CN 172

ORIGINS OF COARSE PARTICLES NEAR AND ON THE IRON RANGE OF MINNESOTA

A Preliminary Report
by the Particle Technology Laboratory
of the University of Minnesota

by
James C. Wilson
Kenneth T. Whitby
Virgil A. Marple
James E. McCormack

Submitted by
Virgil A. Marple and Kenneth T. Whitby
Principal Investigators
State Planning Agency Contract No. 8023
entitled "Particulate Air Sampling
for Minnesota Regional Copper-Nickel Study

and

Kenneth T. Whitby, Principal Investigator
EPA Research Grant R 803851-03
entitled "Formation of Atmospheric Aerosols"

to

The State of Minnesota Regional Copper-Nickel Study Project

August, 1978

Particle Technology Publication No. 373

Introduction

This is [illegible] first report on the initial efforts of the Univeristy of Minnesota Particle Technology Laboratory to study sources of coarse particles ($D_p > 1$ μm) in the Regional Copper-Nickel Study area in Northern Minnesota.

This study utilized the unique mobile laboratory facility developed under USEPA sponsorship by the Particle Laboratory for air pollution research, Whitby et. al. (1978), Wolf (1978). The mobile laboratory (UMML) allows rapid measurement of size distributions and concentrations of particles ranging in diameter from .0056 μm to 38 μm. As configured for this study, the UMML contained a filter sampler that could acquire an adequate sample in 10 minutes, a high sensitivity SO_2 monitor, and wind, temperature and humidity instruments.

The mobility of the laboratory and fast response (on the order of seconds) of the continuous sensors made it possible to seek and find plumes of coarse or fine particles. Thus, it was possible to study intermittant sources such as are loading and other mining operations, vehicles on gravel roads and wind resuspending dust from tree leaves. Attempts were made to detect dust transported from extended sources by sampling downwind of the sources along roads nearly perpendicular to the wind direction. X-ray fluorescence analysis performed on filter samples enabled discrimination between road dust and iron containing dust from the mining operation. The x-ray fluorescence analysis was performed by USEPA laboratories. In these ways, the mobile facility provided information to compliment and supplement that gathered by the fixed stations operated by the Regional Copper-Nickel Study.

The study took place from July 25 through July 29, 1977. The weather conditions during this period were not suitable for a study of wind blown dust; however, the strike by the United Steel Workers which started August 1, 1977 prevented choice of another time or of a longer study. The results reported here are thus limited in generality and usefulness. The factors restricting the usefulness of the data include the amount of precipitation which fell in June and July and during the study itself. 9.63 inches of precipitation is reported for Babbit for June and July, whereas the long-term average for Babbit is 7.95 inches for the two months. Residents of the study area said that the dusty episodes of which they complained the previous year were absent during June and July of 1977. Measurements of dust generated by certain mining operations in the Erie Mine were made while light, intermittent rain was falling. These wet conditions almost precluded suspension of dust from bare surfaces by the wind and reduced the amount generated by vehicular traffic. Also, wind velocities measured during the study did not exceed 22 kph and such winds would not be expected to suspend much dust. Finally, the Erie Mining Company and Pickens-Mather Company have been praised for their efforts on behalf of dust control. Thus, the measurements of mine dust made in Erie Mine cannot be considered typical of what might be found in other mines in Northern Minnesota.

In spite of these limitations, the study did provide some interesting results. The most noteworthy are:

1. Measurements of coarse particles suspended by passenger cars on a gravel road indicated large concentrations of dust. The amount suspended by a car was found to depend strongly upon its velocity and significant amounts of dust were generated even when wind velocities were quite low and conditions rather moist. Vehicles can break the film formed by rain and mix suspended dust several meters into the air in their wakes. These facts coupled with the number and distribution of gravel roads in Northeastern Minnesota imply that travel on gravel roads is undoubtably an important source of coarse particles in the study area.
2. Significant resuspension of dust from tree leaves was observed at wind velocities less than those required to resuspend dust from a bare surface. This may provide a mechanism for the redistribution of dust produced by roads.

This abbreviated study indicates some of the things which are possible with the UMML and suggests additional studies. Many of these same measurements should be repeated during a dry, dusty year. It is necessary to characterize the size distribution and transport of dust from tailings basins and large bare surfaces in mines when conditions are dry and wind high. The same is true of transport from roads. The transport of dust from blasting operations also needs to be characterized. The above information would be necessary before the relative importance of mines and roads as sources of dust could be determined. The relatively infrequent, but presumeably large amounts of dust coming from mines during dry, windy periods may or may not exceed the more continuous quantities of dust emitted from roads. Neither source can be ignored at this time.

This study was performed with funds provided by the Regional Copper-Nickel Study and the United States Environmental Protection Agency. The cooperation of the USEPA laboratories, Pickens-Mather Company and the Erie Mining Company are gratefully acknowledged.

Instrumentation

The University of Minnesota Mobile Laboratory (UMML) was equipped to make rapid size distribution measurements of suspended particles in the diameter range from D_p = .0032 µm to D_p = 38 µm. This was accomplished using an Electrical Aerosol Analyzer and two optical particle counters, Royco 220 and a Royco 245 modified as described by Wilkie and Liu (1976). An Aitken nuclei counter provided a continuous measure of the total number concentration of particles. A ratemeter on the output of the Royco 245 provided a continuous measure of the number concentration of particles in the size range from 5 µm to 38 µm. A Meloy SA 285 provided a measure of SO_2. Wind spread, wind direction and temperature were measured at the van in addition to the radiosonde measurements taken at regular intervals by the Copper-Nickel meterologist. The filter samples were analyzed for elemental abundance by the USEPA using x-ray fluoroscence. This technique is sensitive to elements heavier than aluminum.

Interpretation of Data

The particle size distribution data was analyzed following the methods described by Whitby (1978). Surface and volume weightings of the size distribution reveal the features of the most interest in this study. Figure 1 shows a volume weighting of a size distribution (Run 57) taken in the dust plume of a car on a gravel road. Most of the aerosol volume and hence mass is found at particle sizes larger than 1 µm. Many atmospheric size distributions have been measured showing a similar coarse particle mode, and it is generally true that particles in this mode originate in the earth's crust and are dispersed by mechanical processes. Thus, the particles larger than one micron are assumed to be dusts suspended in mining, travel on gravel roads, agriculture, etc. These particles are usually not transported over long distances.

Figure 2 indicated a surface weighting of the same distribution (Run 57). Another mode presents itself between .1 µm and 1 µm. Commonly called the Accumulation mode, this size range usually contains aged photochemical or combustion aerosol. These particles can be transported long distances.

Figure 3 shows the correlation between the ratemeter reading averaged over the time required to measure the size distributions and the volume concentrations for coarse particles calculated from the size distributions. Using this curve, approximate coarse particle volume concentrations can be inferred from the ratemeter reading. So the magnitude of the ratemeter reading is interpreted to give a measure of the coarse particle concentration.

Fluctuations in the ratemeter reading indicate the nature of the coarse particle aerosol observed. Figure 4 is a strip chart illustrating interpretations of the ratemeter reading. Time interval c through d indicates a background reading. The lowest steady readings observed during a time period were taken to characterize the background coarse particle aerosol. Time interval a through b is an example of an elevated baseline. Such steady baseline readings elevated above the background are interpreted to indicate an extended or area source. Nearby coarse particle generating events caused large fluctuations in the ratemeter readings. Examples of this are indicated by number 1 on the figure.

<u>Meterological Conditions</u> (Data supplied by William Endersen of Regional Copper-Nickel Study)

A large high pushed into Minnesota from the northwest on July 25th and was centered over the state by July 26th. The high moved over the southern Great Lakes by July 27th and set up a southerly flow across Minnesota.

On July 25th, daytime winds were moderate to strong and gusty from the northwest. It was partly cloudy on July 26th, the winds were light and variable, west to northwest and on the 27th, winds were variable from the south with light intermittent rain falling throughout the afternoon.

Calculations of air parcel trajectories indicate that the air masses present on July 25th arrived from the north and northwest. The air mass present on July 27th in the morning and afternoon also arrived from the north of the study area but passed over central and southern Minnesota before returning to the Iron Range. The trajectory calculations for July 26th, show air arriving again from the northwest; however, due to the changing conditions on this day, the result is somewhat suspect.

Background Aerosol

The background aerosol is characteristic of the air mass present at a given time. Background readings are nearly constant in time and independent of small scale changes in location. Local source contributions are seen as increments in aerosol concentration over background levels.

Table 1 lists the background values measured on July 25th, and 27th. Coarse particle distributions are characterized by the geometric mean diameter of the volume weighted distribution (DGV) and the geometric standard deviation of the distribution (σ_g). The ratemeter values are one minute averages taken over the sample time. Papers by Whitby and Sverdrup (1978) and Whitby (1978) have been appended to this report for reference. Table 1 in Whitby (1978) and Table 4 in Whitby and Sverdrup (1978) provide data for comparison. The background aerosol volume concentrations reported for July 25th agree quite well with previously measured clean continental background aerosols and this is what would be expected from the air mass trajectory calculations.

TABLE 1 Background Runs

		VOLUME[1] $\mu m^3/cm^3$					COARSE PARTICLES[1]	
DATE	RUN	Coarse $D_p>1\mu m$	Fine $D_p<1\mu m$	ANC Particles/cm^3	O_3 ppm	RTM	DGV μm	σ_g
July 25	30	4.2	1.1	9.6×10^4	.025	4.9	4.9	1.5
	31	4.4	1.7	12×10^4	.015	5.8	7.8	1.9
	32	3.9	1.7	13×10^4	.004		5.1	1.3
July 26	52	9.4	4.0	$7. \times 10^3$	.03	10	6.2	1.6
	60	12.7	4.1	5.9×10^3	.03	10	7.7	1.7
July 27	72	21.2	5.5	2.4×10^4	.024	11.9	7	1.8

[1] Determined from size distributions

Air from the Northwest is usually quite clean. The ANC readings are a factor of 10 to 100 higher than expected for clean background. These measurements were made on mining roads treated frequently while the UMML was present, with a dust suppressant which emitted a detectable level of sulphur. It is possible that the elevated ANC readings were due to particles formed photochemically from these bases given off by the dust suppressant.

The background coarse and fine particle volumes reported for July 26th are higher than those expected for clean continental background. The locally observed winds had shifted and were out of the west on that day. The trajectory calculation, somewhat suspect as indicated, suggests that the air mass arrived once again from the northwest but aerosol measurements indicate more aged authropogenic aerosol.

The background values measured on July 27th agree fairly well with other measurements of background aerosol mixed with an aged urban plume, (Table 1, Whitby 1978). This is consistent with what would be expected from the trajectory calculation which suggest that the air mass present during the day on July 27th passed near the Minneapolis - St. Paul area. Run 72 is anomalous in that the coarse particle volume from the size distribution exceeds that which would be expected from the ratemeter reading and Figure 3. The reported ratemeter reading characteristic of the lowest values observed at other times during the day. It is reasonable to suggest that the coarse particle background volume is closer to $10\mu m^3/cm^3$ than $20\mu m^3/cm^3$ for this day.

The values of σ_g are surprisingly small and that for Run 32 is almost not creditable. No explanations are offered at this time.

The background values of SO_2 were near zero. Humidity effects and their attendant uncertainties make it impossible to further interpret the numbers at such low values. Hence, the numbers are not reported.

Dust Transport from Mine Sites

Efforts were made to detect long range transport of dust from mine sites. The UMML was operated on July 25th while passing to the south and east of the Reserve Mining pit along Dunka Road. Figure 8 is a map showing the route. Surface winds were from 330° at 14 to 22 km/hr. At this time, Reserve Mine was inactive except for maintenance operations.

The ratemeter reading was usually at background levels (10 c/s or less) except in the immediate vicinity of some activity such as vehicles or trains. Thus, on a day with mining minimal activity there was no clear evidence of dust transported from the Reserve Pits to Dunka Road.

Dusts Generated in Erie Mine Processing Complex

On July 27th, the UMML was operated in and around the pelletizing plant, crusher, and tailings pond at the Erie Mining Company nine. Figure 9 is a map showing some of the measurement sites. Winds were variable and from the south and light rain fell intermittently during the afternoon.

Table 2 lists ratemeter readings taken in the area and correlated volume concentrations from Figure 3.

The background ratemeter readings of between 10 and 20 c/s correspond to a coarse particle volume of between 7.5 and $12\mu m^3/cm^3$. These values were increased slightly to around $15\mu m^3/cm^3$ down wind of the plant and tailings pond. Down wind of the crusher, values as high as $125\mu m^3/cm^3$ were detected. Rain fell intermittently throughout the measurements and emissions and wind were highly variable.

TABLE 2: Coarse Particle Measurements Upwind and Downwind of the Processing Complex 7/27/77

TIME INTERVAL	LOCATION OF MEASUREMENT	RATEMETER BASELINE, C/S	CORRELATED COARSE PARTICLE VOLUME $\mu m^3/cm^3$
10:47 - 10:59	SW of Plant	15	10
11:53 - 12:03	SW of Plant	17	11
12:29 - 12:46	SW of Plant	10	10
14:30 - 14:50	Moving from c to d to c	25	16
14:50 - 15:05	Moving from c to b	25 increasing to 80	16-60
15:30 - 15:44	b	approximately 150	125
15:44 - 15:10	a	50	35

(See Figure 9 for locations)

Dusts Generated in Erie Mine - Loading Operations

Measurements were made on July 27th in the vicinity of a shovel loading operation. After being loaded, 85 ton trucks passed approximately 10 meters from the UMML. Ratemeter readings showed excursions over baseline values, and ratemeter averages were calculated for the duration of these coarse particle events.

Later the same day, measurements were made approximately 100m downwind from a loading pocket. Light rain fell. 85 ton trucks dumped ore from a platform into railroad cars. The ratemeter baseline reading was between 20 and 30 c/s at this point (12 to 20$\mu m^3/cm^3$) compared with a background level of 10 c/s (7.5$\mu m^3/cm^3$).

Average ratemeter readings and correlated volume concentrations are listed in Table 3, and size distribution data is listed in Table 4.

TABLE 3: Ratemeter Readings and Volume Concentrations for Mining Operations in the Erie Mine on 7/27/78.

EVENT	TIME	DURATION	RATEMETER AVERAGE c/s	COARSE PARTICLE VOLUME, $\mu m^3/cm^3$
Truck passes van	11:16:30	60s	610	600
Truck passes van	11:20:30	45s	403	375
Truck passes van	11:25:14	38s	385	355
Truck dumps	16:40:00	88s	190	160
Truck dumps	16:42:00	152s	288	256
Truck dumps	16:47:48	35s	387	358

Table 4. Size Distribution Summaries for Mining Operations.

	VOLUME,	$\mu m^3/cm^3$	COARSE PARTICLE MODE		AVERAGE
RUN	COARSE	Fine	DGV, μm	σ_g	RATEMETER c/s
75 Truck passes	630	4.7	6.6	2	
89 Truck dumps	243		7.2	1.6	152
90 Lull in activity at pocket	34		6.2	1.6	49

Dust Suspended by Vehicles Moving on Gravel Roads

The dust plume of a passenger with one occupant moving at various speeds on a gravel road was measured on July 26th. The UMML was parked at 110m and 265m from the road in a level mowed field. The dust plume was transported by winds perpendicular to the road varying in intensity from 11 to 2 km/hr. and was measured approximately 3m off the ground.

The results of the measurements are shown in Figures 10, 11, and Table 5. Figure 10 shows two examples of the ratemeter output for the passage of a dust plume. By averaging the ratemeter reading over the duration of the plume passage, it is possible to assign an average coarse particle volume concentration to the plume. Such values are given in Table 5 and plotted as a function of car speed and distance from the road in Figure 11.

TABLE 6: Size Distribution Parameters for Road Dust Measured at Varying Distances from a Gravel Road as Automobiles Passed at Several Different Speeds on July 26th.

RUN	DISTANCE FROM MOBILE LAB	CAR VELOCITY MPH	COARSE PARTICLE MODE TOTAL VOLUME $\mu m^3/cm^3$	DGV	σ_g
57	0	-	97	5.8	1.7
55	0	-	52	6.4	2.
58	0	-	5190	9.5	1.8
63	264	40	51	7.4	1.9
64	110	40	649	6.6	1.6
65	110	15 apx.	179	7.3	1.6
66	110	40	863	6.4	1.6
67	110	20	31	7.6	1.9
68	110	10	23	10.3	2.0

It is clear that the amount of dust in the plume is a strong function of distance from the road and automobile speed.

It is possible to estimate the amount of dust generated and transported per unit length of road. In order to make the estimate, plume height must be estimated and the concentration, measured at one point, must be assumed constant throughout the plume. The plume width is calculated from wind speed and the duration of plume measurement, and the plume is assumed to be rectangular. Thus:

$$V_L = (v \Delta t) HC$$

where V_L is estimated volume of coarse particle aerosol emitted per unit length of road and transported to the measuring point. H is plume height, C is average coarse particle volume concentration, Δt is duration of plume measurement and v is wind velocity perpendicular to the road.

The plume height H has been estimated by K. T. Whitby based on roadway studies using gas tracers. Modifications were made in an effort to account for settling of coarse particles. Table 5 shows the values of H, $v, \Delta t$ and V_L. The results are plotted on Figure 12.

The estimate of dust transported in the plume is dominated by the measured concentrations, and depends strongly on automobile velocity and distance from the road.

TABLE 5; Results and Intrepretation of Vehicle Dust Plume Measurements.

Start Time	Distance m	Vehicle Speed MPH	Duration of Measurement-s a)	Average Rate Meter - cps	Correlated Coarse Particle Volume Concentration $\mu m^3/cm^3$	H,m	$v\Delta t$,m	Dust Emmision V_L, cm^3/m
17:10:45	265m	30 mph (Jeep)	211	293	260	110	400	11.
17:20:23	265m	30 mph (Pasgr)	127	23.5	15	110	160	.26
17:32:49	265m	40 mph (Pasgr)	88	65	47	110	110	.56
17:46:00	115m	40 mph (Pasgr)	298	974	1000	60	200	12.
17:59:46	115m	40 mph (Pasgr)	333	637	640	60	210	7.7
18:15:43	115m	20 mph (Pasgr)	298	79	60	60	220	.78
18:20:46	115m	10 mph (Pasgr)	123	32	21	60	140	.17
18:30:09	115m	10 mph (Pasgr)	219	31	21	60	160	.20

a) actually the time for passage of the dust cloud past the UMML

Investigation of Dust Resuspended from Tree Leaves

On July 26th, an investigation was made at site 2 indicated on Figure 8. The ratemeter baseline was elevated over background levels and peaks occured in the absence of known local sources. Figure 4 shows the strip-chart of ratemeter measurements made at site 2. Site 2 is surrounded by broad leaf trees and the reduction of the baseline at time c coincided with the departure from site 2 and entry of UMML into the large cleared around Dunka Road. Leaving the site amount the trees resulted in a large reduction in the more or less constant rate meter c/s as well as the elimination of the sharp peaks. Mechanical disturbance of the trees by beating them with a broom in front of the UMML during calm periods produced spikes very similar to those seen in Figure 4 during period a to b.

This led to the conclusion that the wind was resuspending dust which had been previously deposited on the leaves.

Two time intervals were analyzed to determine what wind velocity was necessary to resuspend the dust. The distribution of windspeed over time was compared with the distribution of ratemeter readings. Cumulative distributions of ratemeter readings and windspeeds (Figure 14) were plotted for the two intervals. Natural break points in cumulative ratemeter plots (Figure 13) occur at 92% for the earlier time and 10% for the later time. Thus, resuspension can be considered to have occured during 8% of the time interval in the former case and during 10% of the time interval in the latter. From Figure 14, the cumulative plots of windspeed, it is seen that in the earlier interval, the windspeed exceeded 16.4 km/hr 8% of the time. In the later interval, the windspeed exceeded 17.7 km/hr 10% of the time. These windspeeds then seem sufficient to resuspend the dust from the leaves.

This mechanism occurs at wind velocities much lower than that required to resuspend dust from a bare surface. In addition, it provides a means of resuspending and distributing dust which was originally resuspended by vehicles on gravel roads. Thus, it may contribute significantly to dust levels in the study area.

Erie Mine Pelletizing Plume

Ground measurements were made in the plume on July 25th late in the afternoon. Large ANC and SO_2 were observed near the plant downwind of pelletizing furnace stacks. SO_2 peaks of around 100 ppb were noted with average values of 40 ppc recorded. Approximately 6.5 km downwind of the stacks, a traverse of the plume was made. The plume was identified by simultaneous increases in EAA total current (fine particles), ANC and SO_2. The average value of SO_2 in the plume was about 3 ppb. The plume was detected while driving along a forest service road through a broad leaf tree forest. The elevated readings persisted over a period of 10 minutes during which time the van traveled 5km. No coarse particles were associated with either plume measurement. And background level of SO_2 was not significantly different from zero.

Filter Measurements

X-ray fluorescence analysis was carried out on filter samples by the EPA Environmental Sciences Research Laboratory. The result is elemental analysis for elements heavier than F. The technique is described by Wagman et. al. (1977). The results of the measurements is presented in Table 7.

The ratio of iron to silicon was calculated for each of the filters and a clear pattern emerges. The results are shown in Table 8.

TABLE 8: Fe to Si Ratio

Source	Filter	Fe/Si Concentration Rate
Resuspended from trees	3	.54
Tailing pond	26	1.53
Downwind pelletizer	28	6.5
Downwind pocket	30	2.4
Shaft furnace plume	7	.46
Road dust	16	.48

The ratio exceeds one in cases where iron would be expected to dominate (26,28,30) and is less than one in the case of road dust (16). Using this result, it can be argued that the dust resuspended from the trees south of the Dunka pit had its origin on the roads and not in the Dunka pit.

TABLE 7: Results of Filter Analysis by X-ray Fluorescence.

SOURCE	FILTER #	Fe μg/m³	Si μg/m³	Ca μg/m³	K μg/m³	Pb μg/m³	Additional Elements with Meaningful Signal (μg/m³)
Dust resuspended from trees	3	6.3	11.6	3.2	1.9	.045	Mn, Ti (.99), As (.05)
Tailing pond	26	9.3	6.06	–	–	.23	Mn, Br
Downwind of Pellitizer and Plant	28	31.2	4.8	2.8	–	.32	Br, Mn, S(1.6), Ni (.19), Zn (.19),As (.15)
Downwind of Pocket	30	42.7	17.9	–	–	–	Mn, S (3.3)
Shaft Furnace Plume	7	36.4	78.7	18.9	16.2	–	K, Ca, Al
Road Dust	16	10.6	22.1	3.86	3.09	.58	Al, S(.46), Cl, Ti, (1.2), Zn (.25), Cu (.47)

Coarse Particle Levels in Towns

While moving from site to site, the UMML was frequently driven through towns such as Mountain Iron and Ely with the instruments running. Although there was not time to pursue the matter in detail, it was observed that often the coarse particle levels on busy streets was several times higher than that observed on the highway outside of the town. For example, when driving east into Mountain Iron on July 29th on a hard surface highway, the ratemeter baseline hovered around 20 c/s. Upon entering the town, however, the baseline moved up to around 55 c/s. This suggests an increase in coarse particle concentration from about $12\mu m^3/cm^3$ to about $30\mu m^3/cm^3$. The source of this increase is likely to be the greater frequency of automobile traffic in town.

Summary of Results

The automobile is an important source of coarse aerosol in the study area. A concentration of $250\mu m^3/cm^3$ was measured over 250 meters from a gravel road after the passage of a single jeep at 30 mph. The dust levels decreased rapidly with distance from the road and depended strongly on the vehicle velocity. In towns, the coarse particle concentrations seem also to be increased by a factor of two or three by automobile traffic.

In a well controlled mine, in a wet year, coarse particles were emitted by individual operations such as loading, crushing or transporting ore. Measured concentrations near these activities reached 600 $\mu m^3/cm^3$ on a day when light rain was falling. Far from such activity, concentrations near background were observed. Resuspension of dust from open areas such as tailings ponds and dumps was not expected since winds were generally below 22 km/hr and conditions were wet and indeed, very little was seen.

Moderate winds of around 17 km/hr were sufficient to resuspend dust deposited on broad leaf trees, however. This may be a significant mechanism for keeping the coarse particle counts up even in the absence of strong winds.

X-ray fluorescence analysis of filter samples revealed variations in the ratio of Fe to Si according to source. Sources in mines produced an average ratio of 3.5 whereas those outside of the mine produced an average of .51. The furnace plume was excluded from the averaging.

Suggested Studies

The generation and transport of dust associated with mining in a dry, windy period need to be examined. Resuspension from tailings ponds and dumps does occur, but was not seen in this study. Generation and transport of dust from blasting needs to be investigated. Resuspension from tree leaves at low wind velocity may increase the importance of such occasional sources.

Plumes from vehicles on gravel roads need to be examined in more depth. Plume height and the variation in concentration with height need to be examined to allow modeling of the contribution of gravel roads to the total coarse particle burden of the study area. The contribution of roads in dry periods needs also to be examined.

In short, this study merely scratches the surface. Each of the things investigated here needs to be studied under different conditions if the origins of the coarse particle aerosol in northern Minnesota are to be understood.

References

Wagman, J., R. L. Bennet and K. T. Knapp (1977), "Simultaneous Multiwavelength Spectrometer for Rapid Elemental Analysis of Particulate Pollutants" in *X-ray Fluorescence Analysis of Environmental Samples*, (T. G. Dzubay, Ed.), pp. 35-56, Ann Arbor Science, Mich.

Whitby, K. T., "The Physical Characteristics of Sulfur Aerosols", *Atmospheric Environment*, Vol. 12, p. 135, (1978).

Whitby, K. T. "The Physical Characteristics of Sulfur Aerosols", *Atmospheric Environment*, Vol. 12, p. 135-159, (1978).

Whitby, K. T. and G. M. Sverdrup, "California Aerosols: Their Physical and Chemical Characteristics", to be published in the ACHEX Hutchinson Memorial Volume (1978).

Willeke, K. and B. Y. H. Liu, "Single Particle Optical Counter: Principle and Application", presented at the Fine Particle Symposium, Mpls., Mn. (May, 1975); *Fine Particles: Aerosol Generation, Measurement, Sampling and Analysis* (B. Y. H. Liu, ed.), pp. 697-729, Academic Press, New York (1976).

Wolf, J. L., "The Design of a Mobile Air Pollution Research Laboratory", *M.S. Thesis*, Univ. of Minn., Mpls., Mn. (March, 1978).

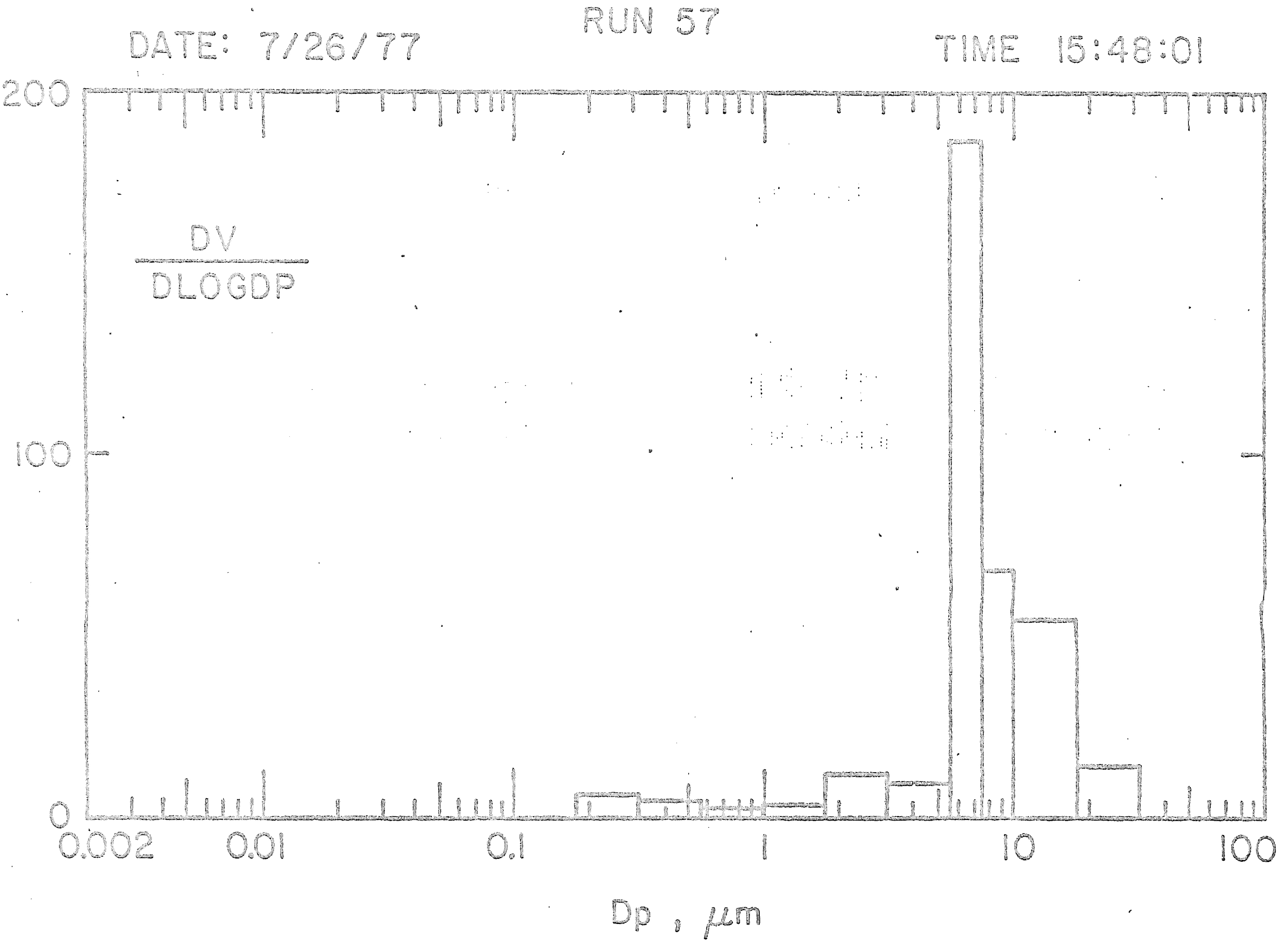


Figure 1. Volume weighting of Run 57. Dust plume of car on gravel road.

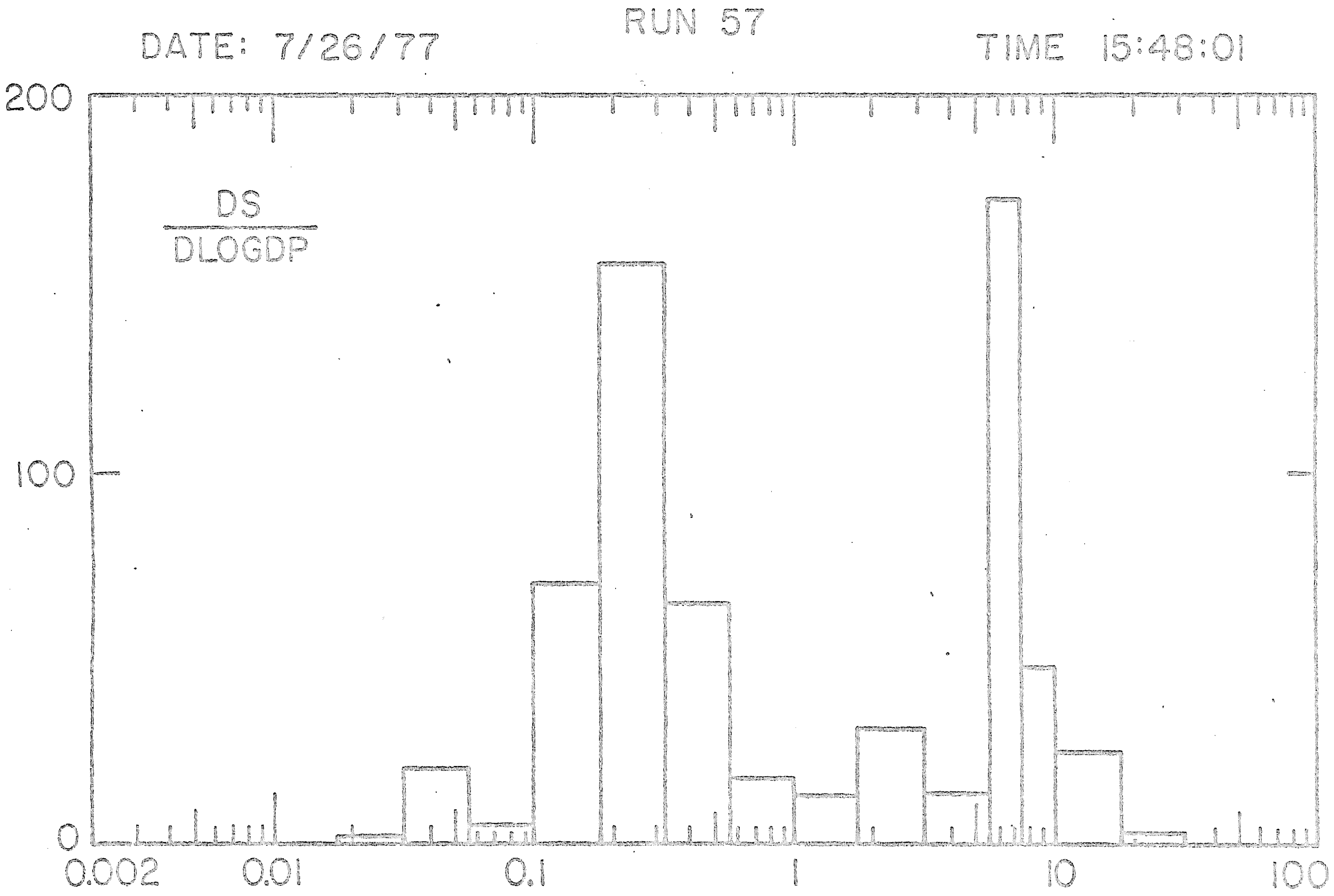


Figure 2. Surface weighting of Run 57.

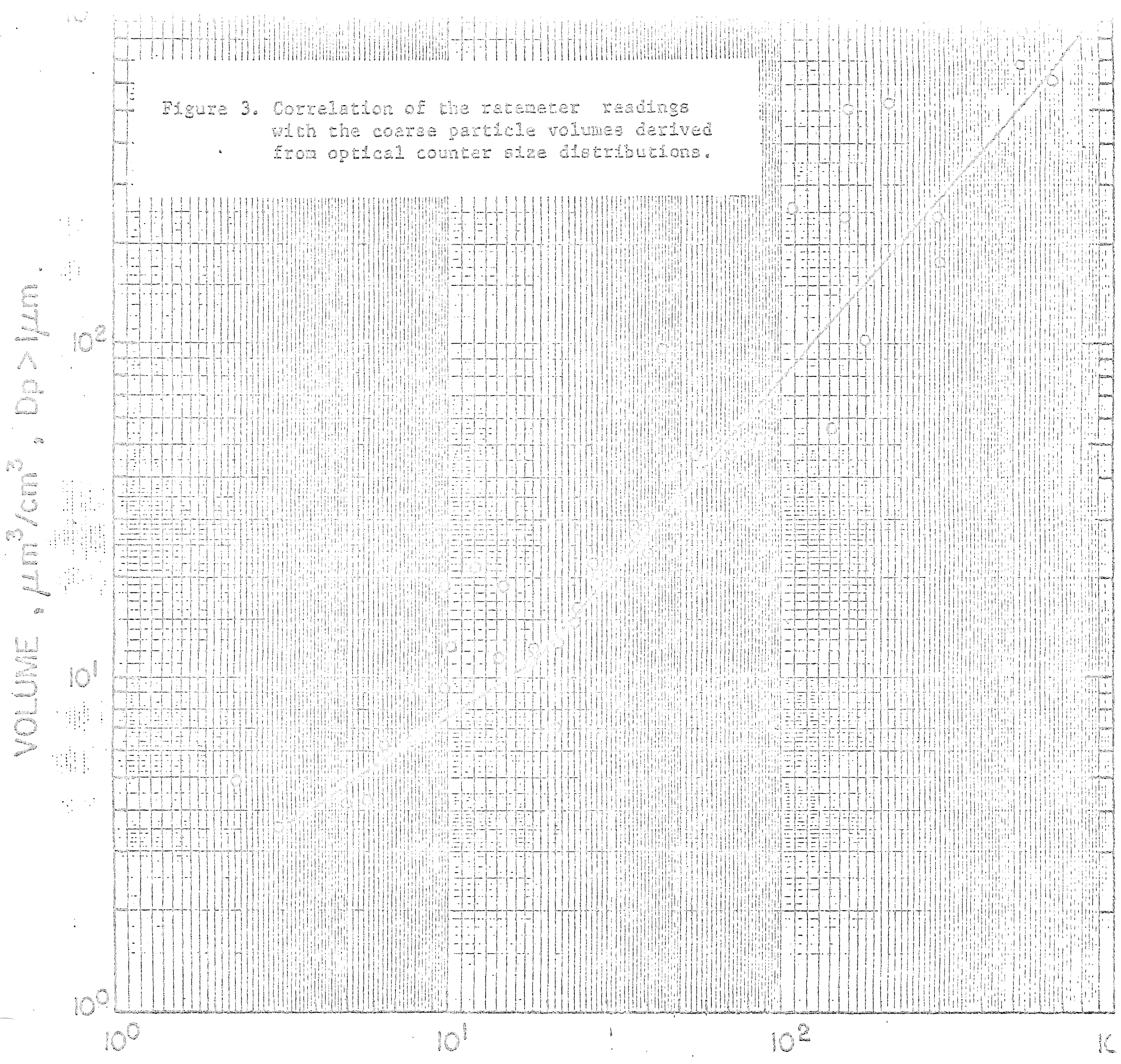


Figure 3. Correlation of the ratemeter readings with the coarse particle volumes derived from optical counter size distributions.

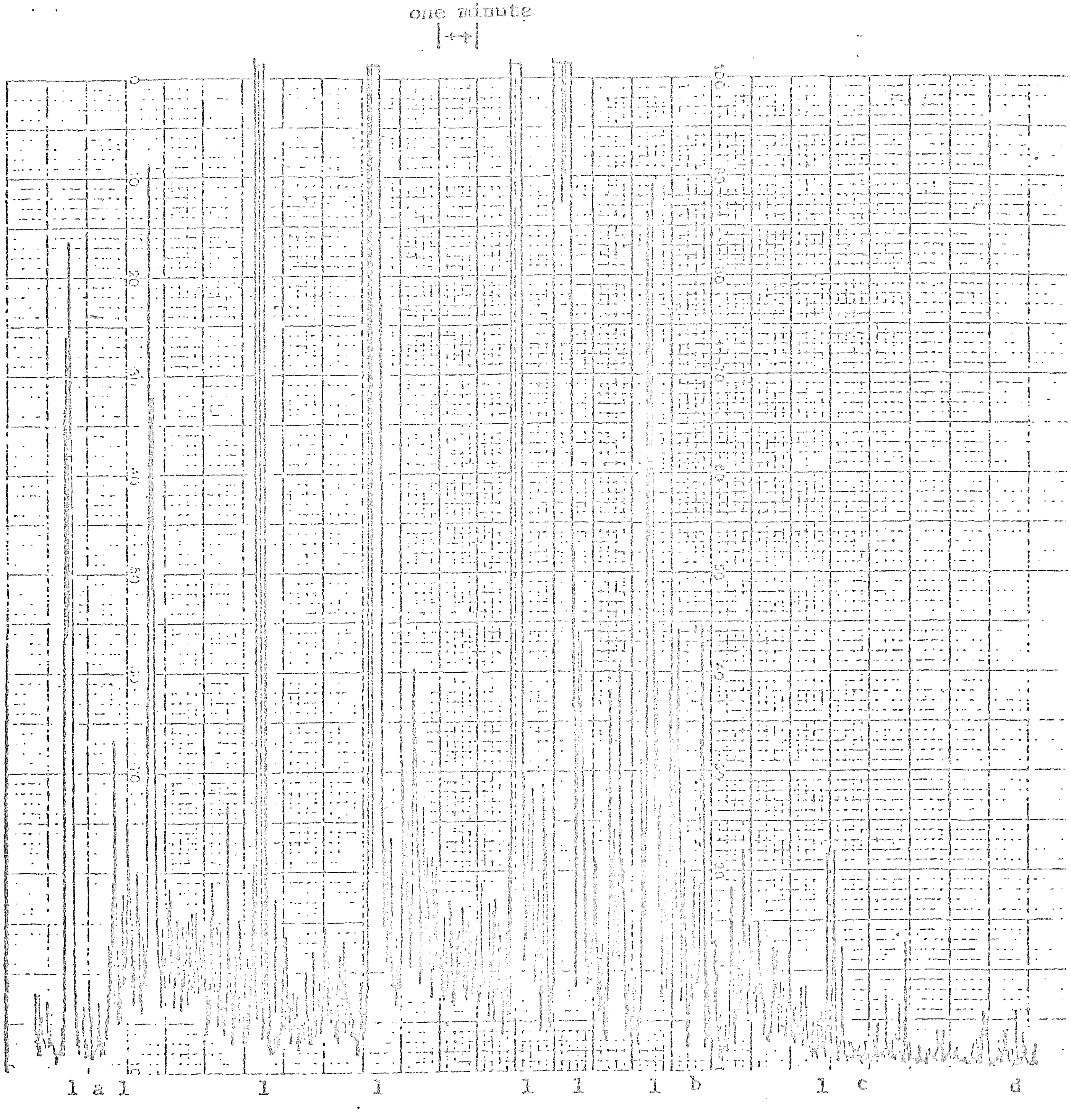


Figure 4. Stripchart of ratemeter readings measured from 14:20 to 14:45 on July 25. During the period from "a" to "b" the UMML was among trees downwind of a road on which trucks were operating. The peaks marked "1" were traced to bursts of dust when gusts of wind agitated the trees. The period from "c" to "d" coincides with the movement of the UMML into a large cleared area near Dunka Road.

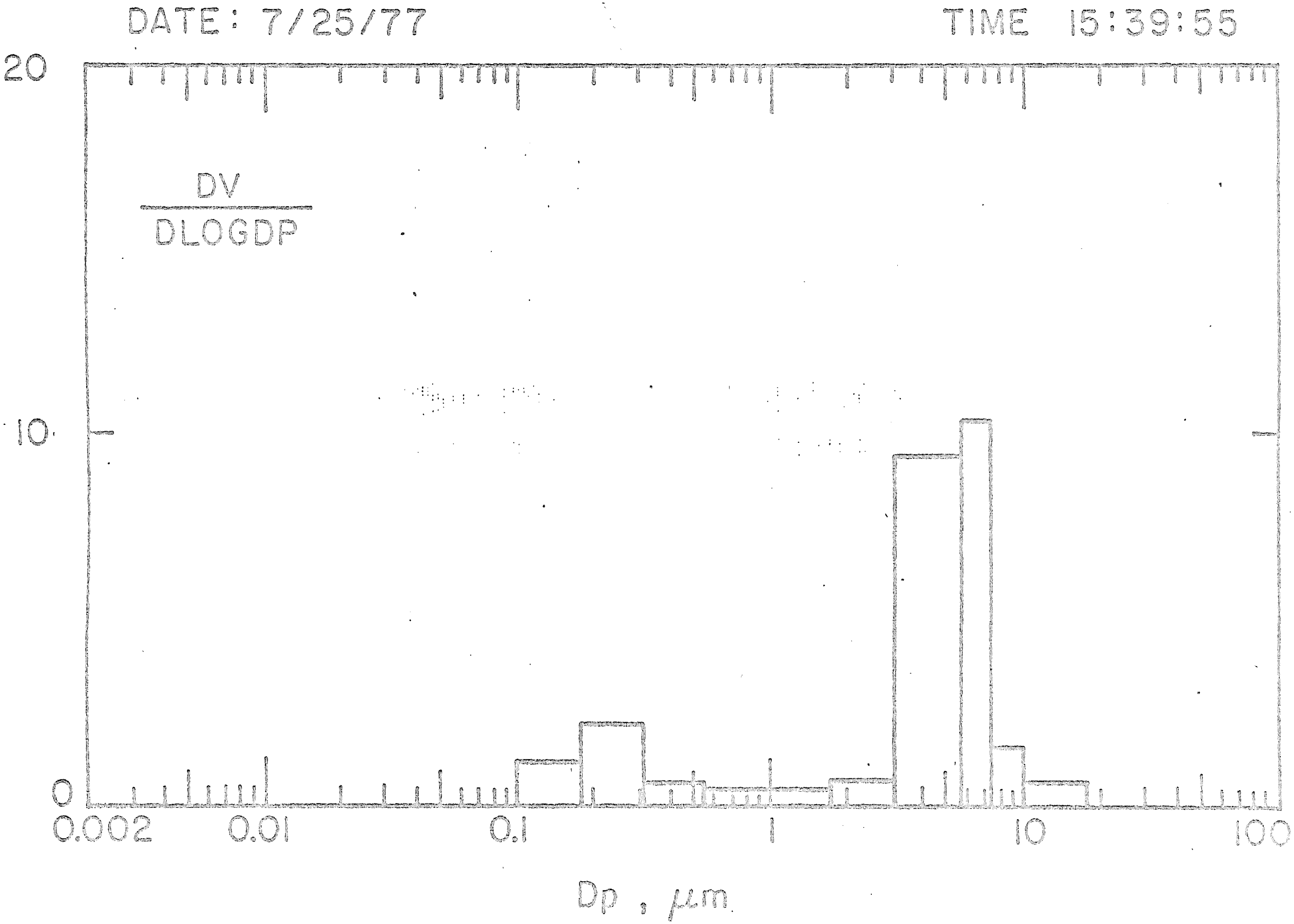


Figure 5. Backround size distribution. Run 32.

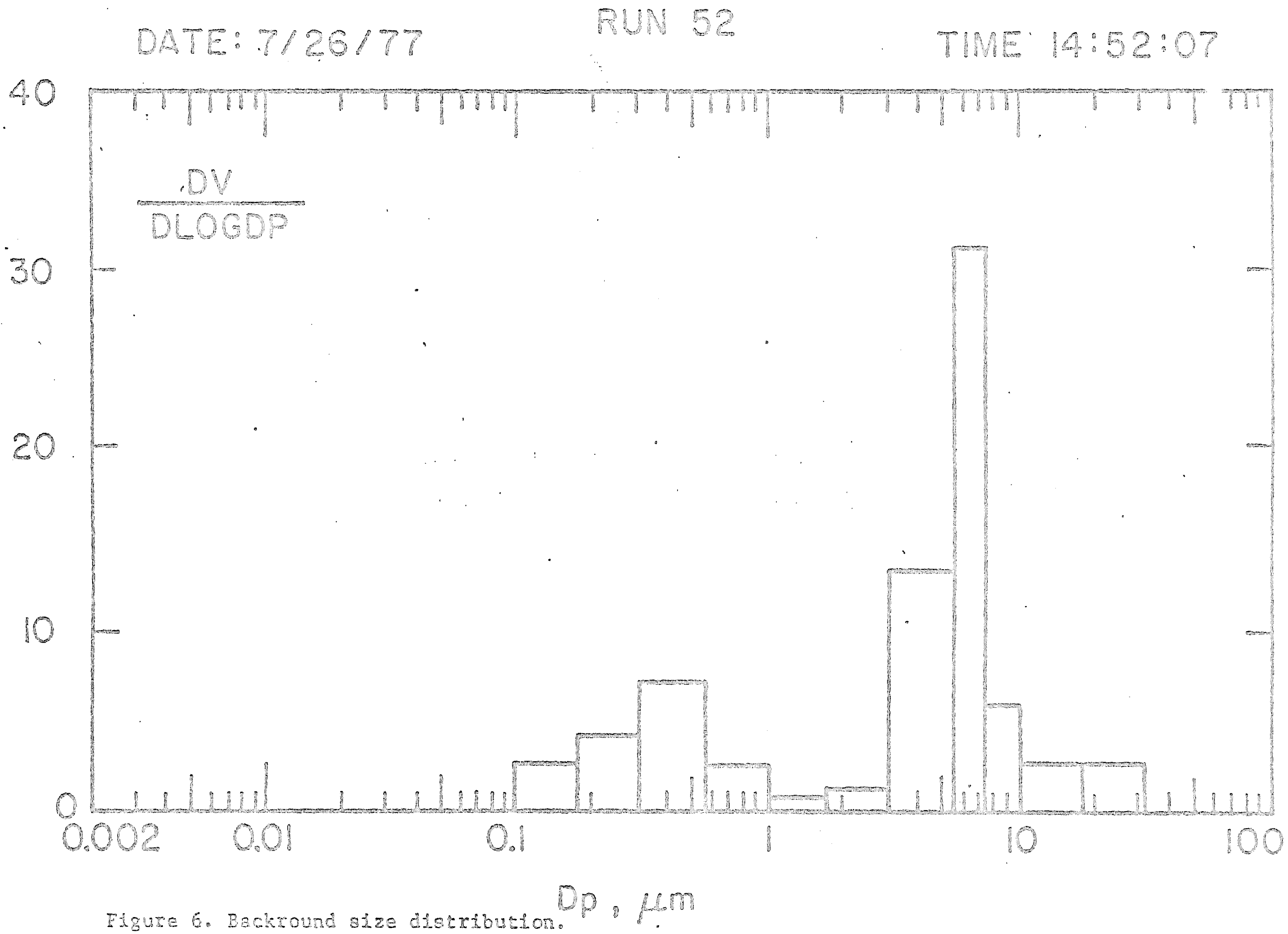


Figure 6. Backround size distribution.
Run 52.

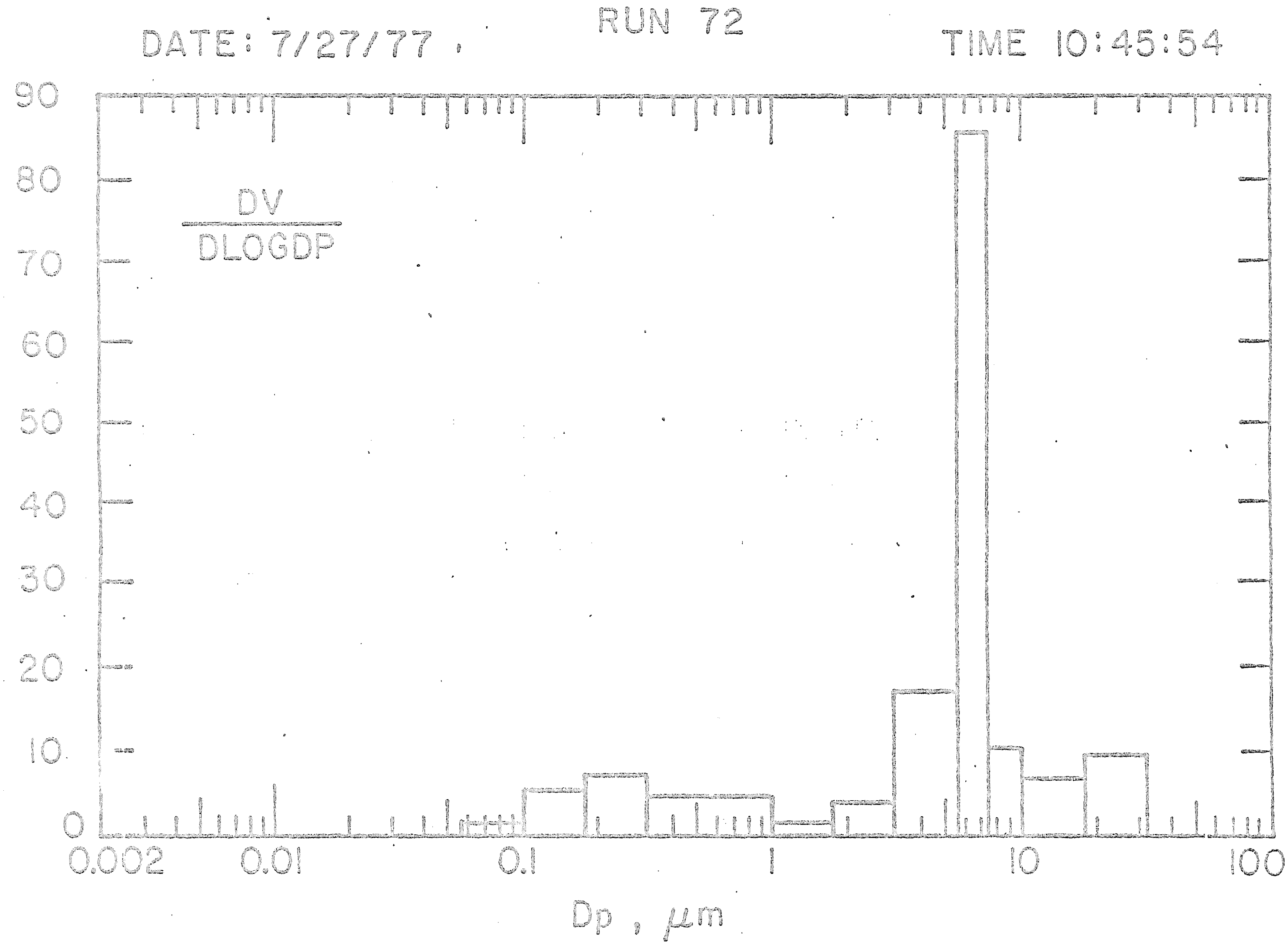


Figure 7. Backround size distribution. Run 72.

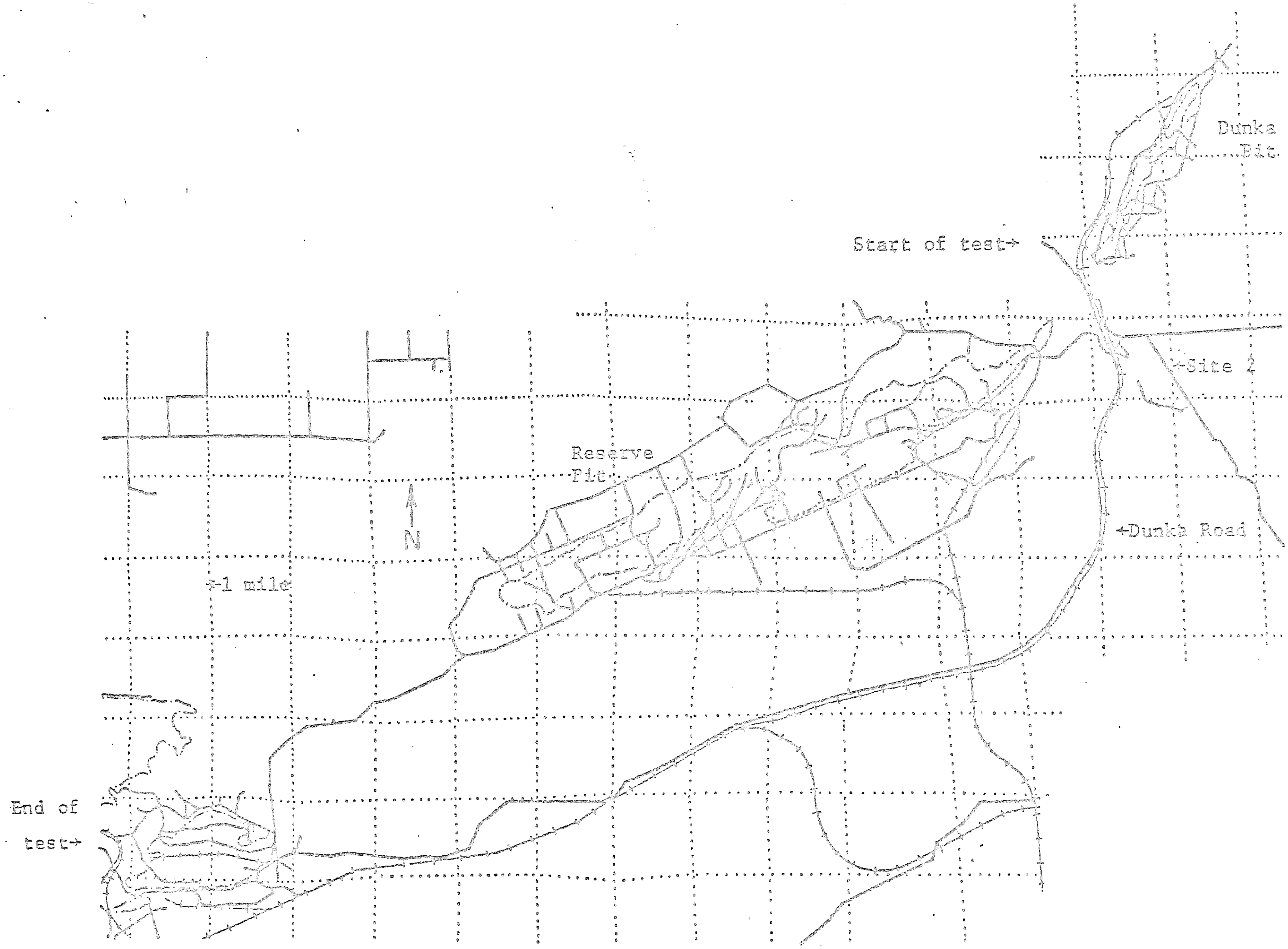
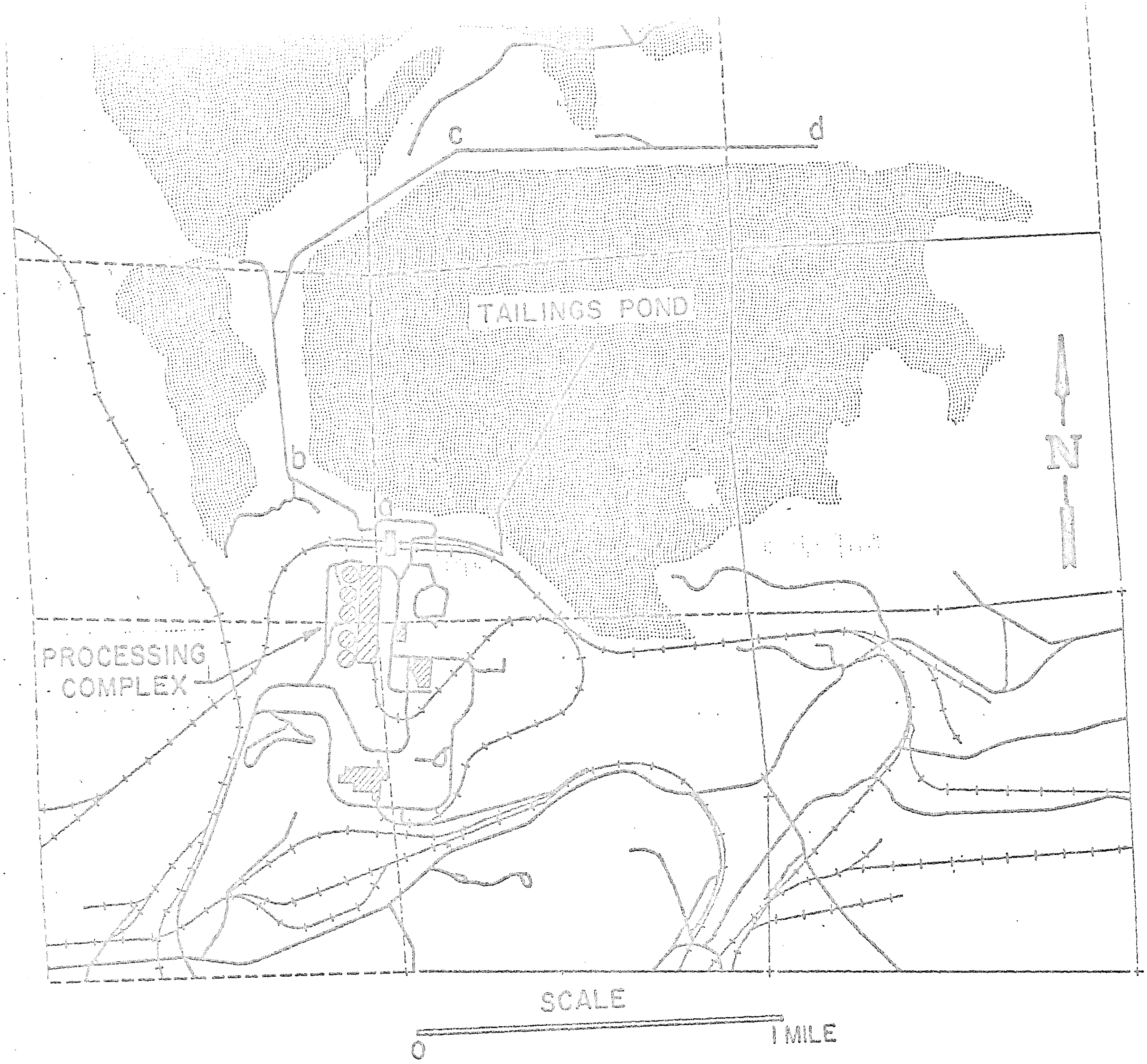
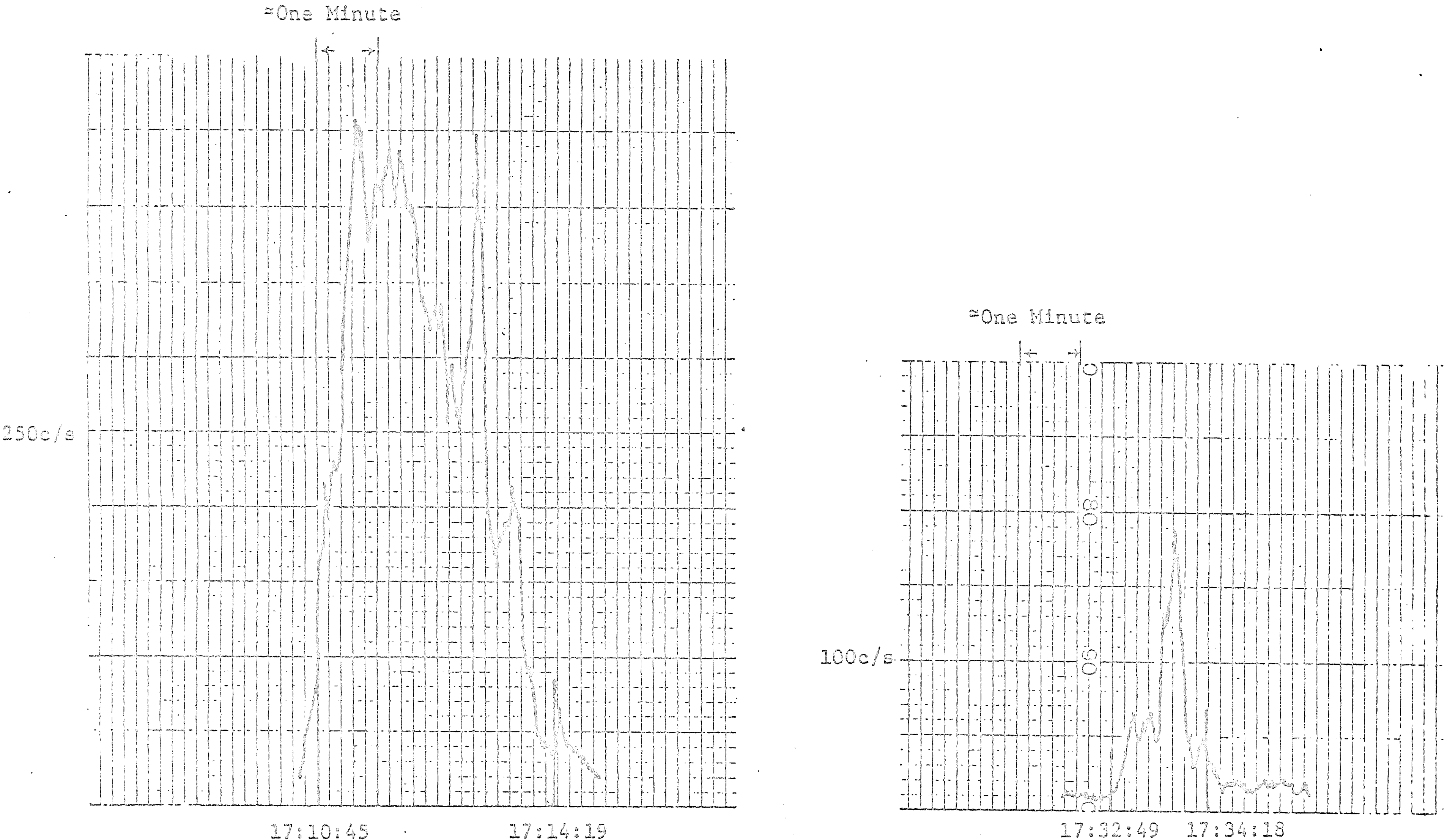


Figure 8. Map of Dunka Road



Fi e 9. Map of Erie Mining processing complex.



Jeep, 30mph, 265m.

Passenger car, 40mph, 265m.

FIGURE 10. Examples of Ratemeter Output for Two Dust Plumes Caused by Cars on Gravel Roads

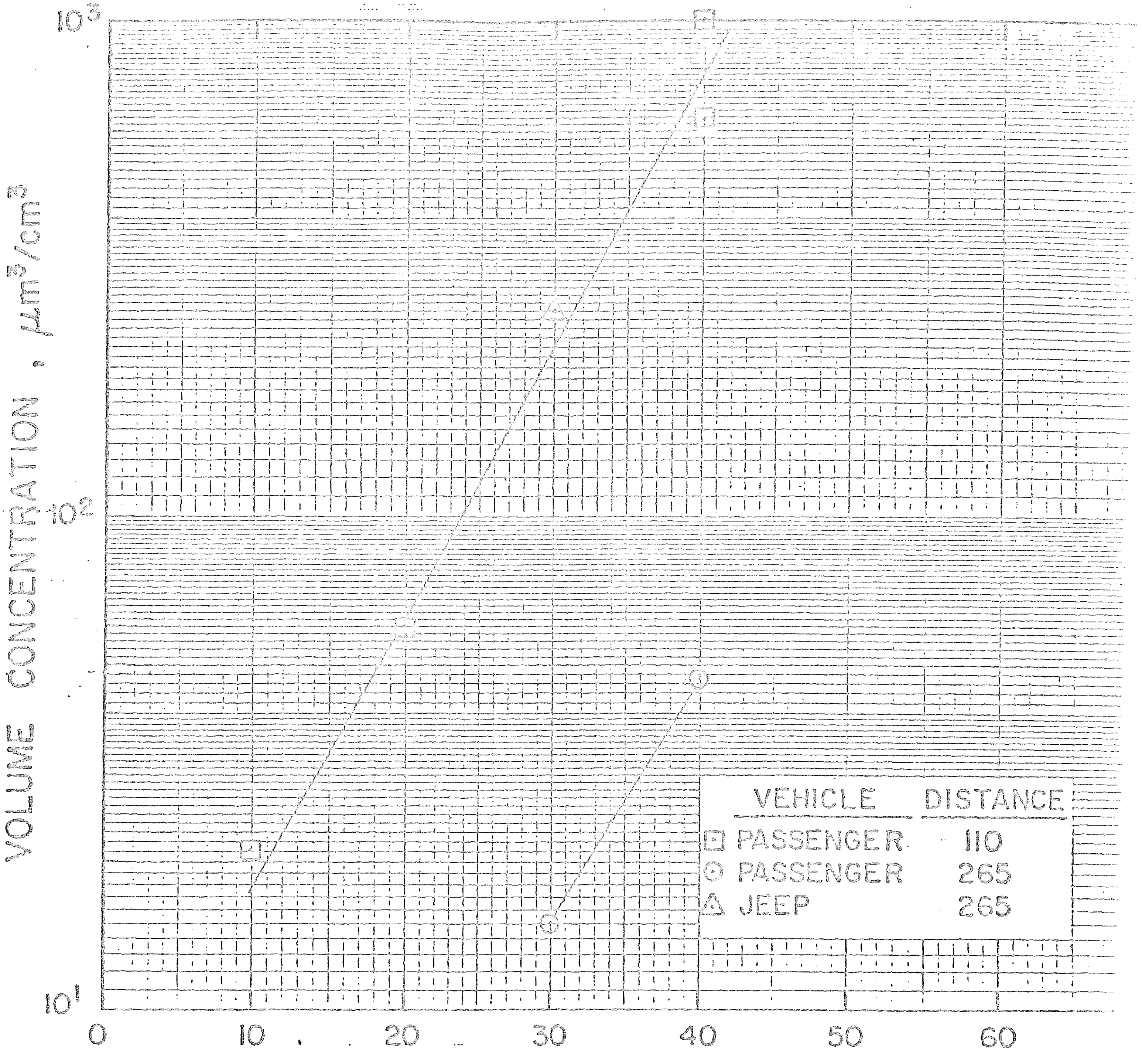


Figure 11. Measured coarse particle concentration in car dust plumes at two distances from the road.

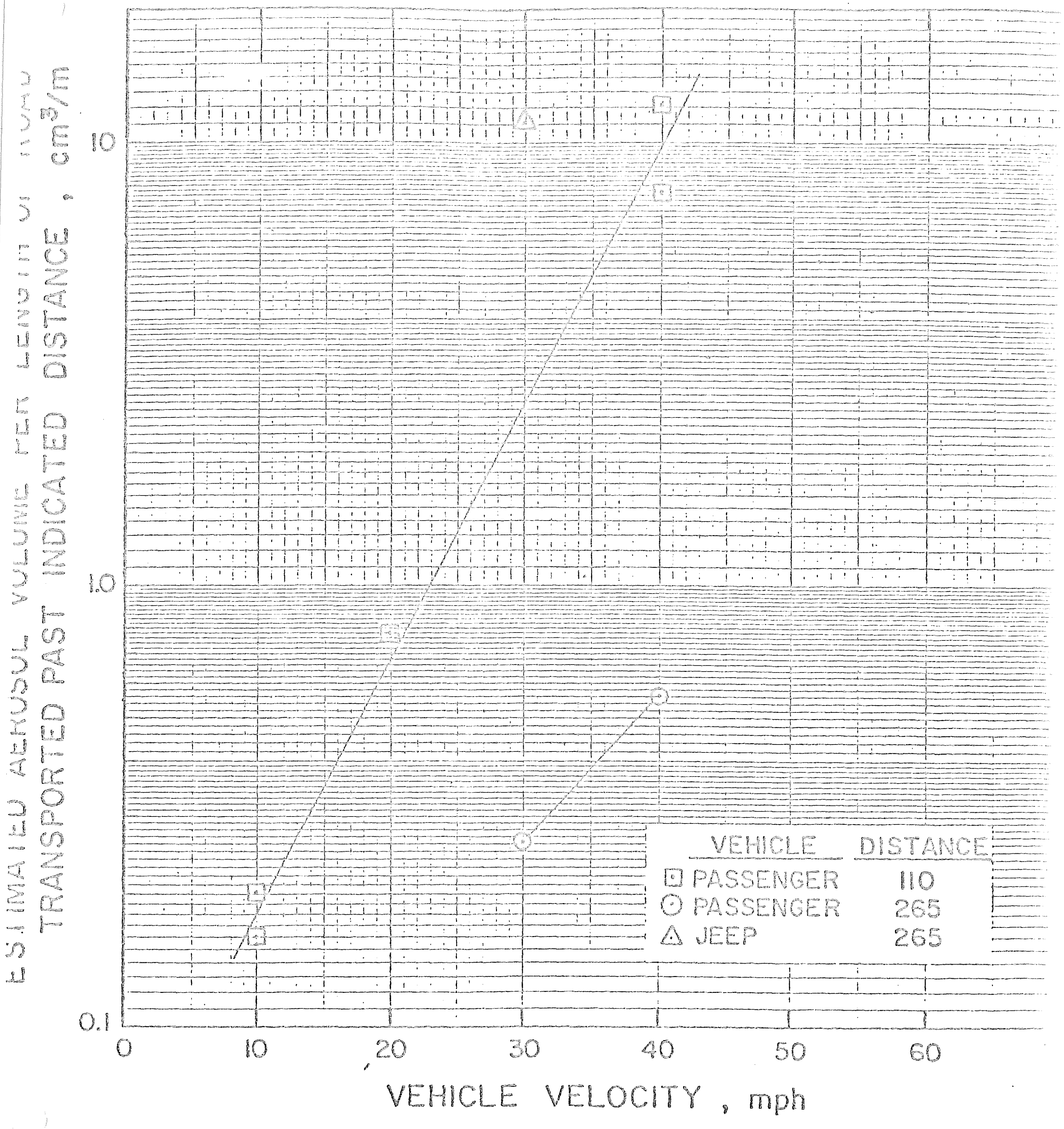


Figure 12. Estimated aerosol volume per unit length of road transported in a car dust plume over two distances.

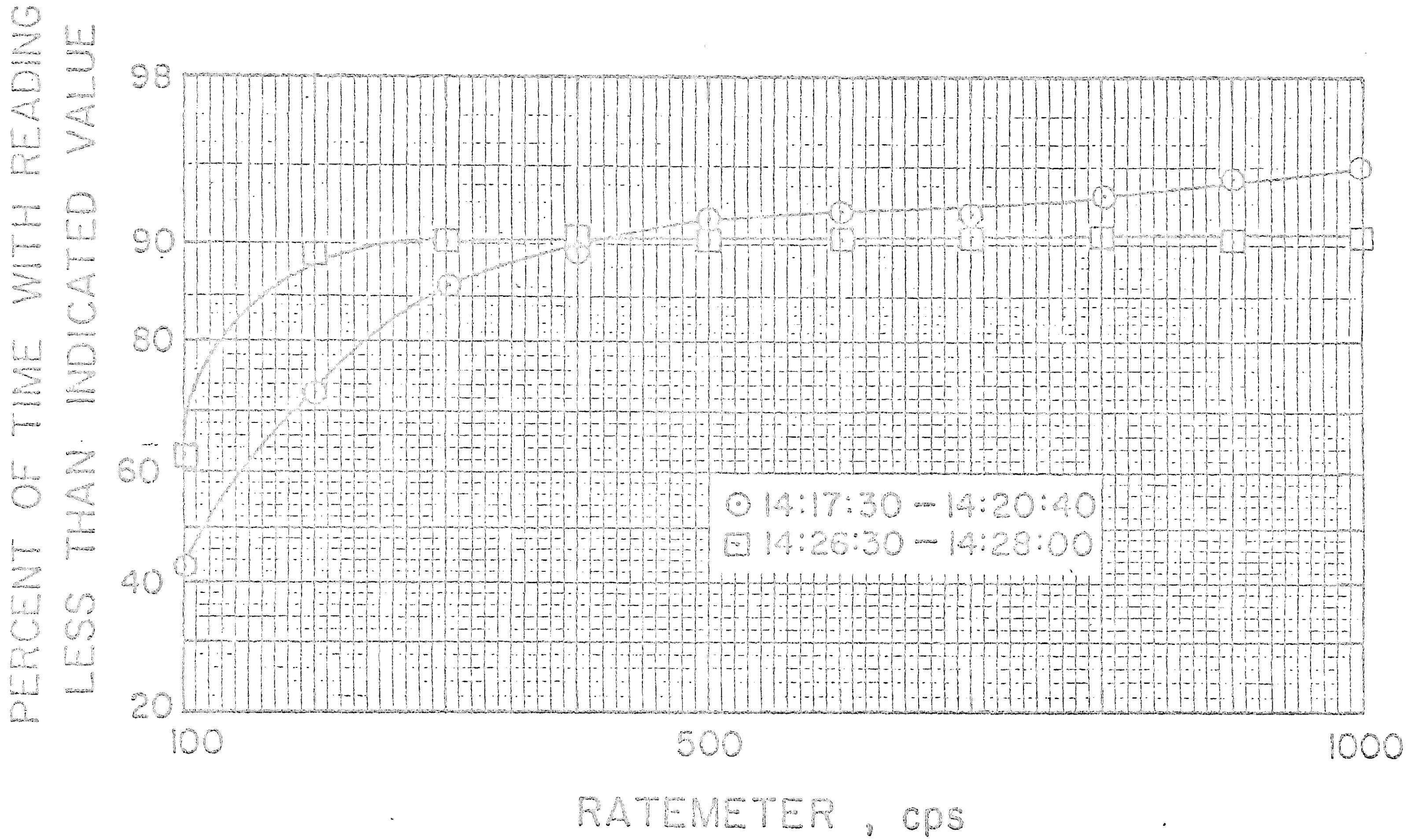


Figure 13. Cumulative Plots of ratemeter readings over two time intervals containing wind blown dust episodes.

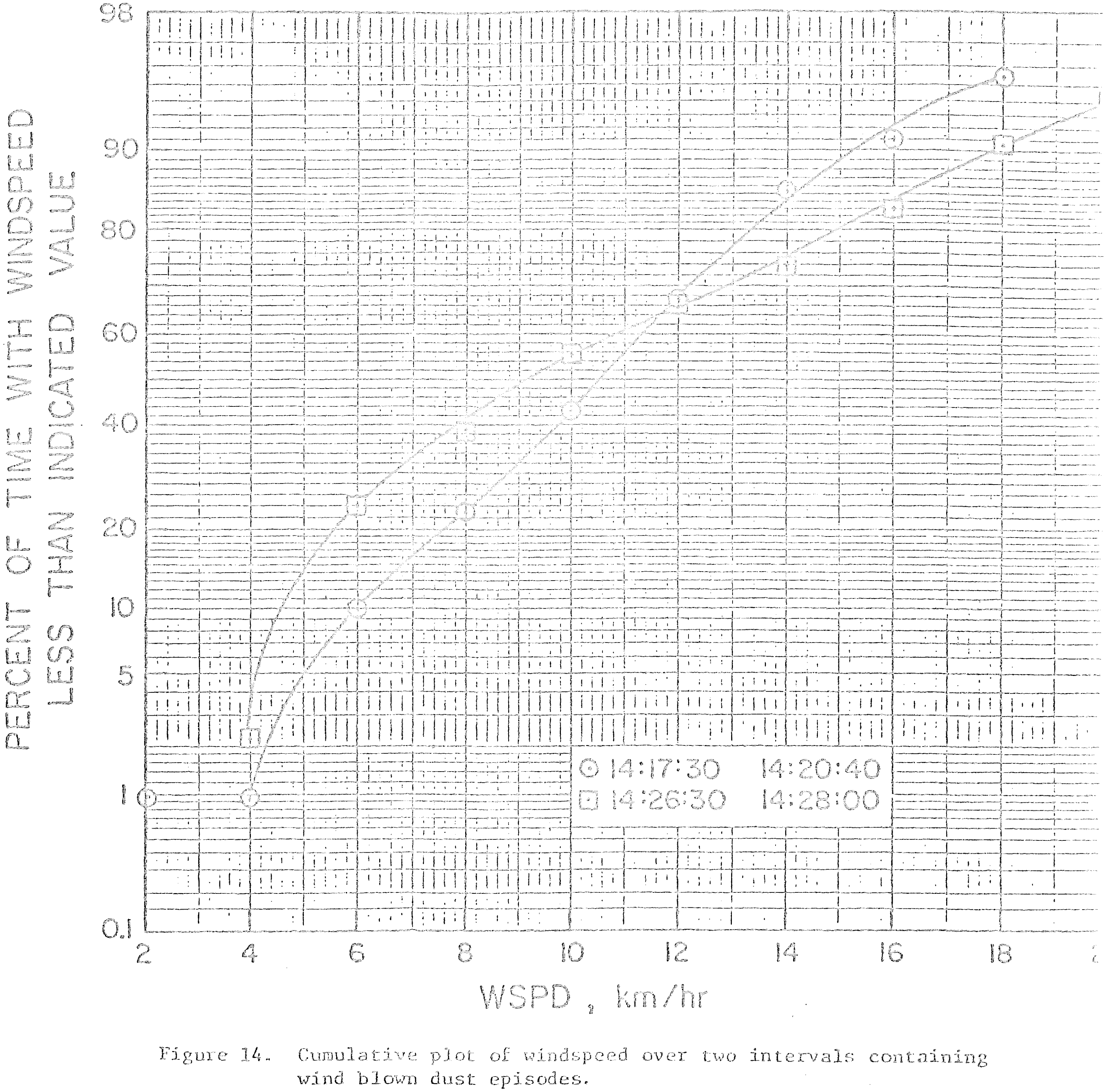


Figure 14. Cumulative plot of windspeed over two intervals containing wind blown dust episodes.