Health implications of

For about $200, off-road enthusiasts can rent a buggy and take an "exhilarating shake, rattle, and roll" ride

through Nevada's Nellis Dunes Recreation Area (NDRA). Just 20 minutes from the Las Vegas Strip, this 10,000-acre swath of the Mojave Desert is open to unrestricted off-road riding over terrain that ranges from dunes to bedrock and hills to arroyos. The combination of easy access and challenging geography has made the NDRA a vast playground for roughly 300,000 visitors each year.

Yet the austere beauty of this sere landscape—a shifting mosaic of russets, grays, golds, and tans—belies a potential danger. There is arsenic in the air. Or, more precisely, there is arsenic in the dust that blows off the dunes and billows from disturbed desert pavements.

SSSA member Brenda Buck, a professor of geology at the University of Nevada–Las Vegas, is one of the scientists who discovered the toxic, semi-metallic element here. At the time that she first turned her attention to Nellis Dunes, she was primarily interested in the chemistry and mineralogy of the particulate matter comprising the dust, rather than possible health risks.

"I was always interested in dust," she says, "because that's a huge component of how arid soils form." Buck says she was "curious about what's in the dust" because the USEPA sets air quality standards only for the size and quantity of airborne particulate matter and not for actual dust constituents.

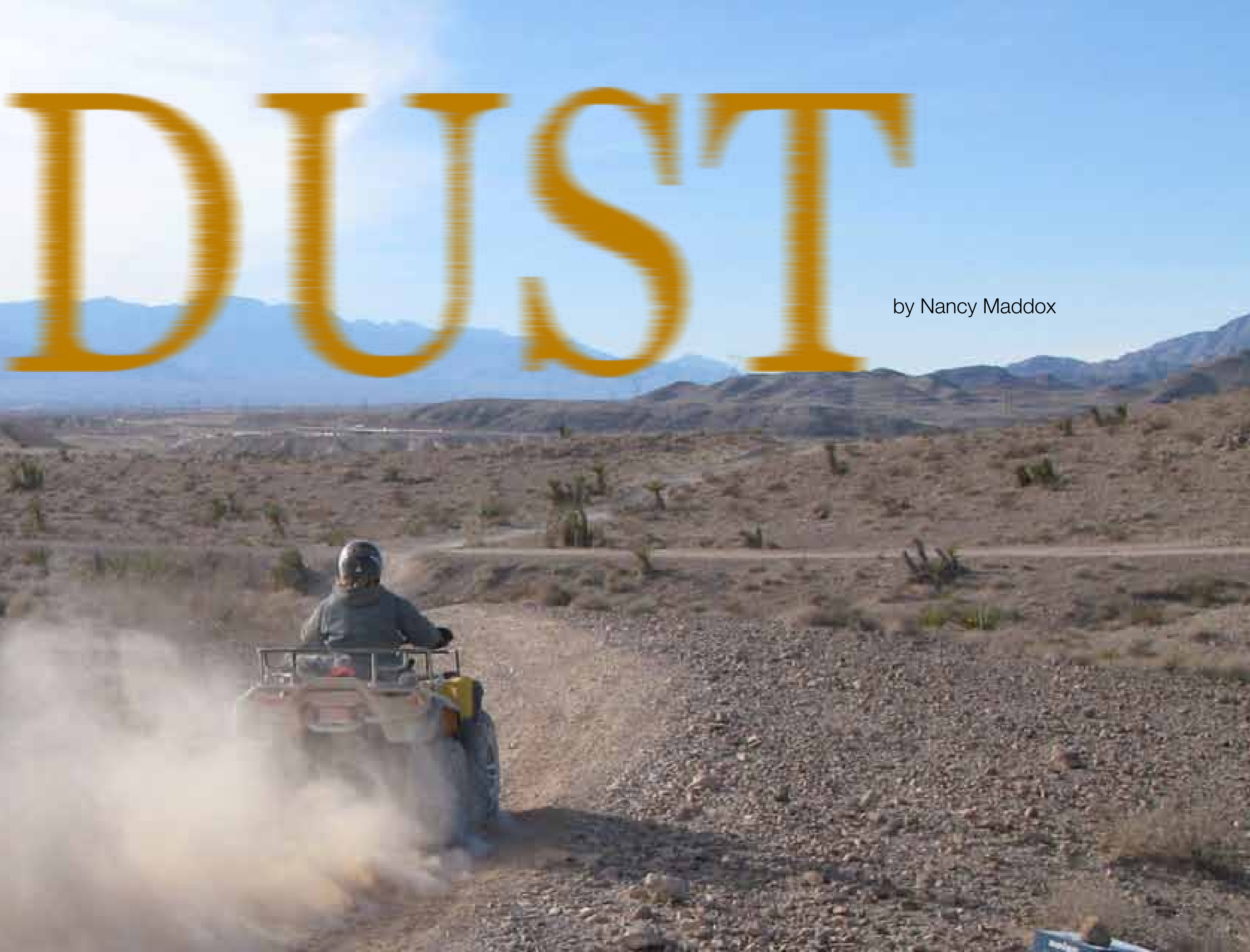
Yet, despite her interest, Buck says, "We actually didn't think we would find anything [of note]." The NDRA, she says, is "typical badlands" and has no history of mining, a known source of environmental toxicants.

Buck and colleagues trekked across the recreational area with a Portable In Situ Wind Erosion Laboratory, a sampling device resembling something one might find on the Mars rover Curiosity. At 68 sites, they clamped the instrument's metal cover down on the surface, forming an airtight seal. Then the scientists activated an interior fan to create the proverbial tempest in a teapot.

"You can ramp up the wind shear inside just like a dust storm," Buck says. Interior monitors measured dust

DUST

by Nancy Maddox



concentration, and a vacuum attachment enabled the scientists to draw off a portion of the particulate matter for detailed analysis off-site.

The research team also measured dust emissions associated with three off-road vehicles: a four-wheeler, dirt bike, and dune buggy.

Findings came as a surprise even to the scientists: Buck and colleagues documented the highest concentration of arsenic in dust ever measured on a natural land surface anywhere in the world. [Buck, however, is quick to point out that many dust studies are now ramping up. "I'm sure our study won't hold that record for long," she predicts.]

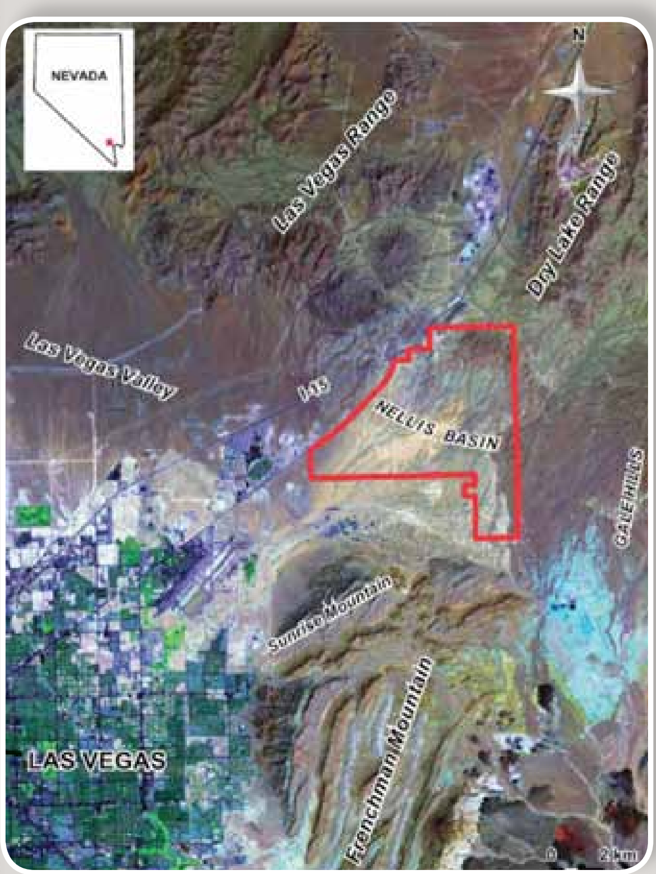
The highest concentrations of arsenic were found in the northern portion of the NDRA in areas dominated by fine sand or silt and in active drainages. Dust emissions—and with it, arsenic exposure—varied widely depending on the ground surface and the particular external impacts to the surface. Wind erosion had the greatest impact on sandy surfaces.

"On a windy day, if you're standing in the sand dunes, you'll get a much higher exposure because the sand dunes are naturally highly emissive under windy conditions," Buck says. "If you drive on the sand dunes, and it's not windy, you don't get much dust because the driving is actually compacting the sand."

Human disturbance meanwhile had the greatest impact on desert pavements—surfaces "armored" by closely interlocking cobbles, with a layer of accumulated silt (a so-called *vesicular horizon*) underneath.

"Desert pavements are not emissive naturally," Buck notes. "In fact, they're dust traps. But if you drive on them, you destroy that protective coating and expose the vesicular horizon, so you get a much greater exposure [to dust-borne arsenic]."

Of the off-road vehicles, four-wheelers produced the largest amounts of dust, followed by the dune buggy and dirt bike. In all cases, emissions rose with driving speed. According to an account of the study published in *Aeolian Research* early this year, "Emission rates for arsenic nearly double when comparing driving speeds of 30 km/hour to 40 km/hour, and at 50 km/hour more than triple." The findings were sufficiently alarming to prompt the U.S.



Left: Nevada's Nellis Dunes Recreation Area (NDRA) is just 20 minutes from the Las Vegas Strip. **Top:** Brenda Buck and her colleagues measured dust emissions in the NDRA associated with three off-road vehicles (left to right): a dune buggy, dirt bike, and four-wheeler. *Photos by Dr. Dirk Goossens, UNLV.*

Bureau of Land Management, which manages the NDRA and funded Buck's work, to post warning signs.

Public Health Impact

So, where did the arsenic come from? No one knows for sure. Arsenic is naturally occurring throughout the western U.S., and the Nellis Dunes study team hypothesizes that it may have been introduced into local geologic strata as a result of long ago Tertiary volcanism, with hydrothermal waters, springs, and groundwater moving and concentrating the arsenic ever since.

"If our hypothesis turns out to be correct," Buck says, "then there is significantly high potential for many more areas in the western U.S. to also contain arsenic and be able to generate dust with high arsenic concentrations."

Potential public health impacts are worrisome. "People who go out there and drive make the choice about how much exposure they get, but what about the people who are downwind?" asks Buck, alluding to the 1.9 million residents of the Las Vegas metropolitan area. "It's like secondhand smoke."

The USEPA classifies inorganic arsenic as a human carcinogen, and exposure to the toxic metalloid has been linked to serious disorders: cancers of the lung, liver, kidney, bladder, and skin; Type 2 diabetes; cardiovascular disease; reproductive and developmental disorders; cognitive problems; immunodeficiencies; and more. The precise mechanisms by which arsenic triggers illness are not wholly established, but the metalloid is known to inhibit more than 200 enzymes and to act as a potent endocrine disruptor.

Buck's research showed that arsenic at the NDRA is concentrated in the finer-grained dust fractions—particulate matter less than 10 microns in diameter (PM10).

"Grain size is so important," she says. "Arsenic may be 10 or 20 parts per million (ppm) for the total soil sample. These are pretty typical values in the western U.S., and no one gets too freaked out about that. But when you take those same samples and look at PM10s, then you see these incredibly increased concentrations," as high as 290 ppm.

Some of the devices used to collect data in the NDRA study (left to right): PI-SWERL (Portable In Situ Wind Erosion Laboratory), DustTrak (used to measure PM10 concentrations), and BSNE (Big Spring Number Eight) dust traps. *Photos by Dr. Dirk Goossens, UNLV.*

"A lot of people are mouth breathers," Buck points out. "PM60 (particles < 60 microns in diameter) will get stuck in your mouth, you'll swallow it, it will go in your nose, and go down the back of your throat, and go in the intestinal tract. PM10 will definitely be going in your lungs."

Of concern, PM10 dust fractions can remain airborne for hours and travel as far as 30 miles—a distance well within range of Las Vegas from the Nellis Dunes. In fact, Clark County, home to both Las Vegas and the NDRA, is currently out of compliance with USEPA PM10 dust standards.

The level of water-soluble arsenic was also disturbing—as high as 15 ppm in the PM60 fractions of dust samples compared with a USEPA drinking water standard for arsenic of 0.01 ppm.

"It's pretty important to know the chemistry," Buck says. "Arsenic that's water soluble is much more likely to dissolve in lung fluids, stomach, and intestine and get into your blood stream. That's pretty concerning."

The unexpected health implications of the NDRA findings were life changing for Buck, leading her to a new field of study: medical geology, a specialty at the intersection of the geological, health, and life sciences. In practice, the field is as old as humanity; even animals know the benefits of licking exposed salt deposits to maintain health and ingesting clay to resolve certain gastrointestinal ailments. The field, however, was not formalized until the 20th century and did not experience significant growth until the 1980s.

Erionite: More Toxic than Asbestos

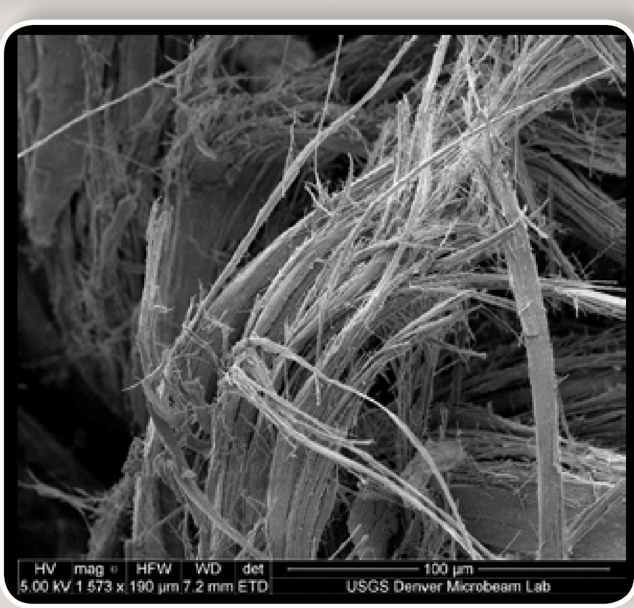
Buck is now an investigator for a $2.5 million, three-year study to gauge health risks associated with exposure to the arsenic-laced dust at the NDRA. She is also one of several researchers examining Nevada cancer registry data to identify possible environmental exposures associated with increased cancer risk. And she is one of a group of scientists funded by the John Wesley Powell Center at the USGS to examine existing datasets related to erionite, a fibrous, zeolite mineral thought to be many times more toxic than asbestos.

"The unique and wonderful thing about the grant program is that it brings together some of the world's best mineralogists, geologists, and medical scientists and epidemiologists," says Christopher Weis, a toxicologist working with Buck on the Powell Center effort. "The geologists know where these [toxic, geologic] materials are. Secondly, they can characterize them using knowledge and laboratory tools that medical scientists don't have at their disposal. The reverse is also true. Medical scientists can understand characteristics of those materials that are of most relevance for human exposure and public health."

Ultimately, the USGS erionite study, like the NDRA study, comes back to dust. Like asbestos, erionite is long and thin and resistant to solubility. And therein lies its health risk.

"Fibers get into your lungs by inhalation," Weis says. "They can align themselves with the flow of air and make their way deep into your lungs." Once these elongated particles makes the "tortuous turns" into the respiratory area of the lungs—the alveoli—removal is difficult; erionite fibers are generally too long to be cleared by alveolar macrophages.

The needle-like fibers are insoluble and can persist and accumulate. Over time, they can pierce the lung tissue and work their way into the surrounding pleural lining causing plaque formation and impaired breathing. The body may try to wall them off by laying down collagen, creating scar tissue.



Erionite, a fibrous, zeolite mineral thought to be many times more toxic than asbestos.

Erionite has become a concern in Dunn County, ND with heavy trucks kicking up dust on back roads. *iStockphoto.*

Weis, who is a senior adviser in the office of the director of the National Institute of Environmental Health Science, says, "It's those inflammatory reactions—scar tissue formation, release of cytokines, and other chemical substances—that can lead to inflammation, pleural, and interstitial disease, which are noncancerous, but can be lethal."

But sufficient exposure may also trigger lung cancer and a particularly aggressive form of cancer, mesothelioma, which, Weis says, "is almost invariably lethal."

Residents of Karain, Tuzkoy, Sarihidir, and Boyali—villages in the Cappadocia region of Turkey—have been long acquainted with the dangers of erionite. Cappadocia occupies a high plateau punctured by volcanic peaks. Villagers here have built their homes of erionite-bearing stone, and in some cases, have taken up residence in caves excavated from the rock face itself. The rate of mesothelioma mortality in Cappadocia runs as high as 50%.

In the United States, erionite deposits have been found in at least 13 states, with numerous deposits in Nevada, Oregon, California, and Arizona. A study published last summer in the *Proceedings of the National Academy of Sciences* (PNAS) found levels of airborne erionite in Dunn County, ND, at least as high as those in Boyali, where the mesothelioma mortality rate is 6.25%.

The variously milky or ash-colored mineral—named after the Greek word for wool—is a natural component of rocks and gravel deposits that have been mined for decades in North Dakota's Killdeer Mountains. Much of the erionite-bearing stone was spread over more than 300 miles of dirt roads to prevent erosion and, ironically, control dust.

Then, in 2008, billions of gallons of oil sitting in the Bakken geologic formation underlying Dunn County suddenly became recoverable with the introduction of rock fracturing technology. The ensuing oil and gas extraction has been an economic bonanza for North Dakota, driving down unemployment to 3% and growing a budget surplus of $1.6 billion.

But the oil boom has also spurred traffic on these gravelly back roads, with a steady stream of heavy trucks pulverizing the brittle, erionite-bearing stone into clouds of toxic dust.

The PNAS study, led by Michele Carbone of the University of Hawaii Cancer Center, documents elevated levels of airborne erionite along roadsides, within school buses, inside cars, and inside a local social services office. Roadside levels were as high as outdoor air levels in Turkish villages suffering mesothelioma mortality rates from 20 to 50%.

Development of mesothelioma takes about 30 years, and the disease is not now a problem in sparsely populated Dunn County. However, at least one study has found lung scarring consistent with erionite exposure in two local road maintenance workers.

The Carbone study was the major impetus for the USGS erionite project. Buck, Weis, and other participants will update maps of erionite deposits in the U.S., standardize mineral identification, discuss sampling and analysis strategies, and identify possible public health interventions.

In a separate study, Buck and other researchers are investigating unusual cases of mesothelioma in Nevada. The cases stand out because some patients are under age 45, and men and women are affected in roughly equal proportion in the youngest age groups. The data suggest the cause of illness is an environmental exposure impacting both males and females early in life, rather than an occupational exposure, which occurs mostly in male-dominated industries and begins later in life. Eight known or suspected dust-borne carcinogenic minerals are under investigation as the source of illness.

We Live in a Dusty World

Dust-borne toxicants like arsenic and erionite are likely to remain a public health concern if only for one reason: the world is becoming ever more dusty.

"There is definitely a consistent line of information suggesting that the U.S.—at least the western U.S.—is getting dustier," says dust expert Thomas Gill, a professor of geology and environmental science and engineering at the University of Texas at El Paso.

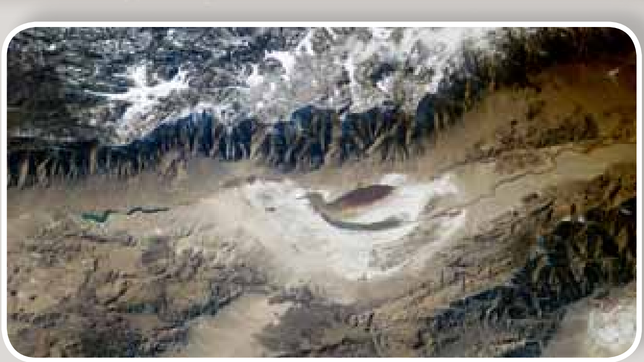
Gill and colleagues just completed a study of global satellite data of dust sources and land use. Gill says they estimate that "about 25% of the roughly 1500 teragrams per year of dust emitted into the atmosphere at the present day comes from anthropogenic contributions, primarily due to human disturbance of the land surface for agriculture and human perturbation of the hydrologic cycle."

In addition to anthropogenic sources of dust, there are also naturally occurring (geogenic) sources and natural sources modified by human activity (geoanthropogenic), according to Geoff Plumlee, a geochemist at the USGS in Denver, CO.

Dry lakebeds are one example of an increasing geoanthropogenic source of dust as drought and water withdrawal have combined to reduce previously rich aquatic environments to barrenness.

Lake Owens on the east side of the Sierra Nevada range in California was a lake, Plumlee says, "until Los Angeles stuck its soda straw in it in the early 1900s and siphoned it dry." After the city diverted most of the flow from Owens River, which fed the lake, the dry lakebed became the largest point source of dust in the U.S.

The fluffy, evaporative salts left behind when the water disappeared were easily windblown and laden with geogenic arsenic that had been deposited in lakebed sediments. Since 1998, Los Angeles has been trying various measures to limit the amount of dust wafting from parts of the lakebed.



Dry lakebeds are one example of an increasing geoanthropogenic source of dust. Above is all that is left of the original Owens Lake in Owens Valley east of the Sierra Nevada mountains in California. The Sierra Nevada is at the top, and Owens Valley is the brown region in the center. *Courtesy of NASA Earth Observatory.*

Similarly, California's Salton Sea, the Aral Sea in Central Asia, Lake Chad in Africa, and the Hamoun Wetlands straddling the borders of Iran, Pakistan, and Afghanistan have all become troublesome sources of dust after being desiccated by irrigation and drought.

Plumlee was one of several USGS earth scientists who investigated a uniquely man-made explosion of dust in 2001: the collapse of the World Trade Center on 9/11. The USGS team found asbestos in the dusts deposited in lower Manhattan and high levels of caustic alkalinity from calcium hydroxide in the pulverized concrete. They also found elevated levels of lead, antimony, and glass fibers from ceiling tiles and other building materials.

"One of the things that is very important," Plumlee says, "is understanding what people were exposed to [in order] to help physicians, toxicologists, and epidemiologists better understand health impacts from short-term intense exposures immediately following the collapse and longer-term exposures during the cleanup."

The need to better understand exposure from dust-generating events and mitigate its effects will only increase with increasing population pressure around the world. and this will likely ensure continued work for medical geologists for years to come.

Nancy Maddox, CSA News magazine contributing writer