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Elemental geochemistry of wind-erodible playa sediments, Owens Lake, California

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Abstract

Wind erosion of the dried bed (playa) of Owens Lake, California is an extremely intense source of mineral aerosol, transporting dust hundreds of kilometers downwind to critical ecological areas and several cities. A dust-producing site on the playa was studied over a four-year period to document the processes associated with aerosol emission. The playa takes on a variety of sedimentary forms and phases with surface crusts of differing susceptibilities to wind erosion. The sediments are classed into three general categories based on appearance: soft (saline), loose with drifting sand (salt–silt–clay), and hard and clean (silt–clay). Sediment samples were collected over a two-year period as the study site cycled through all three crust types, and the samples were crushed and analyzed by PIXE. The results indicate that visual appearance and sedimentary structure does not correlate with elemental composition. All sediment types contain significant concentrations of various elements including sodium, calcium and silicon. Potentially toxic trace elements are also found in the sediments. All sediment types contain lead and/or arsenic in tens of parts per million, as well as various other heavy metals. Pb and As levels do not clearly correlate with salt content or sediment type. Arsenic levels may be slightly higher in the crusts with loose material present and potentially lower in the clean hard crusts, while Pb was least frequently detected in the samples with loose material. Future research will add mineralogical and stable isotope analyses to correlate with the PIXE data. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Owens Lake in east-central California was dried as a result of water diversions in the 1930s. Its

desiccated surface (playa) has become one of the most intense sources of dust aerosols in the Western Hemisphere, as a result of erodible sediments, lack of vegetation, and high winds [1]. Wind erosion of the crusted playa surface releases dust plumes with aerosol concentrations that are known to reach tens of thousands of $\mu\text{g}/\text{m}^3$ [2]. These aerosol plumes may impact tens of thousands of people who live in the Indian Wells Valley, Owens Valley and other receptor sites, and can

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be transported into at least 10 wilderness and critical ecological areas and national parks [10]. Given these potentially extreme concentrations of aerosols and sensitive receptor sites, a concern exists about potential health effects and environmental impacts of metals which may be present in the dust, including arsenic, nickel, chromium and lead.

Potential sources of metals in lakebed sediments include shallow saline groundwater [3], which is discharged and deposits salts on the playa surface in winter, or ores and waste materials from the historic Cerro Gordo silver/lead/zinc mining district, which were carried across the lake before it dried and have been discharged onto the playa by various processes [4]. On some wind-erodible regions of the large (280 km²) lakebed, the nature of the surface sediment at any given point changes from season to season and year to year, as rain falls and groundwater discharges, salts are deposited and eroded, and sand moves across the playa surface. This experiment used Proton-Induced X-Ray Emission (PIXE) analysis for a preliminary assessment of the elemental composition of the dust-emissive crusted playa surface of Owens (dry) Lake at a carefully monitored point as the nature of the crust changed through two annual cycles.

2. Experimental

Sediments were monitored at the US Geological Survey Desert Winds Project Geomet site [5] on the southeast portion of the Owens Lake bed. This site was known to possess an ephemeral (changing its appearance over time) surface crust on the order of 1 cm thick. The crust was regularly inspected every week or two over a period of several years, and its appearance was observed and pho-

tographed. Every time the crust was inspected, a representative sample of the crust was cut out and returned to the laboratory for archival. Crust types were assigned to three classes, based on hardness and presence of loose materials [6] (Table 1).

Sixteen samples of crust spanning August 1995 through May 1997 were selected for analysis. These samples represent all three crust classes, five different wetting–drying cycles, deposition of salts from groundwater, and motion of loose sand across the site. The chemical composition of the surface could be expected to change over time and space with variations in the shallow water table and sand motion and deposition patterns. Therefore, analysis of individual crust samples is only a “snapshot” [6]. Still, this site and the samples represent the variety of sedimentary processes which take place on the Owens Lake bed and furnish particles for aerosol emission. We believe this can provide a preliminary indication of elemental content of the dust source materials, and how it could change with seasonal changes in the crust.

An individual piece of each crust, dimensions on the order of 1 cm³, was dried and pulverized in a synthetic sapphire mortar and pestle. Each sample was prepared for X-ray analysis by pelletizing a 2.54 cm diameter disk against a glass surface. PIXE analysis was performed in vacuum using a Van De Graff style accelerator run at 2.44 MeV and SiLi detector. Samples were irradiated for 12 min. Data reduction was accomplished using a version of the HEX code modified and refined for thick target analysis [7,8]; elemental concentrations were determined by making use of primary X-ray absorption and proton energy loss data from the published literature and a theoretically rigorous model such as described in [9]. The efficacy of the analyses was verified using USA

Table 1
Classification of ephemeral crusts at the Owens Lake Geomet site [2,6]

Class	Sedimentology	Description
S	White, salty appearing	Soft crust on surface or no crust at all, most susceptible to wind erosion
C	Salt–silt–clay	Clean, harder crust, without loose particles present
L	Salt–silt–clay–sand	Loose, broken crust, with loose sediments present atop crust

National Institute of Standards and Technology Standard Reference Material (NIST SRM) 2704, Buffalo River Sediment, which was pelletized and analyzed under the same conditions during the same run.

3. Results and discussion

The results of the analyses are summarized in Table 2. Twenty-four elements were detected in the samples in various concentrations. Sixteen of the elements were present in all 16 samples.

To some surprise, there were no consistent trends of any element over time (i.e. increasing or decreasing throughout the sampling period) or with crust type (for example, grouping highest or lowest in L, S or C class crusts). This indicates that crust appearance is not a clear indicator of its composition, and that potentially toxic elements and high concentrations of salts may be present in all three classes of crusts.

Sodium is present in all samples in concentrations up to 15% by mass. Even the harder crusts may contain over 7% sodium. Chlorine is not consistently correlated with sodium, demonstrating that sodium occurs in other forms than halite. Likewise, even the softest, whitest, most “saline” appearing crusts may contain more than 20% by weight silicon, and silicon levels are consistently 16–22 wt.%. Sulfur and calcium are relatively randomly distributed, probably occurring as constituents of a variety of minerals, not just as salts. Sulfur and sodium levels did show a joint decrease after early December 1996 as the crust state changed from loose to soft and then clean, perhaps indicating a loss of thenardite (Na_2SO_4).

Various transition metals are present in all samples, although not every metal is present in every sample. Chromium, a potential health hazard, was detected in all but two samples at levels of 19–41 ppm (mass), and nickel, a possible human carcinogen, was detected in all but one sample at levels of 9–19 ppm.

Copper and zinc, which may be related to the Cerro Gordo ores and mine wastes, were detected in every sample, as was gallium. Gallium varied between 6 and 17 ppm, copper was present in the

range of 11–36 ppm, while zinc was always present in somewhat higher levels (40–100 ppm). Strontium and rubidium were present in all samples. As would be expected, strontium generally tracked with calcium levels, varying from 450 to 1200 ppm. Rubidium, present in concentrations of 75–150 ppm, was better correlated to potassium than sodium. Bromine, zirconium and barium were detected in almost all samples, with detected concentrations ranging in the tens of parts per million (Br and Zr), and 180–410 ppm (Ba).

Arsenic and lead are two elements of particular focus at Owens Lake due to reports of their enhanced concentrations in the dust aerosols [10] and their known toxicity. One and/or the other was detected in every sample (As in 14 out of 16 samples, Pb in 11 of 16 samples). Arsenic concentrations where detected ranged from 7 to 38 ppm, while detected Pb levels ranged from 17 to 32 ppm. Lead and arsenic levels did not clearly correlate with salt content or sediment type. Arsenic levels appear slightly higher in the crusts with loose material present and potentially lower in the clean hard crusts, while lead was least frequently detected in the samples with loose material.

The sample from 4 November 1995 had high concentrations of several trace elements including nickel, copper, zinc, arsenic and bromine. This sample was described as a platy, cut crust [6] – not significantly different in visual appearance from a number of other samples with lower concentrations of these elements. Otherwise, no individual samples showed notable concentrations of multiple elements.

4. Conclusions

Visual appearance and sedimentary structure of wind-erodible Owens Lake playa crusts do not correlate with elemental composition. Potentially toxic elements and high concentrations of salts may be present in any type of crust at a site. At least at the Geomet site, the surface sediments are geochemically well mixed, no matter their visual form. No clear trends of element concentrations consistently increasing or decreasing over two years were noted. Therefore, the appearance or

Table 2
Analytical results – elemental concentrations expressed as weight fractions

Date	Class	Na	Mg	Al	Si	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Ga	As	Br	Rb	Sr	Zr	Ba	Pb
08-11 1995	L	7.58% ± 2.72%	1.65% ±0.63%	4.30% ±0.36%	18.1% ± 1.2%	1.79% ±0.16%	5.01% ±0.34%	2.26% ±0.15%	5.50% ±0.36%	0.25% ±0.02%		41 ±9	680 ±50	2.83% ±0.19	13 ±4	30 ±4	93 ±8	17 ±3	24 ±5	83 ±8	140 ±10	640 ±50	54 ±13	280 ±60	31 ±7
10-27 1995	L	14.6% 2.7%	1.96% ±0.56%	3.93% ±0.33%	16.9% ±1.1%	2.47% ±0.19%	11.5% ±0.8%	2.05% ±0.14%	4.72% 0.31%	0.19% ±0.01%			510 ±40	2.11% ±0.14%	10 ±3	18 ±3	78 ±6	14 ±3	38 ±5	87 ±8	91 ±9	470 ±30	77 ±12	180 ±50	29 ±6
11-04 1995	L	10.2% ±2.2	1.60% ±0.46%	4.53% 0.34%	18.7% 1.2%	2.49% ±0.19%	7.06% ±0.47%	2.49% ±0.17%	4.44% 0.29%	0.26% 0.02%		31 ±10	730 ±50	2.83% 0.19%	19 ±4	35 ±4	100 ±8	13 ±3	35 ±6	95 ±9	120 ±10	470 ±40	53 ±12	260 ±60	
12-22 1995	L	12.0% ±2.1%	1.76% ±0.44%	4.27% ±0.32%	17.2% 1.1%	4.95% ±0.34%	4.67% ±0.31%	1.94% ±0.13%	4.38% ±0.29%	0.20% ±0.01%	46 ±24	27 ±8	590 ±40	2.28% ±0.14%	9 ±3	21 ±3	73 ±6	13 ±3	15 ±4	37 ±5	100 ±9	450 ±30	53 ±11	190 ±50	24 ±6
01-24 1996	L	8.32% ±1.58%	2.26% ±0.37%	5.34% ±0.38%	20.6% ±1.4%	2.5% ±0.18%	4.17% ±0.28%	2.73% ±0.18%	4.57% ±0.30%	0.27% ±0.02%	95 ±32	21 ±10	750 ±50	3.09% ±0.20%	13 ±4	36 ±4	100 ±10	15 ±3	13 ±5	68 ±7	150 ±13	500 ±37	50 ±12	350 ±60	31 ±7
02-09 1996	L	14.9% ±2.64%	1.96% ±0.54%	4.09% ±0.33%	16.6% ±1.1%	2.80% ±0.21%	11.9% ±0.8%	1.89% ±0.13%	6.03% ±0.40%	0.20% ±0.01%	74 ±25		500 ±40	2.00% ±0.13%		21 ±3	69 ±6	9 ±3	7 ±4	41 ±5	88 ±8	580 ±40	49 ±11		24 ±6
03-17 1996	L	8.02% ±1.88%	2.88% ±0.47%	3.54% ±0.27%	19.3% ±1.3%	3.05% ±0.22%	3.11% ±0.21%	1.82% ±0.12%	11.4% ±0.75%	0.13% ±0.01%		29 ±8	470 ±30	1.41% ±0.09%	10 ±3	11 ±2	46 ±4	9 ±3	17 ±4	11 ±3	88 ±8	0.11% ±0.01%	69 ±14	390 ±60	
08-23 1996	L	8.56% ±2.19%	3.35% ±0.56%	3.02% ±0.26%	19.1% ±1.3%	1.87% ±0.15%	4.07% ±0.27%	1.58% ±0.11%	11.6% ±0.76%	0.13% ±0.01%		19 ±8	400 ±30	1.37% ±0.09	16 ±3	16 ±3	47 ±4	11 ±3	21 ±4	12 ±3	85 ±8	0.12% ±0.01%	54 ±13	190 ±50	
11-17 1996	L	6.80% ±1.74%	3.05% ±0.45%	3.99% ±0.30%	20.2% ±1.4%	1.77% ±0.14%	2.94% ±0.20%	1.98% ±0.13%	11.4% 0.7%	0.16% ±0.01%		24 ±9	520 ±40	1.73% ±0.11%	14 ±3	21 ±3	66 ±6	13 ±3	18 ±4	22 ±4	83 ±8	0.11% ±0.01%		410 ±60	
12-08 1996	S	10.3% ±2.0%	2.8% ±0.5%	4.79% ±0.35%	19.8% ±1.3%	2.44% ±0.18%	5.54% ±0.37%	2.24% ±0.15%	6.05% ±0.40%	0.23% ±0.02%	70 ±28	26 ±9	630 ±40	2.54% ±0.17%	18 ±4	30 ±4	93 ±7	17 ±3		20 ±4	120 ±10	640 ±50	55 ±12	270 ±60	30 ±6
12-27 1996	S	6.82% ±1.76	3.18% ±0.21%	4.54% ±0.34%	20.7% ±1.4	1.39% ±0.11%	3.14% ±0.21%	2.19% ±0.15%	8.75% ±0.58%	0.20% ±0.01%			580 ±40	2.18% ±0.14%	11 ±3	20 ±3	71 ±6	10 ±3	22 ±4	18 ±4	100 ±10	910 ±60	84 ±14	320 ±60	17 ±6
01-10 1997	S	5.02% ±1.80%	4.36% ±0.56%	4.45% ±0.34%	21.5% ±1.5%	0.66% ±0.08%	2.08% ±0.14%	1.93% ±0.13%	10.6% ±0.7%	0.19% ±0.01%	67 ±29	39 ±10	530 ±40	1.97% ±0.13%	13 ±4	27 ±4	69 ±6	16 ±3	12 ±5	13 ±4	100 ±10	0.11% ±0.01%	68 ±16	260 ±60	27 ±7
01-18 1997	S	8.03% ±1.95%	3.47% ±0.52%	3.17% ±0.26%	19.4% ±1.3%	1.11% ±0.10%	6.16% ±0.41%	1.65% ±0.11%	12.4% ±0.81%	0.13% ±0.01%		34 ±8	350 ±30	1.21% ±0.08%	15 ±3	18 ±3	40 ±4	6 ±2	20 ±4	18 ±3	75 ±7	0.12% ±0.01%	93 ±15	320 ±60	
01-27 1997	C	4.19% ±1.80%	2.64% ±0.47%	4.84% ±0.36%	22.3% ±1.5%	0.39% ±0.07%	1.98% ±0.14%	2.07% ±0.14%	9.47% ±0.62%	0.20% ±0.01%		31 ±9	540 ±40	2.13% ±0.14%	14 ±4	21 ±3	69 ±6	15 ±3			110 ±10	950 ±70	62 ±14	350 ±60	32 ±7
03-18 1997	C	6.36% ±1.87%	3.81% ±0.53%	4.04% ±0.31%	20.7% ±1.4%	0.83% ±0.08%	4.05% ±0.27%	2.03% ±0.14%	9.83% ±0.65%	0.16% ±0.01%		27 ±9	460 ±40	1.81% ±0.12%	16 ±4	18 ±3	57 ±5	12 ±3	14 ±4	17 ±4	94 ±9	0.11% ±0.01%		390 ±60	19 ±6
05-12 1997	C	7.51% ±2.02%	2.60% ±0.49%	4.78% ±0.36%	20.9% ±1.4%	1.18% ±0.11%	4.77% ±0.32%	2.22% ±0.15%	7.33% ±0.48%	0.23% ±0.02%		30 ±9	590 ±40	2.46% ±0.16%	12 ±3	28 ±4	86 ±7	15 ±3	11 ±5	32 ±5	130 ±11	740 ±52	62 ±13	250 ±60	31 ±7

Concentrations are in parts per million except where stated as %. Blank fields indicate element not present above minimum limit of detection. Sediment classes are as coded in Table 1.

sedimentary state of a given site on the Owens Lake bed surface cannot reliably predict high levels of salts, arsenic, lead, chromium, nickel or other elements of concern which may be injected into the atmosphere; these elements may be present in various levels in any of the ephemeral forms of the crust at a given point.

Future work in this project will include elemental analysis of airborne particles collected during three different dust storms across a playa transect. Aerosol samples collected at different heights above the lakebed will be tested for elemental and stable isotope (^{13}C and ^{18}O) composition, to determine if there is a geochemical fractionation as dust is injected into the atmosphere from its source sediments. These analyses will also determine whether the chemistry of Owens (dry) Lake aerosols varies with site and date, whether dust composition reflects crust composition, and to assess total exposures to various elements in Owens Lake dust. In addition, scanning electron microscopy and X-ray diffraction analyses are planned to determine the mineralogy of crusts and dust particles and to possibly associate various trace elements with the minerals in which they occur.

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