CHAPTER 2

An Analysis of Historical and Present Dust Deposition on the Columbia Plateau

Most soils on the Columbia Plateau are derived from windblown sediments deposited over the last 15,000 years, although dust deposition has been ongoing in the region for two million years resulting in loess deposits up to 75 m (250 ft) thick. Many of the soils contain significant amounts of fine particulates and if exposed when dry can produce massive clouds of dust during high wind events that may be carried for hundreds of miles or farther in turbulent eddies (Busacca and Sweeney, 2004). The windblown dust and fallout can permeate and settle almost everywhere in the environment where people work and live. The question that needs to be addressed for scientific and policy purposes is to what extent human activities have contributed to the overall "dustiness" of the region. In other words, is the environment of the Columbia Plateau today more or less dusty compared with pre-agricultural times? The answer to this question is important from the standpoint of knowing whether farming and land development are/were contributing more or less significantly to the decline of regional air quality from dust transport and deposition than before human intervention occurred.

Geologic studies in regions other than the Columbia Plateau indicate that windblown sediment fluxes were 10 to 40 times higher at the peak of the last Ice Age about 18,000 years ago than they are today (Busacca and Chandler, 2002). However, as these authors point out, wind erosion intensity is subject to cycles of climate change (over decades to centuries) and variability (over months to years) that can affect sediment transport and dustiness to a far greater extent than might occur with human intervention. Wind erosion has been an ongoing part of the climate history of the Columbia Plateau dating back to the Pleistocene Epoch, or Ice Ages (Busacca, 1991).

Fourth of July Lake Core Study

A team of scientists and graduate students from WSU led by Professor A.J. Busacca conducted a study in the mid 1990s to determine the extent to which human activities, beginning with settlement of the Columbia Plateau by homesteaders in the early 1880s, may have affected windblown sediment fluxes compared with pre-farming levels (Busacca et al., 1998). The methodology consisted of reconstructing the history of sediment deposition over time, both before and after farming began, by analysis of sediment cores obtained in sections from the bottom of Fourth of July Lake, a pothole lake in the central part of the Columbia Plateau surrounded by native sage steppe. This body of

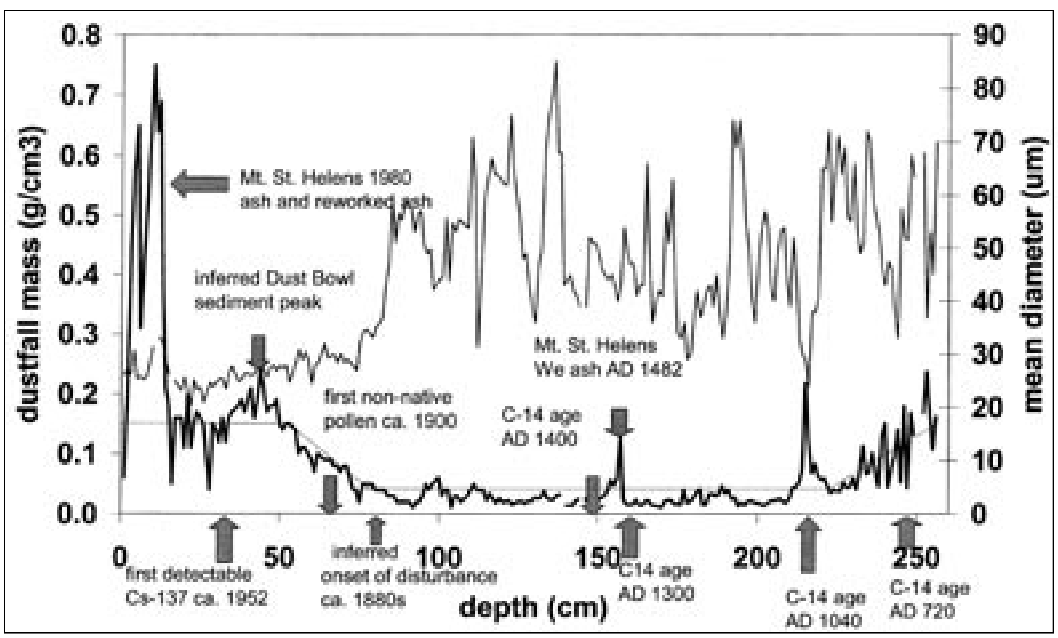

Figure 2.1. *Dustfall mass (heavy line) and dustfall particle mean diameter (light line) versus depth in sediment core from the bottom of Fourth of July Lake in eastern Washington. The dotted line approximates the long-term trend in dustfall mass. Arrows indicate approximate year when dustfall occurred along the length of the sediment core. Reproduced from Busacca et al., 1998.*

water was ideal as a permanent sediment trap because it has vertical basalt rock walls and is spring fed. There is no drainage in or out of it, and sediments have collected in it almost entirely by dust deposition from wind erosion. The scientists were able to establish the sediment history (age of deposition) from analysis of a sediment core for plant macrofossils, fossil pollen, radioisotopes from nuclear fallout with known dates, ash depositions from volcanic eruptions with known dates, and radiocarbon dating.

The total core depth extracted from the lake under 9 m (30 ft) of water was 7.5 m (25 ft). Because of time and financial constraints only the top 2.55 m (8.4 ft) was analyzed in minute detail by one cm (0.4 inch) increments for changes in core properties related to dust deposition during the interval between the post and pre-agricultural eras. The key measurements were bulk density and mean particle size of sediments , and age indicators along the length of the sediment column. Radiocarbon dating indicated the age of the studied part of the core near its base (2.5 m, or 8.2 ft from the top) to be 1330 ± 50 years before present (taken as 1950 for reference), placing it on our calendar at approximately 620 AD.

Results of the core analysis are reproduced from Busacca et al. (1998) and presented in Figure 2.1. The graph retains the original metric units since the information of importance is relative and a change to English units would not improve the interpretations and contrasts in the data.

The data reveal two significant observations. The first is the sharp rate of increase in dustfall towards present times beginning at approximately the 80-cm (31-inch) depth, which on the timetable coincides with the 1880s or when cultivated agriculture began on the Columbia Plateau. Starting with a mean dustfall of 0.04 g cm^{-3} prior to the 1880s back 900 years from present time, the post 1880s dustfall peaks out at 0.24 g cm^{-3} (a 6-fold increase) at about 45 cm (18 inches), which on the timetable matches the dust bowl years of the 1930s. The first appearance of pollen of two introduced plant species, i.e., domestic wheat and Russian thistle (*Salsola iberica*) during the years of increased dustfall support the accuracy of the timetable during the interval from the native state to cultivated agriculture. The increased rate of dust deposition from the 80-cm (31-inch) depth toward the core surface coincides with the increasing acreage of land susceptible to wind erosion as land in native vegetation was converted to crop production that was primarily a bare fallow-small grain rotation.

The second significant observation from Figure 2.1 is the marked reduction in mean size of the mineral dust particulates beginning at approximately the 80-cm depth upward toward the present, again coinciding with the onset in the 1880s of farming on the Columbia Plateau. In prior years dating back all the way through the core, the particle size shows high variability with a mean diameter of about 50 µm (microns, or 0.050 millimeter) compared with low variability and a mean diameter of about 25 µm after the transition to farming.

According to a related study, the larger mean diameter and greater size variability in the earlier period indicates that the source of dust was coarser sediments from sandy dune or dune-loess mixed soils that had little protection from native vegetative cover (Wagoner et al., 1997). As the authors explain, with removal of natural vegetation from the fine-textured soils by tilled wheat–fallow cropping, the sediment sources for wind erosion shifted to soils with a narrower particle size distribution. This ensured a readily available supply of uniform-size dust for wind transport from the inception of agriculture.

The dustfall in Figure 2.1 is reported as mass per unit volume for a given depth increment (proxy for time) of the sediment core sample. These data can be converted to a dustfall depth accumulation by assigning a bulk density value to the dustfall at the time it occurred. For example, Busacca et al. (1998) shows that from about 210 cm to 80 cm of the core depth (130 cm representing about 900 years before agriculture began) the dustfall mass averages 0.04 g cm^{-3}. If we assume a reasonable bulk density of the original dustfall to be 1.0 g cm^{-3} then the depth D of dust accumulation over the 900 years would be: D = (0.04 g cm^{-3} * 130 cm)/1.0 g cm^{-3} = 5.2 cm (2 inches). This flux over 2 million years would indicate a dust thickness of 116 m (380 ft) and nearly 4 times this at the flux rate in the post-farming period.

However, it needs to be pointed out that the above flux estimate is not a net value of deposition that occurs outside a body of water that retains all of the fallout. On the land surface wind erosion consists of simultaneous deposition and emission (i.e., transport) of particles. Thus, the net gain of soil depth is the difference in fluxes between the two processes and would be less than what is captured and retained in the lake sediments.

The Role of Geologic Input on the Generation, Transport and Deposition of Sediments on the Columbia Plateau

The Fourth of July Lake core study produced evidence that atmospheric dust levels were significantly increased during the post-farming period compared with pre-agricultural times on the Columbia Plateau. However, the record does not go back far enough to show dust deposition rates for different time periods relating to geologically-controlled variations in climate (extreme aridity, high winds, increased precipitation, high or low temperatures). These extremes occurring over centuries could overwhelm what might be caused by human intervention. In other words, is the heightened dust activity corresponding to the rather short post-farming era of the Columbia Plateau part of a larger geologic-induced change beyond human control?

The answers to this question have important implications to EPA's Natural Events Policy where geologic-output of dust to the atmosphere is excluded as a contribution to any exceedance of the PM_{10} standard. To gain further insights in managing today's wind erosion/dust emission problems on the Columbia Plateau requires documentation of dust activity through geologic time as well as the response of eolian soils and sediments to controls such as sediment, texture, vegetation cover, and topography (Busacca, 2001).

A research project is underway at WSU to account for the effect of major controls during periods of increased dust activity on the Columbia Plateau over the past 18 to 20,000 years, and to compare mass accumulation (dust fallout) rates with those measured during the post-farming period in the Fourth of July Lake core study in Figure 2.1 (Busacca, 2001). Soil mapping and analysis indicate that the nature and thickness of loess deposits in study areas of the Columbia Plateau of Washington and Oregon are controlled by changes in topography and sediment sources, and climatic fluctuations (Gaylord et al., 2002; Sweeney et al., 2001; Sweeney et al., 2002).

The controls in the form of three biogeophysical models being tested are: 1) topographic-trap model that assumes deeply incised valleys trap saltating dune sand and allow transport and deposition of the selectively suspended material (clay, silt, fine sand) as thick loess on the downwind side of the valleys, 2) bioclimatic (climate and plant cover) model that assumes in the absence of topographic traps that the sand-silt boundary is dynamic and moves in response to climatic shifts that control aridity and vegetation density, and 3) a source sediment model that assumes a source sediment initially depleted in silt results in thin loess (Busacca, 2001; Sweeney et al., 2001). The three models applied individually or in combination may help explain variations in the thickness of loess on the Columbia Plateau where accumulation occurs in the absence of the saltation process. Study sites for testing the control models include Juniper Canyon, Oregon in the Umatilla Basin, Eureka Flat in south-central Washington, and the Quincy Basin in central Washington.

Luminescence techniques are used to age-date loess and sand dunes and provide the resolution necessary to calculate accumulation of sediments over the last 18,000 years, and pinpoint when prehistoric climate fluctuations occurred that were associated with changes in land surface features and soil formation. Detailed mapping of Eureka Flat north of Walla Walla, WA indicates that the area has a history as a major source of sediments for much of the downwind-deposited Palouse loess (Busacca, 2002; Sweeney et al., 2002; Sweeney, et al., 2003).

A loess cap over a sand sheet in the northern part of the Flat provides evidence of a major shift in climate sometime in the past 18,000 years from a more arid to present conditions (wetter climate) with higher plant density. At Juniper Canyon, north of Umatilla, OR, sand dunes are migrating to the edge and into the canyon from the Umatilla Basin from the upwind side and thick loess has accumulated on the downwind side. Recent measurements demonstrate that about 8.5 m (28 ft) of loess have been deposited in the last 15,000 years on the downwind side of the canyon (M. Sweeney, Dept. of Crop and Soil Sciences, WSU, personal communication, June, 2003). This amount of deposition is more than twice the previously known maximum thickness for this time period on the Columbia Plateau. These phenomena provide evidence for the topographic-trap model as the major control at this site (Busacca, 2001; Sweeney et al., 2001).

In the Quincy Basin, sand dunes formed from the erosion of sandy and gravelly flood deposits, while loess occurs as only a thin sheet downwind as a result of the limited silt content of the original flood sediments. Besides pinpointing major fluctuations in climate, more research is needed to determine changes in dust source areas in the last 18,000 years to better understand the nature of geologic input of dust into the atmosphere of the Columbia Plateau.

Summary Observations

The Busacca et al. (1998) lake core study provides strong evidence that fallow-grain agriculture on the Columbia Plateau has markedly increased (by at least 4-fold) the aerial flux of sediments in the region beginning with farming in the 1880s. Moreover, it indicates that farming has not only increased eolian sediment transport but also the atmospheric concentration of small particulates during wind erosion as a result of removal of natural vegetation from finer-textured soils together with intensive fallow cultivation that continually exposes finer materials to the wind. The study strengthens and reinforces the case that to reduce dustiness on the Columbia Plateau we need to employ farming practices that maintain cover on the land, and to minimize or eliminate tillage operations that stir and mix the soil making it more susceptible to wind erosion.

However, from a broader perspective the lake core study does not record back far enough in time to allow comparison of dust deposition rates on landscapes in prehistoric environments with those measured in post-agricultural times on the Columbia Plateau. This information is needed to assess the impact of geologic input to dust emissions relative to emissions in the region generated by human activity that are of consequence to the EPA's Natural Events Policy.

An extension of the Fourth of July Lake core study is underway across eastern Washington and north central Oregon to reconstruct loess accumulation from dynamic source areas under the controlling influences of climate, plant cover, and topography to better quantify dust emissions on a geologic time scale. The geologic data will be used to interpret the role of climate change in relation to wind erosion and dust emissions on the Columbia Plateau during the past 18,000 or so years, and to validate a regional dust emissions model as well as contribute to development of a global dust model.

References

1. Busacca, A.J. 1991. Loess deposits and soils of the Palouse and vicinity. In R.B. Morrison (ed.). Quaternary Non-Glacial Geology of the United States. Decade of North American Geology Ser. Vol. K-2. Geol. Soc. Amer., Boulder, CO. p. 216–228.

2. Busacca, A., L. Wagoner, P. Mehringer, Jr., and M. Bacon. 1998. Effect of human activity on dustfall: A 1,300-year lake-core record of dust deposition on the Columbia Plateau, Pacific Northwest, USA. In A.J. Busacca (ed.). Dust Aerosols, Loess Soils and Global Change. Miscellaneous Publication No. MISC0190. Washington State University College of Agriculture and Home Economics, Pullman, WA. p. 8–11.

3. Busacca, A. 2001. Biogeophysical controls on eolian soils on the Columbia Plateau. 2001 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman, WA. p. 8–10.

4. Busacca, A. and D. Chandler. 2002. Wind erosion and climate change. In R. Lal (ed.). Encyclopedia of Soil Science. Marcel Dekker, New York, NY. p. 1–5.

5. Busacca, A. 2002. Understanding the geologic input of dust into the atmosphere of the Columbia Plateau. 2002 Annual Report. Northwest Columbia Plateau Wind Erosion/Air Quality Project. Agricultural Research Service, US Dept. of Agriculture, and Washington State University, Pullman, WA. p. 8–10.

6. Busacca, A.J, and M.R. Sweeney. 2004. Loess. In D. Hill (ed.). Encyclopedia of Soils in the Environment. Academic Press, New York, NY. Accepted for publication.

7. Gaylord, D.R., Sweeney, M.R., and A.J. Busacca. 2002. Geomorphic development of a late Quaternary paired eolian sequence, Columbia Plateau, Washington. Abstract. Geol. Soc. Amer. Abstracts with Programs, Abstract No. 43422.

8. Sweeney, M.R., D.R. Gaylord, and A.J. Busacca. 2001. Geomorphic, sedimentologic and bioclimatic models for loess accumulation on the Columbia Plateau, Pacific Northwest. Abstract. Session No. 133 Geol. Soc. Amer. Annual Meeting.

9. Sweeney, M.R., D.R. Gaylord, and A.J. Busacca. 2002. Changes in loess-dune deposition in response to climatic fluctuations on the Columbia Plateau, Washington. Abstract. Geol. Soc. Amer. Abstracts with Programs.Vol. 34, No. 5, Abstract No. 34952.

10. Sweeney, M.R., D.R. Gaylord, A.J. Busacca, and B.A. Halver. 2003. Eureka Flat: A long-term dust-production engine of the Palouse loess, Pacific Northwest, USA. Abstract. Paper No. 80-21, XVI INQUA Congress. Geol. Soc. Amer. Annual Meeting, Reno Nevada.

11. Wagoner, L., A. Busacca, P. Mehringer, and M. Bacon. 1997. Modern and geologic rates of dust flux into Fourth of July Lake, Columbia Plateau, southeastern Washington. Abstract. Wind Erosion International Symposium. June 3-5. Manhattan, KS.