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A Comparison of Soils From Twentynine Palms, California and Saudi Arabia

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13. ABSTRACT *(Maximum 200 words)*

Soil samples collected at Twentynine Palms, California, and in eastern Saudi Arabia were analyzed for particle size distribution, moisture content, spectral reflectance characteristics and soil color. The results of the comparison show that, overall, the Twentynine Palms samples are finer grained than the eastern Saudi Arabian samples. Soil moisture in both sets of samples is low. The samples from eastern Saudi Arabia contain quantities of calcite and gypsum not found in the Twentynine Palms samples. The spectral reflectance of the soils from eastern Saudi Arabia is overall higher than that for the Twentynine Palms soils, and shows variations in infrared reflectance due to chemical differences that are not seen in the Twentynine Palms soils.

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PREFACE

This report was prepared under DA Project 4A161102B52C, Task OC, Work Unit A11, "Desert Shield" in January 1991, under the supervision of Dr. J.N. Rinker, Chief, Remote Sensing Division; and of Mr. John Hansen, Director, Research Institute.

Colonel David F. Maune, EN, was Commander and Director, and Mr. Walter E. Boge was Technical Director of the US Army Engineer Topographic Laboratories during preparation of the report.

A COMPARISON OF SOILS FROM

TWENTYNINE PALMS, CALIFORNIA, AND SAUDI ARABIA

INTRODUCTION

The purpose of this report is to present data on soil samples collected at Twentynine Palms Marine Corps Base, located in the Mohave Desert in southern California, and from eastern Saudi Arabia. Soil samples were collected on Twentynine Palms in association with Project Ostrich, a mine detection feasibility study using radar. Project Ostrich was initiated and carried out in a very short time in response to events in the Middle East (Operation Desert Shield). A desert area in the United States was needed to serve as an analog for the deserts of the Middle East with respect to the penetration capabilities of various radar systems. Although Twentynine Palms is similar to deserts in the Middle East in that it is arid, with sparse vegetation and deep, dry, granular soils subject to aeolian processes, it is not an analog. It was selected as the location for the test site for two reasons: (1) preliminary analysis of soil samples indicated that, although soil moisture, which is a major factor with respect to radar penetrability, was much higher than that reported for Middle East soils, it was probably within the range in which adequate penetration could occur and (2) the support and equipment needed to carry out the experiment was readily available.

The data we have obtained, although sparse with respect to Saudi Arabian soils, appears to be in great demand; many requests for this data have been received. This report, which addresses soil moisture, soil particle size, visible and near infrared spectral reflectance, and soil color, results from this need and allows the data to be disseminated in a timely manner and in a format that is both easy to provide and usable. We realize that very little data is presented on Saudi Arabian soils, and that what data we have is far from representative of the soils in Saudi Arabia. It is all we have been able to obtain up to this time. We intend to obtain more soil samples and to address soil characteristics in addition to those discussed here including composition, spectral luminescence, and thermal infrared spectral reflectance measurements. These data will be published at a later date.

We have little quantitative data on soil characteristics either in Saudi Arabia or at Twentynine Palms. Berlin et al. (1986) state that the Al Labbah sand in northern Saudi Arabia (29° 35'N, 41° 50'E) consists mainly of rounded to subrounded quartz grains and is virtually devoid of clays. In addition, hydrated minerals, particularly gypsum, are common in Saudi Arabian soils (J.N. Rinker, 1990, personal communication). Igneous rocks occur adjacent to and within the Twentynine Palms area which suggests the sands should be quartz-rich; because they are windblown, clay content should be quite low as well. Gypsum is known to occur in playa environments in the Mohave Desert adjacent to Twentynine Palms (Henley 1990), so it is likely that gypsum also occurs in the test site soils.

PROCEDURES

Two separate experiments were carried out at adjacent sites at Twentynine Palms near Gypsum Ridge (Figure 1). The first (Phase I) occurred 9 through 14 October 1990, and the second (Phase II), from 13 through 16 November 1990. A third visit was made to the sites December 6, 1990. Soil samples from Twentynine Palms were collected by Dr. Ehlen in Phases I and II and by Mr. John Hansen during the December visit.

During Phase I, 32 soil samples were collected at 12 locations within the 100 X 250-meter study site (Figure 2). Surface (0-4 cm), trench bottom, and backfill samples were taken at 10 locations within 12 triangular-shaped, 150-meter-long trenches that had been dug by machinery. Surface samples only were collected at the remaining two locations. Eight of the 12 trenches were 8 inches deep, two were 12 inches deep, and two were 16 inches deep. The second site (Phase II), identical to the first in size and layout, was located south and slightly west of the first site; the two did not abut each other. Surface, trench bottom, and backfill soil samples were collected from the same locations during Phase II as was done in Phase I; one additional trench bottom sample was collected during Phase II (13, Figure 2). Surface samples were collected just before the trenches were dug and trench bottom samples were taken soon after the trenches were dug. Backfill samples were collected one to two days after the trenches were filled during Phase I, and immediately after the trenches were filled during Phase II. The soil samples were placed in cans, sealed, and weighed immediately using a triple beam baiance. In the laboratory at USAETL, the samples were oven dried at 103 degrees Celsius and the dry weight was determined. Percent soil moisture was then calculated on an oven-dry weight basis.

Sieve analysis was conducted in the laboratory on the oven-dried samples. The sieve sizes were: 2 mm (No. 10), 1 mm (No. 18), 0.5 mm (No.35), 0.25 mm (No. 60), 0.125 mm (No. 120) and 0.075 mm (No. 200).

Spectral reflectance was measured in the laboratory using a Geophysical Environmental Research IRIS MkIV field spectroradiometer. The spectral range covered was 400 nm to 2500 nm with a spectral resolution of 1.5 nm to 4.5 nm. The sample reflectance is presented as a percent reflectance compared to a Halon reflectance standard. The illumination was by a 500-watt tungsten-halogen photo lamp.

Soil color was determined by comparing each oven-dried sample to a Munsell soil color chart. The sample and the chart were illuminated by a color-balanced fluorescent lamp with a color temperature of 5000 degrees Kelvin, which approximates daylight in the visible region.

Figure 3 shows the general locations that were provided with the soil samples collected in eastern Saudi Arabia. These samples were collected by various individuals in various locations at various unknown times. Table 1 gives the latitudes and longitudes for each sample for which we have that data. All samples are surface samples, and their locations suggest that most come from sand sheets.

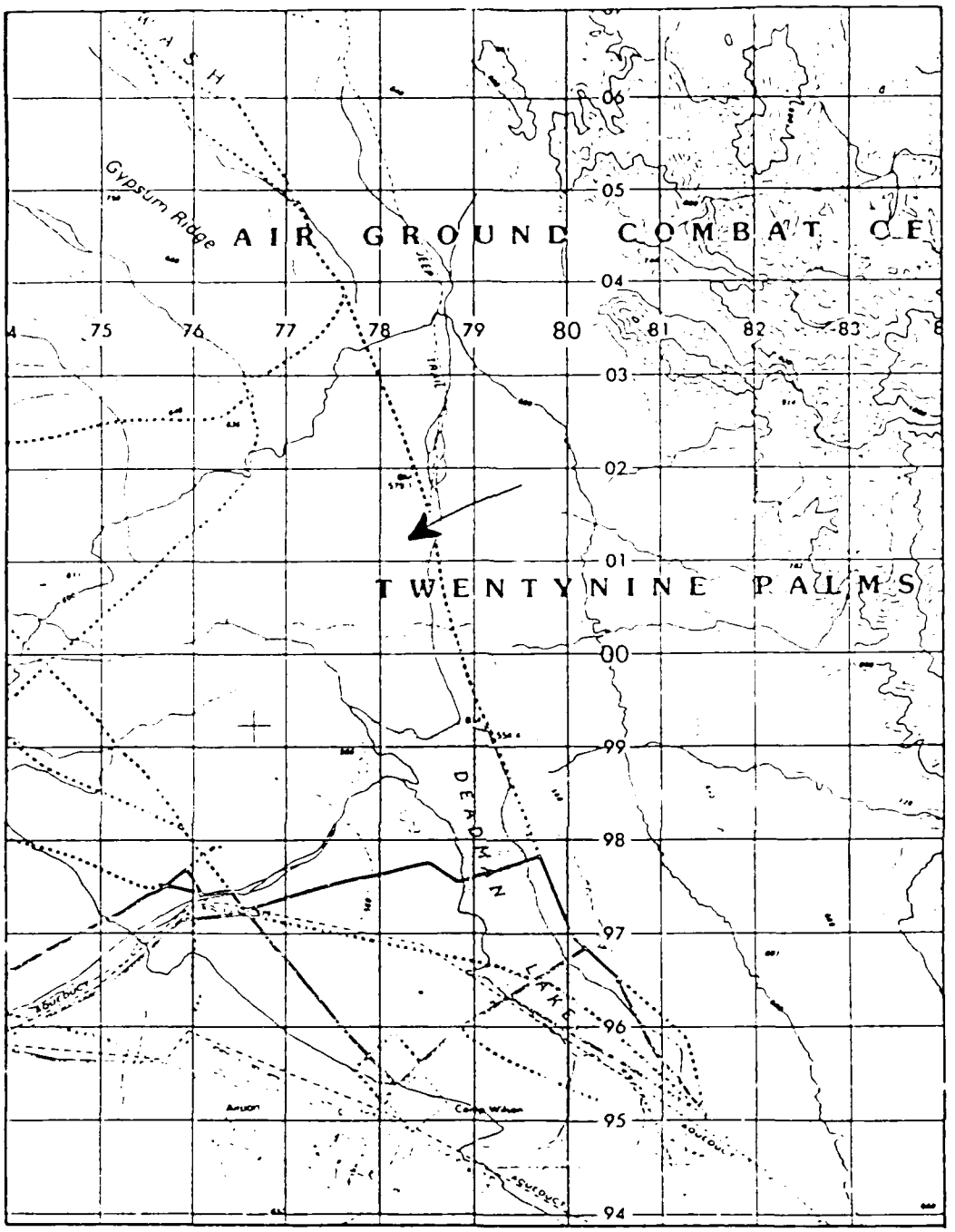

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Figure 1. Map of the Twentynine Palms Test Sites.

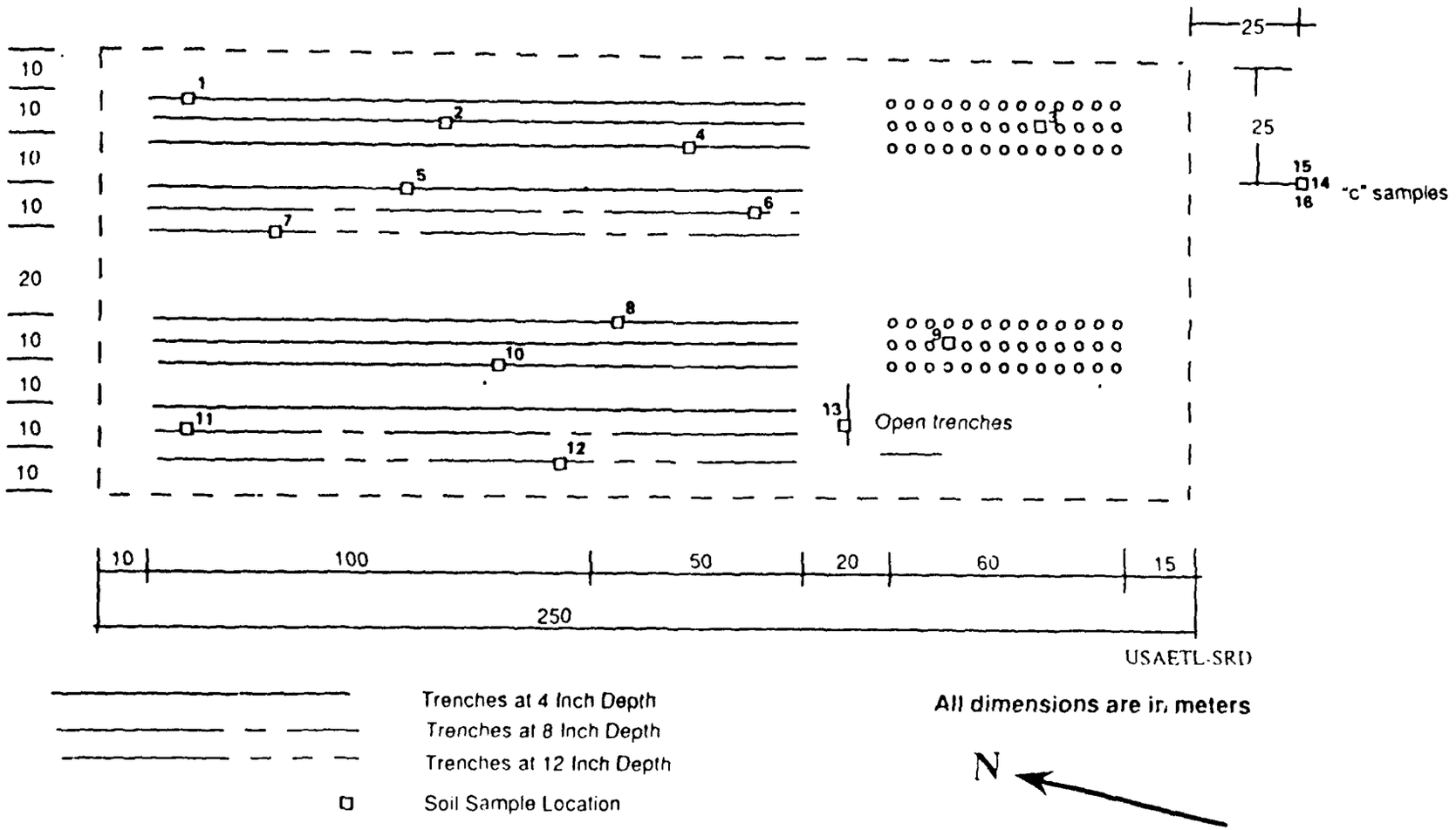


Figure 2. Sampling Locations, Twentynine Palms Test Sites.

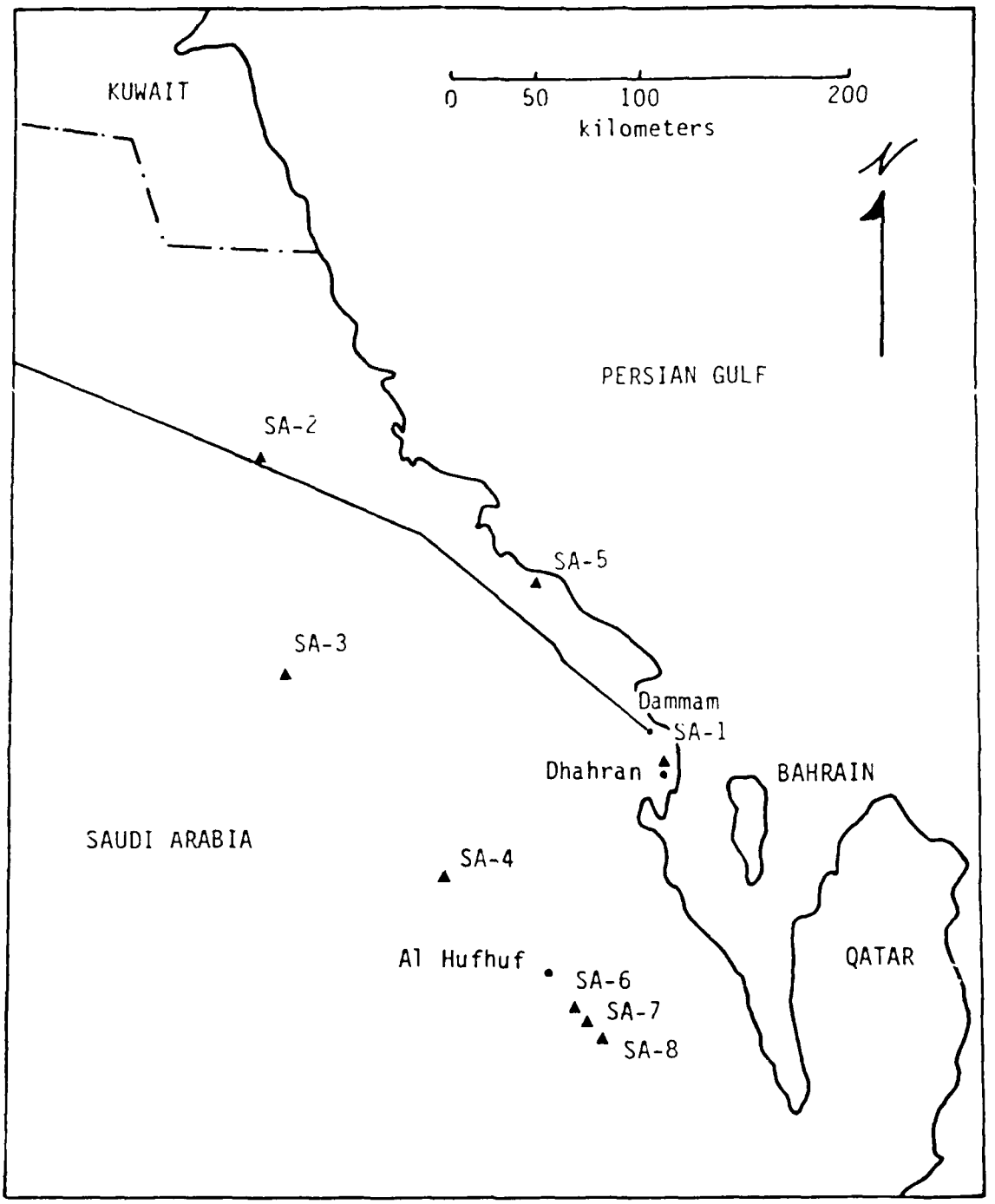


Figure 3. Map of the Saudi Arabian Soil Samples.

Table 1. Locations of Saudi Arabian Soil Samples

Sample Number	Latitude	Longitude
SA-1	26° 14.4'N	50° 9.7'E
SA-2	27° 29'N	48° 27'E
SA-3	26° 52'N	48° 22'E
SA-4	26° 16'N	48° 50'E
SA-5	~140 km south of Kuwait, 500 m inland from the Gulf Coast	
SA-6	25° 17'00"N	49° 38'45"E
SA-7	25° 13'00"N	49° 41'15"E
SA-8	25° 12'30"N	49° 42'30"E

SOILS FROM TWENTYNINE PALMS, CALIFORNIA

Particle Size

Phase I. These soil samples (Tables 2, 3, and 4) consist mainly of fine and very fine sand (usually 40-50%). Gravel in the surface samples ranges from 5.4-26.1% (mean 12.2%); in trench

Table 2. Sieve Analyses: Surface Samples, Phase I (Percent total)

Sample Number	gravel, >2mm	very coarse sand, 1-2mm	coarse sand, 0.5-1mm	medium sand, 0.25-0.5mm	fine sand, 0.125-0.25mm	very fine sand, 0.075-0.125mm	silt+clay <0.075 mm
326a	5.4	7.4	14.1	15.7	30.2	21.8	5.3
327a	16.0	10.5	13.4	13.9	27.8	14.9	3.5
328a	18.7	5.9	8.3	13.4	28.7	18.5	6.5
329a	11.1	8.2	13.2	14.8	31.2	16.8	4.7
330a	26.1	6.2	10.9	14.9	26.5	11.6	3.7
332a	7.5	7.6	13.1	14.1	32.4	19.7	5.6
334a	15.0	9.7	15.5	14.6	24.0	16.5	4.7
336a	9.1	9.0	10.8	11.5	28.3	23.5	7.9
338a	14.6	7.7	13.2	13.7	25.0	18.6	7.1
340a	9.3	8.1	11.5	19.9	33.5	12.8	4.9
341a	7.1	8.8	14.2	15.6	25.9	21.1	7.2
343a	6.6	14.3	23.8	20.8	21.3	10.6	2.6
normalized mean:	12.2	8.6	13.5	15.2	27.9	17.2	5.3

Table 3. Sieve Analyses: Bottom Samples, Phase I (Percent total)

Sample Number	gravel, >2mm	very coarse sand, 1-2mm	coarse sand, 0.5-1mm	medium sand, 0.25-0.5mm	fine sand, 0.125-0.25mm	very fine sand, 0.075-0.125mm	silt+clay <0.075 mm
322a	14.9	10.2	18.6	17.5	21.6	13.6	3.7
323a	9.6	6.5	13.8	20.5	32.7	13.3	3.5
324a	6.2	7.7	15.2	16.8	28.1	19.4	6.6
325a	6.7	5.8	13.9	16.8	35.3	17.5	4.0
331a	16.2	4.1	8.7	20.3	30.6	15.6	4.5
333a	9.4	8.6	16.2	16.5	26.2	17.7	5.4
335a	9.6	7.8	13.3	15.7	29.9	17.4	6.3
337a	16.0	8.1	12.8	14.0	25.3	18.9	4.9
339a	7.4	6.8	12.5	14.6	33.0	20.6	5.0
342a	10.6	10.0	17.0	16.8	27.4	14.7	3.5
normalized mean:	10.7	7.6	14.2	17.0	29.0	16.9	4.7

Table 4. Sieve Analyses: Backfill Samples, Phase I (Percent total)

Sample Number	gravel, >2mm	very coarse sand, 1-2mm	coarse sand, 0.5-1mm	medium sand, 0.25-0.5mm	fine sand, 0.125-0.25mm	very fine sand, 0.075-0.125mm	silt+clay <0.075 mm
312a	14.3	8.1	12.5	15.3	29.3	17.8	2.6
313a	6.1	7.4	13.5	17.2	33.6	18.0	4.3
314a	7.5	6.3	11.7	16.7	33.5	19.3	5.0
315a	15.2	7.0	11.6	14.6	29.7	17.1	5.0
316a	13.6	5.2	13.0	17.1	26.8	18.9	5.3
317a	17.0	7.2	15.7	18.4	27.9	11.7	2.0
318a	6.5	10.4	15.6	16.3	30.2	15.5	5.4
319a	12.3	6.8	12.1	13.3	26.8	21.6	7.2
320a	7.5	7.7	12.4	13.7	33.5	19.1	6.1
321a	13.2	12.4	18.0	13.6	21.8	16.1	5.0
normalized mean:	11.3	7.9	13.6	15.6	29.3	17.5	4.8

bottom samples, from 6.2-16.2% (mean 10.7%); and in backfill samples, 6.1-17.0% (mean 11.3%). The silt+clay (pan) separate is usually less than 7%. Surface samples contain 2.5-7.9% silt+clay (mean 5.3%); trench bottom samples, 3.5-6.6% (mean 4.7%); and backfill samples, 2.6-7.2% (mean 4.8%). Surface samples tend to contain more gravel than either trench bottom or backfill samples, and the silt+clay separate is larger as well. All samples contain more fine sand and very fine sand than any other particle size. The backfill samples, however, contain more fine sand than either

surface or trench bottom samples. Backfill samples contain a mean of 46.8% fine sand and very fine sand; surface samples, a mean of 45.1%; and trench bottom samples, a mean of 45.9%. The normalized means for each sieve separate for each type of sample, i.e. surface, trench bottom, backfill, are shown in Figures 4, 5, and 6, respectively.

Phase II. The soil samples from Phase II ("b", Tables 5, 6, and 7) consist mainly of fine and very fine sand (usually >50%). Silt+clay ranges from 4.1-18.1% for surface samples (mean 9.3%), 3.0-8.7% for trench bottom samples (mean 5.8%), and 3.2-14.1% for backfill samples (mean 7.2%). Gravel ranges from 5.2-34.8% for surface samples (mean 13.4%), 4.9-25.6% for trench bottom samples (mean 12.1%), and 8.2-35.1% for backfill samples (mean 15.9%). The gravel separates in the surface samples are smaller than in either trench bottom or backfill samples, whereas the silt+clay separate is larger. Although all samples contain more fine sand and very fine sand than other particle size ranges, trench bottom samples contain more than either surface or backfill samples. Surface samples contain a mean of 41.3% fine sand and very fine sand; trench bottom samples, a mean of 42.1%; and backfill samples, a mean of 40.0%. The normalized means for each sieve separate for each type of sample, i.e. surface, trench bottom, backfill, are shown in Figures 7, 8 and 9, respectively.

The samples labelled "c" (14, 15 and 16, Figure 2) in Tables 5, 6 and 7 were collected in December 1990. Although a major sand storm had occurred between Phase II and collection of these samples, there are virtually no differences between 338c and the other backfill samples or between 314c and 317c and the other surface samples.

Table 5. Sieve Analyses: Surface Samples, Phase II (Percent total)

Sample Number	gravel, >2mm	very coarse sand, 1-2mm	coarse sand, 0.5-1mm	medium sand, 0.25-0.5mm	fine sand, 0.125-0.25mm	very fine sand, 0.075-0.125mm	silt+clay <0.075 mm
312b	9.0	13.4	11.6	10.1	23.3	22.0	10.6
321b	9.4	13.7	12.9	11.1	18.9	15.8	18.1
323b	13.3	11.4	16.0	15.5	25.1	14.7	4.1
327b	6.6	10.9	13.4	14.3	26.5	20.5	7.8
328b	13.2	9.2	14.0	14.5	22.5	17.8	8.8
331b	14.9	11.0	10.3	13.0	23.7	17.6	9.3
333b	14.5	18.8	13.2	13.8	21.9	11.1	6.8
334b	20.2	10.3	8.6	9.7	21.7	19.3	10.3
337b	7.3	9.5	10.5	10.4	30.4	22.6	9.2
339b	12.3	13.4	12.8	15.1	24.4	16.0	6.0
342b	5.2	11.6	12.9	11.3	25.7	22.7	10.6
344b	34.8	7.3	8.4	8.3	16.6	14.7	10.0
314c	10.9	8.3	9.9	15.6	32.6	16.7	6.1
317c	6.4	8.0	8.7	13.9	32.4	22.2	8.4
normalized mean (b):	13.4	11.7	12.1	12.3	23.4	17.9	9.3
normalized mean:	12.7	11.2	11.7	12.6	24.7	18.1	9.0

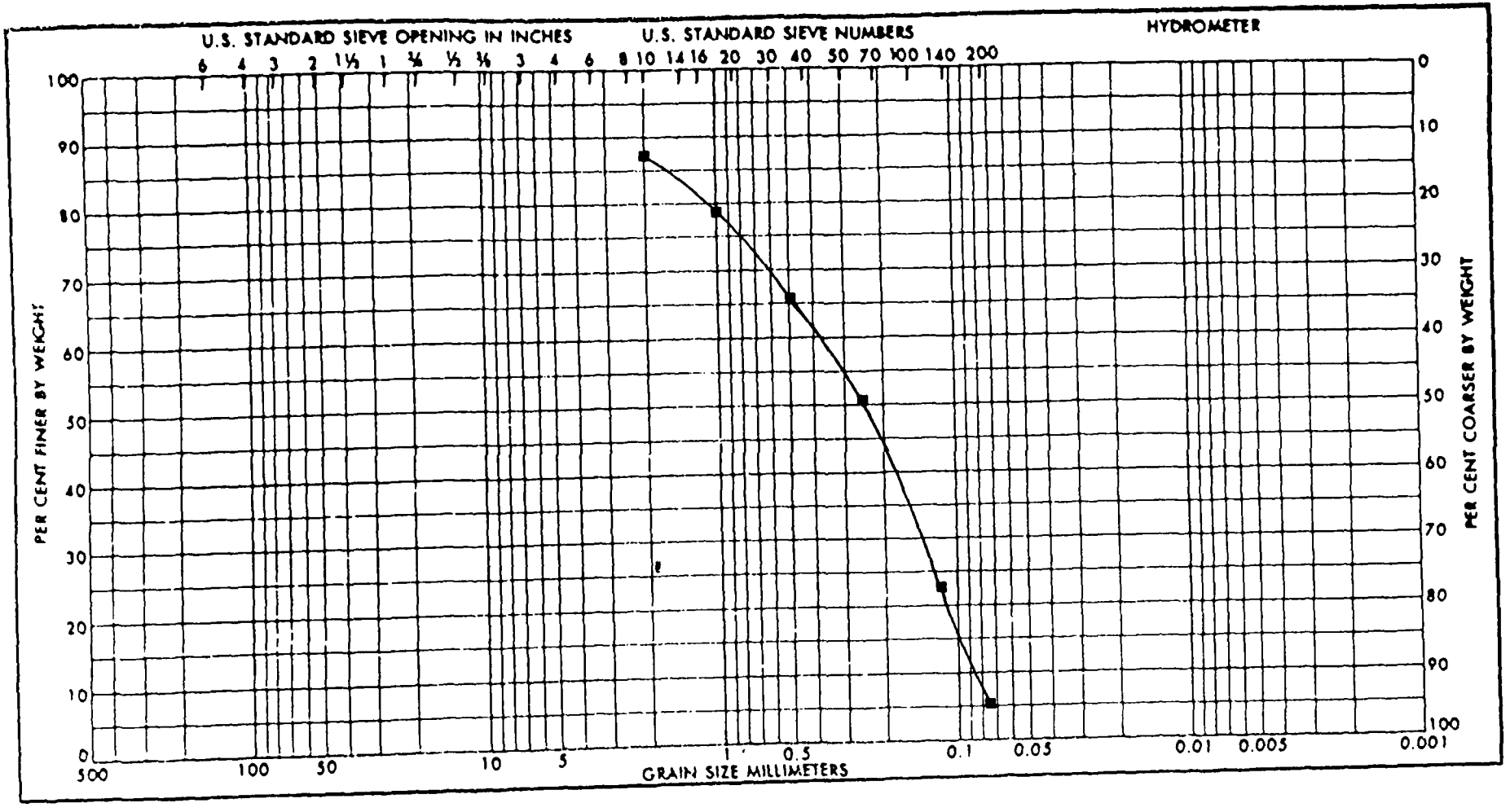


Figure 4. Particle Size – Surface Sample Means Phase I.

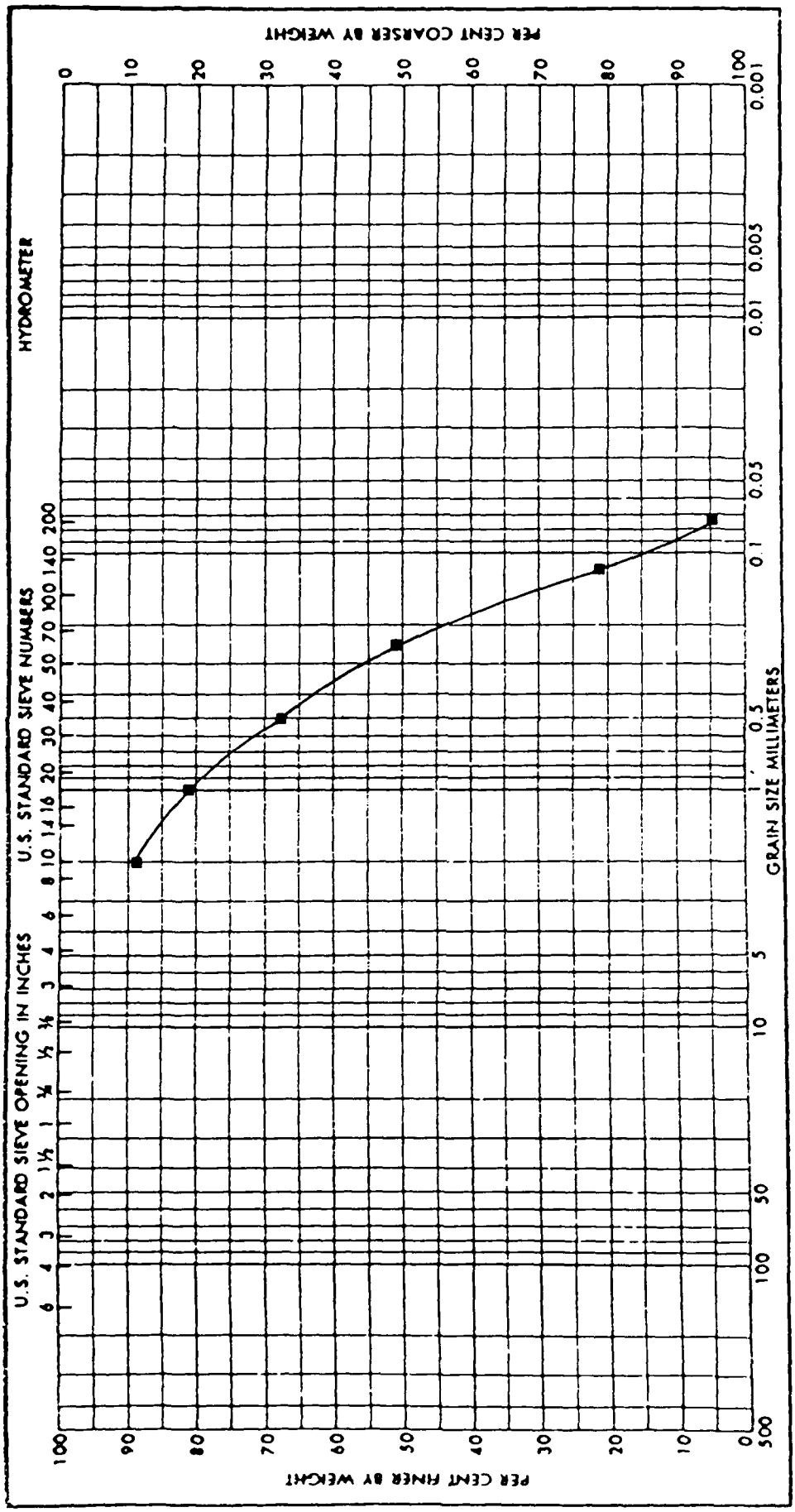


Figure 5. Particle Size – Trench Bottom Sample Means Phase I.

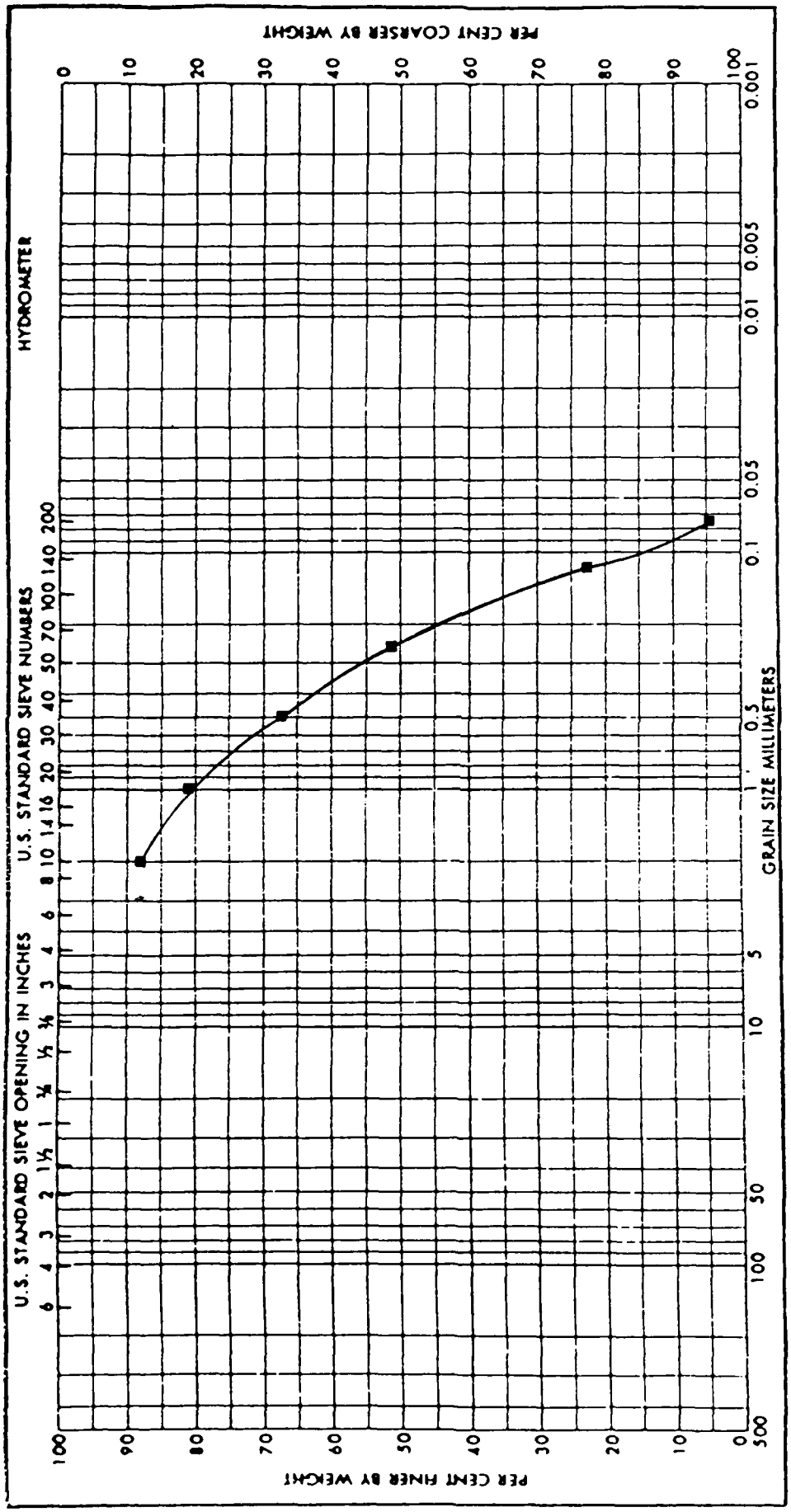


Figure 6. Particle Size – Backfill Sample Means Phase I

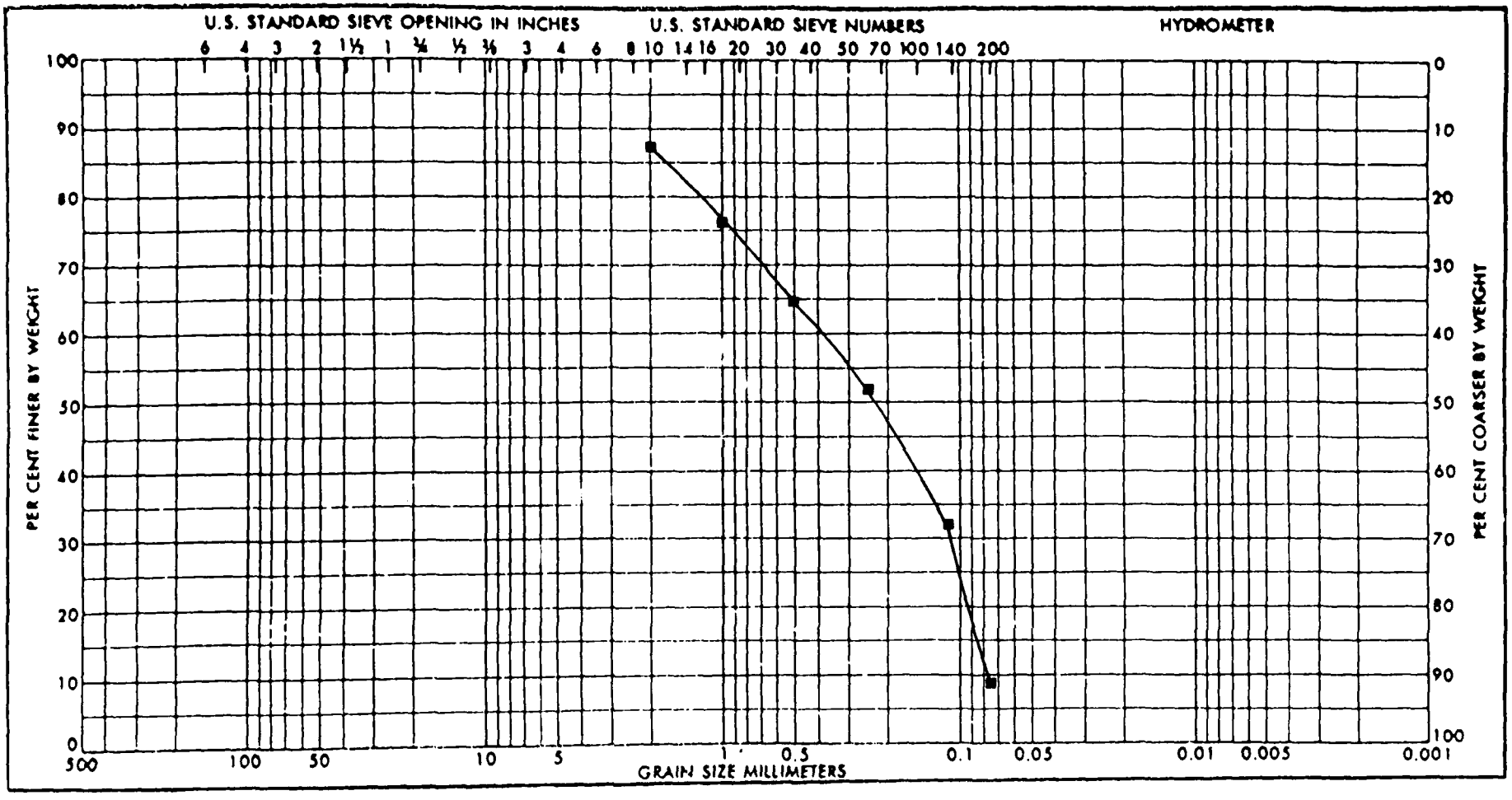


Figure 7. Particle Size – Surface Sample Means Phase II

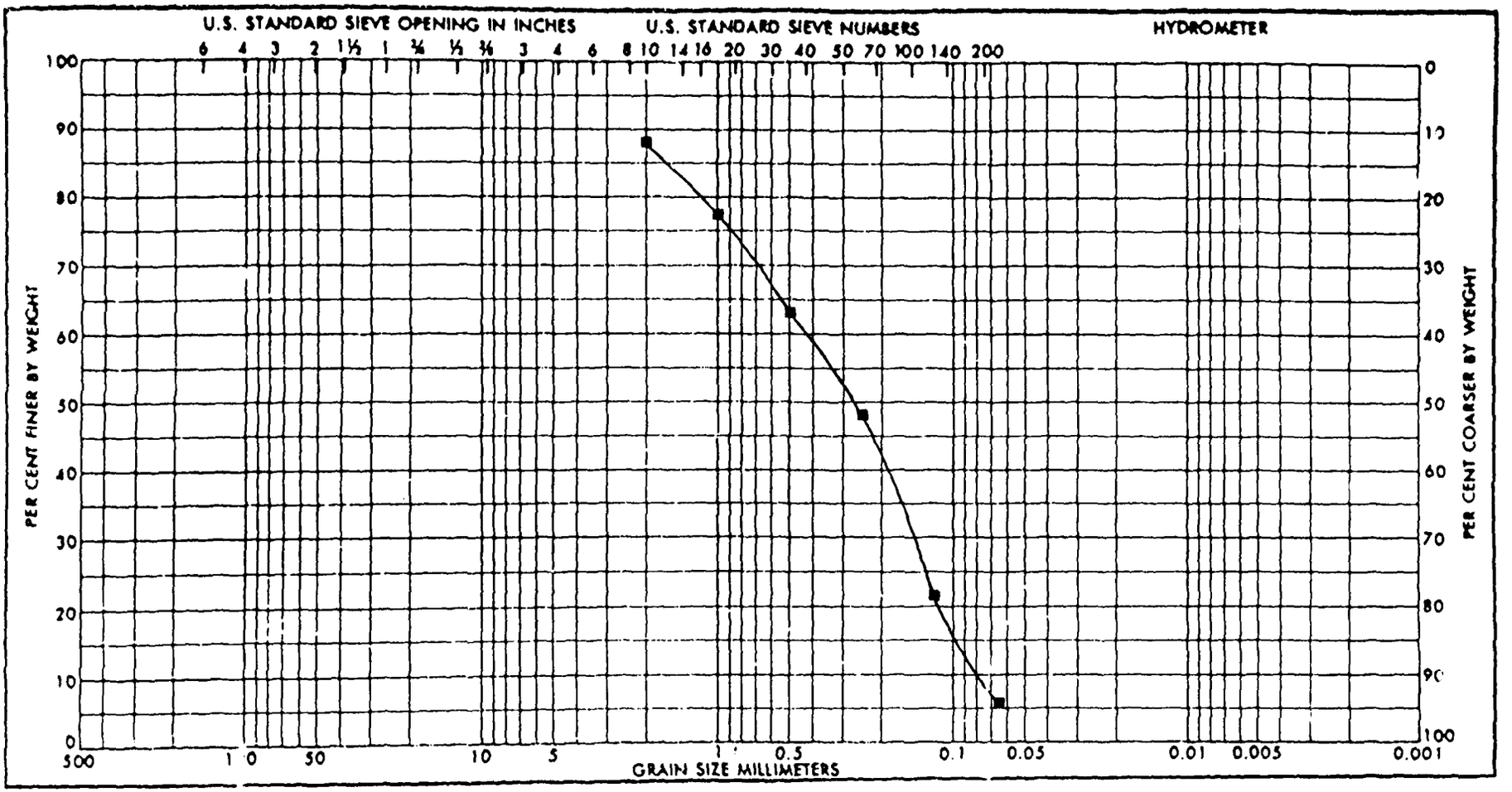


Figure 8. Particle Size -- Trench Bottom Sample Means Phase II.

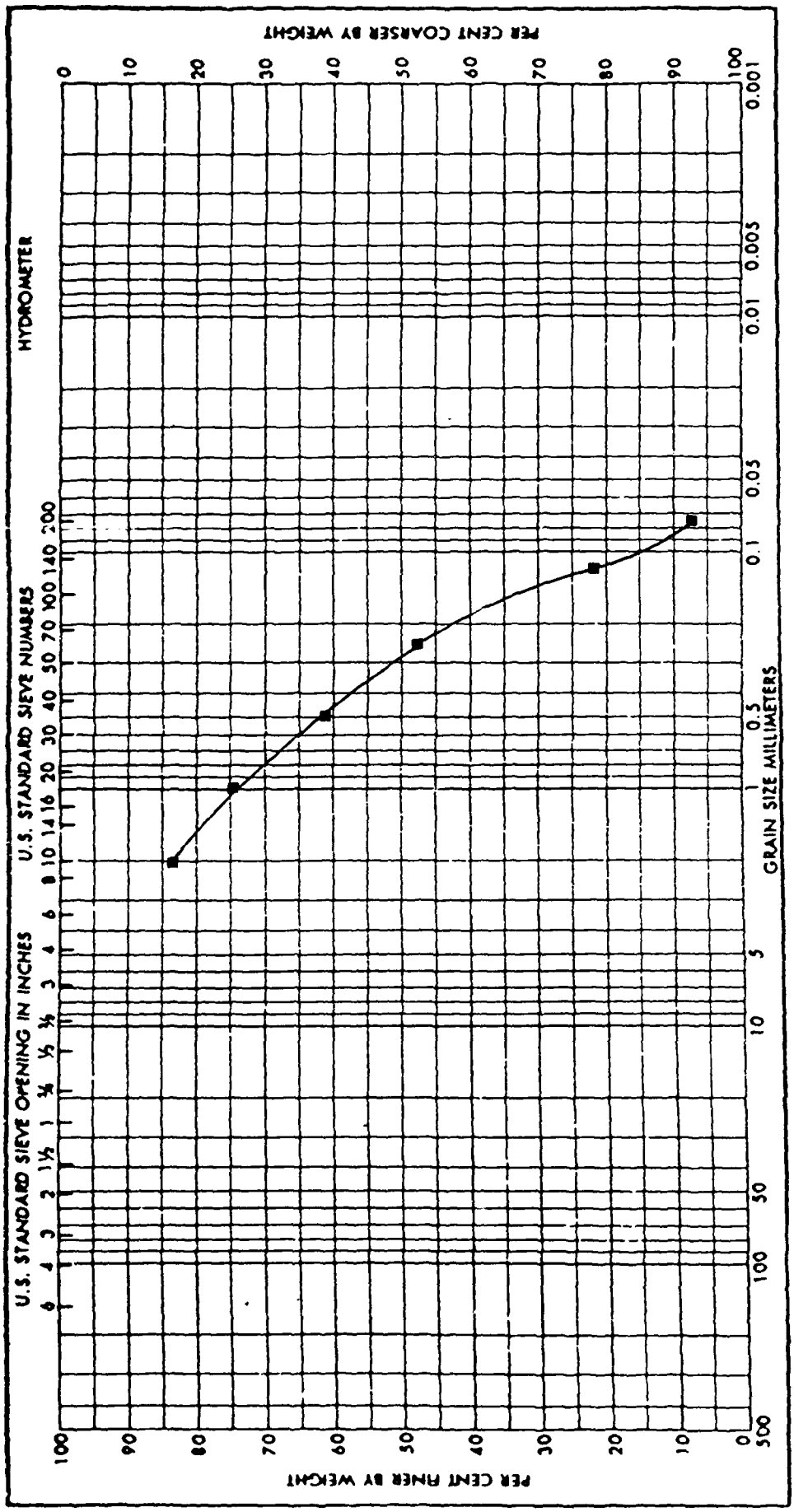


Figure 9. Particle Size – Backfill Sample Means Phase II.

Table 6. Sieve Analyses: Bottom Samples, Phase II (Percent total)

Sample Number	gravel, >2mm	very coarse sand, 1-2mm	coarse sand, 0.5-1mm	medium sand, 0.25-0.5mm	fine sand, 0.125-0.25mm	very fine sand, 0.075-0.125mm	silt+clay <0.075 mm
314b	10.8	9.5	16.7	21.9	26.2	11.0	3.9
317b	14.4	13.6	13.4	16.7	25.6	12.4	3.9
318b	11.1	8.8	12.2	15.4	27.1	17.8	7.5
322b	11.9	10.5	12.5	15.1	33.6	12.7	3.4
324b	4.9	8.1	21.4	20.1	25.3	13.6	6.7
329b	25.6	10.9	12.7	15.2	20.9	10.2	4.6
335b	17.2	12.2	17.5	13.8	19.2	13.3	6.8
336b	6.7	16.9	14.5	11.9	24.6	18.1	7.4
340b	7.2	3.5	4.6	11.1	41.4	24.0	8.3
341b	7.2	5.3	6.6	9.5	36.7	26.1	8.7
343b	16.5	15.6	24.6	16.9	15.8	7.7	3.0
normalized mean:	12.1	10.4	14.2	15.2	27.0	15.2	5.8

Table 7. Sieve Analyses: Backfill Samples, Phase II (Percent total)

Sample Number	gravel, >2mm	very coarse sand, 1-2mm	coarse sand, 0.5-1mm	medium sand, 0.25-0.5mm	fine sand, 0.125-0.25mm	very fine sand, 0.075-0.125mm	silt+clay <0.075 mm
313b	11.7	13.9	25.0	15.6	17.9	10.2	5.6
315b	8.2	7.3	10.8	14.2	45.0	11.2	3.2
316b	35.1	12.1	9.3	8.8	17.5	10.9	6.4
319b	10.3	9.2	9.5	13.4	30.5	20.5	6.6
320b	9.5	6.9	11.1	15.4	28.6	19.7	8.8
325b	17.5	12.9	14.6	11.7	16.3	13.0	14.1
326b	20.8	7.4	21.2	18.9	19.2	9.1	3.5
330b	13.8	10.2	10.5	15.0	28.7	15.3	6.6
332b	16.4	10.2	10.3	12.3	25.2	16.7	8.9
338b	15.2	8.0	8.9	12.7	27.8	19.0	8.4
338c	13.7	8.6	8.7	14.5	29.7	17.5	7.3
normalized mean (b):	15.9	9.8	13.1	13.8	25.7	14.6	7.2
normalized mean:	15.7	9.7	12.7	13.9	26.0	14.8	7.2

Soil Moisture Determinations

Phase 1. Surface samples had the lowest moisture content, trench bottom samples were the wettest and the backfill samples tended to be intermediate in moisture content (Table 8). Surface soil moisture ranged from 0.33-0.50%. Trench bottom soil moisture ranged between 0.73-1.34% in the 8-inch deep trenches, 1.11-1.21% in the 12-inch deep trenches, and 1.34-2.00% in the 16-inch deep

Table 8. Percent Soil Moisture, Phase I

Sample Location	Surface Samples	Bottom Samples	Backfill Samples
1	meas.error	1.01	0.41
2	0.50	0.73	0.29
3	0.38	-	-
4	0.41	1.19	0.23
5	0.34	1.00	0.40
6	0.47	1.11	0.44
7	0.33	1.14	0.43
8	0.46	1.34	meas. error
9	0.45	-	-
10	0.38	1.09	0.58
11	0.35	1.21	0.49
12	0.44	2.00	0.73

trenches. Backfill soil moisture ranged from 0.23-0.73%. There are no statistically significant differences at the 95% confidence level in percent soil moisture among surface, trench bottom and backfill samples.

Soil moisture of the trench bottom and backfill samples tended to increase slightly down slope from north-northeast to south-southwest in the study site. Surface soil moisture was higher in the north-northeast and south-southwest parts of the site than in the northwest/southeast band that extends through the center of the site.

Phase 2. As shown in Table 9, surface soil moisture ranged from 0.47-1.31%; and backfill soil moisture, from 0.78-1.22%. Trench bottom soil moisture ranged from 1.29-4.27% at 8-inch depth, 1.09-1.33% at 12-inch depth, and 1.16%-1.37% at 16-inch depth. Statistically, there are no significant differences between surface, trench bottom and backfill samples in this data set.

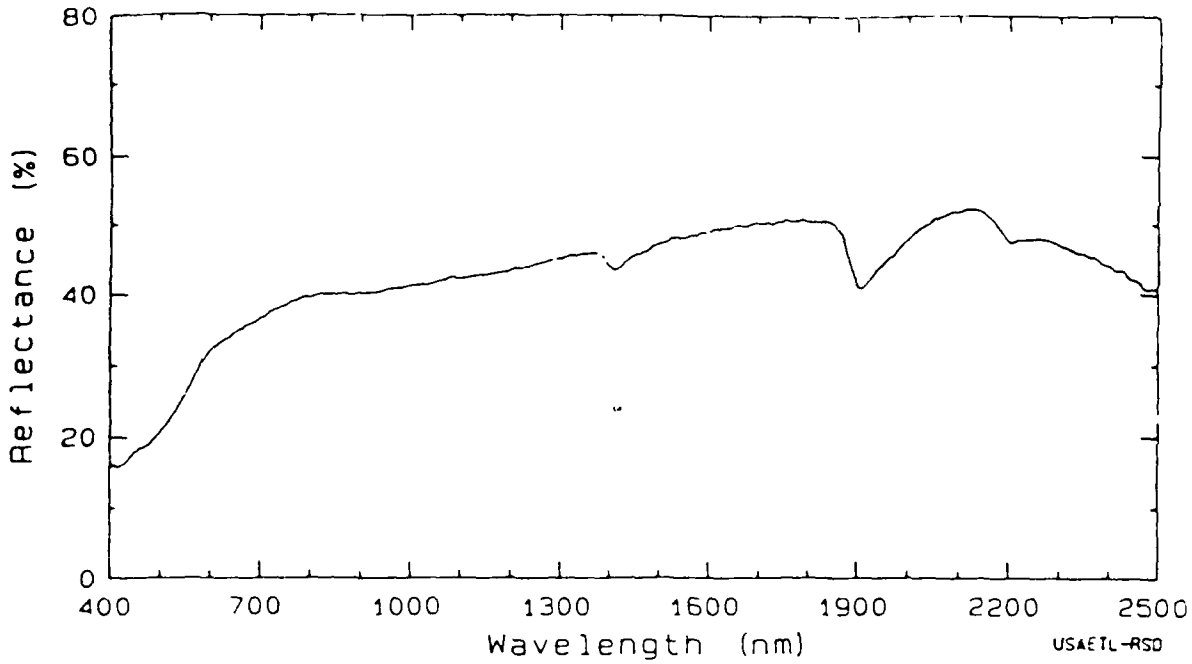
Table 9. Percent Soil Moisture, Phase II

Sample Location	Surface Samples	Bottom Samples	Backfill Samples
1	1.07	meas.error	0.78
2	0.99	1.18	0.89
3	0.47	-	-
4	1.31	2.40	1.01
5	1.06	1.69	0.93
6	1.19	1.09	0.78
7	1.14	1.37	0.72
8	0.79	1.52	0.71
9	0.80	-	-
10	1.06	1.29	1.16
11	0.62	1.33	1.22
12	0.73	1.16	1.18
13	-	1.15	-
14	-	-	1.06
15	0.88	-	-
16	1.21	-	-

Surface soil moisture was highest in the southeast corner and lowest in the southwest corner of the test site. Trench bottom soil moisture exhibited a totally different pattern, being highest in the northeast and lowest in the southwest. Backfill sample soil moisture was lowest in a central north-south band and in the northeast corner, increasing to both east and west. It was highest in the west.

Spectral Reflectance

Not all of the surface samples were measured. After visual inspection of the samples, which indicated that all were very similar in color and particle size range, 24 samples, six each of surface and backfill samples from each of the two phases of the experiment, were selected and measured (Table 10). Multiple scans were made of each sample and the results compared. Figures 10 and 11 show four reflectances curves at reduced scale, one each of surface and backfill samples for each phase. All reflectance curves at full size are in Appendix A.



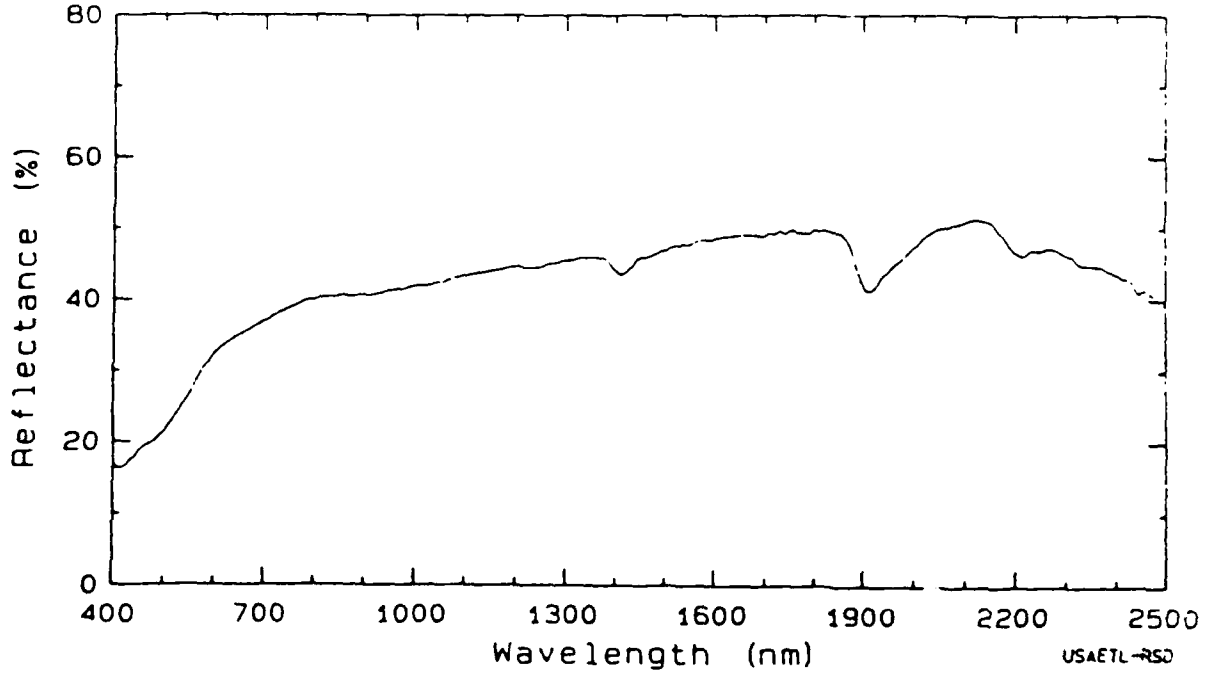
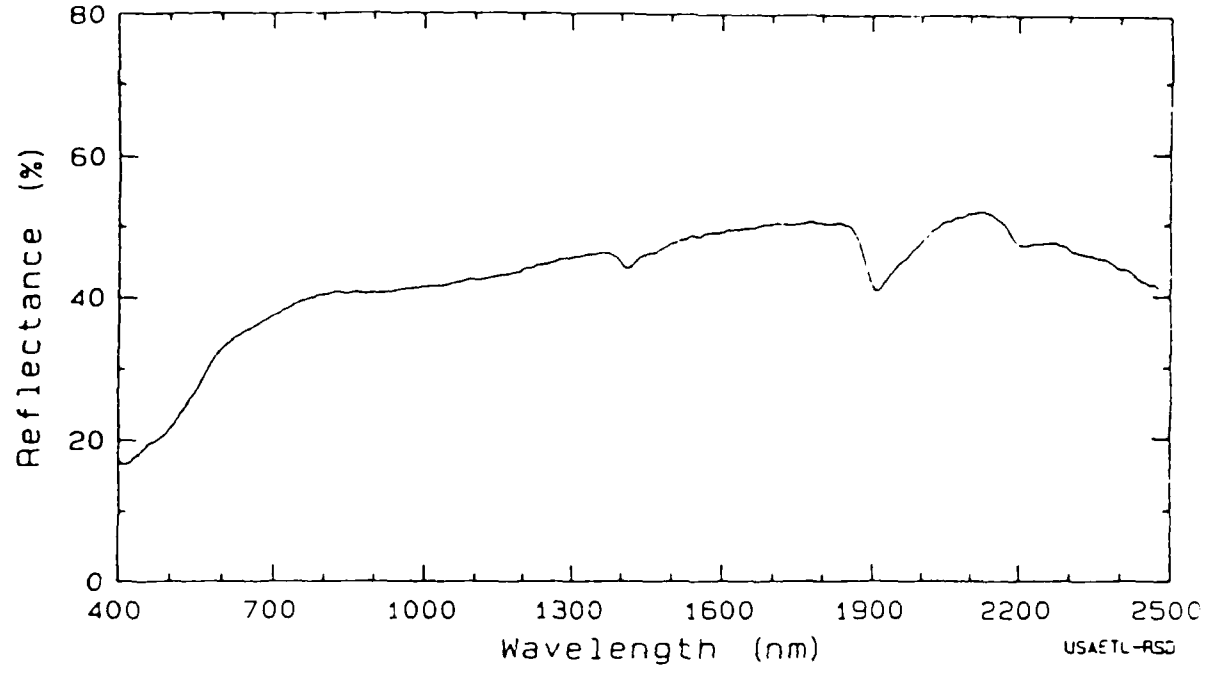


Figure 10. Surface Reflectance – Surface Samples, Twentynine Palms, CA: A. Sample 329a, Phase I, B. Sample 344b, Phase II.



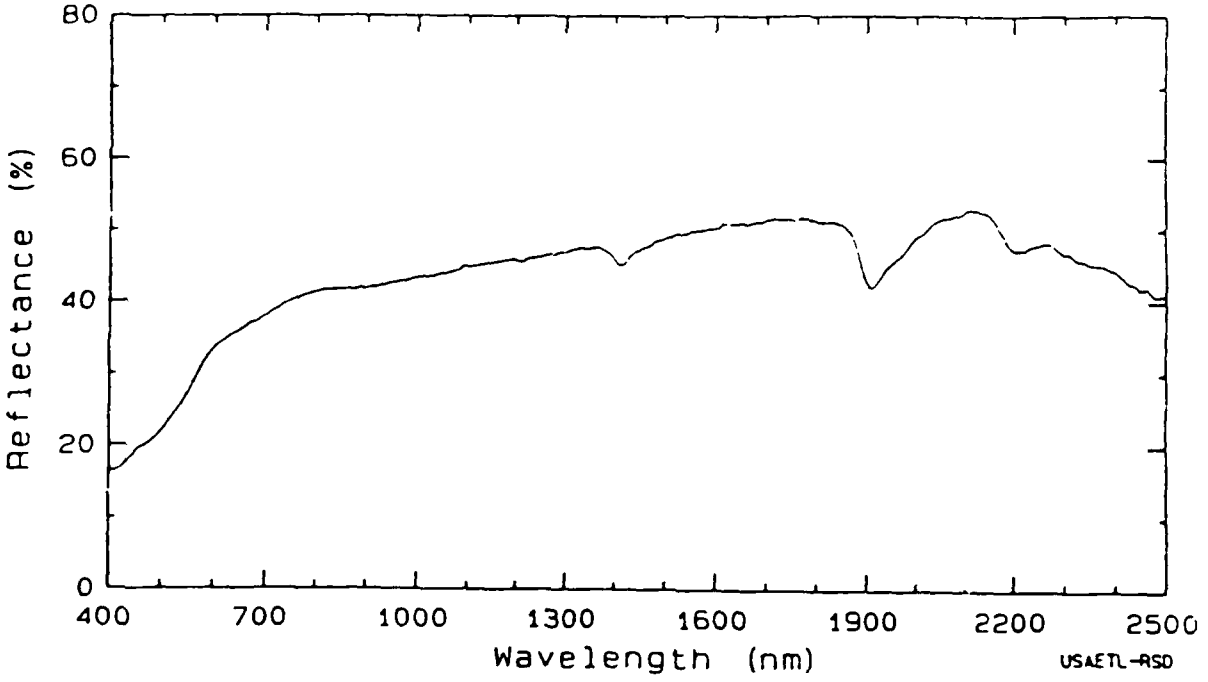


Figure 11. Surface Reflectance – Backfill Samples, Twentynine Palms, CA: A. Sample 312a, Phase I, B. Sample 338b, Phase II.

Table 10. Soil Samples from Twentynine Palms used for Spectral Reflectance

	Surface Samples	Backfill Samples
Phase I	326a	312a
	327a	313a
	329a	315a
	332a	317a
	334a	318a
	336a	319a
Phase II	312b	315b
	323b	316b
	327b	320b
	339b	325b
	342b	326b
	344b	338b

In the visible portion of the spectrum (400-700 nm), all 24 of the samples are virtually identical. This is true for 21 of the samples in the infrared portion of the spectrum (700-2500 nm) as well; there are differences of no more than 4% reflectance among three of the backfill samples. The shape of the spectral curves for all of the samples is typical of a dry, light brown, quartz-rich material. The spectra are featureless with the exception of the water and hydroxyl absorptions at 1400 nm, 1900 nm and 2200 nm, which are present in most soils. The characteristic carbonate absorption at 2350 nm that is seen in some desert soils is not pronounced in these reflectance curves; neither are the characteristic absorptions of gypsum seen. This indicates that if these common desert minerals are present, their amounts are insufficient to be detected spectrally. These spectra are typical of gravelly-sand surfaces derived from various igneous sources, and are typical of Mohave Desert surfaces in general (Satterwhite and Henley, in prep).

Soil Color

The soils from Twentynine Palms are virtually the same color. Fifteen of the 27 surface samples (55.6%) are 10YR 6/3 and eleven (40.7%) are 10YR 6/4; the remaining sample is 7.5YR 6/4. Fifteen of the 21 trench bottom samples (71.4%) are 10YR 6/3 and the remaining six (28.6%) are 10YR 6/4. Fourteen, or 66.7%, of the 21 backfill samples are 10YR 6/3 and the remaining seven (33.3%) are 10YR 6/4. Surface and backfill samples are thus slightly lighter in color than trench bottom samples.

Comparison of Phase I and Phase II Samples

Statistically, there are no significant differences in particle size between surface, backfill, and trench bottom samples in Phase I, in Phase II, or between Phase I and Phase II. Soil moisture is slightly higher in the samples collected in the Phase II experiment than in the Phase I samples. This was expected for two reasons: (1) the second test site is downslope from the first test site and (2) because it is closer to a playa lake, it was expected to contain more silts and clays, which the samples

do. There are statistically no significant differences between the two Twentynine Palms data sets with respect to soil moisture. There are also no differences between spectral reflectance or soil color among surface, trench bottom, and backfill samples in each data set or between the two data sets.

SOILS FROM SAUDI ARABIA

Particle Size

Results of the sieve analyses for the eight samples from eastern Saudi Arabia are shown in Table 11. Sample SA-1 cannot be directly compared to the other samples because the analytical procedures were different from those used for the other samples: the gravel separate was removed from this sample prior to sieving. In addition, SA-3 is composed mainly of very soft gypsum crystals (Moh's hardness 2) that break into smaller particles upon sieving, reducing overall grain size: sieving time itself may thus affect particle size. The remaining six samples can be divided into two groups, those that contain >20% gravel (SA-7, SA-8), and those that are mainly sand and contain <20% gravel (SA-2, SA-4, SA-5, SA-6). The largest separate in these soils (excluding the gravel separate) is fine sand, with the medium sand the next largest fraction. The fine sand separate ranges from 18.5-18.8%; and medium sand, from 15.4-16.3%. The silt+clay separate in these samples ranges from 5.3-7.5%. Medium sand is the largest separate in the sandy samples, ranging from 21.8-34.8% (mean 30.4%). Silt+clay ranges from 3.4-7.3% (mean 5.7%). Statistically, these gravelly and sandy groups of samples are significantly different at the 99% confidence level. The normalized means for each sieve separate for gravelly and sandy samples are shown separately in Figures 12 and 13, respectively.

Table 11. Sieve Analyses, Saudi Arabian Soils (Percent total)

Sample Number	gravel, >2mm	very coarse sand, 1-2mm	coarse sand, 0.5-1mm	medium sand, 0.25-0.5mm	fine sand, 0.125-0.25mm	very fine sand, 0.075-0.125mm	silt+clay <0.075 mm
SA-1	-	10.7	13.8	19.3	27.8	14.7	13.7
SA-2	1.3	13.4	13.3	32.8	26.7	9.0	3.4
SA-3	22.0	16.0	14.7	16.7	17.8	8.0	4.7
SA-4	3.2	0.3	12.2	34.9	33.2	11.0	5.3
SA-5	14.0	5.0	15.9	32.0	20.5	5.9	6.7
SA-6	4.7	19.3	16.4	21.8	19.2	11.3	7.3
SA-7	31.7	6.5	8.6	15.4	18.8	13.6	5.3
SA-8	27.1	4.7	10.6	16.3	18.5	15.4	7.5
normalized mean, sands:	5.8	9.5	14.5	30.4	24.9	9.3	5.7
normalized mean, gravels:	29.4	5.6	9.6	15.9	18.7	14.5	6.4

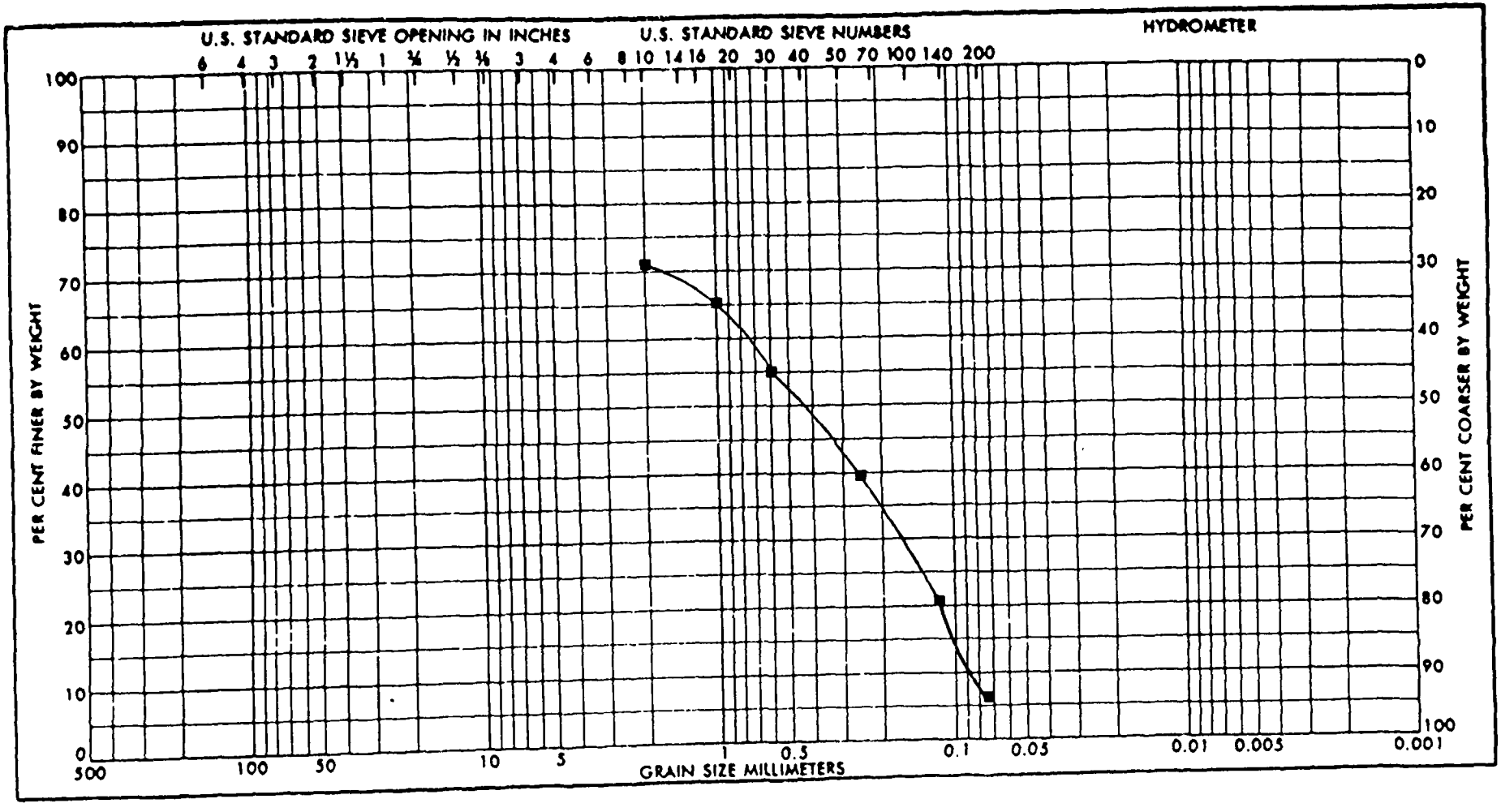


Figure 12. Particle Size – Means For Gravelly Saudi Arabian Samples.

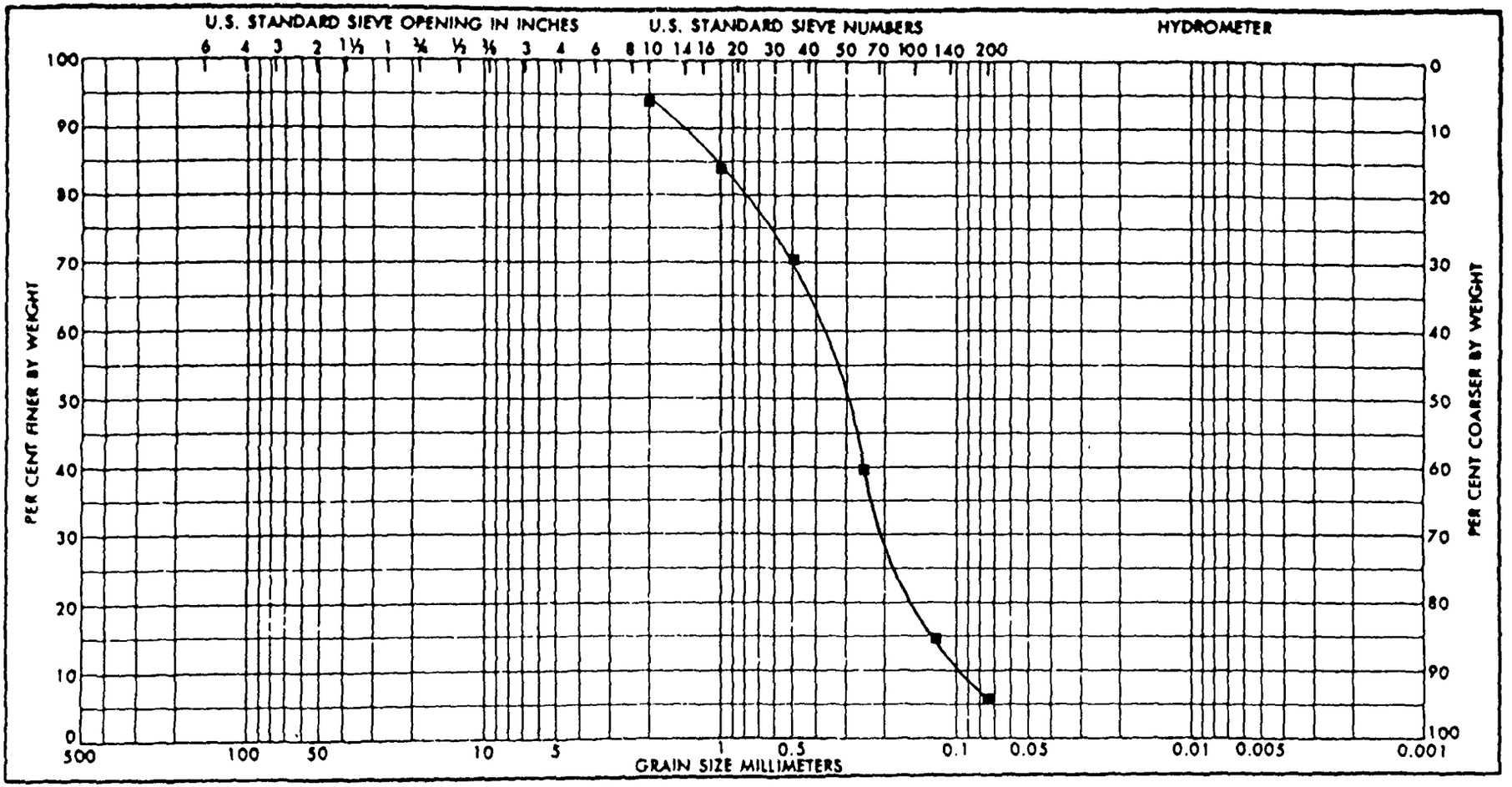


Figure 13. Particle Size -- Means For Sandy Saudi Arabian Samples.

Soil Moisture

Although soil moisture was determined for three of the Saudi Arabian samples, the determinations are not considered reliable and are thus not reported. We do not know the conditions under which they were collected, how well they were sealed, how long they were in transit, or how they were handled while in transit. Any soil moisture determinations made under these conditions cannot be compared to those made for the Twentynine Palms samples under controlled conditions.

Spectral Reflectance

The Saudi Arabian soil samples are of two basic types: (1) those consisting of wind-blown sand with some limey and/or quartz gravels and (2) those composed primarily of gypsum. Overall, the Saudi Arabian samples are light-toned and highly reflective. Figure 14 shows the reflectance characteristics of the light-toned, wind-blown sands with some limey bits, sample SA-4. The spectra for the other sandy samples, SA-2, SA-5 and SA-6, are in Appendix 2. The spectra for the gravelly soils, SA-7 and SA-8, are very similar to the spectra for sandy soils, except that the reflectance is slightly lower (Figure 15 and Appendix B). These soils are highly reflective throughout the infrared region (excluding water or hydroxl absorptions at 1400 nm, 1900 nm, and 2200 nm, which occur in virtually all soils), and they show a small absorption at 2300 nm, which is indicative of carbonate material (limestone). Samples SA-1 and SA-3 are also highly reflective in the visible and near-infrared regions, but show deep absorptions in the infrared region indicative of gypsum, a hydrated calcium sulfate mineral, as well (Figure 16 and Appendix 2). Gypsum-rich soils are among the brightest of all soils in the visible region, but are highly absorptive in the 2100 nm to 2400 nm region due to the presence of water bound in the gypsum crystals.

Soil Color

The soil samples from eastern Saudi Arabia are somewhat variable in color. Five (62.5%) of the eight samples are 10YR 7/3. The remaining three samples are 10YR 8/2, 10YR 7/2 and 7.5YR 6/4.

COMPARISON OF SOILS FROM TWENTYNINE PALMS, CA, AND SAUDI ARABIA

The comparisons made above between soils from Twentynine Palms and those from eastern Saudi Arabia must be qualified. The Twentynine Palms soils come from a very small area that is relatively homogeneous, whereas the Saudi Arabian soil samples come from only a few locations over a very wide area. The few samples from eastern Saudi Arabia cannot be considered representative of soils in Saudi Arabia, and the many samples from Twentynine Palms cannot be considered representative even of the Mohave Desert.

In general terms, the soils from Twentynine Palms are classified as gravelly fine sand and gravelly very fine sand. The fine sand and very fine sand sieve separates comprise approximately 50% of most samples. The sandy soils from eastern Saudi Arabia are mainly medium sand;

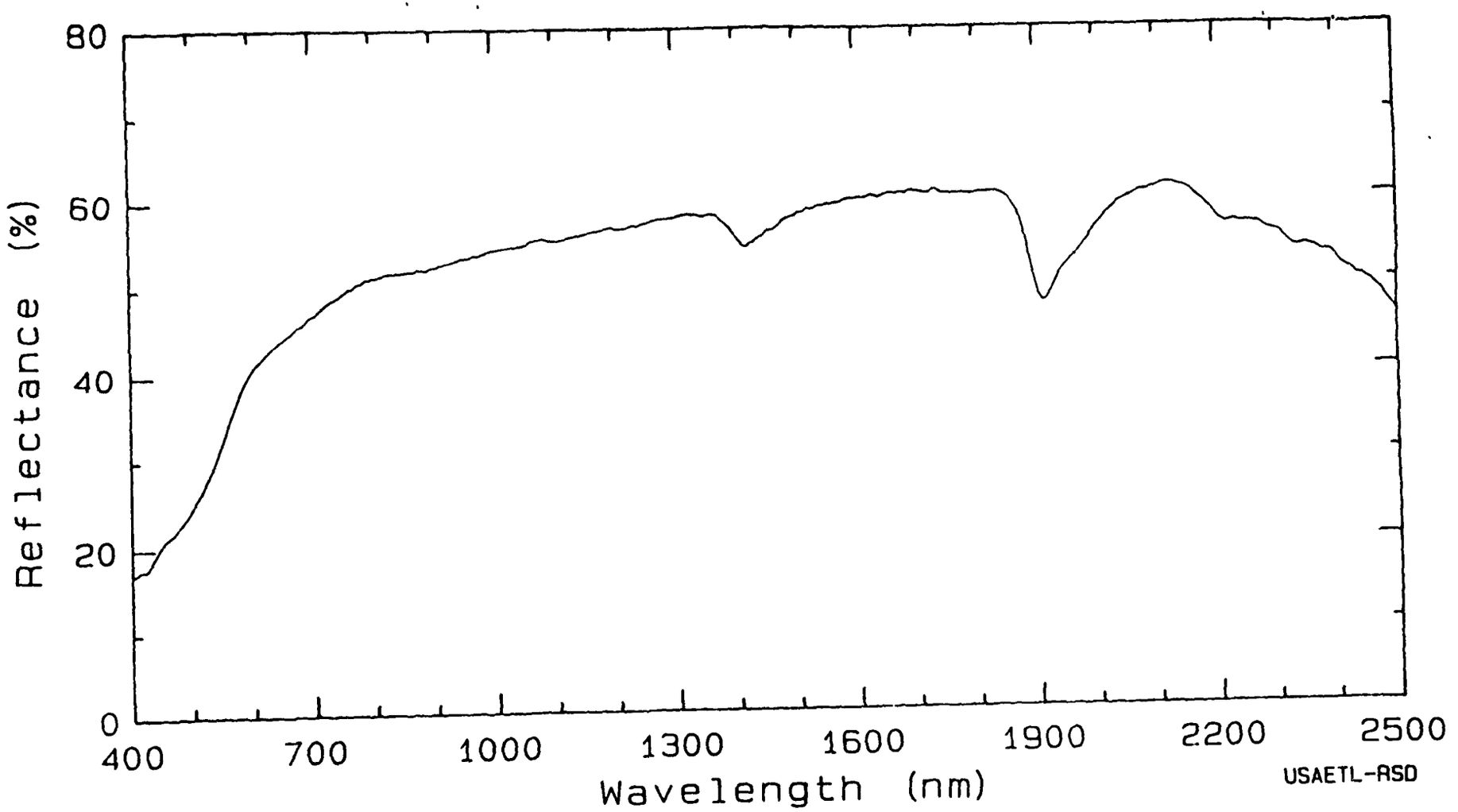
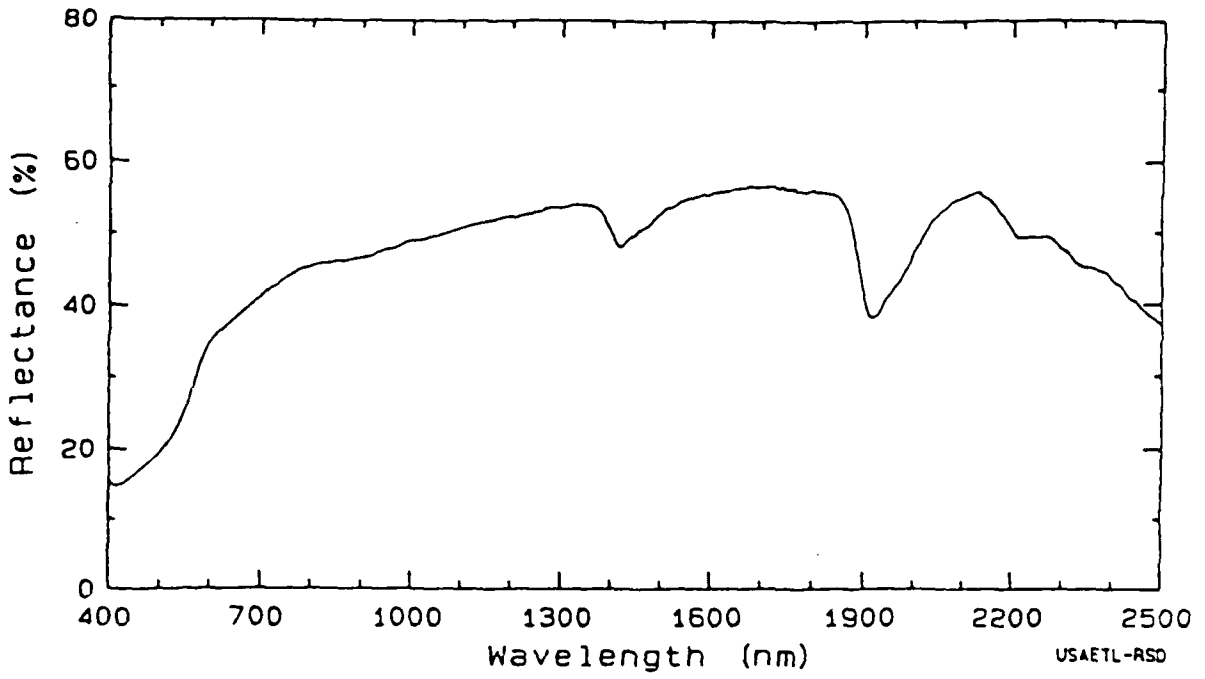


Figure 14. Surface Reflectance -- Sandy Sample, Saudi Arabia.



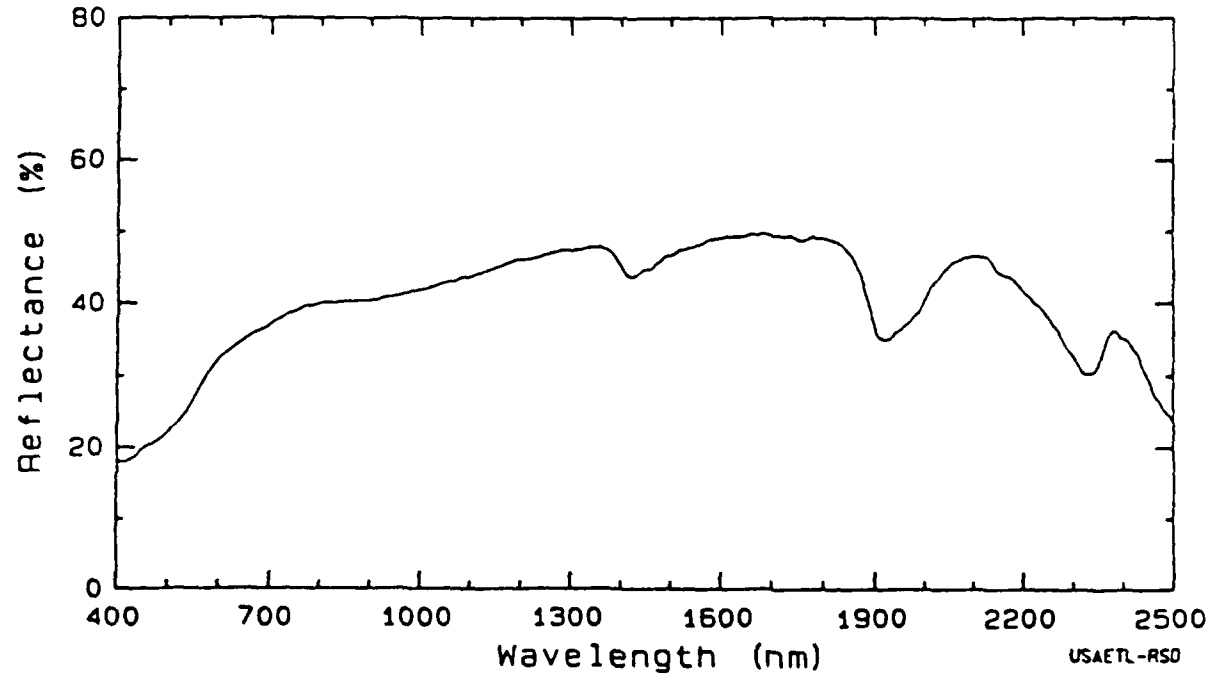
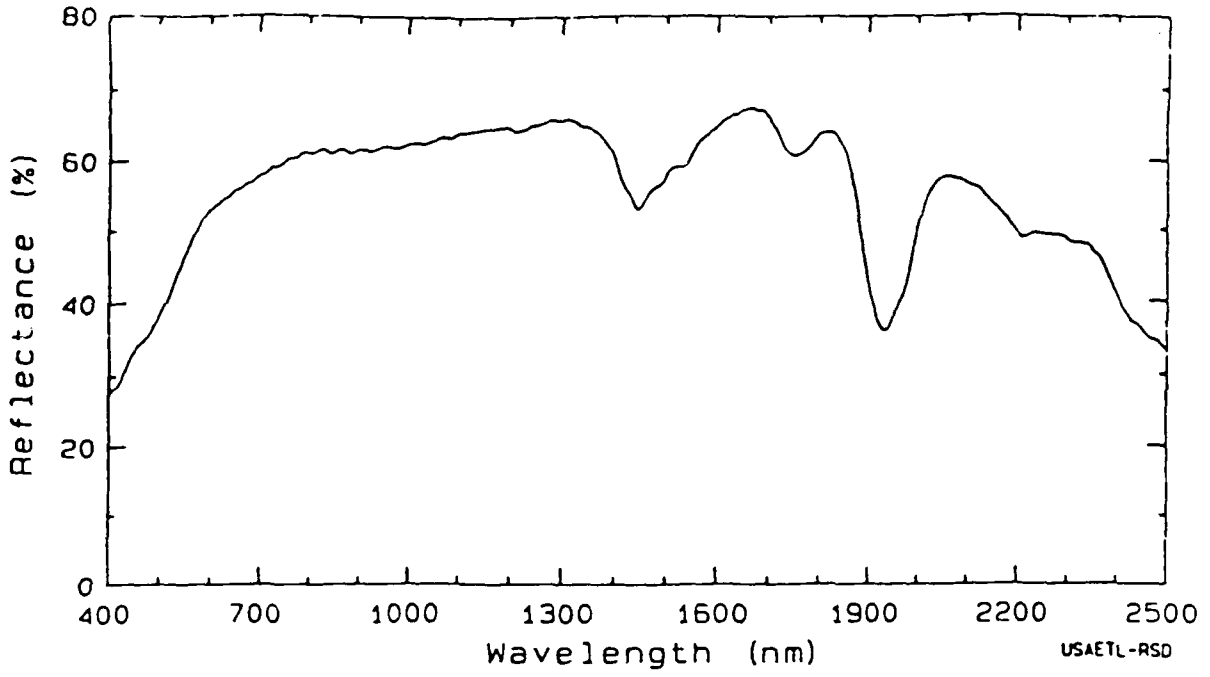


Figure 15. Surface Reflectance – Gravelly Samples, Saudi Arabia: A. SA-7, B. SA-8.



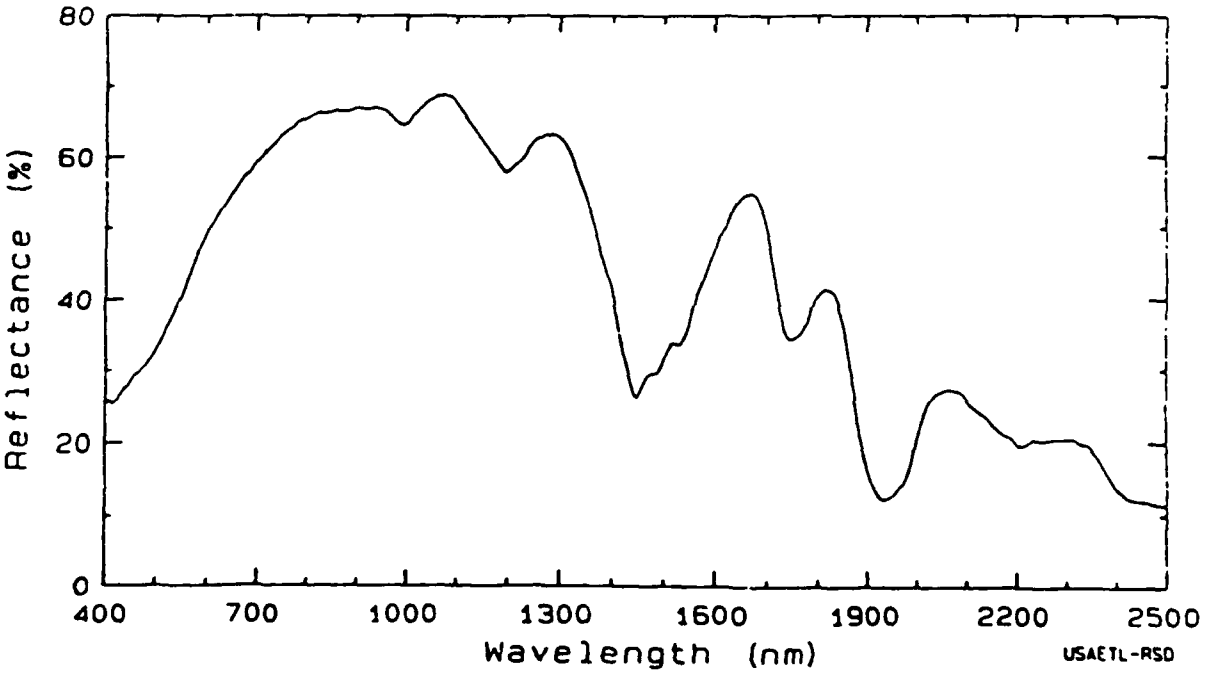


Figure 16. Surface Reflectance – Gravelly Samples Containing Gypsum, Saudi Arabia: A. SA-1, B. SA-3.

approximately 30% of each sample consists of medium sand. There are statistically significant differences between the surface samples from Twentynine Palms and both the gravelly and sandy samples from eastern Saudi Arabia. These differences are significant at the 99% confidence level.

With respect to spectral reflectance, the samples from Twentynine Palms are fairly uniform, as all samples came from a small area. The darker toned gravels, derived from local igneous sources, and the absence of any absorptive mineral such as gypsum give these samples overall featureless reflectance spectra. The Saudi Arabian samples, from several locations and from very different source materials, show more variability. The most obvious difference is that the Saudi Arabian soils are much brighter or lighter toned than the Twentynine Palms soils. The presence of gypsum in some of the Saudi Arabian samples produces reflectance spectra that are very different from the Twentynine Palms soils. The Saudi Arabian soils are more variable in color than those from Twentynine Palms.

CONCLUSIONS

There are some similar characteristics between the soils from Twentynine Palms and those from eastern Saudi Arabia. First, we believe that both sets of samples were collected from sand sheets, so grain size and degree of roundness should be roughly similar. Berlin et al. (1986) describe the Al Labbah sand as rounded to subrounded and fine to medium grained. Our samples from eastern Saudi Arabia are mainly medium sand and the soils from Twentynine Palms are mainly fine sand and very fine sand. Curtis and Tid··ll (in prep) describe soil particles from Twentynine Palms, Phase I, as rounded to subrounded. Second, although we have no soil moisture data on our Saudi Arabian soil samples, Berlin et al. (1986) show soil moisture ranging from 0.054-0.077% in the sand sheet on the Al Labbah Plateau. Although lower in soil moisture than the surface samples from Twentynine Palms, which range from 0.33-1.31%, these soils can be considered rougly comparable with respect to soil moisture.

We have also identified some significant differences between the two sets of samples. There are statistically significant differences between the mean particle size distributions for soils from the two regions. The Saudi Arabian samples, which consist mainly of medium sand or of gravel, are coarser grained than those from Twentynine Palms, which consist primarily of fine sand and very fine sand, as stated above. Also, although we do not yet have petrographic data on any of the samples, analysis of the reflectance spectra as well as visual observations suggest that there are major differences in composition between the two sets. The Saudi Arabian samples contain large amounts of gypsum, whereas gypsum is not readily apparent in the samples from Twentynine Palms. Only parts of the samples from Saudi Arabia may have an igneous source, whereas the Twentynine Palms samples all are igneous in origin. The latter appear to have a higher iron (or dark mineral) component than those from Saudi Arabia. The spectra for the two data sets show a carbonate component in the Saudi Arabian soils that does not occur in the spectra for the Twentynine Palms soils. In addition, the Saudi Arabian soils are much more reflective than those from Twentynine Palms because of their high gypsum content.

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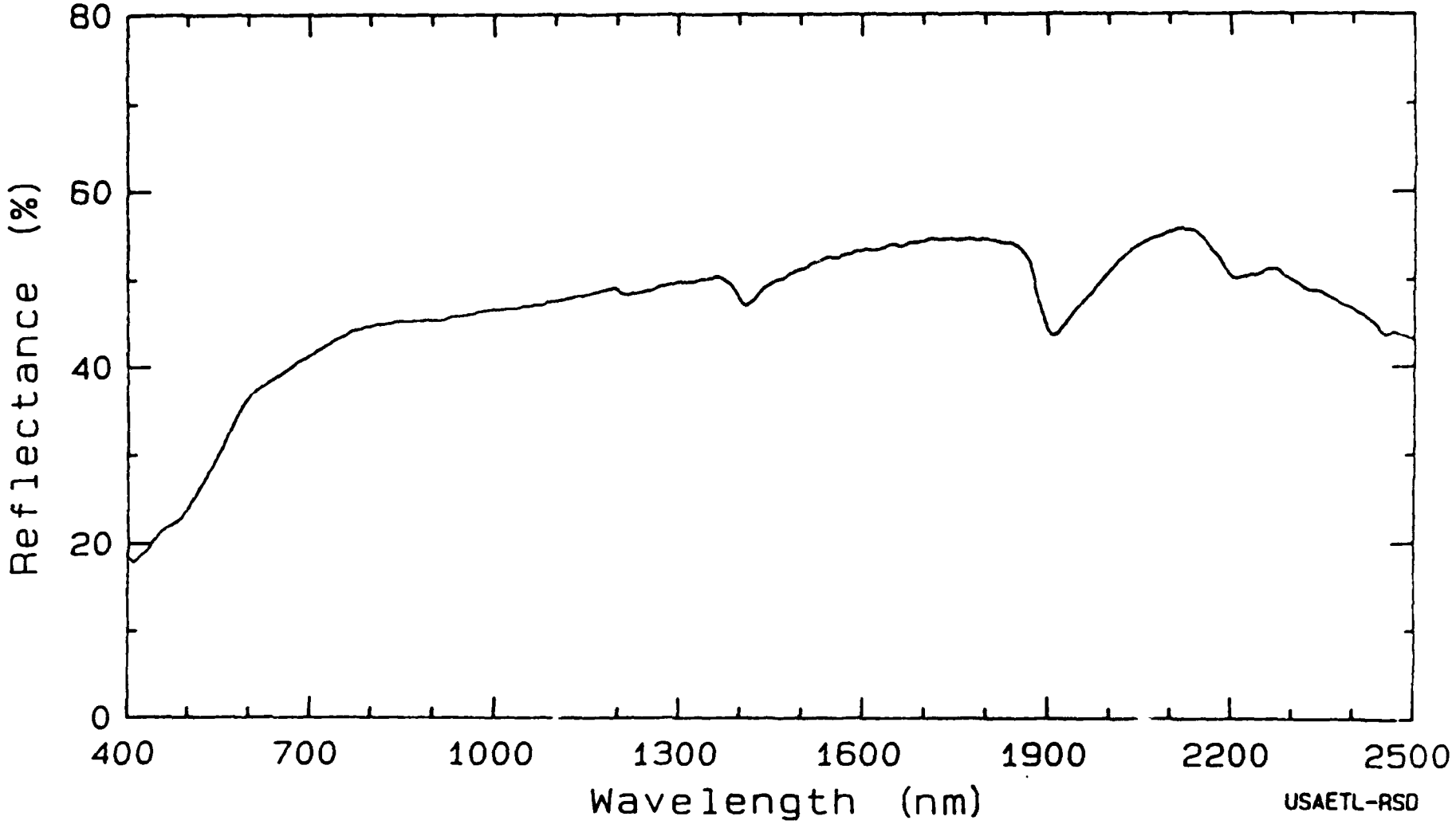
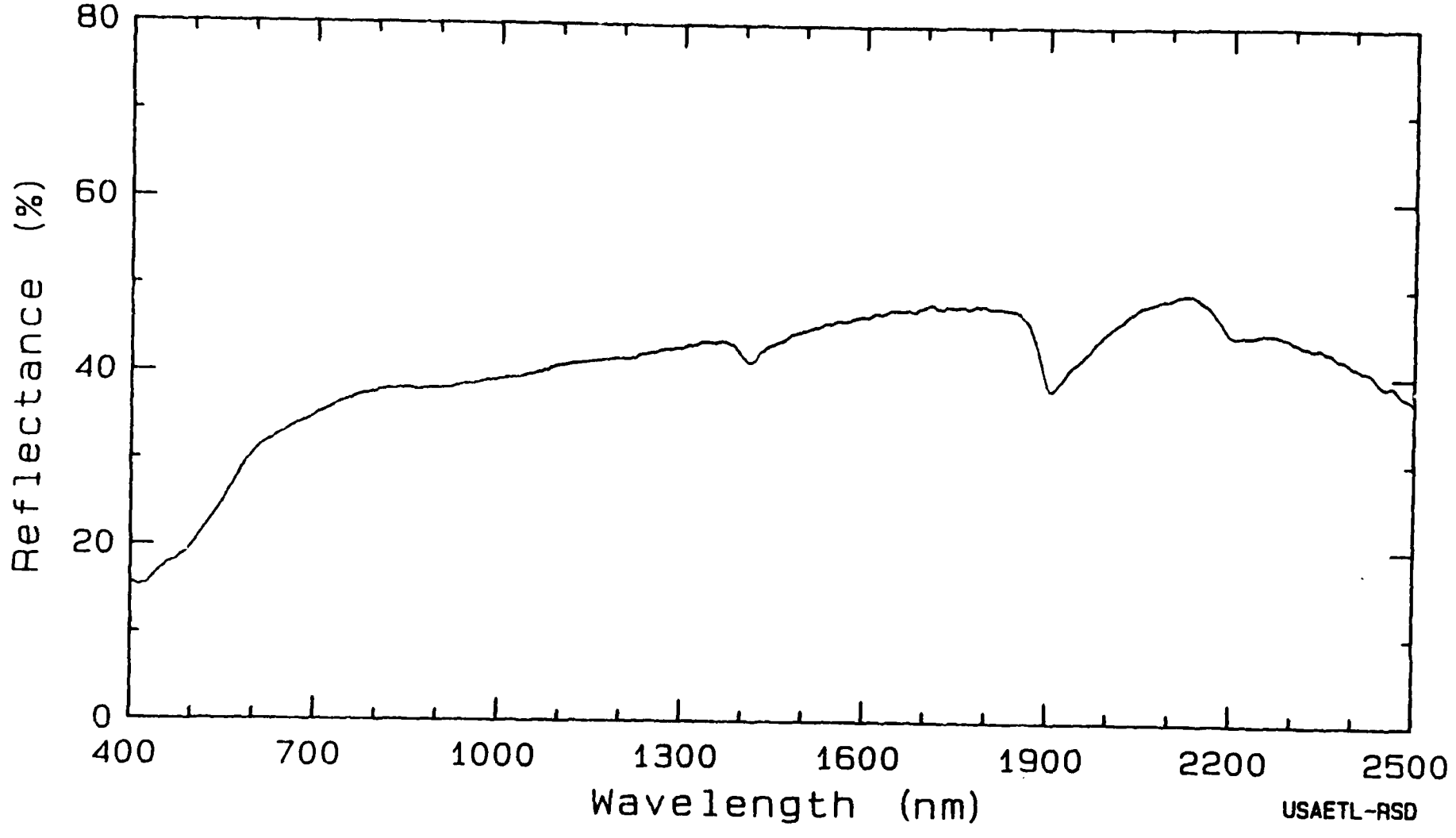
APPENDIX A. REFLECTANCE SPECTRA OF SOILS FROM TWENTYNINE PALMS, CA

1. Surface Samples, Phase I



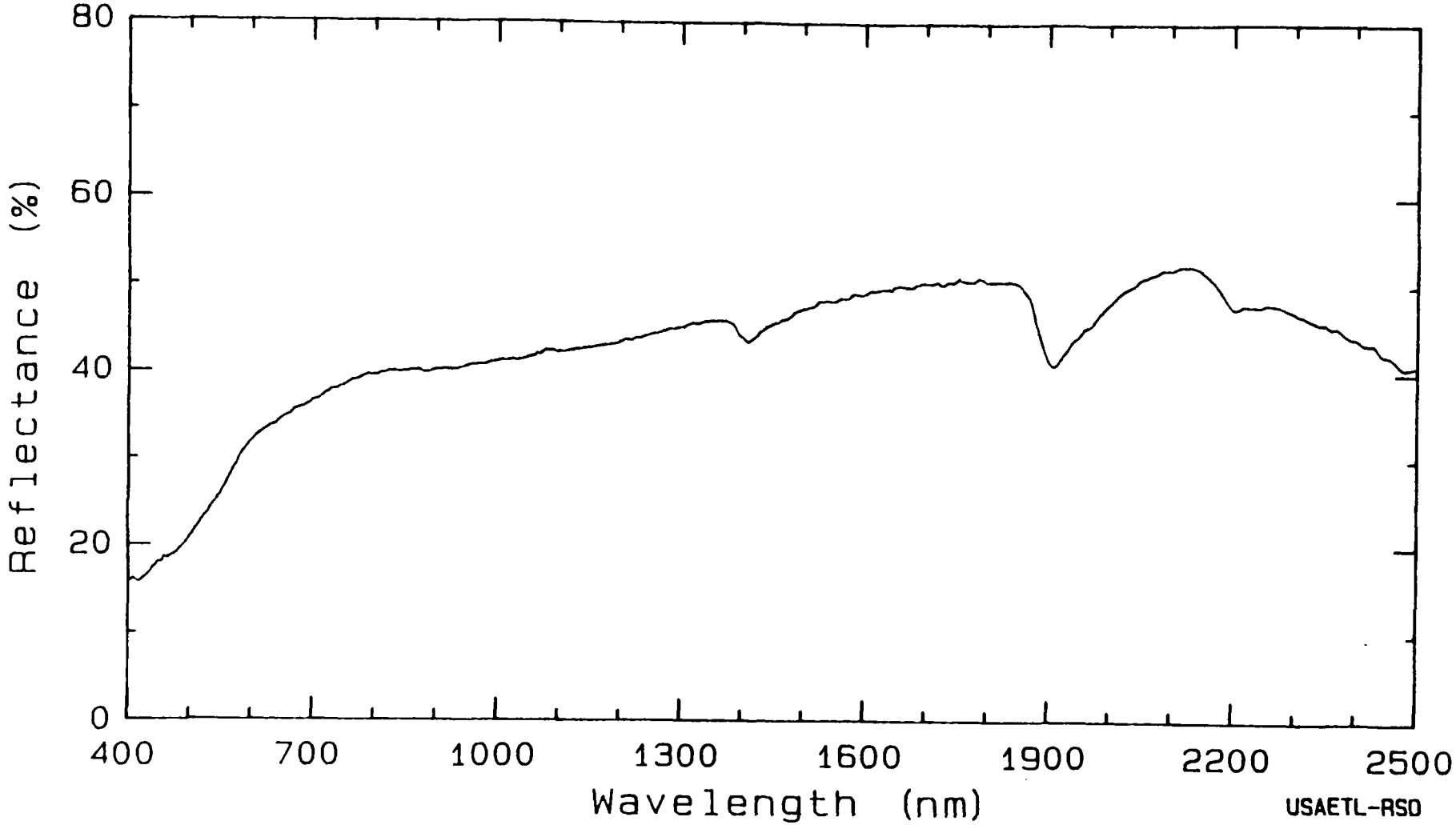
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 326a



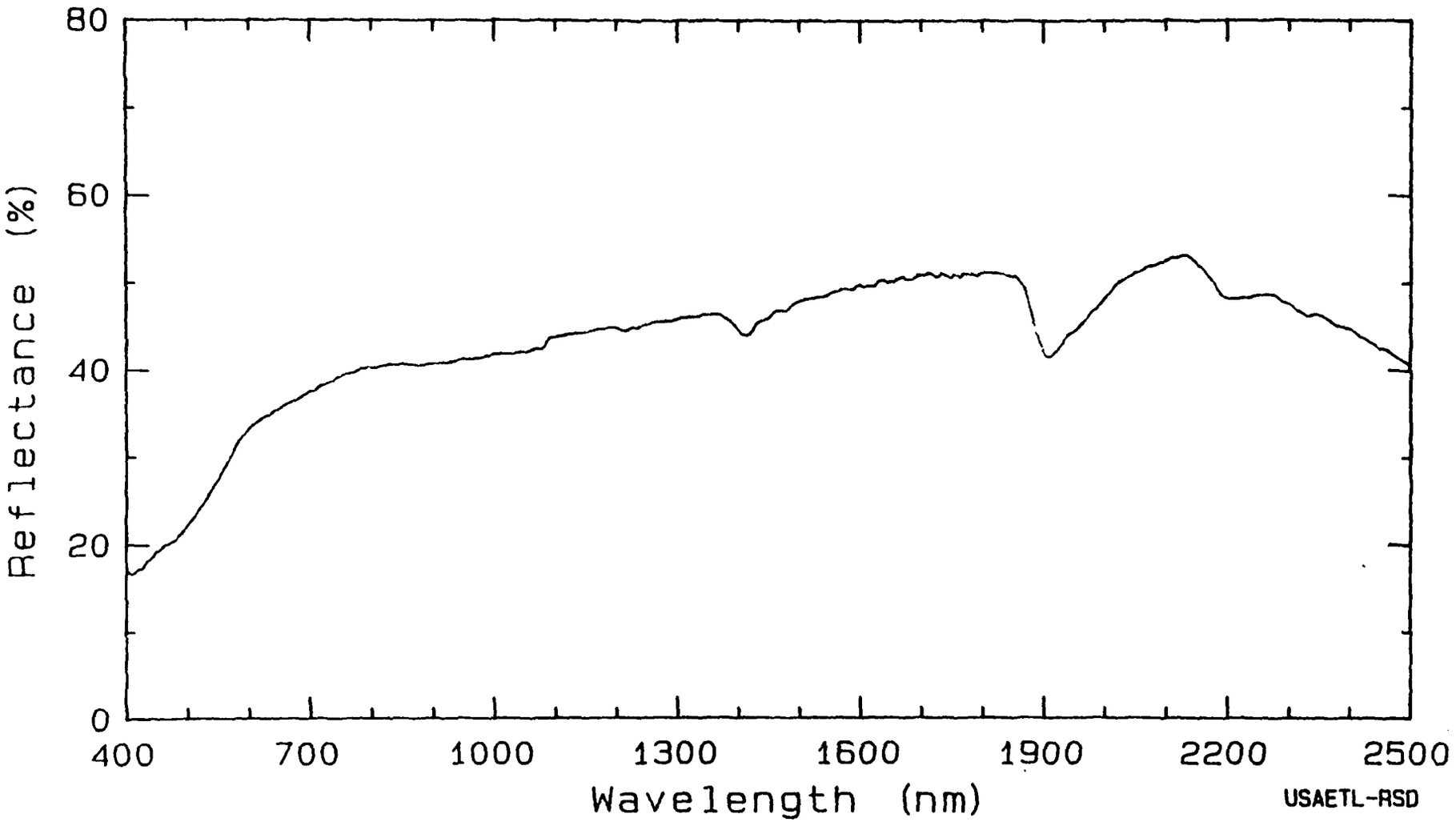
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 327a



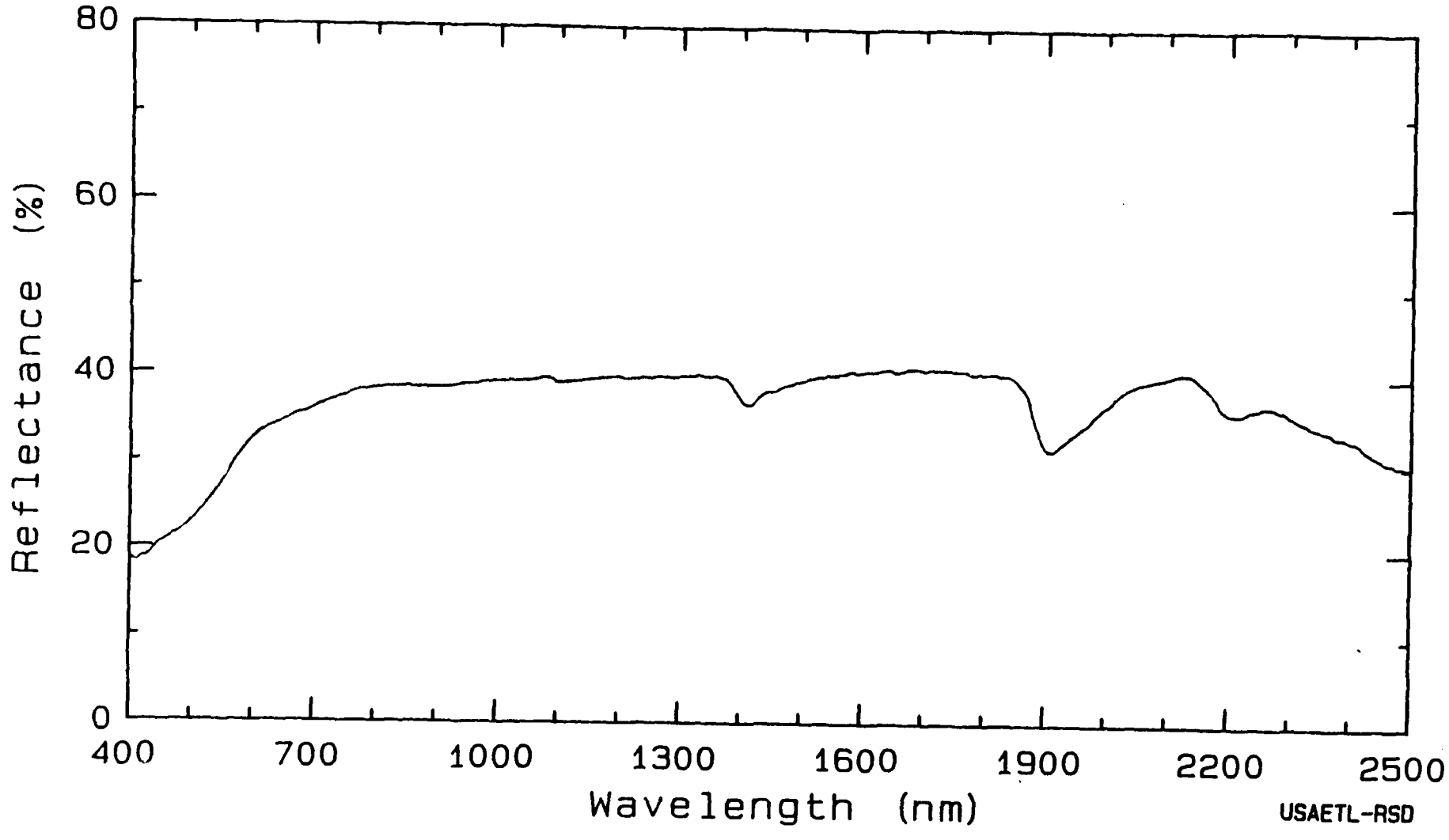
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 329a



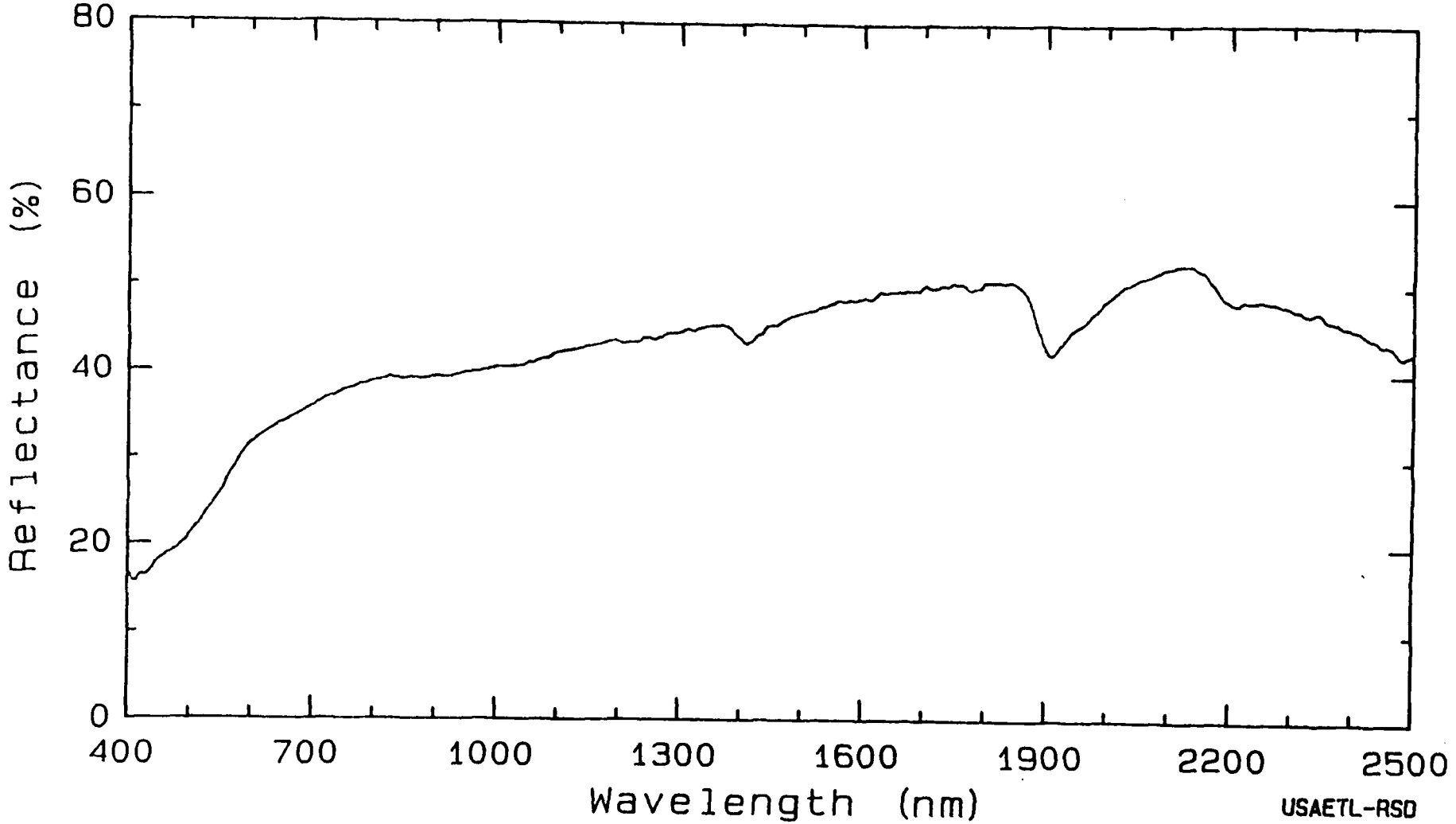
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 332a



Surface Reflectance of Desert Soils

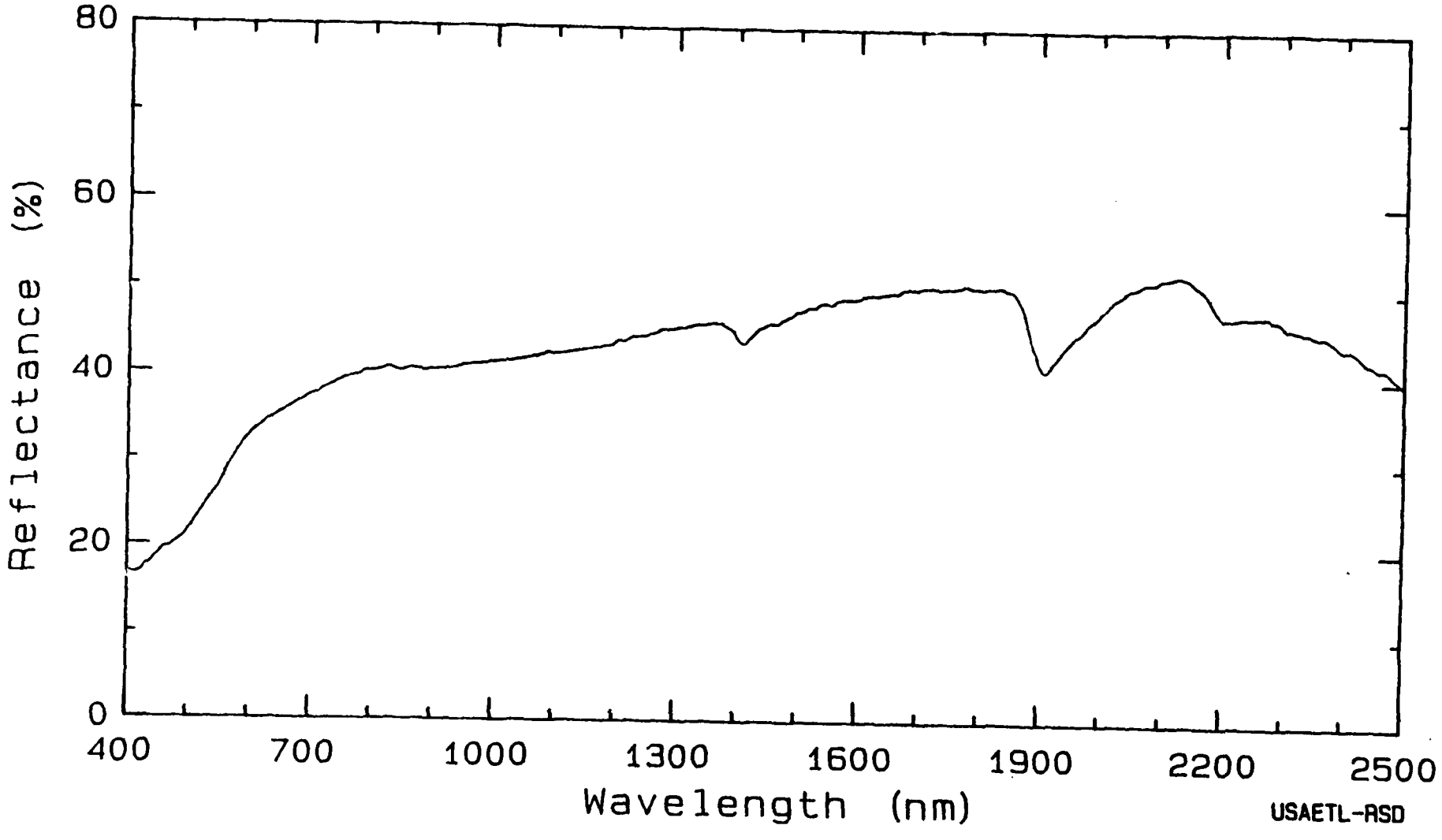
Twentynine Palms, CA. Sample: 334a



Surface Reflectance of Desert Soils

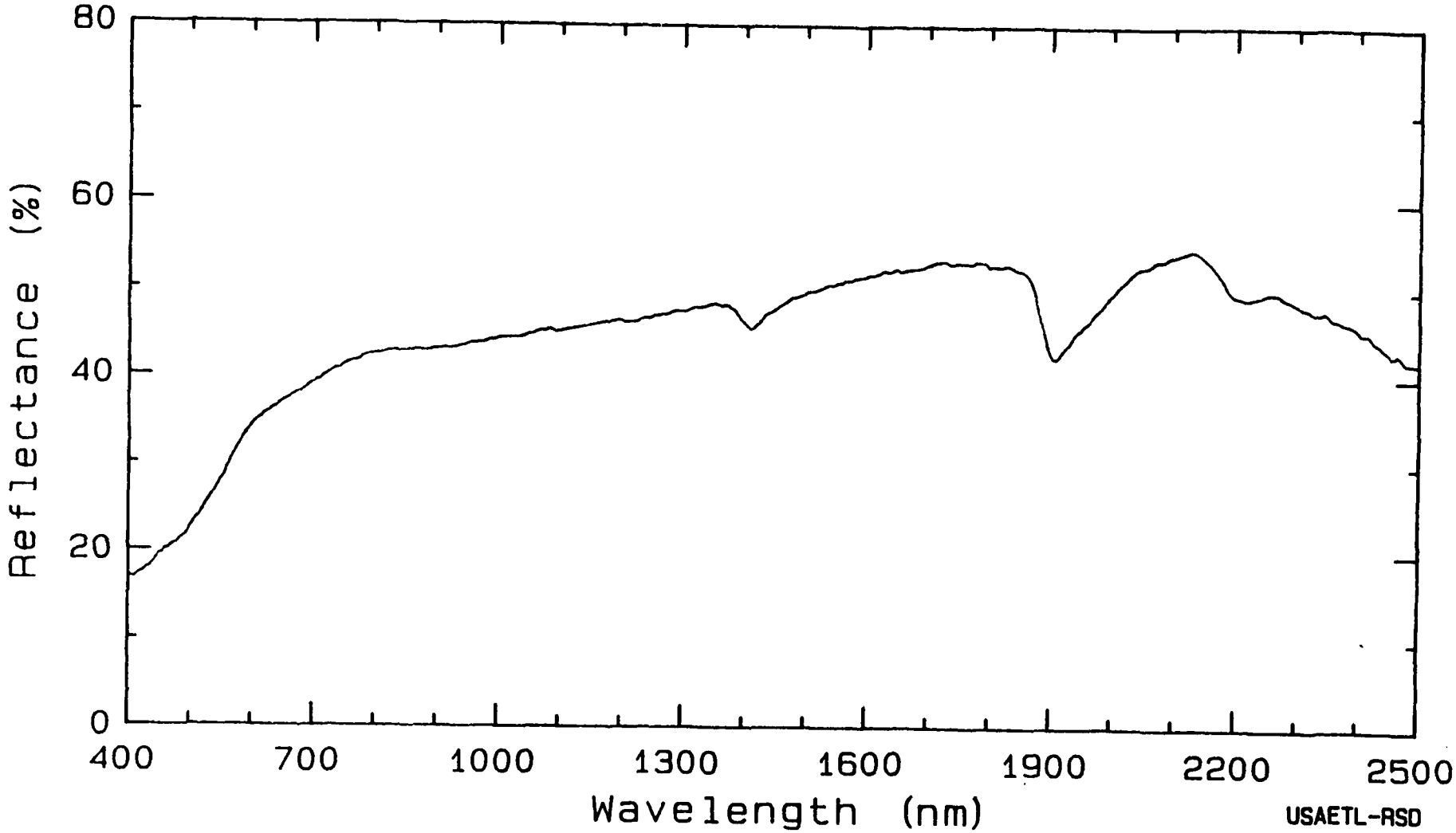
Twentynine Palms, CA Sample: 336a

2. Backfill Samples, Phase I



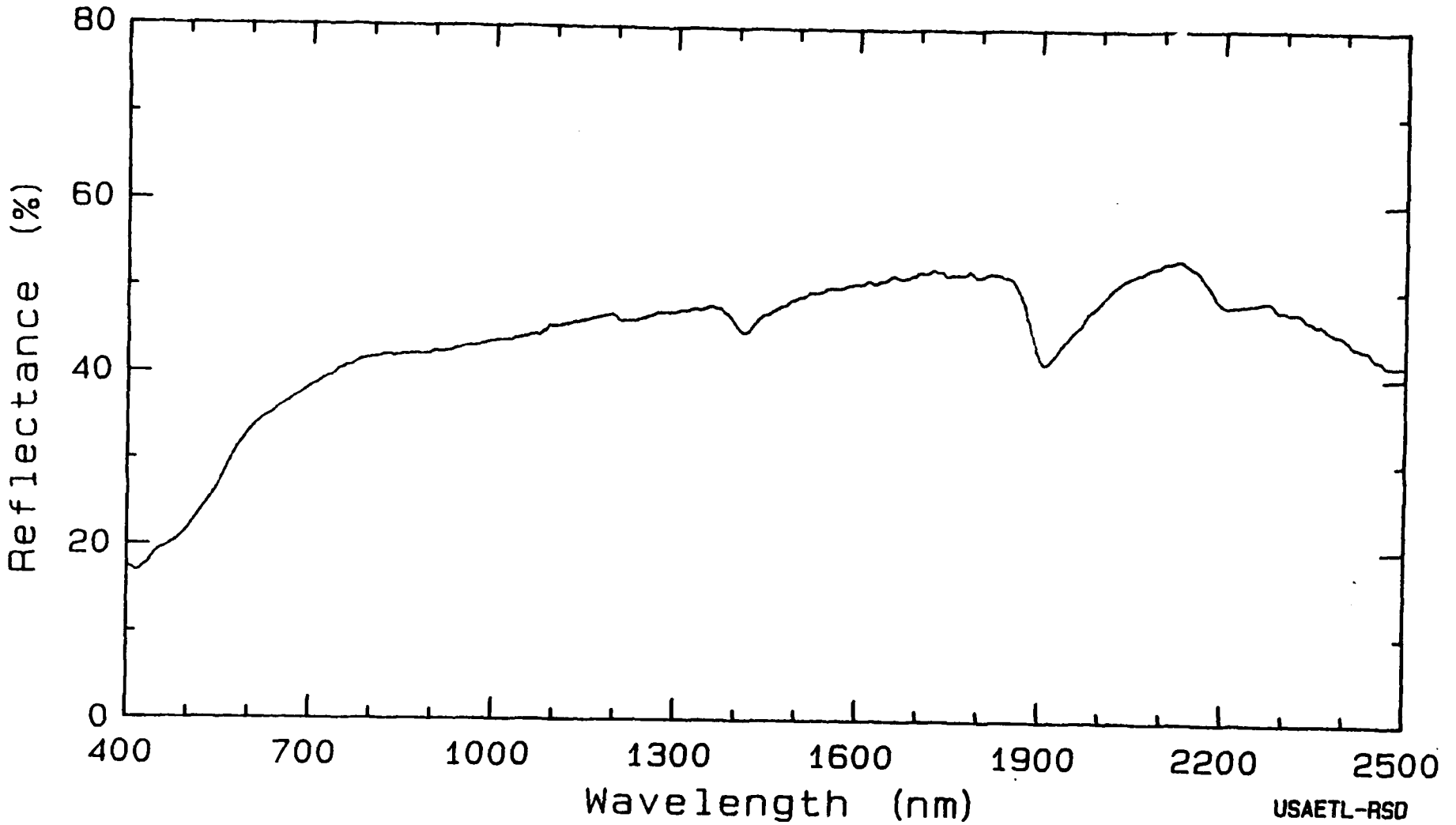
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 312a



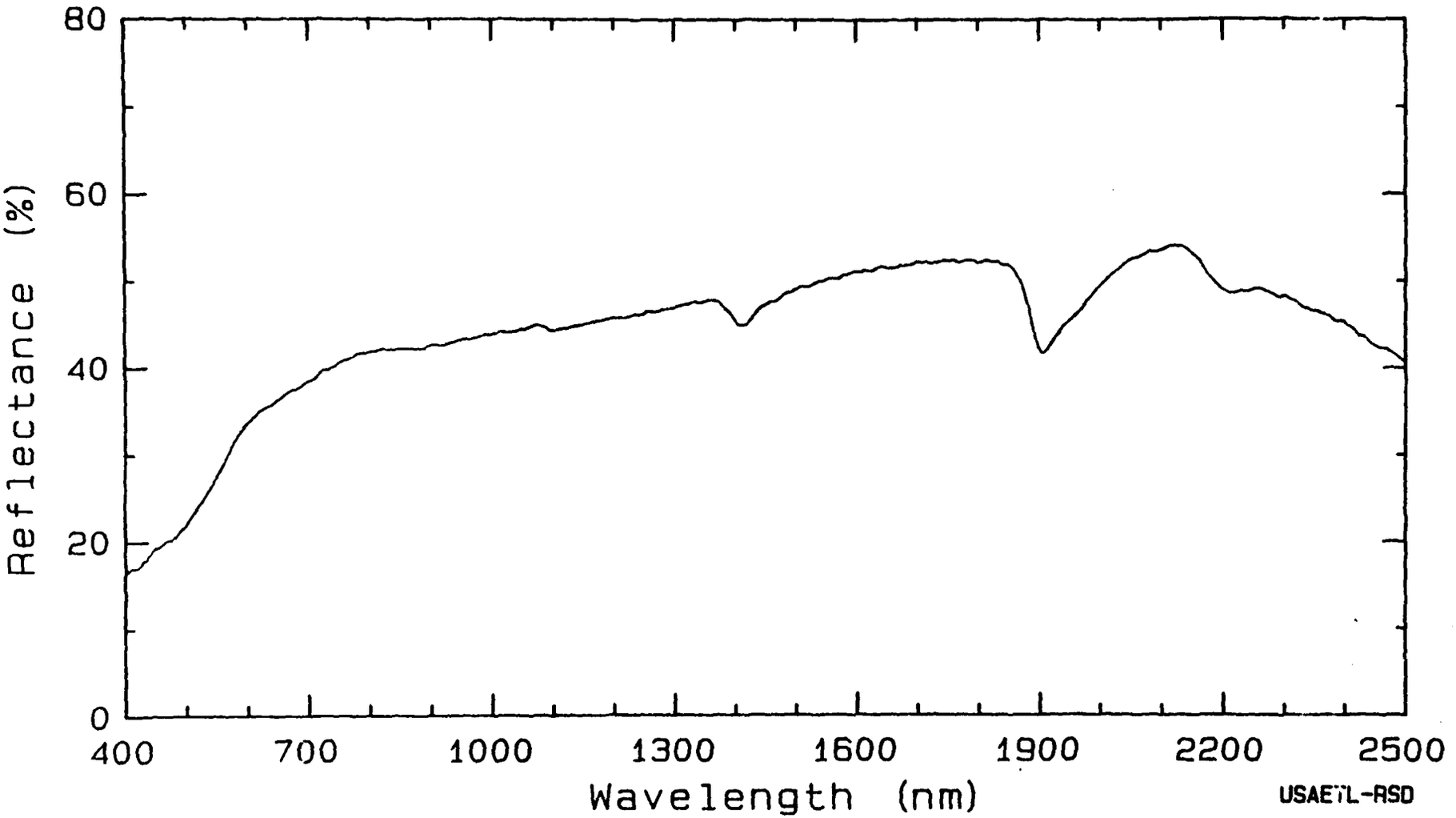
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 313a



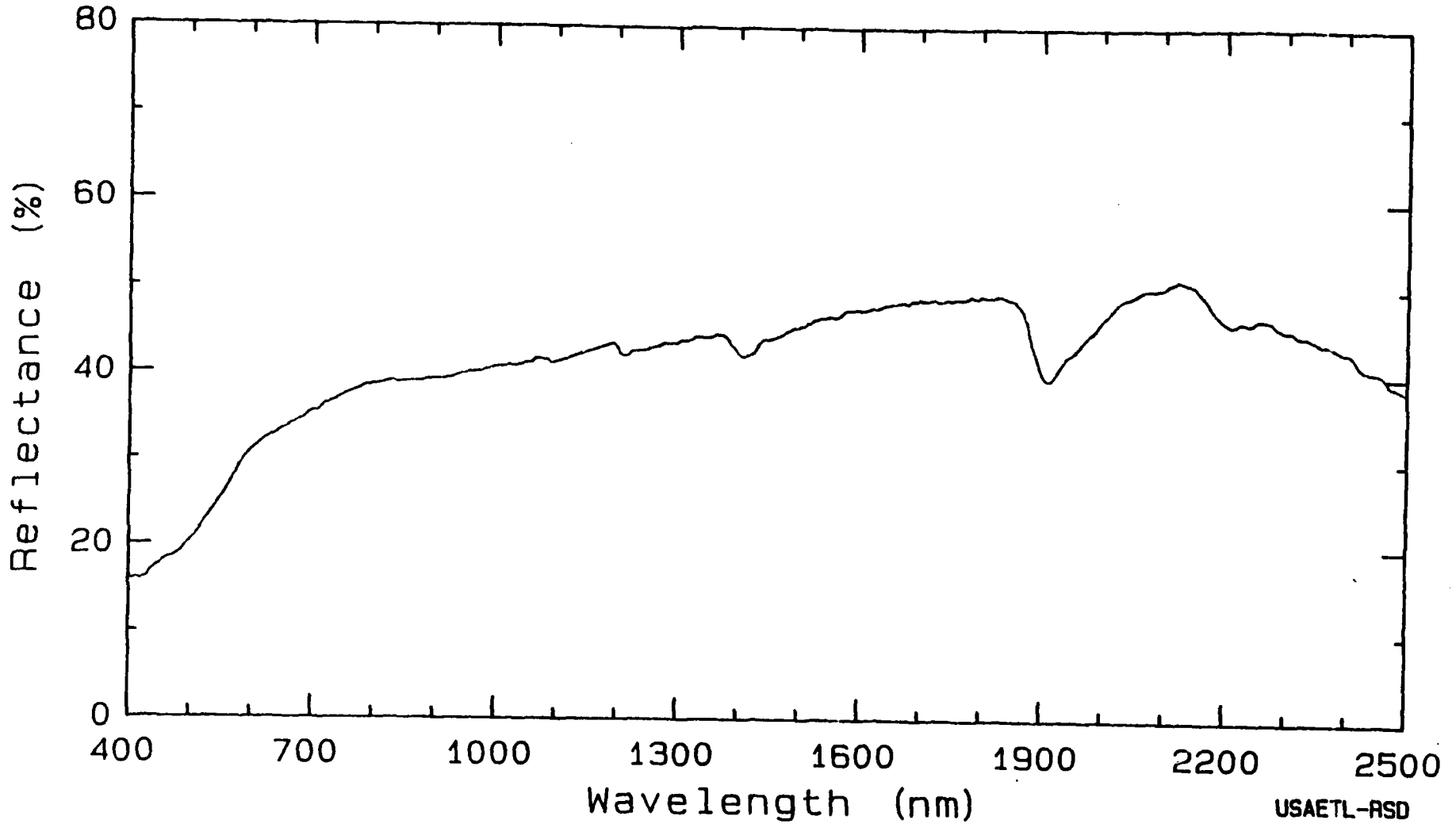
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 315a



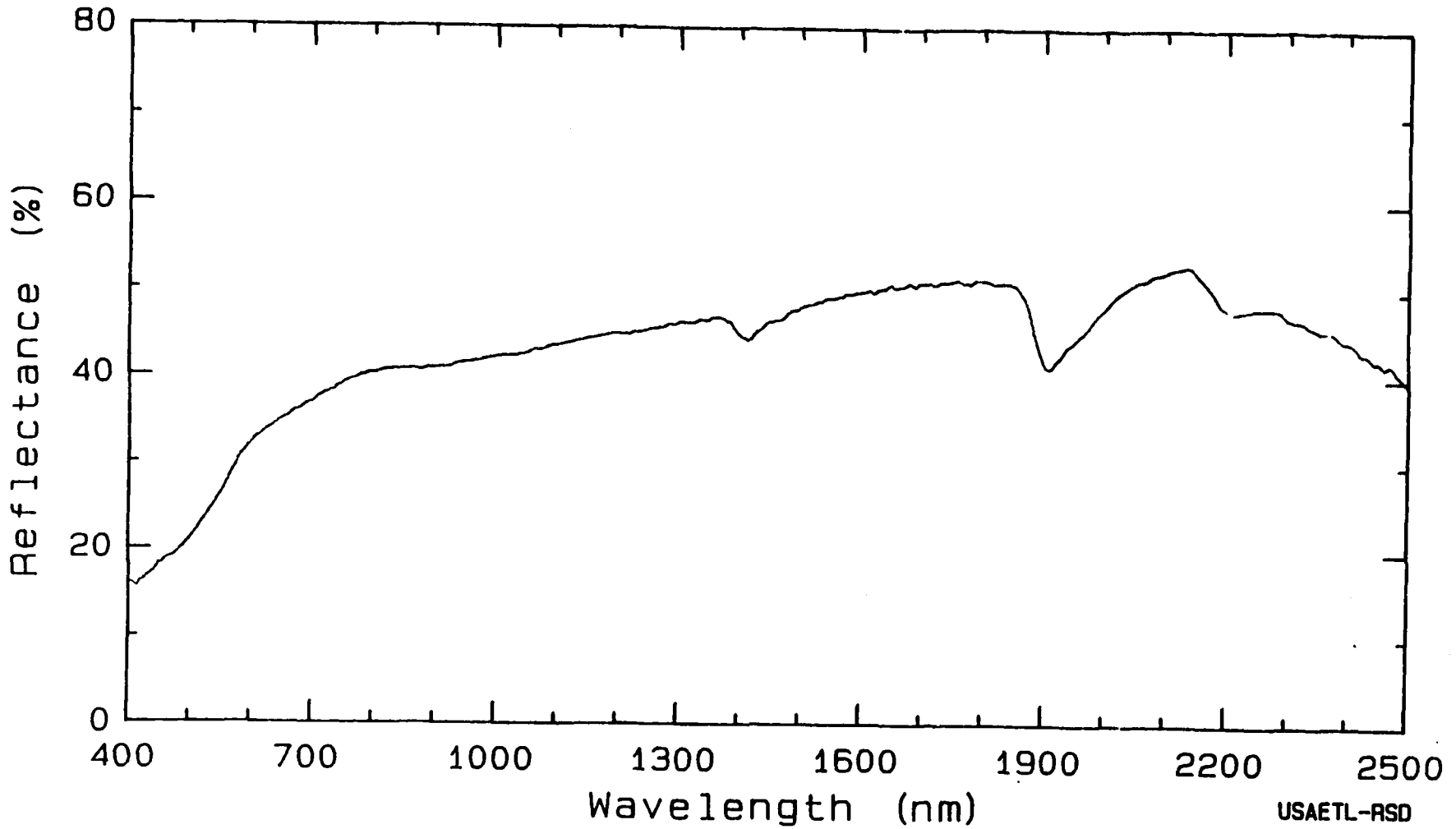
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 317a



Surface Reflectance of Desert Soils

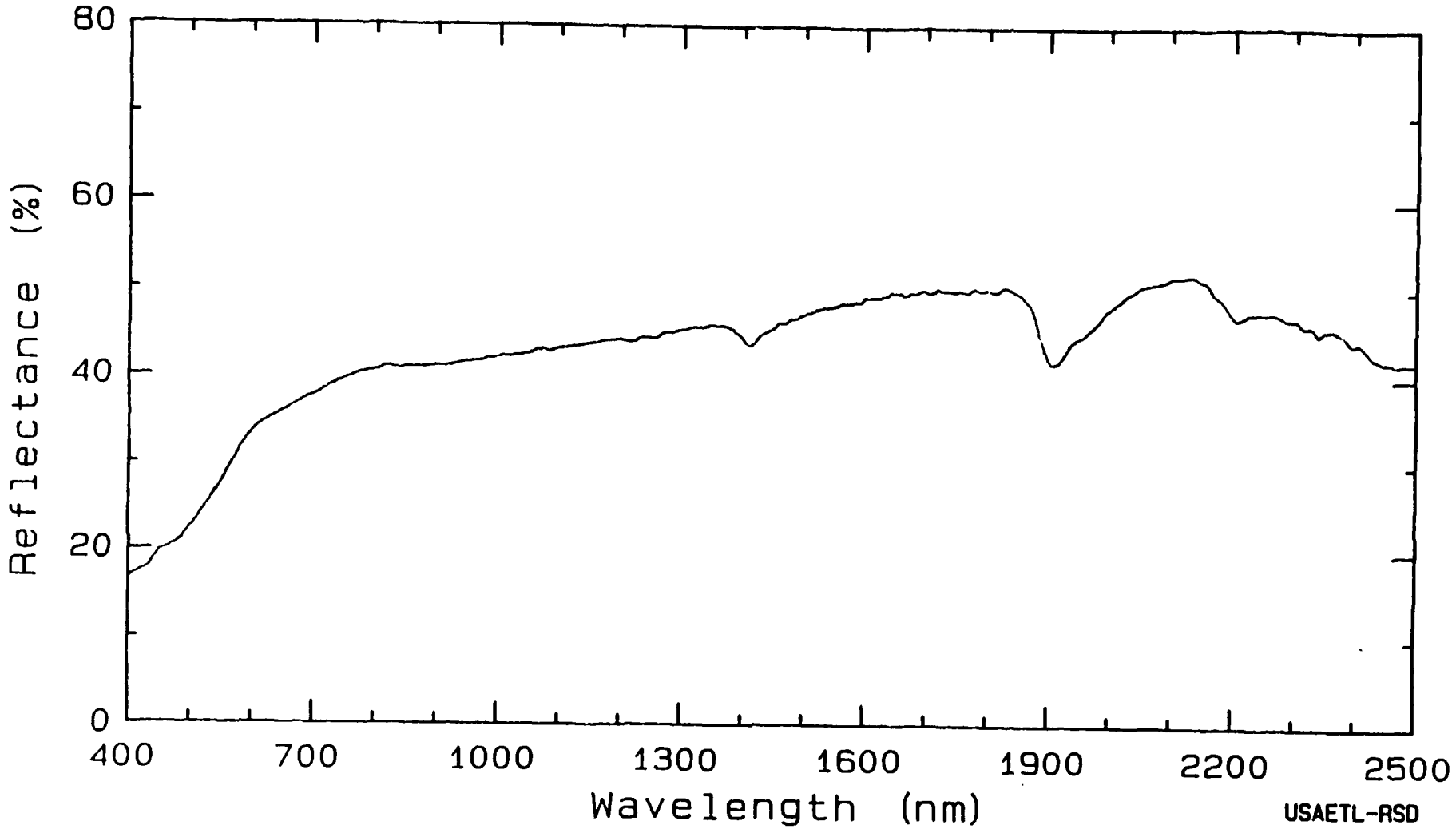
Twentynine Palms, CA. Sample: 318a



Surface Reflectance of Desert Soils

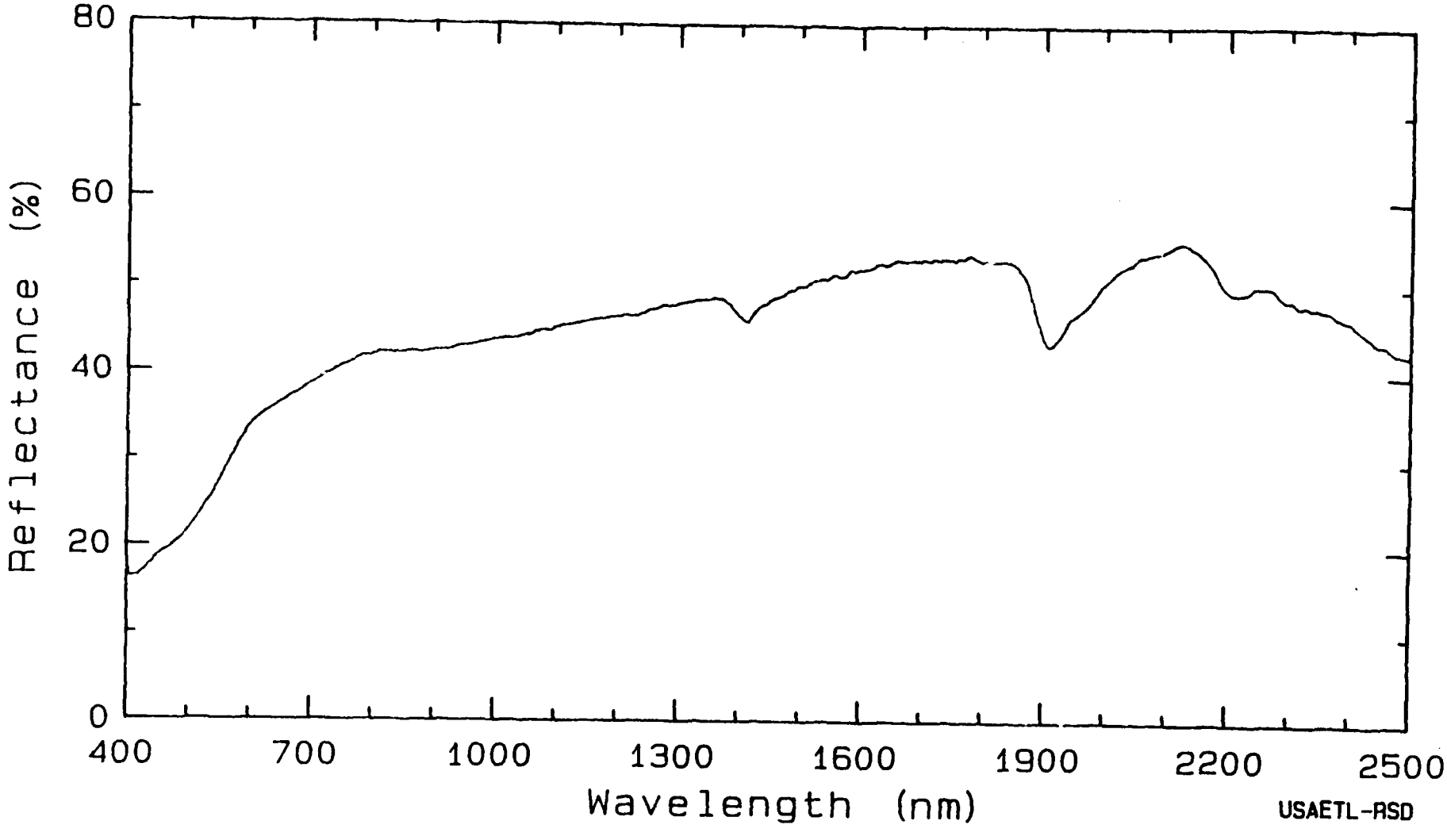
Twentynine Palms, CA. Sample: 319a

3. Surface Samples, Phase II



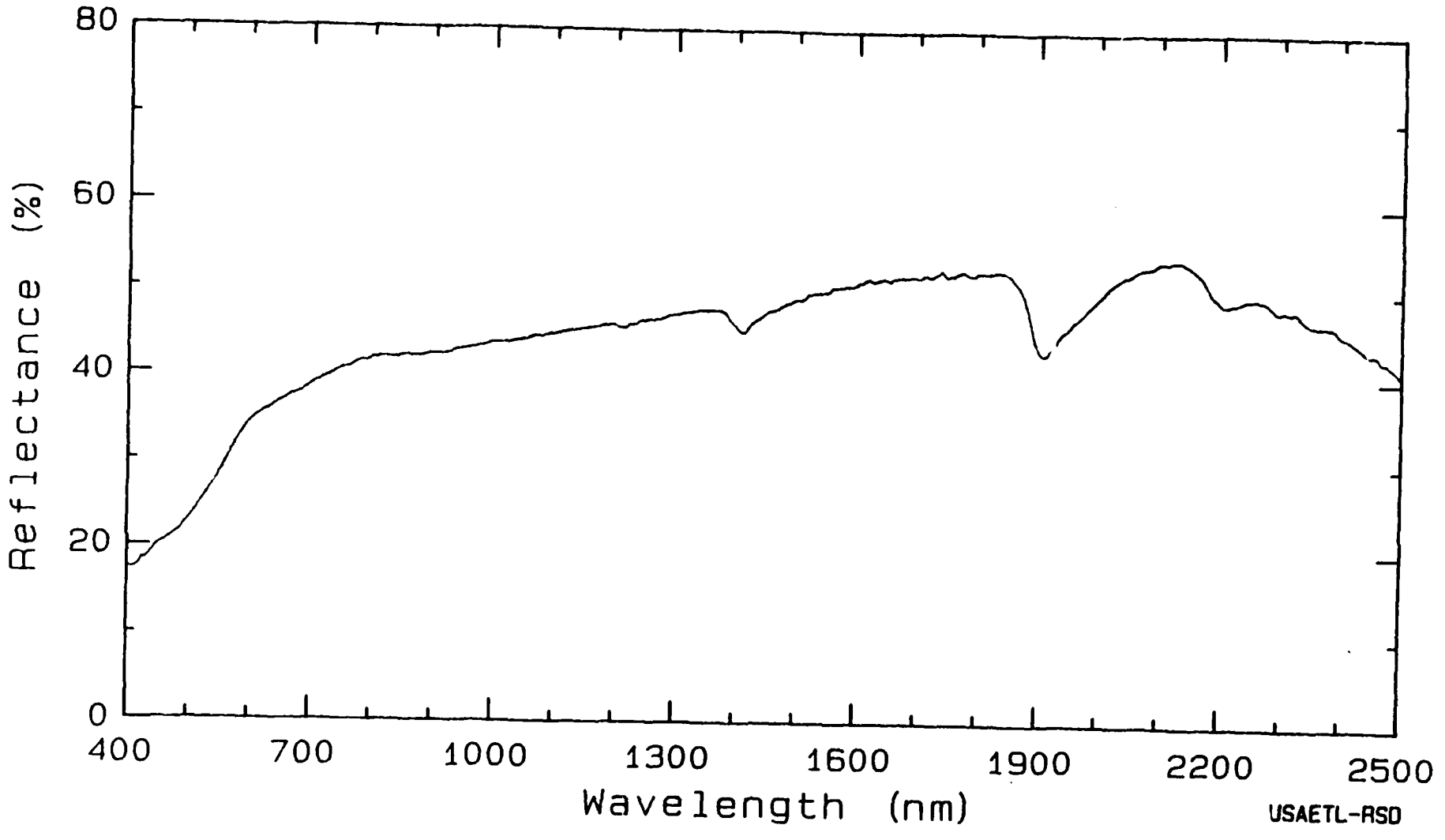
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 312b



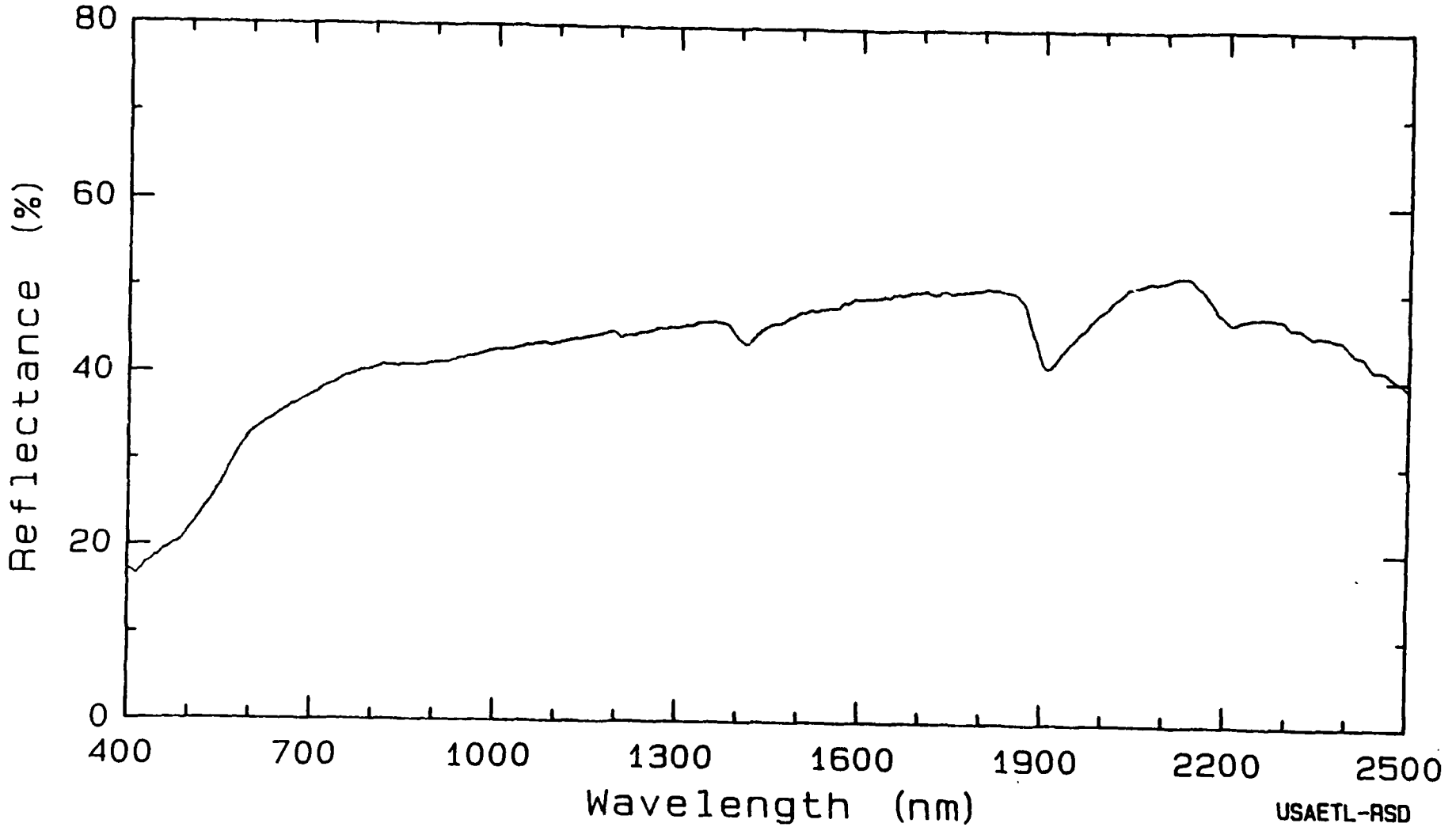
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 323b



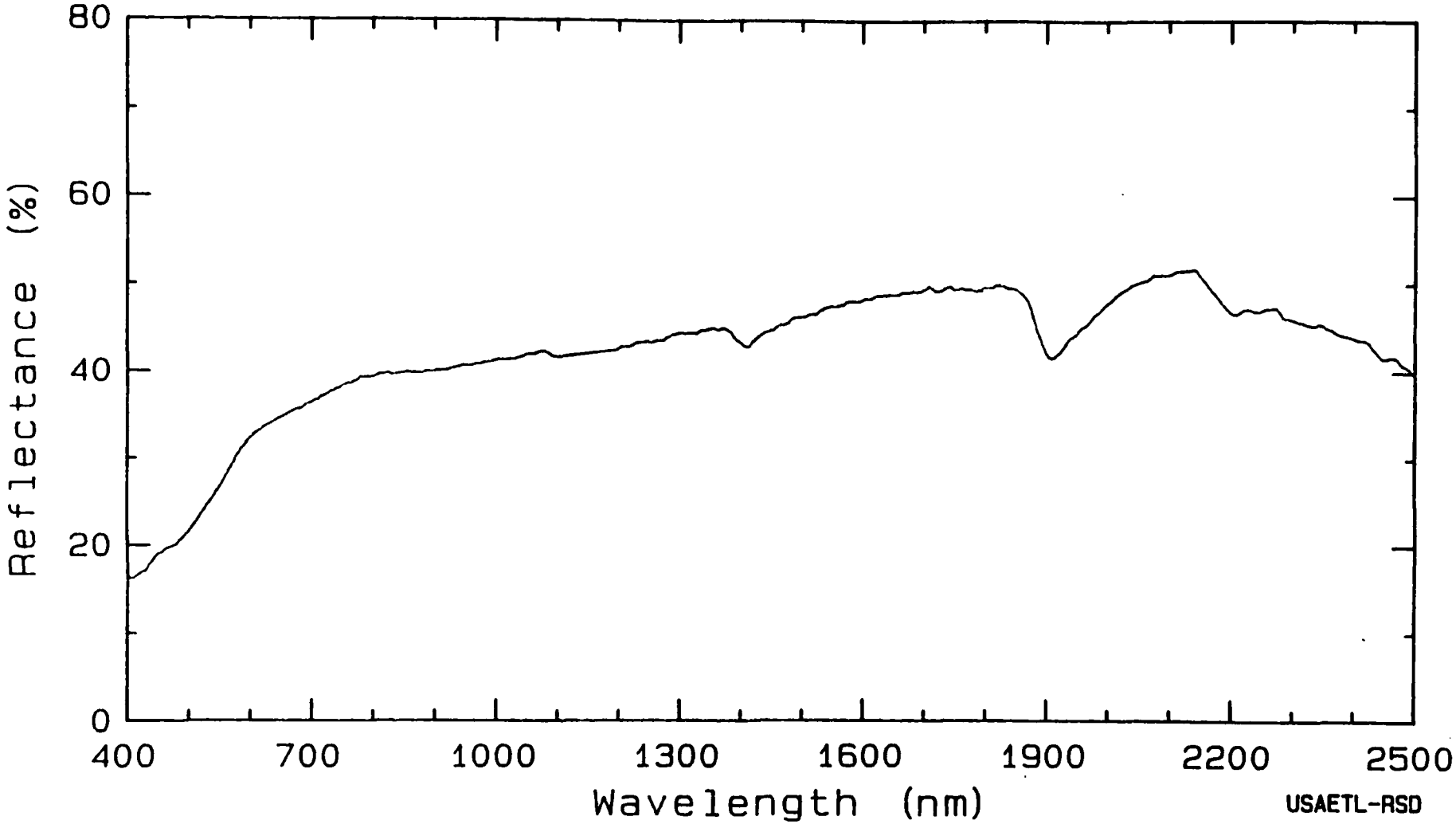
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 327b



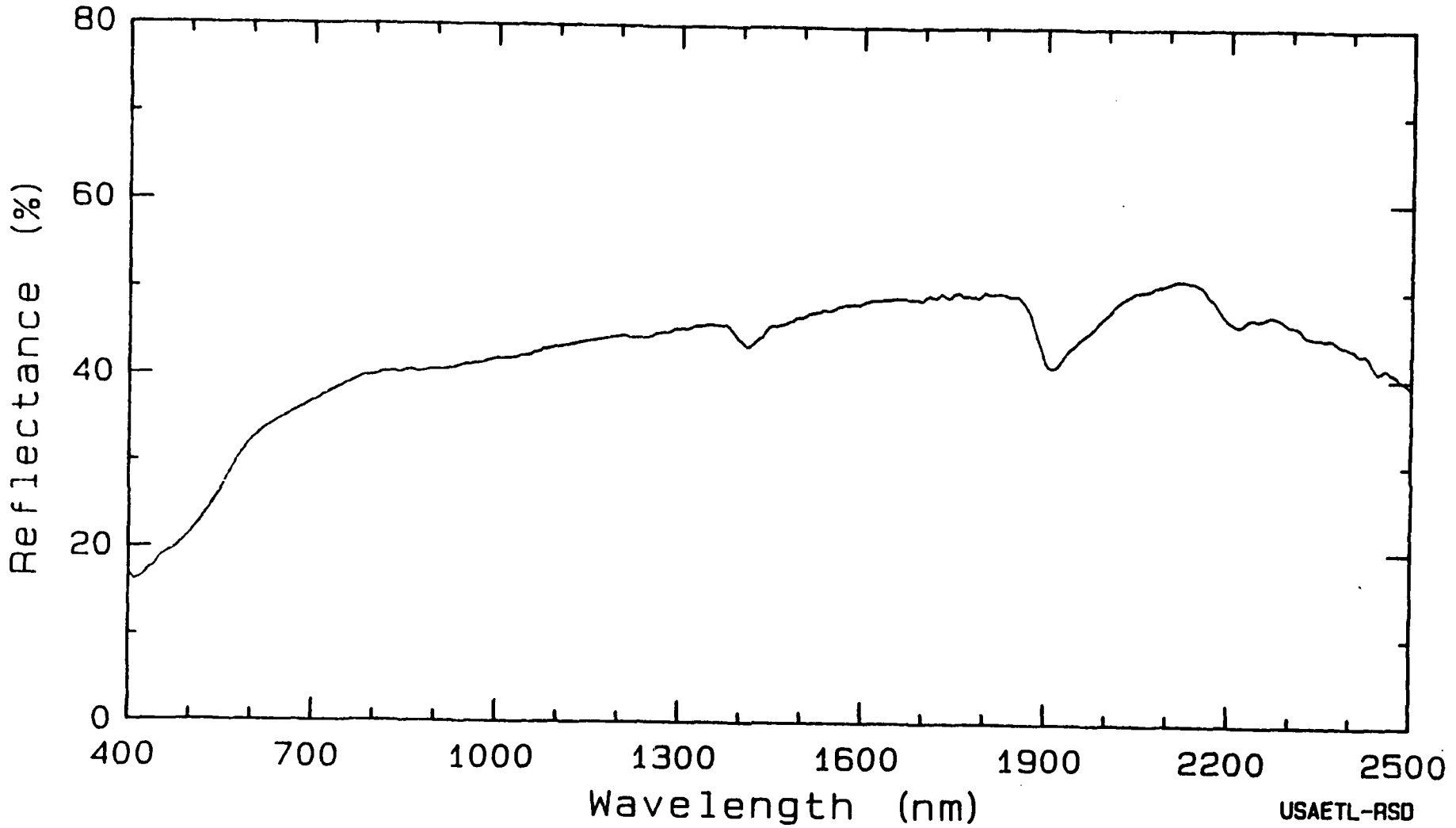
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 339b



Surface Reflectance of Desert Soils

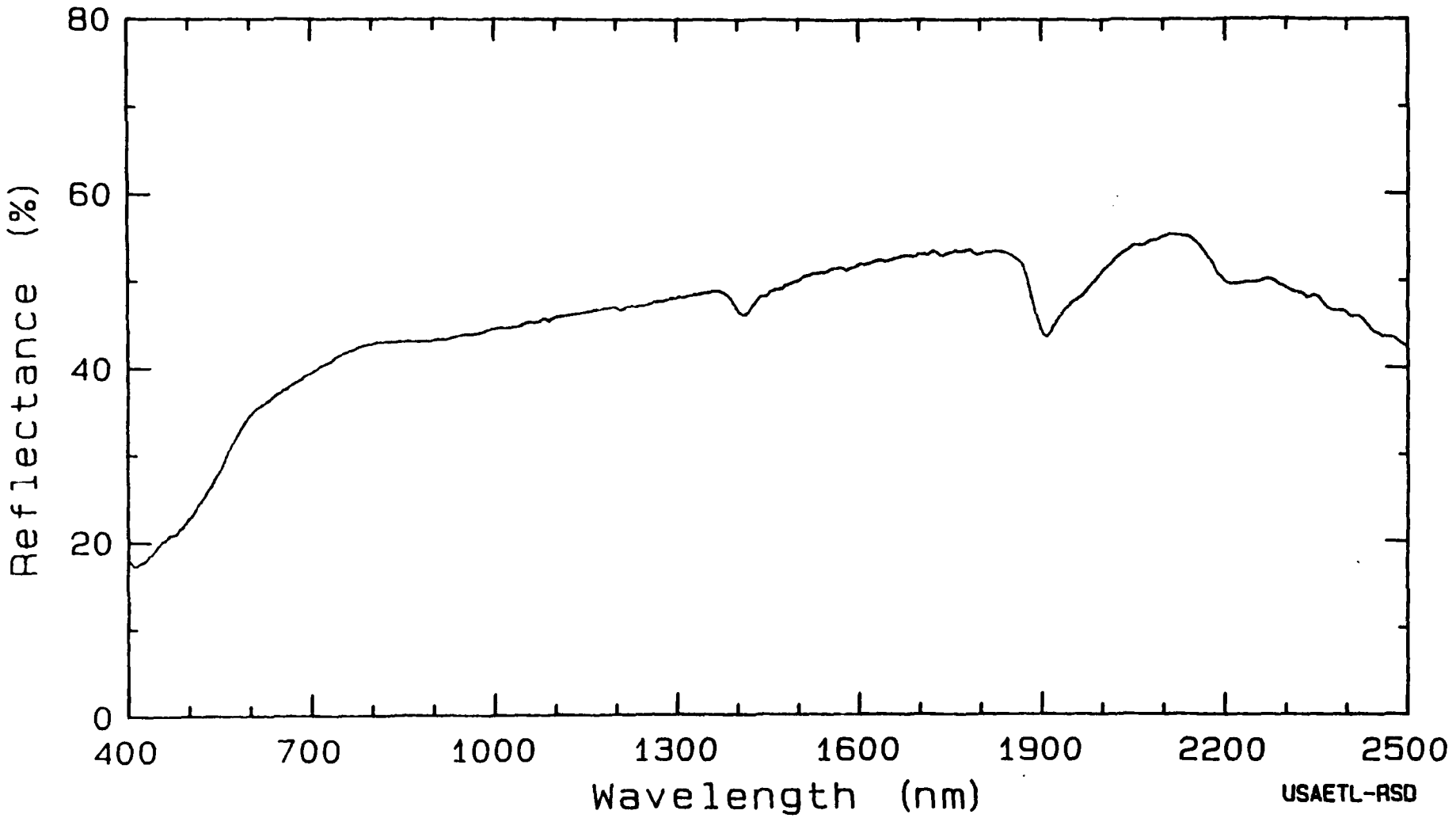
Twentynine Palms, CA. Sample: 342b



Surface Reflectance of Desert Soils

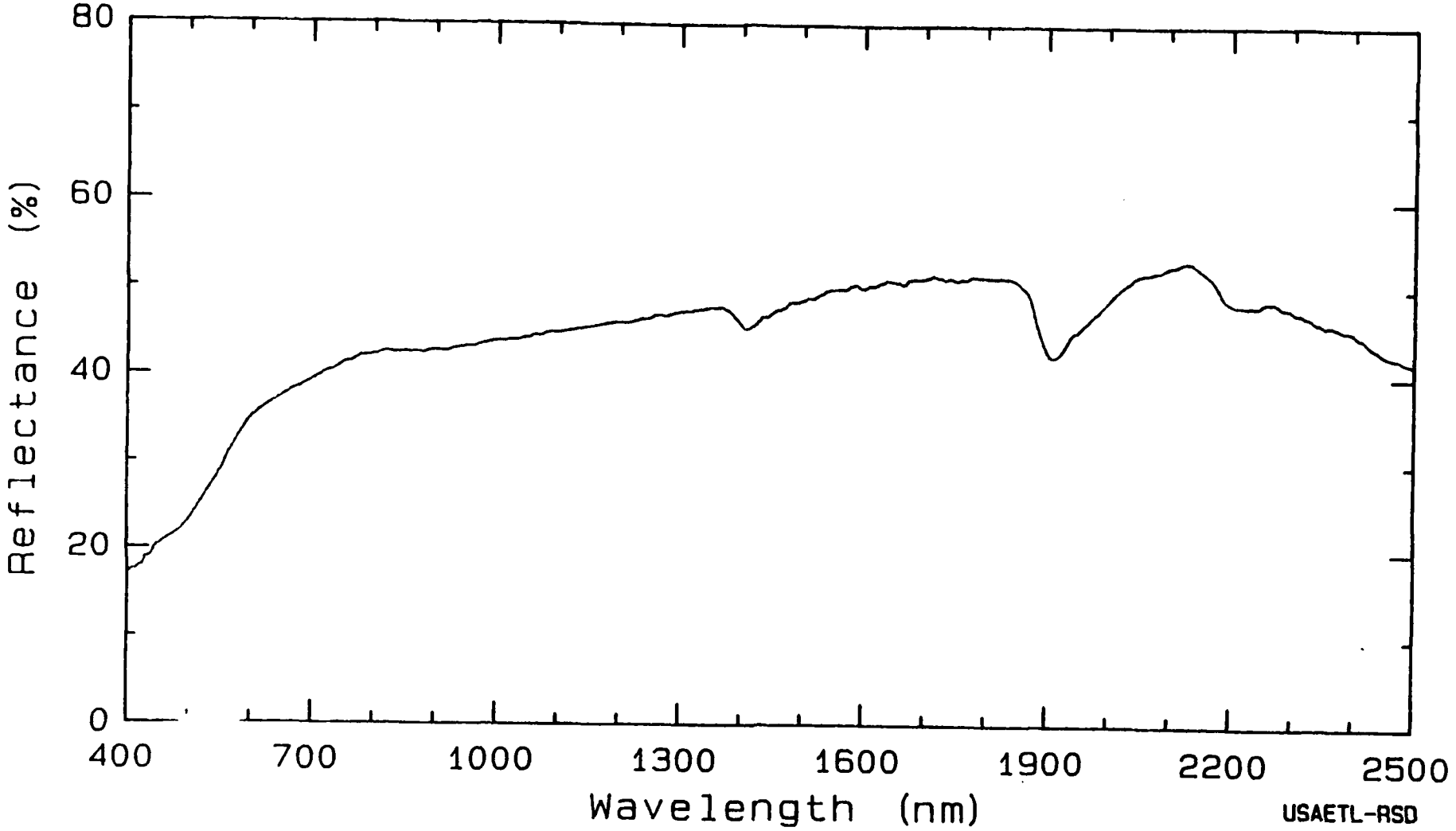
Twentynine Palms, CA. Sample: 344b

4. Backfill Samples, Phase II



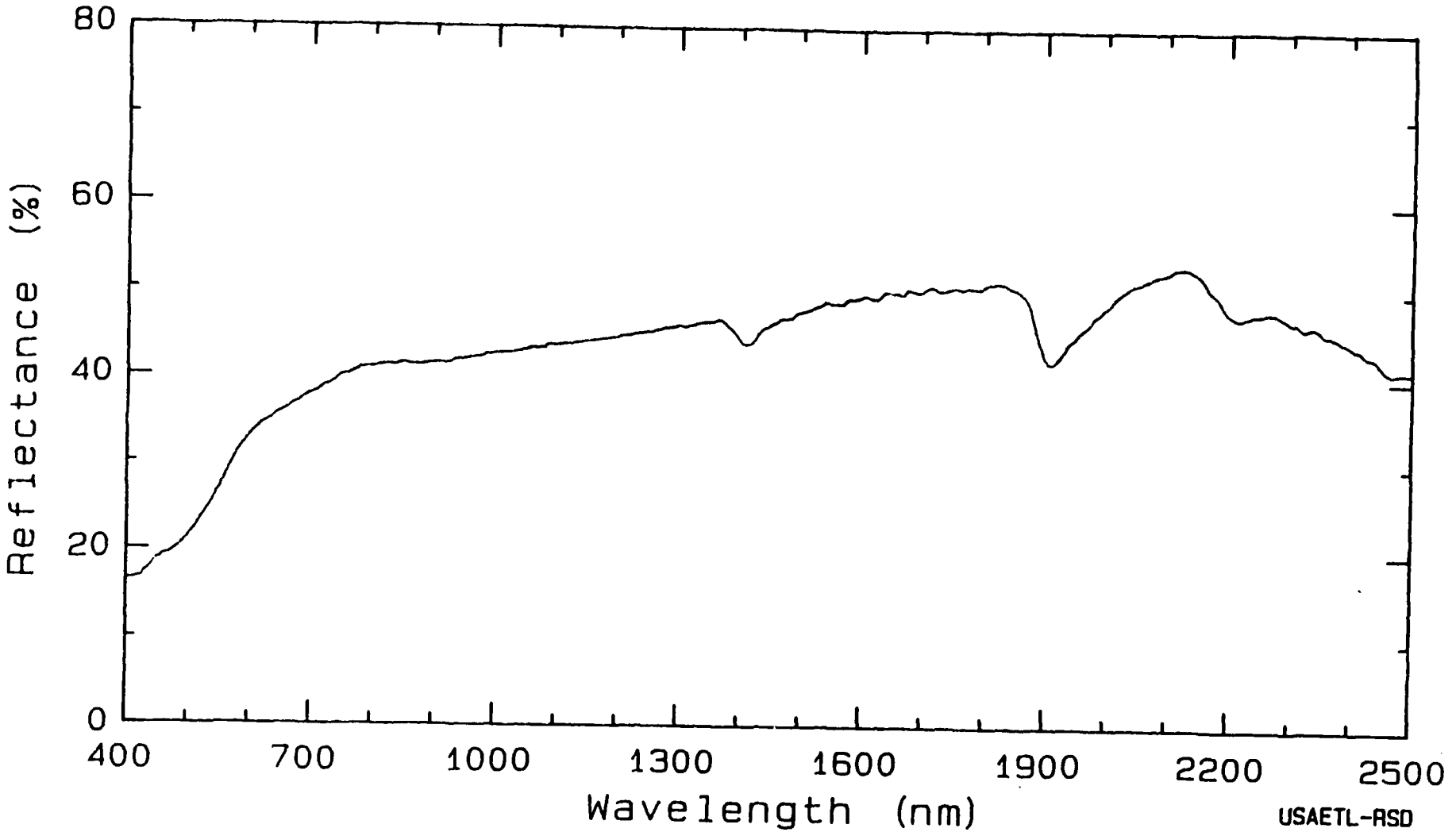
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 315b



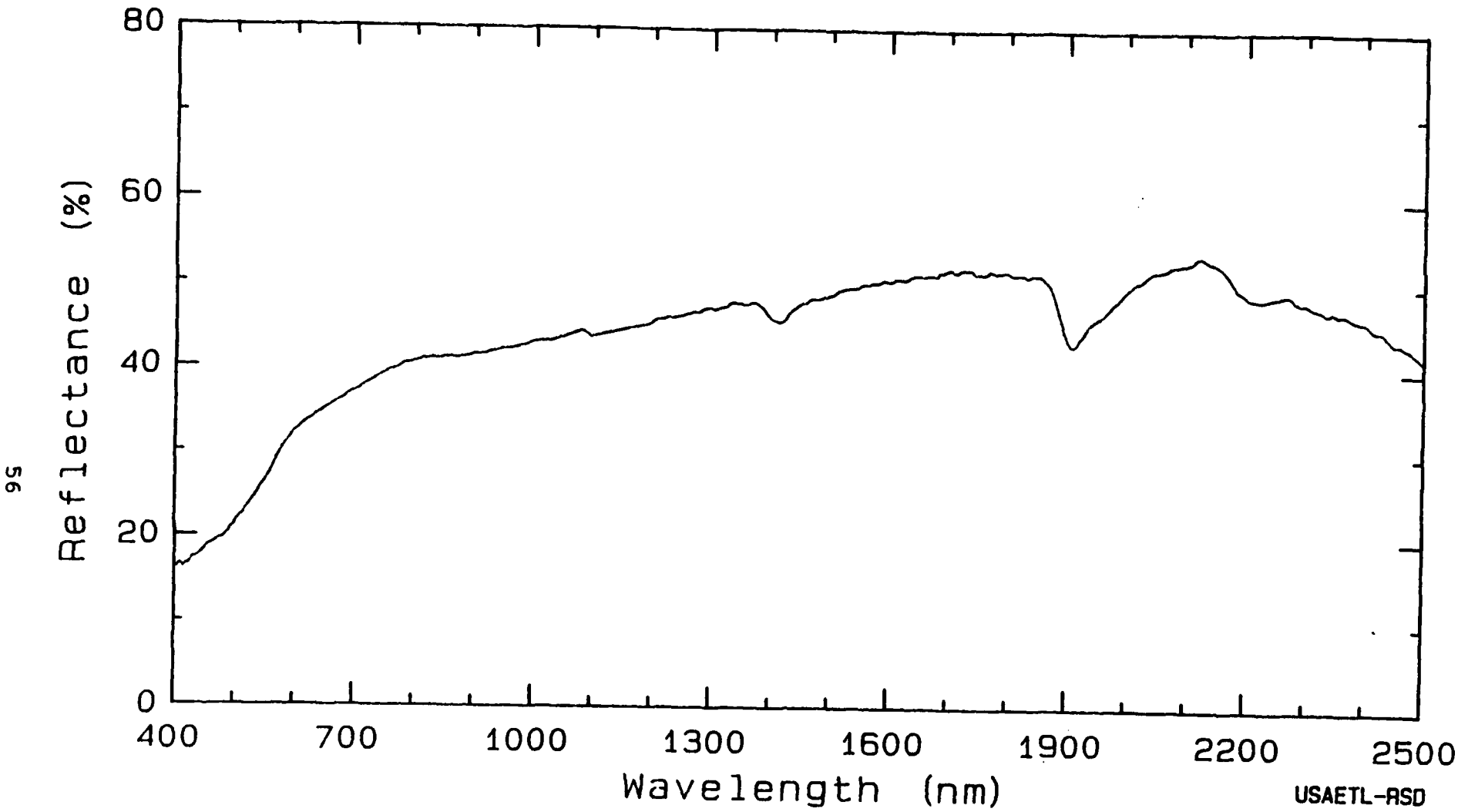
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 316b



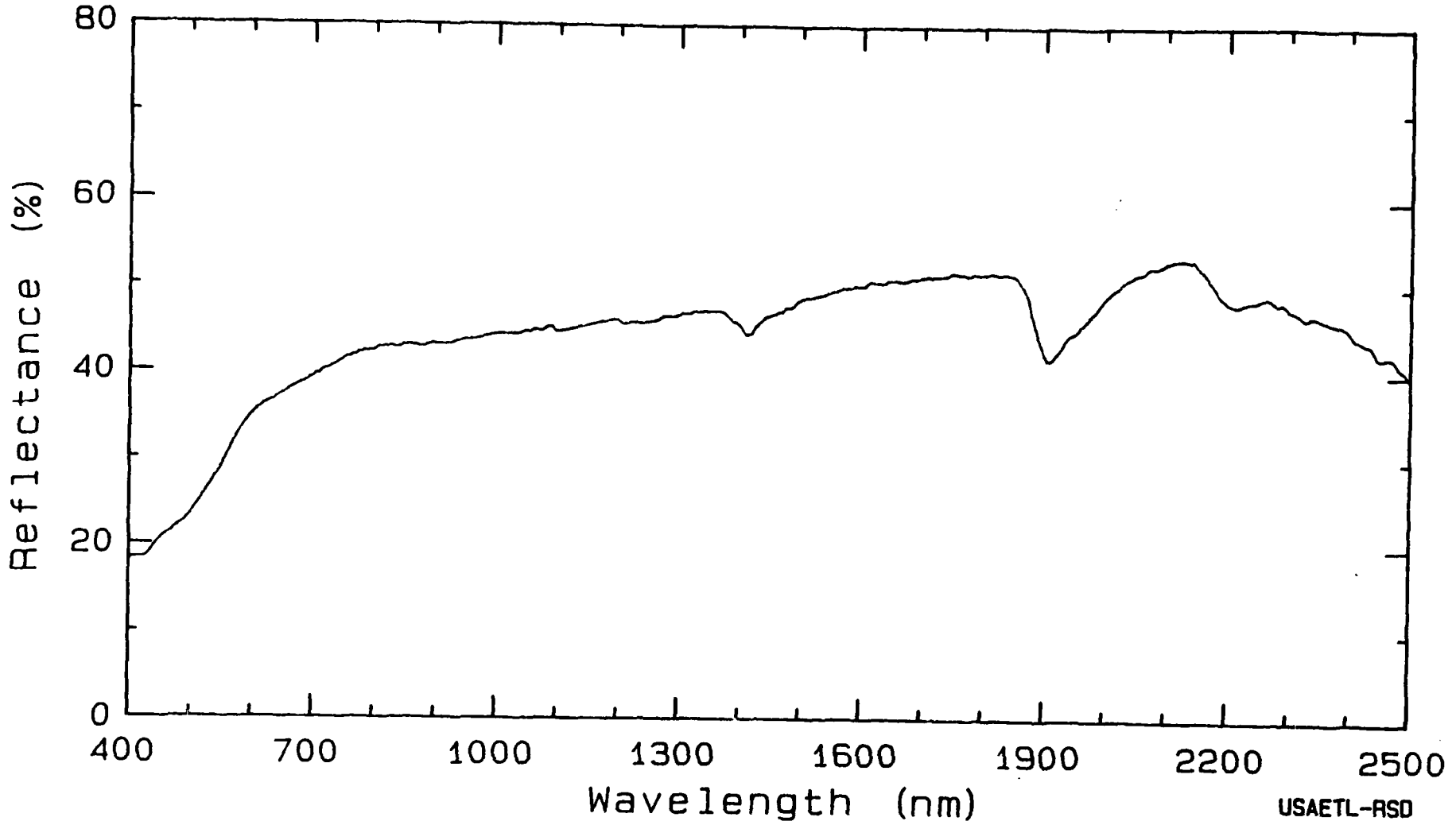
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 320b



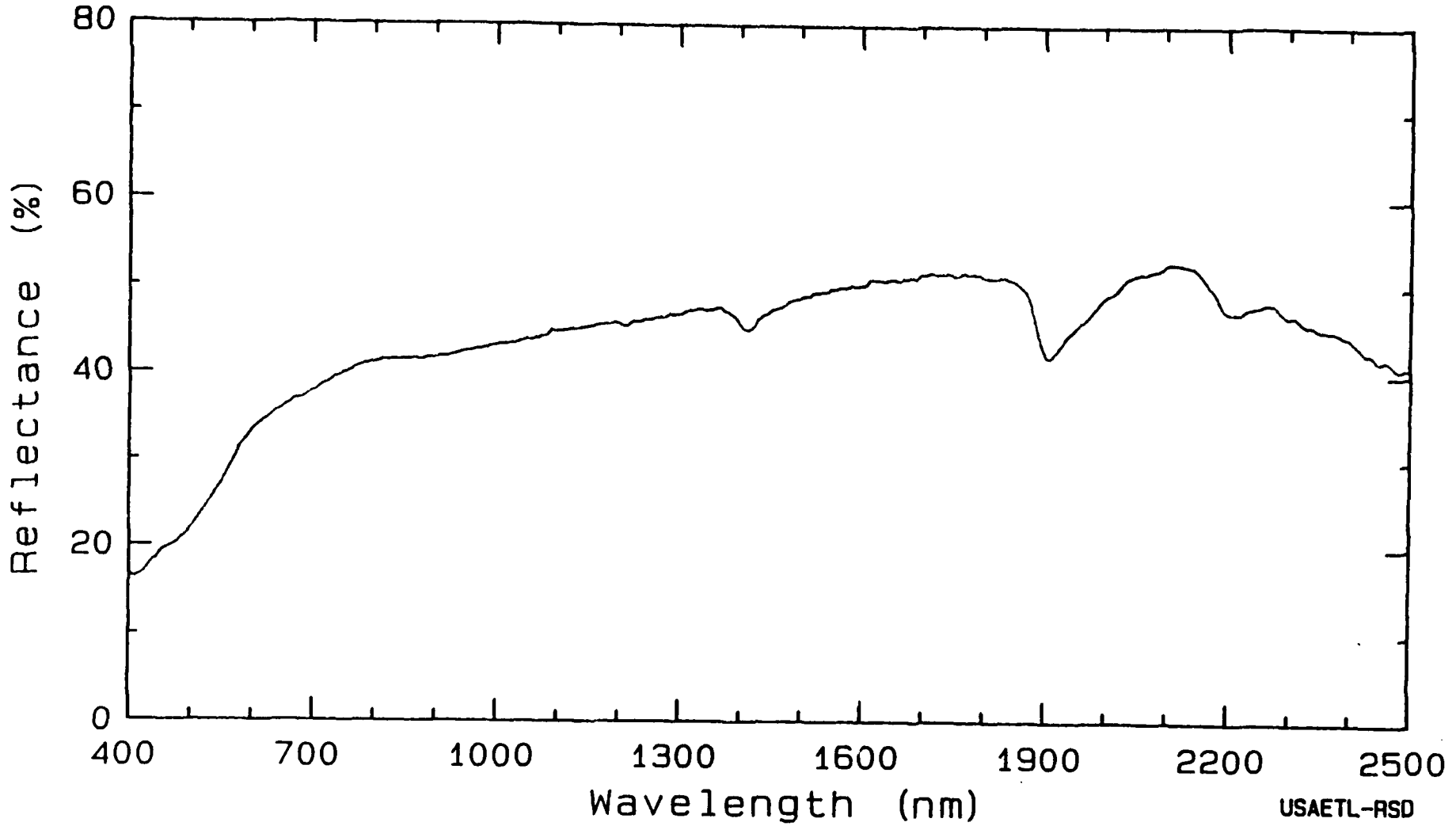
Surface Reflectance of Desert Soils

Twentynine Palms, CA. Sample: 325b



Surface Reflectance of Desert Soils

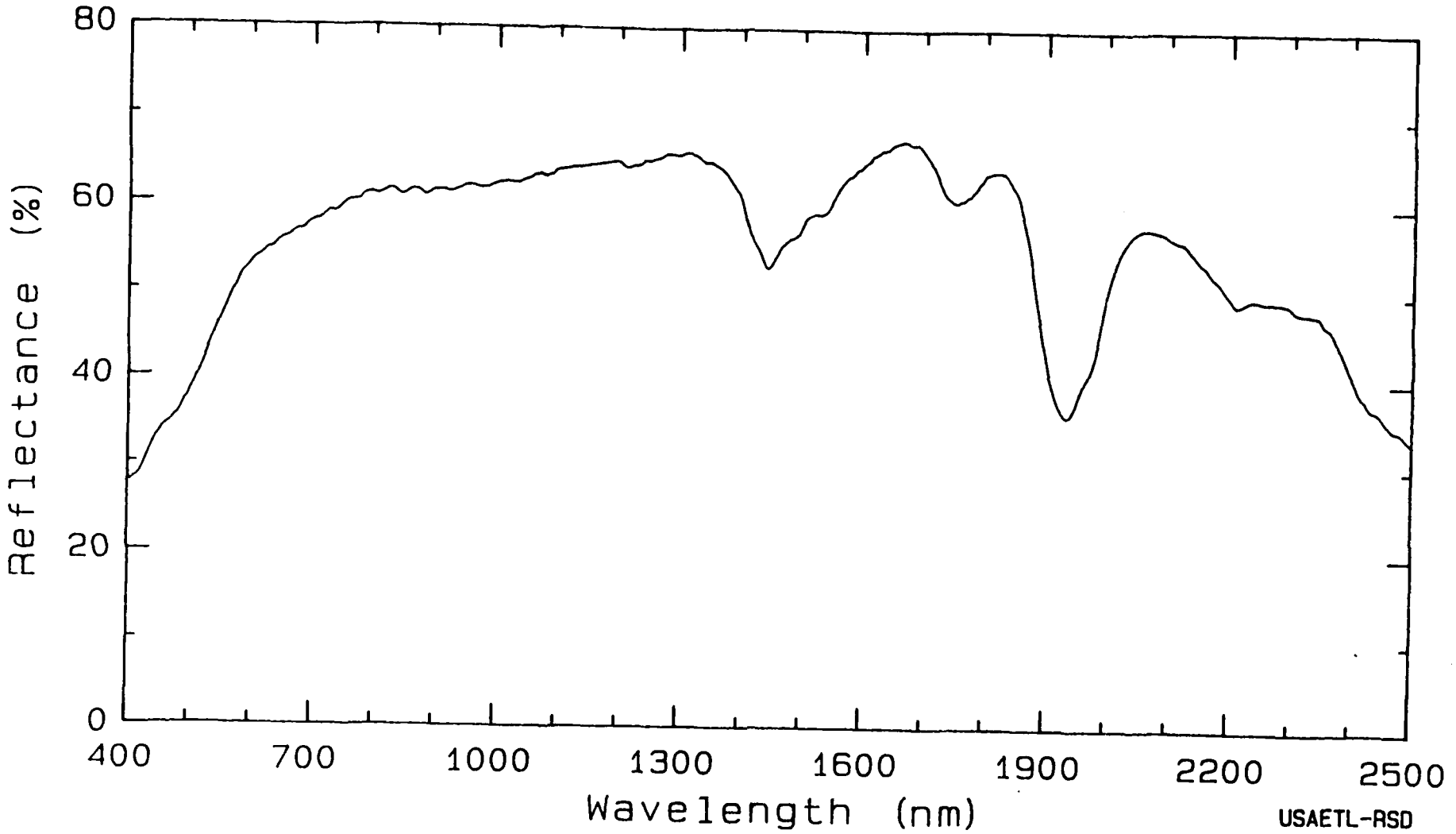
Twentynine Palms, CA. Sample: 326b



Surface Reflectance of Desert Soils

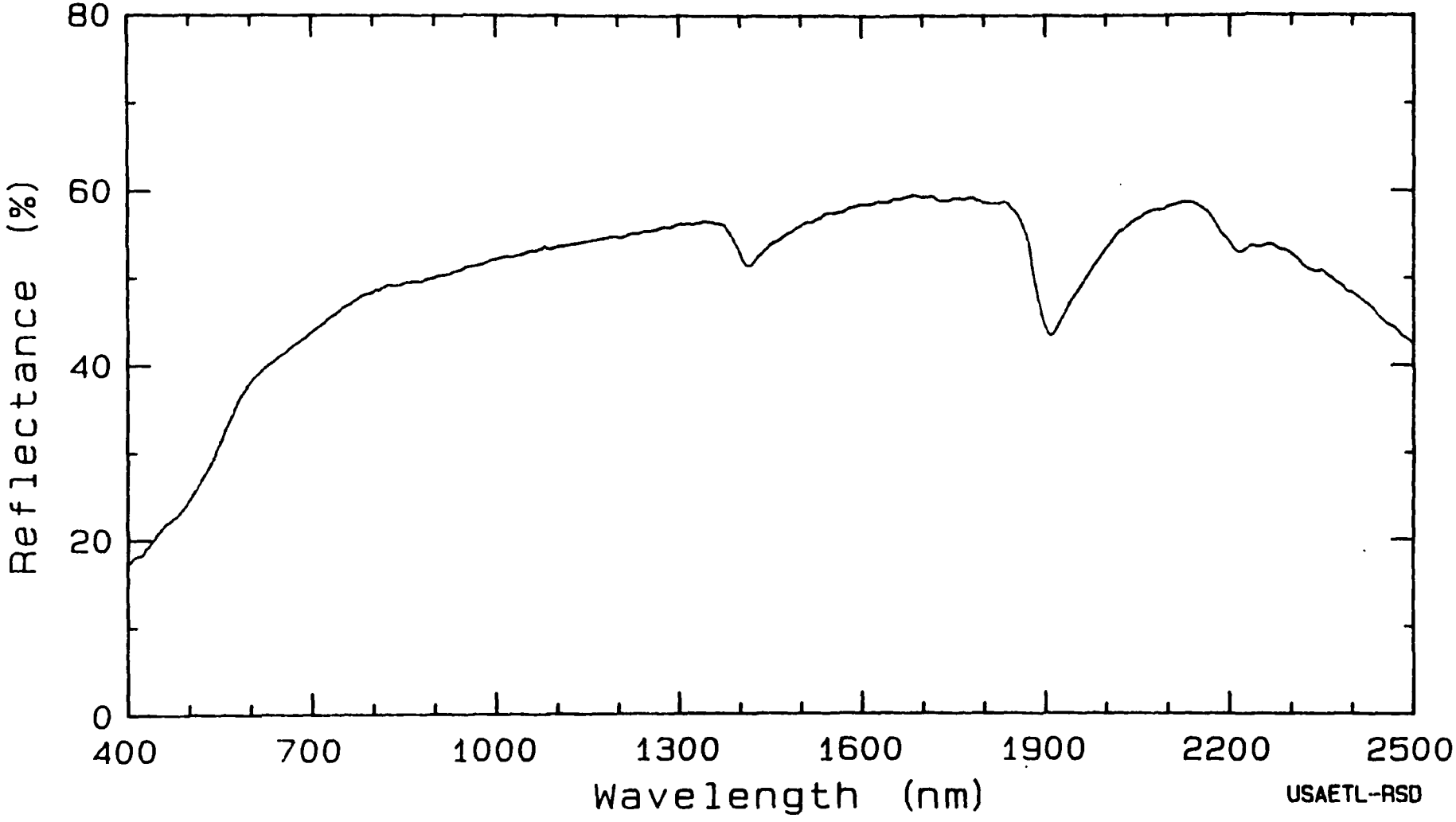
Twentynine Palms, CA. Sample: 338b

APPENDIX B. REFLECTANCE SPECTRA OF SOILS FROM SAUDI ARABIA



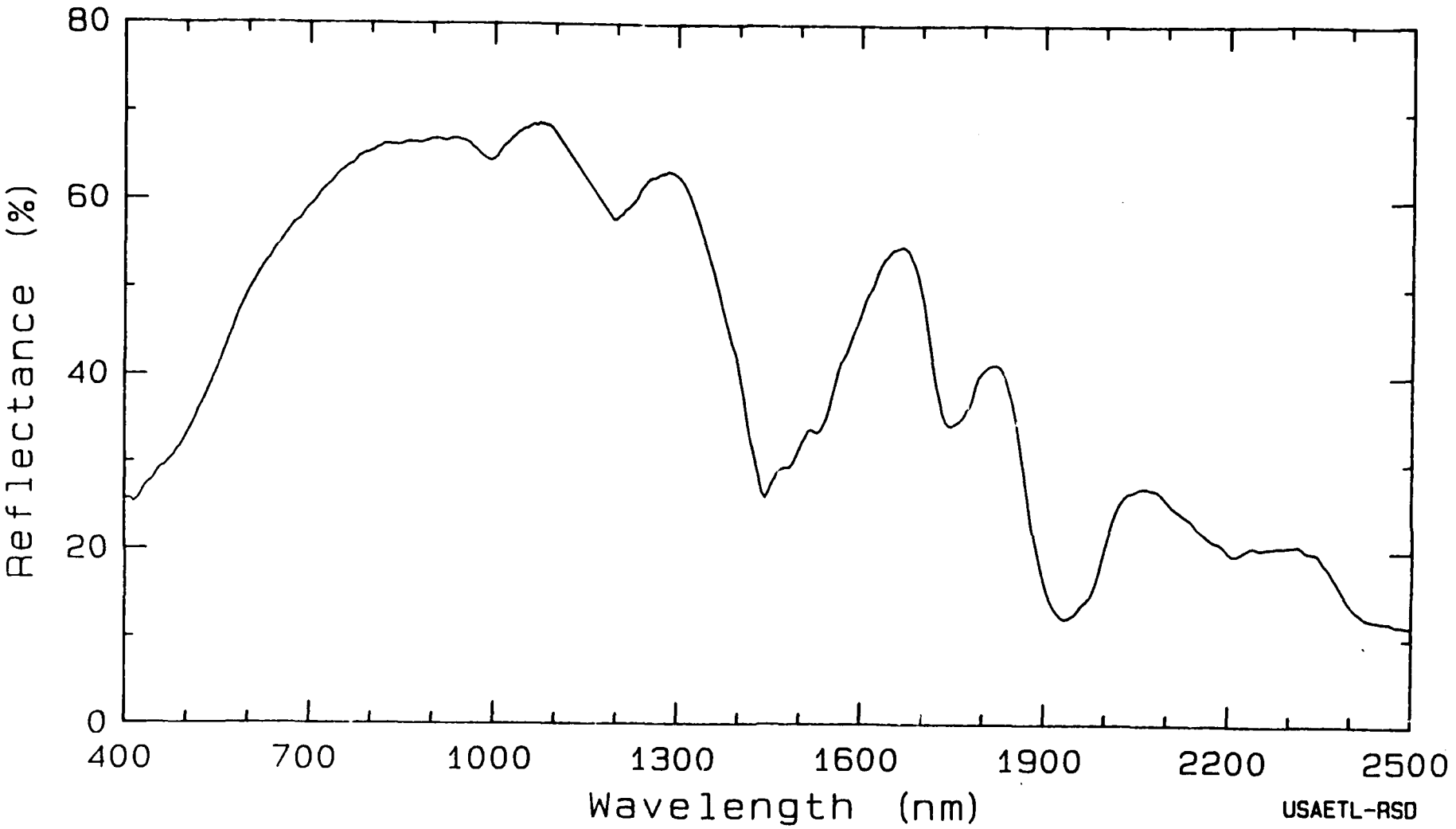
Surface Reflectance of Desert Soils

Sample : SA-1



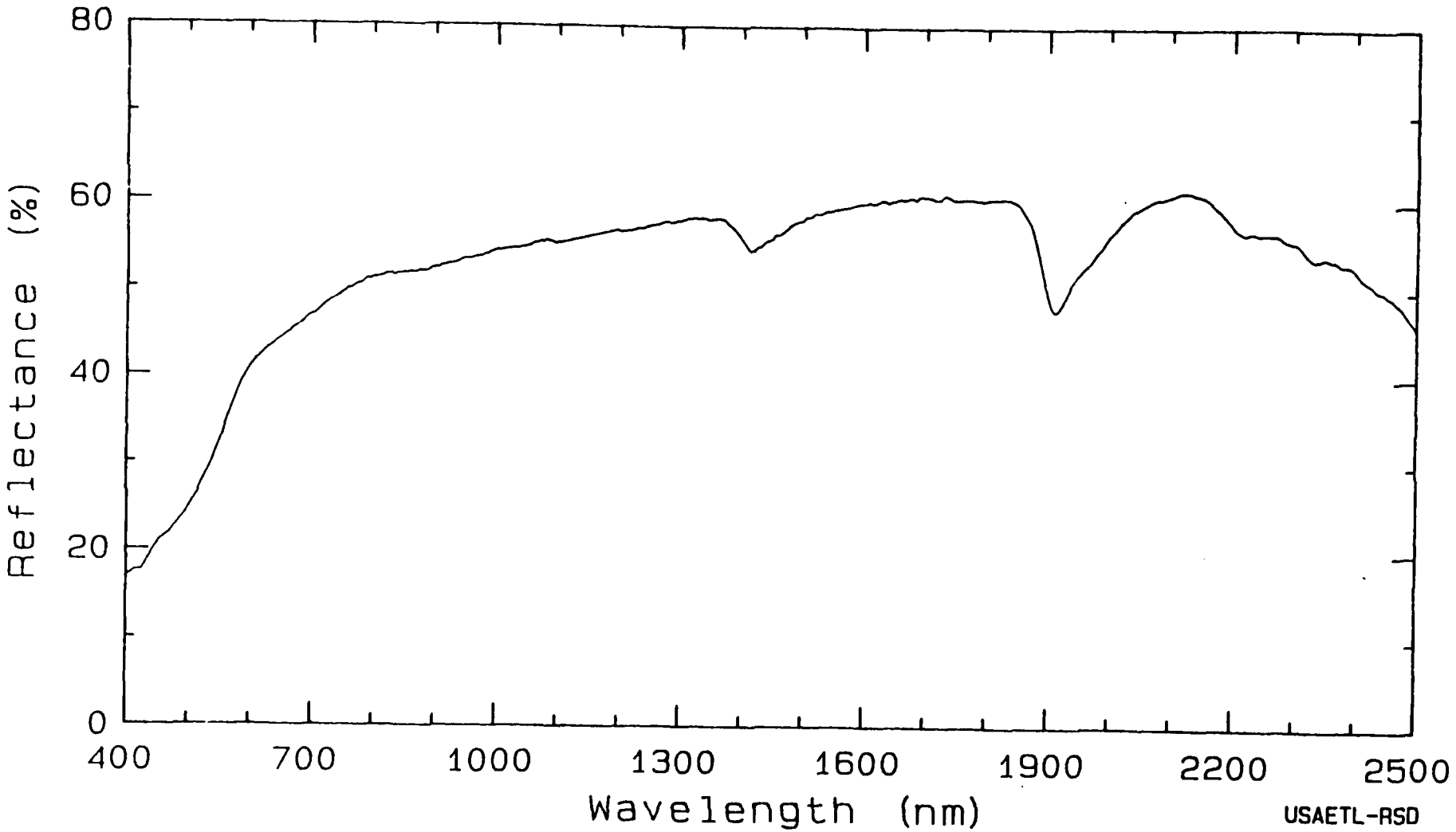
Surface Reflectance of Desert Soils

Sample: SA-2



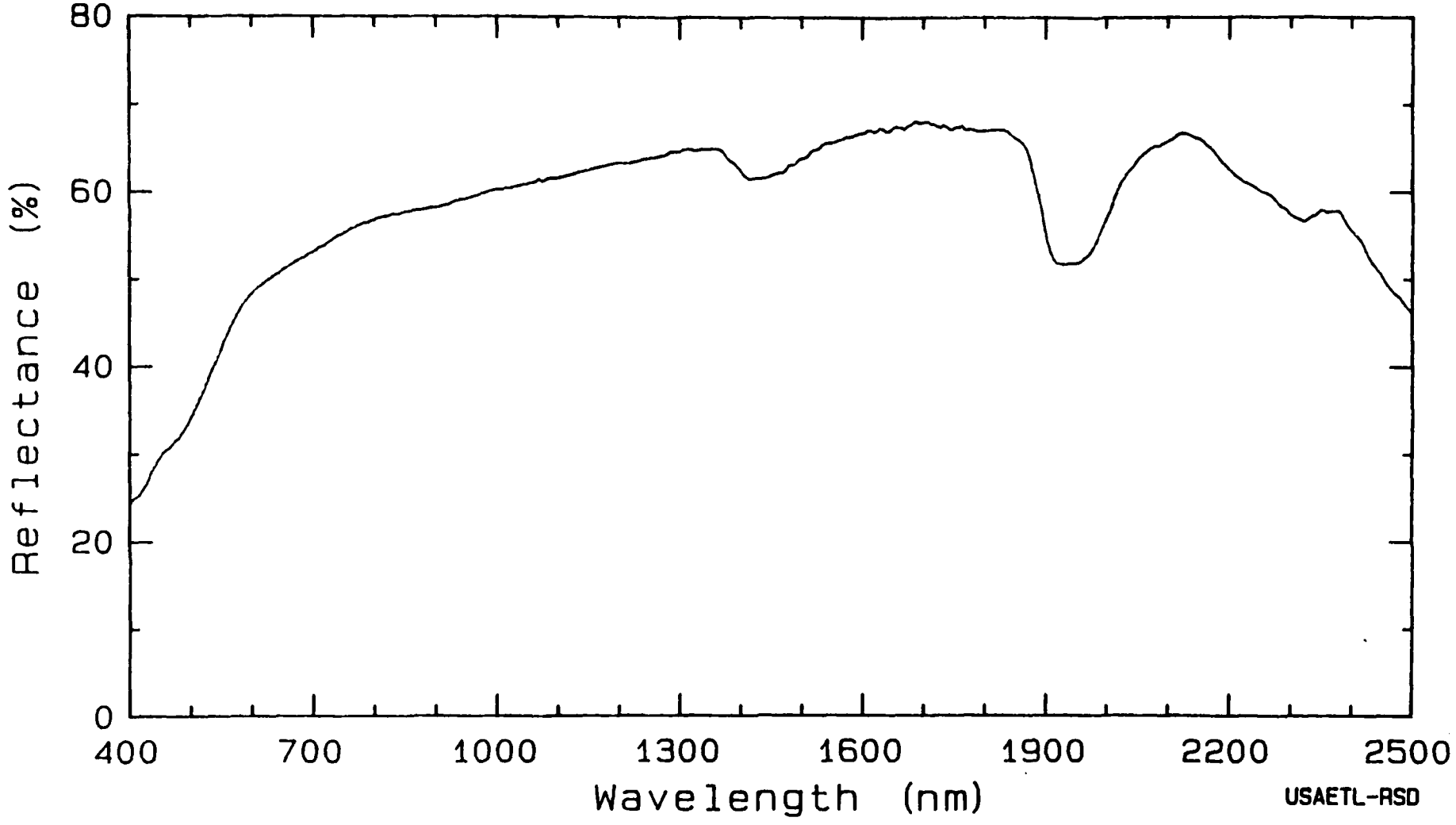
Surface Reflectance of Desert Soils

Sample : SA-3



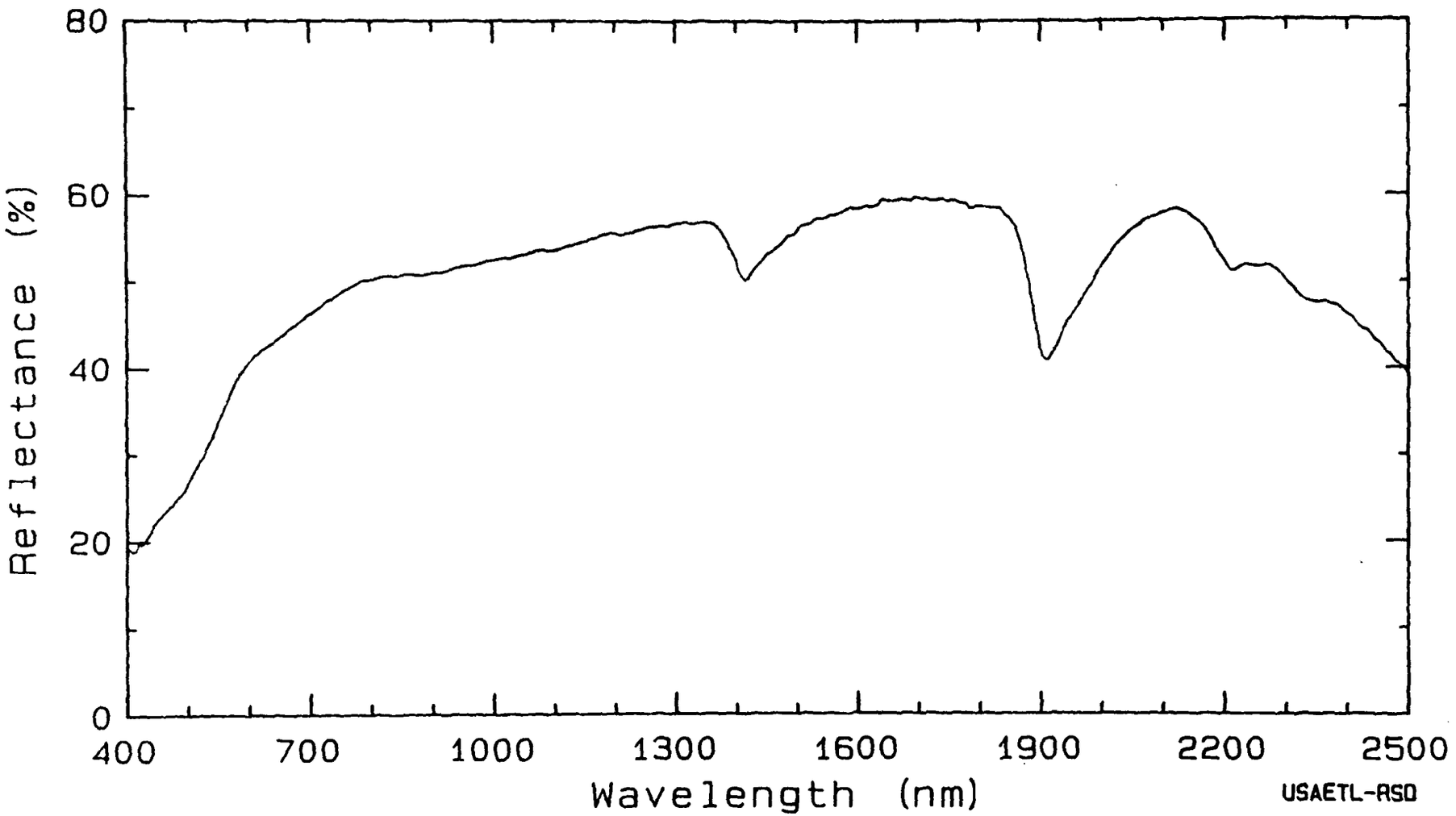
Surface Reflectance of Desert Soils

Sample : SA-4



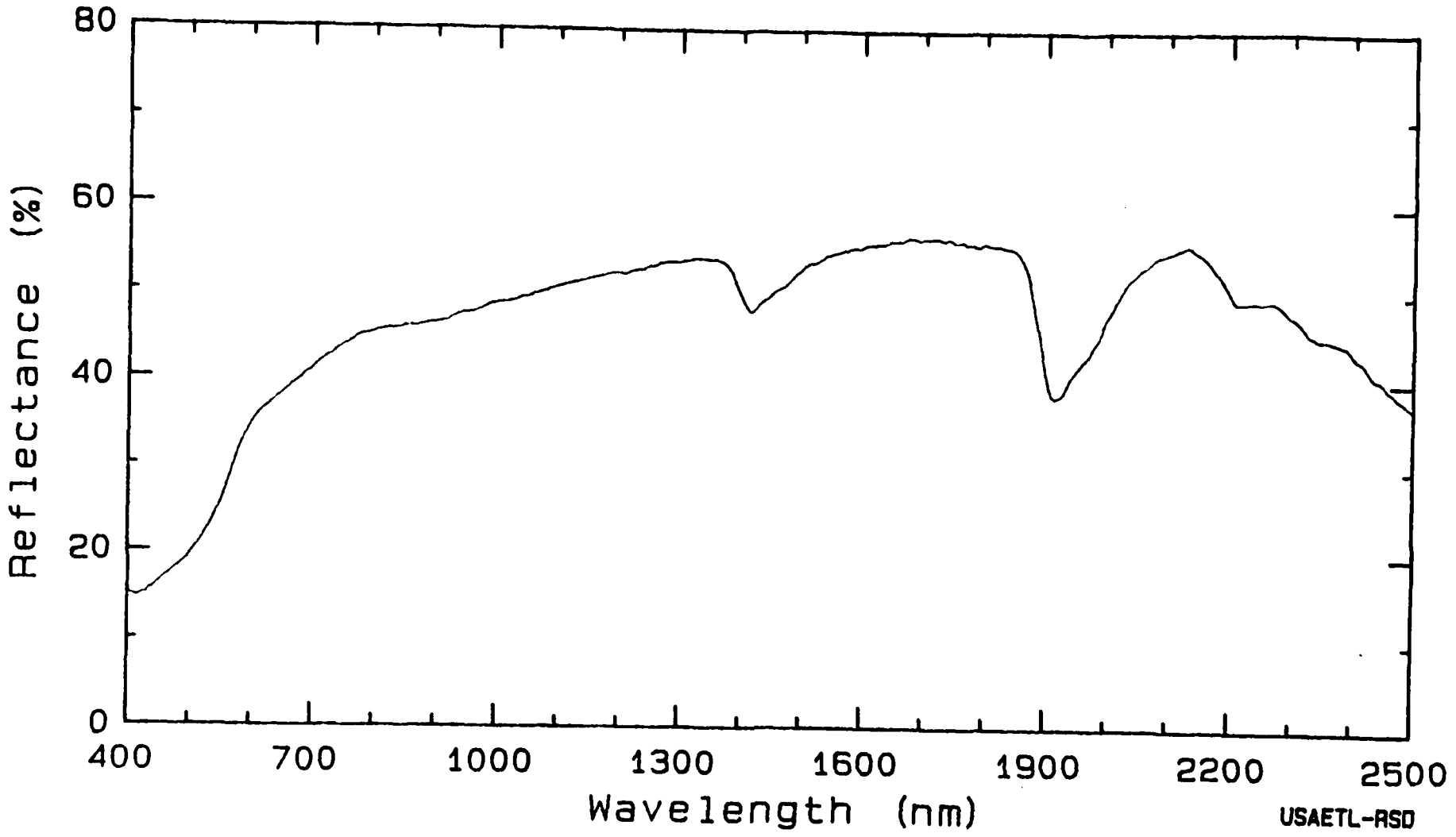
Surface Reflectance of Desert Soils

Sample: SA-5



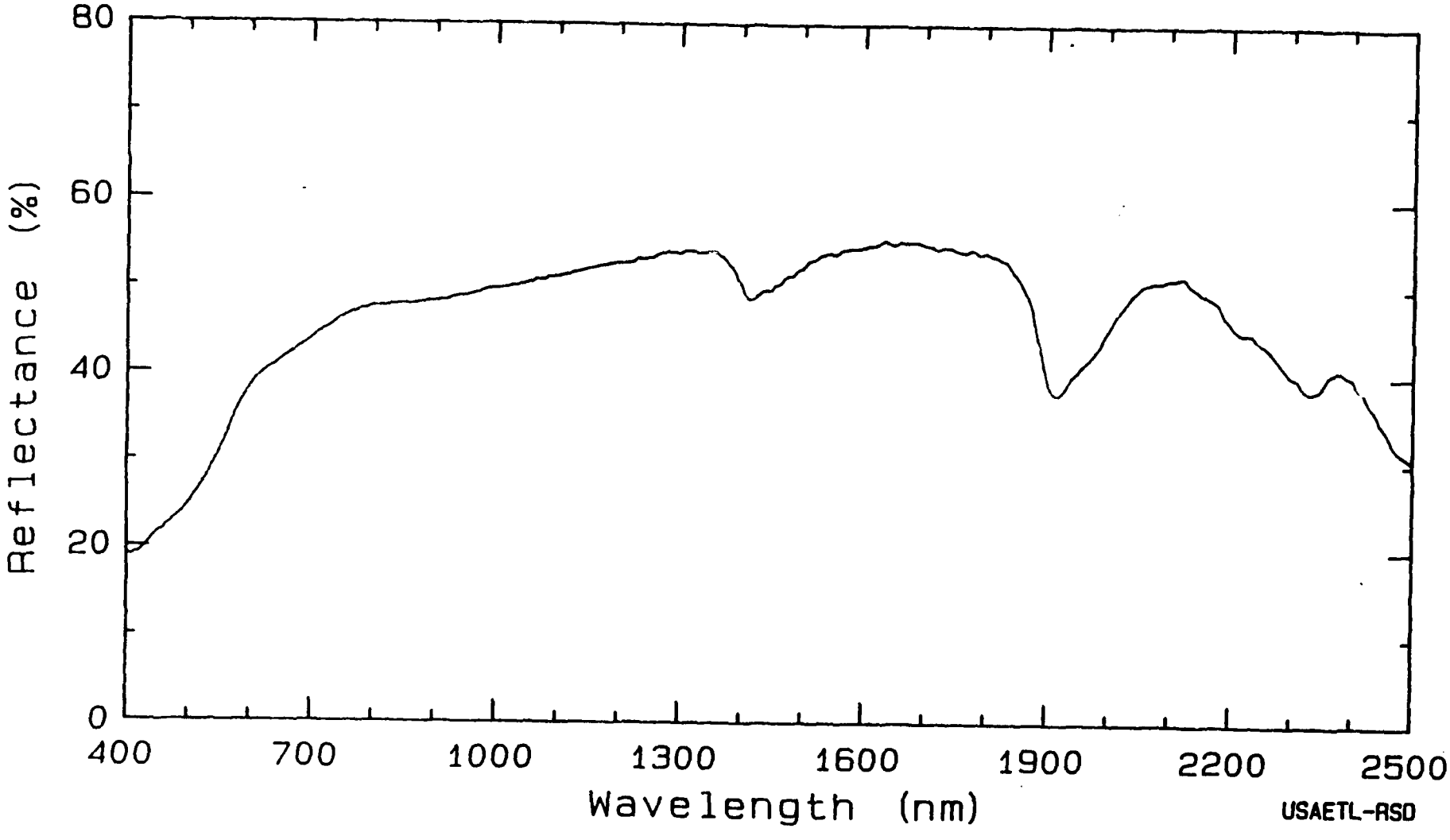
Surface Reflectance of Desert Soils

Sample: SA-6



Surface Reflectance of Desert Soils

Sample : SA-7



Surface Reflectance of Desert Soils

Sample: SA-8