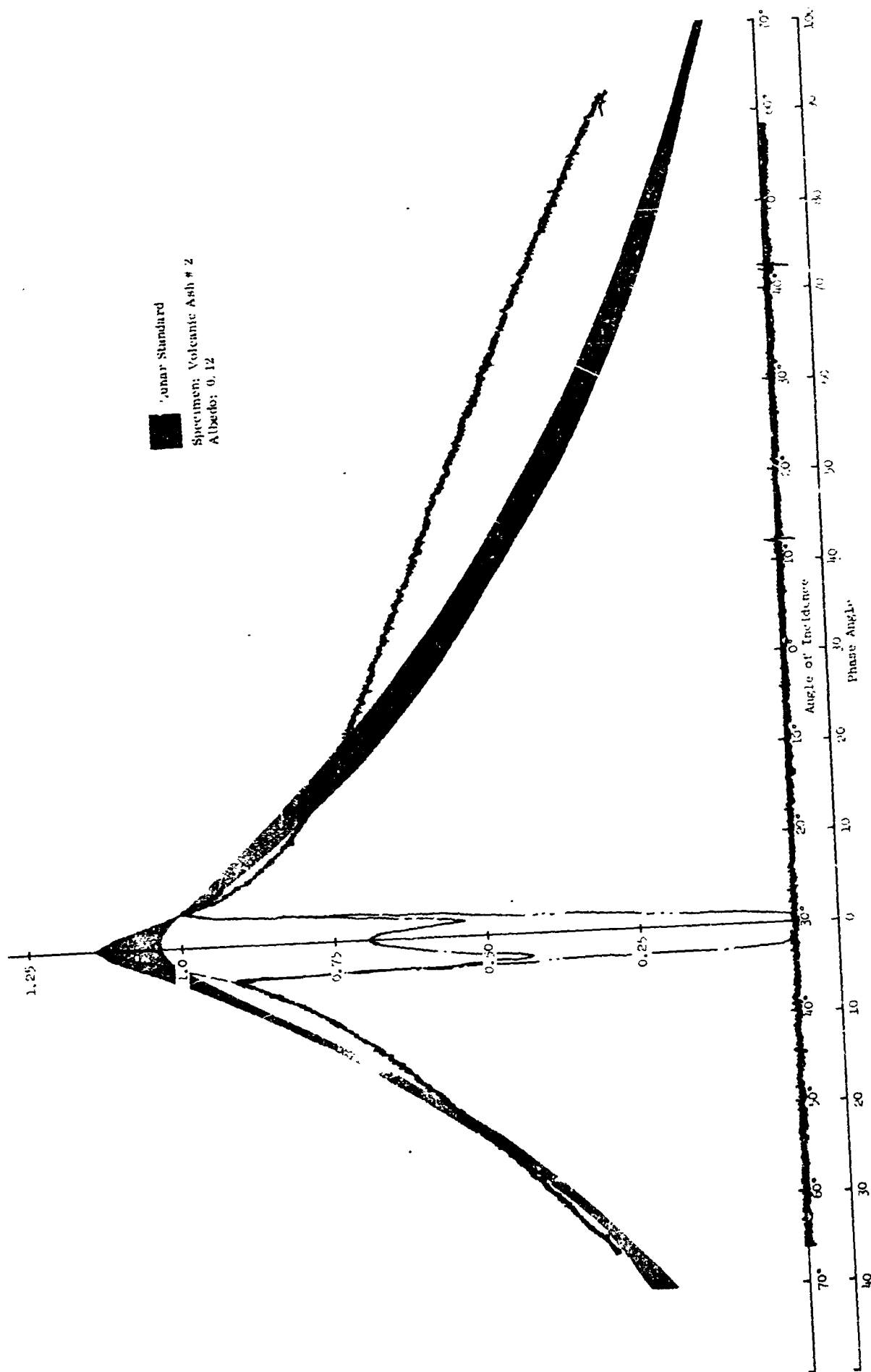


Figure 9b, Volcanic Ash # 2

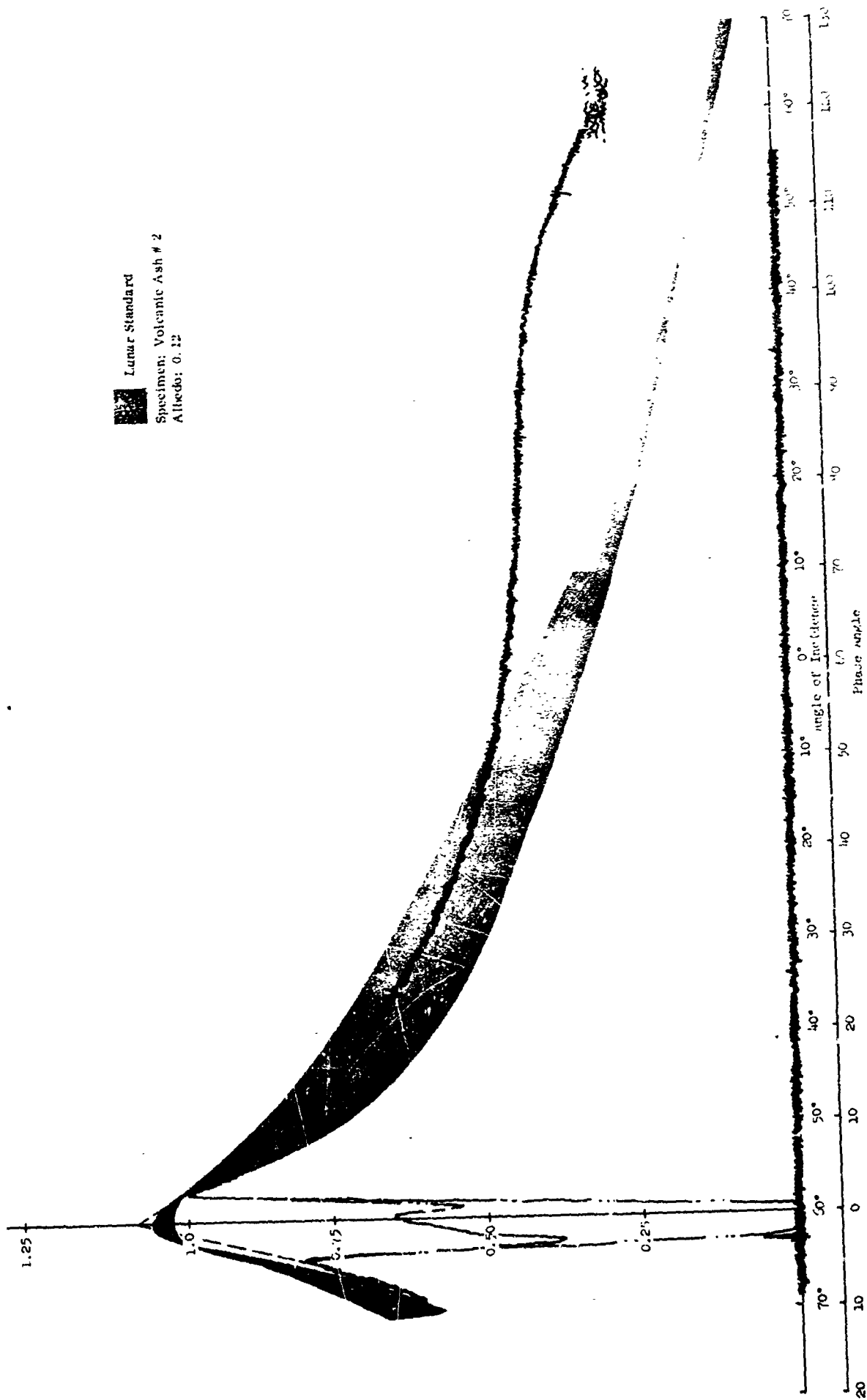
E 50°



Lunar Standard
Specimen: Volcanic Ash # 2
Albedo: 0.12

Figure 9c. Volcanic Ash # 2

E = 60°



Lunar Standard
Specimen: Volcanic Ash # 2
Albedo: 0.12

Figure 14. Volcanic Ash # 2



Figure 10a. Coral # 1

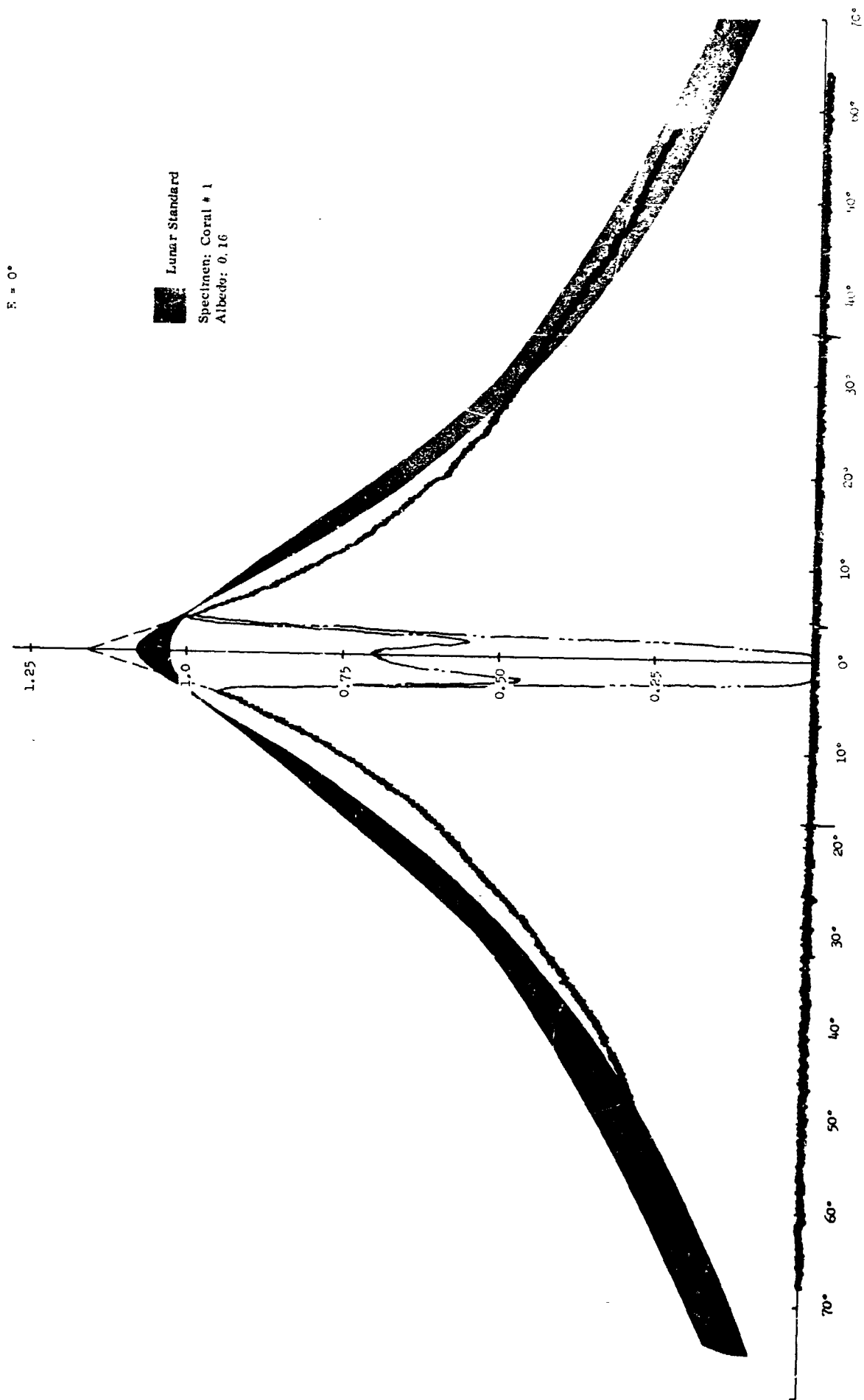
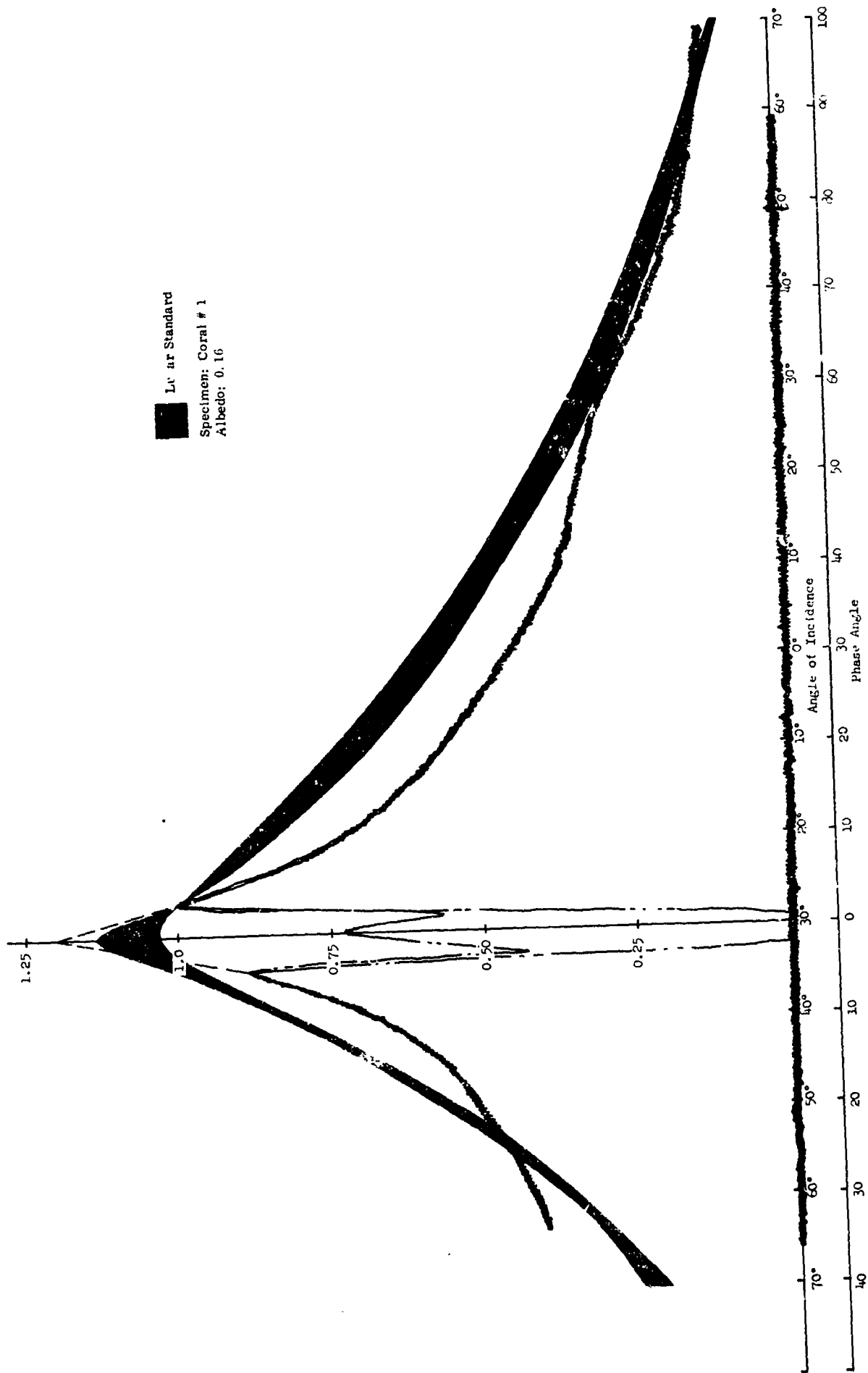


Figure 10b, Coral # 1

E = 30°



$\theta = 60^\circ$

Lunar Standard
Specimen: Coral # 1
Albedo: 0.16

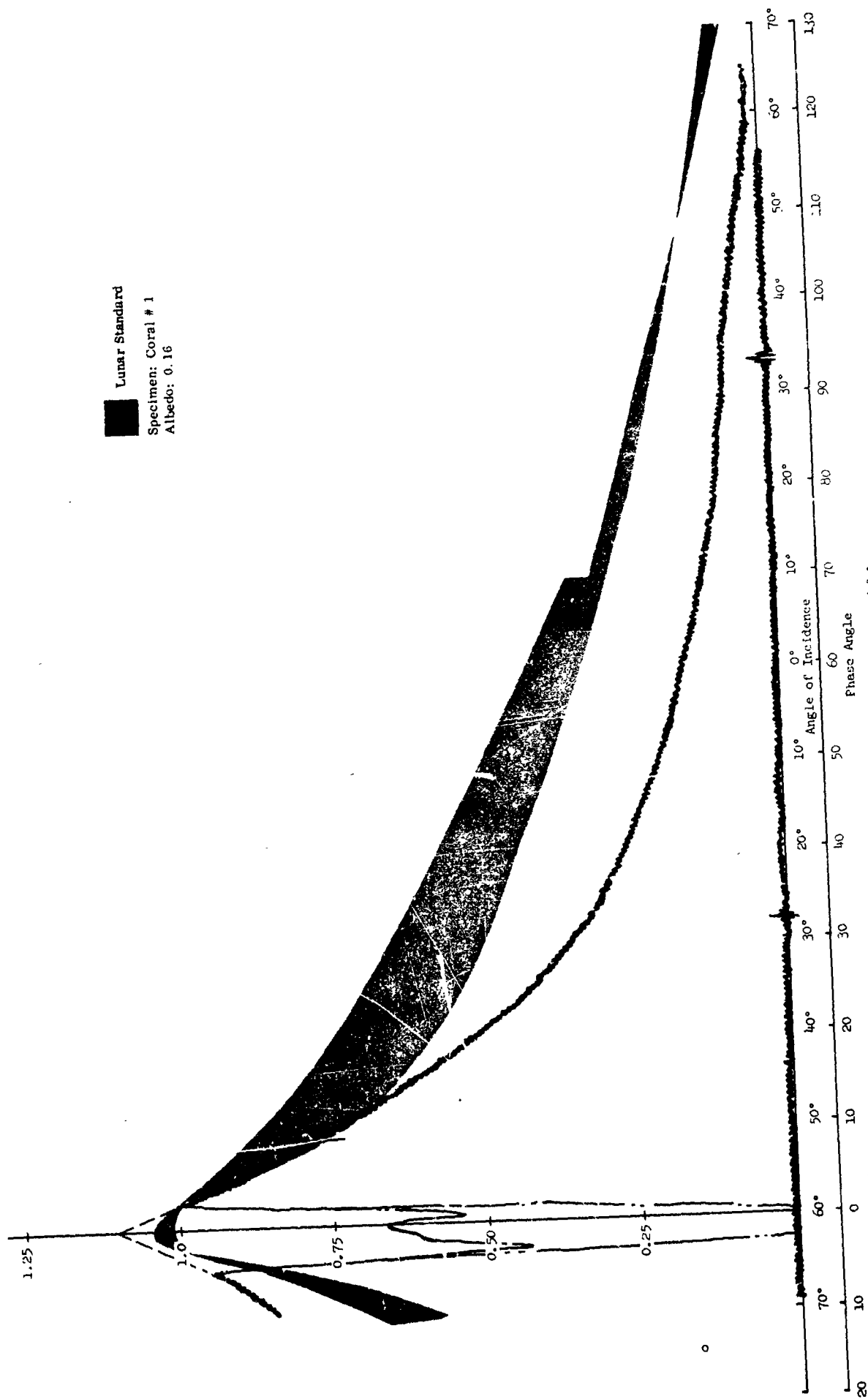


Figure 10d. Coral # 1

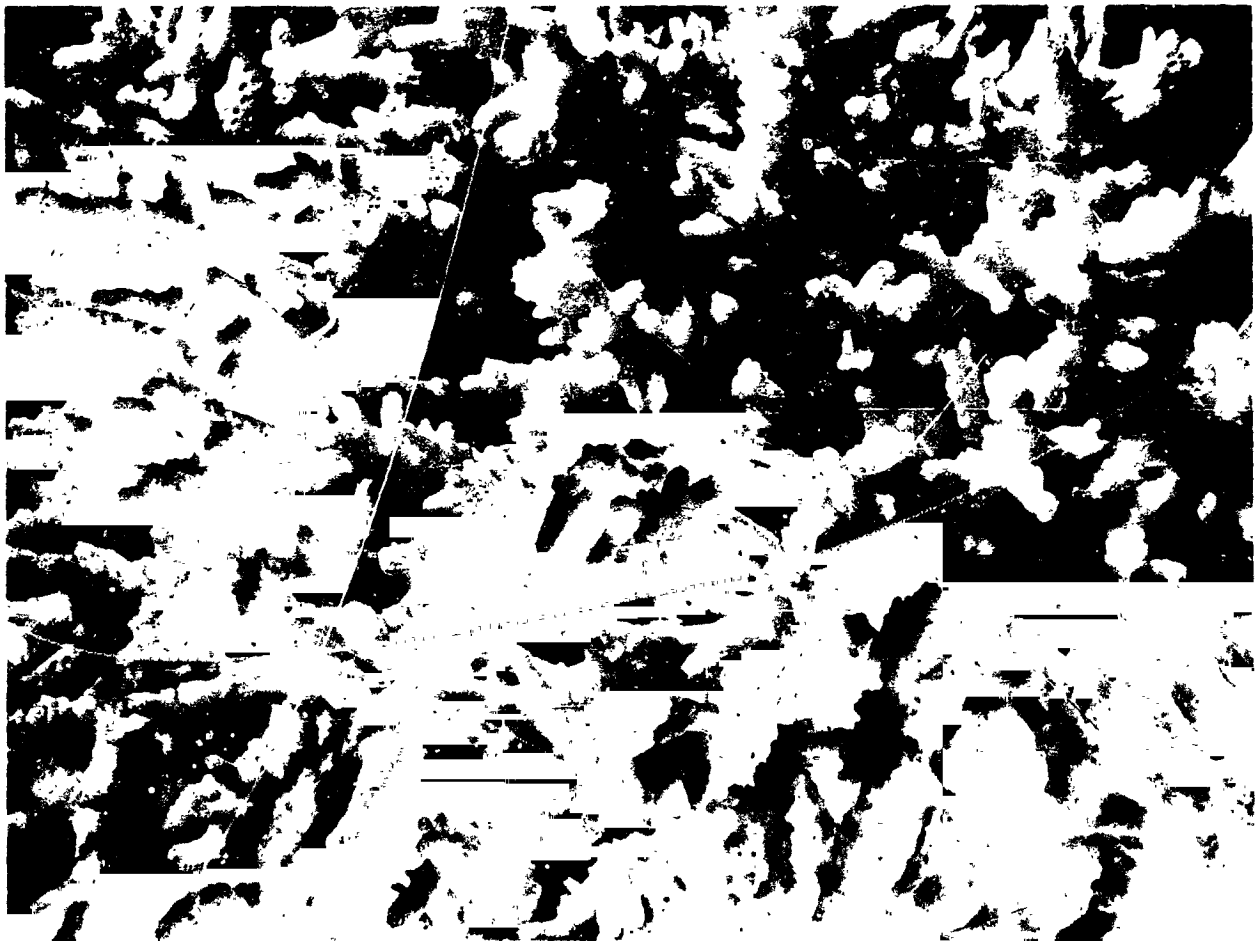


Figure 11a. Coral # 3

$E = 0^\circ$

Lunar Standard
Specimen: Coral # 3
Albedo: 0.25

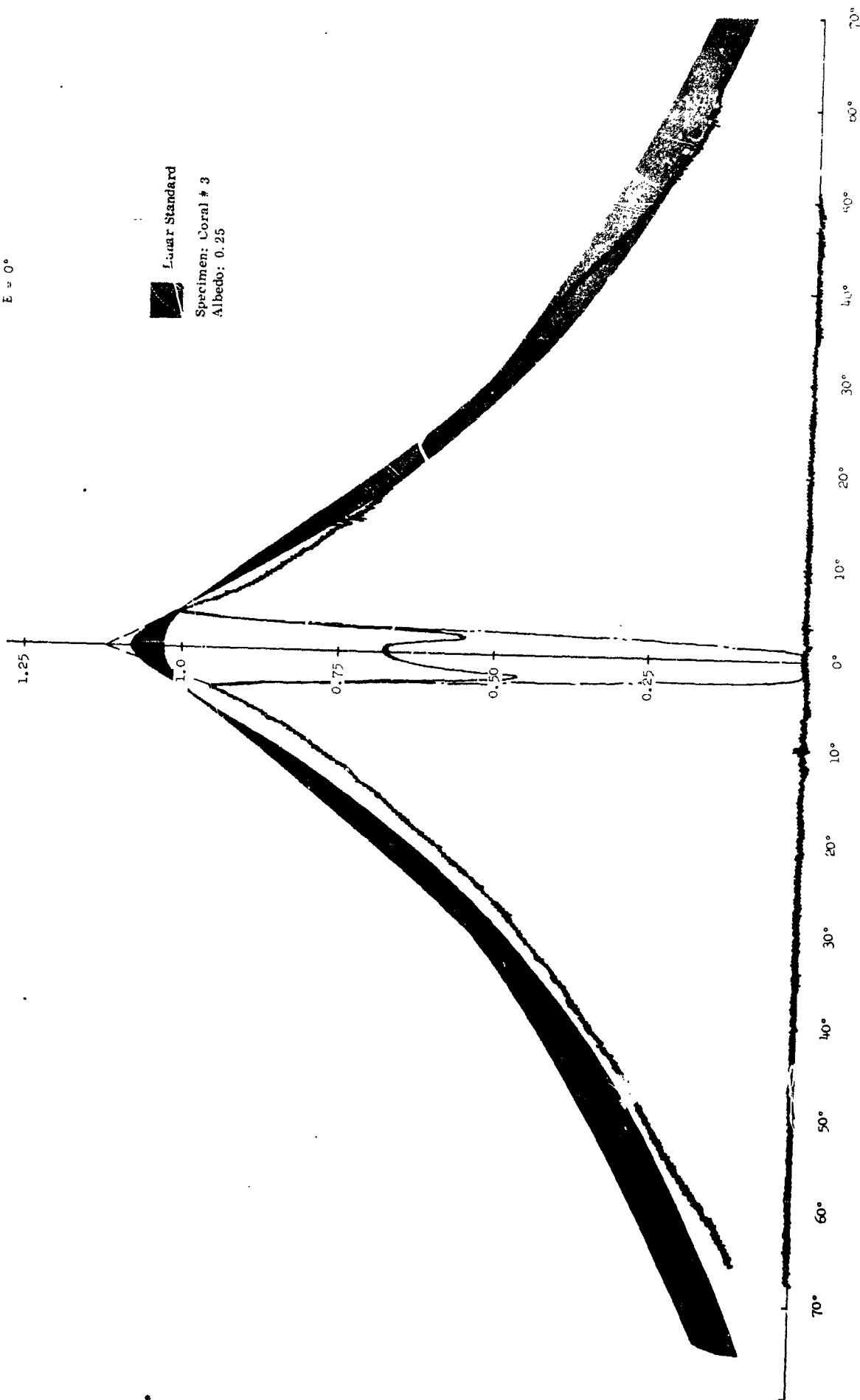
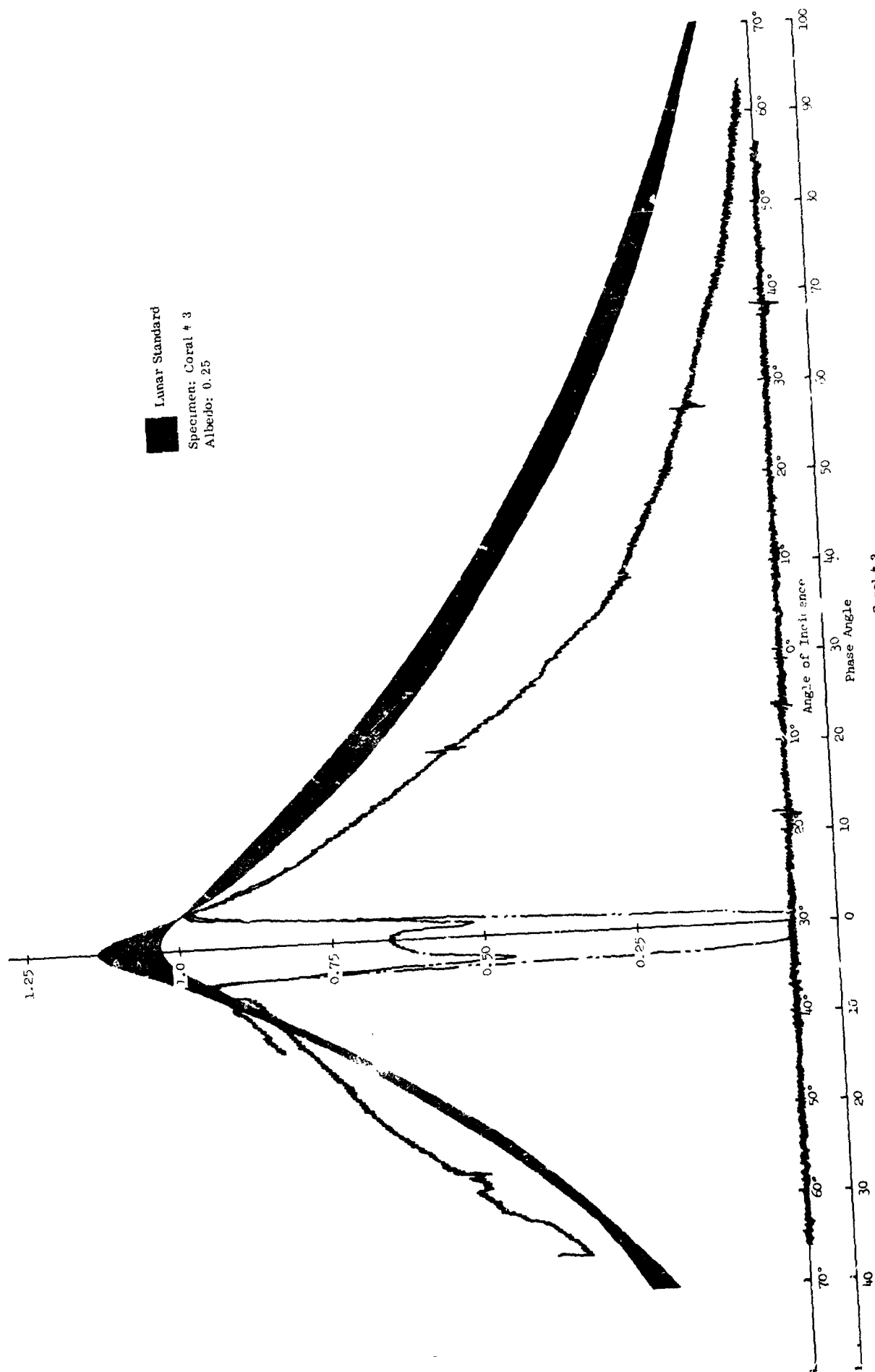


Figure 11b. Coral # 3

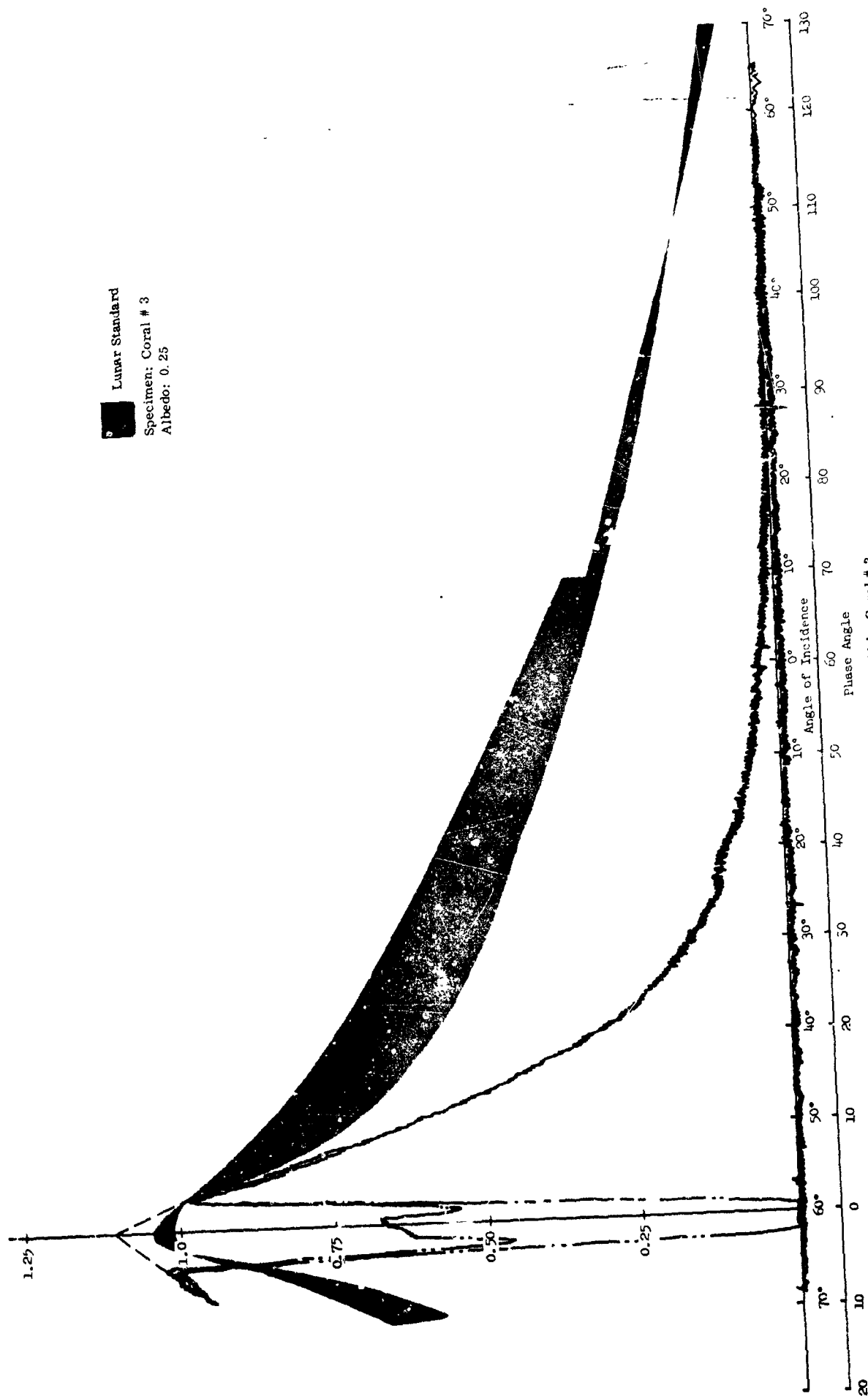
$E = 30^\circ$



Lunar Standard
Specimen: Coral # 3
Albedo: 0.25

Figure 11c. Coral # 3

E = 60°



Lunar Standard
Specimen: Coral # 3
Albedo: 0.25

Figure 11d, Coral # 3



Figure 12a. Coral # 4

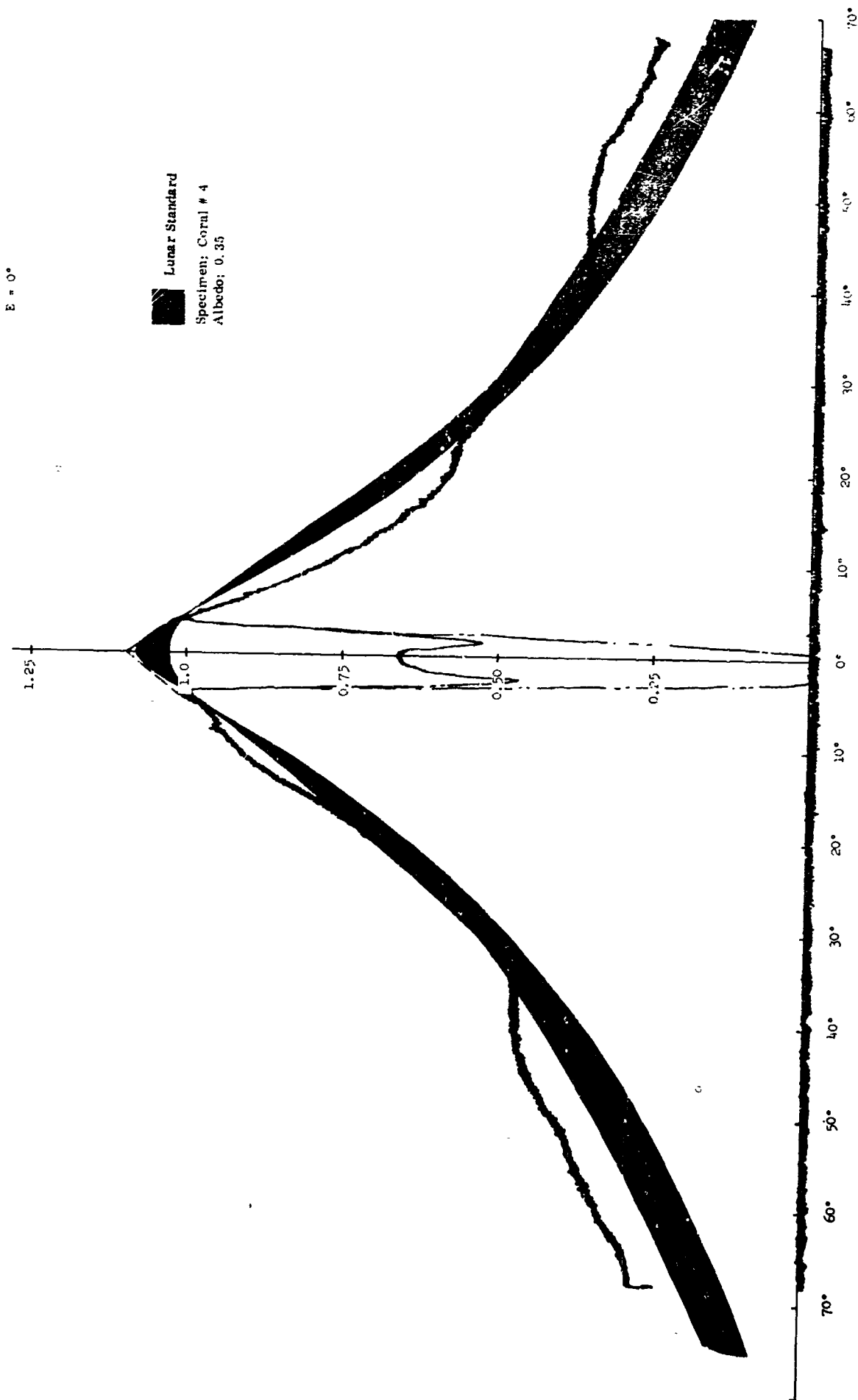


Figure 12b. Coral # 4

E = 30°

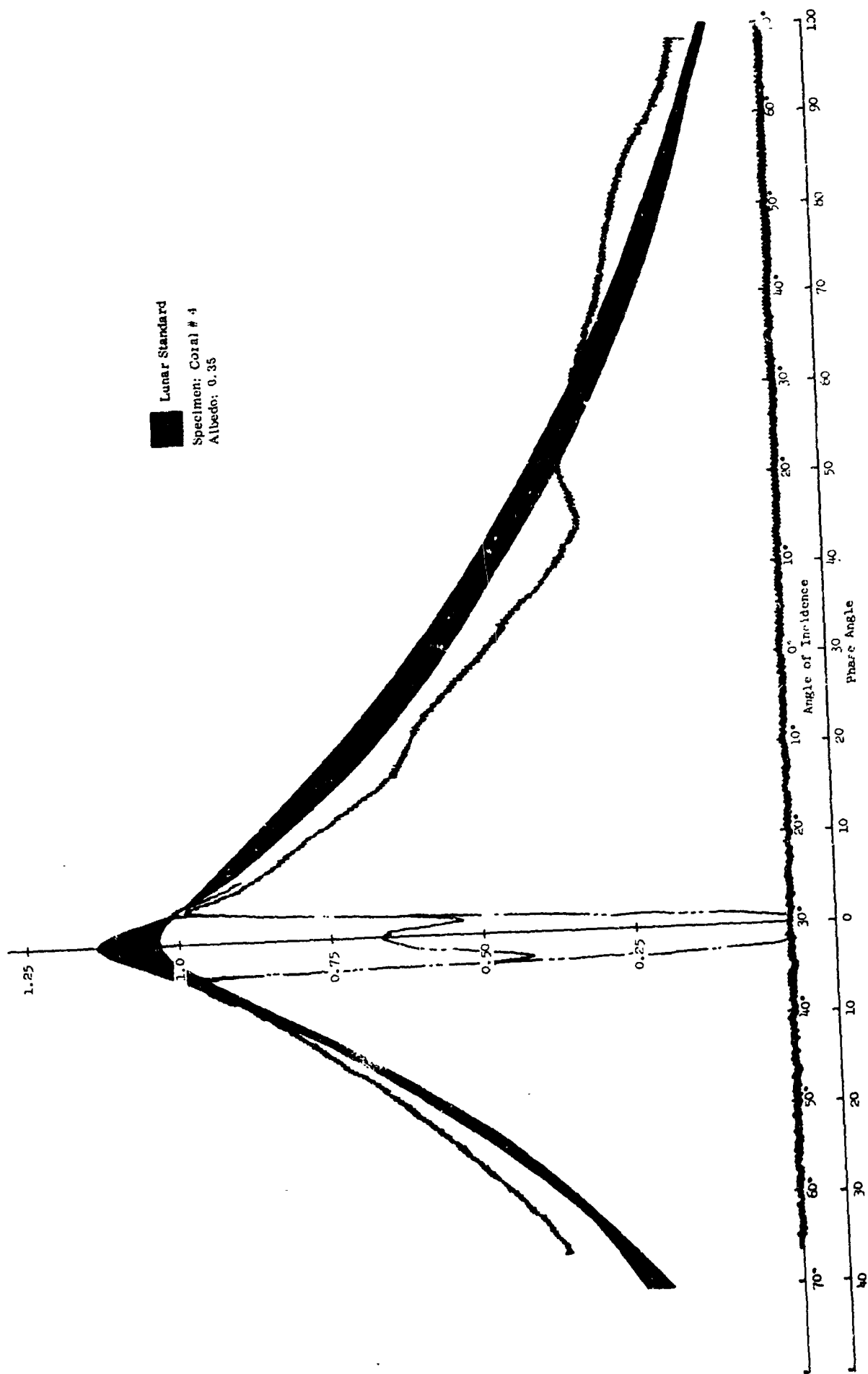


Figure 12c. Coral #4

E = 60°

Lunar Standard
Specimen: Coral # 4
Albedo: 0.35

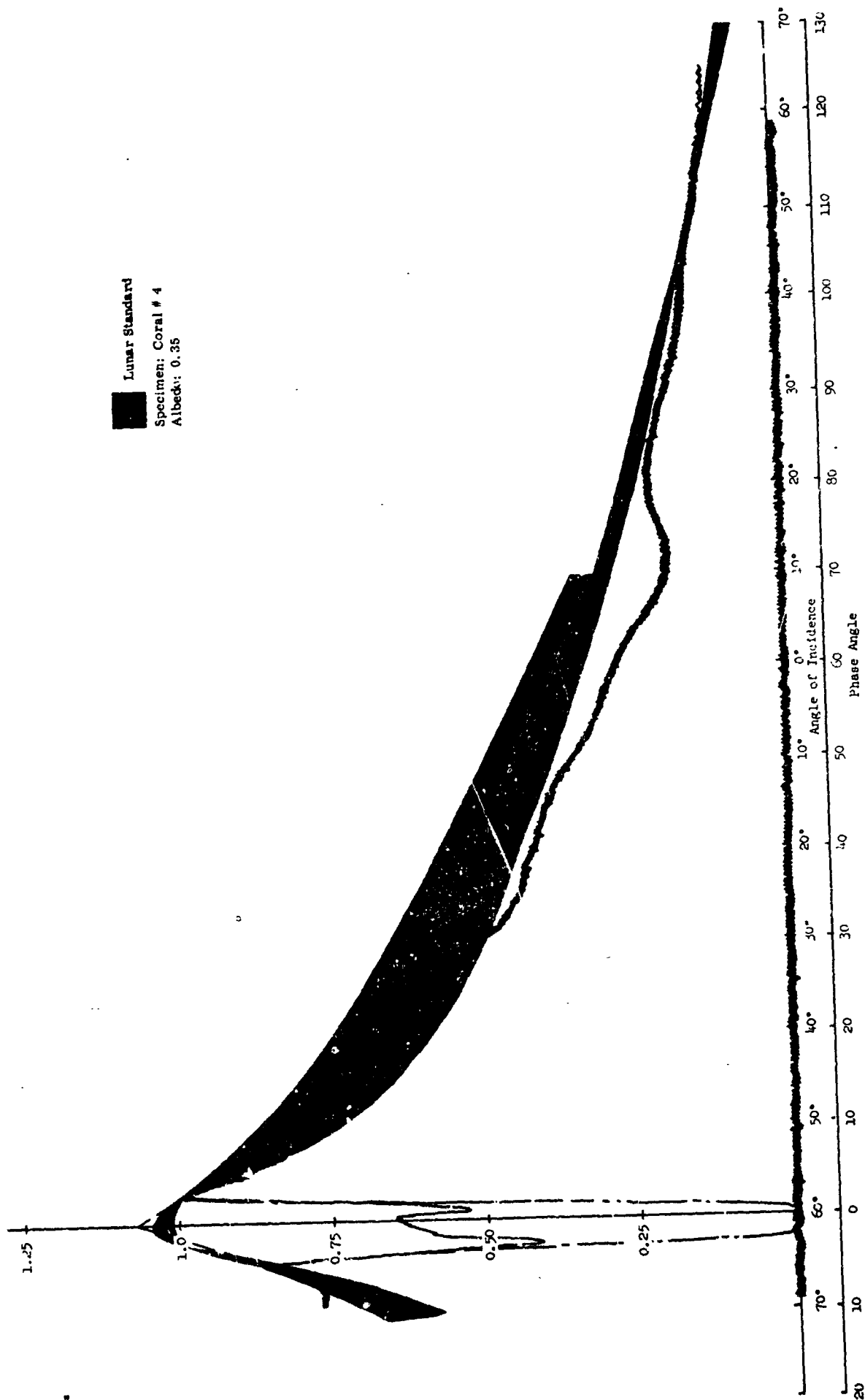


Figure 12d. Coral # 4

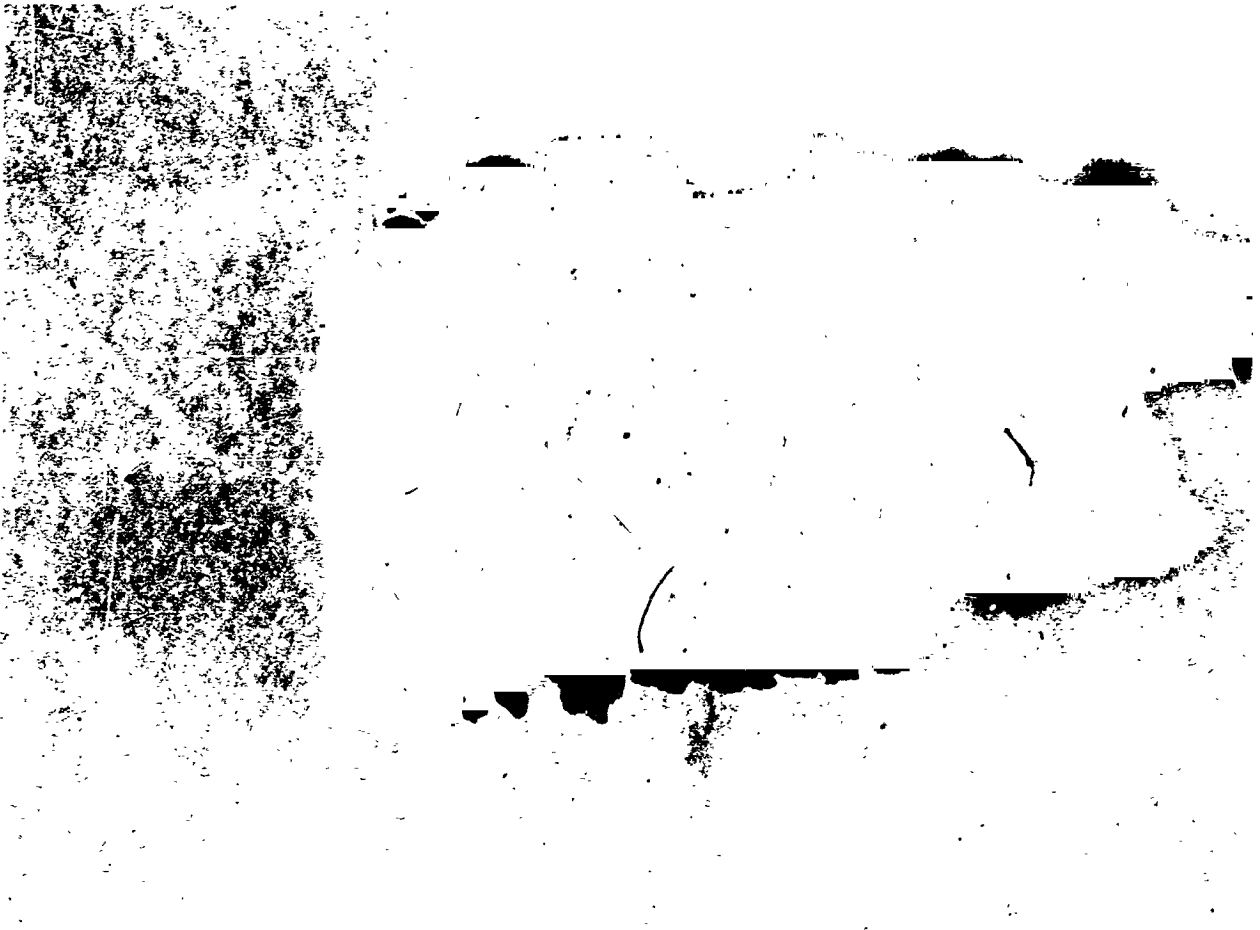


Figure 13a. Meteorite (Krasnojarsk-896)

$\lambda = 0^\circ$

■ Lunar Standard

Specimen: Meteorite (Krasnojarsk-896)
Albedo:

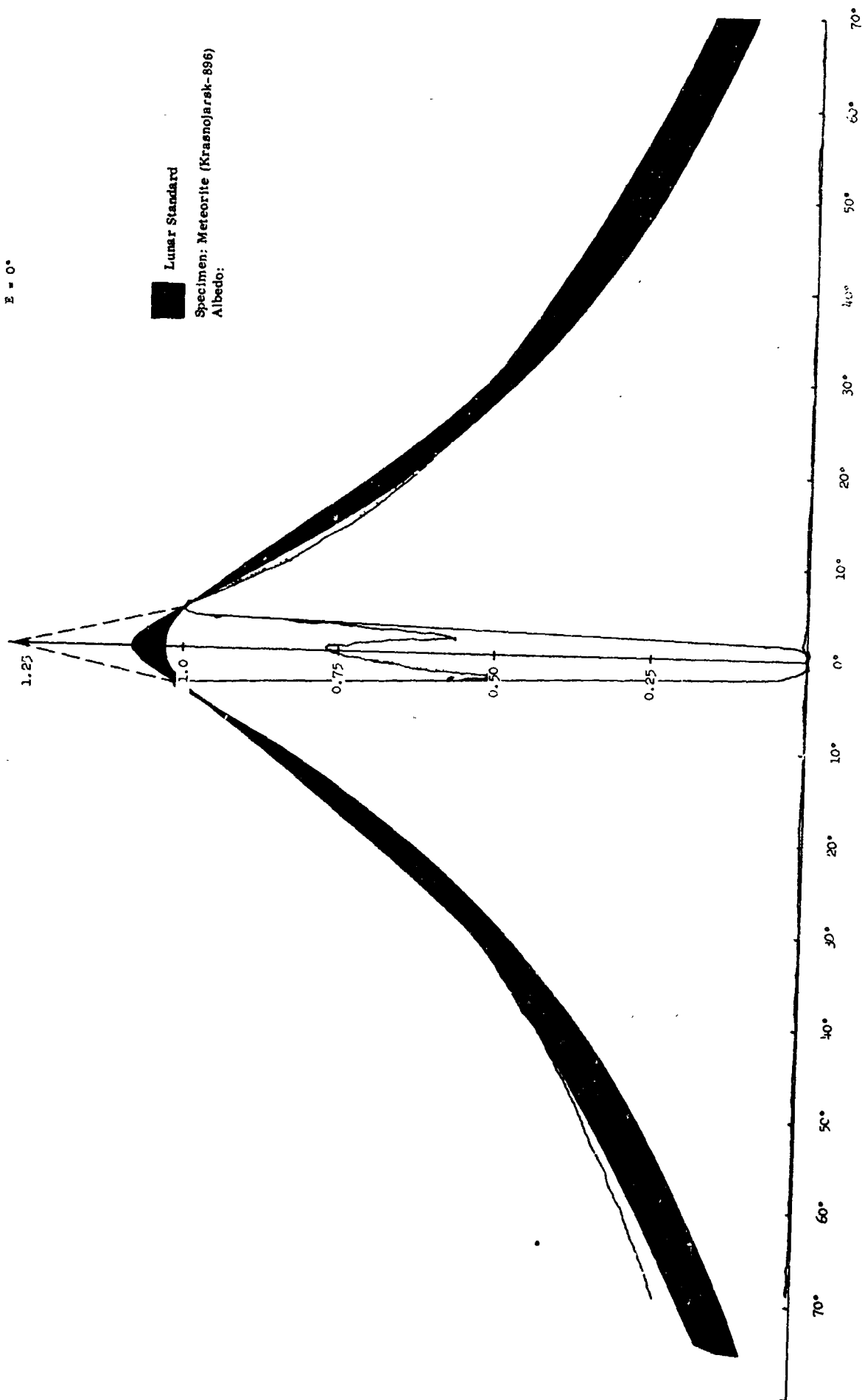


Figure 13b. Meteorite (Krasnojarsk-896)

$E = 30^\circ$

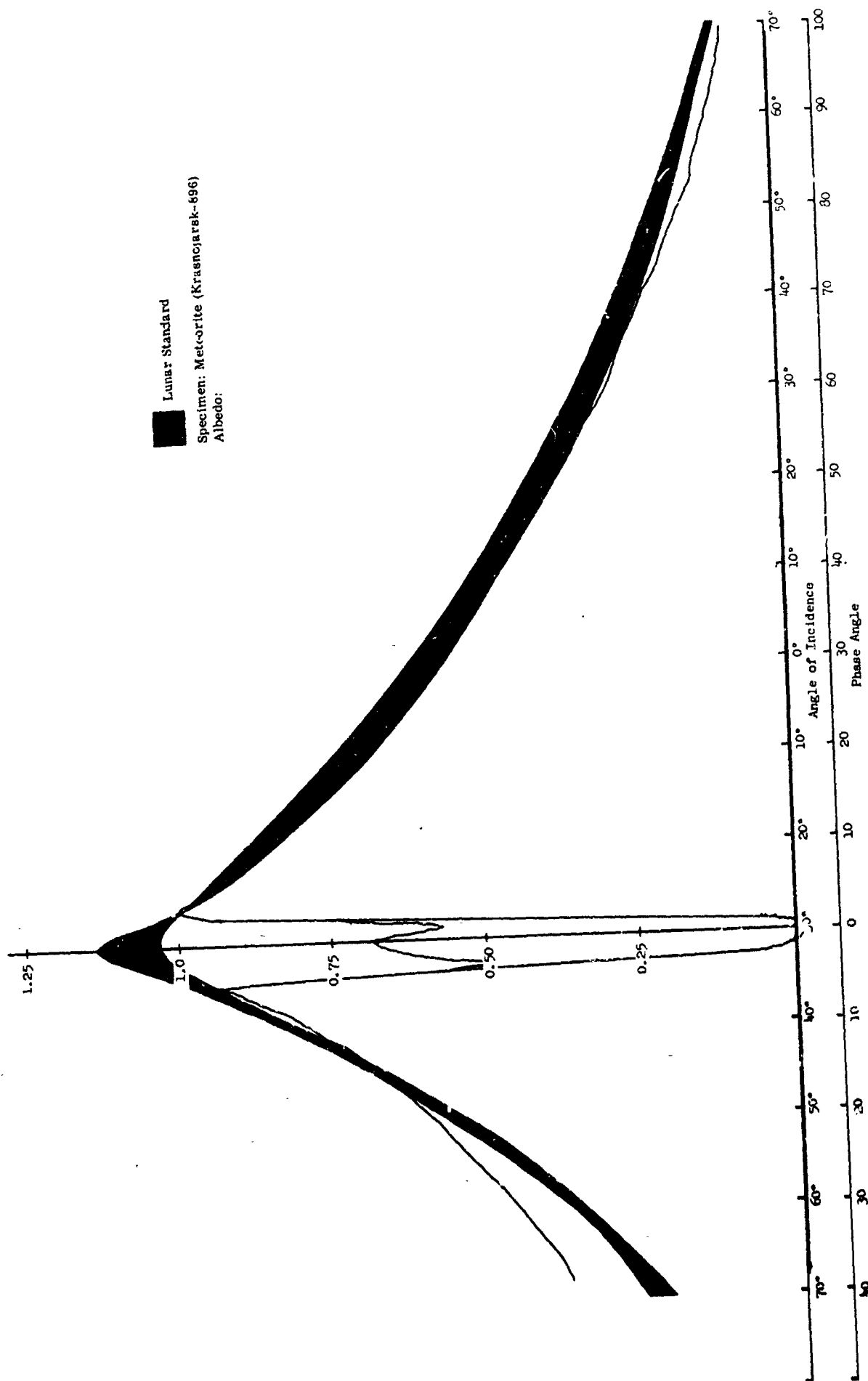


Figure 13c. Meteorite (Krasnojarsk-896)

E = 60°

Lunar Standard
 Specimen: Meteorite (Krasnojarsk-896)
 Albedo:

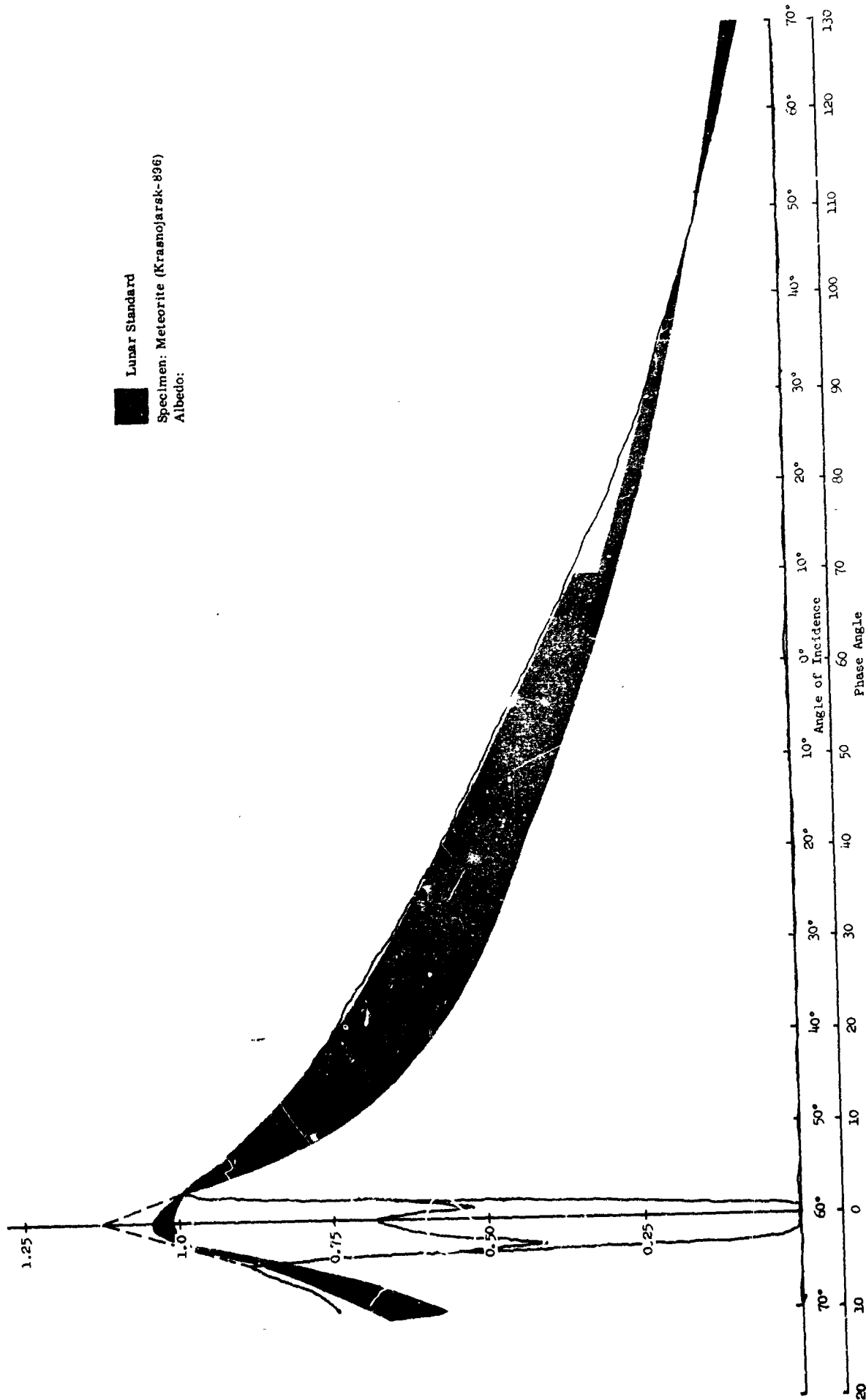


Figure 13d. Meteorite (Krasnojarsk-896)

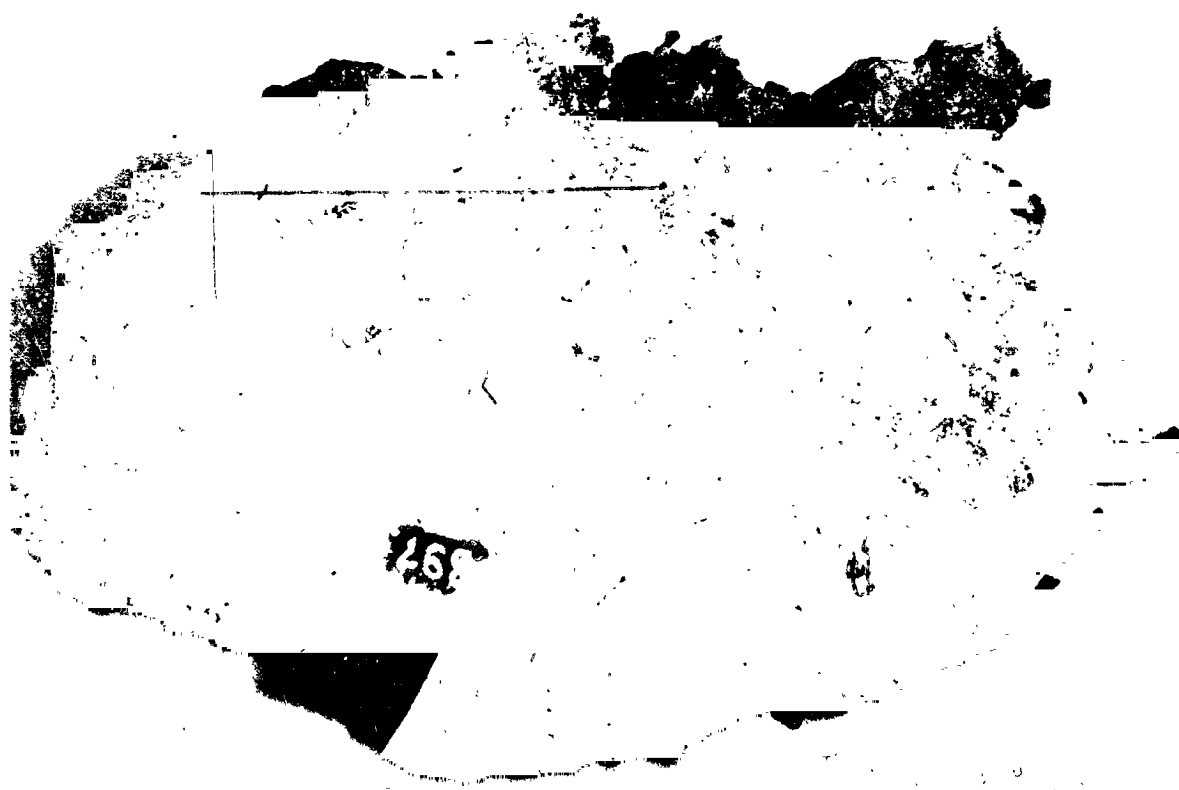


Figure 14a. Meteorite (Krasnojarsk-897)

E = 0°

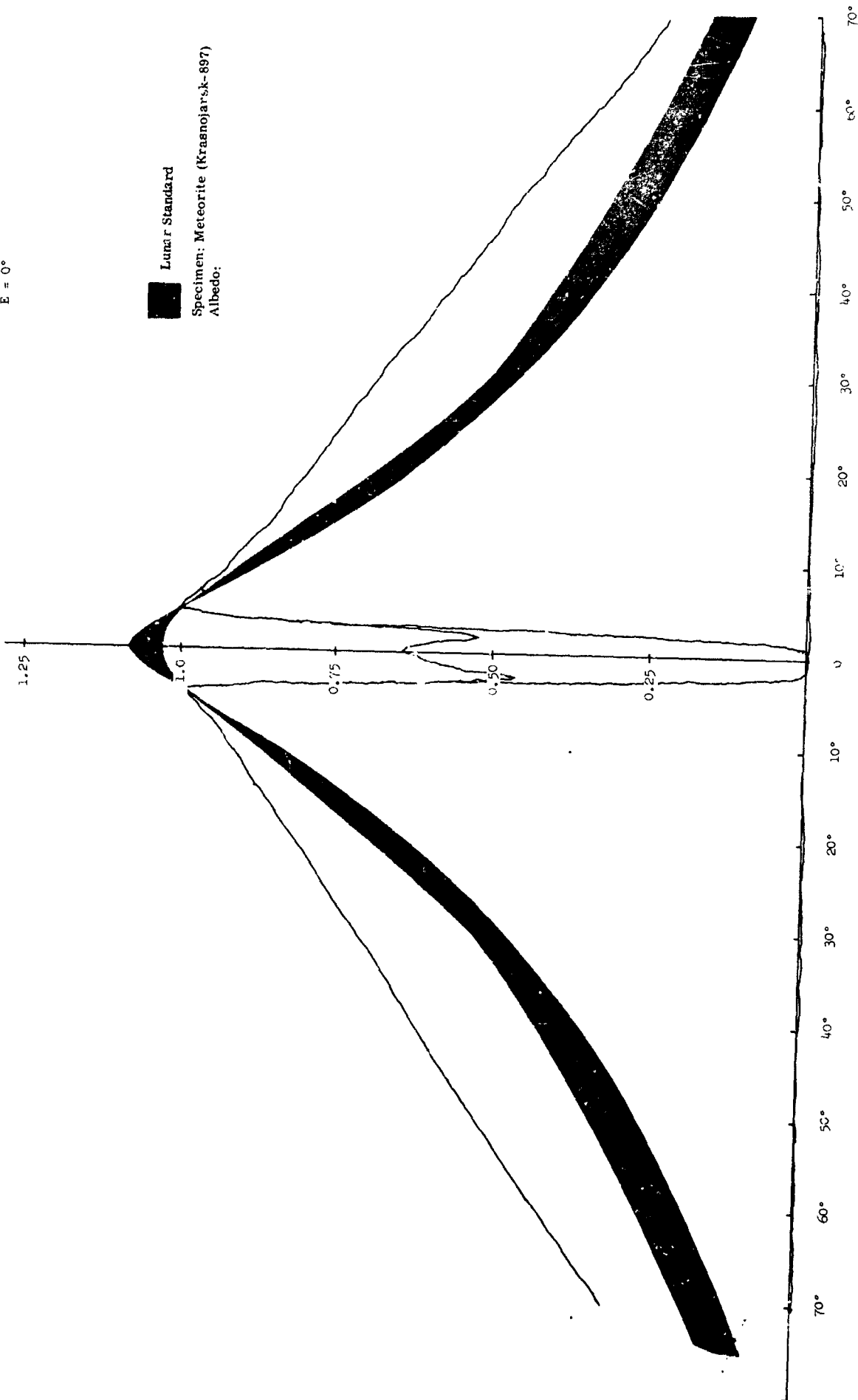


Figure 14b. Meteorite (Krasnojarsk-897)

E = 30°

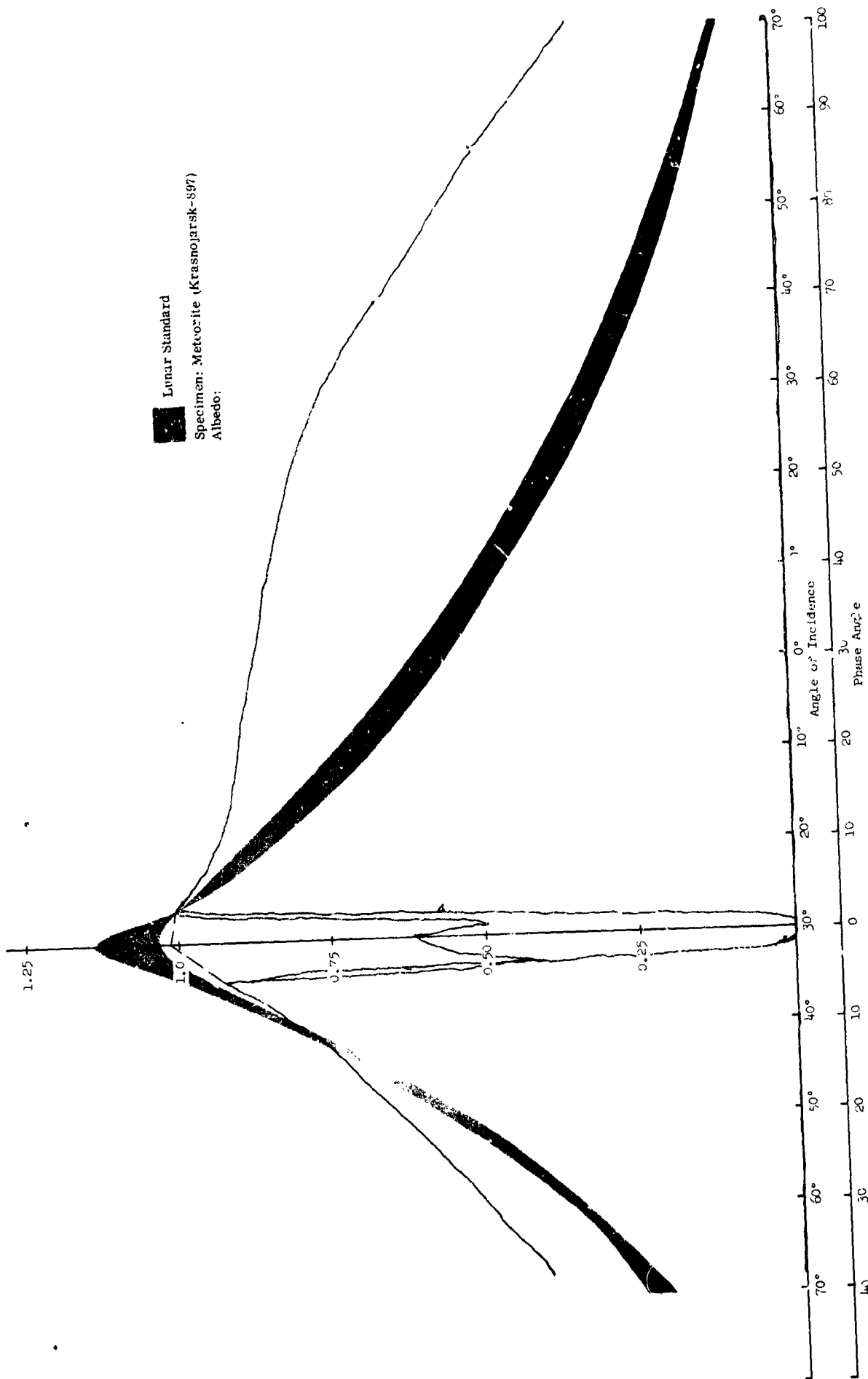


Figure 14c. Meteorite (Krasnojarsk-89).

E = 60°

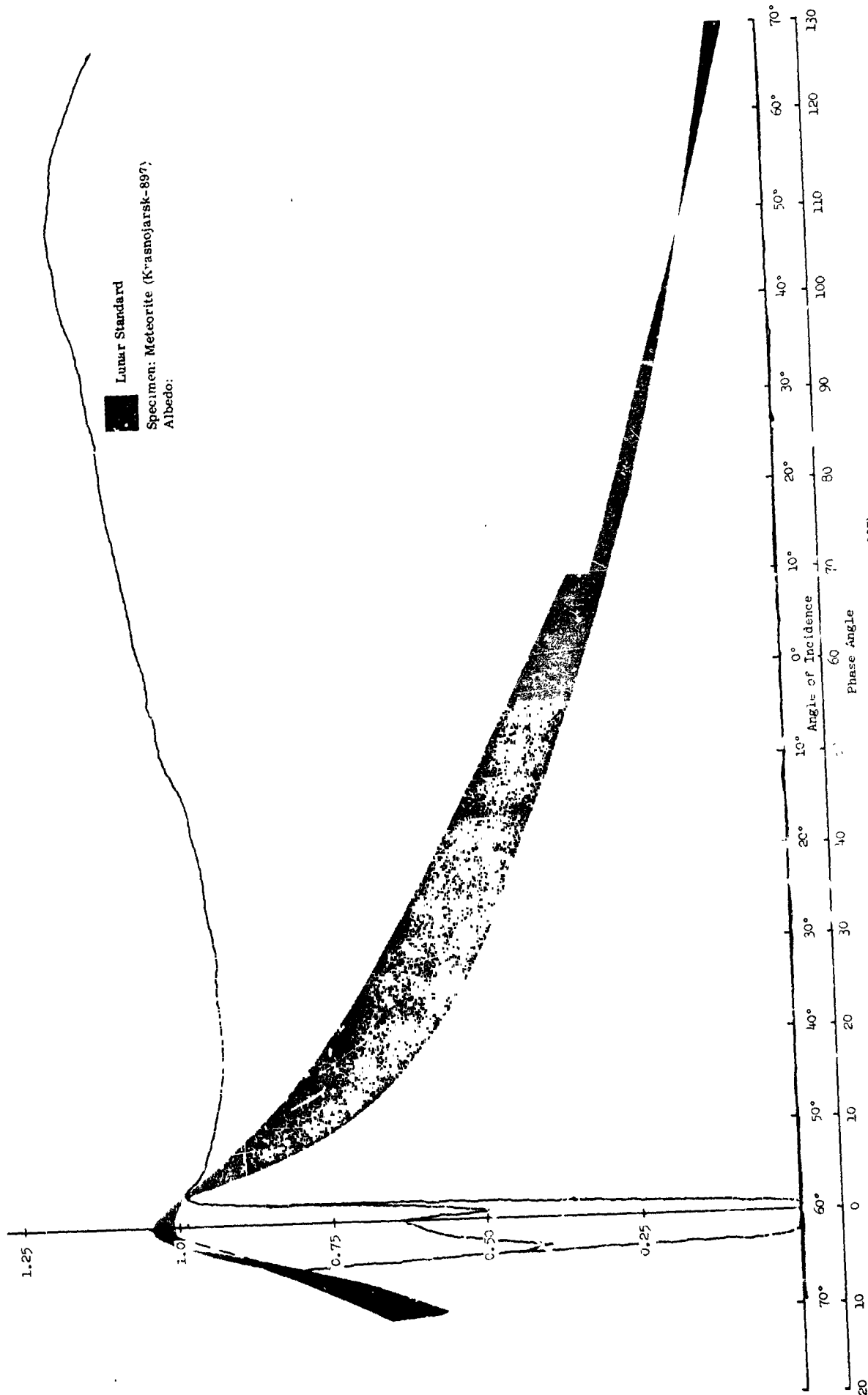


Figure 14d. Meteorite (Krasnojarsk-897)

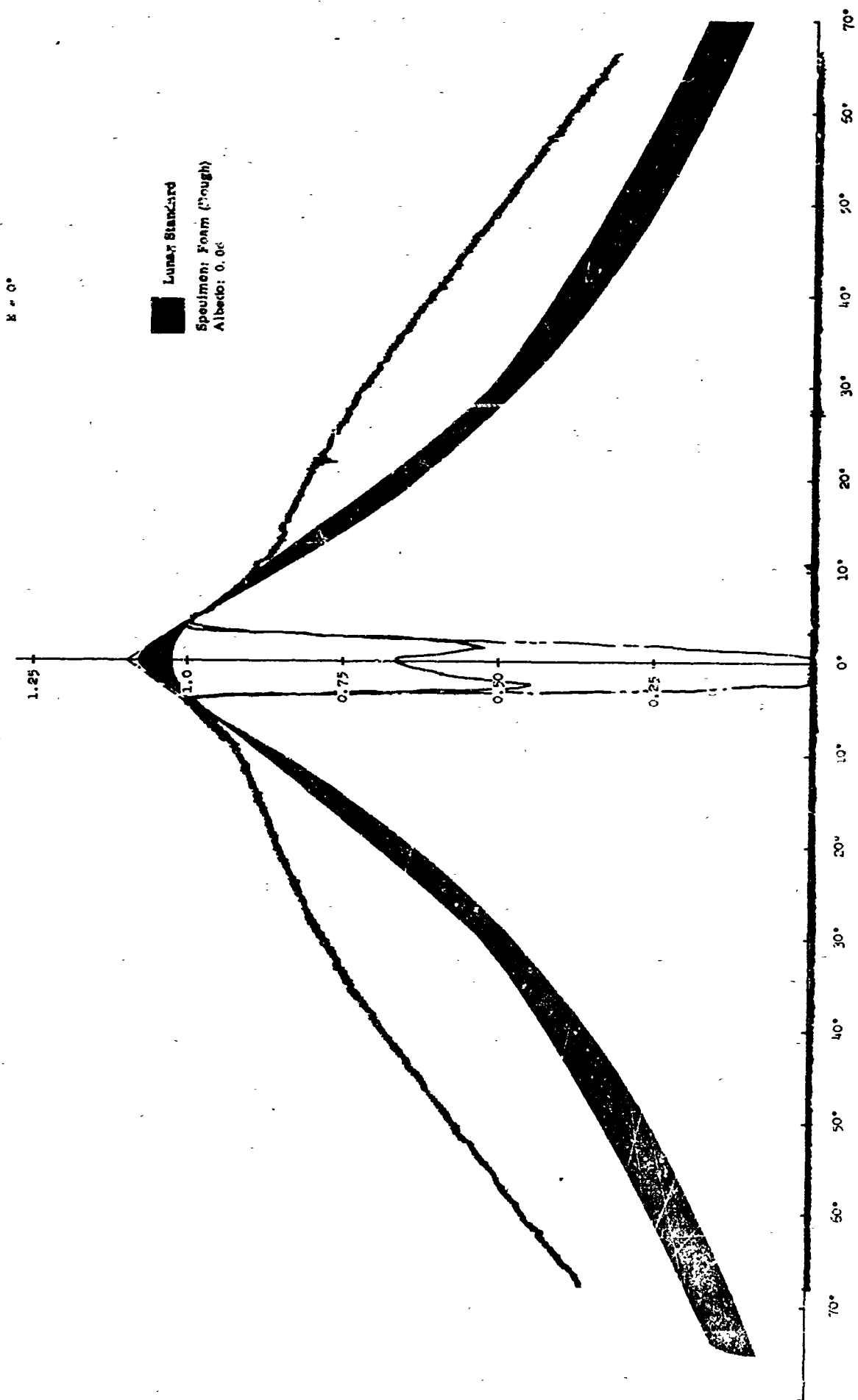


Figure 18a. Foam (Rough)

$\theta = 30^\circ$

Lunar Standard
Specimen: Foam (Rough)
Albedo: 0.06

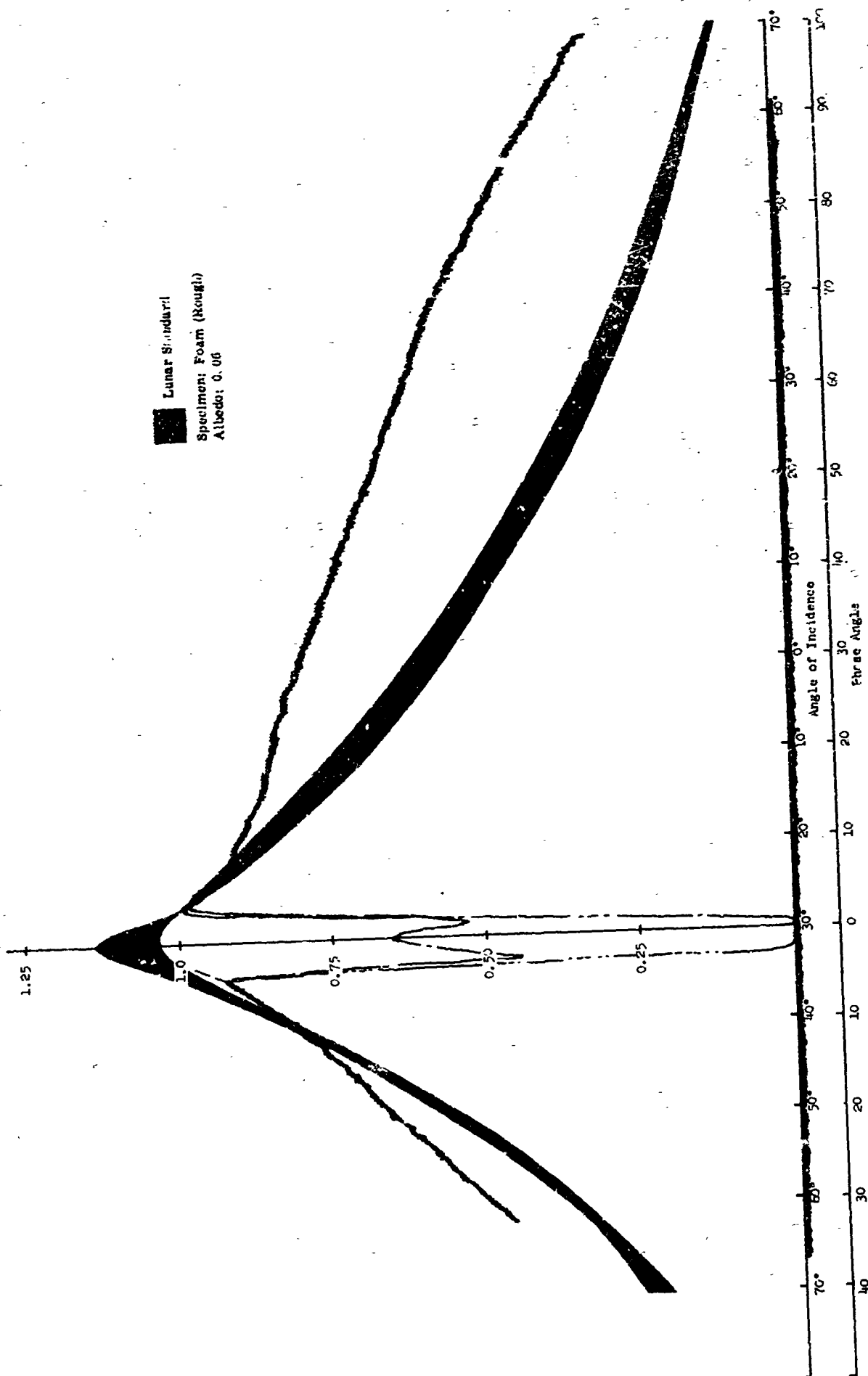


Figure 16b. Foam (Rough)

$E = 60^\circ$

Lunar Standard

Specimen: Foam (Rough)
Albedo: 0.06

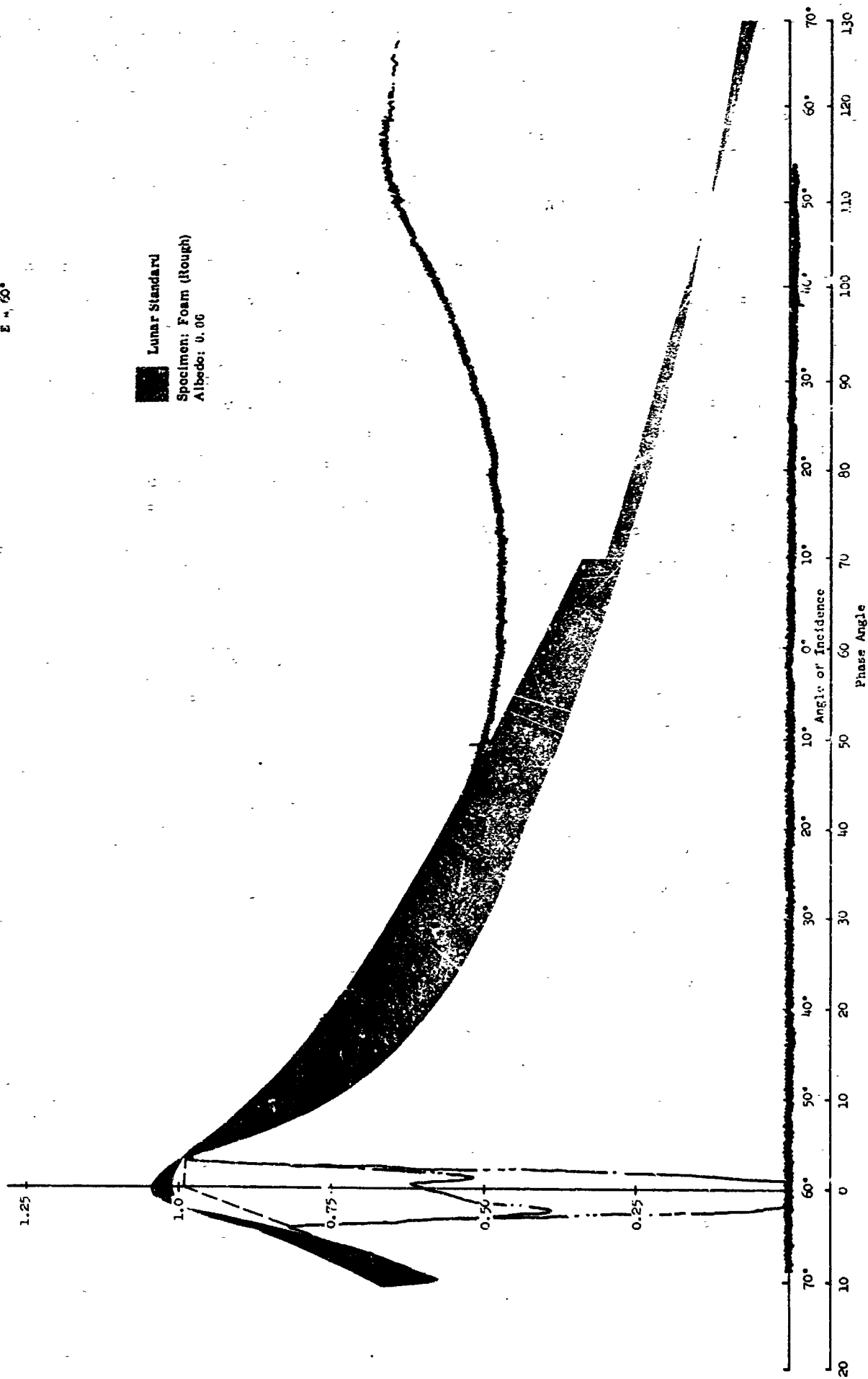


Figure 15c. $F_{0.06}$ (Rough)

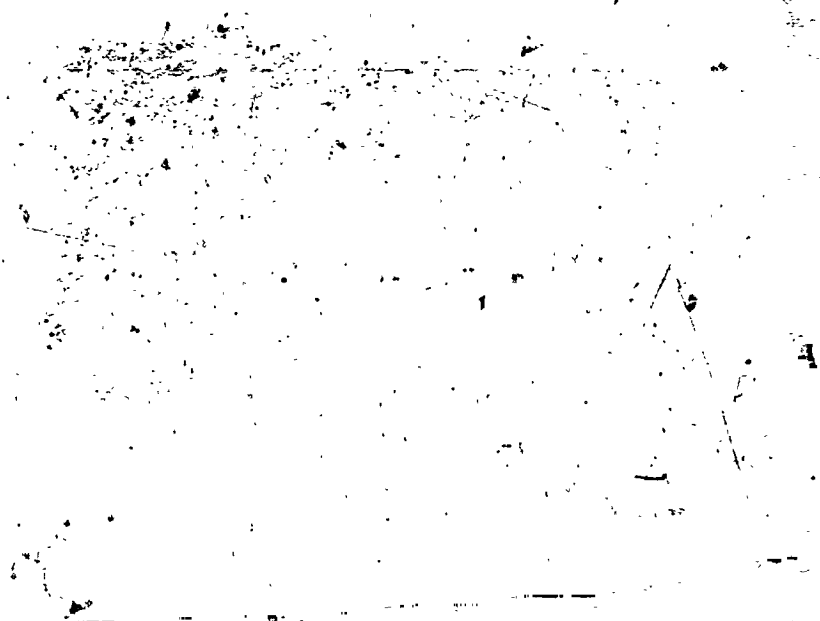
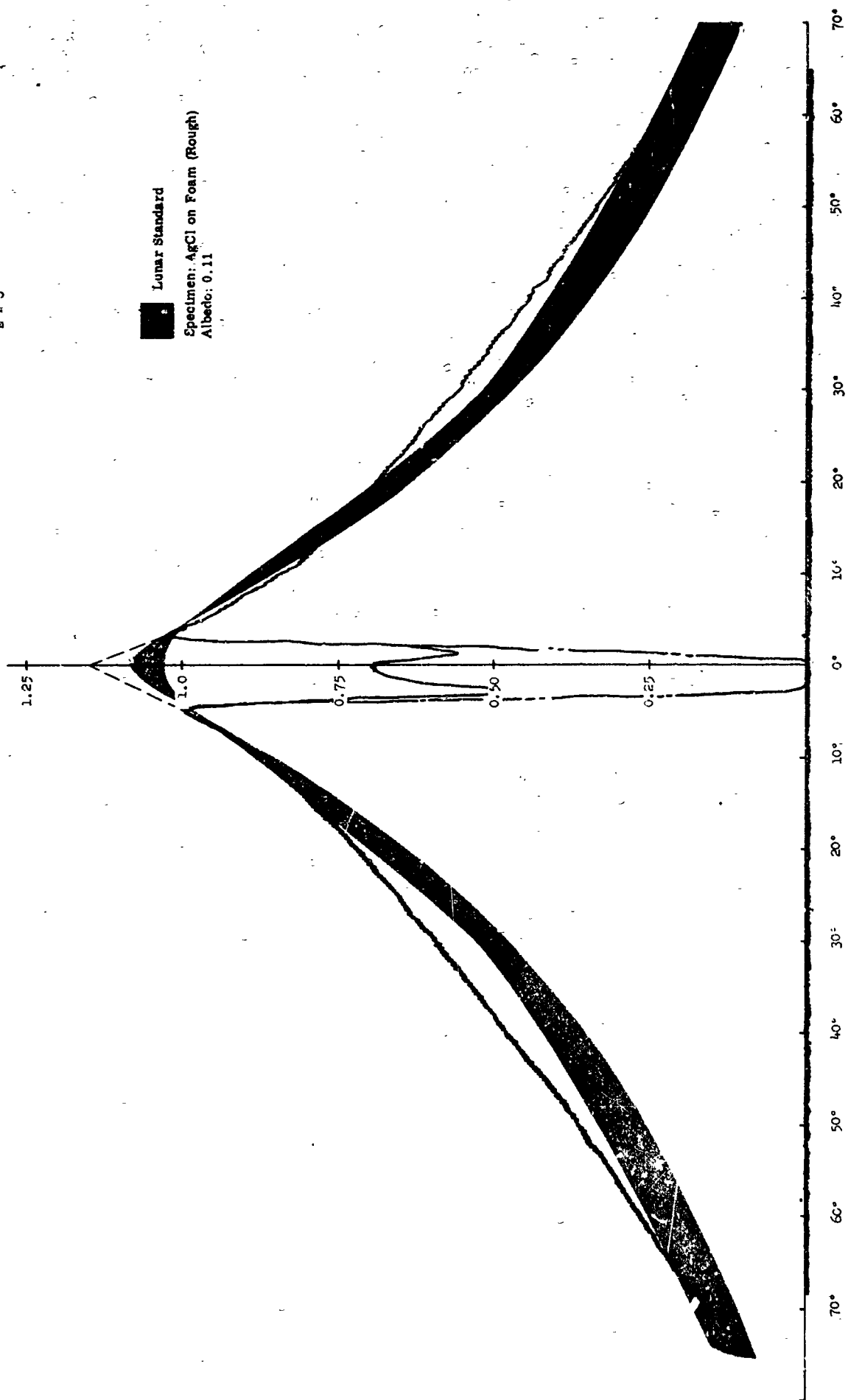


Figure 16a. AgCl on Foam (Rough)

$E = 3^\circ$

Lunar Standard
Specimen: AgCl on Foam (Rough)
Albedo: 0.11



Angle of Incidence and Phase

Figure 16b. AgCl on Foam (Rough)

$E = 30^\circ$

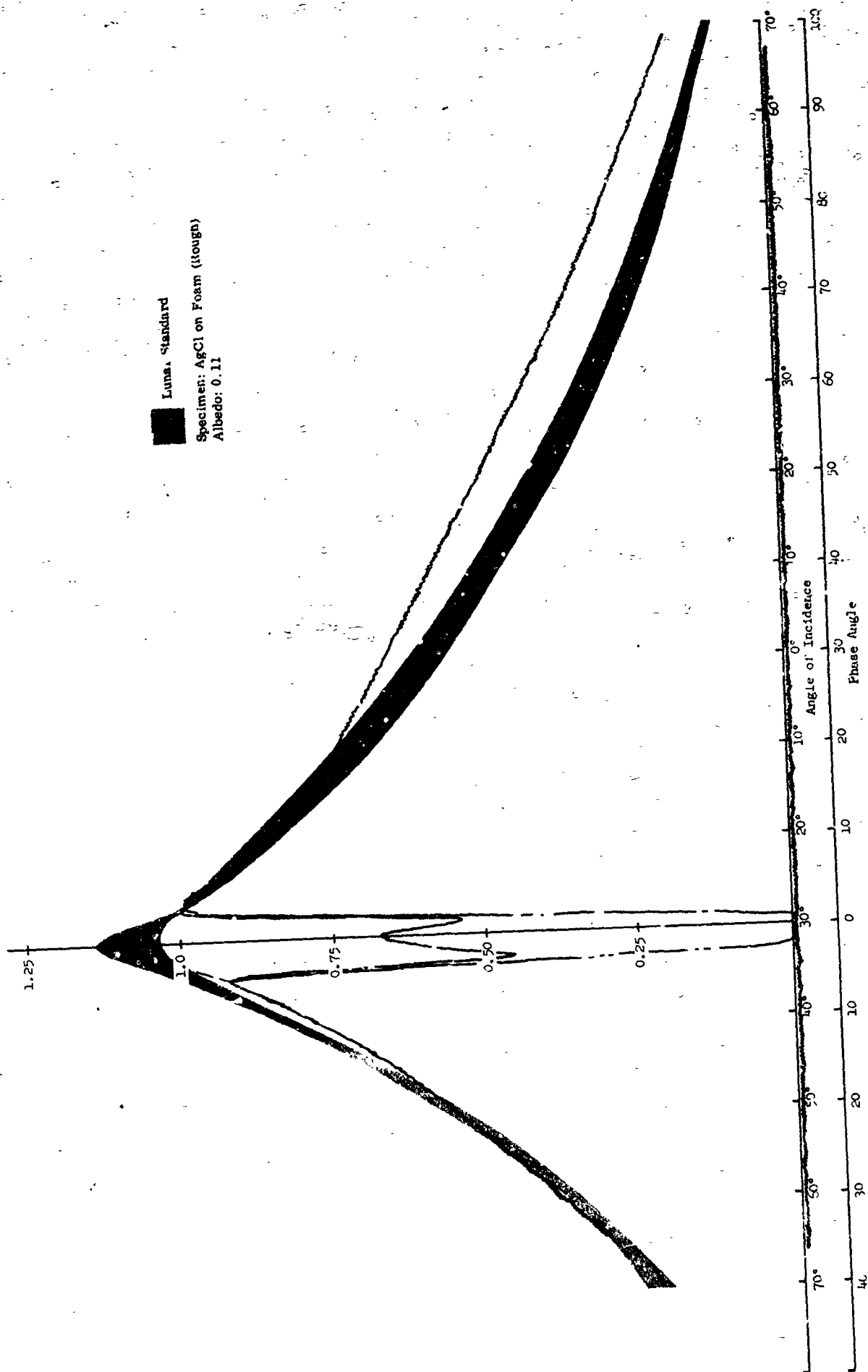


Figure 18c. AgCl on Foam (Rough)

$E = 60^\circ$

Lunar Standard

Specimen: AgCl on Foam (Rough)

Albedo: 0.11

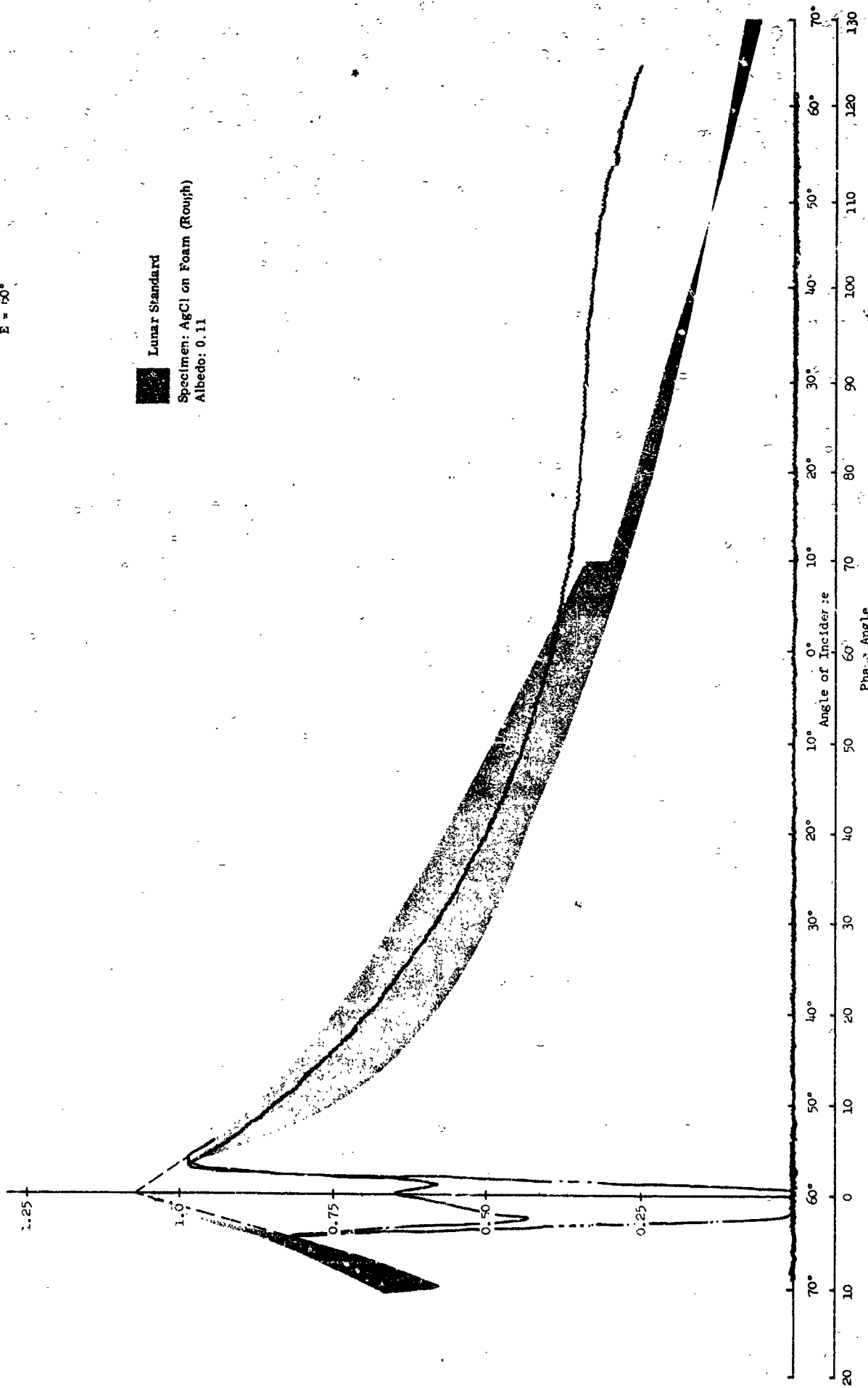
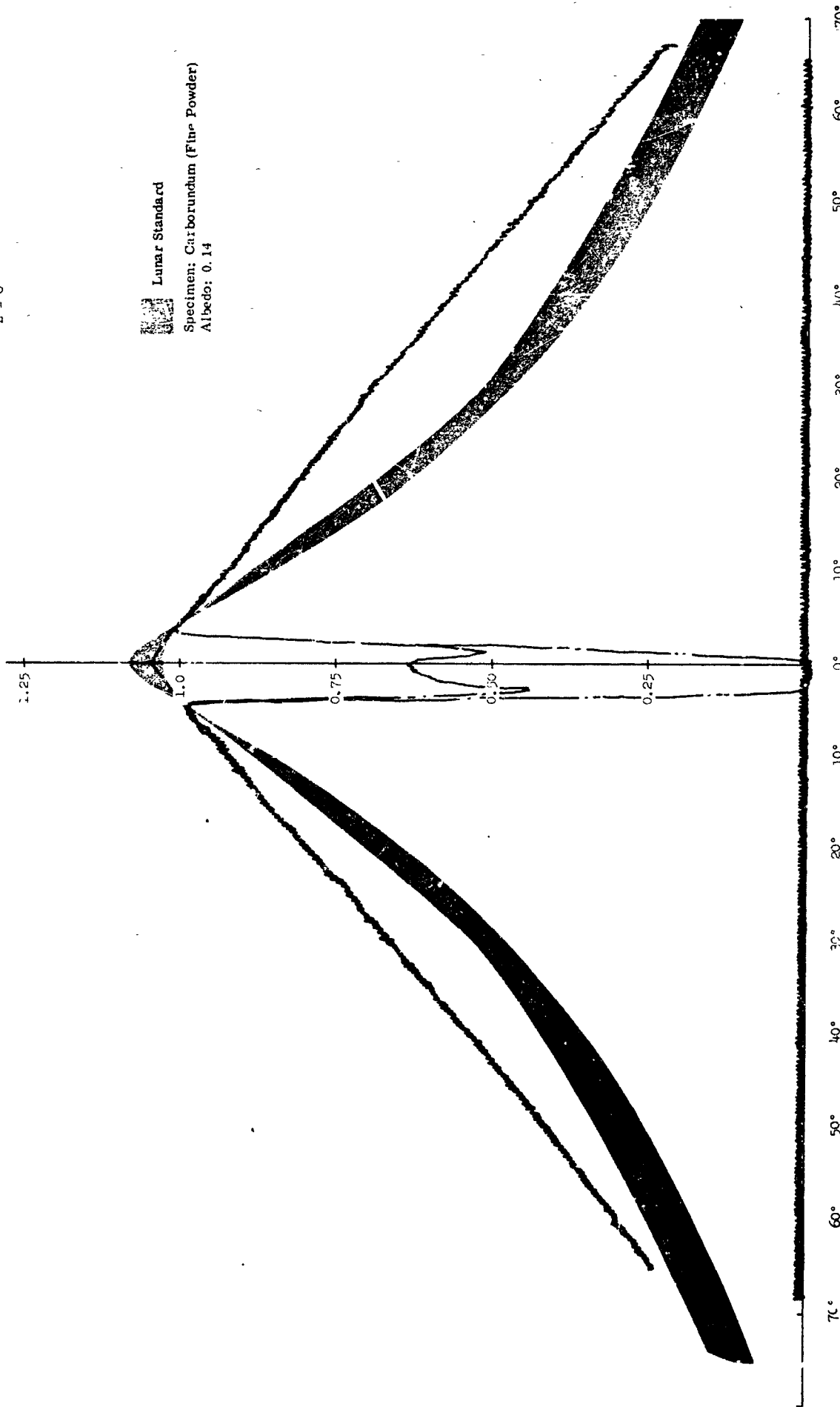


Figure 16d. AgCl on Foam (Rough)

$E = 0^\circ$



Lunar Standard

Specimen: Carborundum (Fine Powder)

Albedo: 0.14

Angle of Incidence and Phase

Figure 17a. Carborundum

$E = 30^\circ$

Lunar Standard
Specimen: Carborundum (Fine Powder)
Albedo: 0.14

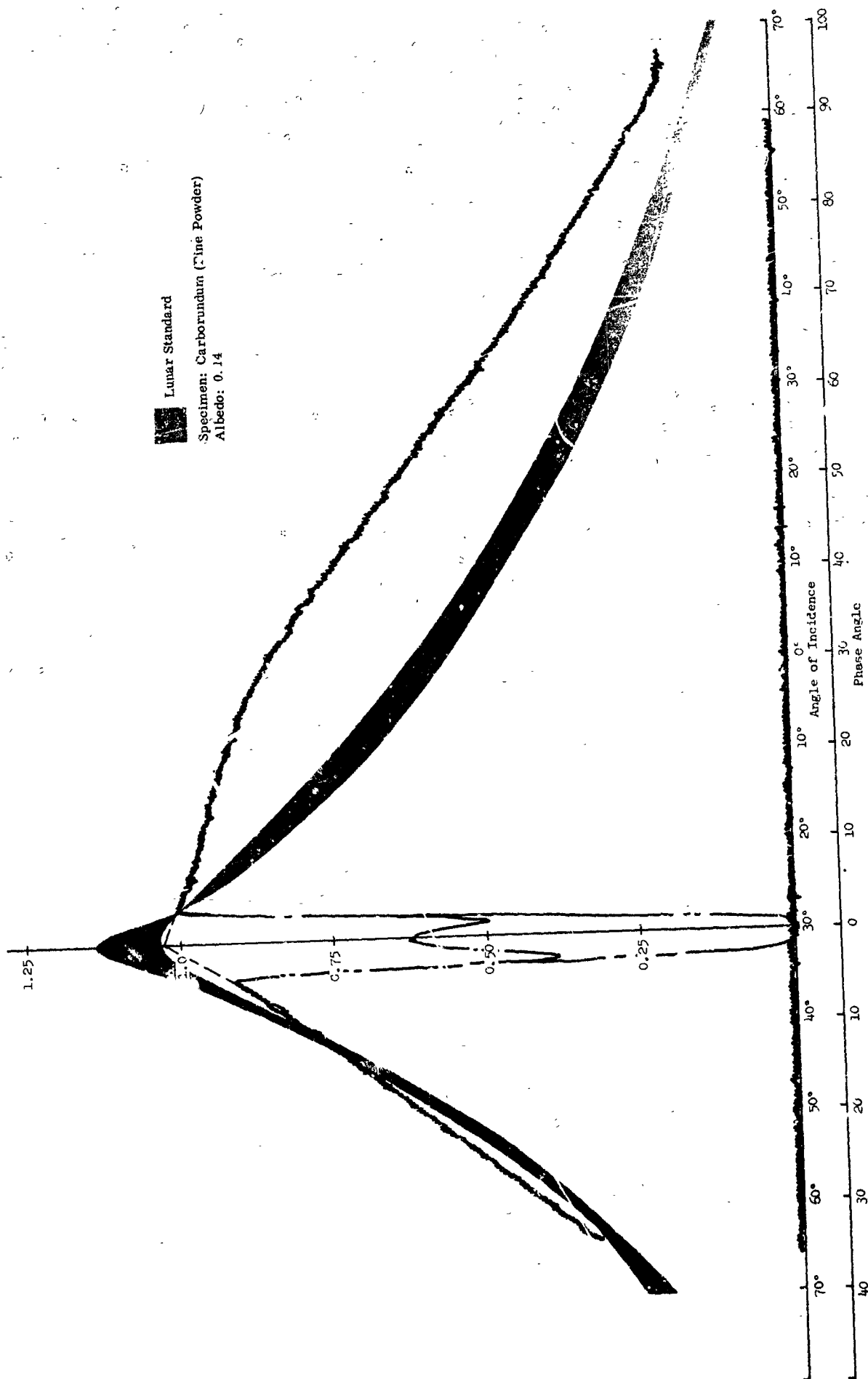


Figure 17t. Carborundum

E = 60°

Lunar Standard
Specimen: Carborundum (Fine Powder)
Albedo: 0.14

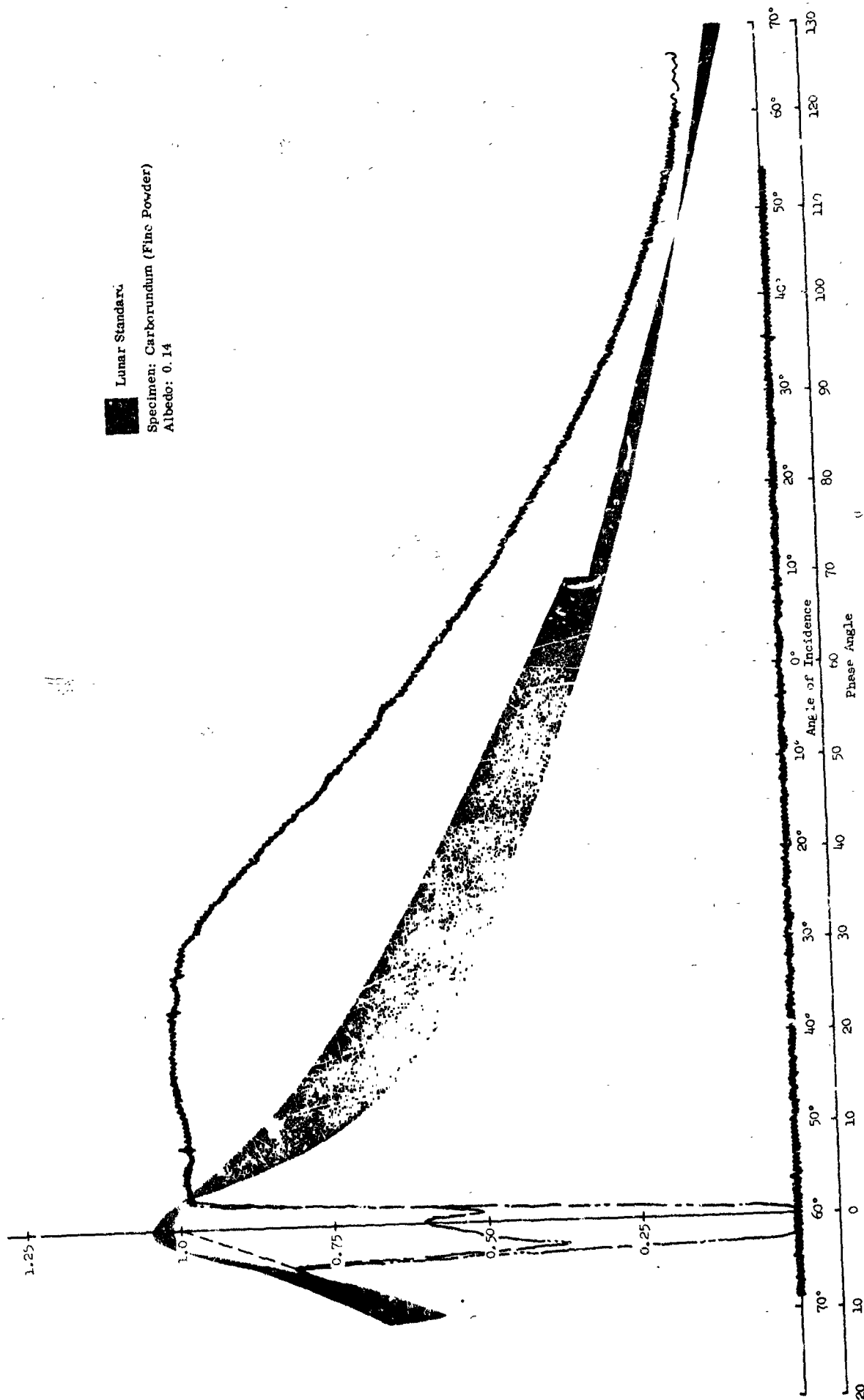


Figure 17c. Carborundum

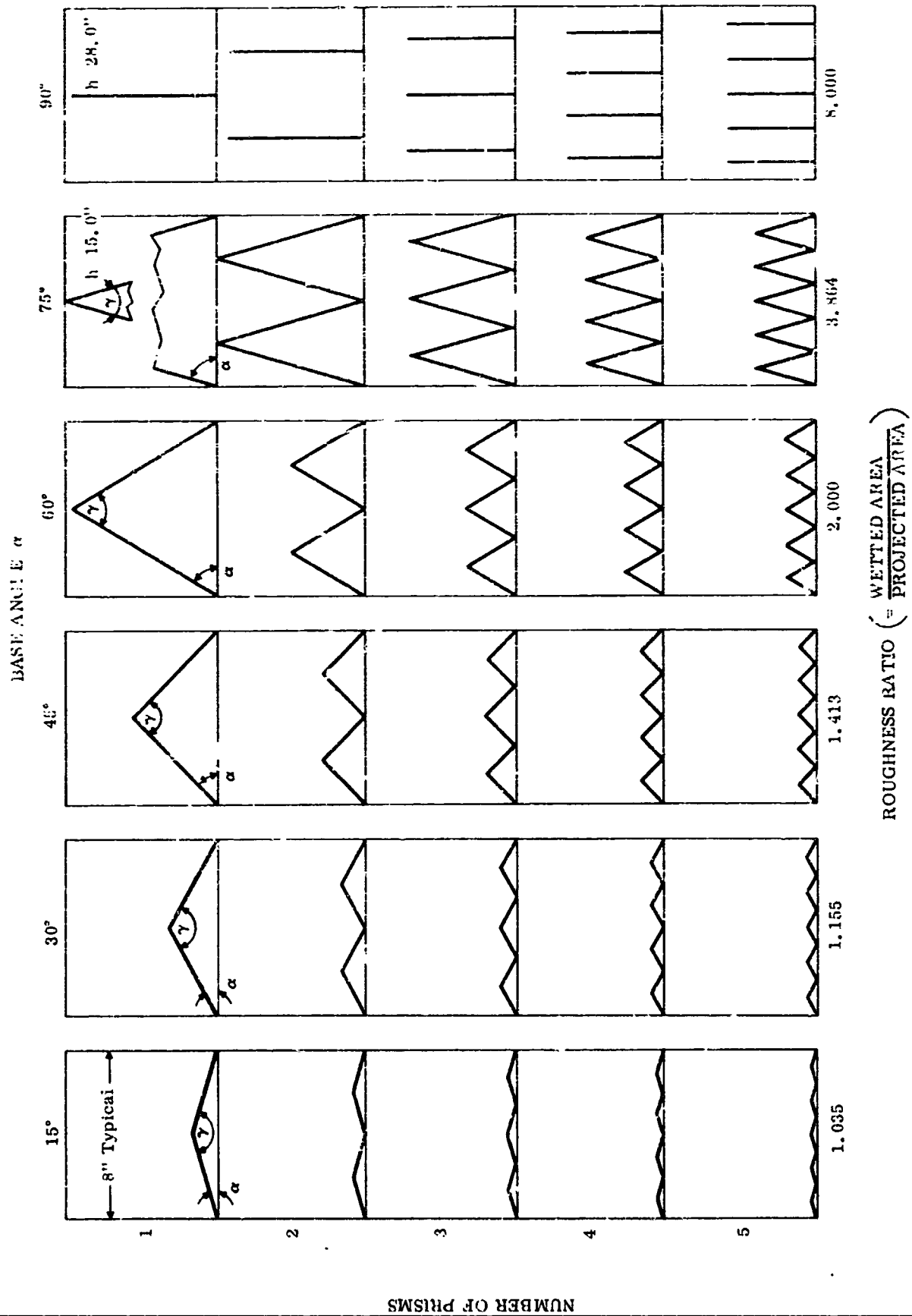
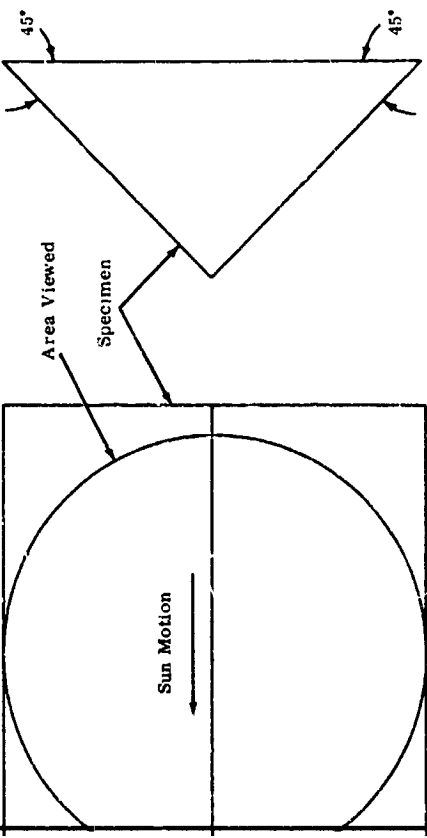
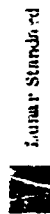


Figure 18. Cross Section of Prismatic Ridges



$\lambda = 0.65 \mu$



Lunar Standard

Specimen: CuO on 1 Prism as Shown
Albedo: 0.07

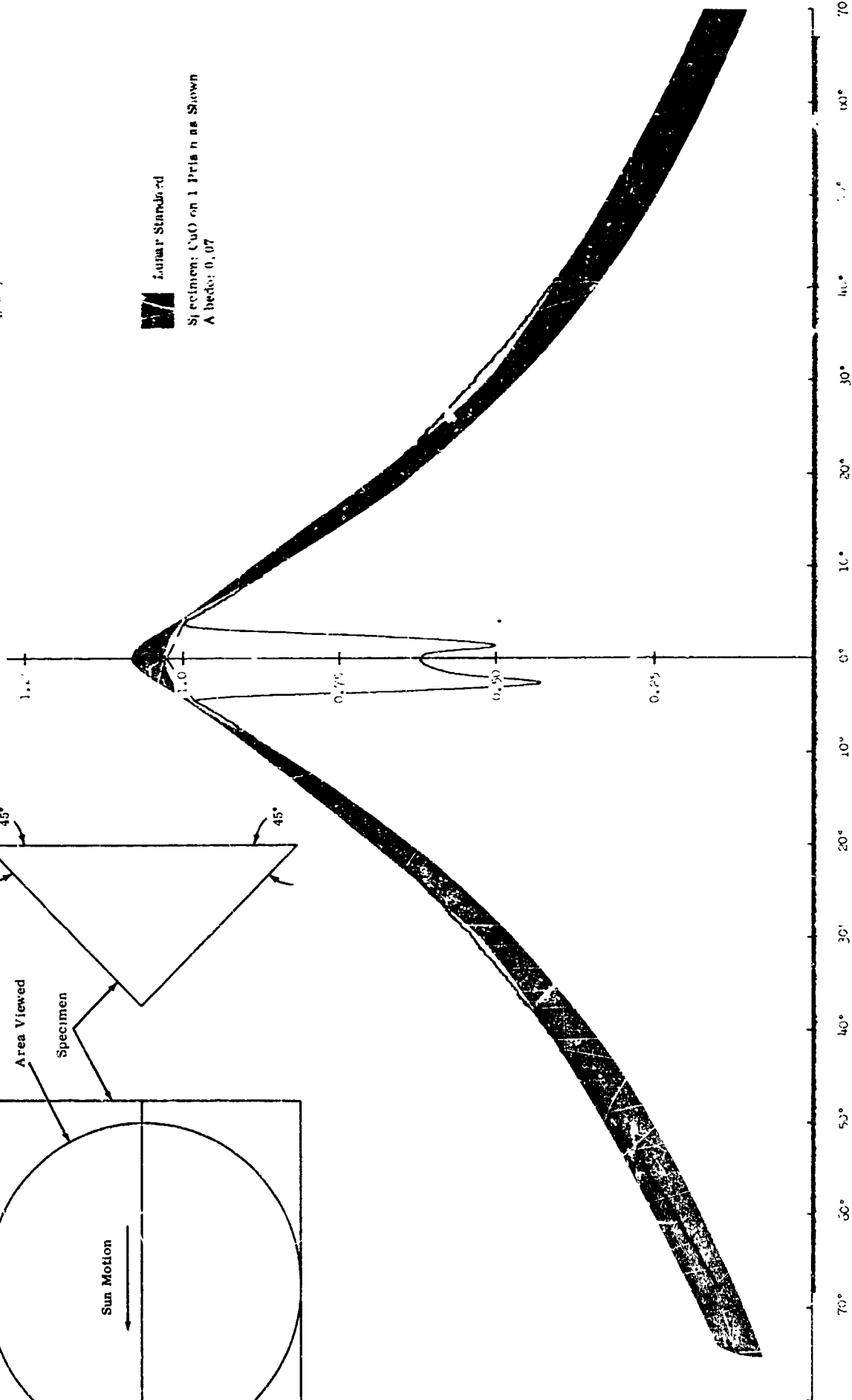


Figure 19a. CuO on 1 Prism

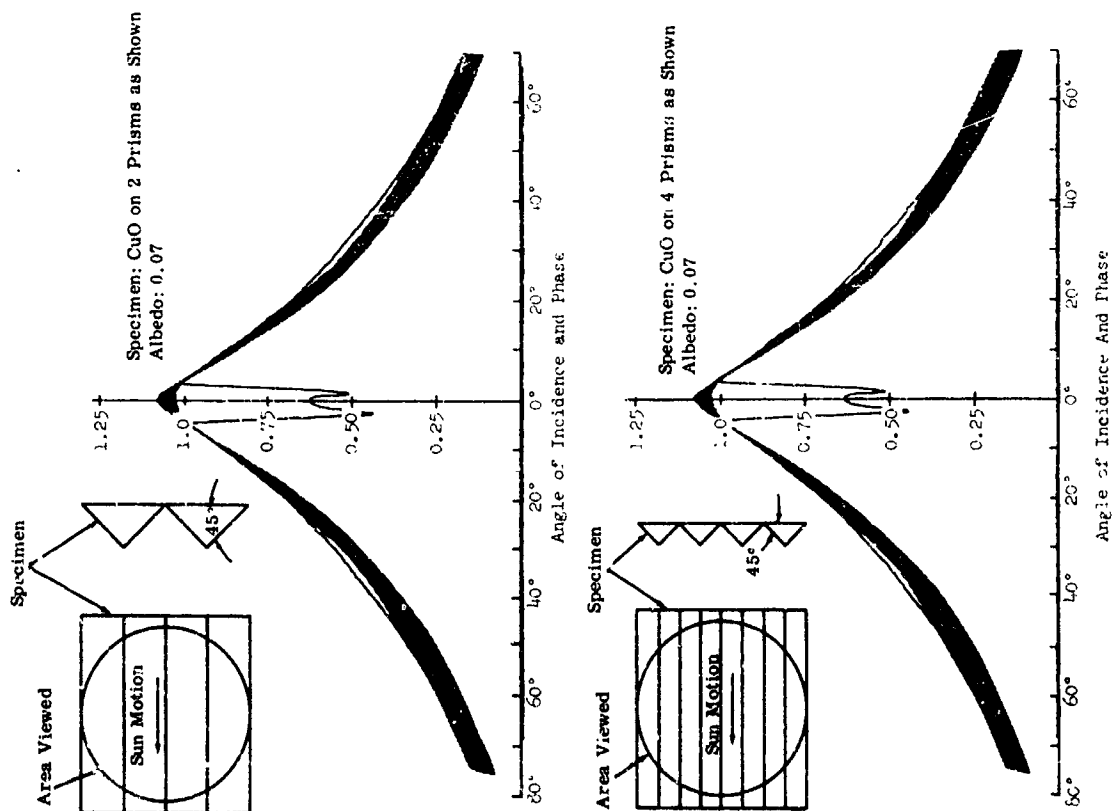


Figure 18b. CuO on Prisms

E 110

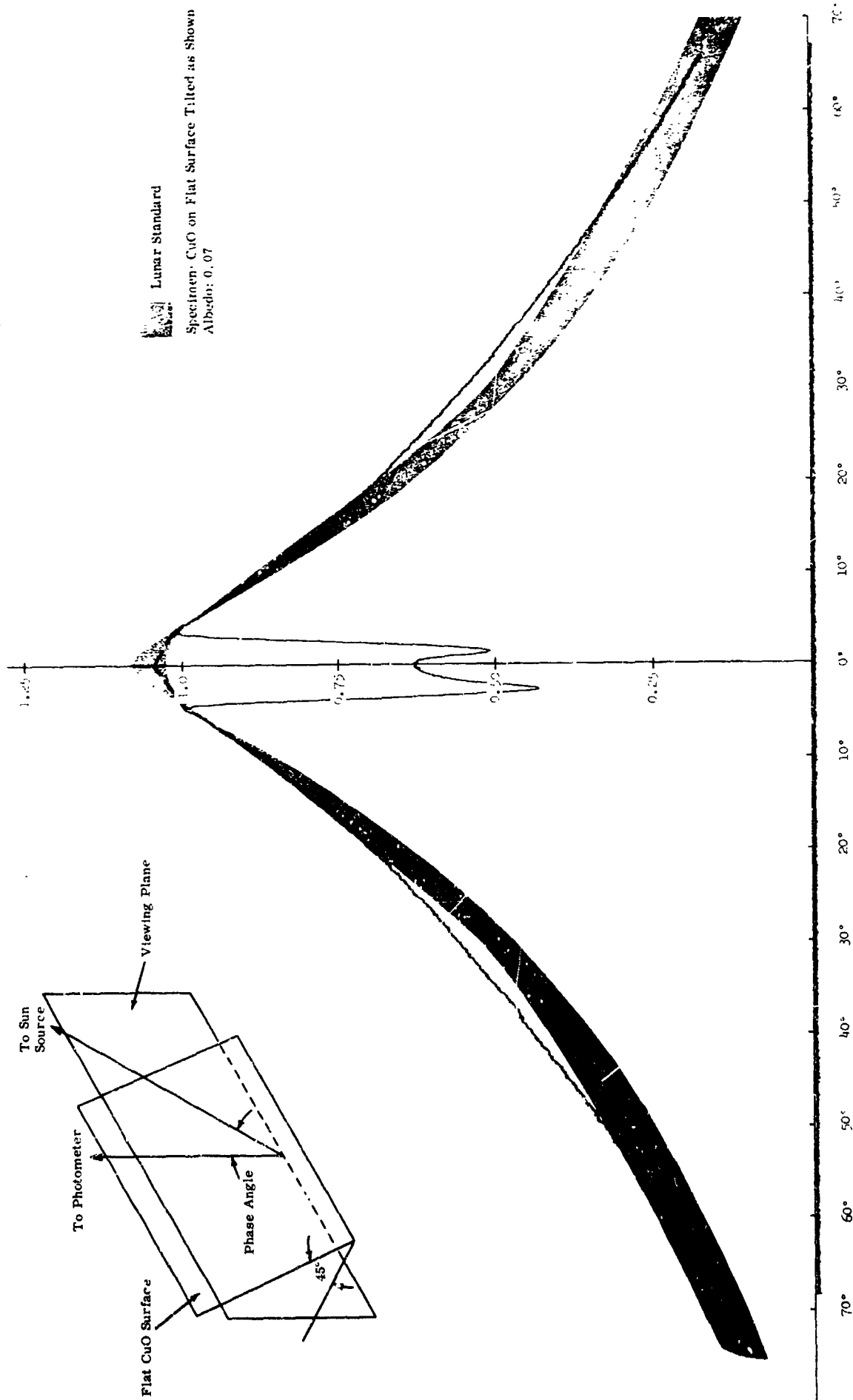
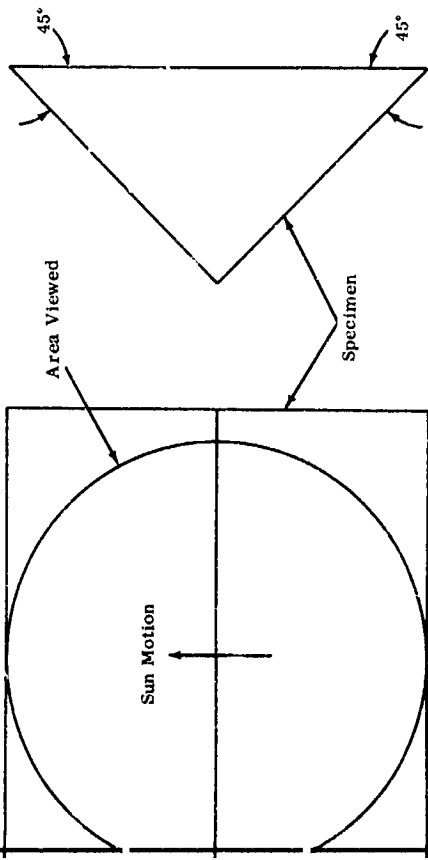
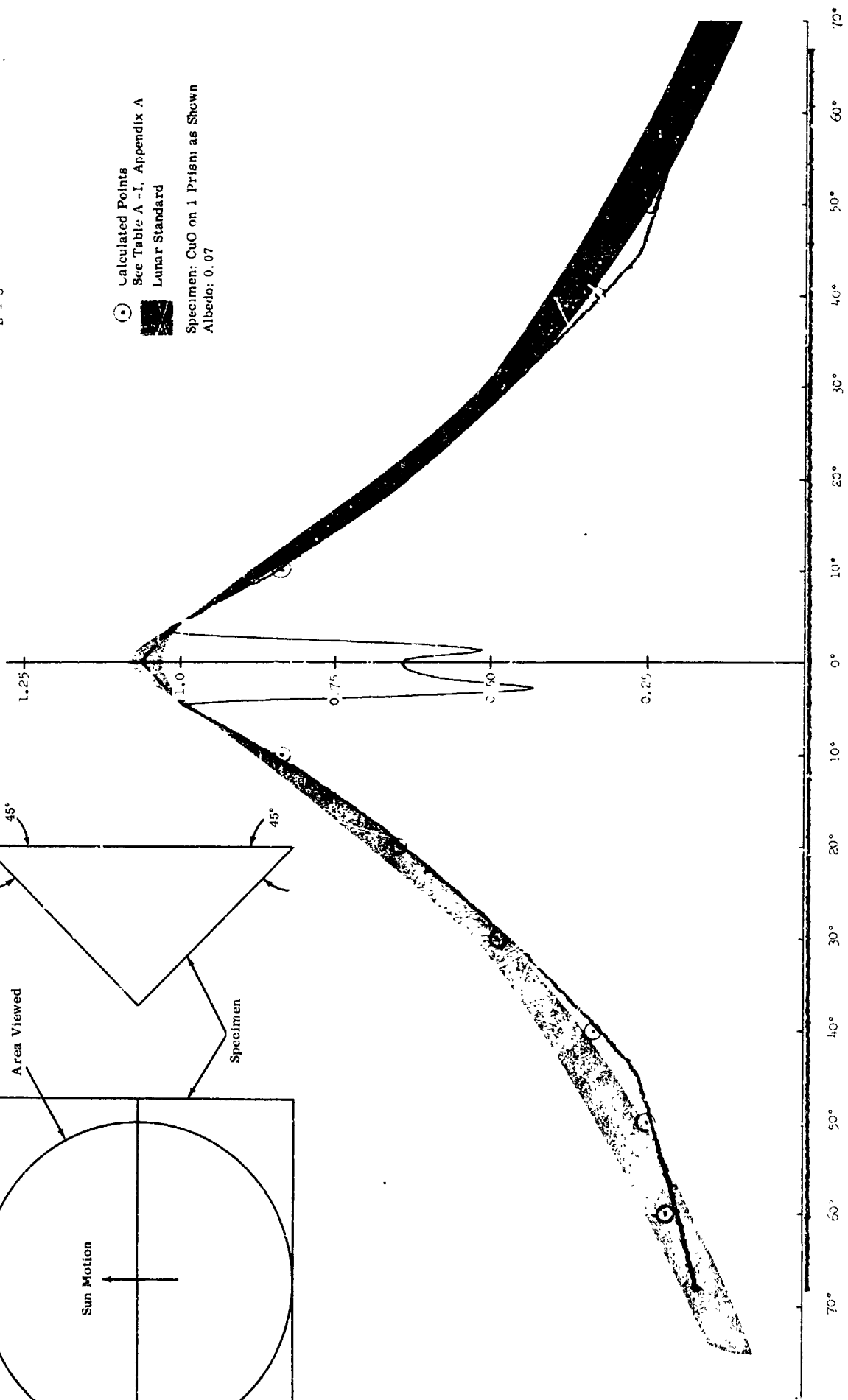


Figure 19c. CuO on Flat Surface Tilted



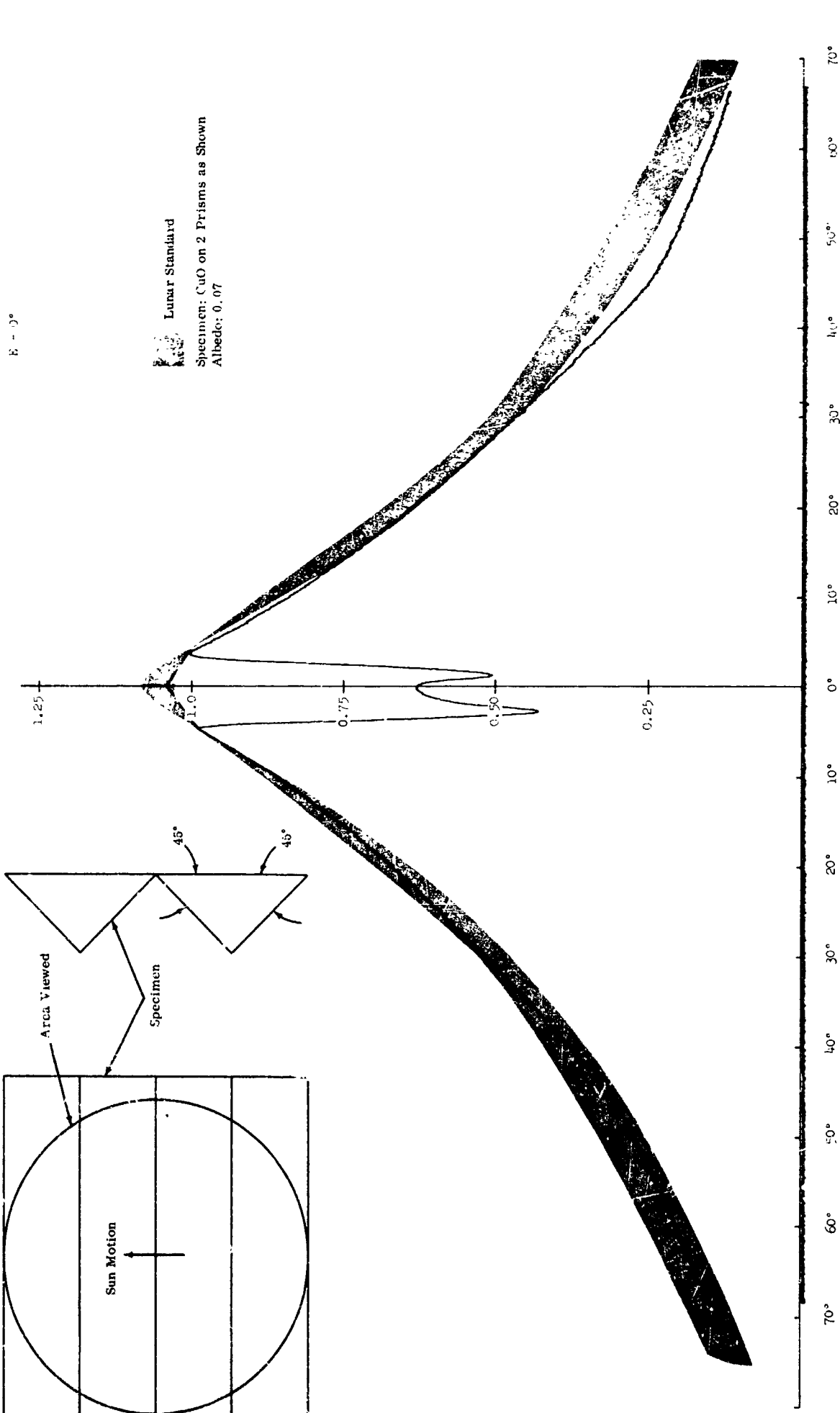
$\bar{E} = 0^\circ$

• Calculated Points
 See Table A -1, Appendix A
 Lunar Standard
 Specimen: CuO on 1 Prism as Shown
 Albedo: 0.07



Angle of incidence and Phase:

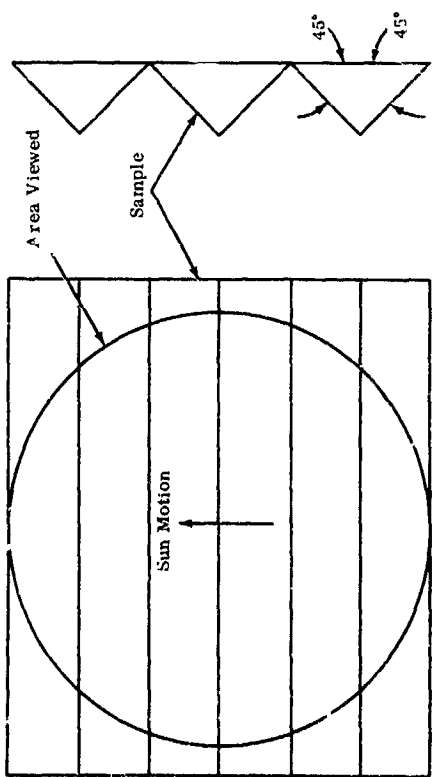
Figure 20a CuO on 1 Prism



Angle of Incidence and Phase

Figure 20b. CuO on 2 Prisms

$E = 0^\circ$



○ Calculated Points
See Table A - II, Appendix A

■ Lunar Standard

Specimen: CuO on 3 Prisms as Shown
Albedo: 0.07

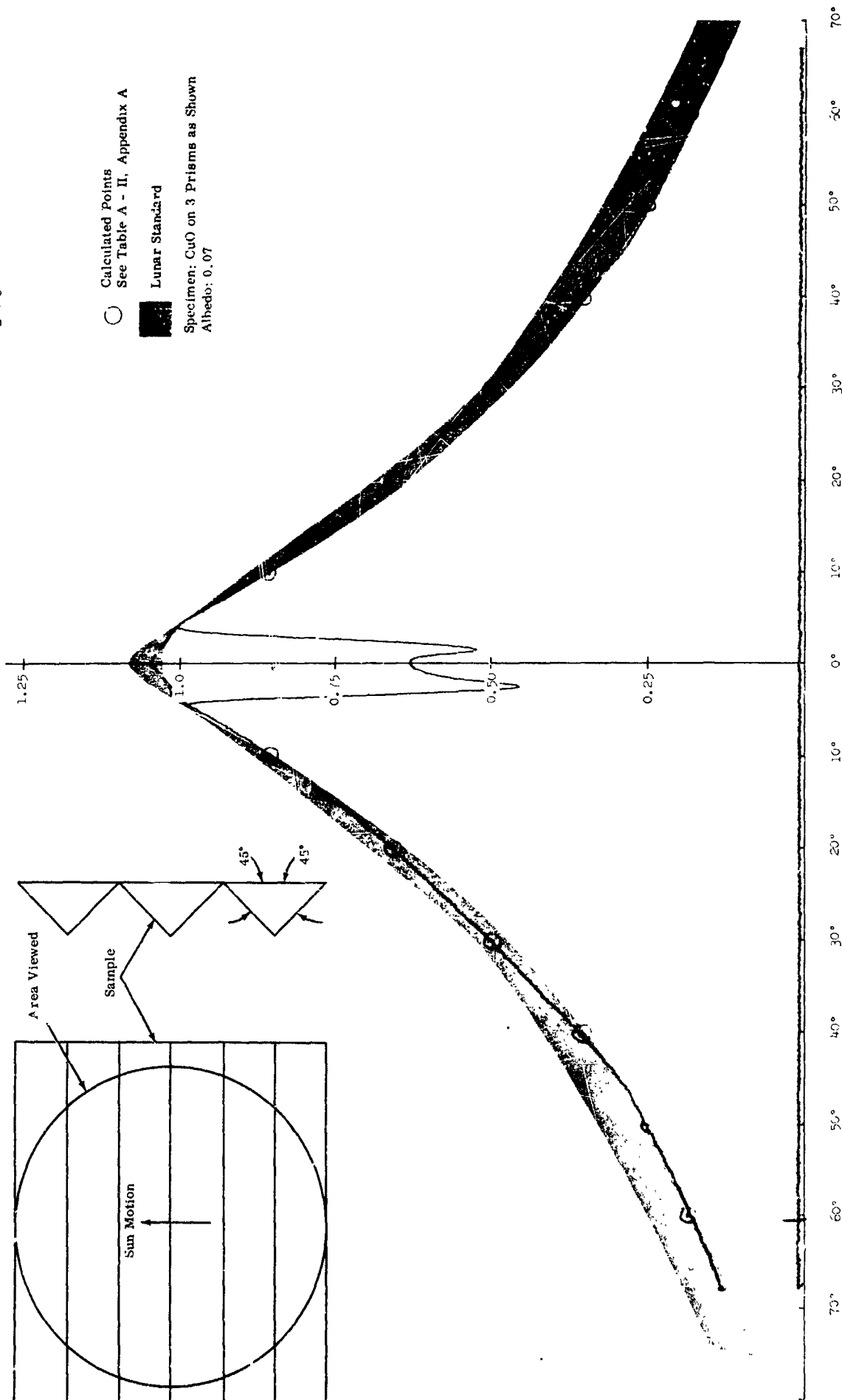
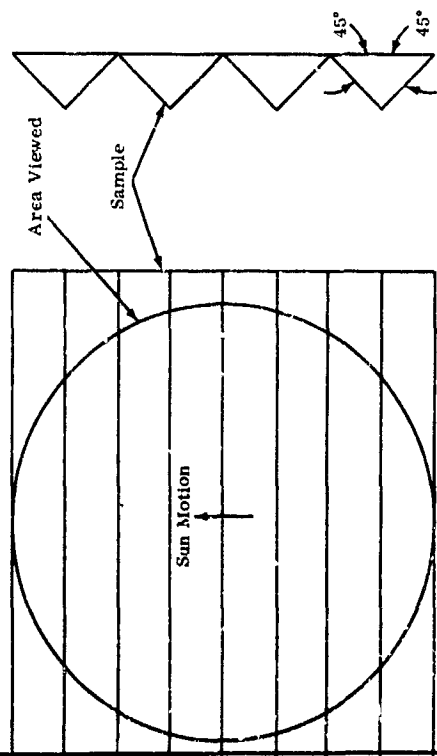
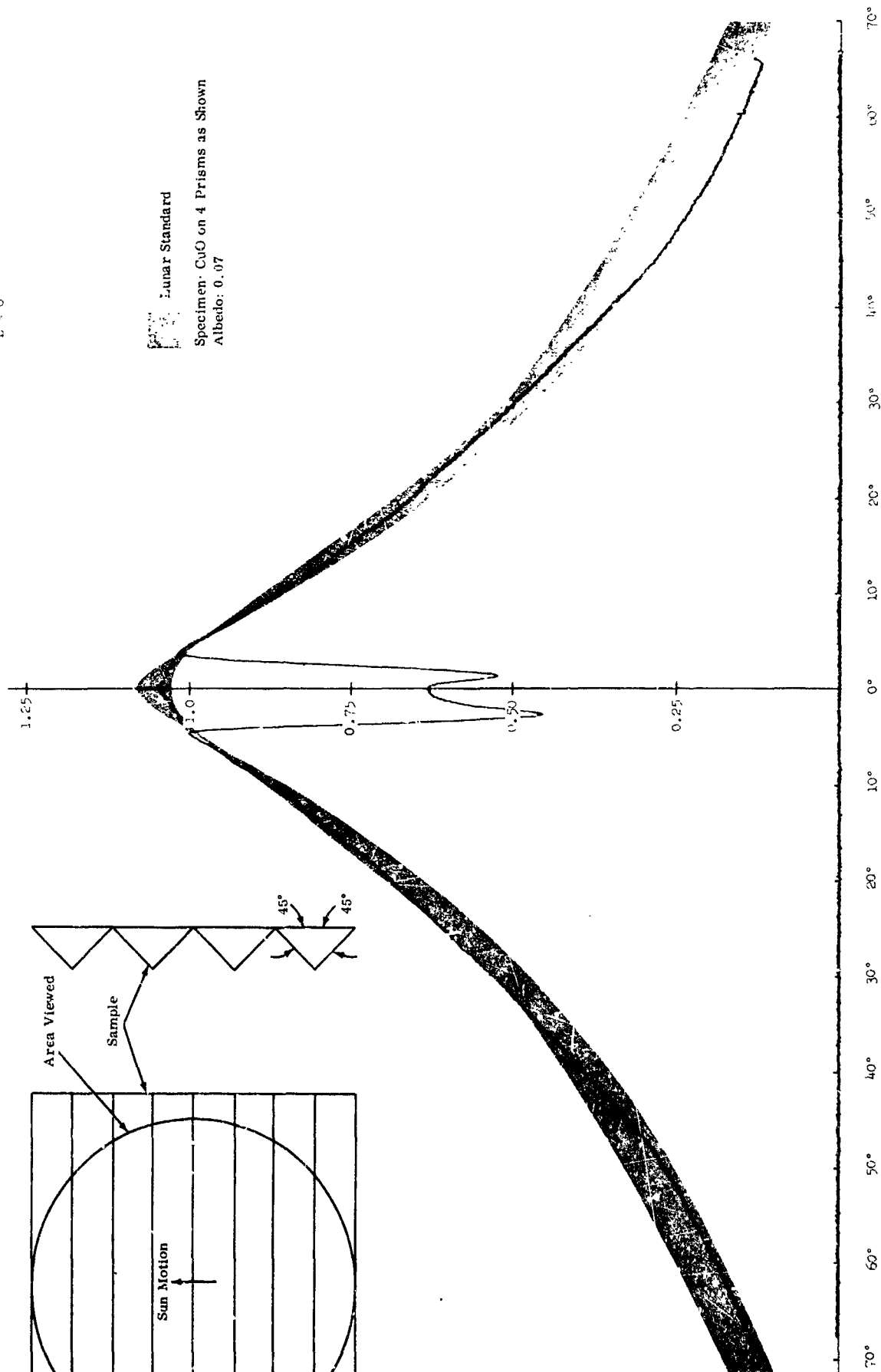


Figure 20c. CuO on 3 Prisms

E = 0°

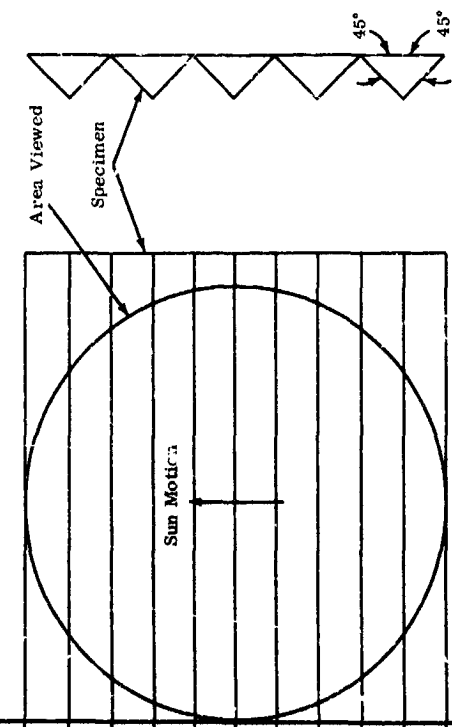


Lunar Standard
Specimen: CuO on 4 Prisms as Shown
Albedo: 0.07



Angle of Incidence and Phase
Figure 20d. CuO on 4 Prisms

$E = C^0$



Lunar Standard
Specimen: CuO on 5 Prisms as Shown
Albedo: 0.07

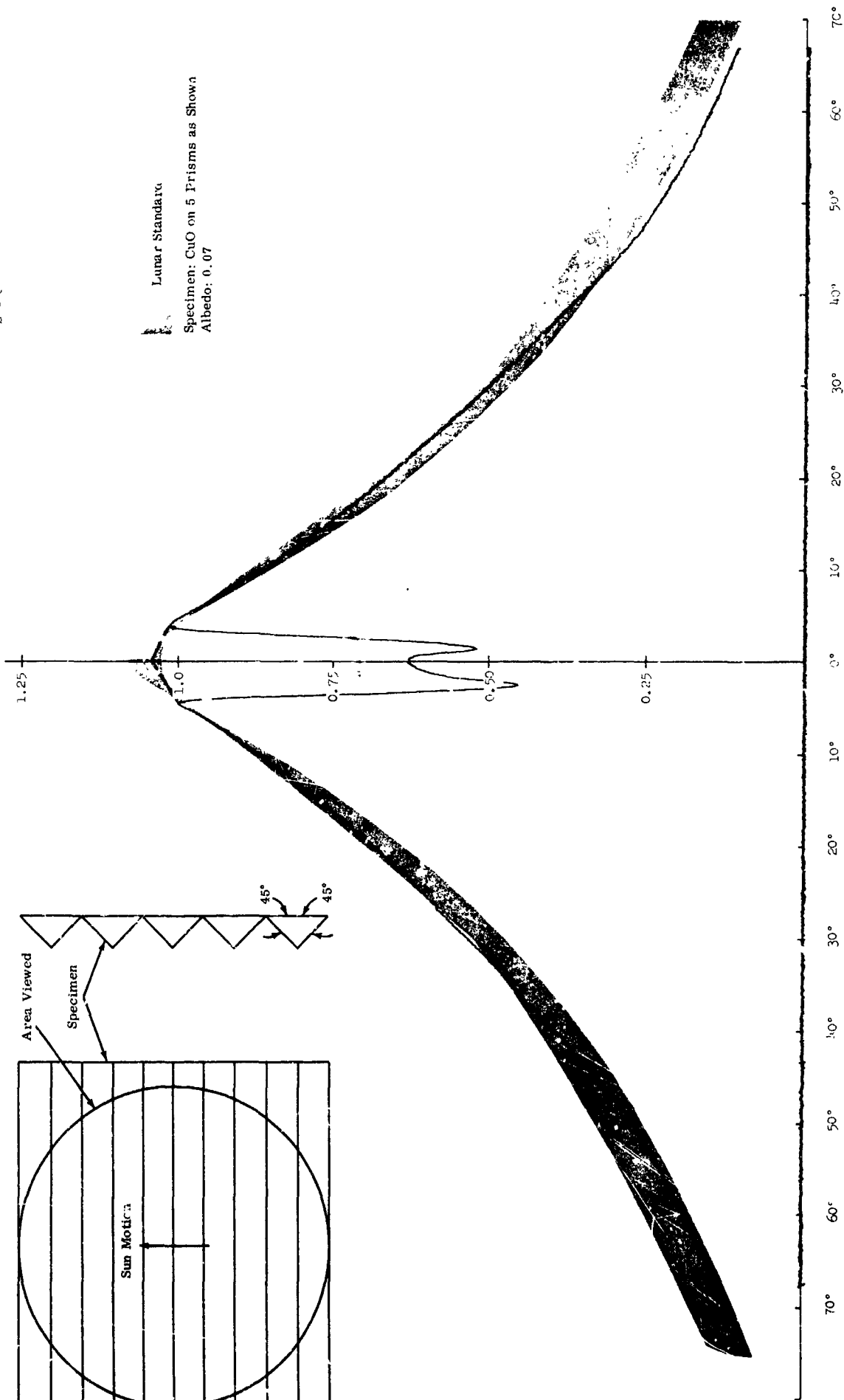
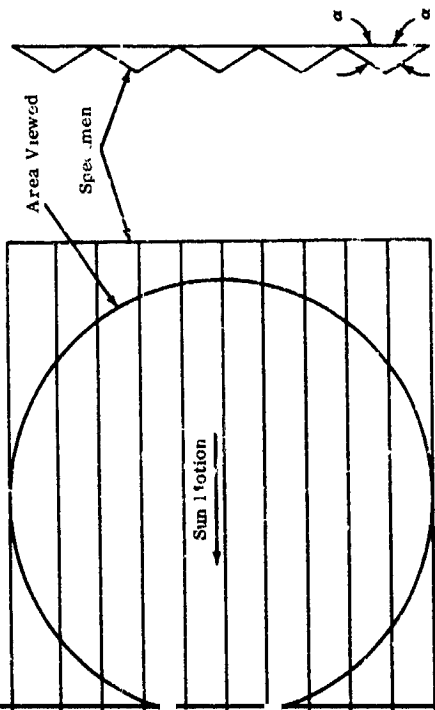
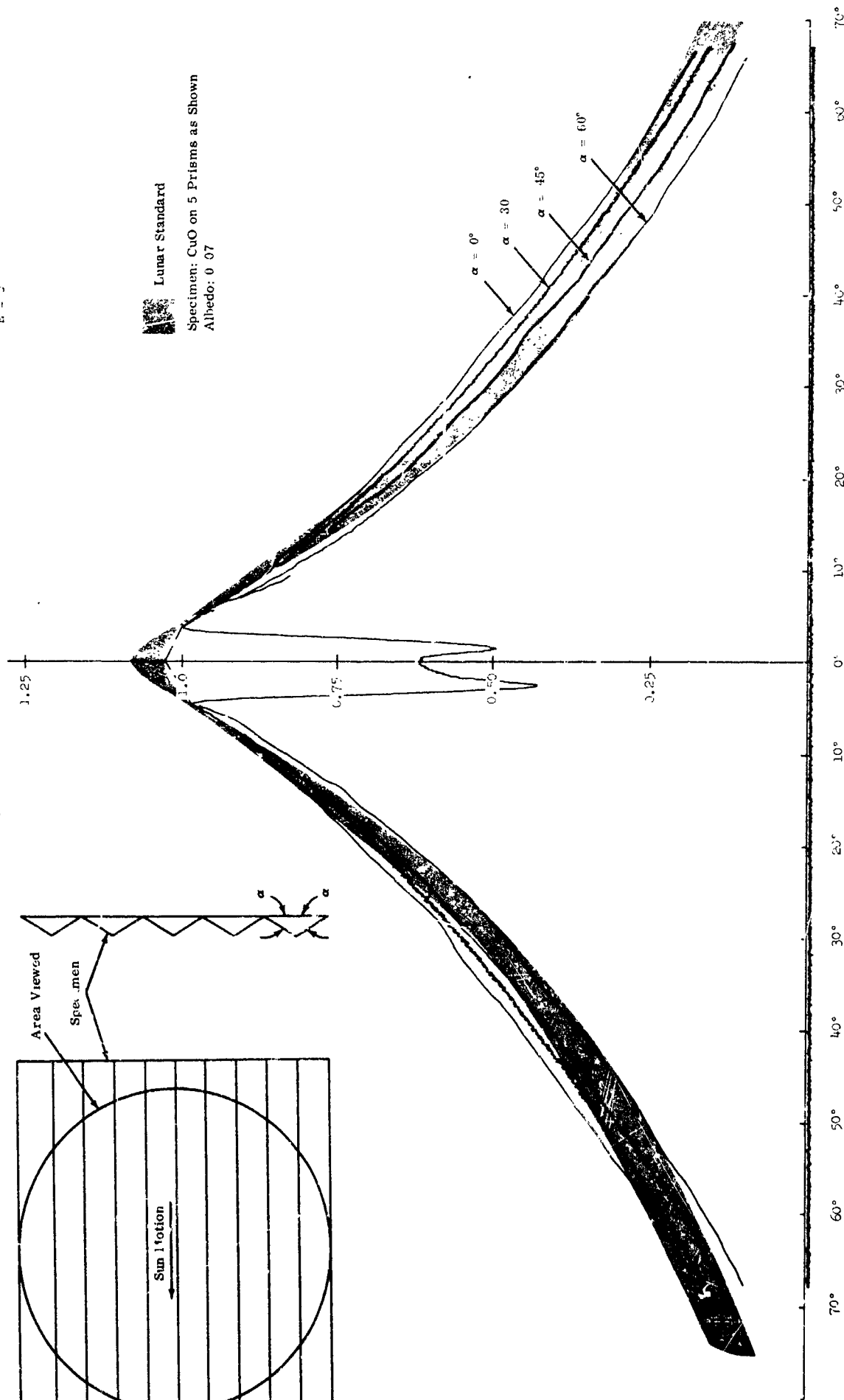


Figure 20e. CuO on 5 Prisms

$\lambda = 0.5$



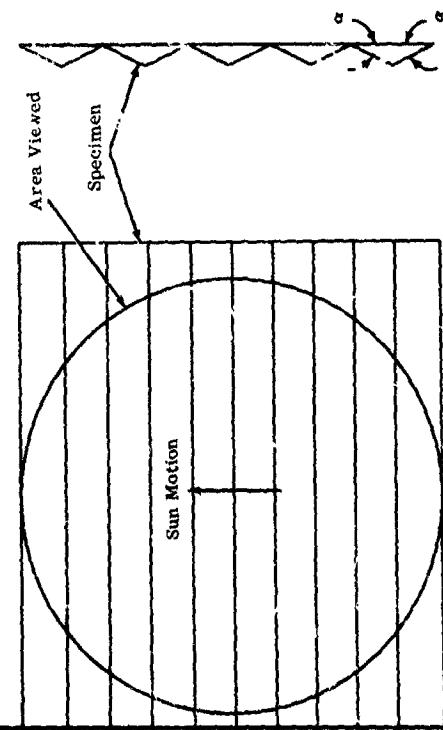
Lunar Standard
Specimen: CuO on 5 Prisms as Shown
Albedo: 0.07



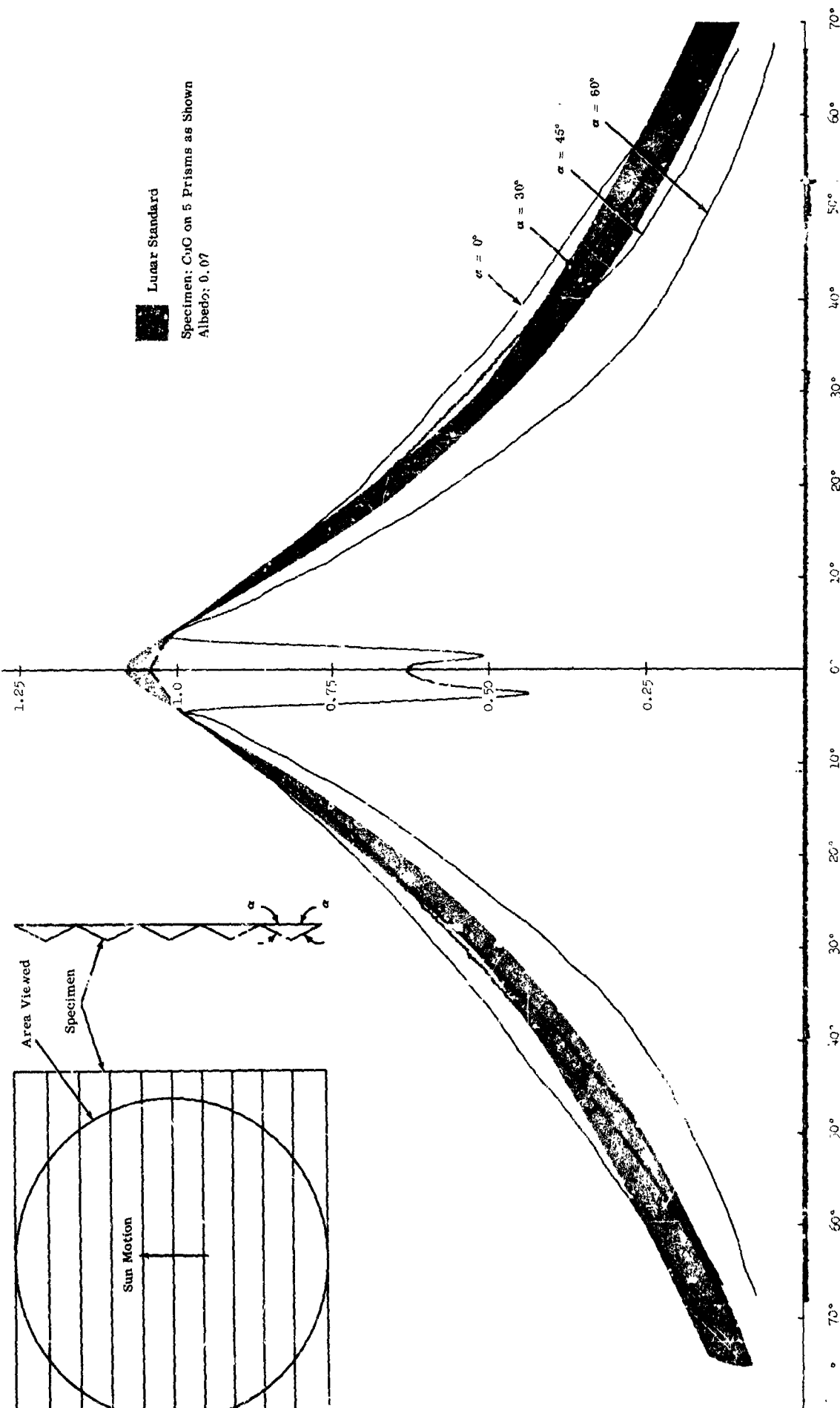
Angle of Incidence and Phase

Figure 21. CuO on 5 Prisms

$E = 0^\circ$



Lunar Standard
 Specimen: CuO on 5 Prisms as Shown
 Albedo: 0.07



Angle of Incidence and Phase

Figure 22. CuO on 5 Prisms

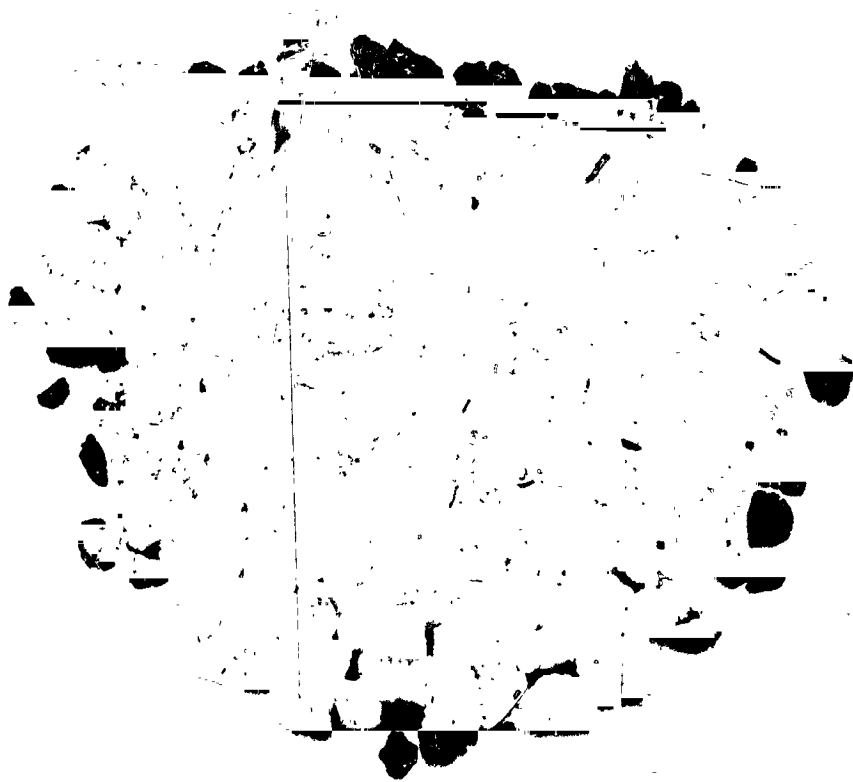
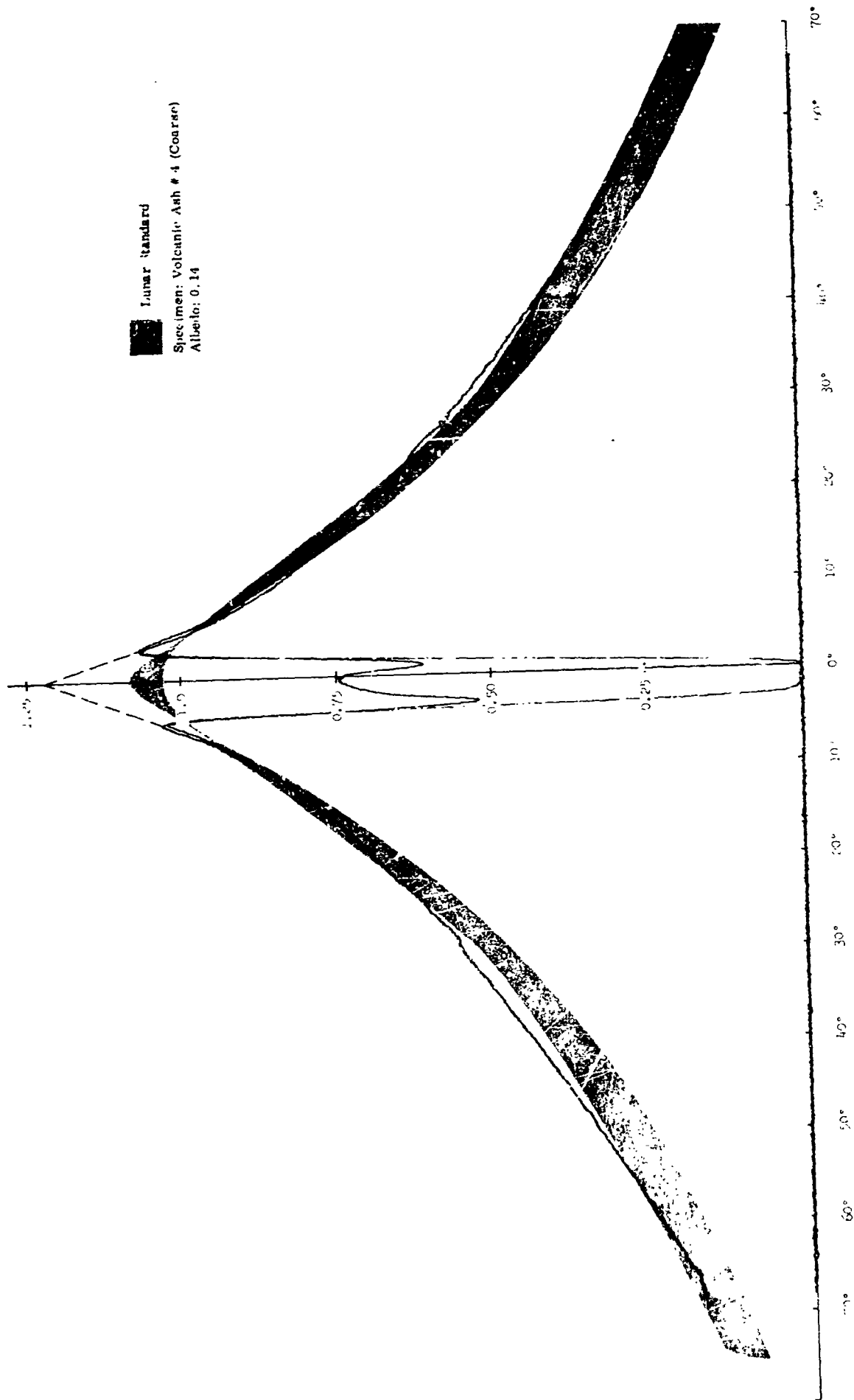


Figure 23a. Volcanic Ash # 4 (Coarse)

$\mu = 0^\circ$



Lunar Standard
 Specimen: Volcanic Ash # 4 (Coarse)
 Albedo: 0.14

Figure 23b. Volcanic Ash # 4 (Coarse)

E 30°

Lunar Standard
Specimen: Volcanic Ash # 4 (Coarse)
Albedo: 0.14

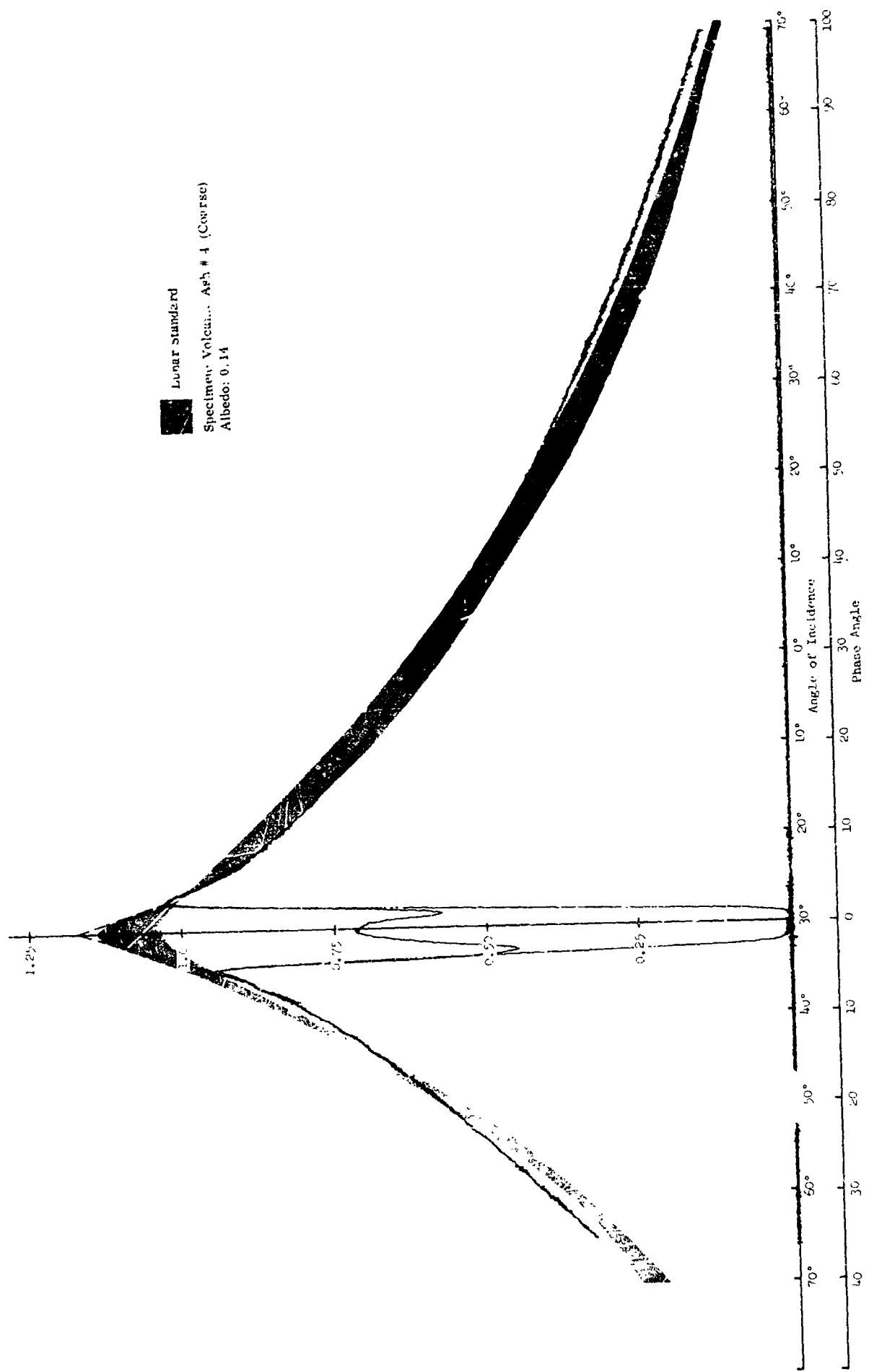
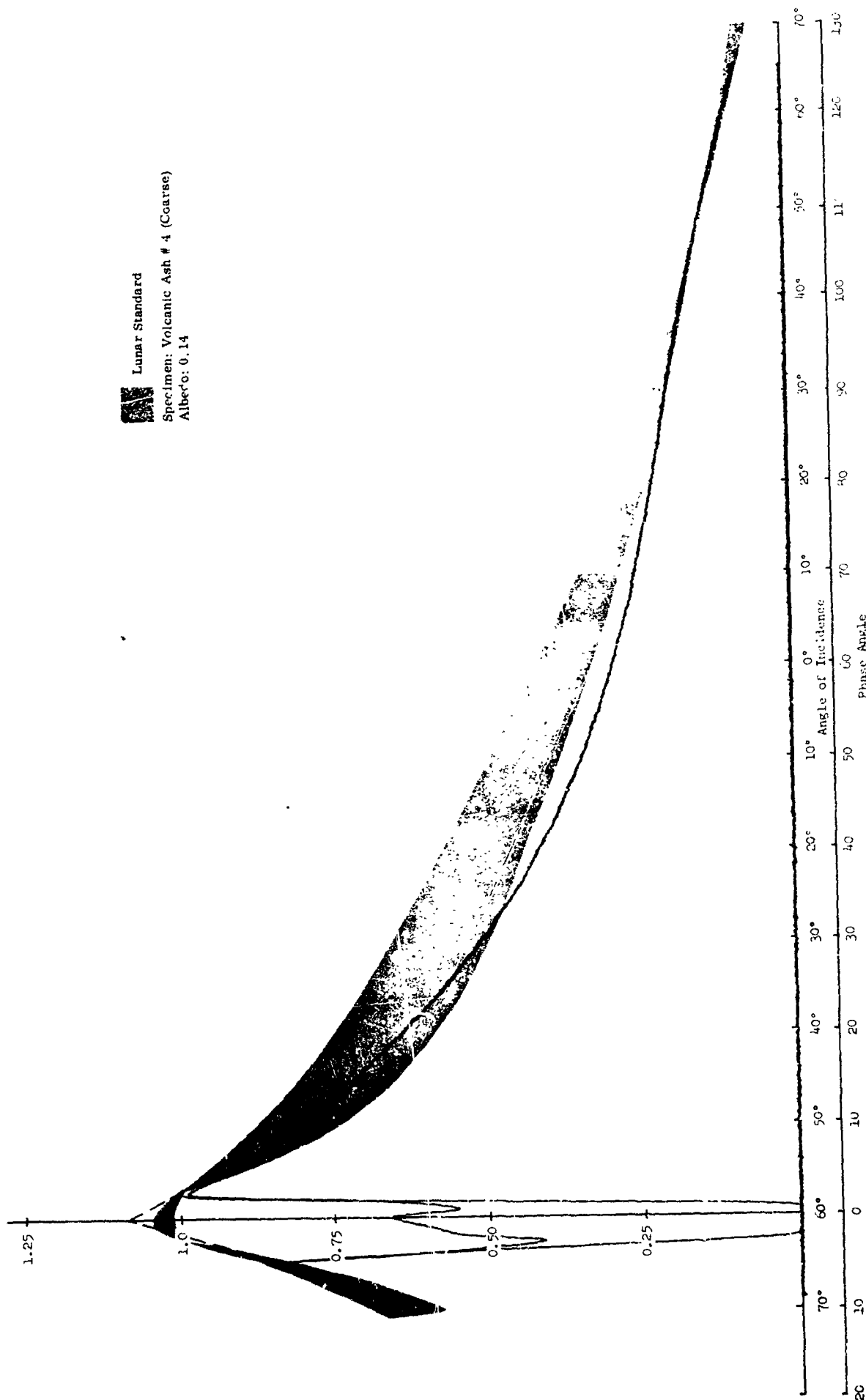


Figure 23c. Volcanic Ash # 4 (Coarse)

E - 0.0°



Lunar Standard
Specimen: Volcanic Ash # 4 (Coarse)
Albedo: 0.14

Figure 23d. Volcanic Ash # 4 (Coarse)



Figure 24a. Volcanic Ash # 5 (Coarse)

$\tau = 0^\circ$

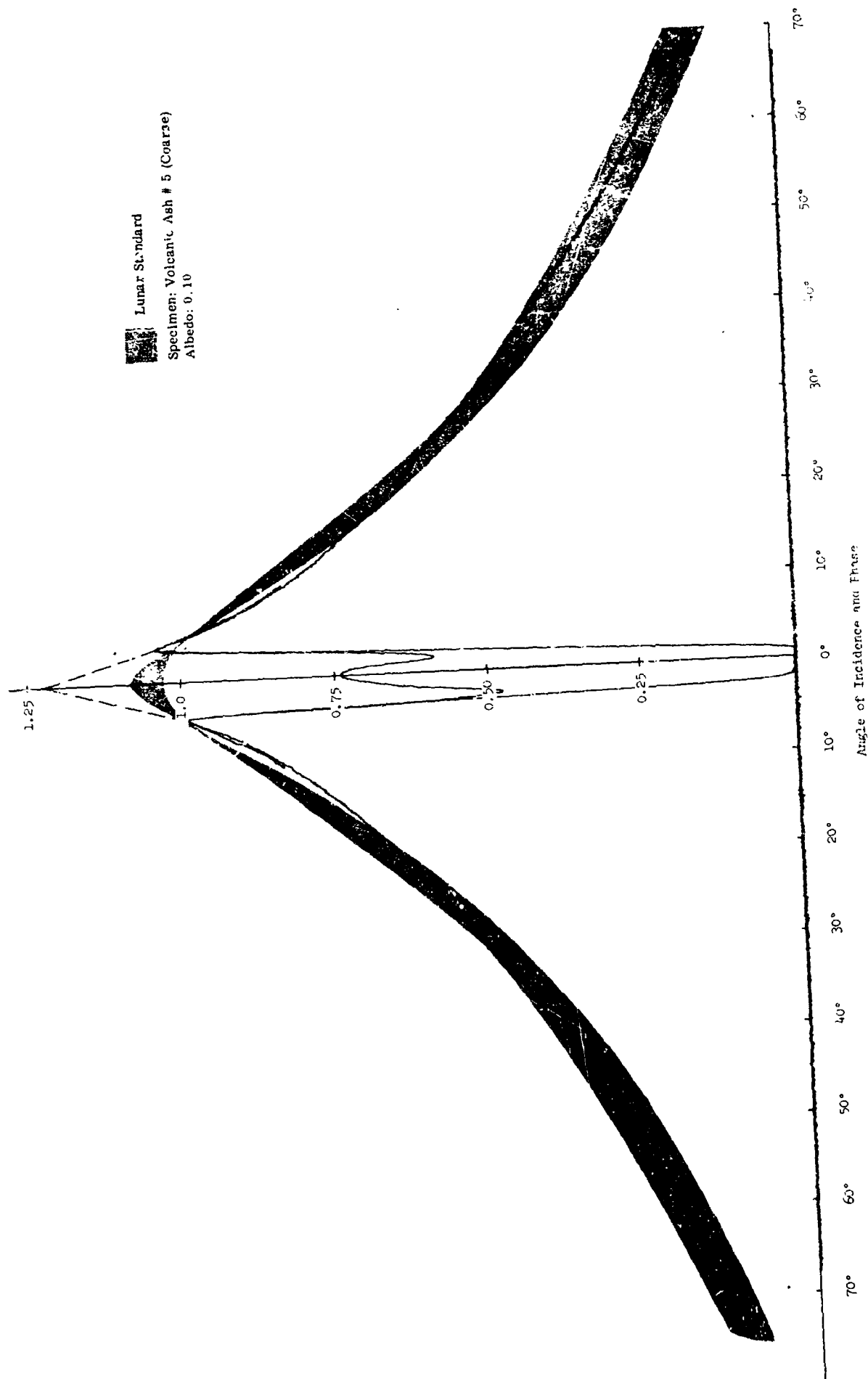
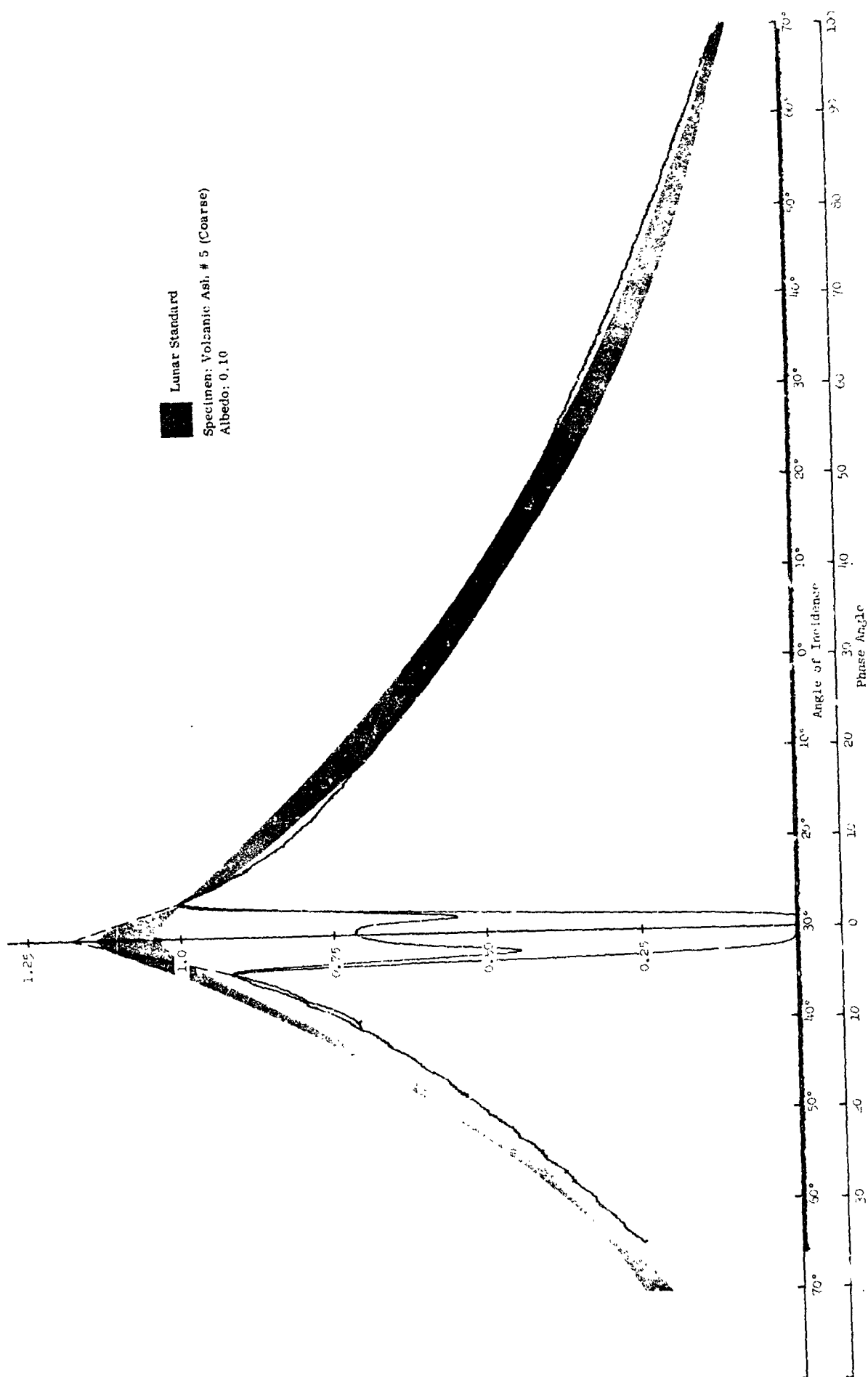


Figure 24b. Volcanic Ash # 5 (Coarse)

E 30°



Lunar Standard
Specimen: Volcanic Ash # 5 (Coarse)
Albedo: 0.10

Figure 24c. Volcanic Ash # 5 (Coarse)

$E = 6.2^\circ$

Lunar Standard
 Specimen: Volcanic Ash # 5 (Coarse)
 Albedo: 0.19

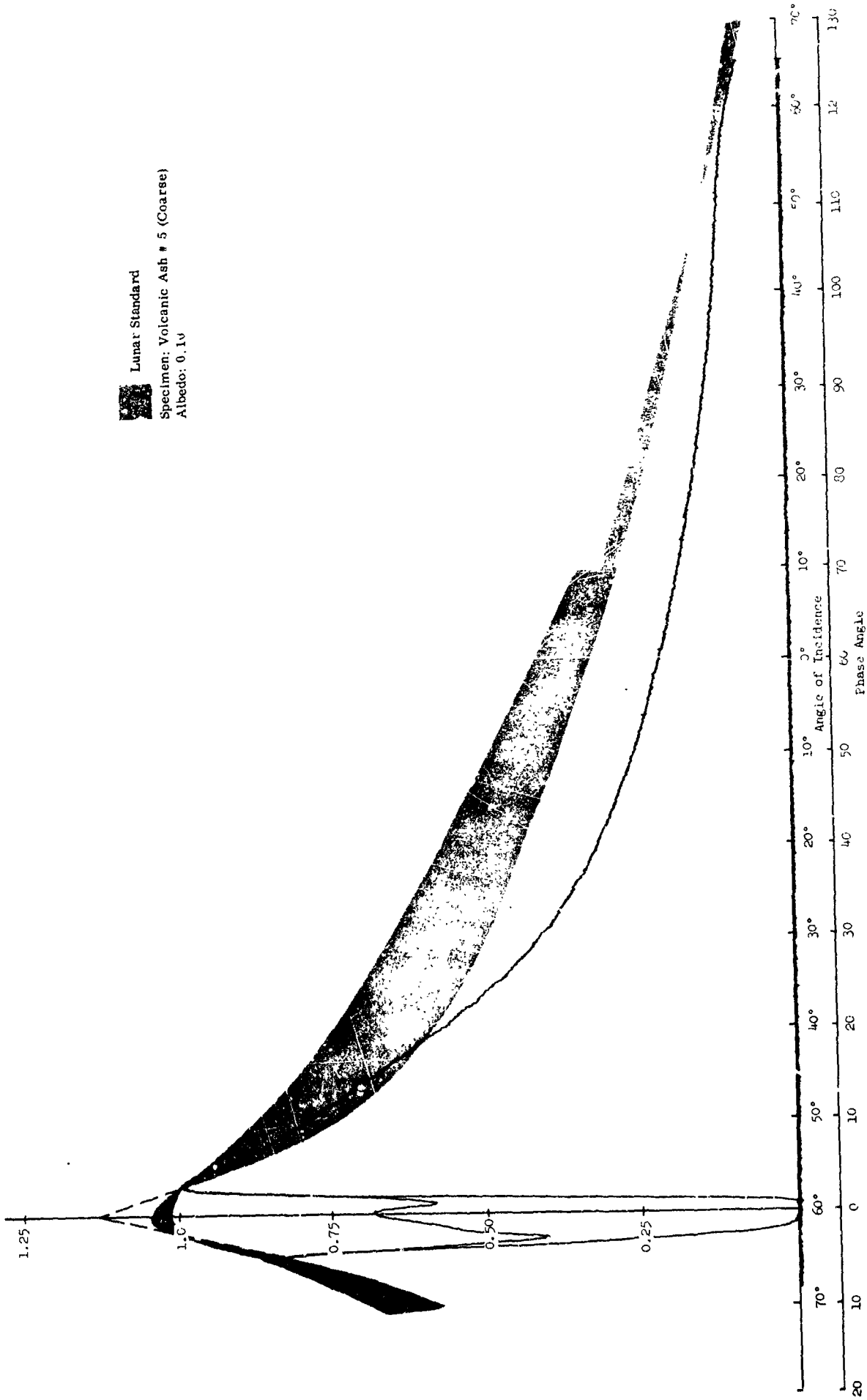
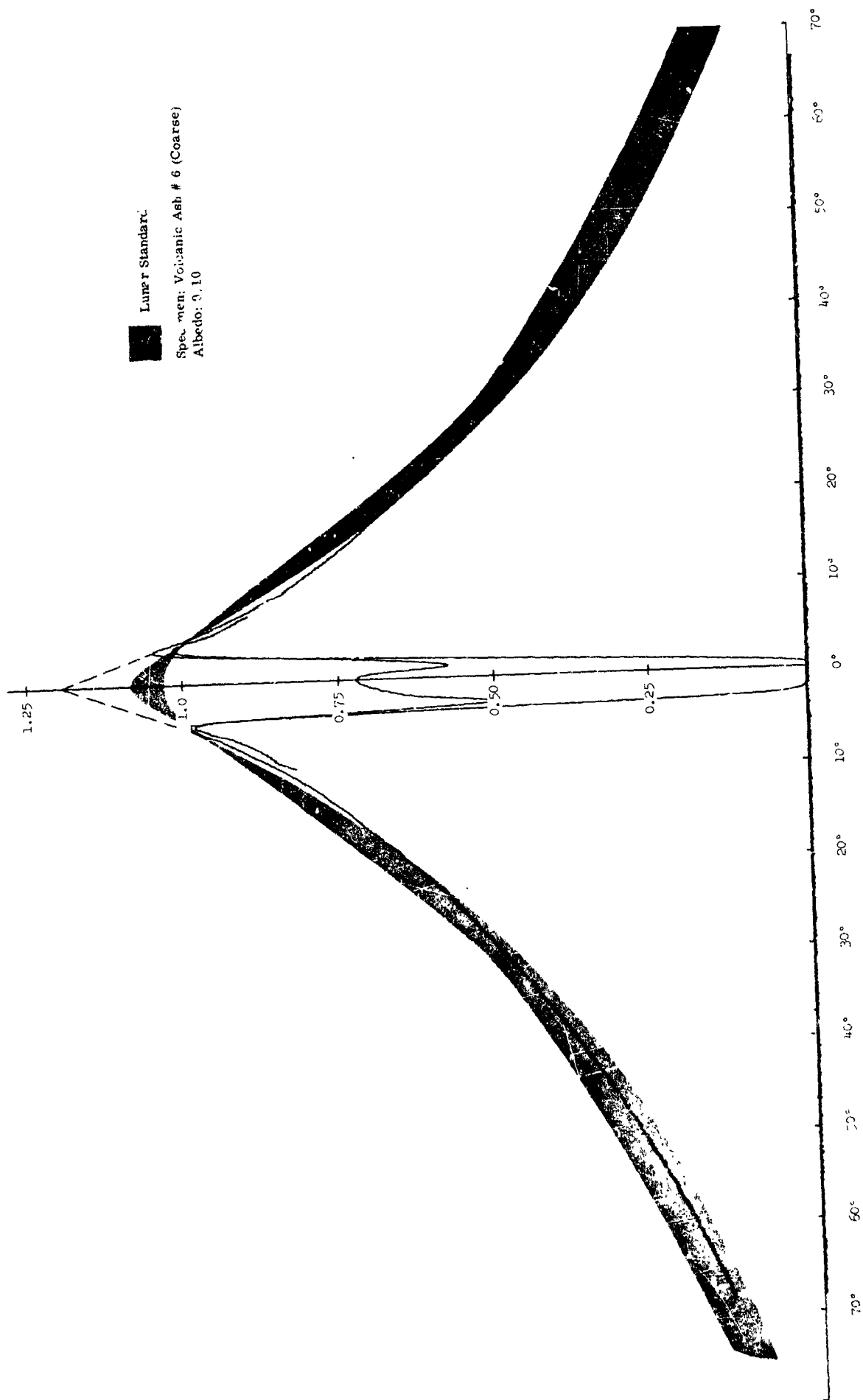


Figure 24d. Volcanic Ash # 5 (Coarse)



Figure 25a. Volcanic Ash # 6 (Coarse)

E = 0°



Lunar Standard
Specimen: Volcanic Ash # 6 (Coarse)
Albedo: 0.10

Figure 25b. Volcanic Ash # 6 (Coarse)

$E = 30^\circ$

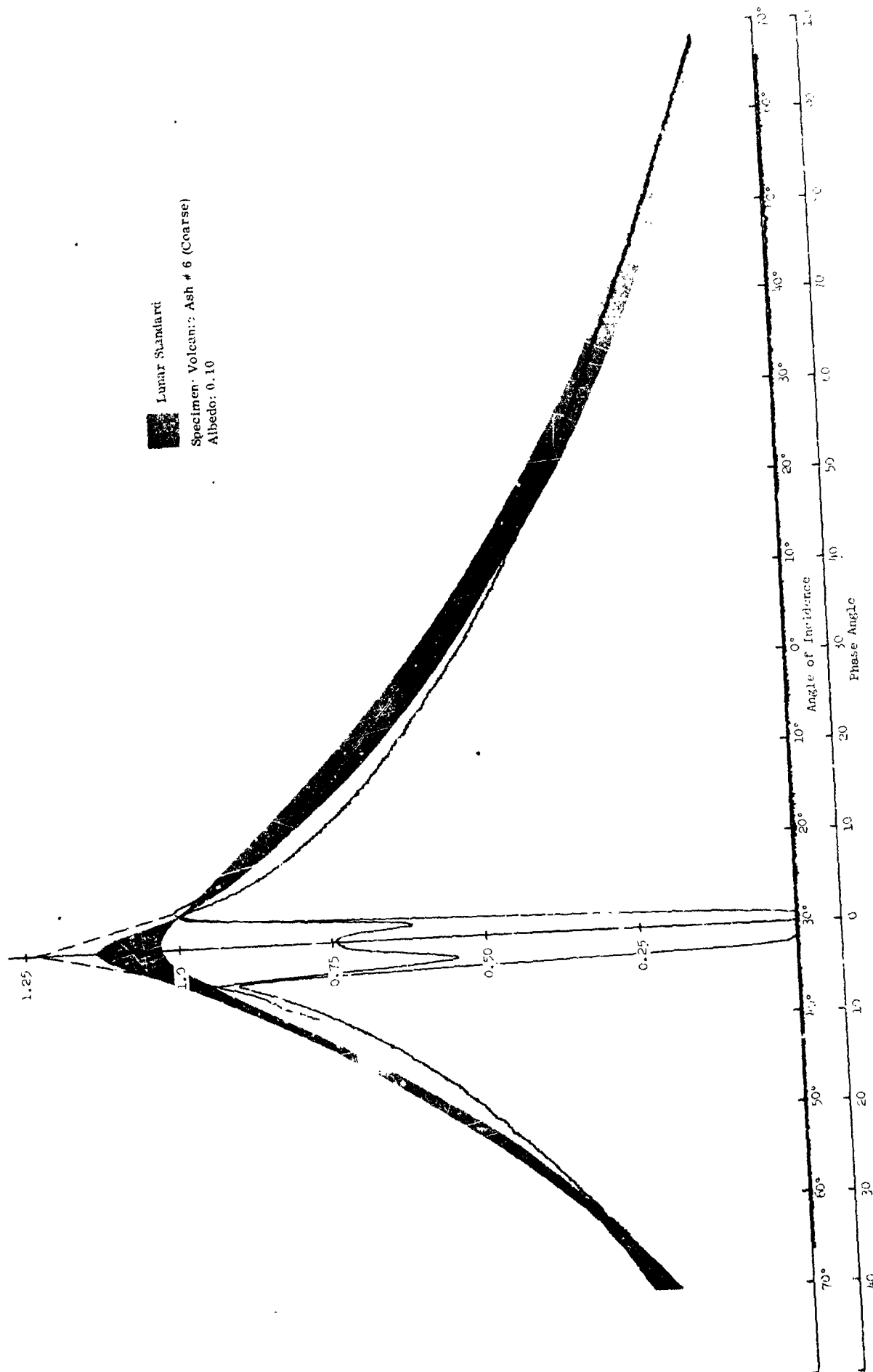


Figure 25c. Volcanic Ash # 6 (Coarse)

E = 60°

Lunar Standard

Specimen: Volcanic Ash # 6 (Coarse)
Albedo: 0.10

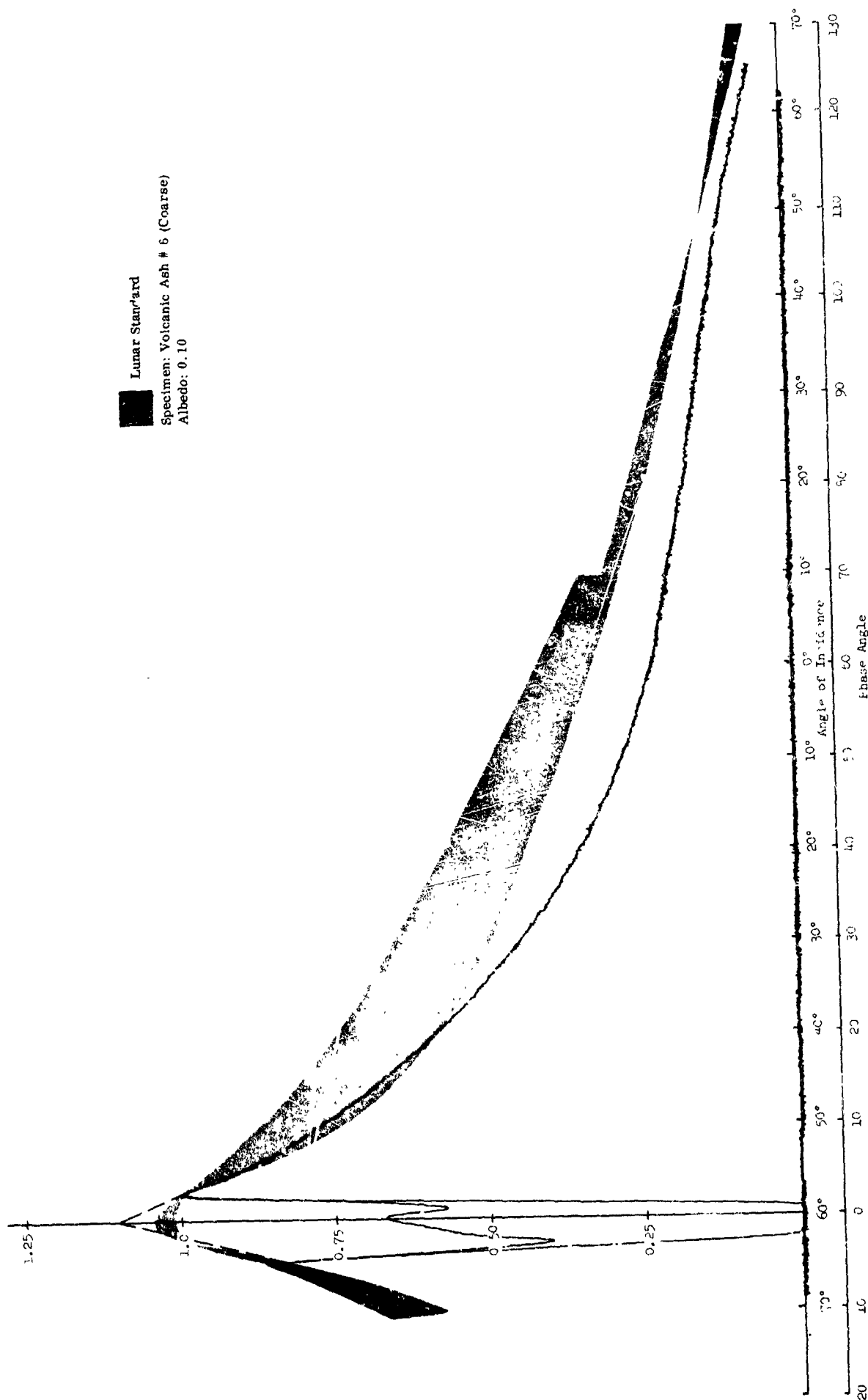


Figure 25d. Volcanic Ash # 6 (Coarse)

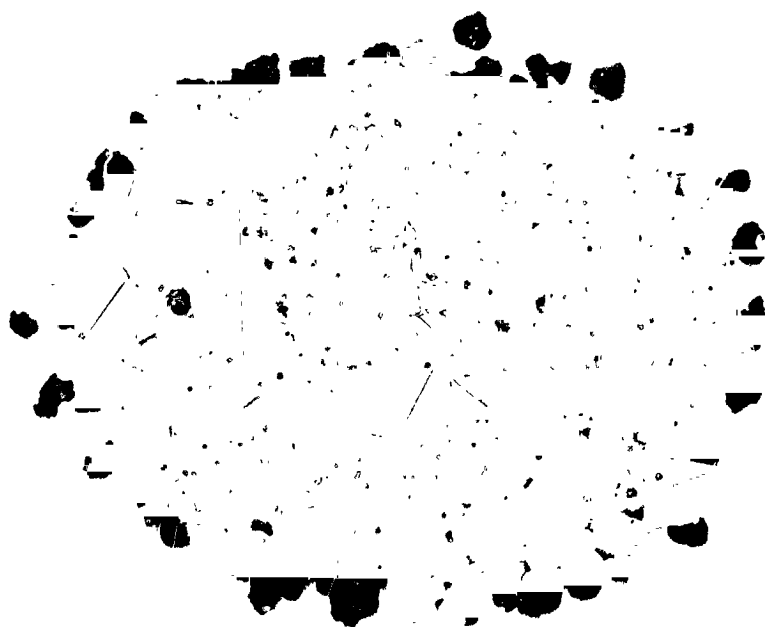
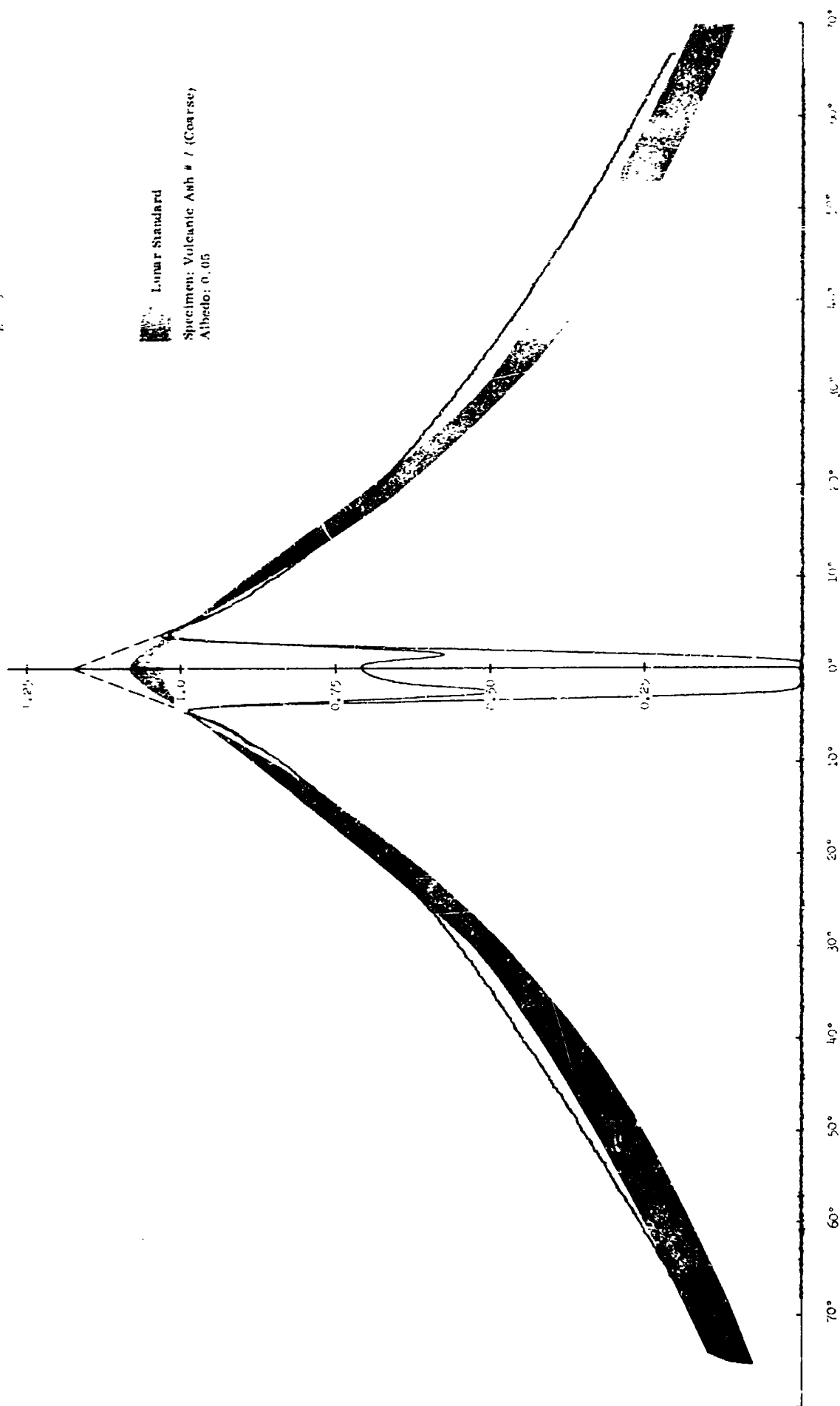


Figure 26a. Volcanic Ash # 7 (Coarse)



Angle of Incidence and Phase

Figure 26h. Volcanic Ash # 7 (Coarse)

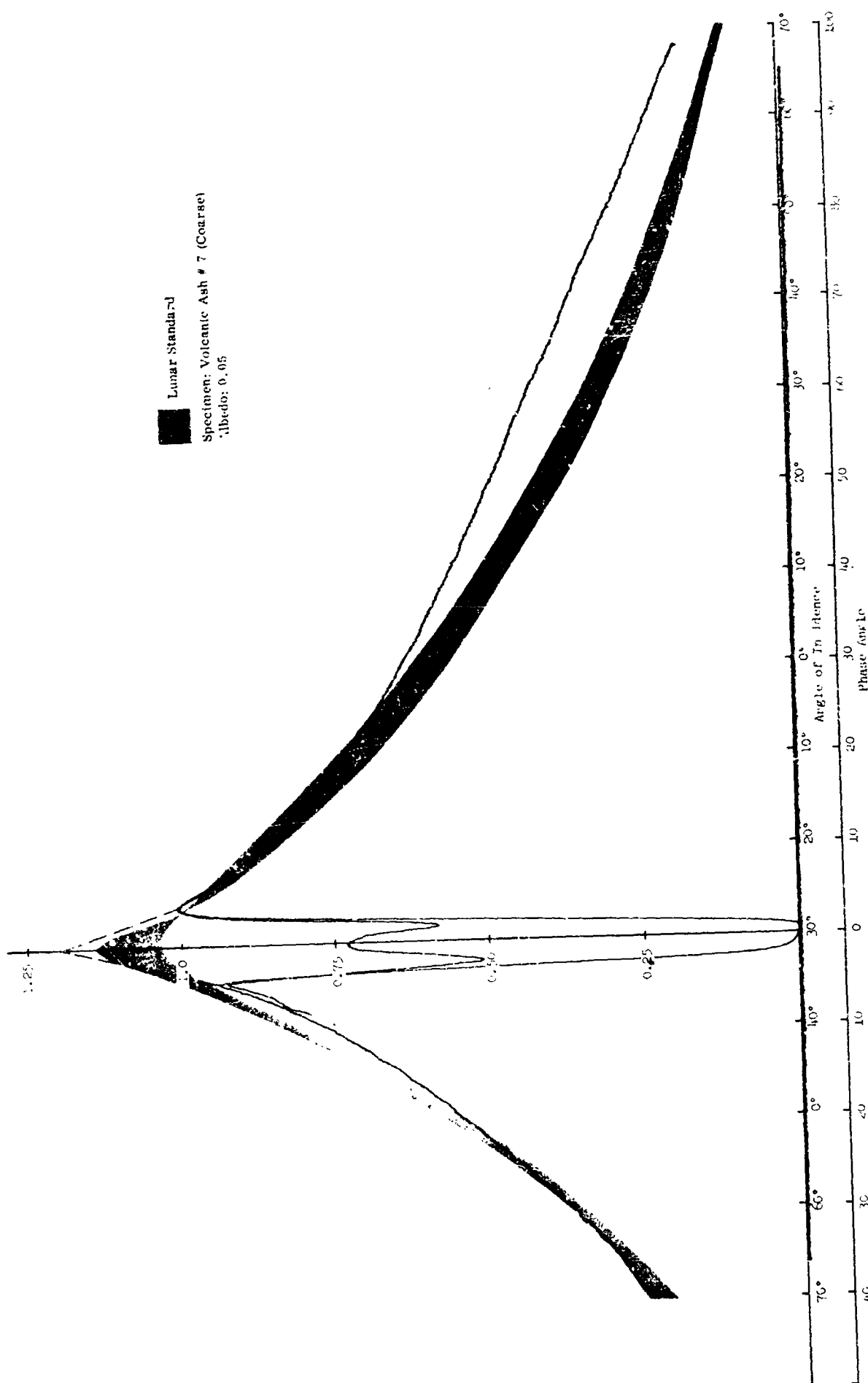


Figure 26c. Volcanic Ash # 7 (Coarse)

E 60°

Lunar Standard
Specimen: Volcanic Ash # 7 (Coarse)
Albedo: 0.05

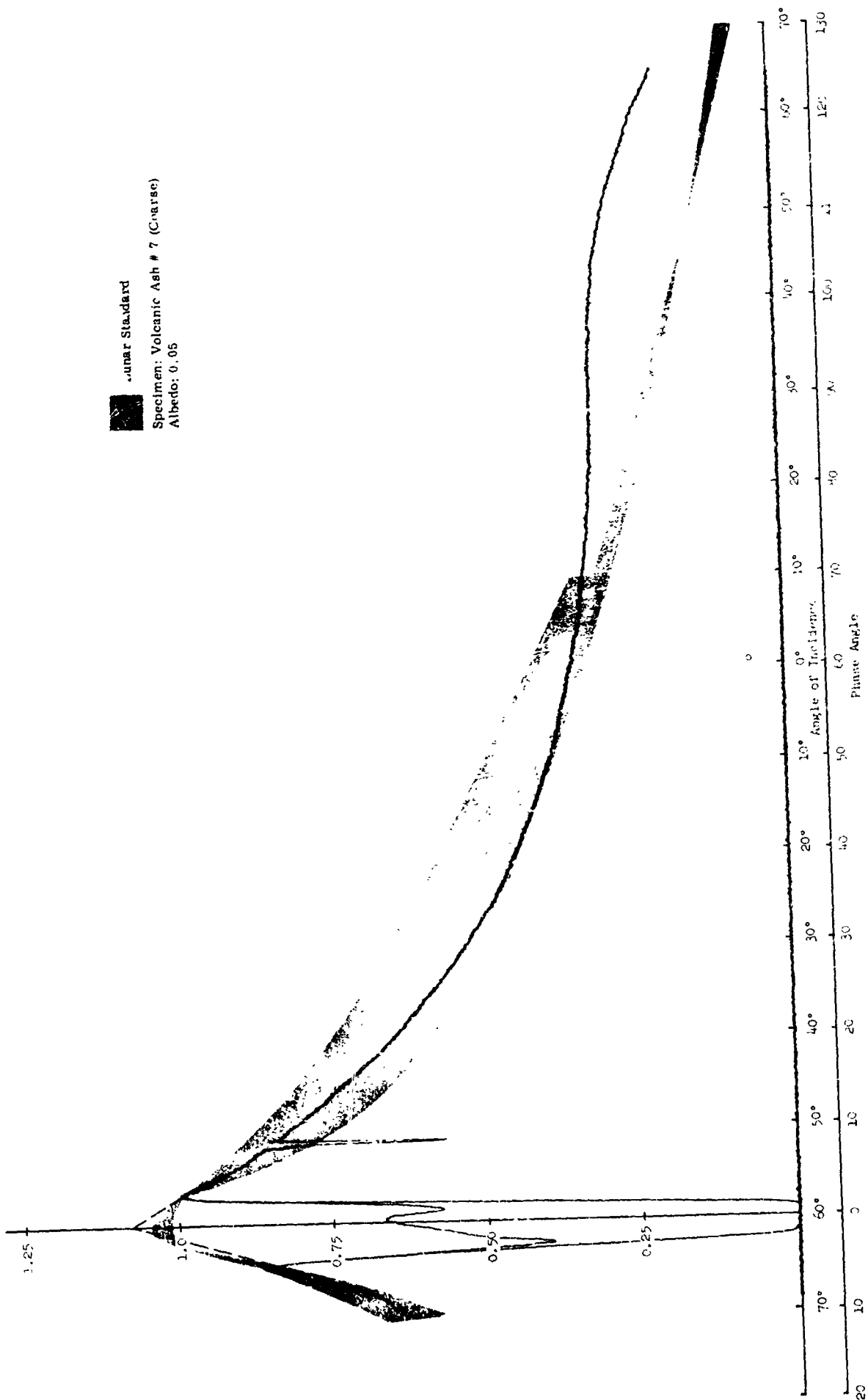


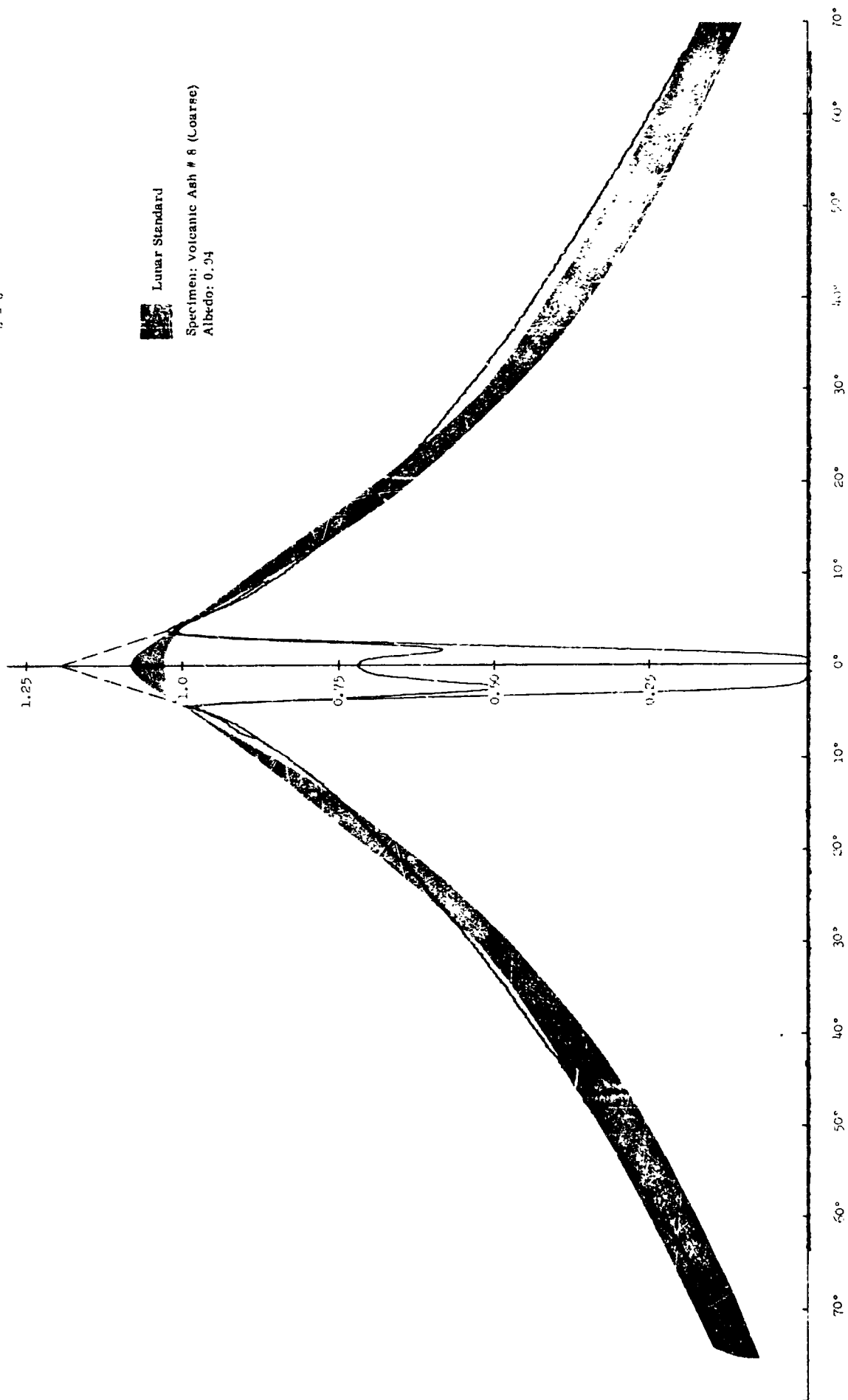
Figure 2nd. Volcanic Ash # 7 (Coarse)



Figure 27a. Volcanic Ash # 8 (Coarse)

$\theta = 0^\circ$

 Lunar Standard
 Specimen: Volcanic Ash # 8 (Coarse)
 Albedo: 0.94



Angle of Incidence and Phase

Figure 27b. Volcanic Ash # 8 (Coarse)

E - 30

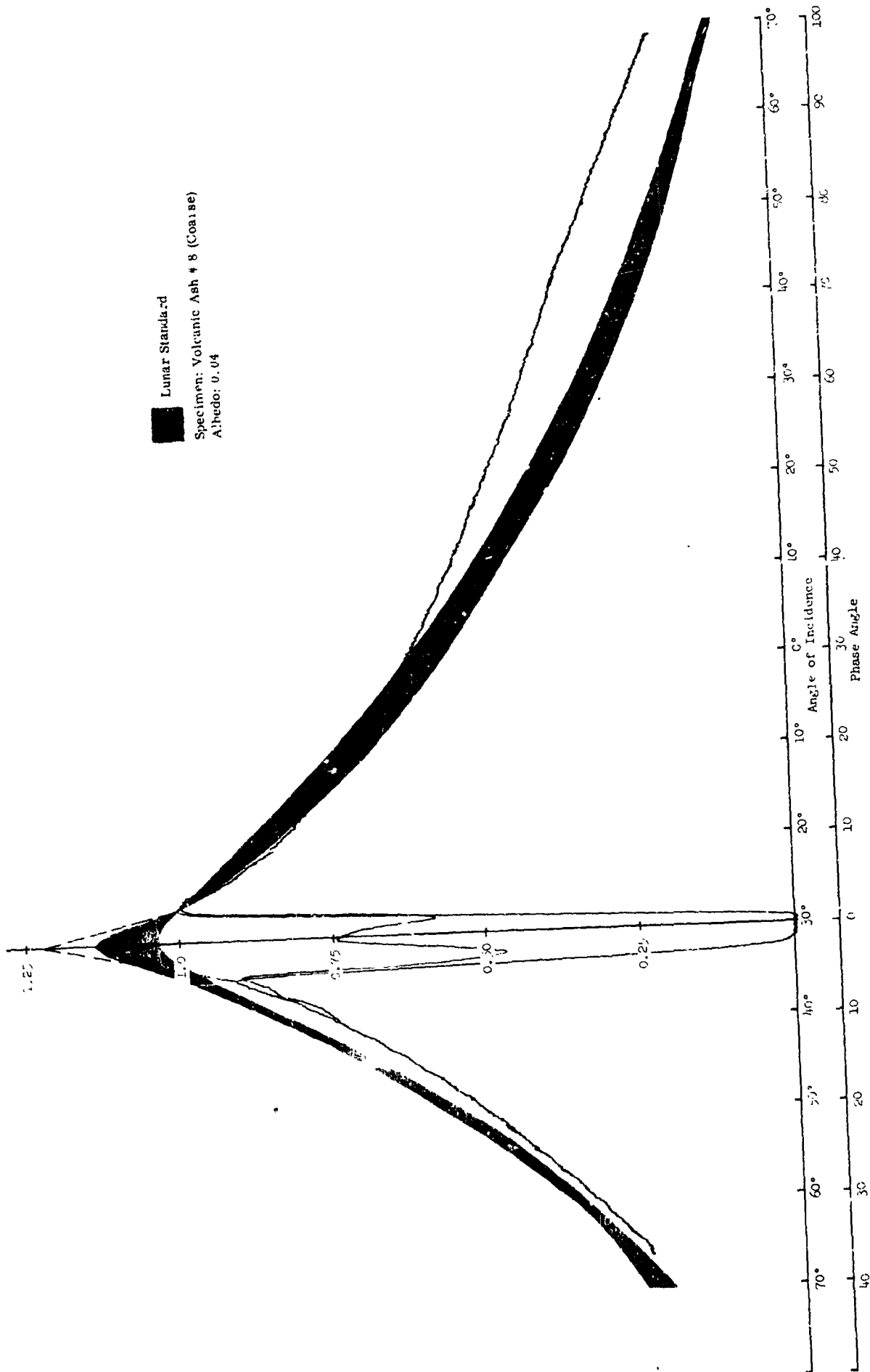
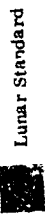


Figure 27c. Volcanic Ash # 8 (Coarse)

$E = 66^\circ$



Lunar Standard

Specimen: Volcanic Ash # 8 (Coarse)

Albedo: 0.04

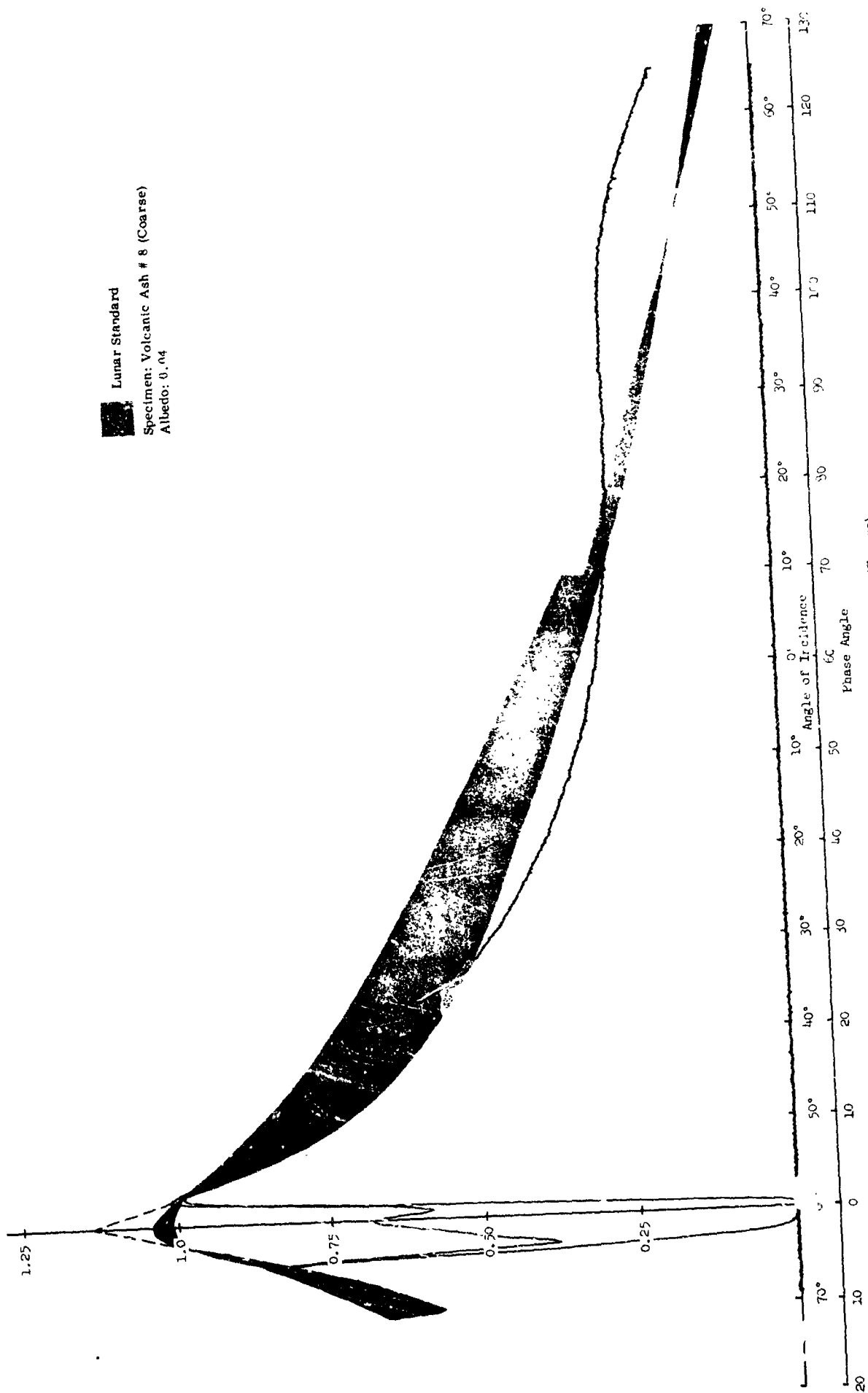


Figure 27d. Volcanic Ash # 8 (Coarse)



Figure 28a. Volcanic Ash # 9 (Coarse)

$E = 0^\circ$

Lunar Standard
 Specimen: Volcanic Ash # 9 (Coarse)
 Albedo: 0.07

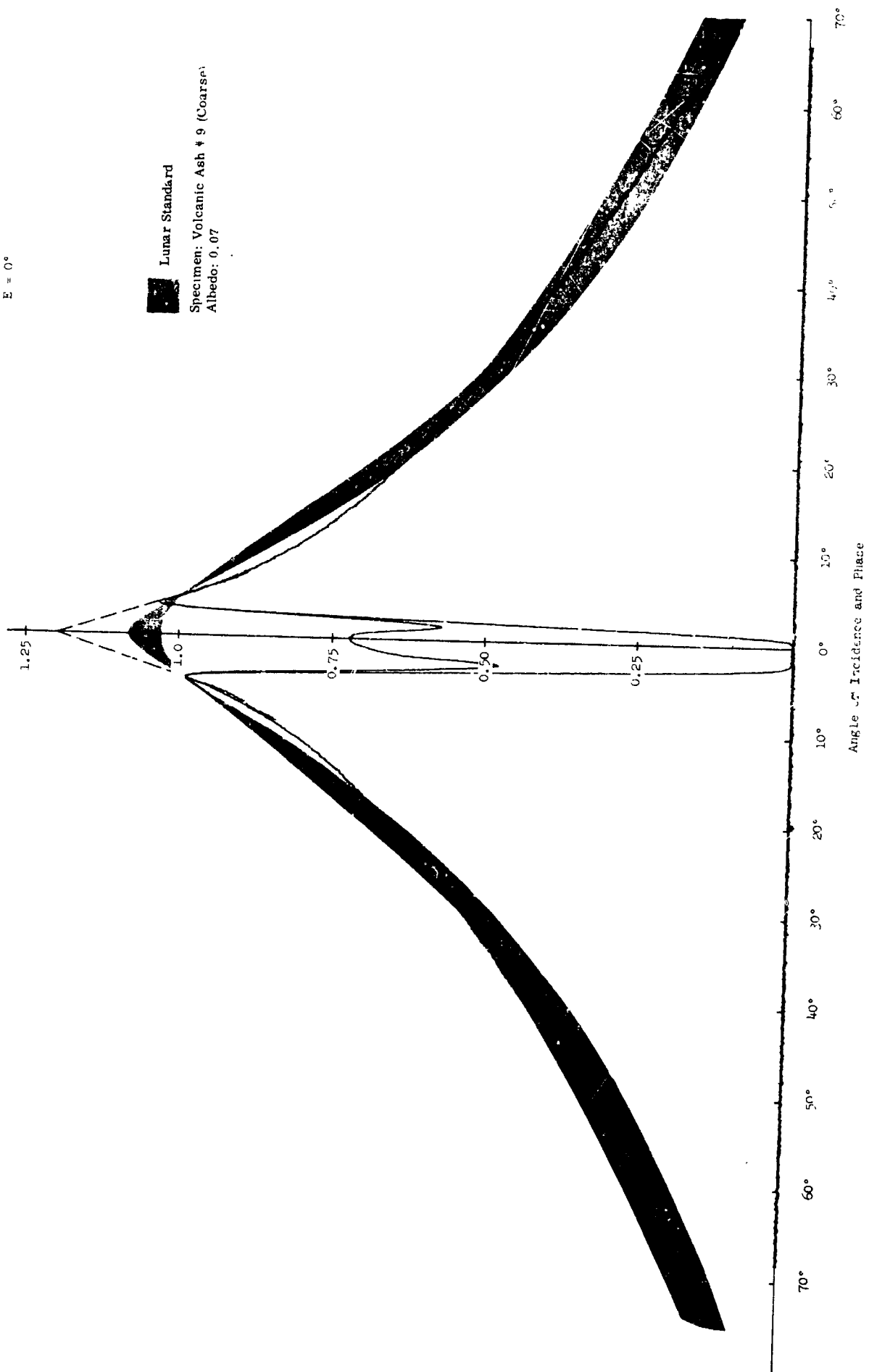


Figure 28b. Volcanic Ash # 9 (Coarse)

E = 30°

1 Solar Standard
Specimen: Volcanic Ash # 9 (Coarse)
Albedo: 0.07

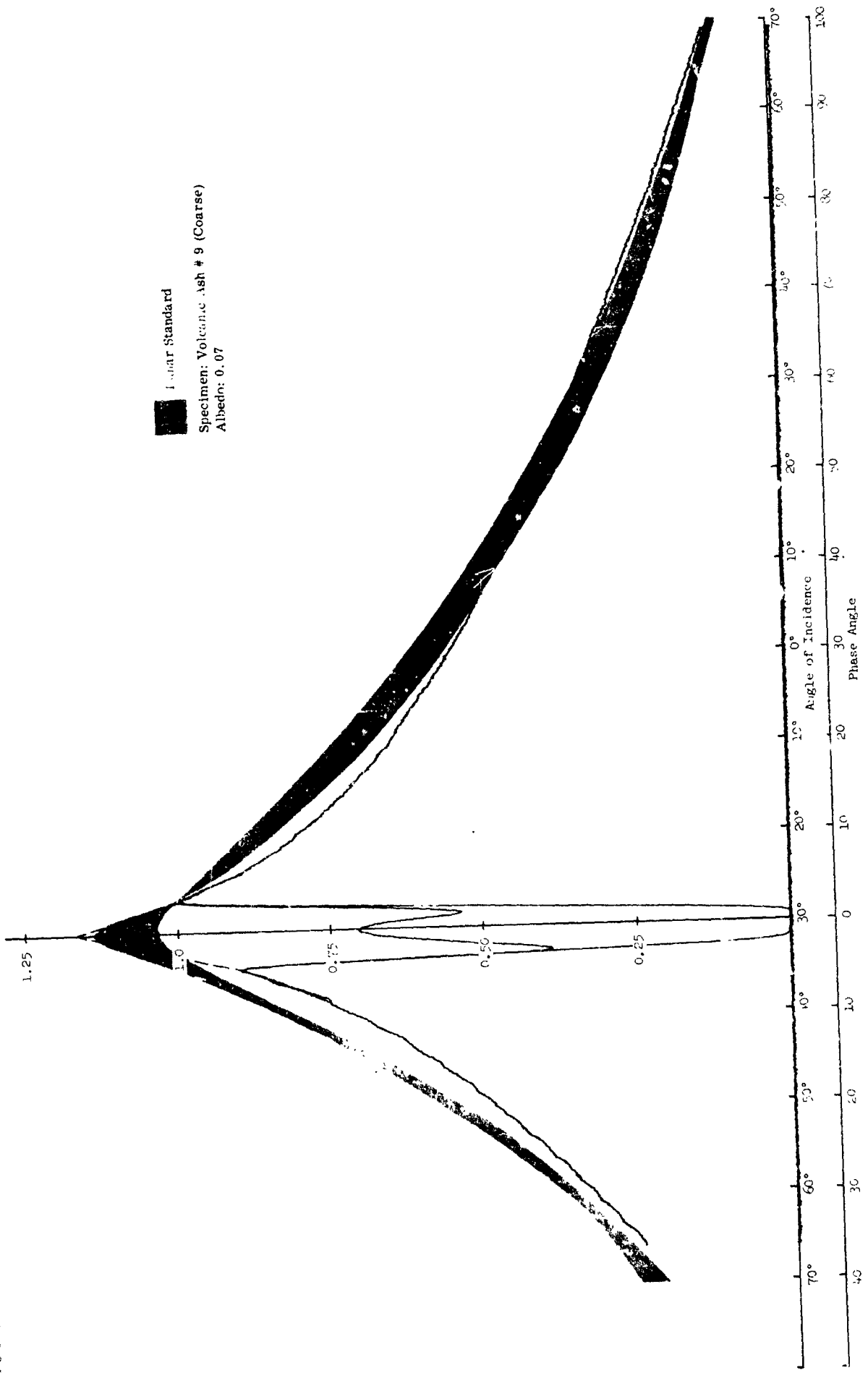


Figure 28c. Volcanic Ash # 9 (Coarse)

$E = 60^\circ$

Lunar Standard
Specimen: Volcanic Ash # 9 (Coarse)
Albedo: 0.07

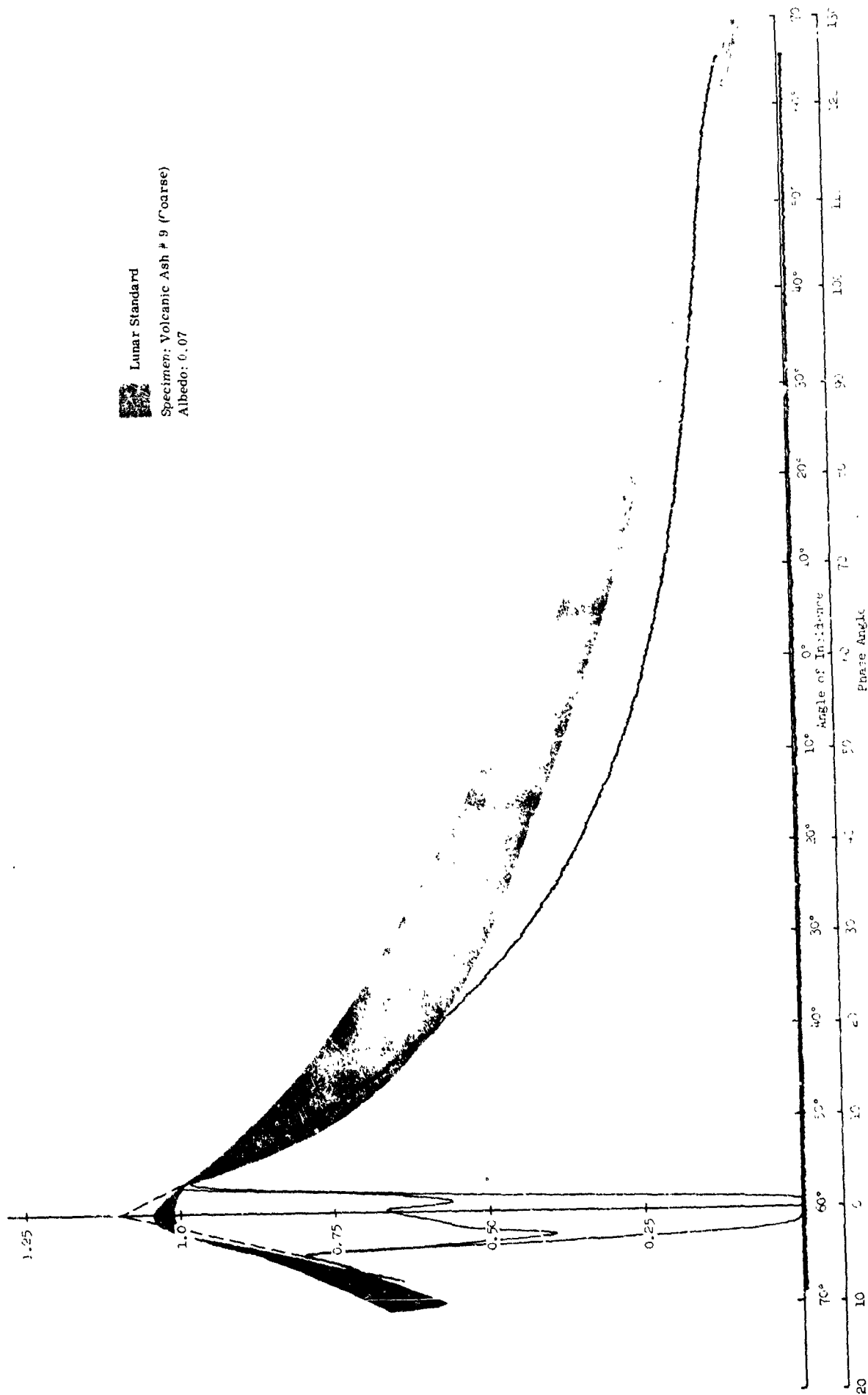


Figure 28d. Volcanic Ash # 9 (Coarse)

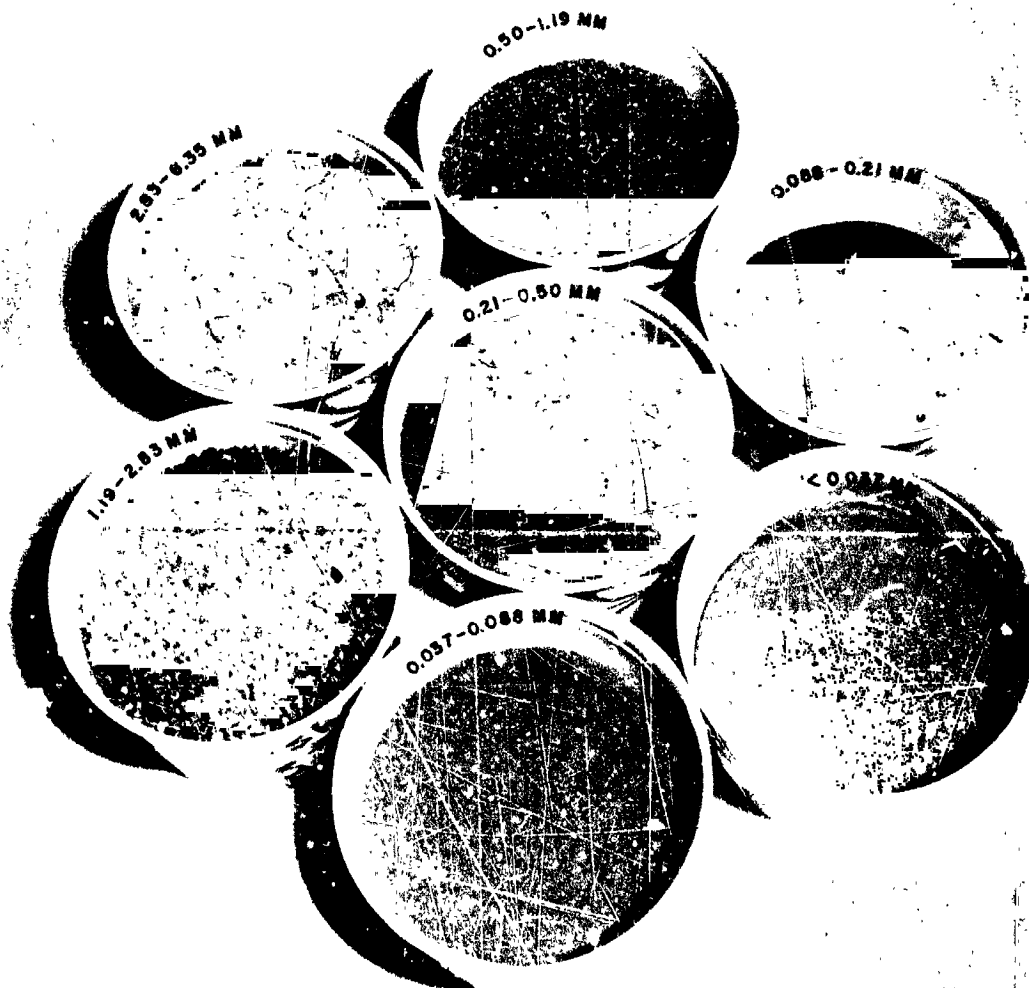


Figure 29. Volcanic Ash # 4, Ground and Sorted

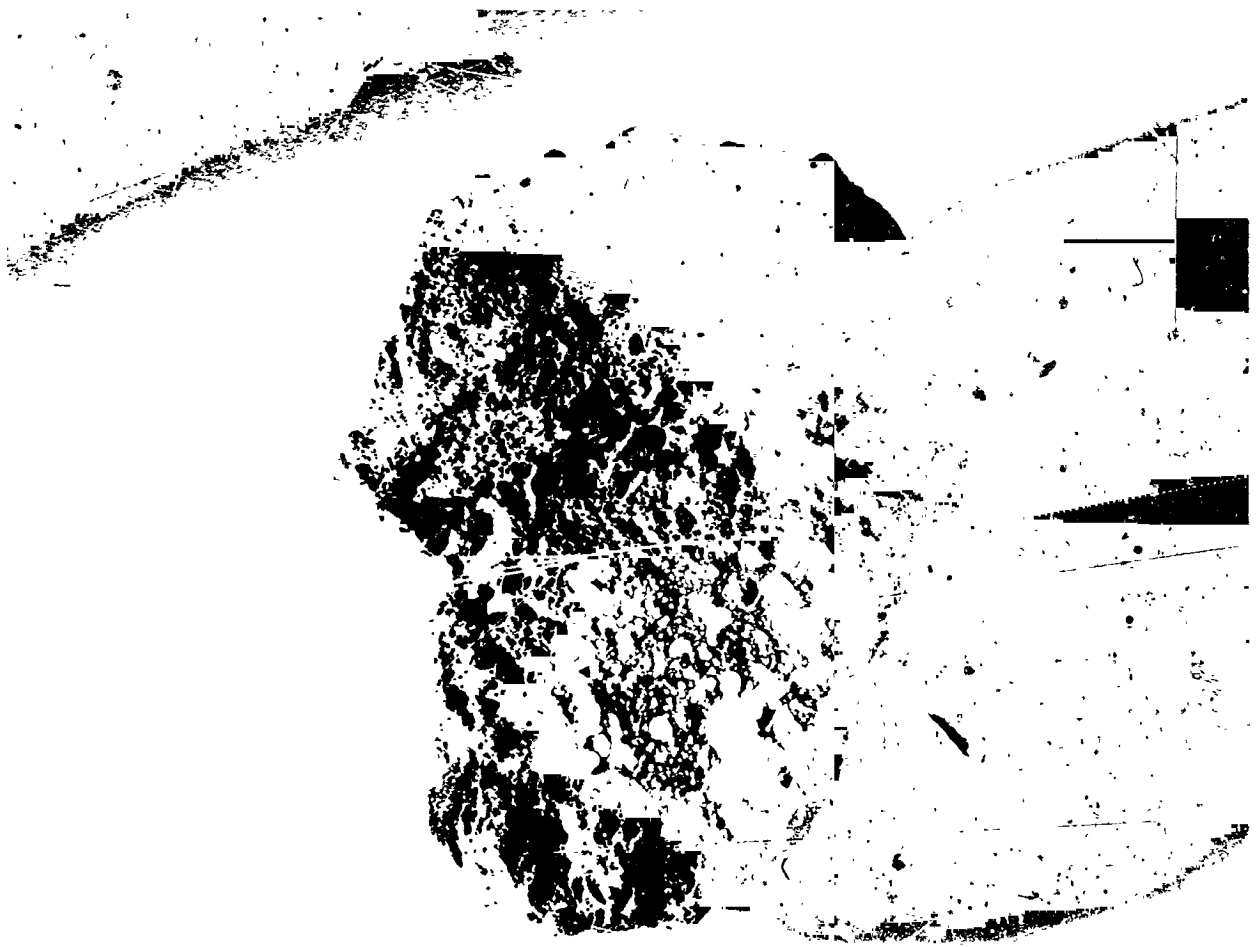


Figure 30a. NASA Slag # 2 (Massive)

Lunar Standard
 Specimen: NASA Slug # 2 (Massive)
 Albedo:

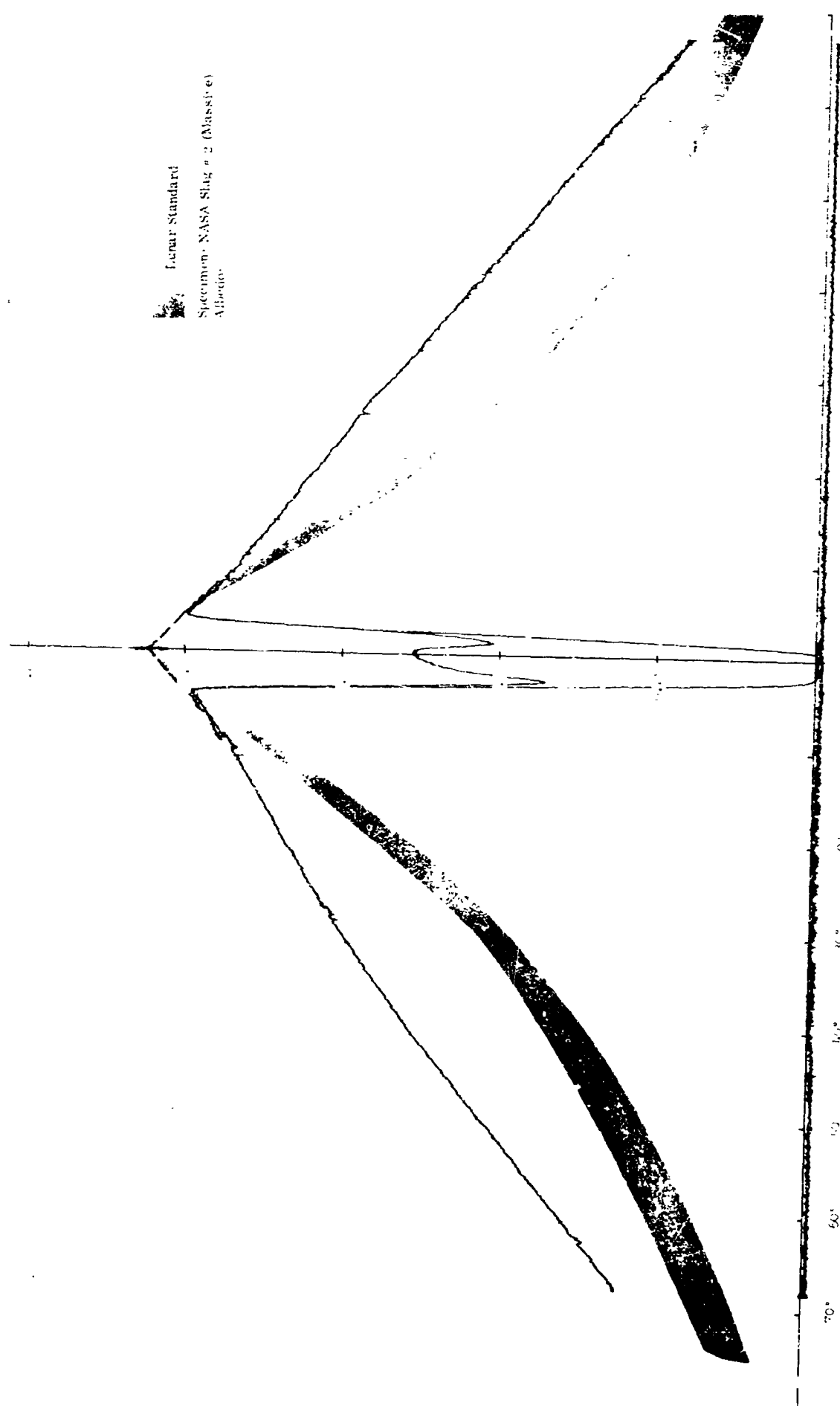
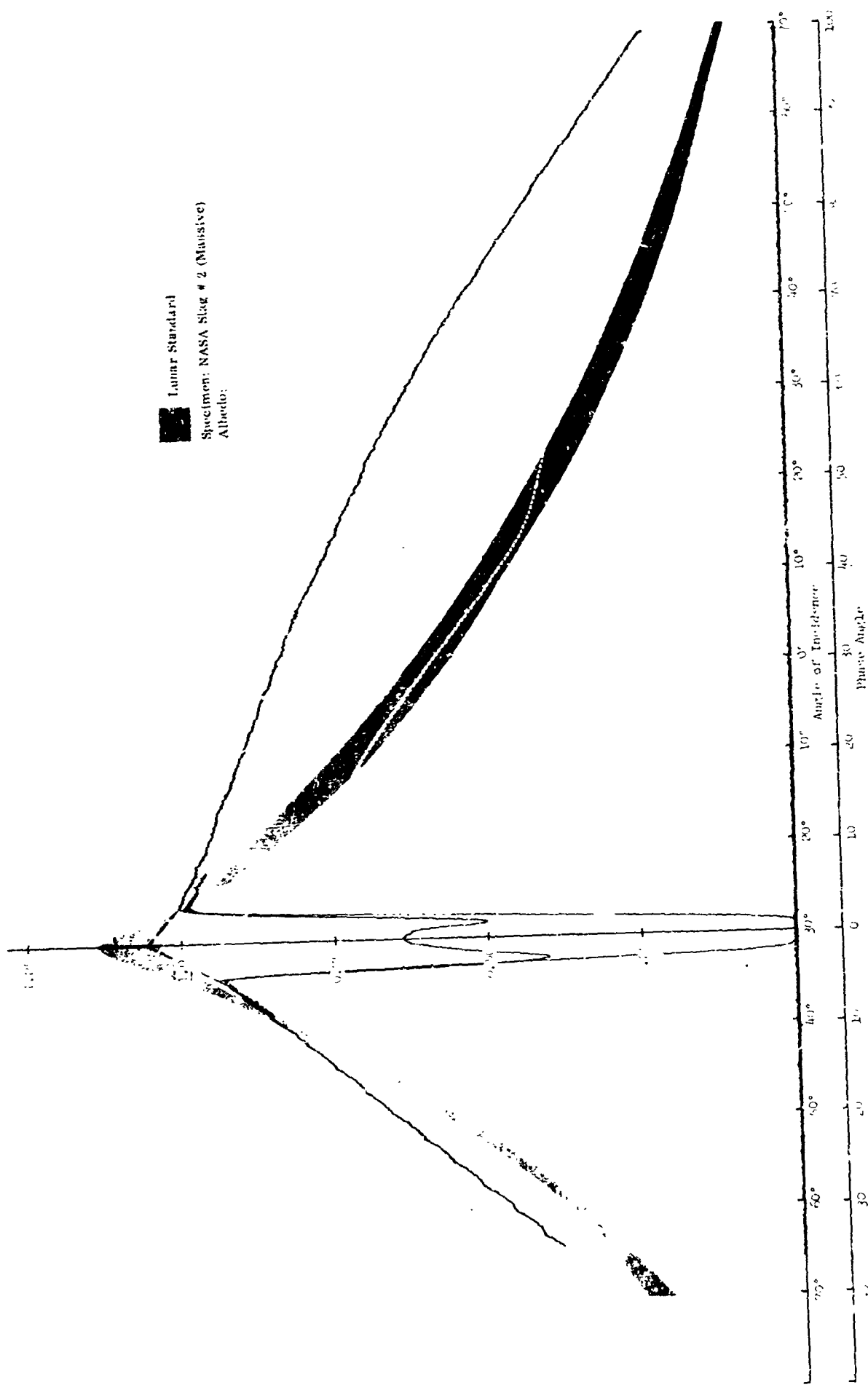


Figure 36b. NASA Slug # 2 (Massive)



Lunar Standard
Specimen: NASA Slag # 2 (Massive)
Albedo:

Figure 30c. NASA Slag # 2 (Massive)

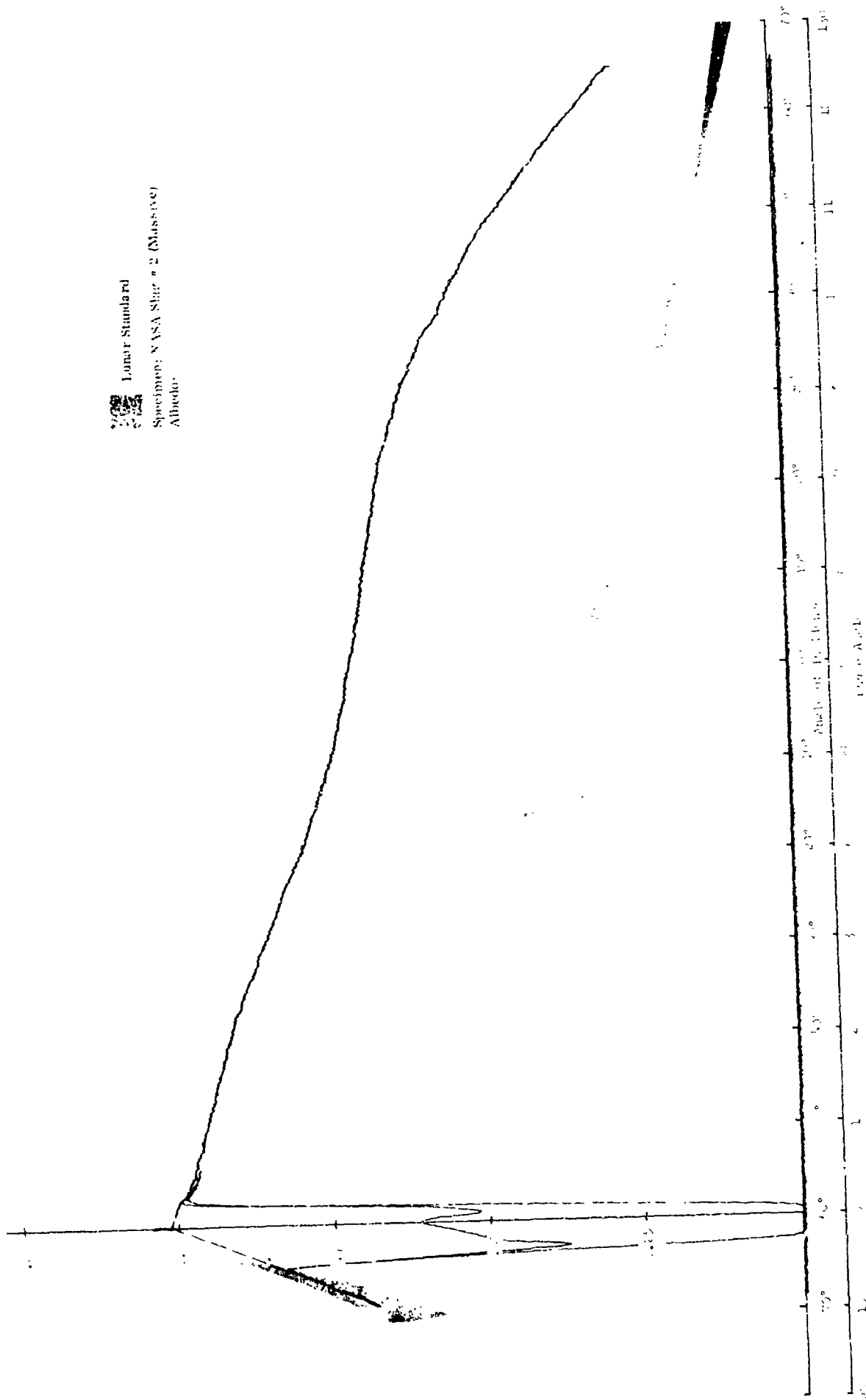


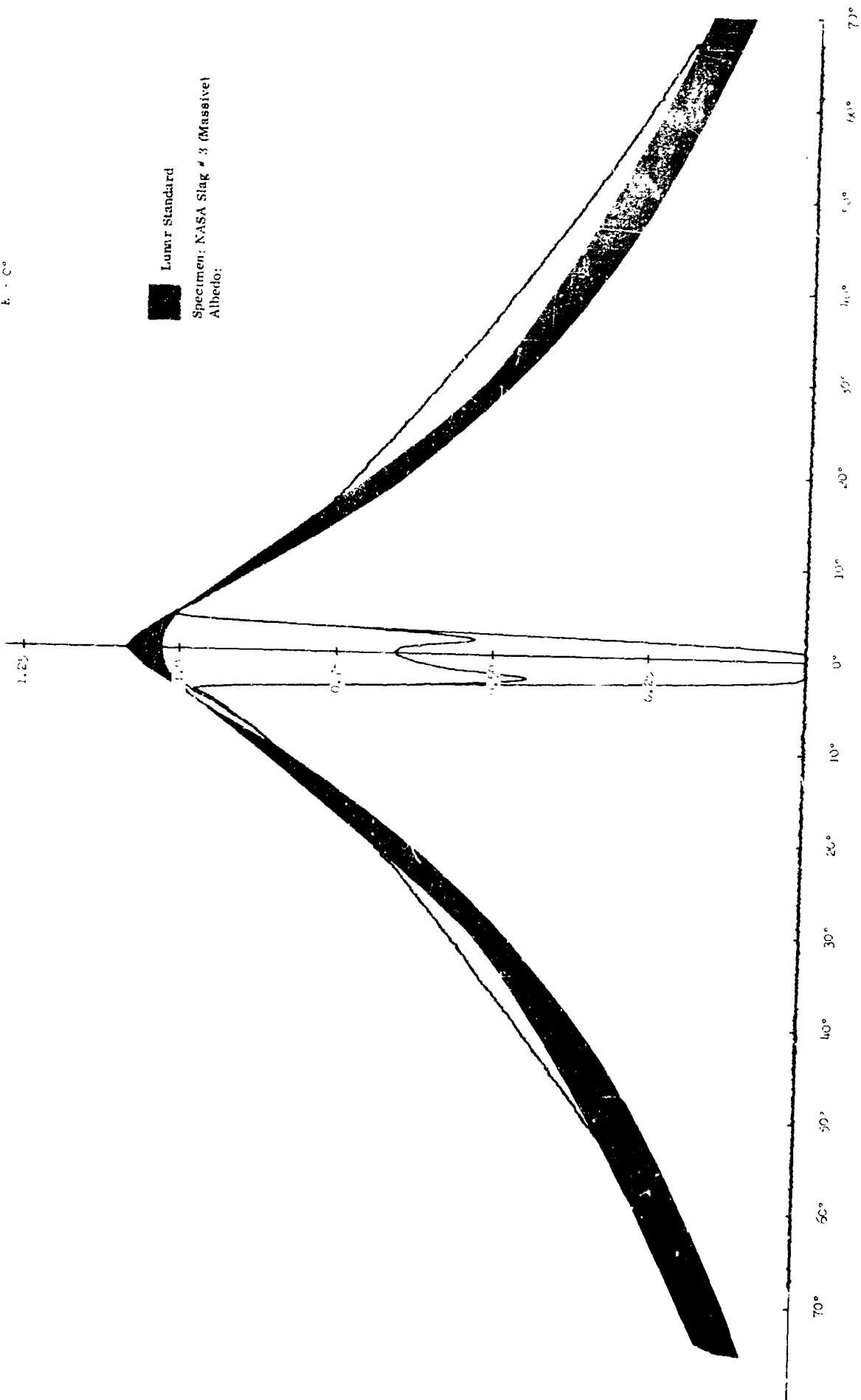
Figure 30d. NASA Slag #2 (Massive)



Figure 31a. NASA Slag # 3 (Massive)

$E = 0^\circ$

Lunar Standard
 Specimen: NASA Slag # 3 (Massive)
 Albedo:



Angle of Incidence and Phase

Figure 31b. NASA Slag # 3 (Massive)

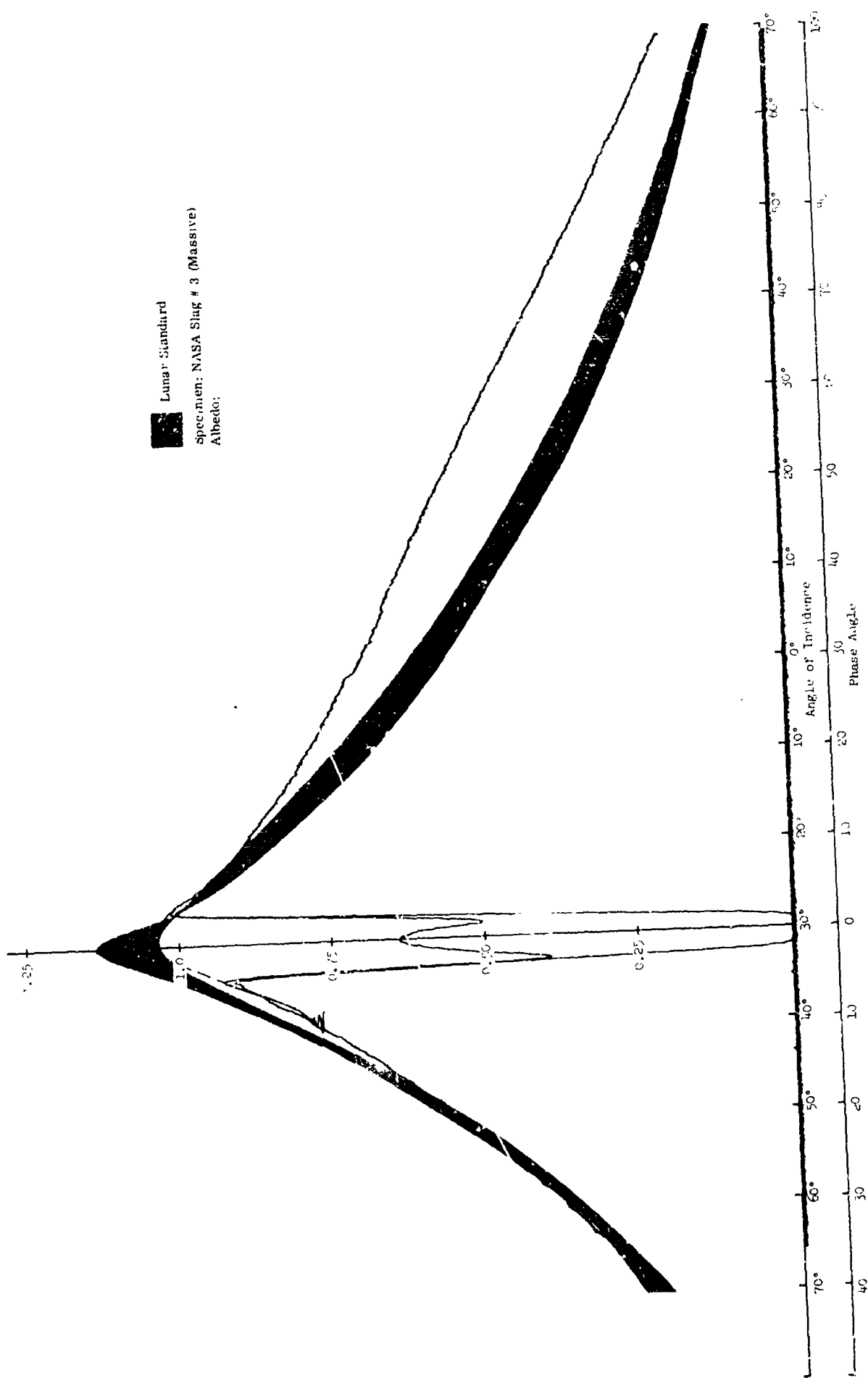


Figure 31c. NASA Slag # 3 (Massive)

60°

Lunar Standard
 Specimen: NASA Slag # 3 (Massive)
 Albedo:

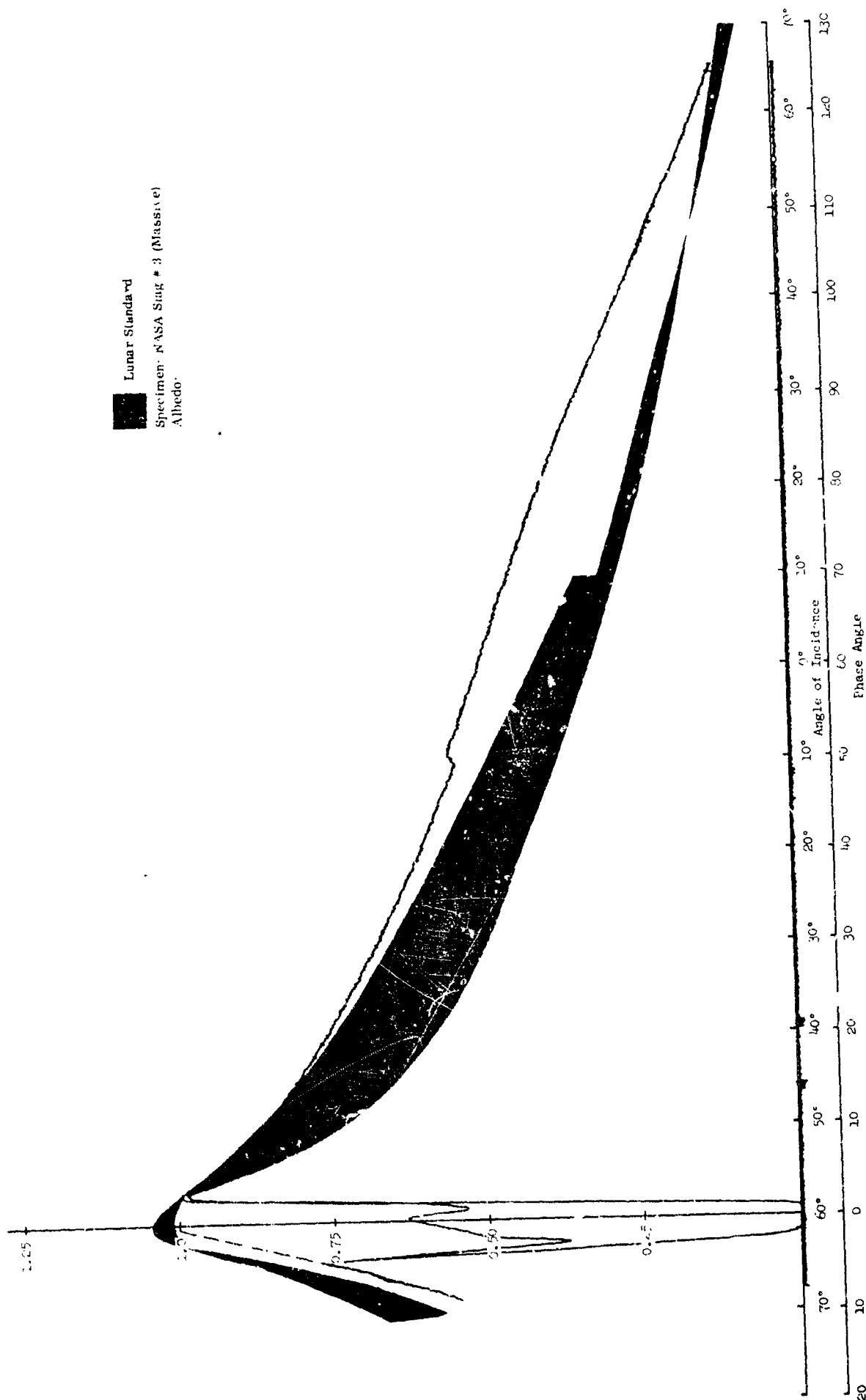


Figure 31d. NASA Slag # 3 (Massive)

APPENDIX A

ANALYTICAL INVESTIGATION OF THE PHOTOMETRY OF CuO-COVERED PRISMS

by

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and

D. Lamberty

PART I

ANALYSIS OF THE PRISMS WHEN SUN MOVES PARALLEL TO PRISM RIDGES

The model and illuminations geometry is shown in Figure A-1. Let:

ϕ_f = photometric function of CuO on flat surface at viewing angle α

ϕ_p = photometric function of sample viewed

V = phase angle

W_n = relative viewed area of surface S_n in Figure A-1

Assume:

collimated incident light

homogeneous surface

viewing from large distance

reflection curve from flat surface of CuO is symmetric

$$\left. \phi_f (\alpha) \right|_V = \left. \phi_f (-\alpha) \right|_V$$

secondary reflection is negligible

From geometry of Figure A-2:

area of S_1 = area of S'_1 or $W_1 = W'_1$

area of S_n = area of S'_n or $W_n = W'_n$

$$\text{and } \left. \phi_f (\alpha) \right|_V = \left. \phi_f (-\alpha) \right|_V \quad \text{or} \quad \left. \phi_f (V) \right|_\alpha = \left. \phi_f (V) \right|_{-\alpha}$$

$$\phi_p (V) = \sum_{n=1}^{N/2} \left. \phi_f (V) \right|_{-\alpha} W_{2n} + \sum_{n=1}^{N/2} \left. \phi_f (V) \right|_\alpha W'_{2n-1}$$

$$\phi_p(V) = \sum_{n=1}^{N/2} \phi_f(V) \left| \alpha \right|_{W'_{2n}} + \sum_{n=1}^{N/2} \phi_f(V) \left| \alpha \right|_{W'_{2n-1}}$$

$$= \sum_{n=1}^N \phi_f(V) \left| \alpha \right|_{W'_n}$$

$$= \phi_f(V) \left| \alpha \right|_{\sum_{n=1}^N W'_n}$$

$$\phi_p(V) = k \phi_f(V) \left| \alpha \right| \quad \text{where } k = \text{constant} = \frac{\sum_{n=1}^N W'_n}{W'_n} = 1$$

PART II

ANALYSIS OF THE PRISMS WHEN SUN MOVES PERPENDICULAR TO PRISM RIDGES

The elongated prisms are covered with copper oxide powder screened through 400 mesh screen. This material is known to have an excellent "backscatter" resembling the lunar signature. Except for possible irregularities in coverage of the geometric forms due to gravitational effects, the essential signature type is unchanged by sprinkling it on the geometric forms. However, the prism surfaces are now of two opposite slopes corresponding to two "viewing angles" for any one orientation of the whole base structure.

As an example, one-prism and three-prism geometries with 45° vertex angles, as illustrated in Fig. A-3b and 3c, are analyzed in Tables A-I and A-II in terms of the photometry of a CuO covered flat plane as shown in Figures A-3a and A-4. In the case of the three-prism geometry, the analysis takes also into consideration a secondary effect of noticeable proportion due to the shadowing of the "trough" areas by the prisms at very oblique incidence (beyond 45°). Light incident from the direction toward the even surface inclination will not strike the odd surfaces until an angle of 45° incidence to base has been reached. Also beyond 45° the even surfaces with the exception of the end one (S_6) are shadowed partly.

The reflection of light from one prism to an adjacent prism face can be neglected since the reflectance is less than 10% and the double reflection could not possibly account for 10% X 10% or 1% of the total.

The geometries defined in Figure 18 restrict the configurations to one with an "edge factor", in which surfaces 1 and 6 are not affected by adjacent structures beyond the base defined.

To analyze the whole structure, a single " 45° viewing angle" photometric curve is taken on copper oxide sprinkled on a flat. This curve, shown in Figure A-4, is

then used to provide the basic photometric values extracted in Table A-II, ϕ_f (photometric function of the flat plate).

Since a circular field of view is involved, a weighting factor for the area of each surface viewed is calculated and tabulated in Table A-II. Shadowing is treated as a per cent figure, shown in the tables as P (%). A product of ϕ_f and the two factors mentioned for each surface can be summed over the entire structure to yield an overall photometric function ϕ_p (photometric function of prisms). Figures 20a and 20c show a comparison of the calculated ϕ_p and a measured ϕ_p for one and three prisms respectively. The analysis for the one-prism geometry is shown in Table A-I.

Table A-I.

ANALYSIS OF ONE-PRISM GEOMETRY FOR SUN MOTION PERPENDICULAR TO RIDGE
Ref. Figures A-3a and 3c

V	S ₁					S ₂						
	I	W	P (%)	ϕ_f	Prod.	I	W	P (%)	ϕ_f	Prod.	ϕ_p	R· ϕ_p
60	105	1	0	0	0	-15	1	1	33.5	33.5	33.5	16
50	95	1	0	0	0	-5	1	1	38.0	38.0	38.0	18
40	85	1	1	7.5	7.5	5	1	1	43.0	43.0	50.5	24
30	75	1	1	22.0	22.0	15	1	1	50.0	50.0	72.0	35
20	65	1	1	38.0	38.0	25	1	1	57.5	57.5	95.5	46
10	55	1	1	56.5	56.5	35	1	1	67.0	67.0	123.5	59
0	45	1	1			45	1	1				

$$\begin{aligned}
 R &= \frac{\phi_p \text{ of sample curve at } V = 10^\circ}{\phi_p \text{ of calculated curve at } V = 10^\circ} \\
 &= \frac{59}{123.5} \\
 &= 0.48
 \end{aligned}$$

NOTE: Data taken from Figure A-4 and plotted on Graph in Figure 20a

Table A-II

ANALYSIS OF THREE-PRISM GEOMETRY FOR SUN MOTION PERPENDICULAR TO RIDGES

Ref. Figures A-3a and 3c

S_1						$S_2 + S_4$				
V	I	W	P (%)	ϕ_f	Prod.	I	W	P (%)	ϕ_f	Prod.
60	105	.53	0	0	0	-15	1.88	73	33.5	46
50	95	.53	0	0	0	-5	1.88	92	38.0	66
40	85	.53	100	7.5	4	5	1.88	100	43.0	81
30	75	.53	100	22.0	12	15	1.88	100	50.0	94
20	65	.53	100	38.0	20	25	1.88	100	57.5	108
10	55	.53	100	56.5	30	35	1.88	100	67.0	126

	$S_3 + S_5$					S_6						
V	I	W	P (%)	ϕ_f	Prod.	I	W	P (%)	ϕ_f	Prod.	ϕ_p	R · ϕ_p
60	105	1.88	0	0	0	-15	.53	100	33.5	18	64	12.5
50	95	1.88	0	0	0	-5	.53	100	38.0	20	86	17.0
40	85	1.88	100	7.5	14	5	.53	100	43.0	23	122	24.0
30	75	1.88	100	22.0	41	15	.53	100	50.0	26	173	34.5
20	65	1.88	100	38.0	71	25	.53	100	57.5	30	229	45.5
10	55	1.88	100	56.5	106	35	.53	100	67.0	35	297	59.0

$$\begin{aligned}
 R &= \frac{\phi_p \text{ of sample curve at } V = 10^\circ}{\phi_p \text{ of calculated curve at } V = 10^\circ} \\
 &= \frac{5}{297} \\
 &= .0199
 \end{aligned}$$

NOTE: Data taken from Graph in Figure A-4 and plotted on Graph in Figures 20c.

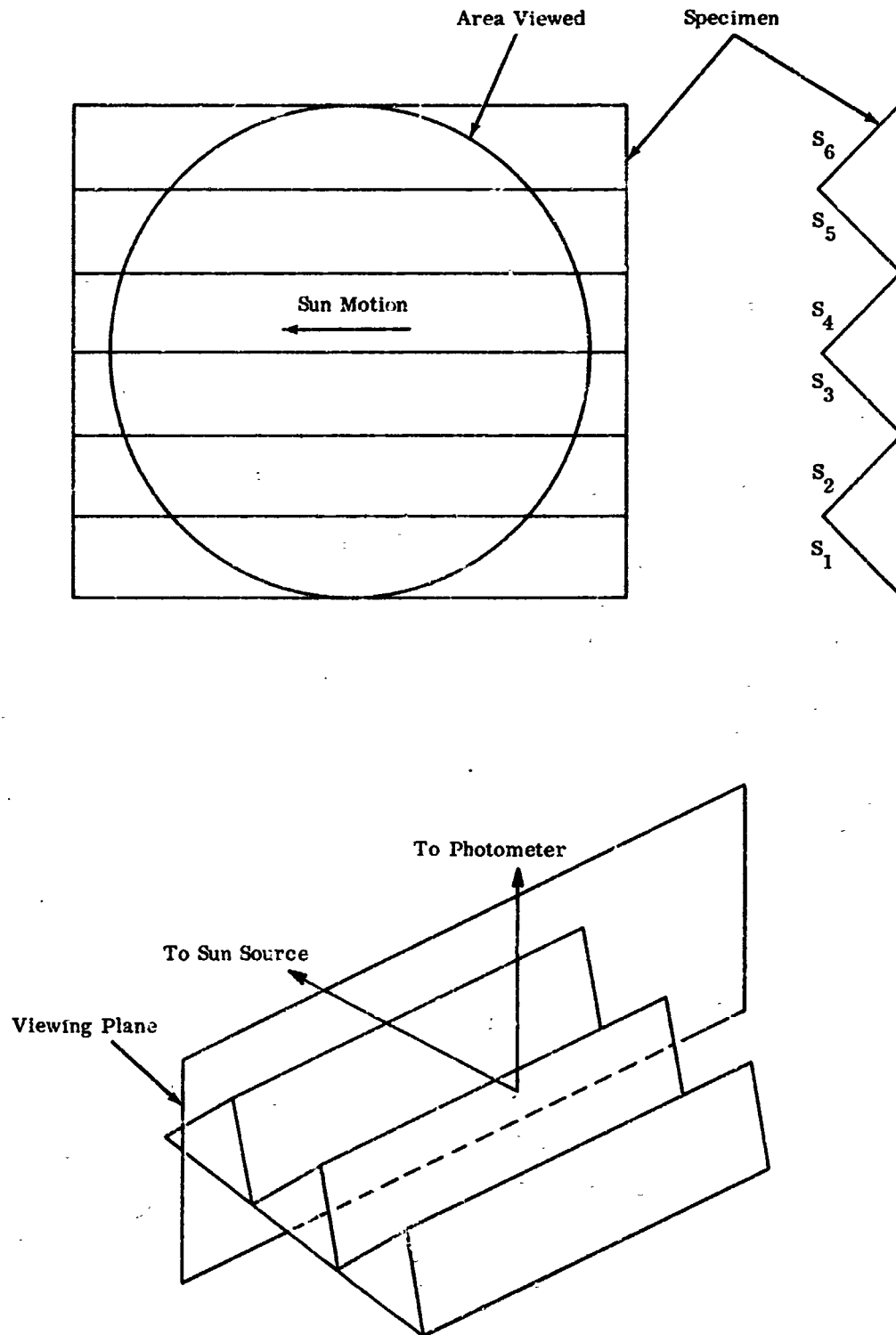


Figure A-1. Three - Prism and Illumination Geometry for Sun Motion Parallel to Prism Ridges (Ref. Figures 19 and 21)

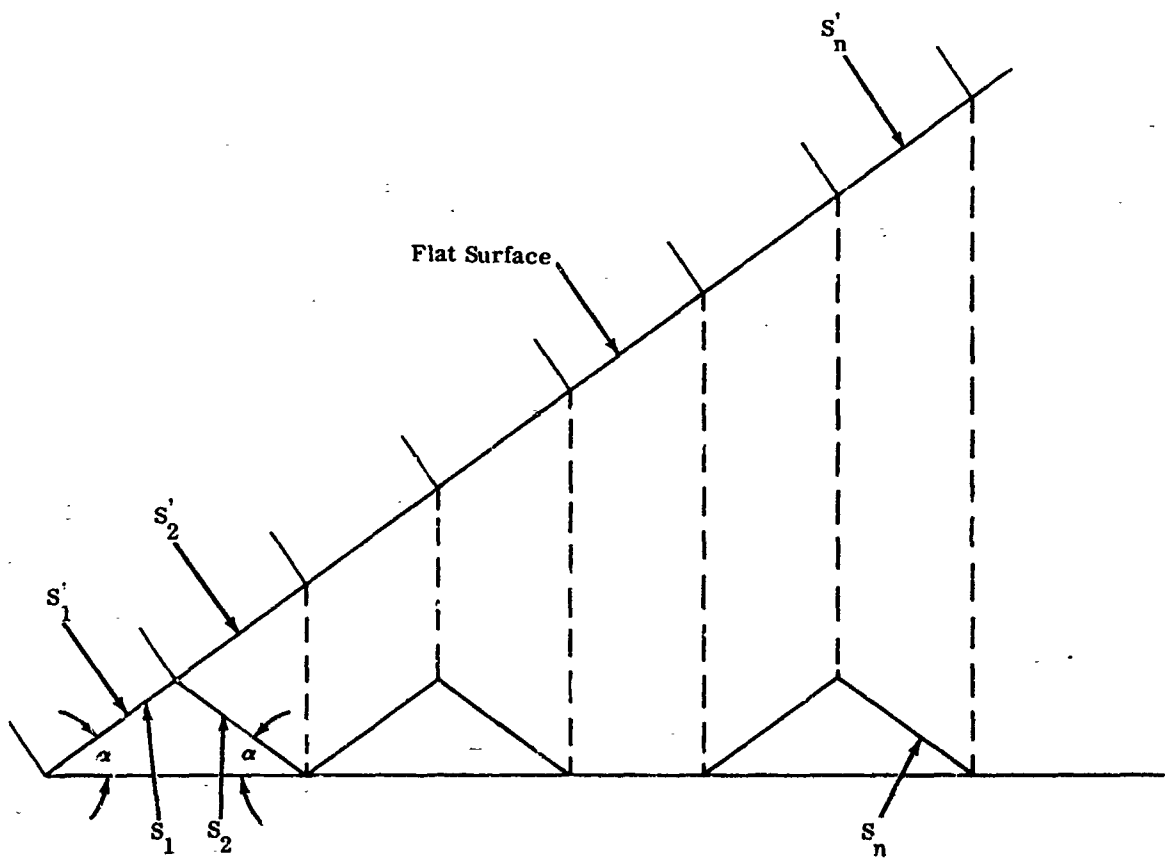
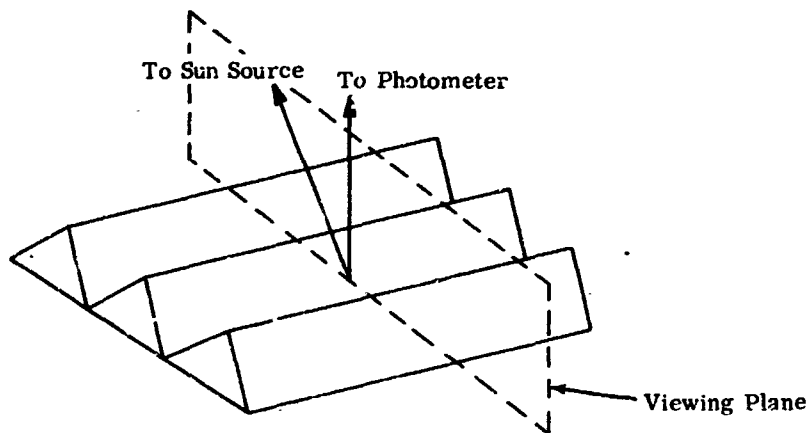
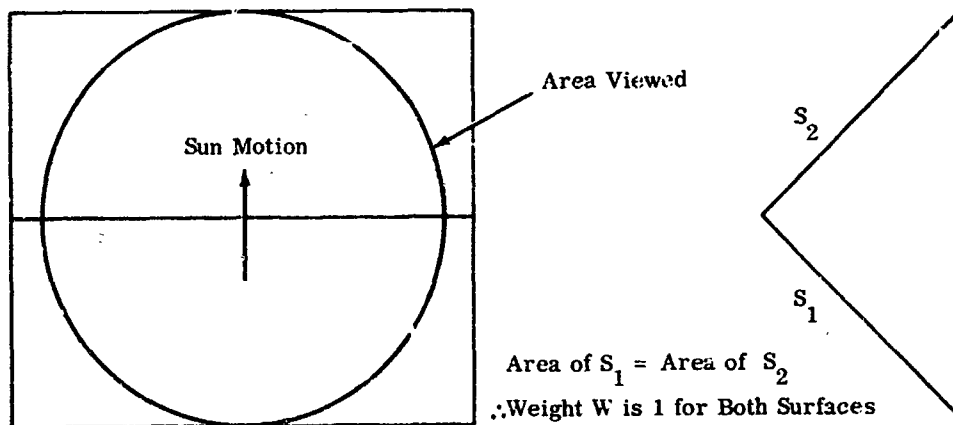


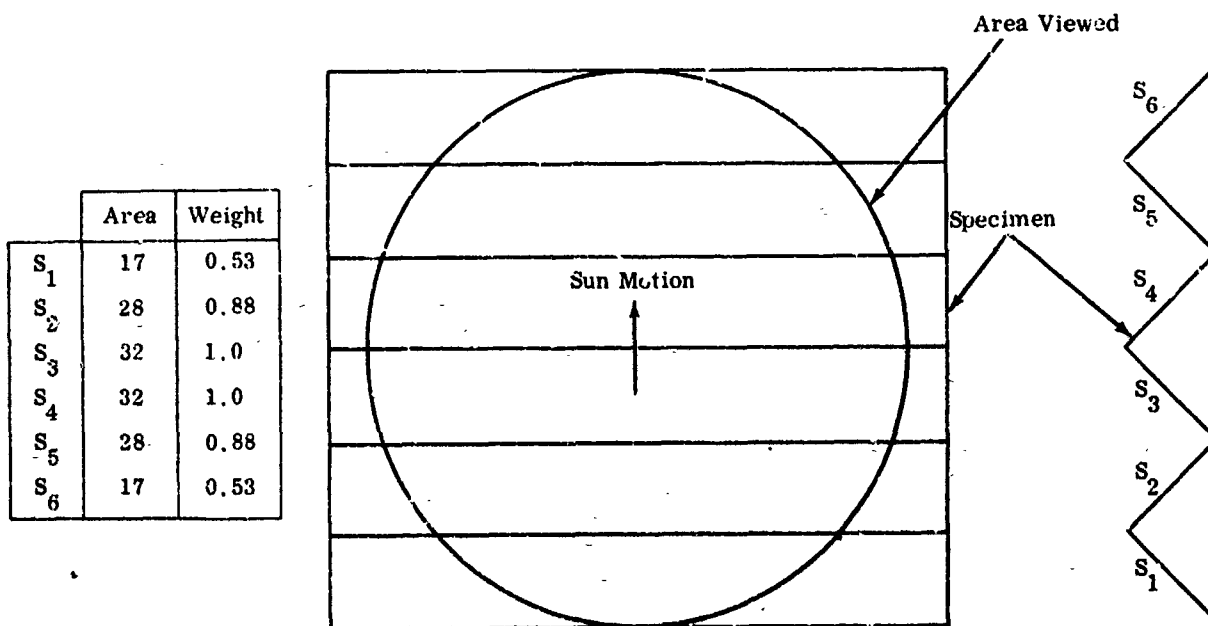
Figure A-2. Prisms and Equivalent Flat Surface



(a) Transverse Illumination (Ref. Figures 20a to 20e and 22)

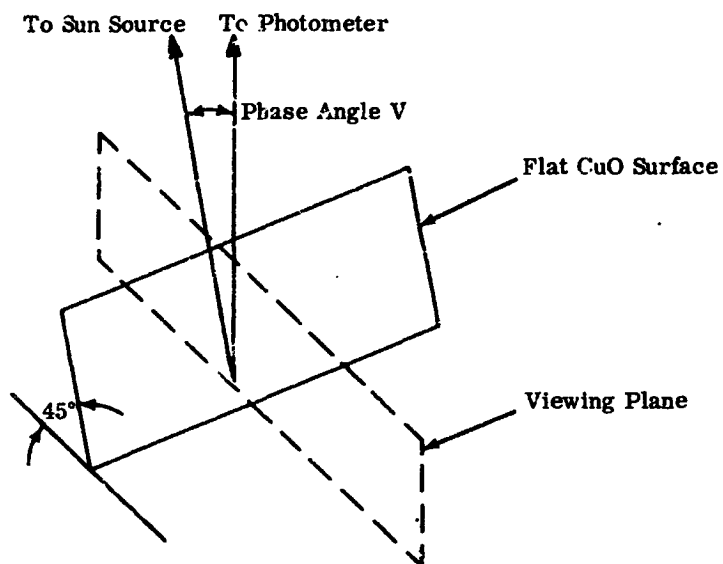


(b) One - Prism Geometry (Ref. Figure 20a and Table A-1)



(c) Three - Prism Geometry

Figure A-3. Prism and Illumination Geometry for Sun Motion Perpendicular to the Ridges



I	ϕ_f
85	7.5
75	22
65	38
55	56.5
45	
35	67
25	57.5
15	50
5	43
-5	38
-15	33.5

Orientation of Sample

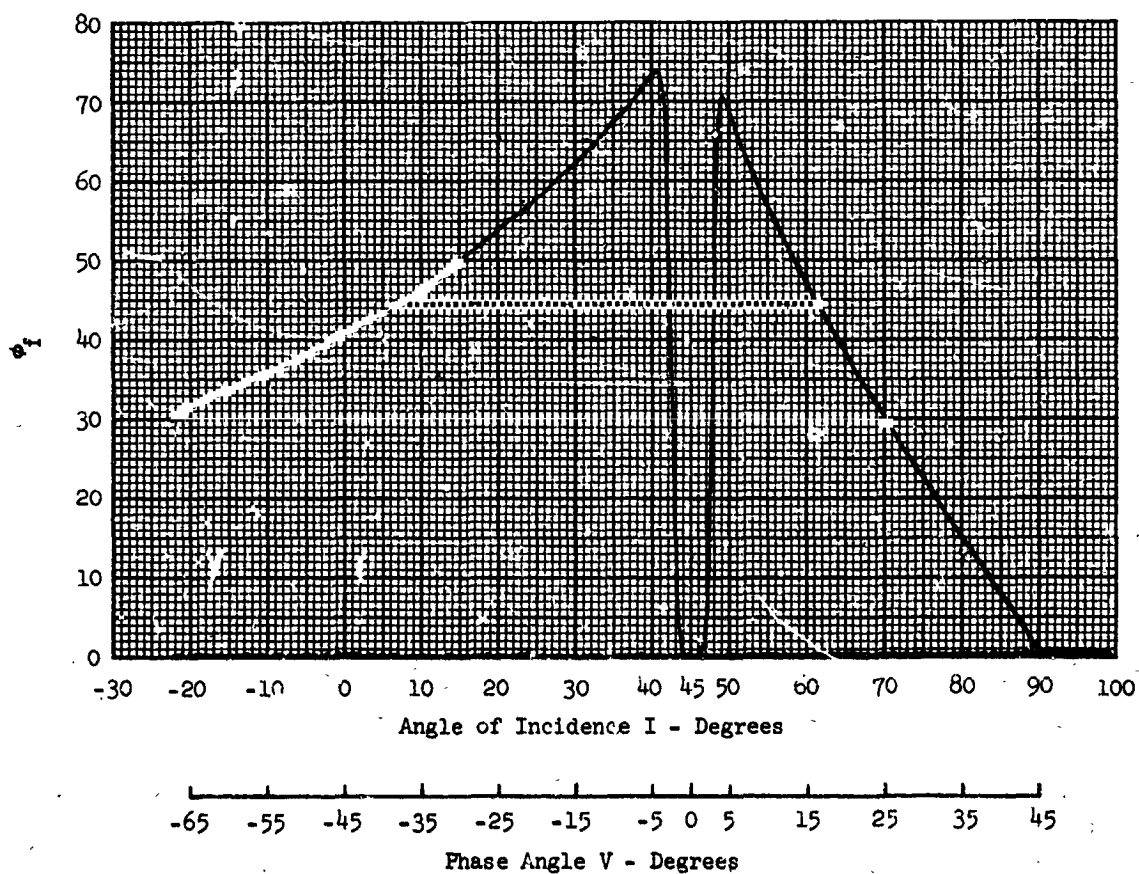


Figure A-4. CuO on Flat Inclined Plate Under Transverse Illumination (as shown)