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EARTH Vol. 55 (No. 6), p. 40

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ARSENIC: A Detective Story in Dusts

Suzette A. Morman

Arsenic. It holds a certain infamy. For centuries, arsenic has been a favorite poison of choice because it was difficult to detect. Francesco de' Medici and his wife were supposedly poisoned with arsenic, as was Napoleon Bonaparte. Today, however, arsenic poisoning is no longer limited to assassinations. In some parts of the world, such as Southeast Asia, people are exposed to arsenic through drinking water — and recent health research indicates arsenic may cause harmful effects at lower doses than previously thought. And more people may be exposed to unhealthy amounts of arsenic than anyone ever realized: Although we typically think of arsenic exposure as being a local or regional problem, our research indicates that airborne dust may be spreading arsenic and its toxic effects within and between continents.

My background is in public health and geology — I am a registered nurse and have master's degrees in geology and public health. Thus, I have a great interest in how earth materials

— minerals, soils, volcanic and wildfire ash, and dusts — affect human health. But recently, I've found myself as a member of scientific teams that are exploring the transport and resulting effects of arsenic. My research eventually led me to wonder whether arsenic in dust blown into the United States from Africa may cause increased rates of respiratory and heart disease in the southeastern United States.

Here's how it all started.

My research at the U.S. Geological Survey (USGS) examines the bio-solubility of earth materials. If we determine how easily an earth material dissolves in fluids that are compositionally similar to those in the human body, then we can make some predictions about the potential health effects of these materials to human and ecosystem health.

The next step in determining how earth materials might affect humans and ecosystems is to determine the bio-accessibility of those earth materials — basically estimating the concentration



Arsenic has been a poison of choice for centuries.

Researchers collected dust from the Mojave Desert to measure the metal content in the dust.





Suzette Morman in the lab at the U.S. Geological Survey in Denver, Colo.

of an element available to the body for uptake by organs, such as the liver or kidneys, for processing within the body. To examine two common exposure pathways — inhalation or ingestion — in the lab, I use simulated lung and gastric fluids to evaluate the solubility and bioaccessibility of a material. These tests are based on physiological models using fluids that are compositionally similar to human body fluids, and have a similar temperature and pH.

These are simplified tests, as the processes by which substances are inhaled or ingested and absorbed by the body

Although we typically think of arsenic exposure as being a local or regional problem, our research indicates that airborne dust may be spreading arsenic and its toxic effects to people across the world.

are complicated and based on many factors. But these tests have shown good correlation with animal studies for arsenic and lead absorption. They are quick, inexpensive alternatives to the traditional animal studies and are useful for identifying what future studies are needed.

Traditionally, researchers have used these studies to examine contaminated soils or mine-related wastes. But

my colleague Geoff Plumlee, a research geochemist at USGS, and I started wondering if these tests could go further — perhaps to examine many naturally occurring but poorly understood earth materials, such as dusts, and determine what potentially toxic elements they may contain, including arsenic. We thought we were on to something.

Many of the earth materials I study are naturally occurring (or geogenic). But some are from “geoanthropogenic” sources, or those produced from natural sources by processes that are modified

Dust blowing off dry lakebeds in the Mojave Desert in California can reach Las Vegas, Nev.



or enhanced by human activities, such as dusts from lakebeds dried by removal of water by humans. In 2008, I was working on one such project — examining dusts from dry lakes in the Mojave Desert with USGS geologist Richard Reynolds — when I became interested in arsenic in the environment. My job was to determine which metals were present in these mineral dusts and how bioaccessible they were. Windblown dusts from some areas of the Mojave Desert can reach Las Vegas, Nev., and surrounding communities, so this study potentially had public health implications.

Dust is a health hazard because exposure to fine particulate matter — including not only dusts but also wildfire and volcanic ash — increases the risk of respiratory and cardiovascular illness in humans.

Particulate matter is described and regulated by two size fractions: coarse and fine. Coarse particulate matter is smaller than 10 micrometers but greater than 2.5 micrometers, and fine particulate matter is less than 2.5 micrometers. To provide a visual perspective: a human hair is about 70 micrometers wide and a grain of beach sand is about 90 micrometers across — so we're talking about very small particles. The size of the particles is important because only the smallest particles, those less than 3 micrometers, can pass through our nose and upper airways and into the farthest reaches of our lungs (inhalation). Larger particles tend to be captured in the mucous lining of our nose and throat and swallowed (ingestion). Categorizing the size of the particulate matter was one component of the study in the Mojave Desert.

One reason the Mojave study described in this article is important is because much of the published research examines

particulate matter in urban areas from anthropogenic sources, such as vehicle exhaust and industry emissions. Fewer studies have considered contributions from mineral dusts. But such dusts may be particularly important on a regional level. Surface sediment from some dry lakebeds, for example, may contribute significant amounts of mineral dusts to the atmospheric load. Owens Lake, a dry lakebed in Southern California, is an important source of particulates as winds have spreads its dust across

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the United States. What's worse is that these sediments may contain elevated amounts of many potentially toxic elements, including arsenic, chromium, copper, lead, nickel and zinc.

We collected the Mojave dusts using an apparatus similar to a wind tunnel. This allowed us to collect dusts of a similar size and amount as what would

normally be produced by the wind. An average of 40 percent of the dusts were considered coarse and thus ingestible and 10 percent were fine and thus inhalable. The metal concentration for some samples indicated they were high in arsenic, and the bioaccessibility was also high — on average 43 percent of the arsenic dissolved in simulated gastric fluids and 11 percent dissolved in simulated lung fluids during lab tests.

These numbers were higher than anything I had observed or seen reported elsewhere. I was intrigued. I had to learn more about how arsenic moves in the environment and what it does in the body. So I went back to the books.

Although poison is arsenic's most infamous use, the element's long history is not so narrow. Arsenic has been used for paint pigments, insecticides, herbicides, wood preservation, military and medical uses. Arsenic occurs naturally in two forms: organic and inorganic. One organic form (arsenobetaine) is found in seafood and is much less toxic than the inorganic form.

Inorganic arsenic is present in minerals and soils, and naturally enters the



Windblown dusts can carry elevated levels of potentially toxic metals, including arsenic.

Dust blowing off Owens Lake in Southern California has been a major source of particulates across the United States.

In the past decade, research has found links between long-term arsenic exposure and cardiovascular problems, such as high blood pressure, arrhythmias and diabetes — at lower levels of exposure than what had been previously observed.



The hands of a Bangladeshi farmer show the effects of chronic arsenic poisoning. Arsenic naturally occurs in the water and soil in Bangladesh and elsewhere.

air and water through the weathering of arsenic-containing minerals, windblown dusts, or from water runoff. Inorganic arsenic is toxic and has been linked to cancer of the bladder, liver, lungs and skin. It also leaves skin lesions and can cause disfigurement. In the past decade, research has found links between long-term arsenic exposure and cardiovascular problems, such as high blood pressure, arrhythmias and diabetes — at lower levels of exposure than what had been previously observed. Although scientists know that arsenic causes these health problems, we are still trying to determine just how it does so, especially given the fact that arsenic tends to work through the body quickly — typically in a day or two. Recent research seems to indicate that exposure to arsenic may affect our endocrine system, blocking receptors, which may contribute to the process by which arsenic causes disease.

In some parts of the world, such as Bangladesh, India and Taiwan, people may be routinely exposed to high levels

Recent research suggests that rice fields in the southeastern United States that once grew cotton may contain elevated levels of arsenic.

of arsenic, greater than 100 micrograms per liter, in their drinking water. They certainly feel the effects: cancers, skin lesions and the like. Studies have also shown an association between high levels of inorganic arsenic in drinking water and an increased risk of type II diabetes in Taiwan, Bangladesh and Mexico.

Generally in the past, we thought that only very high levels of exposure through drinking water were of concern. Many of us in the United States thought we were pretty safe, given that most of our water doesn't naturally contain high levels of arsenic (although some areas exceed the U.S. Environmental Protection Agency's drinking water standards). However, Dr. Ava Navas-Acien of Johns Hopkins University in Baltimore, Md., reported in the *Journal of the American Medical Association* in 2008 that her team had found that the risk for developing type II diabetes increased when people living in the United States were exposed to even low and moderate levels of arsenic.

In addition to exposure through drinking water, we may also ingest arsenic in food, such as rice, cereals and other products made from rice. Rice is very good at absorbing arsenic as it grows under flooded conditions with high arsenic mobility. Obviously this is a problem for places with high natural arsenic levels, such as Bangladesh and India, but it's not just a problem in Asia. Rice grown in areas that used to produce cotton in the United States, for example, is also affected — possibly from arsenic-based pesticides used on cotton crops.

A 2007 study in Environmental Science

I wondered if adding airborne arsenic from dusts might increase the concentrations to which some people are exposed, especially people who work or exercise outdoors.

& Technology reported that arsenic levels in rice samples from south-central states were almost double the arsenic levels of rice grown in California. (For most people, who consume rice infrequently, this is probably not a serious threat.)

Traditionally, public health researchers have only thought of drinking water and food as the primary ways people are exposed to natural inorganic arsenic.

But after realizing that the dry lakebed dusts in the Mojave Desert contained high levels of bioaccessible arsenic, I wondered if we were overlooking an important source of arsenic exposure: airborne dust. I wondered if adding airborne arsenic

Dust blowing off western Africa routinely reaches the Caribbean and United States.



Could dust, in addition to what we drink and eat, be an exposure path to potentially toxic levels of arsenic?

Dust blown off the Sahara Desert in Africa spreads across the world. The Sahara's Bodele Depression in Chad is considered the number one source of windblown dust in the world.

from dusts might increase the concentrations to which some people are exposed, especially people who work or exercise outdoors in areas affected by dusts from dry lakebeds or other sources.

So in 2009, we started to consider it. Dusts blow off agricultural land, dry lakebeds and, of course, deserts. They affect both local and downwind communities, so changes in the composition and volume of dust transported could increase health-related risks, depending on what is in the dusts. Dusts entrain earth materials as well as anthropogenic pollutants from their source location. Dusts may also carry bacteria, fungi and allergens.

One of the sources of dust in the southeastern United States is that blown in from Africa (see sidebar). Winds from the Sahara-Sahel desert region regularly transport large amounts of dust to North Africa, Europe and the Americas. African dust storms transport an estimated 3 billion metric tons of dust annually. Scientists have measured particle size from transported African dusts and found a large portion of these dusts are in the respirable range below 3 micrometers — especially the downwind samples.

Ginger Garrison, a USGS marine ecologist, had been working on a project examining windborne dusts from Africa. She thinks these dusts may be a factor in coral reef decline — and may also adversely affect other ecosystems and human health. She had already completed testing for chemical contaminants such as pesticides, polycyclic aromatic hydrocarbons (PAHs) and microorganisms but wanted more answers. In 2009, we examined dust collected on specialized air filters from three sites: one in Mali, West Africa, and two in the Caribbean: Tobago and the Virgin Islands.

While Heather Lowers, a USGS research geologist, attempted to confirm particle size of the dusts with a scanning

electron microscope, I worked out a way to use my simulated lung and gastrointestinal fluids extraction method to determine the bioaccessibility of metals in the dusts. Paul Lamothe, a USGS research chemist, analyzed a portion of the filters to obtain the concentrations of the different elements in the dusts. We found that the African dusts contained several potentially toxic metals, in addition to arsenic.

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MORE ARSENIC IN A CHANGING CLIMATE?

It seems that we are reminded almost daily of the challenges we will confront with the changing climate and its potential effects. We are already experiencing some of these effects, such as increased frequency and duration of wildfires, and dust production and storms related to a process known as desertification. Many scientific disciplines are engaged in determining probable effects or modeling scenarios to discern how these changes will affect not only our lifestyle, but also our health and the health of many ecosystems. As a scientist, I initially did not see any correlation between my studies related to arsenic and the effects of a changing climate.

Dust has been blowing into the United States and Europe from Africa for millennia. But recently, changes in

both volume and composition have been observed, prompting scientific investigation on several fronts. This geogenic (or natural) source appeared to be changing into a geoanthropogenic source (produced from natural sources by processes that are modified or enhanced by human activities). These changes are related to climate: desertification, drought and urbanization of areas near drylands.

Desertification threatens semi-arid and arid lands worldwide, resulting in part from human practices such as unsustainable water use as well as climate variations and poverty. Desert regions or drylands are threatened by fast-growing urban populations dependent on scarce surface water and groundwater. Estimates indicate that desertification directly affects

Desertification due to climate change may create more airborne dust that is respirable by humans.



Dust devil in Tanzania.

70 percent of all drylands and about one-sixth of the world's population. Worldwide concern for the consequences, which include increases in water- and foodborne illness and respiratory disease, prompted the United Nations to form the United Nations Convention to Combat Desertification in 1994.

The question is, How much is increasing desertification in Africa — which brings dusts containing arsenic, lead, cadmium and other harmful metals as well as possibly biological agents to North America and Europe — going to affect the United States in the future? Unfortunately, it's a question we don't yet have an answer to ... but we're working on it.

SAM



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The U.S. Environmental Protection Agency (EPA) uses soil screening level (SSL) guidelines to help standardize evaluation and cleanup of contaminated sites — these levels are protective to human health. EPA also uses ecological soil screening levels (ECO-SSL) to identify contaminants of potential concern for plants and nonhuman animals. These guidelines are designed to be protective and used during the screening stage of risk assessment. These numbers are a reference point only, as many factors must be taken into account for a specific site assessment. That said, we found that multiple metals — cadmium, chromium, copper, lead, manganese, vanadium and zinc — are in concentrations that exceed the avian and mammalian ECO-SSL guidelines in the African dusts. And although those metals did not exceed the human SSL guidelines, arsenic did.

But the critical thing to remember is that although the actual concentrations are important, what's even more significant is how bioaccessible the metals are. And that's where our results get interesting. For several metals, we saw a general increase in bioaccessibility for the particles that had reached the Caribbean. This increase is probably related to the decreasing particle size of the dusts that arrived at their destination: The larger, heavier particles are lost during transportation across the Atlantic. In the simulated stomach fluid, arsenic was more than 40 percent bioaccessible. The arsenic in the simulated lung fluid results varied between 12 and 100 percent bioaccessible. These values are high, but similar to what I observed in the Mojave dusts — indicating that much of the arsenic in the particles would be available to the body for absorption.

USGS scientists C.W. Holmes and Ryan Miller reported in *Applied Geochemistry* in 2004 that African dusts supply as much as a quarter of the arsenic deposited in the southeastern United States. Right now, all we know is that dust is blown into the southeastern United States and that the dust has highly bioaccessible arsenic in it. We cannot make any statements about disease causation or correlation at this time. There's a lot more research to be done.

Could dust, in addition to what we drink and eat, be an exposure path to potentially toxic levels of arsenic? It is certainly possible. But it is difficult to assess all sources in a study, especially those that are intermittent and/or at low levels. And it's difficult to figure out causation versus correlation. Although



Using these air samplers, researchers also collected dust in Emetteur Kati, Mali (top), and Flagstaff Hill, Tobago (bottom).

scientists don't have all the information to understand how arsenic affects us, it is a top research priority. Scientists are improving techniques to understand where arsenic is, why it behaves differently in different environments and how it causes disease in our bodies. This is one detective story that doesn't have an ending yet.

Morman is a specialist in geology and public health at the Crustal Geophysics and Geochemistry Science Center at the U.S. Geological Survey in Denver, Colo. Morman, who has both a master's degree in public health and a master's degree in geology, is also a licensed registered nurse. Her research involves the interface between minerals and human health, examining concerns such as bioaccessibility and biodegradability of earth materials.



Researchers collected African dust in St. John, Virgin Islands, to test its metal concentrations in 2000 (left) and 2007 (below).



Bottom: courtesy of R. Boulton; top three: courtesy of V. Garrison