[AMERICAN JOURNAL OF SCIENCE, VOL. 255, MARCH 1957, P. 206-213]

SEDIMENTARY CHARACTERISTICS OF DUST STORMS: III. COMPOSITION OF SUSPENDED DUST

W. S. CHEPIL

ABSTRACT. Wind-blown dust varied widely in its composition depending on the composition of eroded soil, the year of measurement, and the distance and height of transport. The composition of the dust was like the composition of many samples of loess. The size distribution of dust and of coarser materials transported at any height or deposited anywhere after any single windstorm was characterized by a single peak diameter of the discrete particles and by arms on each side of the peak falling off independently of each other at some constant rate. The peak diameter varied from one graded material to another, depending on the physical nature of the soil, distance and height of transport, and possibly the velocity of the wind.

INTRODUCTION AND ACKNOWLEDGMENT

In an earlier study the grading patterns of soil materials transported by wind and ultimately deposited in drifts here and there in the vicinity of eroded fields were presented (Chepil, 1957). Considerable proportions of fine soil particles known to be transported by wind were deposited nowhere in the vicinity of wind-eroded localities. These particles were suspended in the form of dust clouds and transported far and wide by the atmosphere. A study was made on the physical characteristics of the suspended dust and of some of the materials transitional between dust and drift. The results of this study are presented herein.

The object of this study was (1) to obtain an insight of the nature of sorting of fine particles from the less mobile portions of the soil and (2) to determine whether dust carried in the atmosphere is comparable in composition with loessal soils.

This paper is Contribution No. 549, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kansas, and Agricultural Research Service, U.S.D.A., Cooperative Investigations on the Mechanics of Wind Erosion.

PROCEDURE

Dust was caught at various heights above the ground in accordance with a method already described in an earlier publication of this series (Chepil and Woodruff, 1957). The equivalent size distribution of the dust particles was determined in accordance with a method also described in the earlier publication. Mechanical composition of the dust, on the other hand, was determined by the method of Bouyoucos (1951).

SIZE DISTRIBUTION AND MECHANICAL COMPOSITION OF DUST

The equivalent size distribution of dust particles carried in suspension is shown in the "percentage smaller" diagrams of figure 1. Since the size distribution curves appear to be quite symmetrical, the mean equivalent diameter of the particles can be determined approximately from a point on the distribution curve corresponding to a percentage smaller value of 50. Figure 1 indicates that for both 1954 and 1955 the mean equivalent diameter of discrete dust particles (shown on curve a) was considerably greater than the average diameter of elementary mechanical particles (sand, silt, and clay,

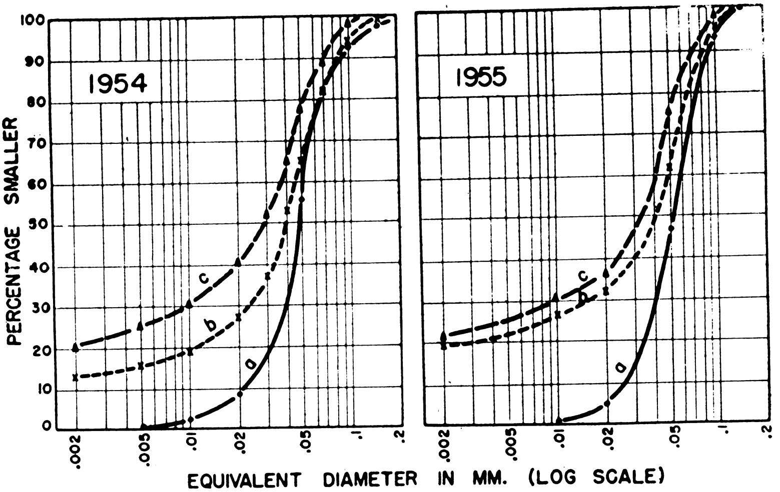

Fig. 1. Average equivalent size distribution of soil particles carried in suspension between 4 and 8 feet height during 1954 dust storms and between 2 and 20 feet height during 1955: (a) discrete particle size distribution as determined by sedimentation in carbon tetrachloride, based on a composite of all samples, (b) mechanical composition of dust after dispersion with sodium hexametaphosphate in water, composite of samples over sandy soils, and (c) composition as in (b) for a composite of samples over silt loam soils.

shown on curves b and c) of which the dust particles were composed. For the 1954 data, the mean equivalent diameter of the dust particles over all of the soil classes investigated was 0.049 mm. The mean equivalent diameter of the mechanical particles, on the other hand, was 0.039 mm for samples collected over sandy soils and only 0.029 mm for samples over silt loam soils. The values of mean equivalent diameter for 1954 were only slightly smaller than the corresponding values for 1955.

It is evident that some dust particles were composed of aggregates of sand, silt, and/or clay, otherwise there would not have been any dispersion of the dust particles by the dispersing agent in water and the size distribution curve of the elementary mechanical particles would have coincided with the size distribution curve of the discrete dust particles. The greater the spread between the two average curves, the greater would be the degree of aggregation of the elementary mechanical particles. It is shown from figure 1 that the greatest spread, and therefore the greatest degree of aggregation, was for the clay particles (< 0.002 mm), less for silt (0.002 – 0.05 mm), and least for sand (> 0.05 mm). It is evident that the largest dust particles were almost entirely composed of individual particles of fine and very fine sand. Considerable deviations between the two curves within the silt and clay range seem to indicate that silt and clay were carried to some degree as aggregates of the size of silt and sand. Furthermore, curve a indicates that virtually all of the clay fraction was aggregated into particles greater than 0.05 mm in diameter. Photographs of dust particles substantiate this conclusion. Although discrete particles of the size of clay amounted to a mere trace of the total weight of the material, their numbers were fairly substantial, especially in some of the finest dust samples. The great majority of the dust particles were larger than particles of clay, were smooth, rounded, and almost transparent, and composed predominantly of individual grains of silt and sand. An occasional dust particle showed some smaller particles clinging to its surface. Still others showed definite angularity and unevenness of surface. The latter particles apparently were aggregates composed primarily of clay, very fine silt, and organic matter.

Although the percentage smaller diagrams of figure 1 serve a good purpose of indicating the general range of size of dust particles, they do not indicate clearly the true size aistribution of the particles. Therefore, it was decided to re-plot the data by following the log diagram method of Bagnold (1943) originally used on dune sand. This was done by plotting the logarithm of the percentage weight of soil per unit of log-diameter scale against the logarithm of grain diameter. Assuming the diameter limits of each grade as determined by sieving to be d_1 and d_2, the logarithmic interval of grain diameter is given by log d_1/d_2 which for convenience is designated by D. The percentage weight p of each grade per unit of log-diameter scale is then equal to $\Delta p/\Delta D$. These percentage frequency values plotted against the logarithm of particle diameter indicated a single "peak" or predominant diameter of the dust particles. Moreover the grades to the left and the right of the peak diameter fell off at rather uniform rates (fig. 2, curve a). Also, the peak diameter coincided with the mean equivalent diameter of the dust particles (table 1). The size distribution pattern of the dust particles was of the same general nature as the size distribution of dune sand (Bagnold, 1943) and of

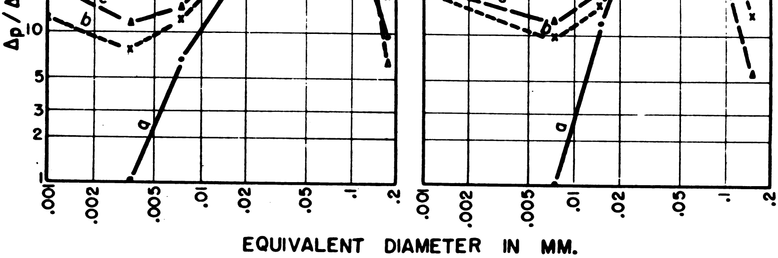

Fig. 2. Average equivalent size distribution of soil particles carried in suspension between 4 and 8 feet height during 1954 dust storms and between 2 and 20 feet height during 1955: (a) discrete particle size distribution as determined by sedimentation in carbon tetrachloride, based on a composite of all samples, (b) mechanical composition of dust after dispersion with sodium hexametaphosphate in water, composite of samples over sandy soils, and (c) mechanical composition as in (b) for a composite of samples over silt loam soils.

drifted soil materials (Chepil, 1957). The only distinguishing features of all the distribution curves were in their positions on the logarithmic scale and in the slopes of each of the two straight arms. It is evident that the same logarithmic law of distribution applicable to sand and soil grains transported in saltation and surface creep is also applicable to suspended dust.

TABLE 1

Equivalent Diameter Distribution and Mean Equivalent Diameter of Dust Particles Carried at Different Heights Over Two Soil Class Groups During 1955 Kansas and Colorado Dust Storms.

Class	Height	Equivalent diameter distribution					Weighted mean equivalent diameter
		0.25-0.1 mm	0.1-0.05 mm	0.05-0.02 mm	0.02-0.01 mm	<0.01 mm	
	feet	%	%	%	%	%	mm
Sandy soils	2	15.0	64.5	19.6	0.9	0	0.082
	5	2.7	43.6	46.1	7.6	0	0.054
	11	3.3	42.1	50.4	4.3	0	0.055
	20	0.8	39.2	56.5	3.5	T	0.051
Mean		5.4	47.4	43.1	4.1	T	0.060
Silt loam soils	2	21.3	63.9	14.2	0.6	0	0.090
	5	7.8	49.1	39.4	3.7	0	0.065
	11	2.0	37.0	51.8	9.2	T	0.050
	20	1.6	31.1	63.6	3.7	T	0.050
Mean		8.2	45.3	42.2	4.3	T	0.064

The average equivalent size of dust particles carried in suspension between the heights of 2 and 20 feet was considerably smaller than the average equivalent size of particles of accumulated drifts analyzed in the previous study (Chepil, 1957, tables 1, 2, and 3). Analysis of equivalent size distribution of particles in the drifts and of particles carried through the air revealed that considerable proportions of intermediate sizes were absent from the two materials. The intermediate sizes were evidently carried predominantly below the height of 2 feet and transported beyond the vicinity of the drifts. They were apparently transitional materials carried partly in saltation and/or partly in true suspension. Comparative differences between soil particles accumulated in the drifts, the transitional particles carried beyond the vicinity of the drifts, and the dust particles carried between the heights of 2 and 20 feet are shown in table 2.

The size distribution of particles collected from the drifts and from the air was characterized by a single peak diameter with arms to the left and the right of the peak falling off each at its own constant rate. The transitional material bore no similarity to such a grading pattern. Nowhere could be found deposited or suspended materials bearing any similarity to this missing material. Evidently the missing material was deposited nowhere in particular but rather constituted parts of materials ultimately deposited at various locations from their source. An example of one such part is indicated as a lee deposit in table 3. The lee deposit was composed of particles generally much finer than those found in drifts or mounds in or near an eroded field; but on the other hand, it contained particles substantially coarser than those generally caught in the air between the heights of 2 and 20 feet.

TABLE 2

Equivalent Size Distribution of Soil Particles in Fields, in Accumulated Drifts, in Areas Beyond the Vicinity of the Drifts, and in the Air Between the Heights of 2 and 20 Feet.

Material	Equivalent diameter of particles						
	>1.38 mm	1.38-.58 mm	.58-.30 mm	.30-.15 mm	.15-.073 mm	.073-.037 mm	<.037 mm
	%	%	%	%	%	%	%
Original soil	21.5	8.4	21.9	25.2	11.0	7.2	4.8
Drifts or dunes	0.5	7.2	35.8	34.2	14.0	5.7	2.6
Eroded but not found in drifts (estimated from composition of original soil)	0	0	T	29.4	25.4	29.1	16.1
Caught in air between 2 and 20 feet	0	0	0	1.1	5.6	40.2	53.1

TABLE 3

Size Distribution of Soil Particles in Drifts and in a Lee Deposit Originating from a Wind-eroded Field of Loess Soil near Salina, Kansas, 1950.

Source of material	Diameter of particles					
	2.0-0.84 mm	0.84-0.42 mm	0.42-0.21 mm	0.21-0.1 mm	0.1-0.05 mm	<0.05 mm
Drifts in and nearby eroded field	% 2.3	% 30.2	% 38.6	% 16.7	% 2.9	% 9.3
Uniformly diminishing deposit in Sudangrass beyond 400 feet to the lee of the eroded field	0	1.0	8.2	34.3	22.4	34.1

The size distribution of particles of the lee deposit, as in all graded soil materials, was characterized by a peak diameter with each of the two arms falling off uniformly but independently of the other. The lee deposit varied from nearly zero to over 2 inches in depth depending on distance from the eroded field. The deposit had no tendency to form drifts or dunes like those formed from coarser materials, but was distributed rather uniformly over the ground well protected by a cover of Sudangrass. The absence of a grass cover no doubt would have caused the material to be moved rapidly and distributed somewhere else by the wind.

The size distribution of the elementary mechanical fractions showed a distinctly different pattern from the size distribution of the dust particles composed of those fractions. The size distribution curves indicated a major bulge in the vicinity of the peak diameter of the dust particles and a small rise in the clay fraction (fig. 2, curves b and c). The predominant equivalent diameter of the mechanical fractions of which the dust particles were composed varied from about 0.05 to 0.07 mm depending on soil class and year of measurement. The corresponding mean equivalent diameter of the mechanical fractions, on the other hand, was only 0.048 mm for sandy soils and 0.035 mm for silt loam soils (table 4). These discrepancies are due no doubt to the fact that the mechanical fractions were not symmetrically graded. The dust particles, on the other hand, were symmetrically graded so their peak diameter (fig. 2, curve a) coincided with their mean equivalent diameter (table 1).

The mean equivalent diameter of the suspended dust particles decreased with height above the ground (table 1). Particles carried at 2 feet above the ground had an average equivalent diameter of 0.086 mm whereas those carried at 20 feet had an average equivalent diameter of 0.05 mm. As determined by extrapolation in the previous study for 1955, the average equivalent diameter of dust particles at one-mile height was only 0.022 mm (Chepil and Woodruff, 1957). The equivalent size of particles carried over sandy soils and over silt loam soils at corresponding heights was about the same. This similarity of equivalent size is to be expected since the same wind force acted on all of the soil classes. The actual size of particles was conceivably different for the various soil classes, depending on their bulk density.

Dust arising from sandy soils contained more sand and less silt and clay than dust carried at corresponding heights over silt loam soils (table 4). However, samples of dust from sandy soils were similar in composition to dust carried at some lower height from silt loam soils. For example, dust carried at 11 feet over sandy soils differed little in mechanical composition from dust carried at 2 feet over silt loam soils. It is reasonable to expect that dust carried at greater heights would be carried to greater distances. If this assumption is true, then some deposits of dust originating from sandy soils would be similar in composition to some deposits derived from silt loam soils, but located farther away from their source.

DISCUSSION AND CONCLUSIONS

The wind-blown dust obtained in this study (fig. 1, curves b and c, and table 4) generally contained somewhat more sand and clay than the samples of loess analyzed by Péwé (1951) and the samples of wind-blown dust analyzed by Swineford and Frye (1945). On the other hand, the clay content of the dust obtained in this study was generally much lower than the clay content of wind-blown dust collected by Warn and Cox (1951). This study shows that considerable variation exists in the composition of suspended dust depending on the composition of eroded soil, year of measurement, and distance and height of transport. Differences obtained in different years probably are associated with different wind velocities. Considerable variations do exist in the composition of loess. For example, Hanna and Bidwell (1955) showed that the elementary particles of loess become finer with distance away from the Missouri River valley flood plain believed to be the source of loess. The com-

TABLE 4
Mechanical Composition of Dust Carried in Suspension at Different Heights over Two Soil Class Groups During 1955 Kansas and Colorado Dust Storms.

Class	Height	Fine sand 0.25-0.1 mm	Very fine sand 0.1-0.05 mm	Coarse silt 0.05-0.02 mm	Medium silt 0.02-0.01 mm	Fine silt 0.01-0.002 mm	Clay <0.002 mm	Weighted mean equivalent diameter mm
	feet	%	%	%	%	%	%	
Sandy soils	2	10.5	36.6	24.8	5.0	7.6	15.5	0.068
	5	2.0	37.3	29.7	5.0	7.1	18.9	0.043
	11	3.3	34.7	27.7	5.6	7.1	21.6	0.043
	20	0.7	30.6	37.5	3.0	5.6	22.6	0.038
Mean		4.1	34.8	29.9	4.6	6.9	19.7	0.048
Silt loam soils	2	3.0	31.6	29.3	6.1	9.8	20.2	0.041
	5	1.4	19.5	43.7	6.1	8.4	20.9	0.034
	11	1.5	20.7	41.8	6.0	8.4	21.6	0.034
	20	0.8	19.9	41.4	5.9	8.4	23.6	0.032
Mean		1.7	22.8	39.1	6.0	8.8	21.6	0.035

position of dust obtained in this study is like the composition of many samples of loess.

Results of analysis of suspended dust and of some deposited materials agree in many respects with previous results on lag materials and drifts or dunes and confirm the existence of a remarkable phenomenon of sorting of soil materials by the wind, namely: soil material transported at any height or deposited anywhere by any single windstorm is characterized by a predominant or peak diameter of the discrete particles and by arms on each side of the peak falling off each at its own uniform rate. The peak diameter varies from one graded material to another depending on the physical composition of the soil and distance and height of transport. Materials deposited at a location by different winds are composed of mixtures of different grades, may have more than one distinct or several indistinct diametric peaks, and show no resemblance to any single grade. The finer the eroded particles the greater is their speed, height, and distance of travel. The individual grades, such as the nonerodible fractions, the lag materials, the drifts or dunes, the lee deposits, and the dusts tend to merge one with the other so that no clear-cut demarkation is found between any of them. The grades are merely descriptive and not strictly categorical.

REFERENCES

Bagnold, R. A., 1943, The physics of blown sand and desert dunes: New York, William Morrow & Company.

Bouyoucos, G. J., 1951, A recalibration of the hydrometer method for making mechanical analysis of soils: Agronomy Jour., v. 43, p. 434-438.

Chepil, W. S., 1957, Sedimentary characteristics of dust storms: I. Elutriation of wind-eroded soil: AM. JOUR. SCI., v. 255, p. 12-22.

Chepil, W. S., and Woodruff, N. P., 1957, Sedimentary characteristics of dust storms: II. Visibility and dust concentration: AM. JOUR. SCI., v. 255, p. 104-114.

Hanna, R. M., and Bidwell, O. W., 1955, The relation of certain loessal soils of northeastern Kansas to the texture of the underlying loess: Soil Sci. Soc. America Proc., v. 19, p. 354-359.

Péwé, Troy L., 1951, An observation of wind-blown silt: Jour. Geol., v. 59, p. 399-401.

Swineford, A., and Frye, J. C., 1945, A mechanical analysis of wind-blown dust compared with analyses of loess: AM. JOUR. SCI., v. 243, p. 249-255.

Warn, F. G., and Cox, W. H., 1951, A sedimentary study of dust storms in the vicinity of Lubbock, Texas: AM. JOUR. SCI., v. 249, p. 553-568.

WESTERN SOIL AND WATER MANAGEMENT SECTION, S.W.C.R.B.
AGRICULTURAL RESEARCH SERVICE, U.S.D.A.
MANHATTAN, KANSAS