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Geomorphic and hydrologic controls of dust emissions during drought from Yellow Lake playa, West Texas, USA

M.R. Sweeney [a,*], V.A. Zlotnik [b], R.M. Joeckel [b,c], J.E. Stout [d]

[a] University of South Dakota, Earth Sciences, 414 E. Clark St, Vermillion, SD 57069, USA
[b] University of Nebraska-Lincoln, Earth and Atmospheric Sciences, 214 Bessey Hall, Lincoln, NE 68588-0340, USA
[c] University of Nebraska-Lincoln, School of Natural Resources, 3310 Holdrege St., Lincoln, NE 68583-0996, USA
[d] USDA, Agricultural Research Service, 3810 4th St., Lubbock, TX 79415, USA

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ABSTRACT

Numerous complex geomorphic and hydrologic factors have been identified that control dust emissions from playas, yet there are few measurements of dust emissions from playas during drought, which is assumed to enhance emissions, or during low-emission seasons. We used the PI-SWERL (Portable in situ Wind Erosion Laboratory) to measure dust emission potential at Yellow Lake, a saline playa in West Texas, USA, during the drought of 2011. Direct aeolian entrainment of dust occurred primarily on supply-limited surfaces consisting of mud-cracked surfaces as well as crusts containing halite, thenardite, and gypsum. High-magnitude, low duration peaks in dust emissions occurred over parts of the playa underlain by shallow groundwater (<1 m) where conditions encouraged the crystallization of efflorescent salts. In contrast, surfaces characterized by loose sand-sized aggregates produced sustained dust emissions two to three orders of magnitude higher than the playa surface because aggregates broke apart during saltation. Prolonged drought at Yellow Lake will significantly change the frequency and type of dust emissions. We propose that a similar scenario characterizes dust production at many hydrologically similar playas. More research is needed to assess the impacts of changing groundwater levels on dust emissions in the context of extended drought and anthropogenic climate change.

1. Introduction

Approximately 30% of global dust emissions are derived from ephemeral bodies of water, including playas (Ginoux et al., 2012). Dust emissions from playas vary widely depending on surface moisture, surface roughness, the strength of surficial sediment or salt crusts, and the availability of saltating grains (Gill, 1996; Gillette et al., 2004; King et al., 2011; Nield et al., 2015; Sweeney et al., 2011; Tollerud and Fantle, 2014). Furthermore, the impact of drought duration, the depletion of groundwater, and other factors influencing water table dynamics exert significant control on the timing of deflation and the composition of the emitted dust (Elmore et al., 2008).

Playas are seasonally or less frequently inundated with surface runoff, some of which infiltrates and some of which evaporates. Two general types of playas – dry and wet – are recognized (Reynolds et al., 2007; Rosen, 1994). Dry playas are characterized by deep groundwater (>5 m) and mud-cracked surfaces that produce dust composed primarily of silicate minerals with low concentrations of salt. Wet playas are underlain by shallow groundwater (<5 m, and frequently $\leq$1.5 m) and strong evaporation and capillary processes keep the playa surface moist, facilitating the precipitation of efflorescent salts that are low density with a fluffy structure. Efflorescent salts are easily entrained by the wind (Cahill et al., 1996; Gill, 1996; Gillette et al., 1980; Reynolds et al., 2007), and deflation of salt dust can lead to the contamination of soils and groundwater (Gill, 1996; Wood and Sanford, 1995; Wood et al., 2011). Zlotnik et al. (2012) quantified the mass-balance of salt in closed shallow saline lakes of the Nebraska Sand Hills. Their proposed “salt-dust conveyor” concentrates large volumes of salt from groundwater at the playa surface, which is episodically deflated, initiating a new cycle of salt accumulation by evaporation. The sediments of these lakes contain smaller volumes of salt than would otherwise be generated over long-term fluctuations in groundwater, making it likely that salts are episodically removed by

* Corresponding author.
E-mail addresses: mark.sweeney@usd.edu (M.R. Sweeney), vzlotnik1@unl.edu (V.A. Zlotnik), rjoeckel3@unl.edu (R.M. Joeckel), john.stout@ars.usda.gov (J.E. Stout).

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the wind (Langbein, 1961; Zlotnik et al., 2012).

Some salt minerals are more susceptible to dust generation than others. Studies have shown that the most emissive salts are hydrous/anhydrous salts and salts with acicular or prismatic mineral habits (Buck et al., 2011; Joeckel and Ang Clement, 2005). Hydrous/anhydrous salts, including mirabilite/thenardite and other Mg-sulfate salts, tend to be unstable, dissolving and reprecipitating with changing temperature and humidity. Salts with acicular or prismatic mineral habits such as glauberite are disruptive as they precipitate and form loose, puffy crusts. Collectively, these salts are the most prone to wind erosion and several studies have documented their contribution to dust emissions (Buck et al., 2011; Gill, 1996; Gillette et al., 1980; Reynolds et al., 2007; Zlotnik et al., 2012). Physical disruption of the surficial sediment by the growth of such salts brings other playa sediments, chiefly detrital grains of silicate minerals, to the surface for aeolian deflation as well (Buck et al., 2011). Dust emissions from playas are further complicated by spatial and temporal changes in salt crust morphology and surface roughness (Nield et al., 2015).

Lunette dunes are deposited on the downwind margins of deflating playas on the Southern High Plains, USA during arid episodes (Holliday, 1997; Holliday et al., 2008; Rich, 2013; Wood and Sanford, 1995). In general, playa sediments deflate to the capillary zone (Wood and Sanford, 1995), yielding quartz-rich sand (low calcareous sand of Holliday, 1997) and aggregates of sand, silt and clay (carbonate sandy loam of Holliday, 1997) to the growing lunettes (Holliday, 1997).

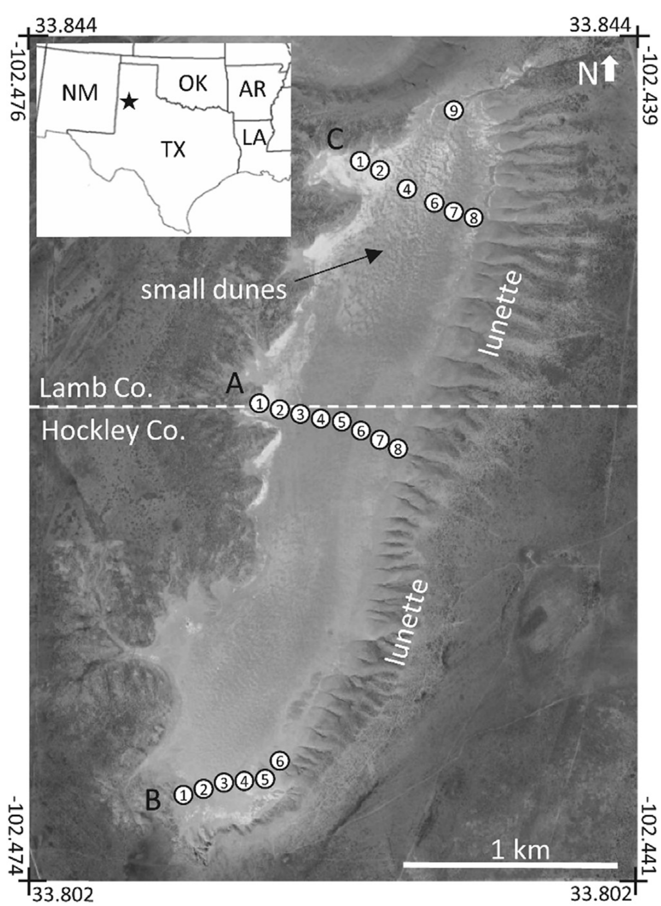

Fig. 1. Location of Yellow Lake playa in Texas. Transects A, B, and C where PI-SWERL tests, surface samples, and groundwater samples were collected are shown. 2012 image from Google Earth. Latitude and longitude are noted on the corners of the image.

Yellow Lake, a 3.5 km^2 wet saline playa in Lamb and Hockley counties on the Llano Estacado of West Texas (Fig. 1), provides an opportunity to investigate how the interaction of geomorphic, hydrologic, and geochemical processes influence salt dust emissions during drought conditions. There are lunette dunes on the downwind, eastern margin of this playa. Its western boundary is a 5-m escarpment eroded into the Pleistocene Blackwater Draw Formation which is underlain by the Ogallala Formation, the principal aquifer for the region (Wood et al., 1992).

Aeolian activity has been continuously recorded on the floor of Yellow Lake using piezoelectric saltation sensors since 1998 (Stout, 2003, 2007, 2014). Saltation primarily occurs in the winter to early spring months (December–March) when wind speed peaks and humidity and precipitation are low. The spring months (April–May) are windy, but precipitation wets the playa surface, keeping saltation low. Aeolian activity at Yellow Lake usually precedes the timing of regional dust emissions from bare agricultural fields (Stout, 2003) that occur mostly in the spring months from strong west-southwesterly winds (Lee et al., 1994; Stout, 2001). Regional dust storms are low-frequency, intermittent events driven primarily by short-term gusts (Stout, 2001). Despite the relatively small area of playas on the Southern High Plains, playas are some of the largest natural dust sources in the region (Lee et al., 2012).

To assess the role of Yellow Lake as a regional dust source, we considered geomorphic properties of the playa surface and bordering dunes, depth to the water table, geochemistry of the salt crusts and associated groundwater, and measured dust emission potential using the Portable in situ Wind Erosion Laboratory (PI-SWERL). Field testing occurred from June 26 through June 28, 2011 when West Texas was experiencing high temperatures and exceptional drought conditions (Table 1). The drought was described by Nielsen-Gammon (2012) as "unprecedented in intensity" and broke the previous record set in 1956 for the least amount of rainfall over a 12-month period, leading to eight consecutive months with the Palmer Drought Severity Index (PDSI) below -5 (with negative numbers indicating drought), and set record high temperatures. While regional droughts are usually linked to an increased occurrence of dust storms (Hahnenberger and Nicoll, 2014; Reheis, 2006), conditions were not optimal for dust production because aeolian activity and efflorescent salt development is at a minimum during the summer months. This methodology provides a baseline for future studies of dust emissions from playas encompassing wet-dry cycles and will require a denser network of groundwater depth and geochemical data collection at groundwater-controlled playas. These studies have important practical implications, such as for suppression of dust emissions or forecasting dust storms.

2. Methodology

The PI-SWERL was used to measure dust emission potential from the surface of Yellow Lake along three east-west oriented transects ('A', central; 'B', south; 'C', north; Fig. 1). The testing surface was photographed and described at each site. Surface samples consisting of the upper 1 cm or less of crust were collected at each testing location for grain size and mineralogical analysis. A 1-m long, 5-cm in diameter hand auger was used to assess the depth to groundwater along each transect. Water samples were collected if groundwater was intercepted and later tested in the lab for solute composition.

The PI-SWERL measures the potential of a surface to emit dust (Etyemezian et al., 2007) and generates dust emissions data approximately equivalent to large field wind tunnels (Sweeney et al., 2008). The rotation of an annular blade within a closed cylindrical chamber creates shear stress that mobilizes sand and dust.