Measurements of Current and Historic Settled Dusts in West Texas

Thomas E. Gill
Texas Tech University, Department of Geosciences, Box 42101, Lubbock, Texas 79409-2101

Richard L. Reynolds
U.S. Geological Survey, Denver, Colorado

Ted M. Zobeck
USDA Agricultural Research Service, Lubbock, Texas

ABSTRACT

The southern Great Plains region of western Texas generally experiences the greatest annual prevalence of blowing dust of any region in North America. From the "Dust Bowl" through the present, fugitive dust has been a major environmental management issue in this region. Dust generated in this area has settled out thousands of kilometers from its source. We have located and collected several samples of settled dust from sites in the southern Great Plains of Texas, including materials apparently deposited in the first half of the 20th century, and present-day samples from dust traps and individual dust storms. Some particle-size, mineralogical and chemical measurements have been performed on these materials. The data are useful in understanding the relationship between settled dust and ambient aerosol in the Southern Plains, in understanding how the magnitude of dustfall in the Southern Plains compares to other areas, and for creating basic source profiles of west Texas dust for receptor studies.

1. INTRODUCTION AND BACKGROUND

The southern Great Plains, especially the Texas Panhandle region and the Southern High Plains immediately south of the Panhandle, is one of the dustiest areas of the United States[1]. Airborne dust has been an environmental nuisance in this region since European settlement (and conversion of the native short-grass and mixed-grass prairie into cropland) began about 100 years ago, and doubtless was an indigenous environmental process long before that. This area was the heart of the disastrous "Dust Bowl" in the 1930s, and the region again experienced widespread dusty conditions during the protracted drought of the 1950s, as well as in the 1970s. In recent years, blowing dust has been reported somewhere in the region in National Weather Service advisories approximately 40 to 60 days per year[2]. Dust or soil aerosols in the Southern High Plains and Panhandle regions of Texas are produced primarily by wind erosion of unvegetated or disturbed soils associated with agriculture, the main industry of the region, as well as unpaved roads.

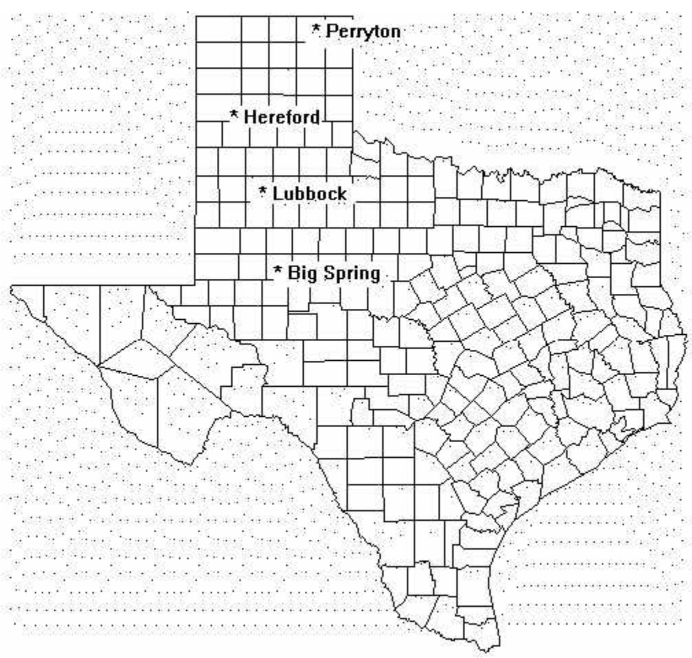
Within the Southern Plains during the Dust Bowl, fugitive dust settled in massive quantities, as stated by Ervin and Lee[3]:

> Cleaning up houses, farm lots and city stores after the 1935 blow season was expensive. Carpets, draperies and tapestries are reported to have been so dust-laden that their patterns were indiscernible. Painted surfaces were sandblasted bare. Automobile and tractor engines operated in dust storms without oil-bath air cleaners were ruined by grit. Amarillo merchants estimated from 3 to 15 percent damage to their merchandise and additional loss of shoppers during storms.

Fugitive dust emitted from west Texas soils also has the ability to travel long distances and settle in noticeable amounts far from its source. During the Dust Bowl era, press reports and meteorological analyses indicate that airborne dust from this region was transported as far east as the Atlantic coast and as far north as Canada. Intense dust storms in more recent times still cause dustfalls thousands of kilometers away from their west Texas source. Dust derived from the Lubbock, Texas area soiled surfaces on the Atlantic coast of Georgia, more than 1800 km downwind[4]. More recently, a dust storm on May 4, 1999, in western Texas resulted in aerosol fallout that coated surfaces as far away as Iowa[2]. However, there has been a paucity of published scientific reports to date regarding the physical and chemical characteristics of fugitive dust from western Texas.

This paper integrates and summarizes data for some samples of settled dusts from the Texas Panhandle and Southern High Plains, both from past decades and present-day deposition. Even though the number of samples is limited, these data allow a preliminary description of the characteristics of settled dust in the Southern Plains, and can be used in developing source profiles of fugitive dust from western Texas for future receptor studies. Locations of samples discussed in this paper are shown on Figure 1 below.

Figure 1. Map of Texas showing sampling locations.

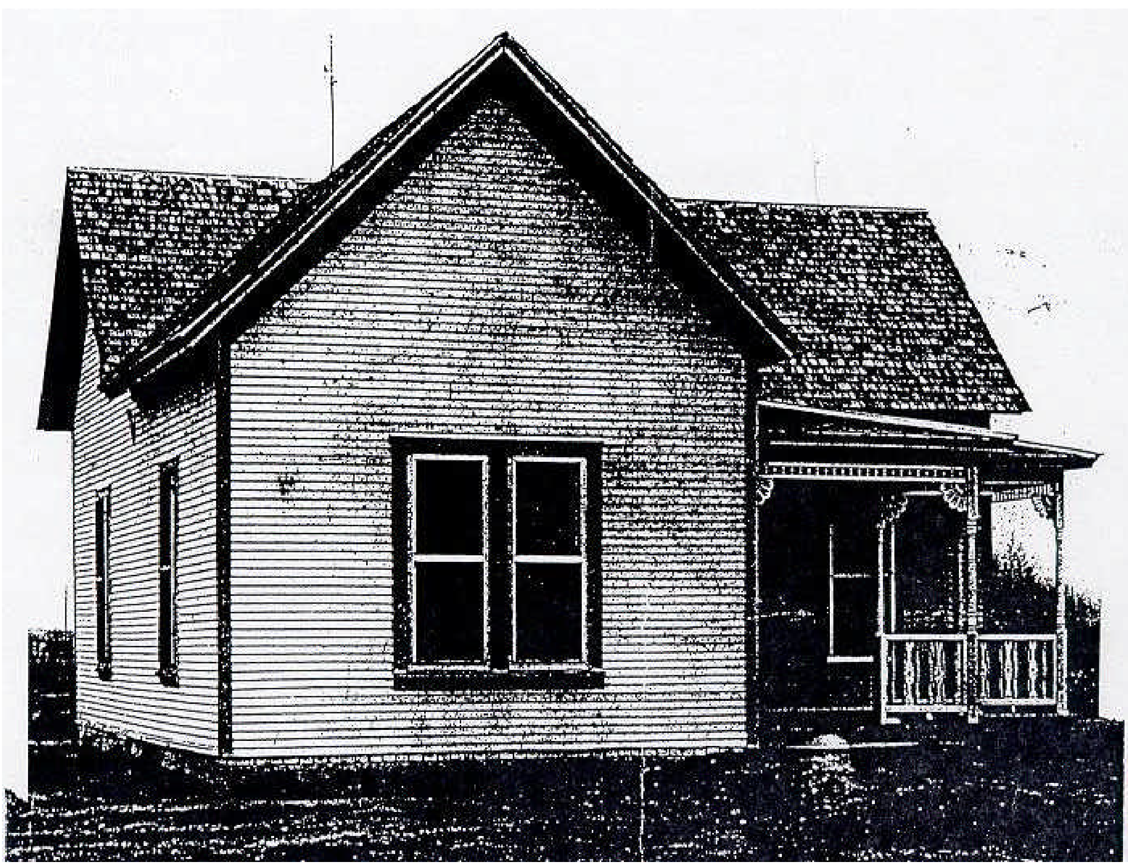


2. SETTLED DUST SAMPLES FROM 1906 TO 1999

Two samples of settled dust were recovered from historic buildings in the Texas Panhandle, and one sample of settled dust was recovered from an outdoor patio following the major dust storm of May 4, 1999. Of course, these sediments were not collected in scientific sampling devices, and the actual origin and relevance of the composition of these sediments is subject to some question. Still, they may provide a preliminary indication of the nature of settled dusts from the heart of the "Dust Bowl" during historic and present days.

The Norwood House (Figure 2) was built in circa 1906 in Ochiltree, Ochiltree County, Texas. In 1919, as a result of construction of the Santa Fe railroad through the region, the entire house was moved twenty-one miles north-northwest to the Norwood family farm eleven miles northwest of Perryton, Texas. The house remained in that site until sometime in the 1960s when it was moved to the town of Perryton. In 1986, the house was donated to the Museum of the Plains in Perryton. In the mid-1990s, during renovation, museum workers inspected the attic and discovered that it was filled with a thick layer of dust. It is believed that the dust had been accumulating relatively undisturbed perhaps since the house was constructed. "Three large wheelbarrows full of dust" were recovered (Gene Riley, Museum of the Plains, personal communication, 1999): aliquots of this material were placed in clean glass vials by museum staff and have been sold as "Dust Bowl Dust" at the museum shop.

Figure 2. Photograph of the Norwood House (courtesy Museum of the Plains, Perryton, TX)



The second sample was recovered from a house in Hereford, Deaf Smith County, Texas, and will hereinafter be referred to as the “Hereford House.” Like the Norwood House, it was built in 1906. The house was remodeled and expanded in 1946- 1950, when the roof was replaced and the walls and skirts were stuccoed, filling the cracks and holes through which dust may have entered. The house has not moved: at the time of its construction, it was built about 1.5 miles west of the city limits, but the town has grown in recent decades, and it now sits one mile inside the west city limit of Hereford. A large quantity of dust was recovered from between the walls of the house during a major repair and renovation project in 1999. The soil was recovered from inside the walls, where it had accumulated to a depth of 3 to 5 inches. Given the remodeling activities of 1946- 50, most of the dust probably accumulated before 1950. Though the house was well constructed for its time, there were cracks between the ends of the floorboards and the sides of the walls; dust could have blown in from beneath the house as well as settling in from above (Buryl Fish, homeowner, personal communication, 1999).

A third sample was collected in Lubbock, Texas on May 5, 1999, a day after the most significant dust outbreak in western Texas in perhaps a decade or more[2]. Dust was produced from western Texas and eastern New Mexico and deposited in amounts sufficient to soil surfaces at least as far away as Iowa and Illinois[5]. Flooding rains and scattered hail throughout the region the previous week had smoothed and crusted the soil surface; widespread runoff mobilized a veneer of fine, loosened soil over the land surface. Once dried, exposed sediments became highly erodible by the wind. Westerly winds sustained at approximately 15-20 m/sec, gusting to approximately 30 m/sec occurred throughout the afternoon of May 4th, lofting prodigious quantities of soil into the air. Unofficial estimates of the 24-hour total suspended particulate matter (TSP) concentration for Lubbock on May 4th was in the hundreds of micrograms per cubic meter (John Stout, USDA Agricultural Research Service, personal communication, 1999). A dusty haze reduced visibilities from southern New Mexico across much of Texas and Oklahoma. The Dallas-Fort Worth metropolitan area was put under an air quality alert due in large part to PM10 emitted from west Texas, which coated vehicles in the Dallas area with fine dust overnight from the 4th to the 5th of May. Wire-service reports indicated that reddish-brown dust coated automobiles in southeastern Iowa on the 6th of May. A sample of settled dust from this event was available from the home of the first author, in an urbanized portion of the southwest side of the city of Lubbock, Texas. The nearest dust-emitting agricultural fields are approximately 2 km south of the location. An east-facing concrete patio area had fortuitously been swept thoroughly the previous weekend so that it visually appeared “clean.” On the morning of May 5th, this surface was covered by a thick layer (including dunelike drifts) of reddish-brown sediment which had settled out during the previous day. A portion of the material was gathered into a clean container and retained for analyses.

2.1 Particle Size Analysis

Settled dust samples were analyzed for their particle size characteristics using standard U.S. Geological Survey procedures for soil and sediment. The samples were oven-dried at 105 degrees Celsius; soluble and organic materials were removed, as were all particles larger than sand size (greater than 2 mm in diameter). Samples were dispersed under ultrasonication in sodium metahexaphosphate. Organic matter was removed using a 30 percent solution of hydrogen peroxide and magnesium chloride. Particle size was determined by sieving and by using a Malvern Mastersizer Long Bed Laser Particle Size Analyzer, a laser-light scattering instrument capable of measuring particles between 0.03 - 2000 micrometers. Samples were introduced in a stream of water, so water-soluble salts were removed before particle size analysis. Particle size results were reported as volume percentage (Table I). Statistical parameters indicated in Table I were derived from the method of moments.

The skewness (the second moment of the particle size distribution) is positive for all the "settled dust" samples. These data lend credence to the probability that these samples represent aeolian (wind-deposited) sediment. It appears that the Hereford sample and the Lubbock May 1999 sample may indeed contain some material which blew in from near the ground (saltating particles), rather that settling down from above; this is evidenced by the fact that they are primarily sand and are slightly less positively skewed, while the Norwood house sample is primarily silt and is more positively skewed. The attic of the Norwood house would be above the saltation layer, and any particles which entered at that level must have been fully suspended in the lower atmosphere.

TABLE I. Particle size characteristics of "historic settled dust" samples**.**

SITE	**% Sand (50- 2000 µm)**	**% Silt (2- 50 µm)**	**% Clay (< 2 µm)**	**% PM10**	**% PM1**	**Texture (USDA class)**	**Skewness**
Norwood House	22.98	70.11	6.92	11.37	4.26	Silt Loam	1.96
Hereford House	58.34	28.25	13.41	18.47	8.44	Silt Loam	0.83
Lubbock 5/5/99	56.26	33.64	10.10	13.59	7.05	Fine Sandy Loam	1.78

Within areas of active dust production, the sediment resulting from dust storms is similar in texture to the source sediment, whereas dust which settles far downwind is finer than the source material[6]. The texture of the two "Dust Bowl" samples (based on the USDA soil classification scheme) is classified as "silt loam," which is slightly finer than the predominant local soils[22], perhaps indicating that the dust which settled in this region over a long period of time was transported some distance. The settled dust from the May 1999 single storm in Lubbock had a "fine sandy loam" texture. Surface soils in Lubbock County and the surrounding area are predominantly fine sandy loams. Therefore, the dust that settled on Lubbock in May 1999 may not have been transported far from its primary source area (confirmed by meteorological and remote sensing analyses summarized in Gill *et al.*[2]).

During an intense fugitive dust event as was experienced during the Dust Bowl or on May 4, 1999, and/or during long-distance transport of aerosol, the particles may be disaggregated into constituent grains by physical processes within the dust cloud. The settled dust samples contain a fairly large proportion (>10%) of respirable particles. The settled dust from the Norwood house (Perryton) contained >11% PM10, approximately 7% clay (i.e. "PM 2"), and >4% particles 1 µm or smaller. The Hereford sample, while coarser overall in terms of the settled dust grain size, contained >18% PM10, >13% clay ("PM2"), and >8% particles 1 µm or smaller.

The settled dust from the May 4, 1999 dust storm in Lubbock contained >13% PM10, about 10% clay and >7% particles 1μm or smaller. Settled dust collected in Lubbock in the early 1950s had an average clay content of 7.2% [7]. The fact that >10% of each sample lies in the PM10 size range- and that >13% of the Hereford sample, which is otherwise relatively coarse, lies in the PM2.5 size range- attests to potential long-distance transport of these mineral particles during Dust Bowl and present-day dust storms.

2.2 Mineralogical Analysis

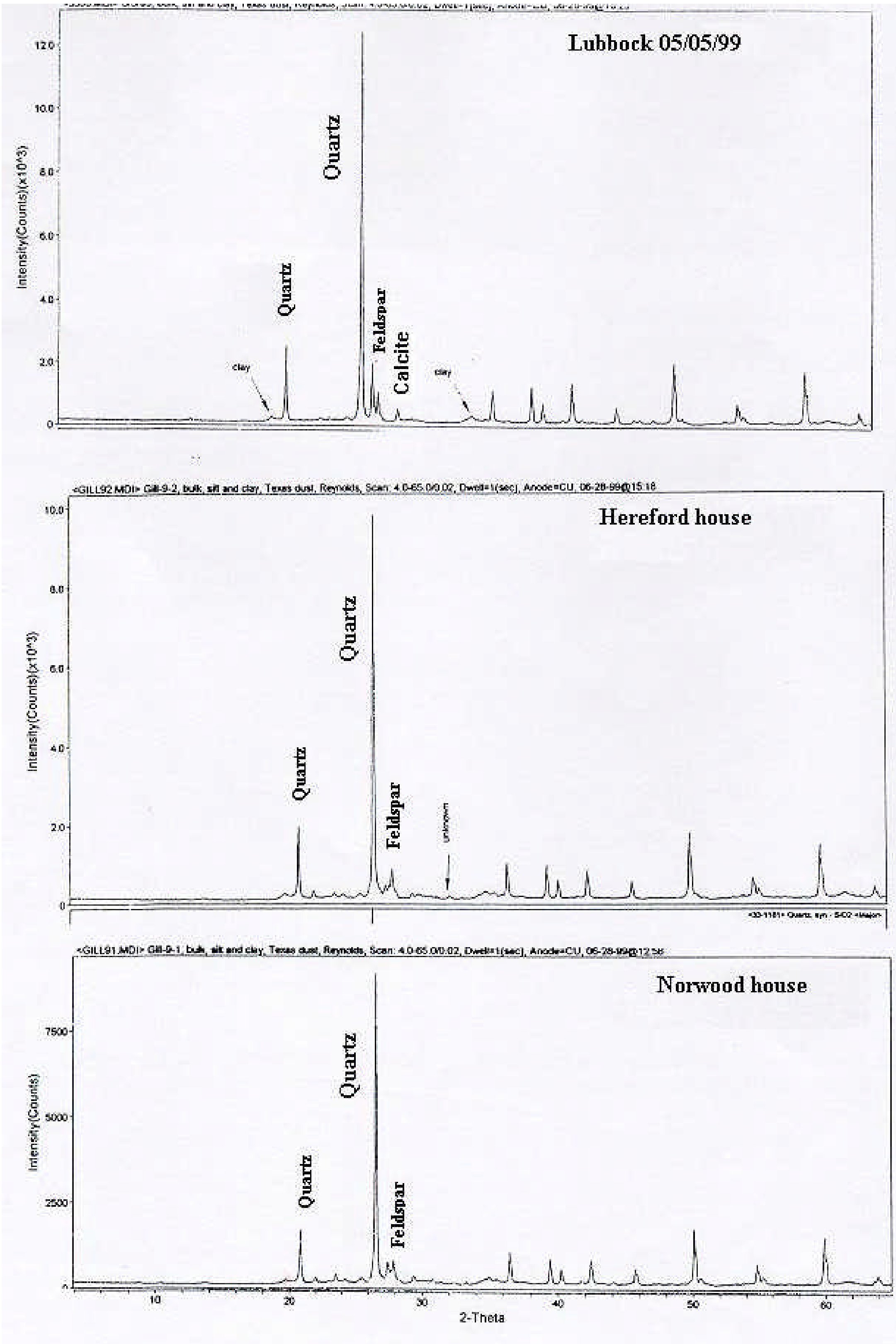
The bulk "historic" dust samples and the sample from the May 5, 1999 Lubbock dust storm were analyzed for their chemical composition by X-ray diffraction (XRD), which identifies the primary crystalline chemical compounds in a dry powder (Table II; Figure 3). X-ray diffraction analysis of a bulk sample is a qualitative technique which identifies the relative abundance of a major (in these analyses, comprising approximately 5% or more of a sample) constituent. Analysis used Cu K-alpha radiation. For non-clay analyses, "primary" minerals comprised more than ~10% of the sample, while "accessory" minerals comprised approximately 5-10% of the sample. Clay mineral analyses were performed separately on <2 micrometer extracts. Each extract was glycolated and run, then air dried and run again.

TABLE II. Mineral composition of settled dust samples (major constituents).

Norwood House	**Hereford House**	**Lubbock 5/5/99**
PRIMARY MINERALS: Quartz (SiO_2) Calcite ($CaCO_3$) Dolomite ($CaMg(CO_3)_2$) Muscovite (Mica group) Anorthite ($Ca_2Al_2Si_2O_8$) CLAY MINERALS: Illite Smectite Kaolinite ACCESSORY MINERALS: Unidentified amphibole	PRIMARY MINERALS: Quartz (SiO_2) Muscovite (Mica group) Anorthite ($Ca_2Al_2Si_2O_8$) CLAY MINERALS: Illite Kaolinite Smectite	PRIMARY MINERALS: Quartz (SiO_2) Calcite ($CaCO_3$) Anorthoclase ($[Na,K]AlSi_3O_8$) CLAY MINERALS: Illite Kaolinite Smectite

All of the settled dust samples are dominated by quartz, which is the primary constituent in the soils of the Southern High Plains and Texas Panhandle. All of the samples also contain feldspars (anorthite or anorthoclase) as primary minerals. Although the reddish-brown color of the Lubbock and Hereford dusts was probably caused by iron oxide coatings on grains, the coatings were not substantial enough (i.e., <5% of the sample) to be detected by these analyses. The two "Dust Bowl" settled dust samples from the Panhandle contained primary amounts (>10%) of muscovite mica, whereas the Norwood house and the Lubbock 5/5/99 dust samples also contained major amounts of calcite (which comprises the ubiquitous "caliche" of the Southern

Figure 3. X-ray diffraction traces for the three settled dust samples, some peaks identified.



Plains “caprock” and is a major constituent of wind-erodible dry saline playa surfaces). LaPrade[7] calculated that quartz comprised 61.5% of settled dust samples in Lubbock and carbonates (calcite) comprised 24% of dust collected in the early 1950s in Lubbock. Settled dust collected in 1983 from traps ~ 100 km northeast of Lubbock consisted “predominantly of silt-sized quartz grains.... feldspar grains.... accessory minerals include calcite, halite... heavy minerals, and mixed-layer clays.”[8] Holliday[9] stated that the non-clay fraction of surface soils of the Lubbock area contained “80%- 90% quartz, with the rest of the fraction composed of feldspar and mica.”

All of the settled dust samples analyzed in this study contained large amounts of the clay minerals illite, kaolinite, and smectite. The clay portion of the surface soils of the region is predominantly illite and smectite, with lesser amounts of kaolinite[9,10]. Samples collected from “dust traps” (design and deployment details unspecified) in Lubbock in the mid- 1980s[10] lacked kaolinite and consisted of 85% illite and 5% each smectite, illite, and mixed-layer illite-smectite.

Rabenhorst *et al*.[11] described the mineralogy of settled dust collected in the Edwards Plateau of central Texas, that was likely derived from a west Texas source area several hundred kilometers upwind. The dust contained primarily quartz with lesser amounts of feldspars, kaolinite, smectite, and mica- matching the west Texas soils and source dusts very well, except for the absence of calcite. However, these are all common rock-forming minerals and not in themselves rare enough to be diagnostic tracers of a particular location. The amphibole in the Norwood House sample may be a contaminant from insulation material, and its presence should not be considered diagnostic of fugitive dust.

3. RECENT MEASUREMENTS FROM DUST TRAPS

Passive dustfall traps have been maintained by the USDA Agricultural Research Service Wind Erosion and Water Conservation Research Unit in the Southern Plains, at Lubbock since January, 1997 and at Big Spring since April, 1998[12]. These dust traps are used to measure vertical aeolian flux (downward settlement of dust) and follow the design of those in a larger USGS dust sampling network in southern California and Nevada[13-15]. The dust traps (Figure 4) utilize an angel-food cake pan partly filled with marbles atop a wire screen, mounted at a height of 2 meters above the land surface in a fugitive dust receptor site. Every three months the settled dust is washed out and weighed, and the traps are cleaned. The mass of dust as well as particle size and some chemical data are determined for each quarterly sample[12]. These data can be used to compare present-day dust deposition in the Southern High Plains to that of other sites, and improve our understanding of the relations between air quality, meteorological conditions, and fugitive dust production.

3.1 Particle-Size Analysis

Particle size characteristics of dust collected through 1998 (Table III) were determined in the same manner as those for the samples in Table I. For seasonal designations, Winter includes January - March; Spring April -June; Summer July -September: and Autumn October-December.

Figure 4. Image of Lubbock passive dust trap.

TABLE III. Particle size data for dust trap samples.

Lubbock

DATE	% Sand (50-2000 µm)	% Silt (2- 50 µm)	% Clay (<2 µm)	% PM10	% PM1	Texture (USDA class)	Skewness
Winter 97	0.00	60.19	39.81	78.23	26.60	Silty clay loam	0.41
Spring 97	25.46	52.51	22.03	41.38	16.39	Silt loam	0.58
Summer 97	24.09	55.28	20.63	40.55	14.35	Silt loam	0.60
Autumn 97	33.91	47.19	18.90	38.50	13.71	Silt loam	0.56
Winter 98	13.30	58.47	28.23	55.44	20.06	Silty clay loam	0.38
Spring 98	11.51	64.56	23.91	52.71	16.44	Silt loam	0.49
Summer 98	45.03	47.34	7.63	23.79	N/A	Loam	N/A
Big Spring							
Spring 98	40.24	46.12	13.64	29.94	9.86	Loam	0.75
Summer 98	44.58	45.85	9.57	23.66	N/A	Loam	N/A

The particle size data show that the quarterly samples were largely (45- 60%) silt, with a lesser amount of sand and relatively large proportions of fine particles- at least 30% PM10 and 8- 28% clay. Both winter dust samples were much finer in particle size than samples from other seasons. The two samples of settled dust from Big Spring were coarser in texture than the Lubbock samples. Dustfall at Big Spring was twice as high in the summer of 1998 compared to the spring, suggesting that individual high-magnitude events (probably thunderstorm outflow “haboobs”) contributed greatly to short-term dust flux.

3.2 Chemical Analysis

Standard wet-chemistry techniques (for details, see Reheis and Kihl[14]) were used to determine the concentration of soluble salts, calcium carbonate and gypsum (calcium sulfate) in the dust trap samples, as well as the total carbon, organic carbon, and inorganic carbon contents (Table IV).

TABLE IV. Chemical data for dust trap samples.

DATE	% Soluble Salt	% Gypsum (calcium sulfate)	% calcium carbonate	% Total Carbon	% Inorganic Carbon	% Organic Carbon
Lubbock						
Winter 97	46.37	9.31	N/A	N/A	N/A	N/A
Spring 97	0.65	0.09	1.80	11.35	0.22	11.14
Summer 97	1.64	0.18	0.55	16.64	0.07	16.57
Autumn 97	1.28	0.22	15.31	14.21	1.84	15.31
Winter 98	1.71	0.09	0.51	10.66	0.06	10.60
Spring 98	0.74	0.09	5.12	6.09	0.61	5.48
Summer 98	2.03	0.50	4.06	10.59	0.49	10.10
Big Spring						
Spring 98	1.85	0.22	4.41	8.86	0.53	8.33
Summer 98	2.20	0.28	4.83	5.50	0.58	4.92

The samples generally contain on the order of 10% organic carbon, which is approximately 20 times higher than the proportion of organic material in local soils. This result illustrates the maxim that soil fertility is robbed by wind erosion. The calcium carbonate content of the settled dust samples was highly variable (0.5- 15.3%) and higher at both sites in 1998 than at Lubbock in 1997, perhaps indicating occasional pulses of erosion of the regional "caliche caprock" and dried, calcite-laden saline playa lakes. Gile *et al.*[16] measured 0.4% to 5.7% carbonates in dust near Las Cruces, New Mexico, using marble-type traps.

The unusual, highly saline composition of the Winter 1997 Lubbock sample precluded its analysis by some techniques. More than an order of magnitude more dust was collected during this quarter than during any other period (see Table V below), and the soluble salt and gypsum contents were strongly enhanced. These values are more typical of the intense saline dust plumes from Owens Lake, California[15]. It is not known what may have caused this unusual "spike" of saline dust in early 1997: perhaps a local dust devil or series of dust devils might be implicated, although we do not know for sure.

4. DUST SETTLING RATES FROM DUST TRAPS

4.1 Dustfall rates from present-day dust traps in Lubbock and Big Spring

In order to facilitate comparison to published values of settled dust, the dustfall data were converted into depositional rates (Table V).

Winter (January- March) 1997 had the largest single quarterly depositional rate (375 g/m^2) by more than an order of magnitude, perhaps due to a localized and anomalous event. If the winter 1997 sample is considered, annual dust fluxes in Lubbock may reach globally significant levels during extreme events. Dustfall rates have been reported up to ˜ 180 to 200 g/m^2/yr for northern Nigeria and southern Israel[17]. The winter 1997 data point from Lubbock exceeds even these values. However, a dust deposition of 272 g/m^2 has been quoted for an individual dust storm in Nebraska during the Dust Bowl period of 1935[6]!

TABLE V. Mass deposition rates for dust traps.

Site	Season	Dustfall, g/m^2
Lubbock	Winter 97	375
“	Spring 97	13.2
“	Summer 97	3.1
“	Autumn 97	4.1
“	Winter 98	5.1
“	Spring 98	11.5
“	Summer 98	7.9
Big Spring	Spring 98	4.0
“	Summer 98	8.2

Results from the first two years of sample collection suggest that dust deposition can be important in all seasons. At Lubbock Lake, relatively high dustfall occurred during spring in both years. Only two seasons of data are shown for Big Spring, so it is hard to draw any conclusions. However, the mass of dust was twice as large in summer, 1998, as it was in spring. Big Spring may have experienced proportionally more haboob (thunderstorm outflow) events, most common in summer, and fewer events related to passage of drylines, fronts, and developing cyclonic storms (more typical of winter and spring).

4.2 Comparison to other dustfall measurements

Discounting the anomalous Winter 1997 sample in Lubbock, the annual dust deposition rates are on the order of 25-30 g/m^2/yr. In a study using the same design of dust trap in southern California and Nevada[14], dust traps adjacent to cropland regions had higher dust flux (>15 g/m^2/yr) than wildland and rangeland sites. At a height of 4 meters, the maximum deposition from individual storms reported for Big Spring in the early 1980s[18] was 15.8 g/m^2; however, these data utilized a sampling device oriented vertically into the wind, not a passive dustfall trap. Rabenhorst *et al*.[11] estimated an annual dust deposition rate in the Edwards Plateau of central Texas (several hundred kilometers SE of the active dust sources near Lubbock and Big Spring) of 12.3 g/m^2/yr and a much higher fraction (˜ 60%) of clay. At locations downwind from active dust sources of west Texas, a lower deposition rate and overall fining of dustfall is expected. The overall annual dust flux rates for the entire Great Plains have been estimated to be 20 - 90 g/m^2/yr[19]. The data for 1997- 98 for west Texas, an important cotton and grain growing region at the southern end of the Great Plains, are at the low end of this range. Drees[17] showed evidence of a north-south gradient in total dustfall across central Texas with an average of 18 g/m^2/yr. This suggests a gradual decrease in dust settling rates away from the active source areas of west Texas.

Analysis of dustfall samples from other sites in the Texas Panhandle[8,20] also led to annual estimates of annual dust deposition on the order of 20 to 30 g/m^2/yr. Dust depositional rates at six sites in the Rolling Plains (˜ 50 km east of the Southern Plains region of the present study) during spring (April- June), 1983, ranged from 10 to 32 g/m^2/yr[8,20], perhaps slightly higher than the spring, 1997, and spring, 1998, dust loadings for Lubbock. However, the early 1980s were somewhat "dustier" than the present, due to the implementation of widespread, government-supported soil conservation programs in the mid- 1980s[3]. In addition, the dust traps were of a different design (glycerol-filled glass jars) and mounted at heights of 1.35 to 1.47 m above ground level, and thus were more likely to have collected some (proportionally heavy) saltating sand grains. Sand content ranged from approximately 2% to 38% of total mass, whereas clay content ranged from 2% to 15%.

5. CONCLUSIONS

It is difficult to compare results of settled dust measurements between studies conducted during different eras, due to differences in dust trap design (which lead to differences in dust collection efficiency), location (including proximity to eroding fields or other sources of airborne particles), height above the ground surface of dust trap deployment (which can influence the amount of sand and thus the particle-size distribution), and different analytical techniques. There is no "standard design" for a settled dust collection device.

Our results show that the rate of dust settling in west Texas appears to be on the order of approximately 20 grams per square meter per year. This rate is roughly in the same range as other published values for this region, and roughly matches dustfall rates for sites with similar land use in the southwestern deserts of the United States. West Texas dust contains more silt and clay and less salt and calcite than sites in the Mojave Desert[12]. Organic carbon is enriched in settled dust in Lubbock by a factor of about 20 compared to source soils. This result adds evidence that wind erosion depletes soil fertility on the Southern High Plains[23], as it does in other highly wind-erodible regions[24-26]. Dust samples collected in west Texas were primarily composed of quartz, feldspars, calcite, and mica, with a clay mineral fraction containing illite, smectite, and kaolinite.

The samples from the dust traps at Lubbock and Big Spring were generally finer in texture (i.e., containing a much higher proportion of PM10 and clay sized [~ PM 2.5] particles) than the samples of dust which accumulated in the Dust Bowl- era houses. The particle size of the Lubbock dust trap samples from the late 1990s roughly matches that of settled dust samples collected at Lubbock in 1950 (~ 25% to 40% particles smaller than 4 μm from different designs of dust traps at different heights)[21] . Nevertheless, a detailed intercomparison is not feasible due to differences in sampler design, deployment, and particle sizing techniques. Was the particle size of settled material during the first part of this century slightly coarser than present-day dust due to more intense wind storms and/or deeper erosion, or did the finest airborne particles flow around the walls of the house and not get deposited within? That is, did the house itself serve as a "size-selective sampler" to some extent? The latter option cannot be dismissed.

Further analyses of these and subsequently collected samples will be forthcoming, in order to improve the source characterization of fugitive dust from the Southern Plains in Texas and better assess how dust settling rates vary with climate, land use, and other factors.

ACKNOWLEDGMENTS / DISCLAIMER

Particle size, carbon and salt analyses were performed under direction of Marith Reheis of the U.S. Geological Survey. Dr. Reheis also provided useful comments on an earlier draft of the manuscript. Additional laboratory analyses of settled dust were provided by Eric Fisher and Gary Skipp at the U.S. Geological Survey in Denver. We thank Gene W. Riley of the Museum of the Plains in Perryton, Texas and Buryl Fish of Hereford, Texas for providing historic dust samples. Jeff Lee, Clay Robinson and Andy Wilkinson provided useful hints regarding where to seek Dust Bowl- era samples.

REFERENCES

1. Orgill, M.M.: Sehmel, G.A. *Atmos. Environ.* **1976,** *10,* 813- 825.

2. Gill, T.E.: Westphal, D.L.: Stephens, G.: Peterson, R.E. In *Preprints, 11th Joint Conference on the Applications of Air Pollution Meteorology with the A&WMA*: American Meteorological Society: Boston, 2000: pp. 370- 375.

3. Ervin, R.T.: Lee, J.A. *J. Soil & Water Conserv*. **1994,** *49,* 430- 437.

4. Windom, H.L.: Chamberlain, C.F.: *J. Sedimentary Petrol.* **1978**, *48*, 385- 388.

5. Des Moines *Register*, 1999. “Tornadoes give Iowa a dusting.” May 6, 1999, page A1.

6. Holliday, V.T. In *Geomorphic Systems of North America*: Graf, W.L., Ed. Geological Society of America Centennial Special Volume 2: Geological Society of America: Boulder, Colorado 1987: pp. 195- 202.

7. LaPrade, K.E. M.S. Thesis, Texas Technological College, 1954.

8. Machenberg, M.D.: In *Geomorphology and Quaternary stratigraphy of the Rolling Plains, Texas Panhandle:* Gustavson, T.C., Ed. Field Trip Guidebook 22: Texas Bureau of Economic Geology: Austin, Texas, 1986: pp. 41- 44.

9. Holliday, V.T.: *Geol. Soc. Amer. Bulletin* **1989,** *101*, 1598- 1607.

10. Holliday, V.T.: *Annals Assoc. Amer. Geographers* **1988**, *78,* 594- 610.

11. Rabenhorst, M.C.: Wilding, L.P.: Girdner, G.W. *Soil. Sci. Soc. Amer. J***.** **1984,** *48*, 621- 627.

12. Gill, T.E.: Reheis, M.C.: Zobeck, T.M. *Geol. Soc. Amer. Abstracts & Programs* **1999,** *31(1),* A8.

13. Reheis, M.C.: Goodmacher, J.C.: Harden, J.W.: McFadden, L.D.: Rockwell, T.K.: Shroba, R.R.: Sowers, J.M.: Taylor, E.M. *Geol. Soc. Amer. Bulletin* **1995**, *107*, 1003- 1022.

14. Reheis, M.C.: Kihl, R. *J. Geophys. Res*. **1995**, *100*, 8893- 8918.

15. Reheis, M.C. *J. Geophys. Res*. **1997**, *102*, 25999- 26008.

16. Gile, L.H.: Hawley, J.W.: Grossman, R.B. *New Mexico Bur. Mines & Mineral Res. Memoir 39*, 1981.

17. Drees, R: Dept. of Soil & Crop Sciences, Texas A&M University: unpublished manuscript, 1997.

18. Fryrear, D.W. In *Particulate and Multiphase Process Contamination Analysis and Control:* Teomon, A. and Veziroglou, T.N., Eds. Hemisphere Publications: New York, 1981: vol. 2, pp. 407- 414.

19. Smith, R.M.: Twiss, P.C.: Krauss, R.K.: Brown, M.J. *Soil Sci. Soc. Amer. Proc*. **1970**, *34*, 112- 117.

20. Machenberg, M.D.: In *Geology and Geohydrology of the Palo Duro Basin, Texas Panhandle:* Gustavson, T.C., Ed. Report to the U.S. Dept. of Energy, Contract No. DE-AC97-83WMM46651, 1987: pp. 337- 343.

21. Warn, G.F.: Cox, W.B.: *Am. J. Sci*. **1951**, *249*, 553- 568.

22. Gustavson, T.C.: Holliday, V.T.: *J. Sediment. Res*. **1999**, *69*, 622- 634.

23. Zobeck, T.M.: Fryrear, D.W.: *Trans. ASAE*. **1986**, *29*, 1037- 1041.

24. Lyles, L.: Tatarko, J.: *J. Soil & Water Conserv*. **1986**, *41*, 191- 193.

25. Sterk, G.: Herrmann, L.: Bationo, A.: *Land Degrad. & Develop.* **1996**, *7*, 325- 335.

26. Larney, F.J.: Bullock, M.S.: Janzen, H.H.: Ellert, B.H.: Olson, E.C.S.: *J. Soil & Water Conserv*. **1998**, *53*, 133- 140.

KEYWORDS: fugitive dust, settled dust, particulate matter, Texas, dry deposition, wind erosion