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## Erionite Studies in Custer National Forest

Daniel Farcas

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# Erionite Studies in Custer National Forest

Daniel Farcas

Dissertation submitted  
to the Davis College  
at West Virginia University

in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in  
Division of Resource Management / Human and Community Development

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Morgantown, West Virginia  
2015

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# **ABSTRACT**

## **Erionite Studies in Custer National Forest**

**Daniel Farcas**

### **Chapter 1. Introduction to erionite**

Erionite is an emerging naturally-occurring carcinogen that through continued and frequent exposure can lead to mesothelioma. Erionite exposure is mostly environmental and it affects individuals that live in areas where a natural deposit of the mineral exists.

### **Chapter 2. What is mesothelioma? Why should I should be afraid? How do you calculate the risk of mesothelioma? What are the results?**

Mesothelioma, a rare cancer and the most dreaded asbestos-related disease affects the lining of the chest cavity and extremely debilitating and terminal. Rates of Malignant Mesothelioma (MM) are dependent on exposure times, concentrations, smoking, age of first exposure, etc. Although there is currently no proof of emerging erionite-related illnesses in the U.S., mesothelioma normally takes 30 to 50 years to develop. In this chapter, a preliminary risk assessment calculation was conducted considering time weighting factors for different activities and exposure years based on the expected age of first exposure according to EPA's excess lifetime cancer risks (ELCRs). The results show an increased probability of mesothelioma occurrence as exposure is prolonged, ranging from 2 to 26 cases in 10,000 individual exposure. This is higher than EPA's acceptability risk standard of 1:10,000.

### **Chapter 3. How do you find these fibers in the environment? How do you separate them? How do you identify them? What was found?**

Asbestos or asbestos-like fibers (erionite) may be present in trace quantities in the environment which are non-detectible with the current analytical techniques. A recent advance in technology, the Fluidized Bed Asbestos Segregator (FBAS), is enabling us to identify and measure very small concentrations of erionite and asbestos in soil. This technique effectively and efficiently separates out erionite fibers from sampled soils while maintaining the integrity of the erionite fibers. Thus, the true structural characteristics and quantity of erionite fibers in the soils can be determined. The results show that traces of erionite in the analyzed soil samples, although well below the detection limit of 1% by traditional PCM/PLM methods, were reliably detected by the FBAS method and identified by Transmission Electron Microscopy (TEM) / Scanning Electron Microscopy (SEM) analysis.

#### **Chapter 4. Where is erionite found? How did you map its location using soil sample data?**

The soil samples were collected by Center for Disease Control (CDC) / National Institute for Occupational Safety and Health (NIOSH), North Dakota University, and the U.S. Forest Service (USFS) in Slim Buttes region of the Sioux Ranger District on the Custer National Forest (CNF) in Harding County, South Dakota. The spatial variation of erionite concentrations in the soil across this research area was mapped using ArcGIS 10.2 software. The results show that the typical soil concentration of erionite on the surface of erionite-hosting geological layers is significantly higher, reaching almost 23%, compared to surrounding soils where the concentration was less than 0.01%. Figure 45 presents a map the predicted priority areas for additional research and investigation into erionite concentrations.

#### **Chapter 5. What is the purpose of risk communication? How can it be accomplished within Harding County?**

The purpose of this chapter is to describe potential risk communication methods that can be used to convey a general sense of the increased risk of developing mesothelioma from breathing in erionite in Harding County. All the risk calculations presented in Chapter 2 have significant uncertainties associated with them. However, these calculations show similar results, i.e. there exists an amplified risk of mesothelioma from erionite exposure in the CNF. This last chapter provides an outline for developing recommendations for a risk communication plan that could be used by the local officials to formulate and convey risk messages to the three main audiences potentially impacted by exposure to erionite on the CNF: Harding County residents, USFS workers and CNF visitors. Based on extended risk literature research, demographic and epidemiological data and risk assessment calculations from previous chapters provide a framework for dialogue between community and authorities. Demonstrations of risk assessment results are communicated through visual displays in the form of numerical data, log scale presentation, and persuasive graphic images.

#### **General conclusions: Take home results and research contributions.**

Naturally occurring erionite is generally consider safe if it is left undisturbed and encapsulated by soil and/or vegetation. There is currently very little evidence that living above or near geology that includes mineral fibers is a hazard, although risk calculations indicate a level of concern about erionite that justifies further investigations.

The contributions of this research include: demonstrating the ability to detect soil mineral fibers below the conventional microscopic detection limit of 1%, mapping of erionite soil concentrations in the study area, providing a comprehensive investigation of the study site through geological investigation, chemical, and morphological analysis of erionite fibers present in the soil, and lastly, examining the potential risk of exposure to erionite through modeling, calculations of cancer risks in order to develop a risk communication framework for the local authorities to interact with the general public, USFS employees, and recreational visitors.

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## **List of Abbreviations and Definition of Terms**

AHERA - Asbestos Hazard Emergency Response Act

ASTM - American Society for Testing and Materials

CDC – Center for Disease Control

CNF – Custer National Forest

EDS - Energy Dispersive Spectroscopy

EPA - US Environmental Protection Agency

ELCR - Excess Lifetime Cancer Risks

EPC - Exposure Point Concentration

ESRI - Environmental Systems Research Institute

FBAS - Fluidized Bed Asbestos Segregator

HMC - Human Mesothelial Cells

GIS - Geographic Information System

IDW - Inverse Distance Weighting

IUR - Inhalation Unit Risk

MCE - Mixed Cellulose Esters

MM – Malignant Mesothelioma

NIOSH - National Institute for Occupational Safety and Health

NOA – Naturally-Occurring Asbestos

NOE - Naturally-Occurring Erionite

OSWER - Office of Solid Waste and Emergency Response

PCM - Phase Contrast Microscopy

PLM - Polarized Light Microscopy

SAED - Selected Area Electron Diffraction

SEM – Scanning Electron Microscopy

TEM - Transmission Electron Microscopy

TWF - Time Weighting Factor



USDA - United States Department of Agriculture

USGS - United States Geological Survey

USFS - United States Forest Service

XRD - X-Ray Diffraction

# Chapter 1

## Overview of the Research Study

### 1.1. Introduction

Erionite is an acicular zeolite and it has been shown that people exposed to erionite have a higher risk to develop malignant mesothelioma (MM) than people exposed to all the other mineral fibers that are currently exposure regulated in the United States. <sup>(101)</sup> Although erionite does not have the same extensive and various commercial applications as the other regulated asbestos fibers and is rarely found in the environment, disturbance of natural-occurring erionite at specific sites may generate airborne fibers with similar or even worse health effects as the well-known asbestos fibers.

Exposure to naturally-occurring asbestos, (as opposed to asbestos found in commercial products, mining or processing operations) is usually involuntary and any adverse health effects are observed decades after the initial exposure. People with significant exposure to asbestos or naturally-occurring asbestos are at risk for developing mesothelioma. <sup>(102)</sup> Worldwide, there is a small number of known erionite sites. In the United States, most of the erionite deposits are located in Oregon, Arizona, Nevada, California, Wyoming, North Dakota, Montana and Utah. Erionite is generally found in places where volcanic ash and rock have been weathered by alkaline waters. <sup>(103)</sup>

## 1.2. Schematic Research Flow

This dissertation will address many of the issues involving erionite which is found in the Custer National Forest (CNF). The linkages between the four essays is presented in figure 1 and brief descriptions of each essay are provided below.

A. Essay one, entitled “Review of Erionite and Risk Assessment” (chapter 2) will analyze potential health concerns related to erionite exposure due to naturally occurring deposits of zeolite.

B. Essay two, entitled “FBAS Preparation Method for the Analysis of Erionite in Soils” (chapter 3) will comprise the evaluation of the Fluidized Bed Asbestos Segregator (FBAS) preparation method for the analysis of erionite in soils.

C. Essay three, entitled “Location of Erionite Deposits in the Sioux Ranger District” (chapter 4) will analyze the location of erionite by the use of Geographic Information System (GIS) technology to map where soil concentrations of erionite would be likely to occur in the Slim Buttes area of CNF as well as the surrounding region.

D. Essay four, entitled “Risk Communication” (chapter 5) will address possible risk communication strategies that can be utilized for possible audiences (general public, USFS employees, and recreational visitors) who face risk from erionite exposure in Harding County, South Dakota.

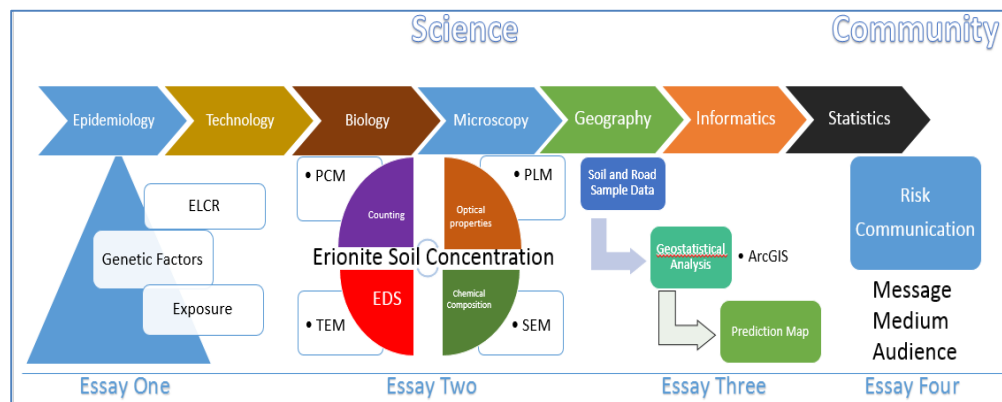


Figure 1: Schematic Research Flow

### 1.3. Description of the Investigatory Site

The CNF is located in the central U.S. and has a climate with four distinct, fluctuating from cold, dry winters to hot, semi-humid summers. The CNF is within Harding County in northwestern South Dakota. Average annual precipitation is around 15 inches (380 mm).<sup>(101)</sup> There is an average of 19.7 days per year with at least 0.01 inches of precipitation according weather data collected from 1981 to 2010 from the NOAA National Climatic Data Center.<sup>(104)</sup>

According to the 2010 U.S. Census Bureau, Harding County has a total area of 2,678 square miles and a population of 1,255. 92% of the Harding County residents have high school degrees or above. The population density is very low at 0.49 people per square mile. Historically, the population has shown a decline from 4,228 people in 1910. In the 57651 postal zip code that encompasses Slim Buttes area, there are only 39 single family addresses (farm residences) and one business address.

The study site, Slim Buttes Forest Reserve, is located in the Sioux Ranger District of the CNF (approx. coordinates 45.525866, -103.177894) (Figure 2). Slim Buttes comprises 58,160 acres (235.4 km<sup>2</sup>) and became part of the national forest system in 1907. Slim Buttes is a faded agricultural area where most farm houses exhibit various states of disrepair and abandonment. Some streets are unpopulated but they still have standing buildings. The closest cities or towns to this area by distance and population are shown in table 1.

Table 1: Closest cities to CNF, Slim Buttes Area

City / Town	Distance	Population
Buffalo, SD	17.72 mi / 28.51 km	335
Hettinger, ND	20.22 mi / 32.54 km	1269
Bowman, ND	45.06 mi / 72.51 km	1668
Rapid City, SD	100.22 mi / 161.28 km	70,812
Bismark, ND	143.13 mi / 230.34 km	67,034
Billings, Montana	257.46 mi / 414.34 km	109,059
Sioux Falls, SD	346.32 mi / 346.32 km	164,676

*Data Source: ArcGIS analysis of the data made available by South Dakota State GIS website*

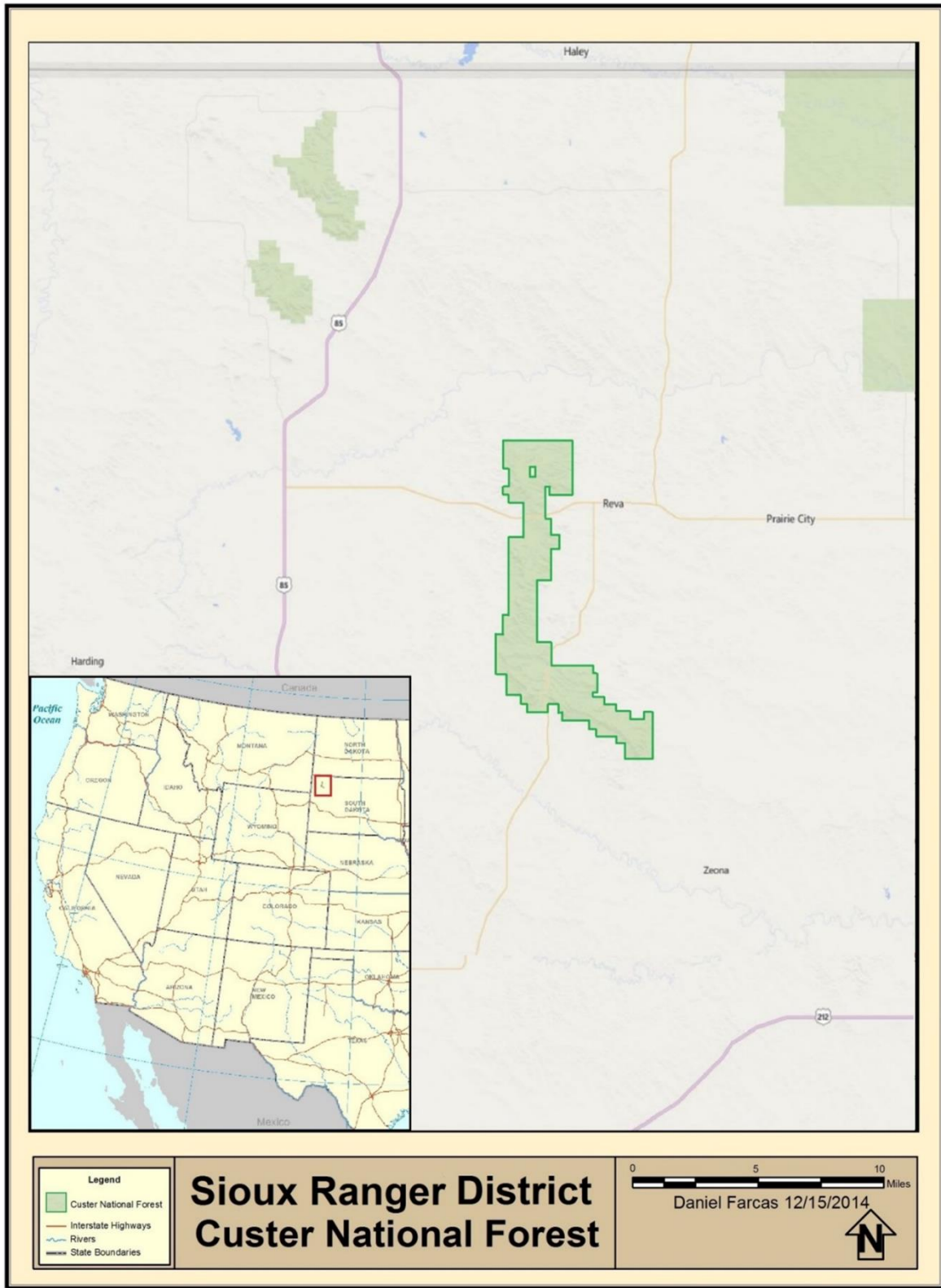


Figure 2: Slim Buttes of Sioux Ranger District of Custer National Forest in South Dakota

## **Chapter 2**

### **Review of Erionite and Risk Assessment**

#### **Abstract**

Exposure to erionite has been clearly demonstrated to have adverse health effects on humans and animals. Epidemiological studies have assisted in establishing a causal relationship between mesothelioma and erionite exposure in both inhabitants of the Cappadocia Region of Turkey and in laboratory studies where the disease has been produced experimentally. The probability of occurrence of mesothelioma increases as exposure to erionite is prolonged and the fiber burden remains in a person's lung for the majority of their biological life. Occurrences of erionite have been identified recently in the Sioux Ranger of the Custer National Forest in South Dakota. From the findings of this study, the local population will benefit by understanding the potential for adverse health effects from erionite exposure.

The objective of this first essay is to conduct preliminary risk assessment calculations considering time weighting factors for different activities and exposure years based on the expected age of first exposure. The methods utilized included a literature review and calculation of the EPA's excess lifetime cancer risks (ELCRs) based on exposure starting at different ages. The results show an increased probability of mesothelioma occurrence as exposure is prolonged, ranging from 2 to 26 per 10,000 individuals exposed compared to EPA's acceptability standard of 1:10,000. Further soil and air sampling is necessary in Harding County due to the identified large number of potential erionite-containing unpaved roads found through GIS analysis.

## 2.1. Introduction

The environment can impact people's health in numerous ways. For example, the geological settings in a geographic area can influence the air that a local community breathes. Medical geology, an emerging interdisciplinary scientific field of study, requires professionals from medicine, public health, geology and community development fields to help understand the relationship between trace contaminants and bioavailability for naturally occurring materials. <sup>(201)</sup>

Asbestos is a common-occurring mineral in many geological settings and has been highly commercialized during the last two centuries. Analysis of its contamination levels in water, dust, waste and soils is used to evaluate exposure levels and to assess risk to people in the past and future. Asbestos is a commercial term used to describe six minerals specifically designated under exposure regulations by OSHA and US Environmental Protection Agency (EPA), but humans don't regulate nature, and thus, the universe of minerals of concern has expanded to non-commercial and non-regulated minerals such as erionite. The World Health Organization defines a fiber as a structure longer than 5  $\mu\text{m}$ , less than 3  $\mu\text{m}$  in diameter, and with a greater aspect ratio length to diameter of 3:1. <sup>(202)</sup> The particle's alveolar deposition depends on the aerodynamic diameter and only fibers with a diameter of 3  $\mu\text{m}$  or less and length up to 40  $\mu\text{m}$  might be transported to the alveolar region. <sup>(203)</sup> Fibers below 5  $\mu\text{m}$  are low in pathogenicity which increases at fibers beyond 8  $\mu\text{m}$ . <sup>(204)</sup>

Most studies today infer health effects in the general population from asbestos exposure based almost entirely on studies of asbestos workers exposed to relatively high commercial-grade asbestos materials for several years. In contrast, NOA exposures begin at very young age and typically occur at levels below the permissible exposure limit (PEL). For occupational



exposure the mean age of the patients with mesothelioma is approximately 60 years <sup>(205)</sup>, while for non-occupational exposed erionite patients the mean age is 49.7 years. <sup>(206)</sup>

The objective of this first essay is to conduct preliminary risk assessment calculations for erionite assuming similar potency to asbestos considering time weighting factors for different activities and exposure years based on the expected age of first exposure. The risk assessments were conducted in Slim Buttes area of CNF to evaluate the potential exposure for USFS employees, CNF tourists and Harding County residents.

## **2.2. Erionite in the Environment and Its Relationship to Disease**

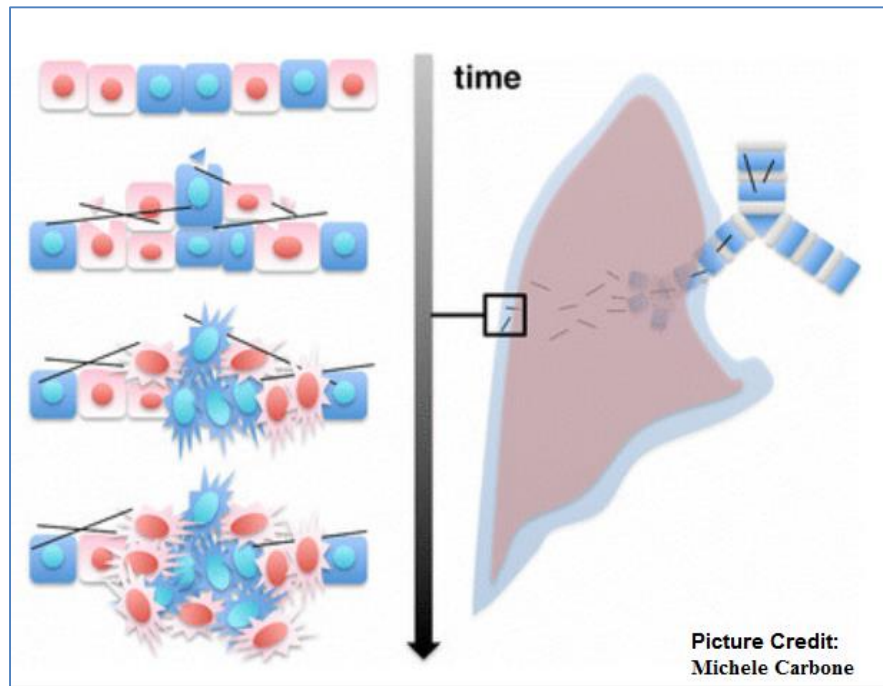
Mesothelioma is a unique cancer that initiates from the mesothelial cells found in the pleural, pericardial, and peritoneal surfaces. Every year around 2500 new cases are diagnosed in the United States. <sup>(207)</sup> Although worldwide there are known erionite deposits locations in U.S.A., Mexico, Iran, Germany, New Zealand, Russia, Japan, Kenya, Turkey and Italy, only in Turkey and Mexico have there been cases of mesothelioma clearly associated with naturally-occurring erionite. Currently in the U.S.A., studies <sup>(201)</sup> are underway among residents living near erionite deposits combined with an ongoing mesothelioma cancer clusters search.

According to the World Health Organization (WHO) and the International Agency for Research and Cancer (IARC), erionite is a Class I carcinogen along with six well-known asbestos minerals (chrysotile, amosite, crocidolite, anthophyllite, tremolite, and actinolite) <sup>(206, 207)</sup>. Although currently there are no specific regulations or guidelines relevant to reduction of exposure to erionite worldwide, this mineral has been proved to be the most toxic mineral for humans based on several studies of carcinogenicity in humans and animals. <sup>(205,206, and 210)</sup> There are 52 sites that have been found in 12 states in U.S.A. <sup>(211)</sup>

### 2.2.1. Development of Diseases and Risk

Because erionite shares many similar characteristics with amphibole asbestos, it is also able to stimulate autoimmune responses similar to amphibole asbestos. Once the erionite fibers reach the alveoli through the airways they migrate through the lung and arrive at the mesothelium, the protective lining that covers the lungs. Over time large areas of cells on the mesothelium surface are affected by a carcinogenic alteration also known as the “field effect” (figure 3). Several studies have examined the toxicity of erionite in macrophages, whose role in the immune system is to phagocytize invading fibers.

Macrophages try to internalize fibers, sometimes unsuccessfully due to fibers length, releasing in the same time reactive oxygen species (ROS) as seen in figure 5.

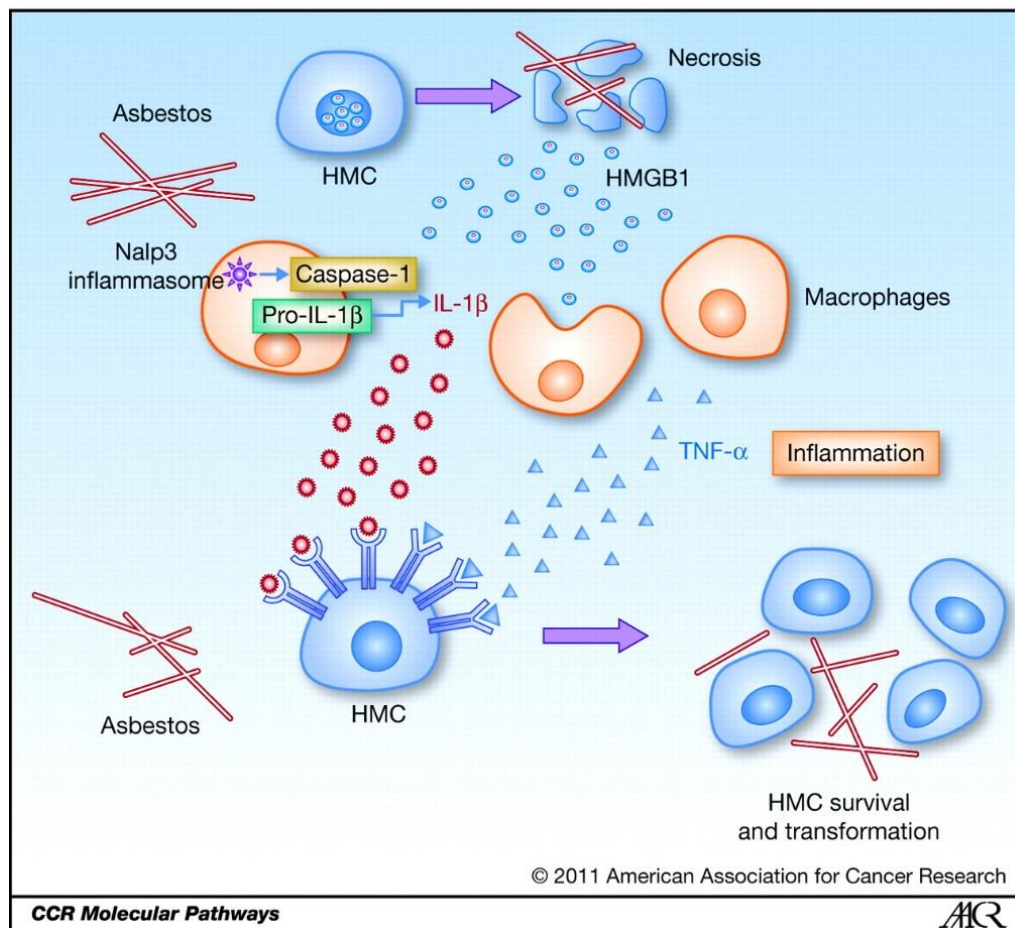


Picture Source: “Targeting Mechanisms of Asbestos and Erionite Carcinogenesis in Mesothelioma” 2012

Figure 3: The carcinogenic “field effect” of erionite fibers

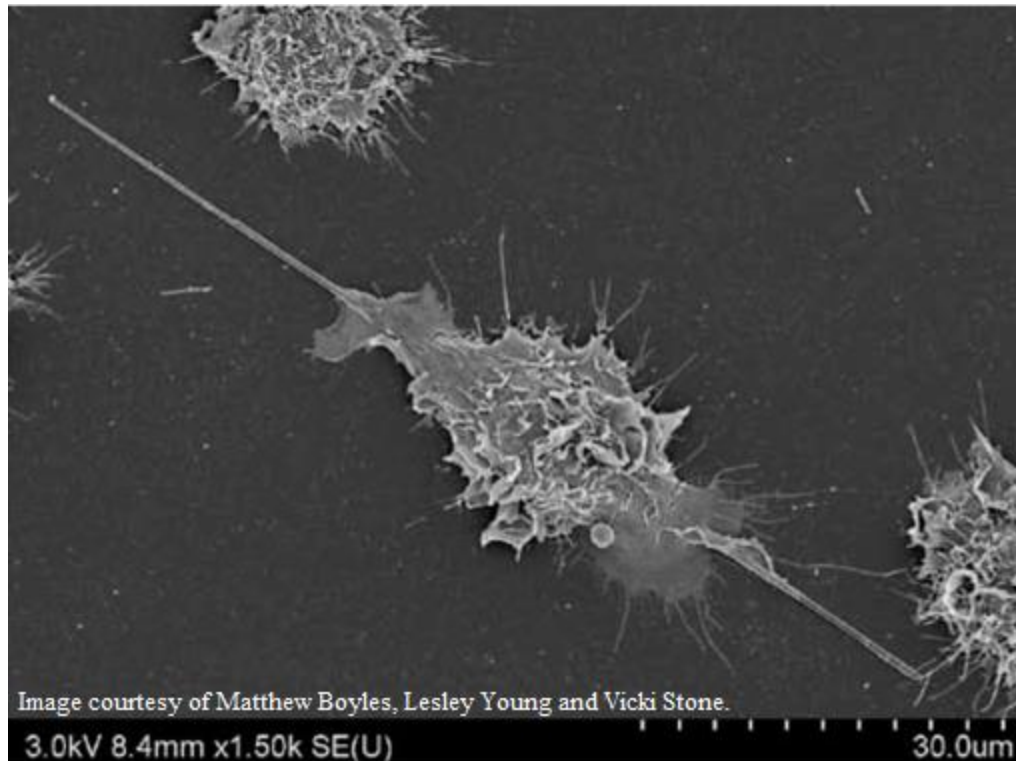
Human mesothelial cells (HMC) are very sensitive to the genotoxic effects of erionite. Necrotic HMC releases High-Mobility Group protein B1 (HMGB1) into the extracellular space that will activate Nalp3 inflammasome and subsequent IL-1 $\beta$  secretion.

During apoptosis HMC also elicit macrophage accumulation which trigger the inflammatory response and TNF- $\alpha$  secretion that will help increases the survival of erionite-damaged HMCs<sup>(212)</sup>, as seen in figure 4.



Picture Source: "Targeting Mechanisms of Asbestos and Erionite Carcinogenesis in Mesothelioma" 2012

Figure 4: Molecular pathways of erionite carcinogenesis



Picture Source: "The Significance and Insignificance of Carbon Nanotube-Induced Inflammation" 2014

Figure 5: Macrophages unsuccessful trying to internalize a fiber while releasing ROS

The mechanism of carcinogenicity in mesothelioma starts with erionite engraving in the mesothelial surface leading to pleural inflammation directly through mechanical interference of the erionite fibers with chromosome segregation during mitosis , <sup>(213)</sup> or indirectly through oxidative stress caused by free radicals and ROS that, when generated in close proximity to DNA, can cause point mutations, crosslinking and DNA strand breaks.<sup>(214)</sup> The oxidative stress of ROS is usually alleviated by molecules with antioxidant effect such as glutathione S-transferase.

However, some gene polymorphisms not expressing glutathione S-transferase (metabolic isozymes catalyze with the purpose of detoxification) showed increased risks of mesothelioma in a subset of studies. <sup>(215)</sup> Glutathione S-transferase is used in detoxification of electrophilic compounds, such as carcinogens, drugs, environmental toxins and ROS, and its downregulation by genes polymorphism creates customized cancer risks in humans. <sup>(216)</sup>

People who carry a mutation of the gene called BAP1 (germline mutations in the gene encoding BRCA1 associated protein-1) are prone to developing mesothelioma and melanoma of the eye. BAP1 is functionally implicated in numerous biologic processes like chromatin, dynamic, DNA damage response and regulation of the cell cycle and growth. Following DNA damage, BAP1 gathers DNA repair proteins and RNA that is meant to fix the double strand breaks in DNA. Understanding genetic mutations like PAB 1 gene may lead to finding a cure for mesothelioma in the near future but screening for susceptible individuals today can also help reduce the MM rates.

### **2.2.2. Commercial Use of Erionite**

Fibrous materials are traditionally used in diverse industrial applications for thermal and electrical insulation or for flexibility and strength. Although erionite itself is rarely used in industry; there is an occupational exposure potential risk during the production and mining of other zeolites that are commercially used because they selectively adsorb molecules from water or air. Erionite itself is not currently mined or marketed for commercial purposes but the primary potential occupational exposure to erionite typically occurs during the production and mining of other zeolites that may be contaminated with erionite.

Zeolites are usually used to extract trace amounts of heavy metals in water purifying systems. Zeolites can extract radioactive species from nuclear plant waste because of their ion-exchange capacities and they also have high resistance to nuclear degradation. Zeolites retain the fixed nitrogen released from animal waste and they are used in fertilizers which increases the fertilizer value.

Around 60,000 tons of commercial zeolites were mined by 10 companies and sold in 2010 in the U. S. A. for animal feed, pet litter, odor control, water purification, gas absorbent, wastewater cleanup, fertilizer, desiccant, oil absorbent, aquaculture, fungicide or pesticide carrier and catalyst. <sup>(218)</sup>

Zeolites are also used in patented chemical methods. Mobil Oil Corporation (New York, NY) patented the “Hydrocarbon conversion over activated erionite” method on Jul 17, 1974 (Patent number US 3925191 A). <sup>(219)</sup> The selectoforming process removes the low octane alkanes by selective hydrocracking on erionite.

### **2.2.3. Erionite in the Environment**

It is difficult to correlate soil mineral fiber concentration to the actual exposure. Steps are still taken in finding a procedure that will be the equivalent of the air’s “aggressive sampling” for soils. Soils completely covered by vegetation should be less hazardous than bare, dusty soils.

## **2.3. Literature Review**

Environmental exposure to fibrous forms of naturally occurring erionite resulted in extremely high incidences of mesothelioma in three small villages from the Cappadocia region of Turkey.

Until 1980s, erionite had been largely overlooked as a potential health hazard in the U.S., but in the last decade concerns about the potential for environmental exposures to erionite were raised by the scientific community and then was greater interest in identifying locations and geologic environments in which erionite can form.

Using a detailed literature survey, this dissertation updates and expands the identification of erionite occurrences in South Dakota by recognizing specific geologic settings and formations, which are hosts to erionite. This description can be used in developing community management plans intended to reduce the public exposure.

### 2.3.1. Erionite in Turkey

In the central region of Turkey, in Karain village, MM is known as “cancer of the stones”. Stones containing erionite fibers were used to build most human inhabited structures of Karain village, as seen in figure 6. The soft yellow rocks used in construction are materials remaining from depositions by volcanic eruptions in the Cappadocia plateau.

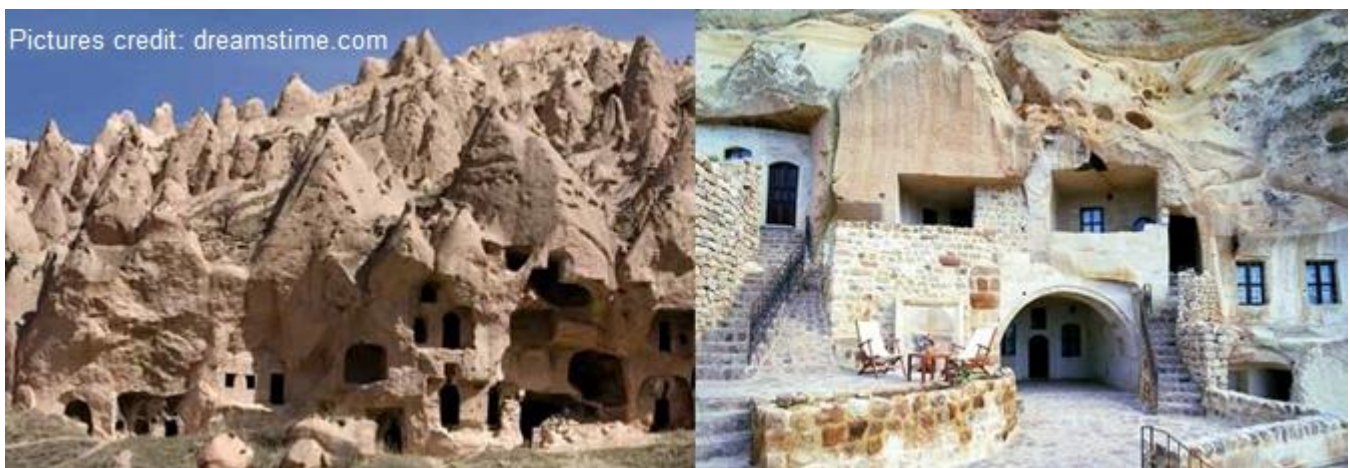


Figure 6: Homes in Karain, Turkey

Although tuberculosis was suspected in the 1970s <sup>(220)</sup> as the cause of the disease cluster, a 40-year-long comprehensive research study conducted by Dr. Izzettin Baris investigating airborne dust, samples of food and drink, chest radiography survey, lymphocyte counts and pleural tissue biopsy successfully identified MM as the cause of death among villagers who died of respiratory malfunctioning. It was also shown that young people moving from Karain village may develop the respiratory disease later in life while young people moving to Karain will not develop the disease. <sup>(221)</sup>

A recent article contests the 50.5% of all deaths <sup>(222)</sup> well-known landmark of MM in Karain. Iman Roushdy-Hammady argues that the stigma brought to the local population is changing significantly the number of deaths reported as MM. The article successfully challenges the toxicity of erionite through important societal elements and medical ethnography that has not been addressed in previous papers. <sup>(223)</sup> Another article, from 1979, argues that no correlation exists between the mesothelioma cases and the minor to trace quantities of erionite found in 212 sample taken in 9 village's in the region. <sup>(224)</sup>

In 1985 an erionite exposure study in rats using zeolite fibers from the Cappadocian region of Turkey and Oregon, U.S. revealed a high potency of erionite to cause MM in almost 100% of the exposed rats. <sup>(225)</sup>

### **2.3.2. Erionite in Iran**

Ancient Kandovan village has a geological continuity with Cappadocia and has area that contains sedimentary and volcanic rocks with zeolite deposits and ophiolitic complexes comprising with both serpentine and amphiboles. <sup>(226)</sup> Almost all homes in Kandovan are cone-shaped (as seen in figure 7) and naturally formed from compressed volcanic ash and well known



for being cool in the summer and warm in the winter. Although there are reasons to believe that mesothelioma due to zeolite fibrous fiber will be found in Kandovan, an epidemiologic survey could not be conducted because cancer prevalence records are absent or unavailable and tuberculosis is still a major problem in the region. <sup>(227)</sup> Also ophiolitic complexes host asbestos, so any disease could be to asbestos.



Figure 7: Homes in Kandovan, Iran

### 2.3.3. Erionite in Mexico

In 2008 a new mesothelioma disease cluster was identified in the state of Zacatecas, Mexico. Two mesothelioma cases were found at first, father and son, coming from the remote village of Tierra Blanca De Abajo located in a zeolite rich geological area. Further medical investigations discovered nine other cases. The two cases were in the high 'occupational' category with more than one million fibers per dry weight gram lung although the work is primarily agricultural in the village with no opportunity of exposure to industrial asbestos. The erionite in the study was initially identified by Energy Dispersive X-ray Analysis (EDAX), later confirmed by Selected Area Electron Diffraction (SAED). <sup>(228)</sup> Ongoing epidemiological and environmental studies may lead

to the future classification of Tierra Blanca De Abajo as the second example of respiratory cancer caused by erionite.

#### **2.3.4. Erionite in U.S.**

Erionite fibers found in continental Cenozoic silicic tuff of the western U.S.A. may become a health hazard if they become airborne while being disturbed. An activity-based study conducted in Killdeer, Dunn County, North Dakota sampling the breathing zone air confirmed that when gravels containing erionite are disturbed, erionite fibers have the potential to become airborne. <sup>(229)</sup> Erionite concentrations vary within geologic formation units, according to the Bureau of Land Management, ranging from traces to 20%. <sup>(204)</sup> The Arikaree and Brule Formations contain in general between 5 to 15%, while Chadron Formation contains less than 1%.

A large mountaintop removal of Arikaree Formation took place in 1965 when stone laced with erionite was ground into gravel and used to pave approximately 300 miles of road in Dunn County, according to the North Dakota Department of Health, but no mesothelioma cases were reported in the region although the latency period is now 50 years.

#### **2.3.5. Air Concentrations of Erionite in North Dakota**

The 2011 study “Erionite exposure in North Dakota and Turkish villages with mesothelioma” found elevated airborne erionite concentrations within school buses and inside cars (0.235 structures/cc) in North Dakota. <sup>(230)</sup>

Outdoor activity-based samples (0.031 structures/cc) and indoor activity-based samples (0.018 structures/cc) showed important air concentrations of erionite while indoor stationary

samples (0.002 structures/cc) representative of sleeping or watching TV showed low air concentrations of erionite.

### **2.3.6. Genetic Factors**

Individual genetic makeup may influence susceptibility to mesothelioma. Not all asbestos-exposed people develop mesothelioma, clustering was observed in some families with genetic predisposing factors.

A 2011 study of two U.S. families with high incidence of mesothelioma shows that when the family members with proclivity to MM are exposed to mineral fibers there is a markedly increased risk of developing the disease. <sup>(231)</sup> Independently, a six-generation extended study of 526 individuals from the villages of Karain and Tuzköy, Turkey confirmed that mesothelioma susceptibility can be genetically transmitted. <sup>(232)</sup>

### **2.3.7. Case Study**

In 1981 a case report was published describing a local road construction worker from Utah with extensive parenchymal and pleural fibrosis whose lung biopsy revealed fibrous particles determined by Energy Dispersive Spectroscopy (EDS) to be consistent with erionite. <sup>(233)</sup> Since then, no new mesothelioma cases due to erionite exposure were reported in the U.S. Various reasons, such as misdiagnosis, poor surveillance, a lack of general awareness that MM may be a link to NOA exposure, and the analytical problem of identifying fibrous erionite in lung tissue may have constrain the discovery of new MM cases discovery in U.S.

### **2.3.8. Exposure Regulations**

No specific state or federal regulations or guidelines relevant to reduction of exposure to erionite itself were found but OSHA Act of 1970 section 5 (a) (1) states, "the employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees" which means the employers are actually responsible for protecting their employees from toxic substances such as erionite.

## **2.4. Exposure Assessment in Slim Buttes Area of Custer National Forest**

Erionite bearing rocks in this area have been reportedly mined, crushed, and used to gravel hundreds of miles of roads in Harding County since the 1950s..

### **2.4.1. Fugitive Dust Sources in CNF**

Atmospheric dust risen from mechanical disturbance of granular material and soil is named "fugitive" and two of the most common sources include unpaved roads and agricultural tilling operations. Fugitive dust in CNF takes place through pulverization and abrasion of soil and entrainment of dust particles by air currents. <sup>(234)</sup>

Vehicular traffic on roadway is a one-dimensional line source of air pollutant emissions close to the ground, more like an idealized geometric emitter. Vehicles elevate dust in the air by two mechanisms: first the dust adheres to the tire as the tire rolls over the unpaved road and then is detached by centrifugal forces and is pulled along in the air turbulence. Secondly, the eddies created by the passage of the vehicles sweep the fine layer of dust from the road surface upward

by the vortices trailing behind the moving vehicle. Sometimes continuous line sources are modeled as a volume of constant concentration called the mechanical mixing cell with the width of the cell being the distance shoulder-to-shoulder. <sup>(235)</sup>

A line source is less readily measurable or controlled and the daily fluctuations in traffic are mostly unknown. The dispersion of pollutant from a line source may accumulate and concentrate in the plume due to the air drafts at the ground level or/and due to terrain features. The downwind dispersion patterns of pollutants are significantly determined by the geometry of the sources. The line source of a well-traveled road looks like a long ribbon of point sources with an inefficient crosswind dilution of the emitted pollutant. The only dilution that takes place is vertical, while for point sources the crosswind or lateral transport does dilute the pollutant. Emissions on a gravel road can be from re-suspension of surface material due to vehicle-induced road turbulence but also due to wind erosion of road surface. <sup>(236)</sup>

During weekends there is considerable traffic at Slim Buttes of Custer National Forest and being downwind of an erionite-containing gravel road in SD may result in exposure to airborne erionite fibers.

According to ATSDR "ambient" air concentrations of mineral fibers are between 0.00001 to 0.0001 fibers/cc. For the communities throughout the area in South Dakota where NOE occurs the risk of developing mesothelioma increases as the cumulative dose increases, so even a relatively minor source of airborne erionite fibers from NOE should be abated in order to maintain the cumulative dose at a minimum. The median survival for pleural mesothelioma due to erionite exposure is significantly shorter than non-erionite asbestos exposure ( $13.5 \pm 0.7$  months for erionite versus  $21.5 \pm 0.8$  months for non-erionite asbestos), proving the high carcinogenic potency of erionite. <sup>(206)</sup>

#### **2.4.2. Aeolian Transport of Erionite**

Climate change has produced widespread drought, higher temperatures, earlier snow-melt and expanded insect and disease infestation. Commonly high winds in the dry Sioux Ranger District area and loss of vegetative cover due to climate change or wild fires might be highly conducive to off-site mineral soil transport. “Trace” amounts may sometimes result in rather high airborne fiber concentrations and exposure hazard.

A study published in 2013 researching potential human exposure to actinolite, a NOA, in Southern Nevada suggested wind erosion could cause dust emissions of this fibrous amphibole.

(237)

#### **2.4.3. Daily Exposure Assessment**

According to the American Time Use Survey (ATUS) of Bureau of Labor Statistics the time weighted activities in a household with children are 1.8 hours/day transport, 12.4 hours/day home and work activity, 1.8 hours/day outside activity and 8 hours/day sleep. Young children sleep longer than adults and so they are less exposed to the outside environment. (238)

#### **2.4.4. Roads of Harding County**

Since the early 1980, gravel from erionite bearing rocks in the Tri-State area had been crushed and used to surface local roads along with parking lots and recreation sites, as seen in figure 8. Traveling on an erionite-containing gravel road is likely to stir up into the air the harmful

mineral <sup>(239)</sup>, as demonstrated in figure 9. Volcanic rocks are also frequently used as roadbed or applied as “sand” during icy conditions. Some of the unpaved road in Harding County may contain erionite-containing gravel extracted from pits found in CNF.



Figure 8: Graveled road in the sampled area in Sioux Ranger District

A 2011 study revealed that North Dakota airborne erionite concentrations along roadsides and inside school buses amount to or exceed the concentration in Boyali, Turkey where 6.25% of all deaths are caused by MM. <sup>(240)</sup>



Figure 9: School bus and 18 wheeler truck on gravel road containing erionite in SD

A common phenomenon in the area is commuting, giving rise to a daily driving flow from more dense populated to less dense areas.

## 2.5. Methods

A schematic of the risk calculation methods utilized in this chapter are presented in figure 10. These methods are based on exposure/disease studies of asbestos workers who were healthy males in the prime of life when they started their exposure to commercialized mineral fibers. EPA's Integrated Risk Information System does not include communities with children that could be more susceptible to asbestos-like related health complications. These risk methods were developed based on workers studies and no inference is made that they are directly applicable to NOA exposures. Thus, these risk calculations represent approximations at best of the actual risk due to NOA exposure. ArcGIS 10.2 software from Environmental Systems Research Institute (ESRI) and GIS data from the South Dakota State Government website was used to



identify unpaved roads in Harding County. These roads with gravel surfaces require further sampling to determine if they contain erionite.

Erionite concentration results from the sampled roads have been incorporated into EPA's fugitive dust equation followed by the Gaussian dispersion model which lead to different exposure scenarios. These exposure scenarios for normal and worst case situations yield the cancer risks based on EPA's Risk Estimates if erionite is considered to have a similar cancer potential as asbestos.

Also, secondary data from the North Dakota study <sup>(240)</sup> have been personalized based on the time weighed average (TWA) to find the airborne erionite fiber concentration in air and exposure times which were included in the Excess Lifetime Cancer Risk equation. The resulting exposure scenarios produce another set of cancer risks based on EPA's Risk Estimates.

As a caveat, these risk assessments require further modeling to individually assess risk as it can vary drastically by individuals who are exposed based on genetic predisposition, smoking habits, etc.

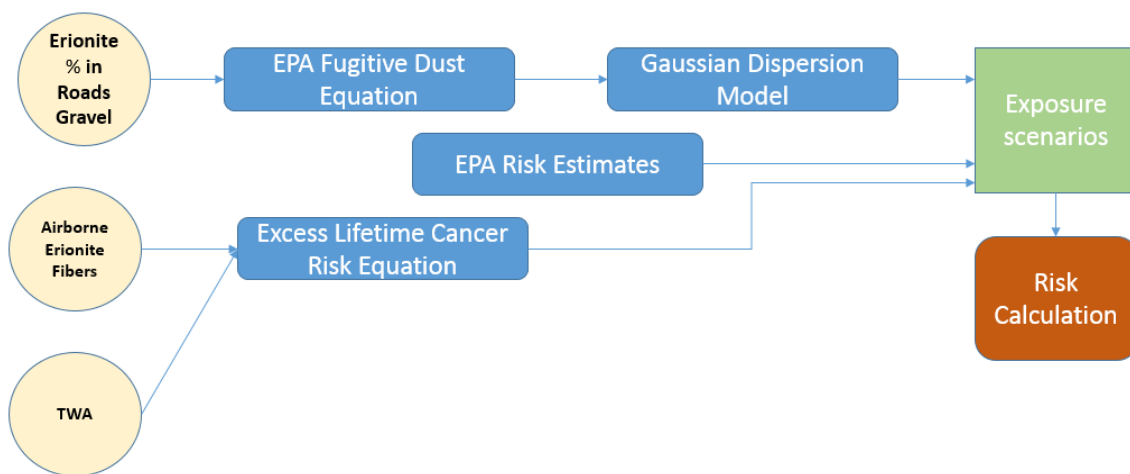


Figure 10: Risk calculation Schematic

### 2.5.1. Risk of Developing Cancer - Site-Related Exposure

EPA developed a general equation for risk estimation from inhalation of asbestos for Investigations of Asbestos-Contaminated Superfund Sites in 2008 <sup>(241)</sup>. This equation was used to determine if the airborne concentrations of erionite are associated with unacceptable risks to human life according to EPA's acceptable risk levels of 1 in 10,000 to 1 in 1,000,000. As stated in 40 CFR Part 300 "For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upper bound lifetime cancer risk to an individual of between  $10^{-4}$  and  $10^{-6}$  using information on the relationship between dose and response."

EPA's calculation of excess lifetime cancer risks determines whether airborne concentrations of asbestos are associated with unacceptable risks. Cancer risk from asbestos is calculated as a function of exposure concentration, duration of exposure, and time from first exposure.

The general equation for risk estimation from inhalation of asbestos is:

$$\mathbf{ELCR = EPC \cdot TWF \cdot IUR} \text{ (Equation 1)}$$

Where:

**ELCR** = Excess Lifetime Cancer Risk

Excess lifetime cancer risks were estimated in our study for adult exposures, child exposures, toddler exposure and senior exposure scenarios.

**EPC** = Exposure Point Concentration

Exposure Point Concentration is a conservative estimation of the chemical concentration existing from a particular environment or route of exposure. In this study, EPC was customized for adult exposures, child exposures, toddler exposure and senior exposure based on Bureau of Labor Statistics for average sleep, transport, inside and outside activities hours.

**TWF** = Time Weighting Factor

Time Weighting Factor is fraction of eligible time units in the period from the number of available units. Exposure time was considered 24 hours a day and 360 days per years for area residents.

and

**IUR** = Inhalation Unit Risk

The concentration-response for IUR varies as a function from the time of first exposure and so consequently, estimation of cancer risk depends not only on exposure frequency and duration but also on the age of first exposure, as shown in table 2. The IUR values are based on airborne fibers measured using (Phase Contrast Microscopy) PCM which makes no distinction between different mineral forms of asbestos or organic fibers.

Life time risk IUR is 0.23 according to the framework of OSWER Directive 9200.0-68 dated September 2008 <sup>(227)</sup>.

Table 2: Lifetime Inhalation Unit Risk (IUR)

Age at first exposure (years)	Duration of exposure (years)								
	1	5	6	10	20	24	25	30	40
0	0.010	0.046	0.055	0.084	0.14	0.147	0.15	0.17	0.19
5	0.0085	0.039	0.046	0.070	0.11	0.13	0.13	0.14	0.16
10	0.0068	0.031	0.038	0.058	0.094	0.098	0.10	0.11	0.13
20	0.0046	0.021	0.027	0.038	0.063	0.065	0.066	0.075	0.83
30	0.0031	0.014	0.018	0.025	0.042	0.043	0.045	0.048	0.052

Table Source: EPA's Integrated Risk Information System ([www2.epa.gov/iris](http://www2.epa.gov/iris))

### 2.5.2. Calculation of Unpaved Roads Fugitive Dust Emissions

In the AP42, Section 13.2.2 Unpaved Roads, EPA uses the following equation for light duty vehicles and trucks traveling on publicly accessible roads likely to be present in the study area:

$$E = k \cdot (5.9) \cdot (s/12) \cdot (S/30) \cdot (W/3)^{0.7} \cdot (w/4)^{0.5} \cdot (365-p/365) \quad \text{(Equation 2)}$$

Where:

**E** = emission factor in pounds (lb) per vehicle miles traveled (VMT)

To be calculated:

**k** = particle size multiplier (dimensionless)

Particle size multiplier 0.36 for PM<sub>10</sub>

**s** = silt content of road surface material (%)

Commonly 12% mean silt content for dirt rural roads

**S** = mean vehicle speed (miles per hour [mph])

The mean speed assumed to be 25 mph

**W** = mean vehicle weight (ton)

The mean weight for vehicles is assumed to be 2 tons.

**w** = mean number of wheels

The mean number of wheels is assumed to be 4.

**p** = number of days with at least 0.01 inches of precipitation per year

The average daily traffic of 1,820 light vehicles (2 tones) and 218 trucks (4 tones) was taken from the neighboring Medora County, North Dakota since no data was available for Harding County, South Dakota from the National Bridge Inventory (NBI) Statistics website.

Eleven surface road samples were collected by United States Forest Service (USFS) from Camp Ground Road including 3 secondary roads and 2 from North End Road as detailed in Figure 11.



Figure 11: Road Sampling Locations

### 2.5.3. Gaussian Dispersion Model

The classic atmospheric Gaussian plume dispersion model has become the standard approach for studying the transport of airborne contaminants. <sup>(242)</sup>

$$C(x, y, z, H) = \frac{Q}{2\pi u_s \sigma_y \sigma_z}$$

(Equation 3)

Where:

**C**<sub>(x,y,0,H)</sub> = downwind concentration at ground level (z=0), g/m<sup>3</sup>,

**Q** = emission rate of pollutants, g/s,

**σ<sub>y</sub>** and **σ<sub>z</sub>** = plume standard deviation,

**σ<sub>y</sub>** =  $ax^{0.894}$  and **σ<sub>z</sub>** =  $cx^d + f$  (where x is the distance downwind in km and a, c, d and f are constants)

**u** = wind speed, m/s,

**H** = distance, m

Harding County Airport does not have any wind data available. Erionite air concentrations will be calculated at different wind speeds.

## 2.6. Results

The magnitude of exposure to airborne erionite fibers is associated with activities which cause fibers to be released from the soil and the duration of the activities and their frequency over time.

### 2.6.1. ELCR Using North Dakota Data

Based on the exposure assessment and air concentrations of erionite in North Dakota detailed in the sub-sections above, the following exposure calculations are made:

$$\text{N.D. EPC}_{\text{adults}} = (0.031 \cdot 1.8 + 0.018 \cdot 12.4 + 0.002 \cdot 8) / 24 = 0.0123 \text{ f/cc}$$

$$\text{N.D. EPC}_{\text{seniors}} = (0.031 \cdot 1.8 + 0.018 \cdot 11.4 + 0.002 \cdot 9) / 24 = 0.0116 \text{ f/cc}$$

$$\text{N.D. EPC}_{\text{children}} = (0.031 \cdot 1.8 + 0.018 \cdot 10.4 + 0.002 \cdot 10) / 24 = 0.0109 \text{ f/cc}$$

$$\text{N.D. EPC}_{\text{toddlers}} = (0.031 \cdot 1.8 + 0.018 \cdot 6.4 + 0.002 \cdot 14) / 24 = 0.0083 \text{ f/cc}$$

IUR = 0.23 according to OSWER Directive 9200.0-68

$$\text{TWF} = (\text{Exposure time in hours} / 24) \cdot (\text{Exposure frequency days} / 365) = 24/24 \cdot 360/365 = 0.986$$

Using equation 1, lifetime risks are computed for seniors, adults, children, and toddlers:

$$\text{N.D. ELCR}_{\text{adults}} = 0.0123 \cdot 0.986 \cdot 0.190 = 0.0089 \text{ or } 23:10,000$$

$$\text{N.D. ELCR}_{\text{seniors}} = 0.0116 \cdot 0.986 \cdot 0.230 = 0.0026 \text{ or } 26:10,000$$

$$\text{N.D. ELCR}_{\text{children}} = 0.0109 \cdot 0.986 \cdot 0.140 = 0.0079 \text{ or } 15:10,000$$

$$\text{N.D. ELCR}_{\text{toddlers}} = 0.0083 \cdot 0.986 \cdot 0.010 = 0.0060 \text{ or } 2:10,000$$



## 2.6.2. Fugitive Dust Emissions from Roads and Erionite Concentrations in Air

The unpaved road samples analyzed by REI Labs Denver, Colorado (table 3) showed an erionite content between 1 and 20%. Six samples from the road sampling collection were not analyzed because the samples were not received by the laboratory.

Table 3: Erionite concentration in Unpaved Roads

Road Sample	Erionite %
SB-RG-SS-03	2
SB-RG-SS-12-1	1
SB-RS-3126-01	5
SB-RS-3124-01	20
SB-RS-3124-02	12

*Table Data Source: REI Labs Denver, Colorado*

GIS analysis yielded a total of 68 unpaved roads that were found in Harding County with a total length of 115.2 miles (figure 12).

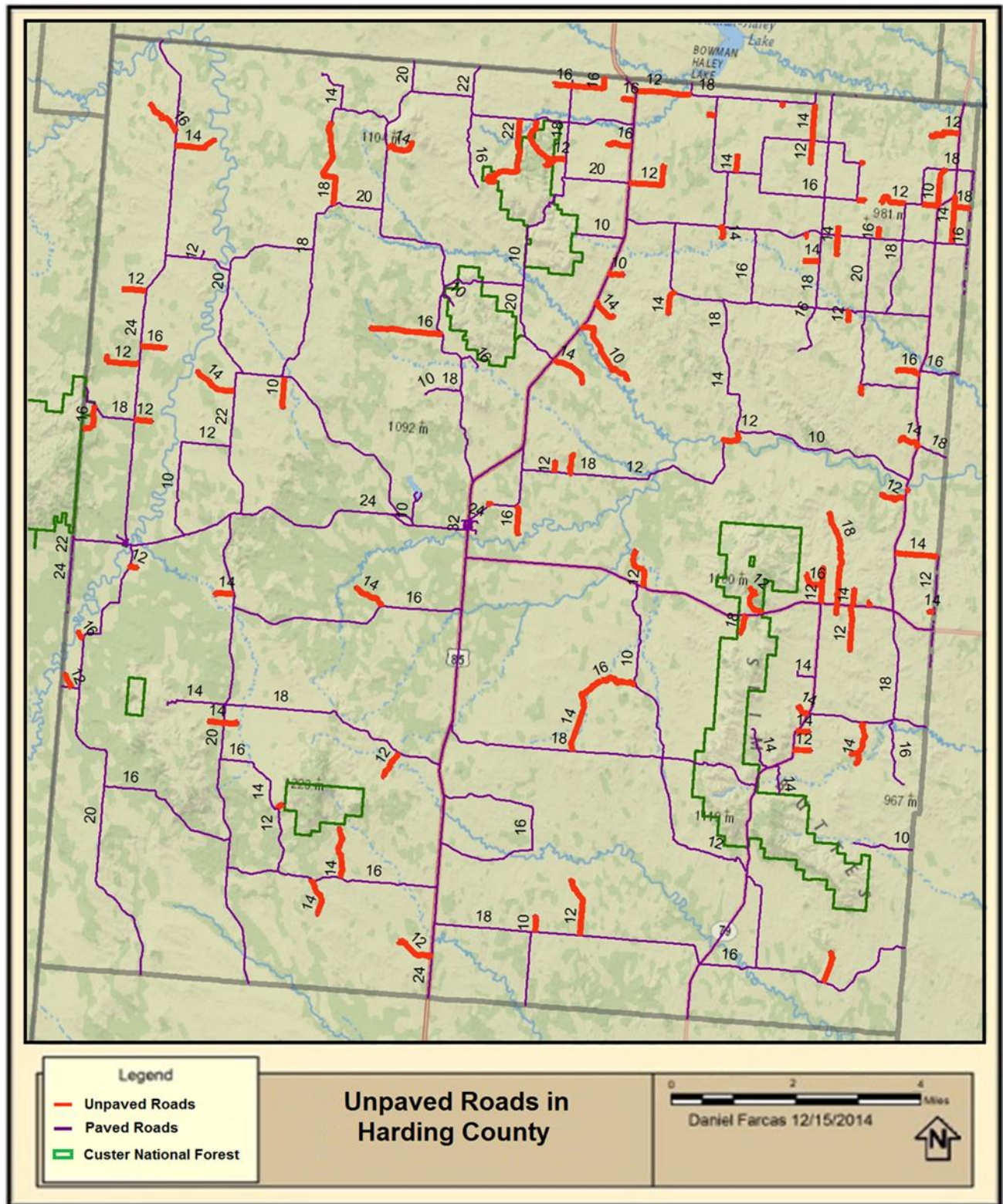


Figure 12: Unpaved Roads in Harding County

Applying equation 2, emission factors used for erionite dispersion calculations for vehicles and trucks that travel over unpaved roads in the study area yielded:

$$E_{\text{vehicles}} = (0.36)(5.9)(12/12)(25/30)[(2/3)^{0.7}][(2/4)^{0.5}](365-19.7/365) = 0.891 \text{ lb (404.15 g)/VMT}$$

At a different speeds:

$$25 \text{ MPH we have: } (25 \times 404.15) / 3600 = 2.81 \text{ grams/second}$$

$$20 \text{ MPH we have: } (20 \times 404.15) / 3600 = 2.25 \text{ grams/second}$$

$$15 \text{ MPH we have: } (15 \times 404.15) / 3600 = 1.68 \text{ grams/second}$$

For trucks:

$$E_{\text{trucks}} = (0.36)(5.9)(12/12)(25/30)[(2/3)^{0.7}][(4/4)^{0.5}](365-19.7/365) = 2.048 \text{ lb (928.95 g)/VMT}$$

At a different speeds:

$$25 \text{ MPH we have: } (25 \times 928.95) / 3600 = 6.45 \text{ grams/second}$$

$$20 \text{ MPH we have: } (20 \times 928.95) / 3600 = 5.16 \text{ grams/second}$$

$$15 \text{ MPH we have: } (15 \times 928.95) / 3600 = 3.87 \text{ grams/second}$$

Vehicle speed did not show substantial variation (CV 25% for both types of vehicles) in the amount of fugitive dust disturbed by light or heavy vehicles and as seen in the figures 13 through 20, the speed curves adhere closely to each other.

### 2.6.3. Worst Case Scenario

Based on the Gaussian-plume Dispersion Model for light and heavy vehicles which can estimate the concentration of erionite as a function of distance we obtain the tables detailed in Annex 8, for the worst vs. normal case scenario (with F atmosphere stability class and the highest erionite gravel concentration 20% and 8% respectively). F class is the most stable or least turbulent that occurs during night times with 50% or less cloud cover and winds below 3 m/s (approx. 1km/hour)

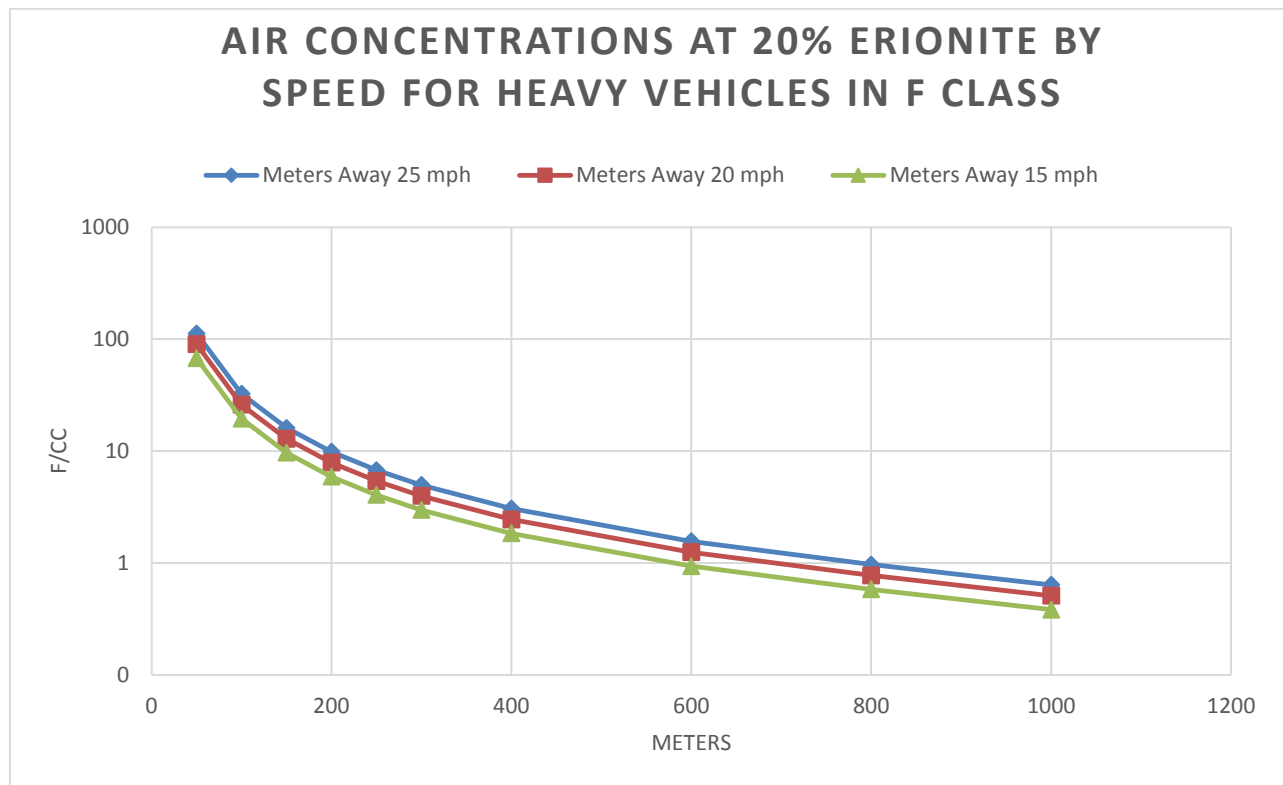


Figure 13: Worst Case scenario for Heavy Vehicles – Meters Downwind

Figure 13 shows that at 50 meters behind heavy vehicles on a gravel road containing 20% erionite and in F class atmospheric stability the erionite fiber concentrations will reach 100 fibers/cc. This fiber concentration in the air requires a high level of respiratory protection such as full face powered air purifying respirator (PAPR) with HEPA filters or Full face supplied air respirator (SAR) in continuous flow mode or pressure-demand.

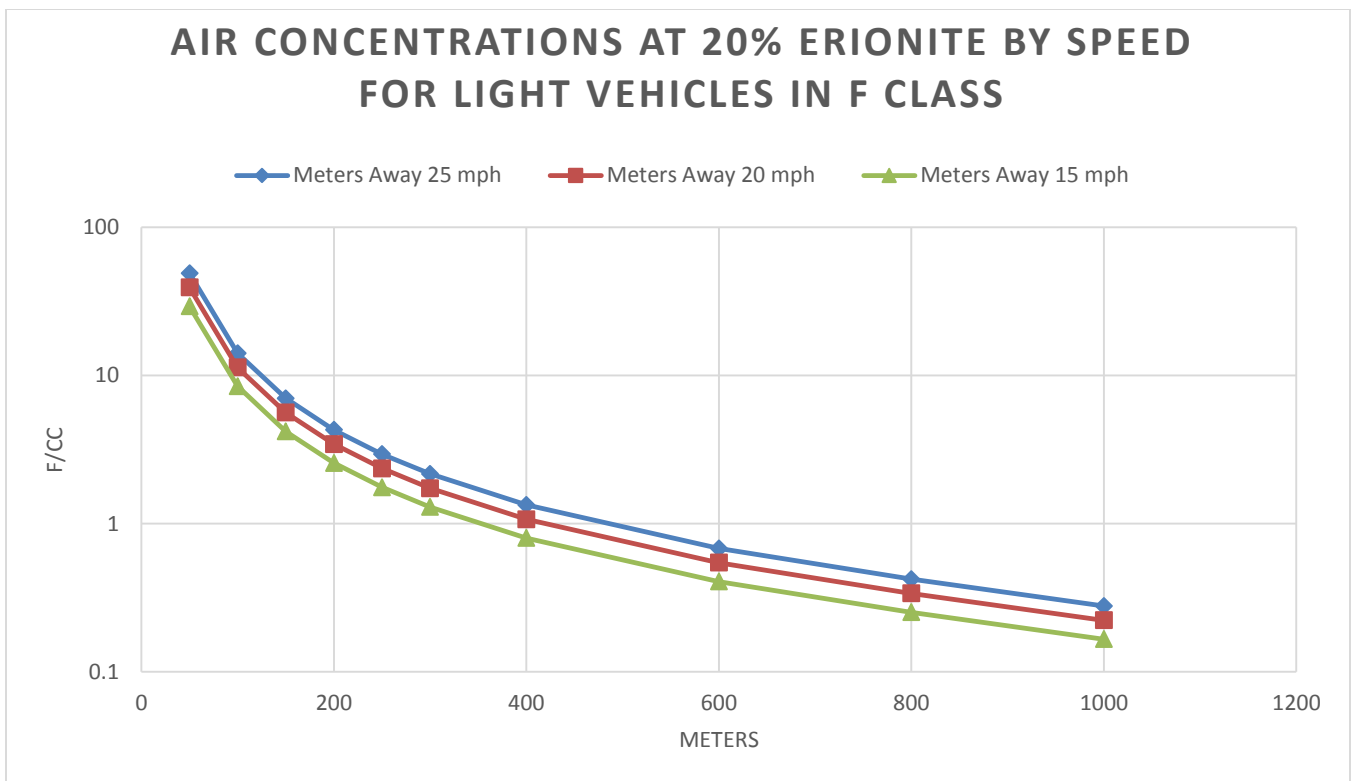


Figure 14: Worst Case scenario for Light Vehicles – Meters Downwind

For light vehicles although the levels of erionite are lower they don't reach the PEL level even 1 kilometer behind the car raising fugitive dust plume, as shown in figure 14.

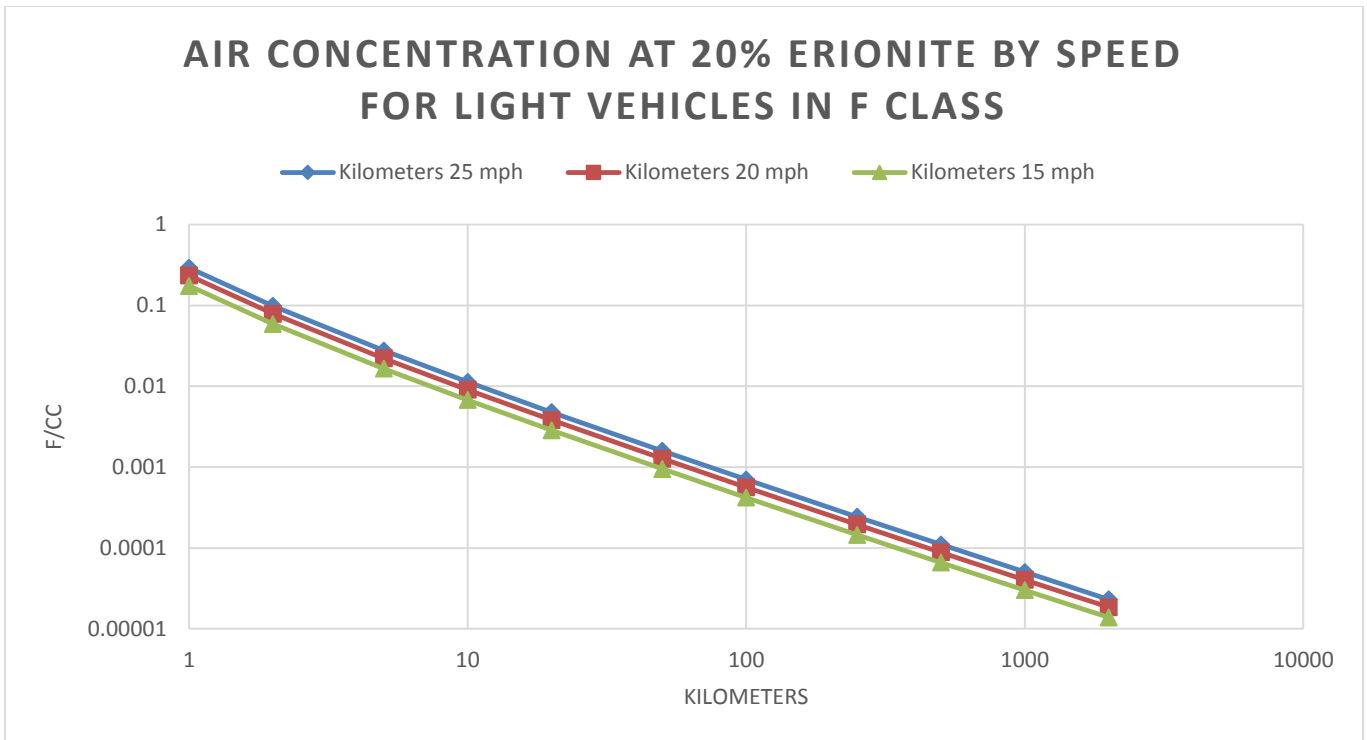


Figure 15: Worst Case scenario for Light Vehicles – Kilometers Downwind

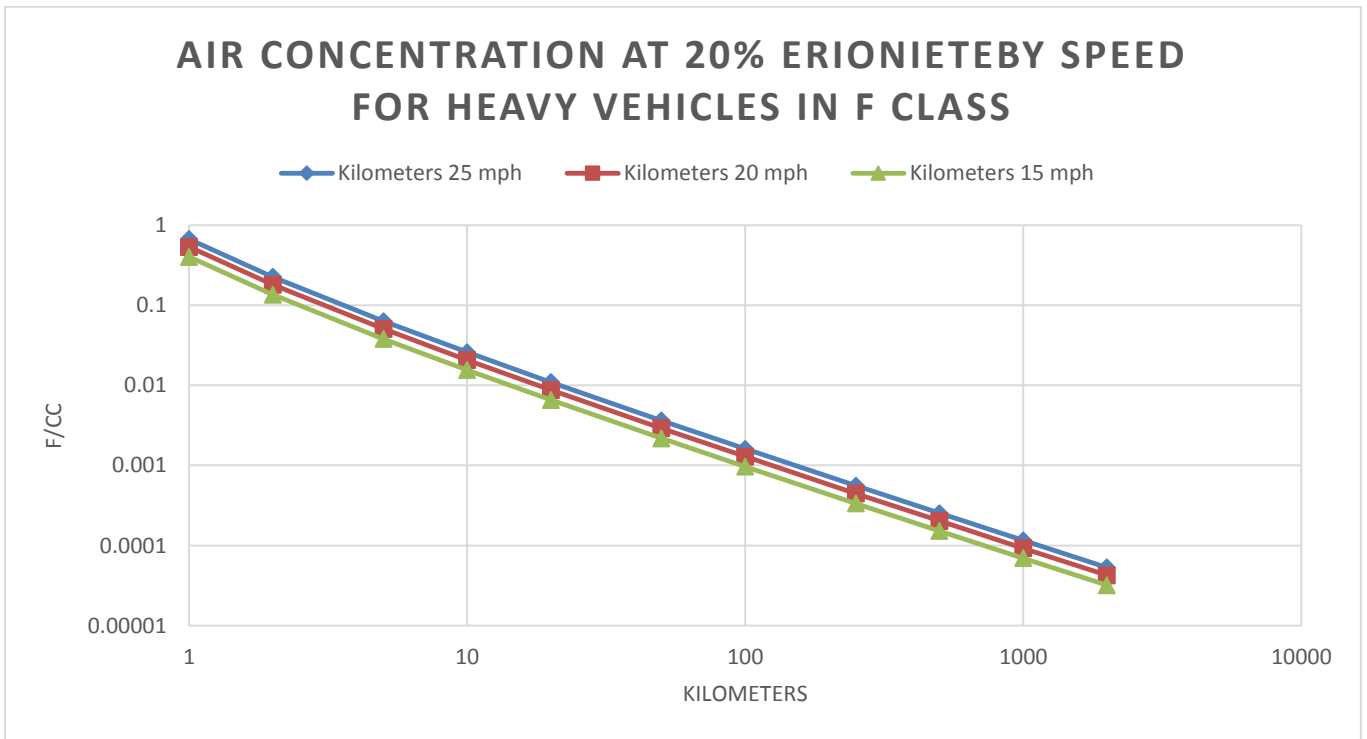


Figure 16: Worst Case scenario for Heavy Vehicles – Kilometers Downwind

As seen in figures 15 and 16, although it requires about 2 km downwind for the erionite concentration to reach the PEL level of 0.1 f/cc, the erionite concentration plume decreases to the ambient level of 0.0001 f/cc only at 500 km downwind for light vehicles and 1000 km downwind for heavy vehicles.

#### 2.6.4. Normal Case Scenario

Although the normal case scenario were the road gravel is assumed to contain 8% erionite in D weather class has lower values, this scenario should not be relied upon as the normal dispersion of erionite in air.

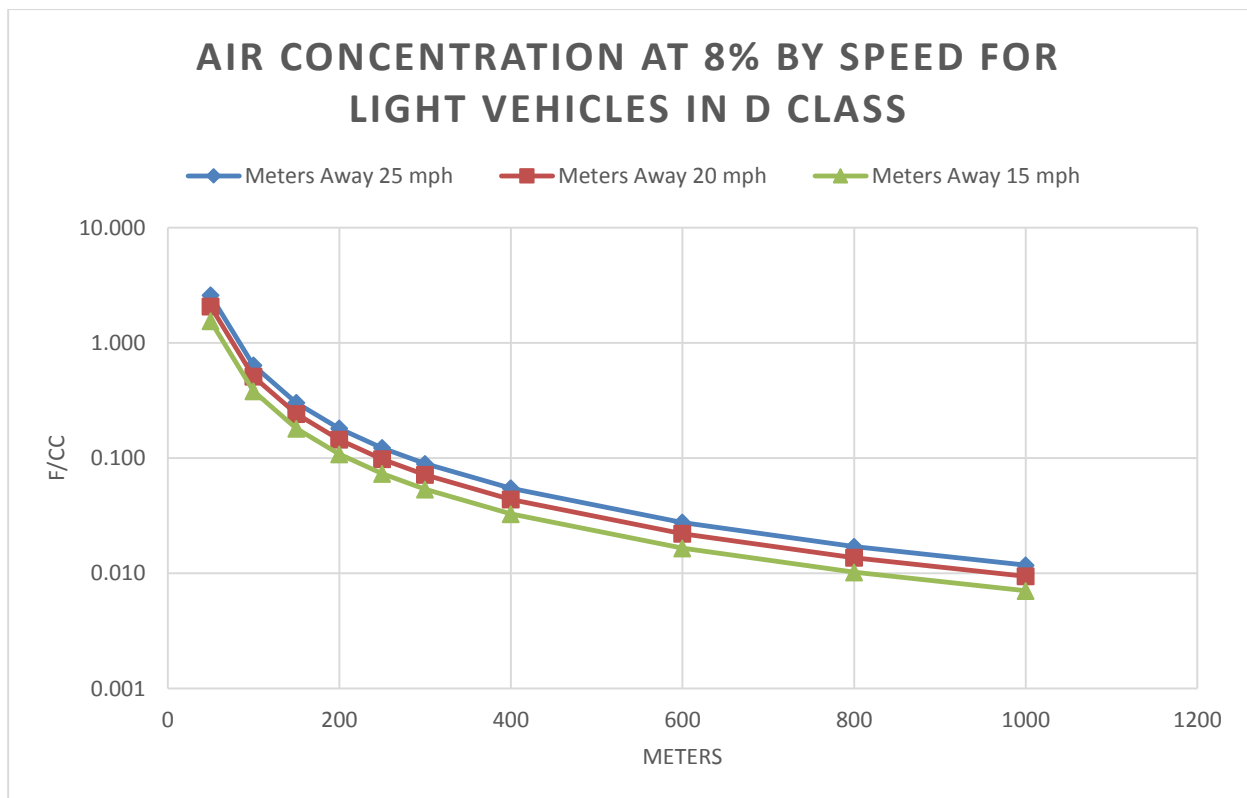


Figure 17: Normal Case scenario for Light Vehicles – Meters Downwind

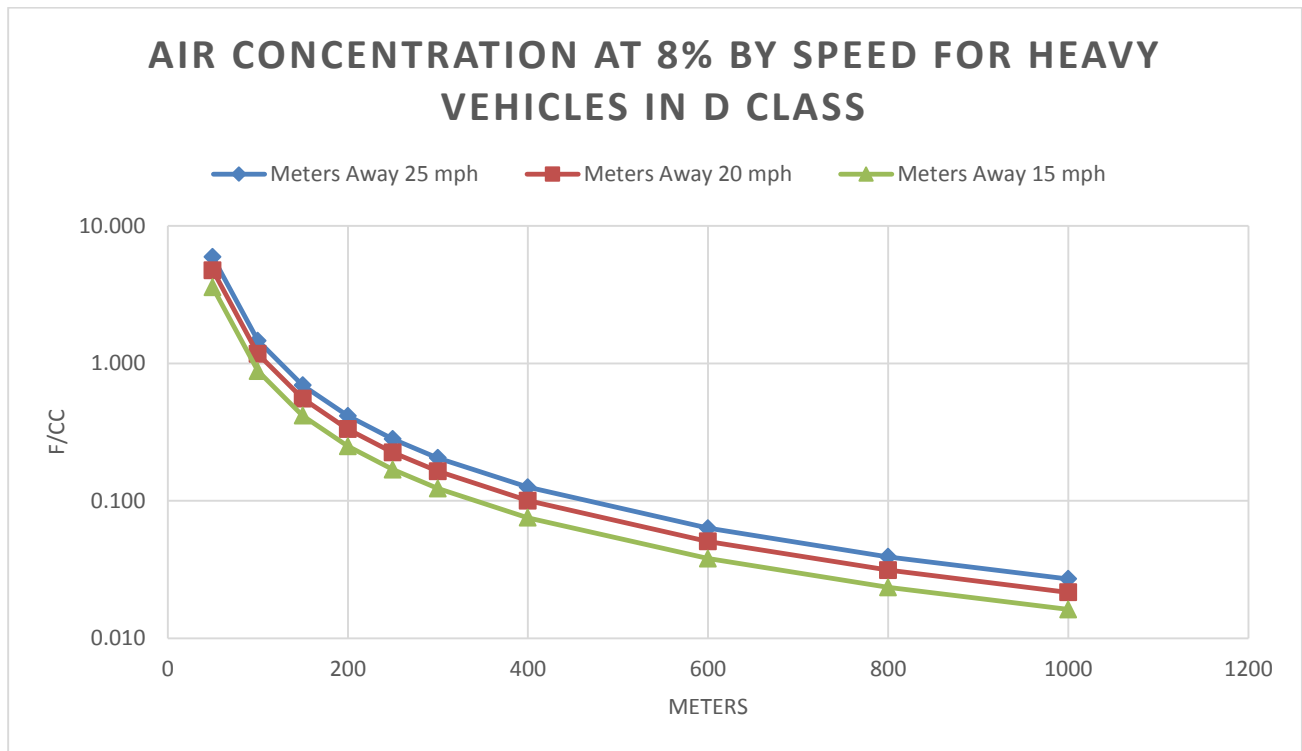


Figure 18: Normal Case scenario for Heavy Vehicles – Meters Downwind

Figures 17 and 18 show that on a gravel road containing 8% erionite and in D class atmospheric stability the erionite fiber concentrations will decrease to the asbestos PEL concentration at 300 meters for light vehicles and 600 meters heavy vehicles.



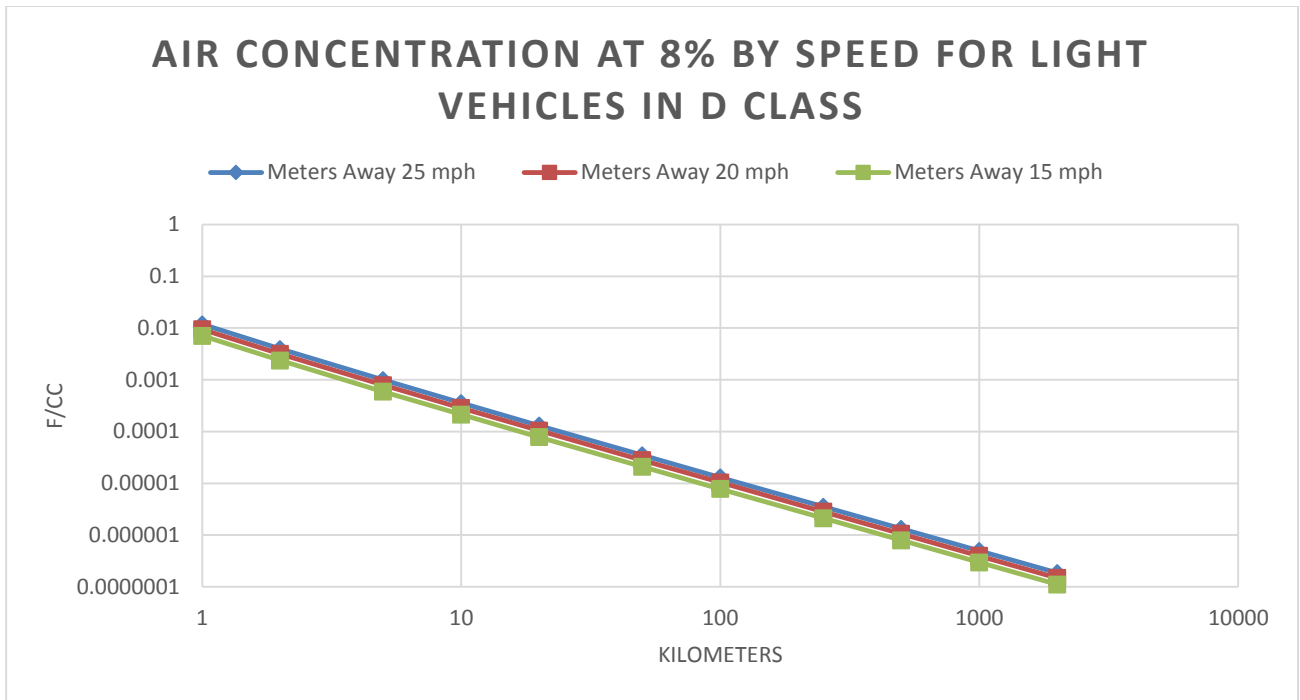


Figure 19: Normal Case scenario for Light Vehicles – Kilometers Downwind

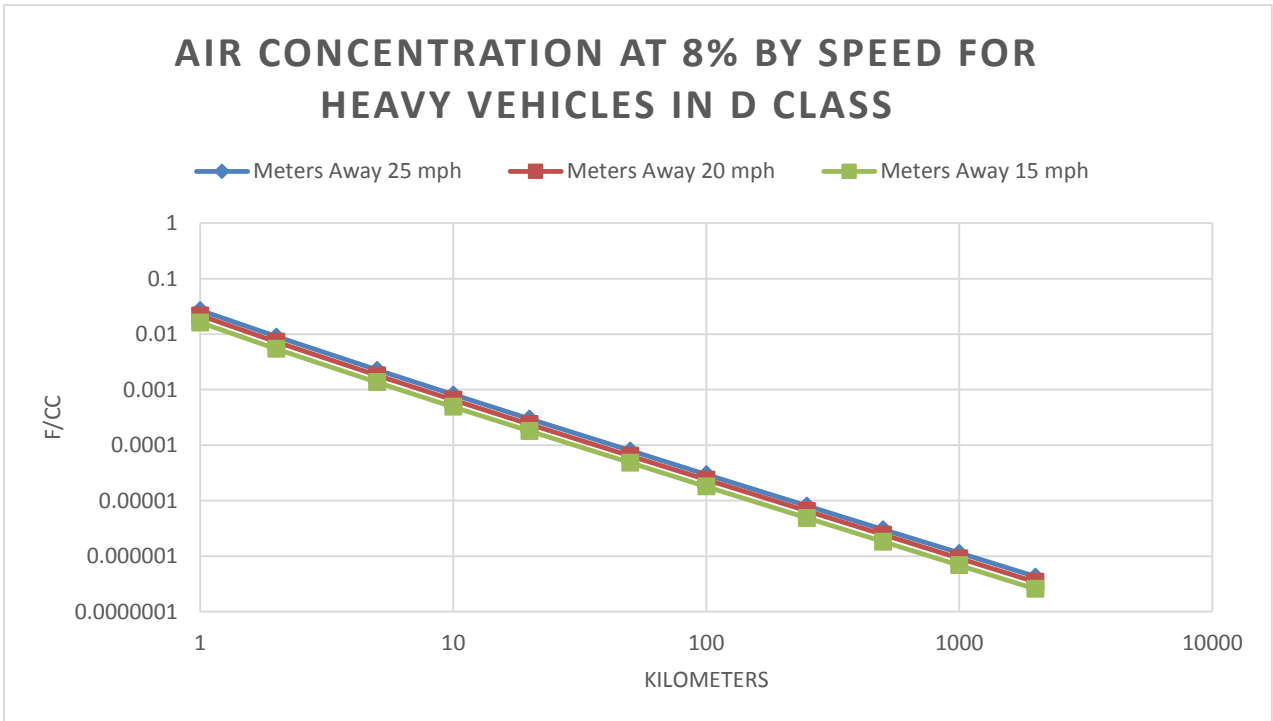


Figure 20: Normal Case scenario for Heavy Vehicles – Kilometers Downwind

As seen in figures 19 and 20, it takes approximately 20 km downwind for the erionite concentration plume to reach an ambient level of 0.0001 f/cc for light vehicles and 50 km downwind for heavy vehicles.

### 2.6.5. Epidemiological Investigations

Erionite concentrations within a radius of one kilometer from CNF may reach as high as 0.48 f/cc through these calculations (table 4). However, there have been no cases of mesothelioma recorded in Harding County according to Center for Disease Control's (CDC) National Program of Cancer Registries (NPCR). The EPA's Integrated Risk Information System (IRIS) <sup>(243)</sup> provides estimates of carcinogenic risk from inhalation exposure to asbestos fibers. Three risk levels are estimated in the IRIS, 1 in 10,000 for  $4 \times 10^{-4}$  f/cc, 1 in 100,000 for  $4 \times 10^{-5}$  f/cc and 1 in 1,000,000 for  $4 \times 10^{-6}$  f/cc as shown in figure 21.

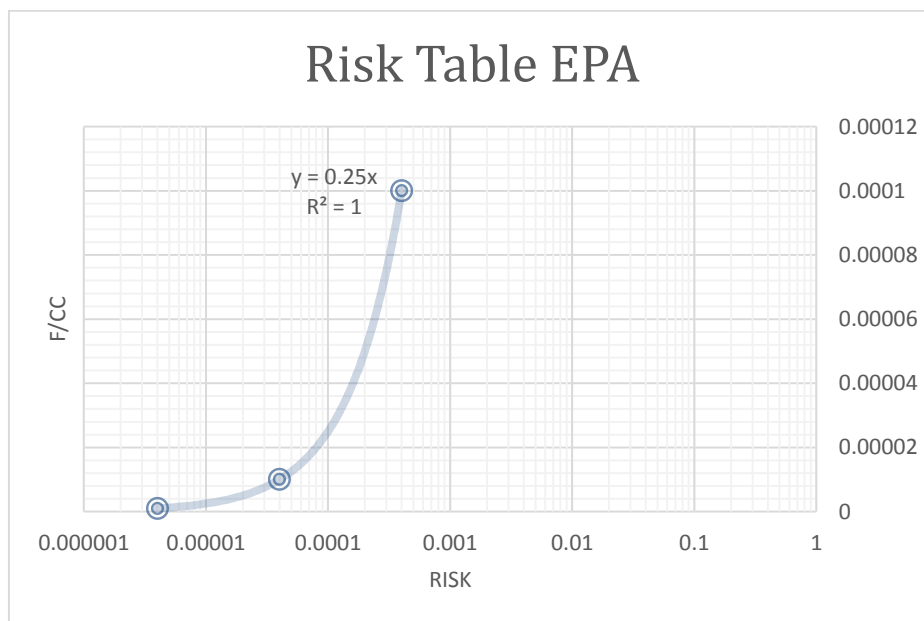


Figure data source: EPA's Integrated Risk Information System website

Figure 21: EPA Risk Estimates

These estimates were calculated assuming a linear relationship between cancer risk and asbestos fiber concentrations. Following this assumption, I have extrapolated the risk level for residents of Harding County at the measured concentrations of erionite assuming similar potency to asbestos. These estimated cancer-risk levels are summarized in table 4. The levels of risk decrease with increasing distance from the source.

Due to the low population present in Harding County (0.18 people/ km<sup>2</sup>) it is very unlikely that an uncommon event like Mesothelioma will be detected. Also the small effect size of the correlation sample size requirements <sup>(244)</sup> for a statistical analysis with significant power ( $\alpha$  (two-tailed) = 0.05 and  $\beta$  = 0.8) cannot be met under these limitations.

Table 4: Sample estimation for Harding County area.

Source	f/cc	Cancer Risk	Sample Size Needed	Actual Number of People
<b>Whitin 50 KM</b>				
Worst	0.0026	0.0007	2,958,402	455
Normal	0.000000600	0.0000002	N/A	
<b>Whithin 20 KM</b>				
Worst	0.0078	0.0020	328,713	73
Normal	0.00000021	0.0000001	N/A	
<b>Whithin 10 KM</b>				
Worst	0.018	0.0045	61,727	18
Normal	0.00000059	0.0000001	N/A	
<b>Whithin 5 KM</b>				
Worst	0.045	0.0113	9,878	5
Normal	0.00000163	0.0000004	N/A	
<b>Whithin 1 KM</b>				
Worst	0.48	0.1200000	89	0
Normal	0.000038	0.0000095	13,849,573,409	

Table data source: Calculated results based on EPA's Fugitive Dust Emissions and IRIS

\*where N/A is over 6 billion

Events with an occurrence of 1 in 1,000 or less are considered relatively uncommon. In order to have a good chance of detecting one of such uncommon events, a large number of people must be observed. Guess et al. <sup>(245)</sup> discussed the probability of detecting an event as a function of the number of people under observation. Using this function, one can estimate that in order to have a good chance of detecting a 1/x event, 3x people must be observed. These sample size calculations for rare events can be further defined by estimating a minimal sample size and a maximum sample size as a function of probability. The minimal sample size (n) for observing one event with 95% probability is estimated as  $n=(1/PE)$ , where PE is the Probability of the event. The maximum sample size is estimated as  $n \leq 3/PE$ .

The closest community to the CNF is Buffalo, SD which is located at a distance of 28 km from the sites where the erionite samples were collected. At this distance we have extrapolated from the EPA risk estimates a worst case cancer risk between 0.002 and 0.0007 (table 4). Based on these estimates, the minimal sample size required for observing one case of mesothelioma in Buffalo is between 500 and 1428 people and the maximum sample size is between 1500 and 4286 people.

According to 2010 census data there are 1263 people living in Harding County and 310 people in the town Buffalo <sup>(246)</sup>. These sample size calculations and those reported in table above for increasing distances from the source, further corroborate that epidemiological investigations and statistical analyses with significant power to detect mesothelioma in Harding County are simply not feasible.

## 2.7. Discussion

Detectable levels of fibers in our ambient air are a fact of life and all levels of exposure to asbestos fibers may have the risks of cancer development. Establishing an association between environmental erionite exposure and mesothelioma depends on the characterization of multiple factors like fiber size, genetics, and intensity of exposure. Because asbestos or erionite fibers do accumulate in the lungs the risk of developing mesothelioma does increase as the cumulative dose increases. In this regard, asbestos or erionite fibers may serve as a "cancer promoter" in synergy with other cofactors that elevate the risk of developing mesothelioma.

Malignant mesothelioma is a highly aggressive and lethal cancer whose current incidence largely reflects past occupational exposure to asbestos from the 1960s and 1970s. Population-based studies, however, have demonstrated that many mesothelioma cases had no occupational exposure to asbestos which instead might be attributed to low-dose naturally-occurring asbestos (NOA) exposure. <sup>(247)</sup>

Some people develop mesothelioma after exposure to minor amounts of mineral fibers while other people who are exposed to large amounts never develop mesothelioma. Asbestos fibers are generally widespread in the environment and even a 70 year old mesothelioma-free healthy lung may contain up to one million fibers per gram of lung tissue. <sup>(248 and 217)</sup> Approximately 3,000 people die of mesothelioma in the United States each year and 5,000 in Western Europe. <sup>(210)</sup> The census of 2000 in Harding County revealed there were 1,353 people and 525 households out of which 35% had children under the age of 18 living in the household. <sup>(246)</sup> Thus, Harding County consists of a very small population pool and with a low probability of clinical observational of cases of mesothelioma.

### **2.7.1. Erionite Disturbance and Take-Home Exposure**

The analysis of the recently sampled outcrops and eroded sediments derived from the Arikaree, Brule, and Chadron formations clearly show a high content of erionite in these geologic layers. Erionite disturbance and exposure may occur through aggregate mining, road construction, timber harvesting or recreational uses. Erionite fibers can adhere to clothes and cars' interior tapestry. These adherent fibers result in future exposure outside the erionite-containing soil areas. This off-site exposure also increases the risk of MM.

### **2.7.2. Erionite in Roads and Wind Regime**

Drivers or people working on the roads that are constantly exposed to the erionite in the area roads' gravel may have a significantly increased prevalence of mesothelioma in the future when compared to the unexposed population. Documents and interviews from the 1980's <sup>(208)</sup> confirm that there was at that time interest in evaluating the risks of erionite exposure in the U.S., but researchers and officials did not follow through and erionite still remains unregulated.

Atmospheric stability plays an important role in erionite dissipation in the air. In unstable conditions (class D - neutral) the erionite concentration drops below the PEL level reaching 0.068 f/cc 300 meters away from the fugitive dust source at 25 mph for light vehicles, while in stable conditions (class F) it takes 2 kilometers to reach a concentration below the PEL of 0.049 f/cc.

Natural dust distributed by numerous anthropogenic activities occurs throughout the Sioux Ranger District and many erionite-containing roads are swept by the strong summer and spring wind regime blowing from south to southwest. The "oil boom" in western South Dakota that

began some years ago will become a major nuisance once the erionite-containing roads begin to fall apart.

A long-term solution for erionite/dust suppression could be developed by the state and local governments. A viable short-term solution could be frequent road watering, using water from Park Pond Dam.

### **2.7.3. Genetic Predisposition**

A preventive strategy to lower the incidence of mesothelioma in future generations could be developed for identified genetic individuals with high risk of mesothelioma. Such a strategy could be from close monitoring for targeted early detection and cure. In these cases MM development may be due to shared familial tendency, shared exposure or both. The research in Turkey shows there are families in the Karain and Tuzköy villages who never developed MM although they had the same erionite exposure and they live next door to the families that developed MM. When someone with a mesothelioma-prone gene married someone with a non-mesothelioma gene, their children develop mesothelioma, which means BAP1 is a dominant gene.

Also, the study has been limited to three villages in Turkey that had a cluster of MM; although the neighboring villages used the same building materials for their homes they are mesothelioma-free. This is a classic case of the genetics loading the gun and the environmental exposure pulling the trigger.

#### **2.7.4. Smoking**

Several studies have shown that smoking is particularly hazardous when associated with asbestos exposure and appears to be synergistic for lung cancer. <sup>(249)</sup> Smokers exposed to asbestos have ten times the risk of developing lung cancer. Quitting smoking will drastically reduce the risk of lung cancer among asbestos-exposed workers <sup>(250)</sup>.

Although smaller particles like erionite fibers that impact the mucous coated walls of airway during breathing are caught by the ciliated cells, cigarette smoking temporarily paralyzes these cells which normally constantly beat upward sweeping into the back of the mouth all the small particles that normally get swallowed and so reducing the risk of the fibers reaching the alveoli.

#### **2.8. Conclusions**

In the center of each mesothelioma tumor is a mineral fiber, and not all of the cancer-causing fibrous minerals are called asbestos. Breathing in naturally occurring erionite in the Sioux Ranger District area, over a life time, has the potential to harm people's health. The results indicate that there is environmental exposure to erionite in the Sioux Ranger District. In this part of South Dakota, erionite has been exposed naturally by erosion and transported around the local area through the hydrological and aeolian systems and anthropogenic activities, including road construction materials.

The risk calculations computed in this chapter are based on formulas and equations developed by the EPA for asbestos. There is on-going research that suggests that erionite is more toxic to human health than asbestos <sup>(205,206, and 210)</sup>. This suggests that uncertainties exist about the risk calculations from erionite exposure presented in this chapter and these calculations may represent underestimates of the actual risk posed by exposure to this material.



Although outdoor work, is not traditionally associated with exposure to hazardous substances, soil disturbance in the dry Western States can lead to measurable airborne particle concentrations. Erionite exposure is directly related to the activity and the degree of soil disturbance and dust creation. Children are of special concern because they have the highest corresponding excess lifetime cancer risk, and reducing children exposure to erionite will reduce the risk of future MM cases.

Due to the latency period from erionite exposure to the first signs of the MM advances in the medical field therapies could soon prevent or delay carcinogenesis in individuals that are currently exposed which could lead to a substantial decrease in MM mortality. Clinical research is focusing on strategies to reduce the impact of the carcinogen by targeting inflammatory factors. Genetic testing for BAP1 mutations in exposed individuals should help identify who are genetically susceptible and have the highest risk of developing MM. Further studies of early detection, for example monitoring HMGB1 levels, should also help in early diagnosis

The results demonstrate clearly the need for more sampling and analysis of the geological formations in the Sioux Ranger District. Research into toxicity and risk is still necessary in order to inform and support a rational response to the presence of the mineral hazard. The geologic layers observations in this study provide an important basis for the beginning of the epidemiological investigations in the Harding County area.

## **2.9. Future Research**

Future research should take in consideration the following issues:

- A. Water Ingestion. Studies so far sought to determine if erionite could pose a health risk to the respiratory system. Whether erionite could pose a health risk if ingested remains to be determined. There are numerous aquifers and surface waters that come in contact

with zeolites throughout the western states. Groundwater/drinking water toxicological studies should be conducted to evaluate erionite concentrations in drinking water and possible health risk for exposed populations.

B. Different Zeolites. Erionite is currently the only zeolite that has begun to be studied extensively. Different minerals exhibit different biological responses based on the interactions between the mineral surfaces and biological components. Future research should also investigate potential hazards from different zeolites beside erionite.

C. Sands used for fracking. With the growth of fracking industry, millions of tons of sand are being transported in the Eastern U.S. from the Western U.S. The sand translocation creates considerable sand dust beside its use at the drilling site location. Currently, there is no documentation that these sands are being derived from non-erionite containing deposits.

## Chapter 3

### FBAS Preparation Method for the Analysis of Erionite in Soils

#### Abstract

As the general public becomes more aware that erionite released from soil may be a public health hazard, there is a need for a method to evaluate human health risks due to exposure from erionite contaminated soils. Erionite contaminated soils can release fibers into the air by wind or human disturbance activities. These exposures can be an ongoing source of fiber inhalation with outcomes that may range from pulmonary deficit to mortality.

The objective of this second essay is to evaluate the Fluidized Bed Asbestos Segregator (FBAS) method for its effectiveness and efficient separation of erionite fibers from sampled soils. Furthermore, this method maintains the integrity of the erionite fibers so that the true structural characteristics and quantity of erionite fibers in the soils can be determined.

The FBAS is a sample preparation method that utilizes air elutriation and fluidization to separate mineral fiber structures from different matrix materials. These structures are deposited onto a filter which can then be analyzed by microscopic techniques with sensitivity to levels as low as 0.002% by weight. The FBAS method produces an approximately linear relationship between mineral fiber concentrations and the reported soil concentration.

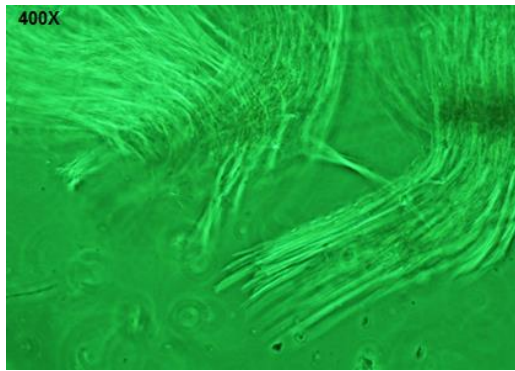
### **3.1. Introduction**

The objective of this second essay is to evaluate the Fluidized Bed Asbestos Segregator (FBAS) method for its effectiveness and efficient separation of erionite fibers from sampled soils while maintaining the integrity of the erionite fibers so that the true structural characteristics and quantity of erionite fibers in the soils can be determined. The fiber counting was done by Phase Contrast Microscopy (PCM) and Transmission Electron Microscopy (TEM) and the fiber identification was done by Polarized Light Microscopy (PLM), Scanning Electron Microscopy (SEM), and EDS.

#### **3.1.1. Erionite Mineralogy and Morphology**

There are two well-known families of asbestos: amphiboles and serpentines. Erionite belongs to the group of hydrated alumino-silicate minerals called zeolites found in volcanic and sedimentary rocks. The mineral group was named by Baron Axel Fredrik Cronstedt, a Swedish mineralogist, in 1756 zeolite from the Greek “boiling stone”, for the reason that the rock loses water when it is heated. Erionite absorbs up to 20% of its weight in water.

In 1898 Arthur Starr Eakle discovered and named erionite after the Greek word “ερion” meaning wool in allusion to the "wooly" thin delicate fibers appearance, forming a compact felt. There is a “woolly” erionite, as shown in figure 22, which appears as compact masses of long, curly fibers and is actually rare, but can be found in Reese River zeolite deposit in Nevada.



*Image courtesy to Dr. Martin Harper*

Figure 22: Woolly erionite

The morphology of erionite is acicular to asbestiform, as shown in figure 23. Erionite usually occurs in diagenetic alteration of sediment, cavities in altered basaltic lavas or by hydrothermal alteration.

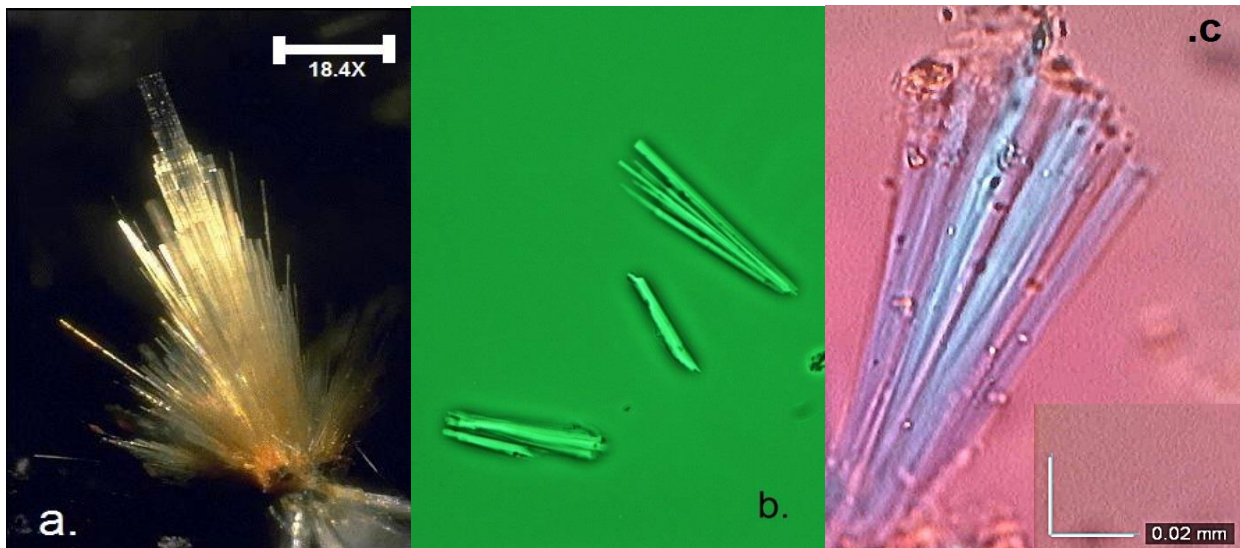


Figure 23: a. Microscopic image 18.4X, Agate Beach, Oregon U.S.A. Courtesy to mineralatlas.com

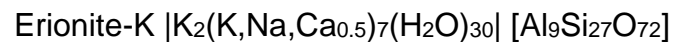
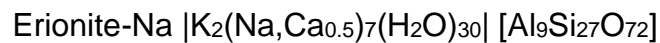
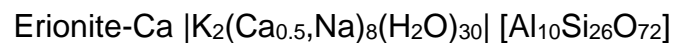
b. Microscopic image 400X, PCM, Killdeer Mountains, North Dakota, U.S.A. Courtesy to NIOSH/CDC

c. Microscopic image 200X, PLM, Buffalo, South Dakota, U.S.A. Courtesy to BVNA Laboratory

Erionite is registered in the Chemical Abstracts Service (CAS) Registry No. 66733-21-9<sup>(301)</sup> and has the general molecular formula  $(\text{Na}_2, \text{K}_2, \text{Ca}, \text{Mg})_{4.5} \text{Al}_9 \text{Si}_{27} \text{O}_{72} \cdot 27\text{H}_2\text{O}$  with a structure

characterized by a framework of connected tetrahedra, separately consisting of four oxygen atoms surrounding a cation. <sup>(302)</sup> Erionite chemical composition varies both in the Si, Al content of the framework of connected tetrahedra but also in the cation content of the erionite cavities.

Three types of erionite were described in 1997 depending on the predominant exchangeable cation, as erionite-Na, erionite-K, and erionite-Ca. <sup>(303)</sup>



Other fibrous zeolite minerals like mordenite  $[(Ca,Na_2,K_2)Al_2Si_{10}O_{24} \cdot 7H_2O]$ , thomsonite  $[Ca_2Na(Al_5Si_5O_{20}) \cdot 6H_2O]$  and offretite  $[CaKMg(Al_5Si_{13}O_{36}) \cdot 16H_2O]$  are commonly found with erionite and either X-Ray Diffraction (XRD) or EDS is required for confirmation.

Erionite morphology is hexagonal prisms ending with the basal pinacoid, as shown in figure 24. The stacking structure creates columns of cancrinite cages alternating with double 6-ring cages. <sup>(304)</sup>

Due to similarities in the framework structure of erionite with levyne and offretite, the three minerals commonly exhibit epitaxial intergrowths. The individual erionite crystals typically found in vesicles of mafic volcanic rocks range from 2 to 200  $\mu\text{m}$  long and are 0.1 to 10  $\mu\text{m}$  thick. However, finer fibrils of 30-40 nanometers diameters are observed in sedimentary erionite.

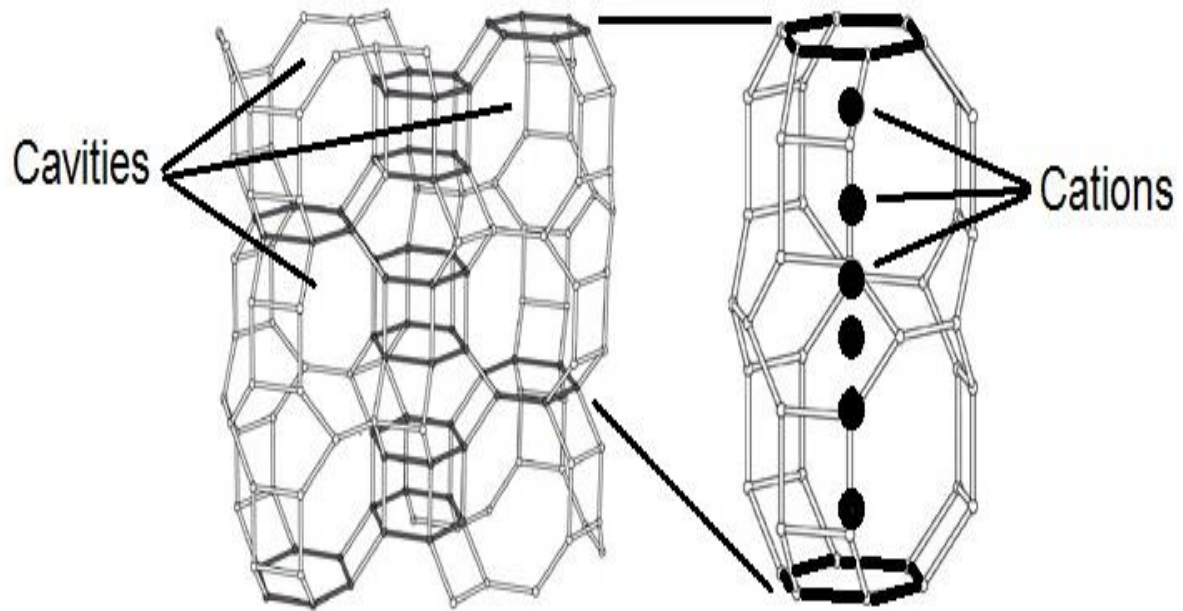


Figure 24: Erionite morphology.

Erionite from Pillars of Rome, Oregon (CBES- 6120) <sup>(305)</sup> has been collected and used as an erionite standard, as shown in figure 25. This standard has already been well characterized quantitatively by optical microscopy, SEM, EDS and XRD. SEM is used to determine the morphology of the fibrous minerals and EDS is used to determine the elemental composition of the erionite fiber.



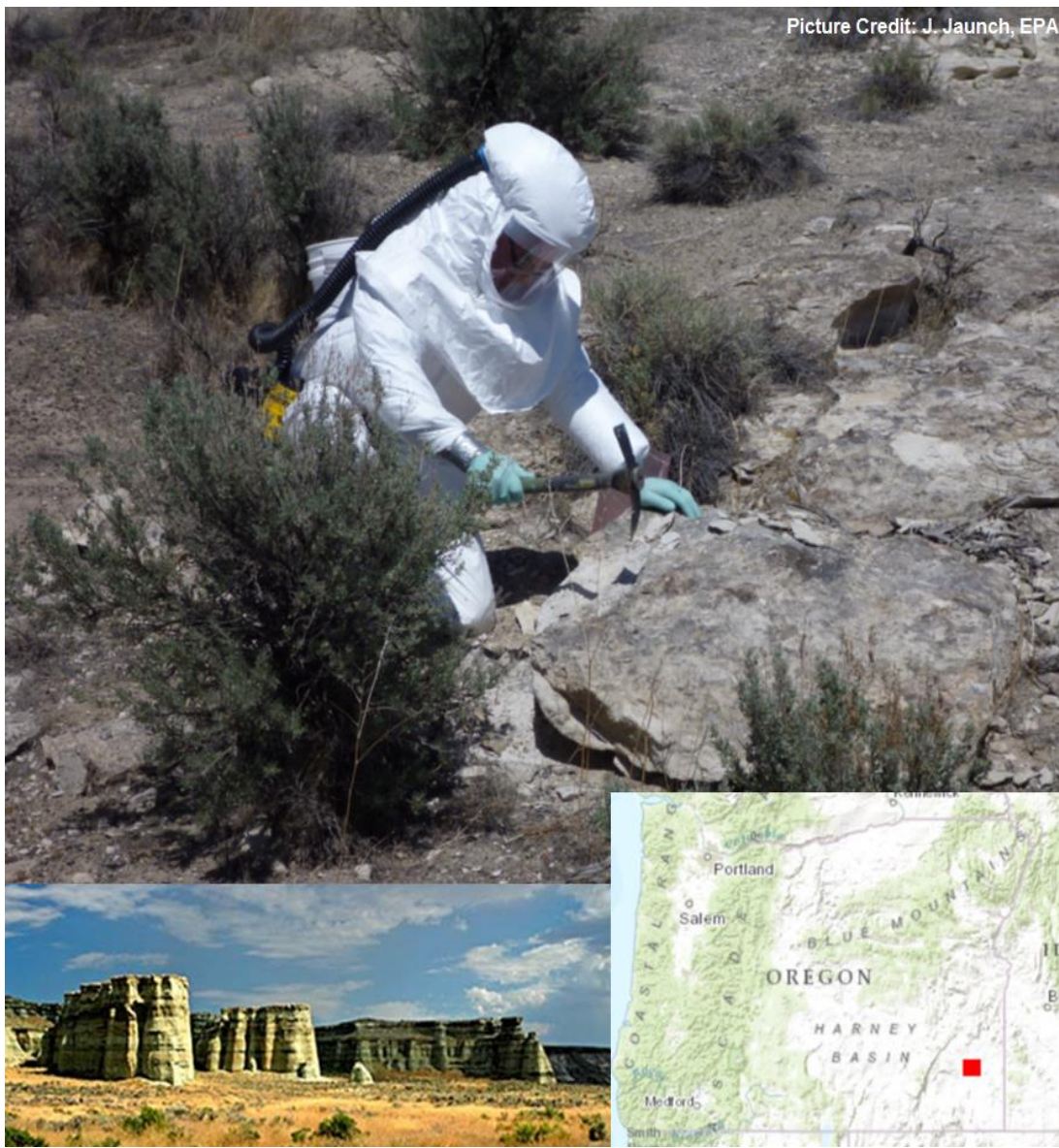


Figure 25: Erionite standards collection and location of Pillars of Rome, Oregon

In the figure 26 we can also see three erionite reference structures from the American Mineralogist Crystal Structures Database, where light blue is Ca, purple is K, red is O, dark blue is Si and gray is H<sub>2</sub>O. This sample are viewed down the  $[-1\ 1\ 0]$ ,  $[-2\ 2\ -1]$  and  $[-1\ -4\ 1]$  axes.



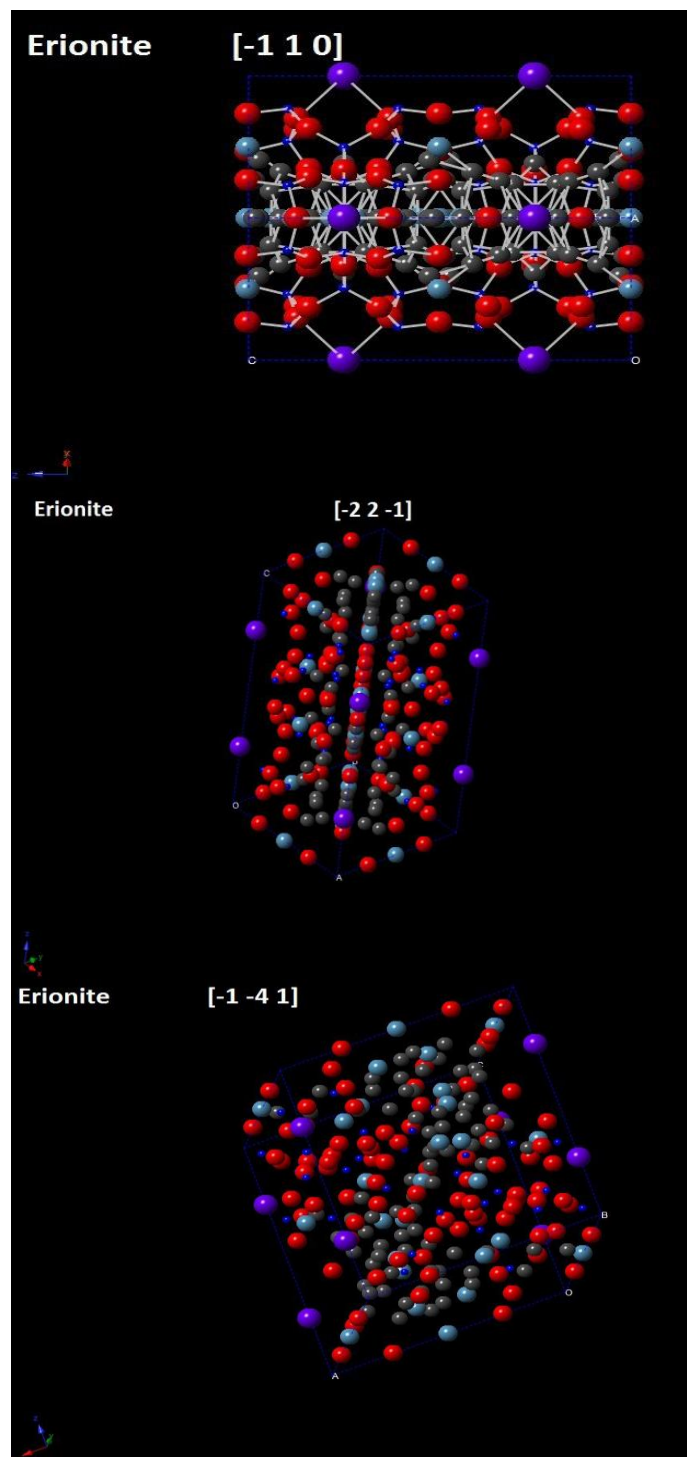


Figure 26: Reference of Erionite from the American Mineralogist Crystal Structures Database

Phase Contrast Microscopy (PCM) cannot distinguish between different fibers, but TEM identifies fibers by Selected Area Electron Diffraction (SAED) and EDS, which yields the chemical composition of the fiber.

Polarized Light Microscopy (PLM) identification of fibers is based on the optical properties of morphology, refractive indices, color, pleochroism, birefringence, extinction characteristics, signs of elongation and dispersion staining characteristics, but requires particles to be at least 1µm wide to observe these characteristics.

The most difficult task in calculating the mass percentage of mineral fibers in a soil sample is homogenizing the soil sample to a level that will yield good reproducibility and assure that the examined portion of a sample is representative of the whole. Almost all soil asbestos analyzing techniques use an indirect approach to prepare the sample and were developed by adapting existing methods used to identify asbestos in soil, construction waste or insulation. It is also difficult to obtain reliable and reproducible results for asbestos analysis in soils with the usual bulk material methods.

Heating, use of solvents and acid washing treatment can alter the index of diffraction and color of the asbestos fibers, <sup>(306)</sup> while grinding can destroy the fibers structural characteristics. Asbestos fiber separation from soil is typically achieved by air or liquid suspension and filtration onto a membrane. The elutriation technique facilitates the separation of mineral fibers from the bulk of the soil matrix and offers the ability to identify and quantify the fibers. TEM, SEM, XRD and PLM are the only methods that can verify that a soil sample contains asbestos or erionite.

There are currently seven different methods used to separate mineral fibers from soils:

- A. CARB 435 (California Air Resources Board Method) – Determination of Asbestos Content of Serpentine Aggregate with TEM Confirmation. The sample is dried in a drying oven and the 3/8" material is removed by sieving and fine milled at 200°C for 4-8 minutes to create a homogenous mixture reduced to the particle size of 75 microns (potentially producing cleavage fragments with large aspect ratios by altering size dimension). A

milled sample mass is put in water suspension, sonicated, filtered through a 0.4 micron filter and analyzed at 20,000X. Asbestos is identified using the EDS spectrum showing the chemical composition and SAED analysis which provides information on the crystalline structure of particles. The mass is calculated by measuring length and width of fibers.

- B. Chatfield Method It is best suited for organically-bound construction materials. Chatfield method is regarded as the most accurate method for non-friable materials. Samples are prepared using gravimetric reduction technique, i.e. heating in a muffle furnace, the residue is placed in aqueous suspension with distilled water and agitated to ensure an even distribution of suspended fibers and filtered through a Mixed Cellulose Esters (MCE) filter. A drop of the liquid sample is mounted on a specialized grid and analyzed by TEM at 20,000x magnification. <sup>(314)</sup> The asbestos type and percentage is based on a calibrated visual estimate. Laboratory results are reported as percentages for each type of asbestos identified.
- C. ELAP 198.4 (TEM with Gravimetric Prep Analysis by NY State) Non-friable organically bound (NOB) samples are gravimetrically reduced first; the soil sample is reduced organically in a muffle furnace and afterwards digested in concentrated hydrochloric acid. The sample is weighed again and compared to the initial weight. If the weight is less than 1% of the initial weight, it cannot be defined as an asbestos containing material (ACM) but if the residue is greater than >1% of the original sample weight, the sample is analyzed by PLM analysis. If the PLM analysis results in asbestos concentrations greater than >1%, the sample will be analyzed by TEM in order to finally determine NOB.
- D. EPA 600/R-93/116 (section 2.5.5.1) method originally referred to as the “Chatfield Method”. Asbestos fibers are often tightly bound to the matrix material and not easily

isolated and detected by PLM often resulting in a false negative. Non-Friable Organically Bound Preparation include gravimetric reduction by ashing the samples several hours in a muffle furnace at high temperatures, followed by dispersion of the remaining residue with hydrochloric acid which is analyzed by TEM for the presence of asbestos.

- E. ASTM D7521-13 Soil Quantitative, TEM. In this analysis method the bulk building material is separated from the soil and analyzed and reported separately. Dry sieved particles of soil are shaken for 5 minutes and separated into ranges less than 2 mm, (19 mm/2 mm/106 microns). Each fraction is weight and analyzed. If asbestos is not found by PLM in the three fractions then TEM is performed. Wet sieving is usually preferred since it yields higher 106 microns fraction.
- F. EPA 540-R-97-028, The Elutriator Method (Superfund Method): The soil sample is gravimetrically tracked through sieving into coarse and fine fractions. The fine fraction is then tumbled in a closed chamber (the elutriator) and any respirable dust generated is collected on air cassettes. Analysis is performed by the ISO 10312 direct transfer method. It also includes additional fiber size information, such as length, width, and aspect ratio, not recorded under Asbestos Hazard Emergency Response Act (AHERA) protocols.
- G. FBAS Method (which will be detailed in chapter 3.1.2)

### **3.1.2. Fluidized Bed Asbestos Segregator (FBAS)**

The FBAS, as seen in figure 27, is a bench-top apparatus developed by scientists at the EPA and Battelle Energy Alliance, LLC <sup>(307)</sup> as an improvement over the equivalent Berman Elutriator method which was considered to be time consuming, costly, and the equipment was very difficult to decontaminate between samples.

Soil fluidization is achieved by flowing air (at a flow rate of approximately 200 cm<sup>3</sup>/min) upward through a bed of sand and soil sample with a pressure drop through the bed equal to the weight of the bed, when the solid particles begin to behave and act like a fluid.

The velocity required to fluidize the soil and sand particles depends on the shape, density and size of the particles. The fine particles and fibers separated from soils are collected through an isokinetic port at top of the vertical elutriator onto an MCE filter for approximately 3 minutes. A mechanical vibration device is used to prevent larger particles build-up on the glass vessel inner surface. The vibration velocity is 15 mm/s and at a frequency of 1 kHz. <sup>(307)</sup>



Figure 27: The Fluidized Bed Asbestos Segregator unit

### 3.1.3. Environmental Regulation Landscape

U.S. Environmental Protection Agency (EPA) defines 1% in soil as the "action level" for asbestos although EPA does not identify any level of exposure to asbestos as safe. EPA has investigated erionite occurrence but does not regulate erionite and has not engaged in any

remedial activities with respect to erionite. Currently there are numerous techniques calculating mass percentage of asbestos in soil, nevertheless there is little connection to soil asbestos release risk due to interfering particles in the soil that bind and coat the asbestos fibers.

EPA will only remediate man-made pollution and will not remediate below natural background. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), section 9604 authorizes EPA to perform removal or remedial for “any hazardous substance that is released or there is a substantial threat of such a release into the environment” but in section 9604 (3) (A) limits EPA’s response to NOA saying that “the President shall not provide for a removal or remedial action under this section in response to a release or threat of release of a naturally occurring substance in its unaltered form, or altered solely through naturally occurring processes or phenomena, from a location where it is naturally found.”

There are currently three methodologies of counting airborne asbestos fiber based on their characteristics. National Institute for Occupational Safety and Health (NIOSH) 9002 method has a visual percentage estimation, EPA/600/R-93/116 “fibers with mean aspect ratios of 20:1 to 100:1 or higher” while CARB 435 requires an aspect ratio of 3:1 and AHERA/ ISO 10312 requires an aspect ratio of 5:1 for asbestos fibers, although there are no studies showing a specific aspect ratio will stimulate apoptosis in human alveolar macrophage. <sup>(310)</sup> Regarding length AHERA consider fibers longer than 0.5 µm while all the other PCM methods require the fibers to be longer than 5 µm to count as asbestos. The Berman Crump method takes into account fibers longer than 10 µm and thinner than 0.4µm

Because it is believed by some that erionite may be as least as hazardous as crocidolite <sup>(308)</sup>, an American Society for Testing and Materials (ASTM) standard is being developed for screening and identification of erionite in soils and gravels using (Central Stop Dispersion

Staining) CSDS in conjunction with PLM attributes for the identification. These methods in concurrence with other analytical techniques such as TEM, SEM and XRD will help identify and characterize erionite in soil, gravel and air samples. <sup>(309)</sup>

The samples studied here were analyzed according to the standard operating procedure (SOP) document number OEAFIELDSOP-102 Revision 1.0. <sup>(313)</sup> The sample preparation technique is intended to segregate asbestos fibers from soil onto an air filter which allows determination of the releasable mineral fiber content of the soil. Evaluation studies have shown that the FBAS technique is able to detect mineral fibers at levels ranging from 0.002% to 0.005% by weight, which is approximately 100-times lower than the standard analytical methods in bulk materials. <sup>(307)</sup>

## **3.2. Methods and Data Collections**

To adequately characterize the areas studied here, multiple samples from each area provided by CDC, USFS and NIOSH were analyzed.

### **3.2.1. Sample Collection and Preparation Methods.**

Sixty-two samples were analyzed in triplicates (Annex 4 - 6) to minimize the laboratory subsample bias. Soils were further sieved and dried according to the ASTM D7521-13 method.

After collection the soil sample was sieved on a shaker for 5 minutes according to the standard ASTM D7521 which segregates the soil in 3 sieving levels (19 mm, 2 mm, 106 um): coarse fraction (<19 to > 2mm), medium fraction (< 2mm to > 106 um), and fine fraction (< 106 um). The fine fraction was dried in an oven at 60C<sup>0</sup> for 12 hours, homogenized and fluidized in

the FBAS. A random aliquot of 1 gram soil material was extracted from each sample container using a stainless steel spatula and mixed with 9 grams of sand for the FBAS procedure. The MCE filters were prepared for PCM counting according to NIOSH 7400 method. The erionite fibers were visually identified based on their structure (long, thin, parallel and straight) and crystallinity contrast which are the characteristic for erionite fibers.

### **3.2.2. SEM Sample Preparation**

Carbon coating was used because of the low X-ray absorption factor of C for EDS analysis. Gold was sputter coated to obtain high-definition images of the erionite fibers using a SPI Module™ Sputter Coater.

### **3.2.3. Microscopy Techniques**

Samples for SEM analysis were prepared through direct transfer method, which retained the particles in the similar position during SEM analysis as they were on the sampling filter. After carbon-coating, 62 samples were examined with a Hitachi S-4800 Field Emission Scanning Electron Microscope operated at 20 kilovolts and 0.1-1.0 nanoamperes current and equipped with an Bruker EDS package.

Each sample was scanned at 500 and 20,000 times magnification for the presence of fibrous zeolite minerals. An image and quantitative chemical data were acquired for each of the individual fibers through (EDS) X-Ray microanalysis SEM Sample Preparation. Filters were counted using the ISO 10312:1995(E) and the concentrations of asbestos were expressed as mass percentage (grams of asbestos per 100 grams of soil).<sup>(311)</sup>



### 3.2.3.1. Counting and Mass Calculations

The erionite collected in this study was composed of single fibers, bundles of fibers and radiating bundles of fibers. Nikon Eclipse 50i microscope was used with Nikon's CFI60 400X optical magnification and a Nikon Digital Sight Series HD 5-megapixel camera DS-Fi2 with image resolution images of 2560 x 1920 pixels to capture the field of view images. Fibers length and width were recorded using the measurement function of the standalone control unit DS-L2.

The volume of each fiber structure was calculated from its dimensions (length and width) as a cylinder:

$$V_f = \pi \cdot (W_i/2)^2 \cdot l_i \quad (\text{Equation 4})$$

Where:

$V_f$  = volume of the fiber structure

$W_i$  = width of the fiber structure

and,

$l_i$  = length of the fiber structure

The erionite mass percentage was calculated according to EPA method OEAFIELD SOP-102 Revision 1.0:

$$m_i = V_f \delta \cdot 1E^{-12} \quad (\text{Equation 5})$$

Where:

$m_i$  = mass percentage of erionite in soil

$\delta$  = density of erionite

and,

$1E^{-12}$  = conversion factor (cm<sup>3</sup> per  $\mu\text{m}^3$ )

### 3.2.3.2. Quality controls.

Validation of sample collection and analysis was done by means of lot filters blanks and sand blanks.

#### A. Lot Blanks

Two Lot Blanks from each filter lot were analyzed to determine the fiber structure loadings. The filter lot is rejected when the mean count of the fiber structures is 10 s/ mm<sup>2</sup> or if the mean count of fibers and bundles longer than 5  $\mu\text{m}$  is above 0.1 s/ mm<sup>2</sup>. No fiber structures were found on the Lot Blanks filters.

## B. Preparation Blanks

Preparation Blanks are a measure of laboratory cleanliness. Two preparation blanks were left uncovered during sample preparations for each series of samples on the top bench inside the FBAS.

## C. Sand Blanks

Two sand blanks were analyzed with clean sand added to a clean glass vessel but without adding any soil after each series of samples.

### **3.2.3.3. FBAS Sample Preparation**

The samples were made by combining 19 grams of sand with 1 gram of soil samples and placing them in to the glass vessel through the top opening. PVC tubing was attached on top of the isokinetic splitter and a low flow rate was selected for a 25-mm MCE filter with a pore size 0.8  $\mu\text{m}$ . The digital timer was set for three minutes. The vacuum pump and the vibrator unit were monitored during operation and no further adjustments where necessary.

## **3.3. Results**

BVNA Labs performed TEM analysis of a reference sample of erionite from Rome, Oregon in order to validate that the program Single-Crystal could match simulated data with experimental

data. Qualitative determination of the reference mineral structure was performed visually and the identity confirmed, utilizing the overlay function of the Single Crystal program. The overlay grid maps X-ray intensity peaks to simulate the best fit for the zone axis.

Figure 28 validates the claim that this mineral fiber sample is in fact erionite viewed along the  $[-1\ 1\ 0]$ ,  $[-2\ 2\ -1]$  and  $[-1\ -4\ 1]$  axis. The reference sample of erionite (black) is compared with the simulated diffraction pattern (Red) using Single-Crystal, viewed along these axes.

Several erionite fibers were identified by SEM (figure 31) and TEM (figure 30) and their identity confirmed by EDS spectra (figure 29).

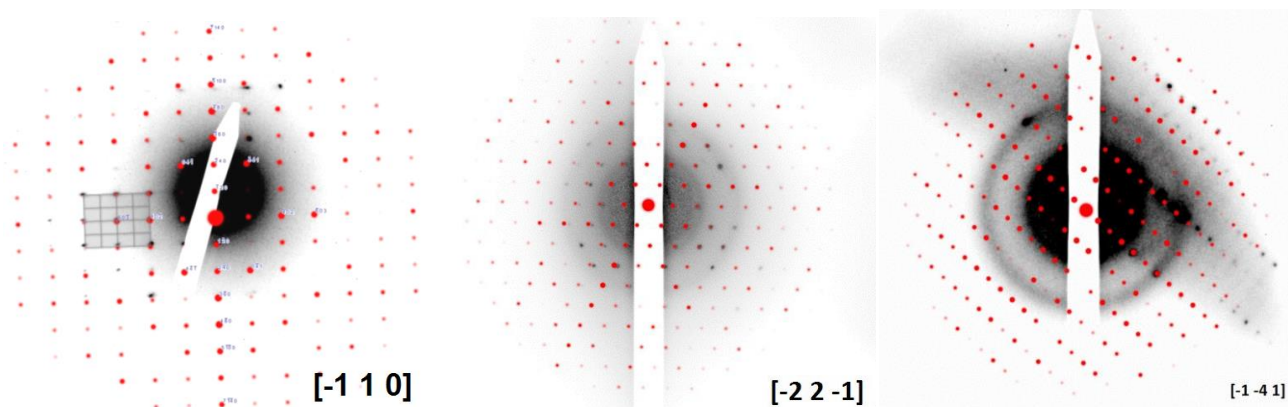
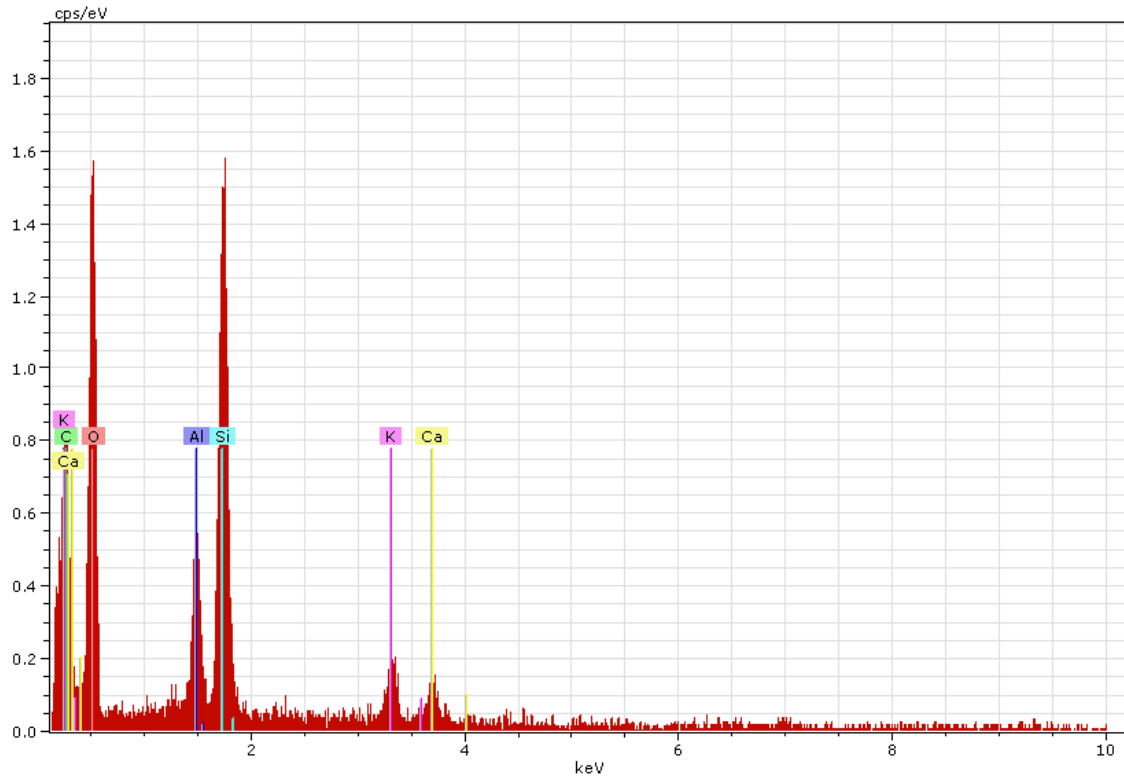
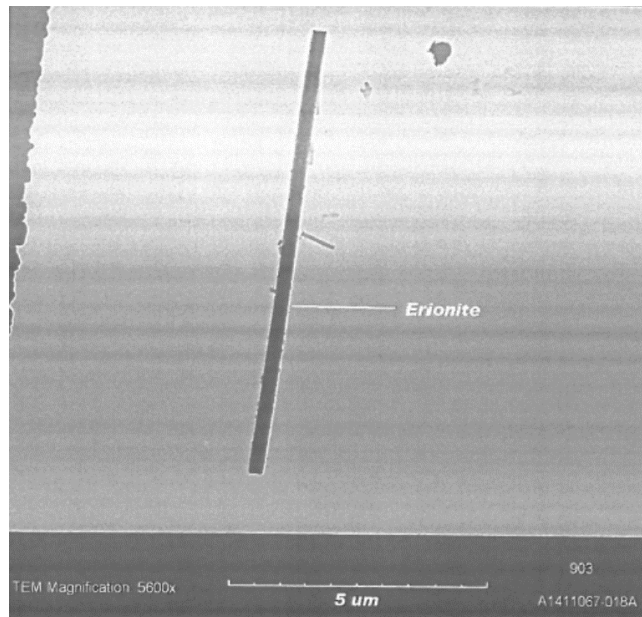


Figure 28: Reference sample of standard erionite (black) vs. CNF (red)



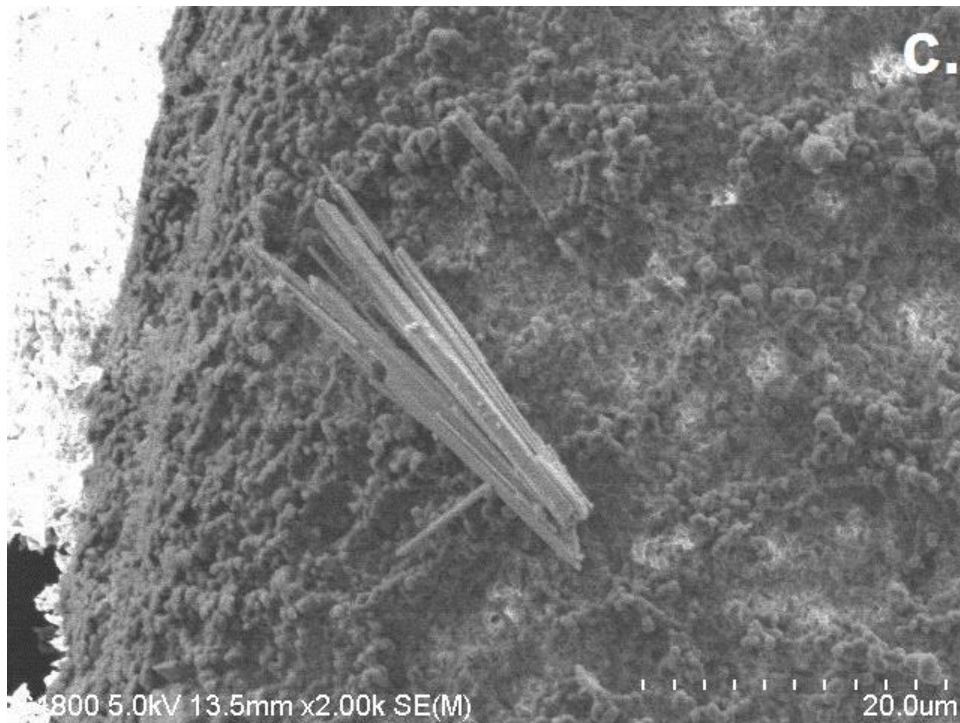
*Courtesy of NIOSH/CDC*

Figure 29: Erionite Spectrum of sample 401, Sioux Ranger District, South Dakota, U.S.A.



*Courtesy of NIOSH/CDC*

Figure 30: TEM photomicrograph of sample 903 at 5600x showing erionite fiber



*Courtesy to NIOSH/CDC*

Figure 31: SEM image 2000 X, Sioux Ranger District, South Dakota, U.S.A.

### 3.3.1. USFS Samples

BVNA Labs identified erionite by PLM based on the unique optical properties including birefringence, sign of elongation, dispersion staining and shape and color. Becke-line technique was used to estimate and compare refractive indexes (RI) of fibers from each sample submitted for comparison to the RI reference material of Rome, Oregon which RI's are between 1.472 (Par.) and 1.474 (Par.)<sup>(312)</sup>

The results in table 5 are reported as relative visual estimation percentages in the PLM method and as mass percentage, grams of asbestos per 100 grams of soil in the FBAS method. The FBAS values represent the PCM readings performed by NIOSH.

Table 5: Forest Service Soil Samples FBAS and PLM concentration

Soil #	FBAS	PLM
Soil 1	5.1%	5%
Soil 4	3.9%	3%
Soil 11	1.0%	<1%
Soil 12	1.3%	<1%
Soil 13	1.4%	<1%
Soil 16	2.5%	2%
Soil 17	4.2%	3%
Soil 19	0.1%	ND
Soil 21	0.1%	ND
Soil 22	0.0%	ND

### 3.3.2. NIOSH Samples

The results from the NIOSH samples collected on November 2, 2014 in table 6 are expressed also as mass percentage, grams of erionite per 100 grams of soil.

Table 6: NIOSH Soil Samples FBAS and PLM concentration

Sample #	FBAS/PCM	FBAS/TEM
4	0.000168	0.000036
5	0.000091	0.000186
6	0.000333	0.000166
7	0.000329	0.000000
8	0.001832	0.002439
9	0.000898	0.000065
10	0.000985	0.000132
11	0.002528	0.000997
12	0.002463	0.000963
13	0.002762	0.000276
14	0.002188	0.000091
15	0.002396	0.000669
16	0.002096	0.000294
17	0.001467	0.000176

The soil samples from the Aug 11-12, 2015 collection in table 7 yield erionite concentrations ranging between 0.07% and 22.9%.



Table 7: NIOSH Soil Samples from the second collection

SAMPLE	Average
1	0.119169
2	0.040189
3	0.035147
4	0.046242
5	0.026522
6	0.026163
7	0.046194
8	0.068473
9	0.027013
10	0.040548
11	0.02295
12	0.038643
13	0.084473
14	0.229658
15	0.000705
16	0.001423
17	0.001091

### 3.3.3. Comparison of CNF Arikaree vs. Cappadocia, Turkey.

The CNF erionite fibers are in general larger than the erionite fibers from Karain, Cappadocia as shown in figure 32.

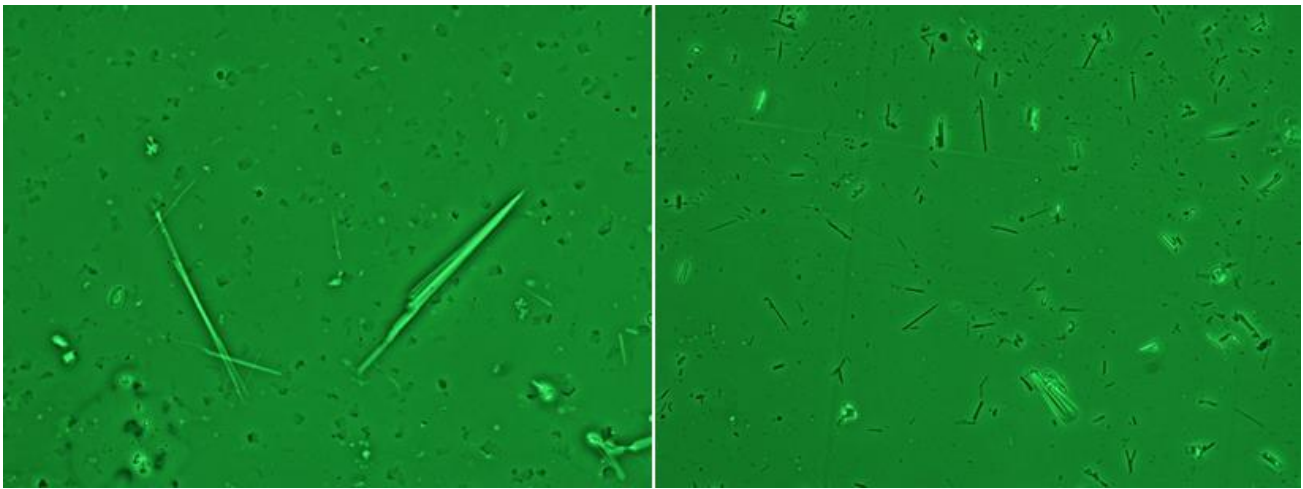


Figure 32: CNF Arikaree vs. Karain, Cappadocia

### 3.3.4. Erionite Fiber Distribution by Length, Width and Ratio

A total of 1110 erionite fibers and their distribution were measured by length and width and can be seen in the figures 33 and 34.

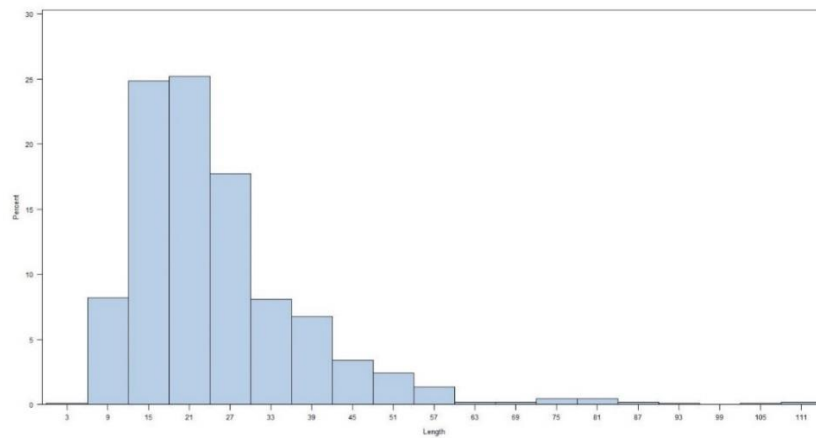


Figure 33: Fiber Length distribution

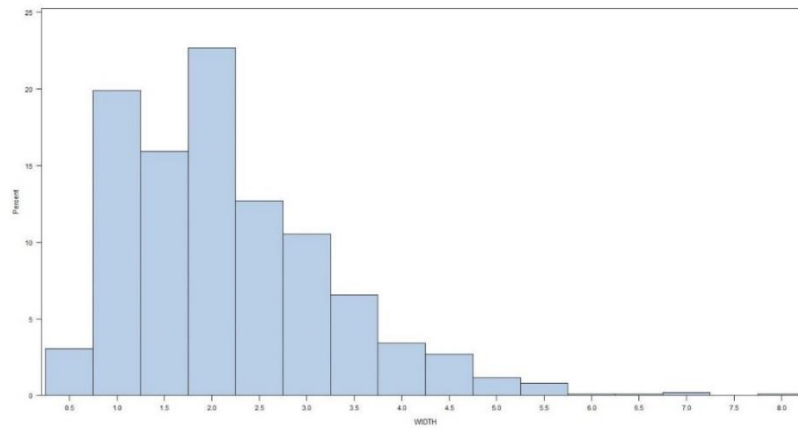


Figure 34: Fiber Width distribution

The average width is 2.15  $\mu\text{m}$  with a SD of 1.07 and a minimum of 0.43  $\mu\text{m}$  and max of 7.85  $\mu\text{m}$ . The average length is 24.89  $\mu\text{m}$  with a SD of 13.09 and a minimum of 2.41  $\mu\text{m}$  and max of 110.51  $\mu\text{m}$ . The average aspect ratio of the erionite from all samples is width:length 1:14.36 with standard deviation 11.23 and minimum 1:3.26 and maximum 1:137.88 as seen in figure 36. The fiber size distribution by length and width is seen in figure 35.

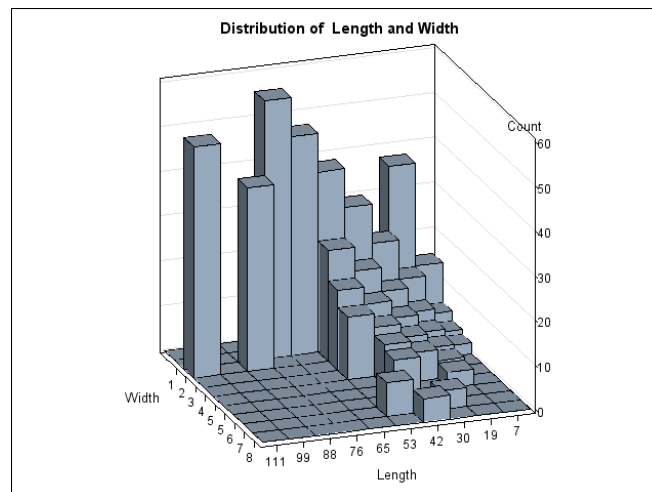


Figure 35: Fiber size distribution by Length and Width

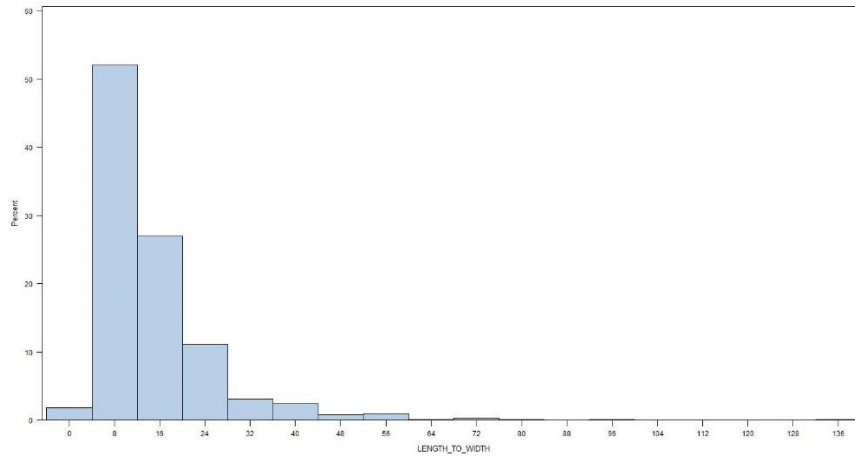


Figure 36: Fiber aspect distribution by Frequency

In the respirable range, 80.63% of fibers had widths less than 3  $\mu\text{m}$ , 89.01 % of fibers had lengths between 8 and 40  $\mu\text{m}$  and 71.89 % from all the fibers had widths less than 3  $\mu\text{m}$  and lengths between 8 and 40  $\mu\text{m}$ . 1110 fibers together weighed 0.00000028611 grams and 1 gram of erionite was calculated to contain 3,879,641,940 fibers.

### 3.3.5. Si:Al ratio

Table 8 shows the erionite fibers Si:Al ratio for a random sample of fibers analyzed by BVNA Labs. The boxplot in figure 37 shows a range of ratios from 2:1 to 7:1 with an average of 4.88, a minimum of 2.29, and a maximum of 7.33.

Table 8: Si:Al Ratio

Sample #	Si	Al	Ratio
401	2010.29	383.88	5:1
402	1867.03	276.11	7:1
501	2238.54	380.98	6:1
502	2082.5	326.41	6:1
503	2290.1	362.07	6:1
601	1168.48	161.11	7:1
602	464.05	91.27	5:1
603	2096.45	354.8	6:1
801	2035.89	344.21	6:1
802	1344.33	217.43	6:1
803	854.87	232.08	4:1
901	1222.26	266.45	5:1
1002	1263.36	295.82	4:1
1003	405.06	83.65	5:1
1101	794.46	108.28	7:1
1103	683.03	153.71	4:1
1201	313.77	67.13	5:1
1202	118.79	22.36	5:1
1203	1062.7	234.32	5:1
1303	703.56	157.43	4:1
1401	642.54	158.31	4:1
1402	978.97	223.62	4:1
1403	561.25	123.98	5:1
1501	769.05	192.94	4:1
1502	609	129.86	5:1
1503	1527.03	381.43	4:1
1601	722.03	151.86	5:1
1602	758.33	269.63	3:1
1603	568.48	134.73	4:1
1701	559.03	123.88	5:1
1702	410.31	178.41	2:1
1703	437.41	159.25	3:1
<b>Average</b>			<b>4.88:1</b>

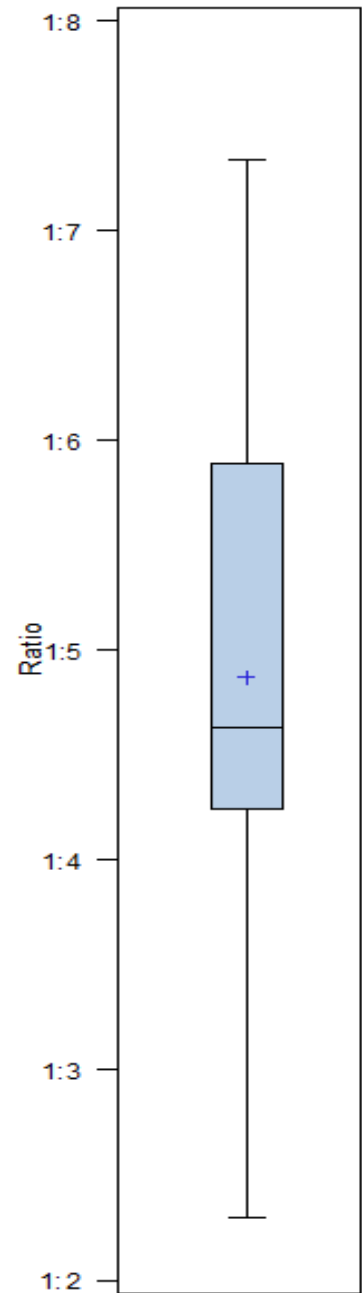


Figure 37: Si:Al Boxplot

### **3.4. Discussion**

The erionite fibers are small enough to reach deep into the lung. The carcinogenicity of asbestos or erionite fibers are dependent on numerous fiber parameters including fiber dimensions which are still debated in literature.

Microscopy analyses confirmed that all the soil samples contained erionite fibers with the exception of soil 22 in which no fibrous zeolite minerals were observed. The morphology of erionite fibers found in this study ranges from acicular to asbestiform. The erionite fibers from Karain, Cappadocia tend to have higher aspect ratio but smaller diameters and length than the Slim Buttes samples, although both samples have fibers with diameters less than 0.5  $\mu\text{m}$ .

The variability between replicates can be explained based on Poisson counting variation and variation in the FBAS filter preparation procedure. The FBAS filter preparation procedure may vary due to erionite variation between different samples of the tested soil, random variations in the concentration of erionite in the FBAS vessel air during fluidization, and elutriation, and uneven particle distribution on the filter.

### **3.5. Conclusions**

Based on the results from the investigations discussed above, the following conclusions can be made:

1. Erionite structures have been detected in the soils within the Sioux Ranger District that that may be due to anthropogenic releases from road construction and gravel processing

activities and normal weathering of erionite-containing rock. The average erionite concentration in background soil is approximately 0.14% by mass.

2. The concentration of erionite in the Sioux Ranger District background soils (<0.2% by mass) is well below the detection limit of traditional PCM/PLM methods, but is reliably detected by FBAS method and detected by TEM analysis according to ISO 10312 due to the high confidence in the fiber discrimination.

The results support the conclusion that there is a non-zero level of erionite in the soils surrounding CNF in Sioux Range District that can be attributable to natural occurring erionite originated from normal geologic, geomorphic or anthropogenic processes. However, the soil samples were taken at sufficient distance from the nearest road that the most likely source is geologic or geomorphic, either from formations containing erionite on the outcrops, or remnant particles after the erosion of the more extensive outcrops of the formations or wind erosion or downslope fluvial transportation from current outcrops.

## Chapter 4

### Location of Erionite Deposits in the Sioux Ranger District

#### Abstract

The principal goal of this third essay is to determine the prevalence of natural occurring erionite in Custer National Forest among the geological features of the Slim Buttes area. For this research, data collection of soil samples were performed by the CDC/NIOSH, North Dakota University, and USFS. This goal is accomplished by mapping the spatial variation of the erionite concentrations across the area using ArcGIS 10.2 software from ESRI. Inverse distance weighted interpolation is used to map the erionite concentrations in surface soils.

The typical accumulation of erionite on the surface of erionite-hosting geological layers is high, reaching almost 23%, compared to background soils where concentrations are less than 0.01%. These results lead to conclusions that the erionite prediction maps created can be used to quantify and map the spatial variation of total erionite concentration in surface soils. This research has significant implications for the identification of areas with naturally occurring erionite, which is important for monitoring and implementing best public health management practices across the Slim Buttes area and implementing risk communication to the affected audiences.



## **4.1 Introduction**

Numerous fibrous zeolite deposits are found in the Great Plains and Intermountain West region of the U.S.A. Erionite is a naturally-occurring zeolite that is confirmed to be present within the United States Forest Service (USFS) CNF Tri-State area (Montana, North Dakota and South Dakota). <sup>(401)</sup> CNF has three Ranger Districts: Ashland Ranger District, Beartooth Ranger District and Sioux Ranger District. The Sioux Ranger District encompasses eight distinct land areas in SE Montana and NW South Dakota of which we choose to investigate Slim Buttes area located in Harding County. The principal goal of this third essay was to determine the prevalence of natural occurring erionite in Slim Buttes area.

The Sioux Ranger District visiting attractions include two national landmarks (Capitol Rock and The Castles), a campground, an antelope reservation, a deer and turkey hunting, fishing, and bird watching areas. The Castles is a 1,005 acres National Natural Landmark that was added to the National Register of Natural Landmarks in 1978 and is located in the northern part of the Slim Buttes area of the Sioux Ranger District.

### **4.1.1. Erionite in South Dakota**

The Slim Buttes area consists of very deep canyons with well drained soils shaped by colluvium weathered from sandstone or siltstone, with up to 12% silt. <sup>(402)</sup> Slim Buttes contains the same geological formation as the neighboring Killdeer Mountains in Dunn County, ND where

the presence of erionite was identified by Nels Forsman in the 1986 Geological Survey Report of Investigation. <sup>(403)</sup>

The historic events of the area include the Battle of the Slim Buttes, which is adjacent to the studied area in this project and considered sacred to the Lakota Sioux tribes, and several abandoned uranium mines in undisclosed locations. The current use for Slim Buttes area is almost exclusively recreational and is maintained by USFS.

Federal agencies have written health and safety programs and protocols for fire suppression and response activities designed to limit forest workers and firefighters' exposure to potential hazards during forest fires and maintenance activities as seen in figure 38, but no procedure is currently in place to minimize the exposure to NOA although soils in U.S. National Forests are known to contain mineral fibers. For example, the 2012 Chips Fire in the Plumas National Forest, CA burned over 75,000 acres and much of the burn scar was over soils containing up to 1.75% chrysotile <sup>(404)</sup>. Another recent fire in West Long Pines Hills of Custer National Forest (figure 39) burned as much of 10,200 acres as of end March, 2015 and may include the same geological zeolite fiber-rich formations as Slim Buttes.



Figure 38: Firefighters digging fire-lines



Figure 39: Fire in West Long Pines Hills, Custer National Forest

There is currently no known safe level of exposure to erionite due to limited literature documenting the adverse effects of levels of exposure. There is also a risk of exposure to NOA present in farming and agribusiness as shown in figure 40, where prudent measures to reduce the generation of dust and the likelihood of breathing in dust should be taken. Harding County is primarily rangeland that is grazed by cattle and sheep. While grain production is a small part of the agricultural industry in the county, it does provide a substantial income for a number of farmers with the primary crop being corn. <sup>(405)</sup> Although advice for controlling dust release for farmers for personal protection and around residential buildings is available on United States Department of Agriculture (USDA) /USFS websites, there is little or no references to NOA.

Lately, drilling permits for oil and gas production have also raise questions about possible erionite exposure due to drilling activities along with the well-known fugitive dust release from road usage that are a potential source of erionite exposure. (406)



Figure 40: Fugitive dust released through agricultural tiling

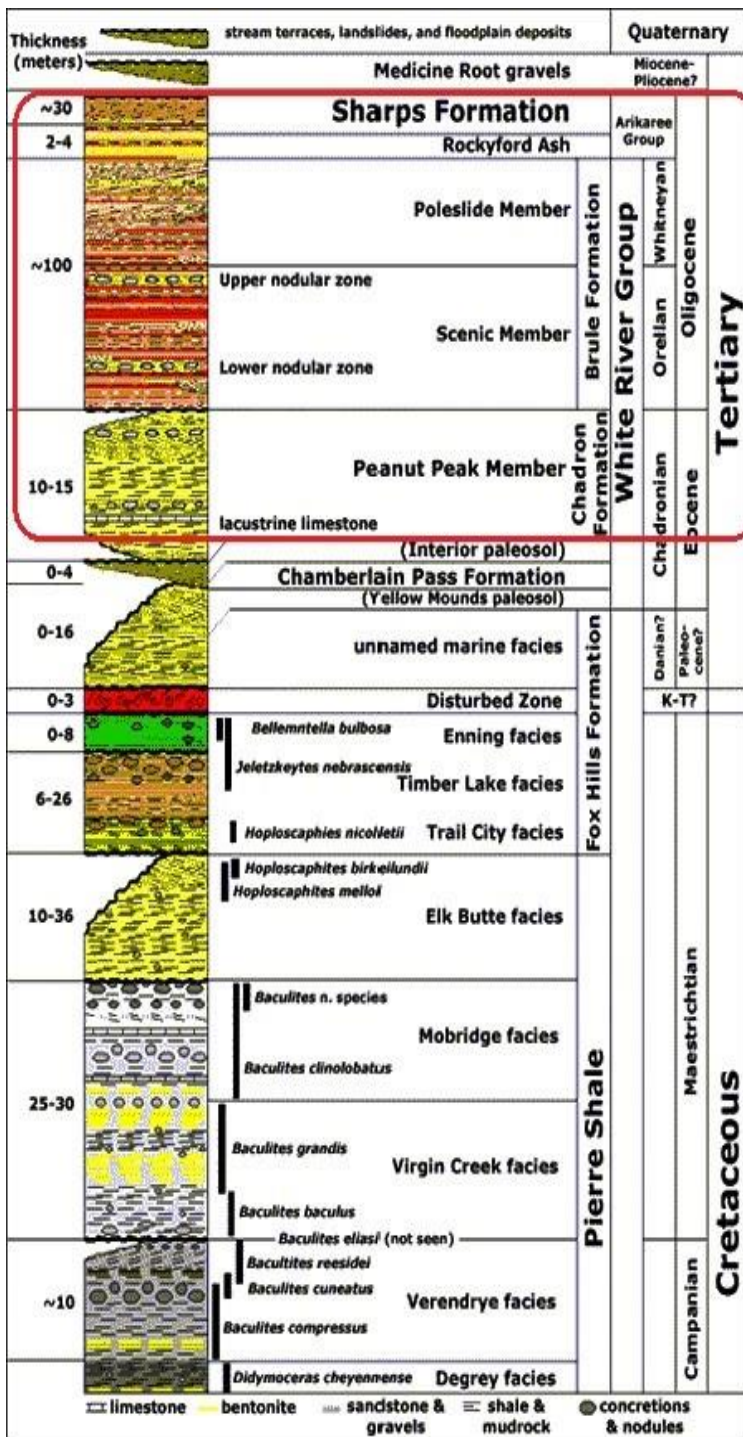
Erionite occurs naturally in soils where volcanic ash and rock have been altered by alkaline water or tuff deposited in lake environments. These erionite bearing rocks come in a number of colors. These include yellow, orange, green, and occasionally white. Layer thickness ranges

from one centimeter to several meters. In the U.S., erionite originates from nonmarine tuffaceous rocks that are mainly lacustrine in the Miocene Sharps Formation.<sup>(407)</sup> The erionite bearing rocks in Sioux District are comprised of three distinct layers: Arikaree formation (massive white flat-lying beds), Brule-White River Formation (pink color dipping beds) and Chadron- White River Formation, detailed in figure 41 and 42. All of these geologic formations have been analyzed and determined to contain erionite mineralogy.<sup>(408)</sup> Exposed portions of the Chadron, Brule, and Arikaree formations are scattered throughout the South Dakota (including the CNF), North Dakota and Montana area in isolated buttes. Also, fibrous erionite tends to form focally as a alteration product in the host rock and so the exact location within a geological stratum can be variable.<sup>(409)</sup>

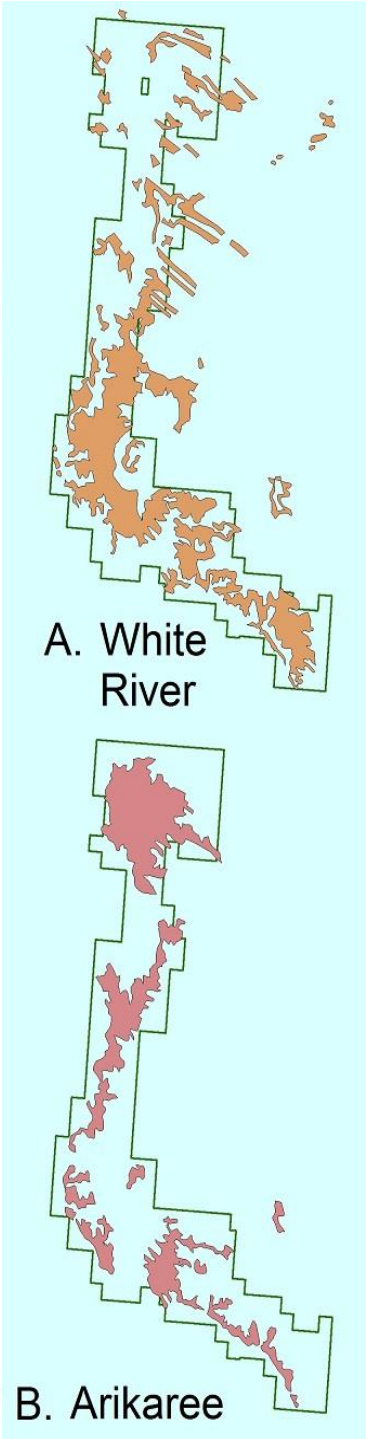
The principal outcrops in Slim Buttes are known locally as “The Castles.” The erionite fibers in these formations, under certain climatological conditions, may become either water borne and accumulate in sediment and steam beds or become airborne and transported by winds. Wind transport of mineral dust occurs commonly in semi-arid areas like the CNF due to wind erosion/deflation from lands with sparse vegetation cover. Therefore, NOA-bearing rock or soil can easily release mineral fibers into the air.

Studies<sup>(220, 227 and 240)</sup> have suggested that breathing naturally-occurring erionite has the potential to harm a person’s health over a lifetime and erionite-disturbing activities could result in higher levels of exposure that can increase the risk of developing and mesothelioma. Identifying specific geologic settings and formations that are hosts to erionite can be useful in developing Public Health management plans.<sup>(408)</sup> For example, road and building constructions, grazing, tilling, hiking and drilling activities could be permitted only in areas that are erionite-free locations.





ERIONITE BEARING ROCKS



Picture credit: Philip Stoffer

Figure source: Stoffer, 2003, Geology of Badlands National Park: A Preliminary Report

Figure 41: Composite columnar section for NW South Dakota



Figure 42: Erionite Bearing Rocks in Sioux Range District displaying layers of Arikaree on top, Brule in the middle section and Chadron at the bottom.

## 4.2 Methods and Data Collection

The analytical results were drawn from the following surface soil samples collections.

### 4.2.1 Soil Samples

A total of 62 locations in different background areas were sampled in CNF of Harding County. This sampling was conducted according to the U.S. EPA Preparation of Soil Sampling Protocols. (408) Figure 43 provides the location of these soil samples. The location of these sample were selected to evaluate the exposure of USFS employees (USFS and NIOSH sample collections) and Harding County residents (North Dakota University sample collection).

The soil samples listed in table 9 were collected by USFS personnel in 2014 by using a plastic scoop and sampling the uppermost, less than 2 cm, loose soil from the surface.

Table 9: Samples collected by USFS on September 9-10, 2014

Soil #	Coordinates N	Coordinates W	Elevation (ft.)	Soil Description
Soil 1	45.377150	-103.722767	3915	Dry, sand/ gravel/rocks
Soil 4	45.378500	-103.715100	3986	Dry, vegetation, compact sand,
Soil 11	45.376867	-103.719467	3946	Dry, heavy vegetation sand/gravel
Soil 12	45.378050	-103.710500	3940	Dry, vegetation, gravel/rocks
Soil 13	45.376967	-103.719917	4051	Dry, light vegetation, sandy
Soil 16	45.525983	-103.178567	3301	Wet, light vegetation
Soil 17	45.528067	-103.176883	3342	Wet, heavy vegetation, rocks
Soil 19	45.531450	-103.178517	3299	Wet, heavy vegetation
Soil 21	45.530867	-103.178650	3347	Wet, heavy vegetation
Soil 22	45.582750	-103.198633	3632	Light vegetation, compact sand

Additional soil sampling was done by CDC/NIOSH personnel in 2014. The goal of this sampling was to obtain representative samples to characterize the erionite concentration in soil outside the CNF boundary. See table 10 for a listing of locations of these samples.



Table 10: Samples collected by CDC/NIOSH on November 2, 2014

Sample #	Coordinates N	Coordinates W	Elevation (ft.)
4	45.469217	-103.318183	3090
5	45.412633	-103.233300	3239
6	45.400200	-103.159467	3227
7	45.547833	-103.319433	2910
8	45.412833	-103.237117	3209
9	45.277367	-103.190117	2870
10	45.515333	-103.319650	2915
11	45.332483	-103.163267	3230
12	45.457550	-103.055283	2970
13	45.301650	-103.167317	2960
14	45.515350	-103.095850	3044
15	45.414567	-103.277933	3060
16	45.560000	-103.465650	2900
17	45.414750	-103.255950	3127

Further sampling was done by CDC on Aug 11-12, 2015 to acquire sampling data inside CNF boundaries as seen in table 11. Lastly, the samples in table 12 were supplied by Dr. Larry Stetler, Professor of Geological Engineering at South Dakota School of Mines & Technology and collected by personnel at North Dakota University. Samples 26 and 27 were duplicates and also sample 8 and 9 were duplicates

Table 11: Samples collected by CDC/NIOSH on Aug 11-12, 2015

ObjectID	Coordinates N	Coordinates W
1	45.53905	-103.18144
2	45.54728	-103.18293
3	45.55962	-103.19855
4	45.59187	-103.18725
5	45.5753	-103.1663
6	45.44608	-103.19988
7	45.47336	-103.20515
8	45.41441	-103.20588
9	45.40302	-103.22163
10	45.38825	-103.21935
11	45.37328	-103.1889
12	45.369194	-103.152639
13	45.352444	-103.120333
14	45.371778	-103.136611
15	45.278361	-103.141111
16	45.255167	-103.077
17	45.320667	-103.142222

Table 12: Samples collected by North Dakota University

Sample	Latitude	Longitude	Elevation
SB-SD-1-1	45.32469829	-103.1139631	2930.1
SB-SD-2-1	45.30676228	-103.1175469	2867
SB-SD-3-1	45.31940002	-103.1984953	2897
SB-SD-4-1	45.32680293	-103.1567773	2967.6
SB-SD-5-1	45.34129737	-103.199613	3022.18
SB-SD-6-1	45.37684486	-103.0825115	3202
SB-SD-7-1	45.39049101	-103.1008463	3181
SB-SD-8-1	45.41461604	-103.1299648	3144.6
SB-SD-9-1	45.41461604	-103.1299648	3144.6
SB-SD-10-1	45.45274794	-103.1497903	3201
SB-SD-11-1	45.42905731	-103.161165	3228
SB-SD-12-1	45.42880526	-103.0896765	3092
SB-SD-13-1	45.44784583	-103.0993425	3098
SB-SD-14-1	45.43141033	-103.0326934	2944
SB-SD-15-1	45.4873971	-103.1172949	3069.6
SB-SD-16-1	45.49611463	-103.061126	3022
SB-SD-17-1	45.54336872	-103.1246102	3107
SB-SD-18-1	45.53857377	-103.0741043	3037
SB-SD-19-1	45.57151565	-103.0947792	3064
SB-SD-20-1	45.51616438	-103.2974295	2890
SB-SD-21-1	45.5253162	-103.215963	3151
SB-SD-22-1	45.46971003	-103.3186352	3073
SB-SD-23-1	45.45188605	-103.2870743	2969
SB-SD-24-1	45.41521587	-103.2789634	3048
SB-SD-25-1	45.41515603	-103.3270926	3168
SB-SD-26-1	45.35338703	-103.2506547	2982
SB-SD-27-1	45.35338703	-103.2506547	2982
SB-SD-28-1	45.35981328	-103.284032	3069
SB-SD-29-1	45.38946725	-103.2700573	3062

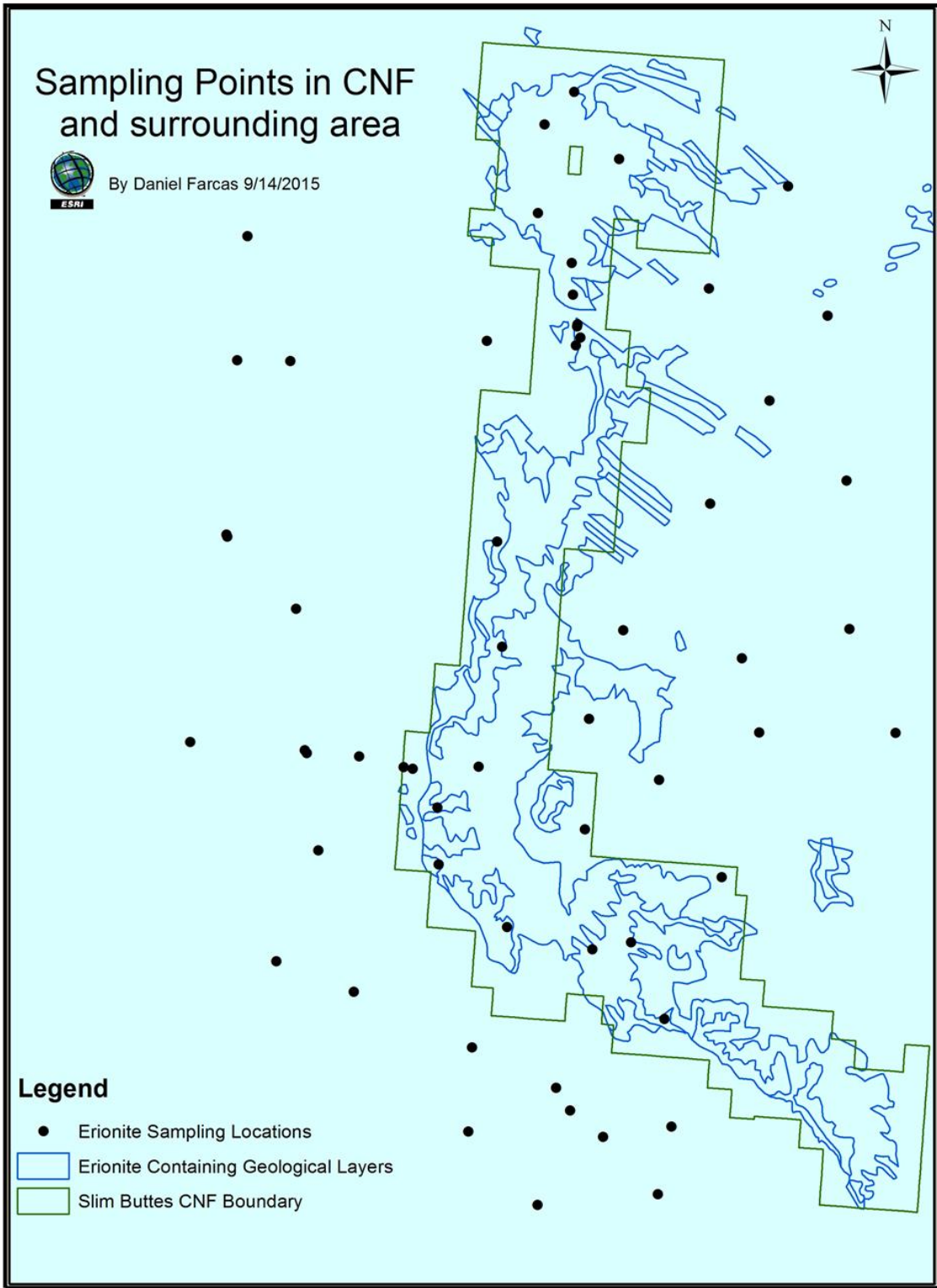


Figure 43: Soil sample locations NIOSH, NDU and USFS

## 4.2.2 Geostatistical Methods

The fitting of mathematical erionite models was done using GIS software ArcGIS 10.2 with the help of the Geostatistical tool. Geostatistics is a sub-discipline of statistics that focuses on spatio-temporal datasets developed to predict probable distributions. <sup>(410)</sup> The use of Geostatistics utilizes an assumption that adjoining points are spatially related, based on spatial autocorrelation of continuous surfaces. The Geostatistical extension of ArcGIS employs the cross-validation technique that removes one or more data locations and then predicts their associated data using the data at the rest of the locations.

The prediction maps in this study were created with ArcGIS 10.2 software, using Geostatistical Analyst Tool. Geostatistical interpolation techniques can be used to predict values for unmeasured locations but they also assess the uncertainty associated with the predicted value. There is no one best universal interpolation method that works best for any data set. <sup>(411)</sup>

In this study, spatial interpolators help us estimate the value of properties of unsampled locations within the area covered by known samples. The most commonly used interpolation models in soil science and geology are Inverse Distance Weighting (IDW), Ordinary Kriging and Global Polynomial. <sup>(412)</sup>

Each interpolation method has inherent assumptions and algorithms for estimation. The basic rationale of all these methods is that the points close together are more alike and have similar values as compared to points that are far apart. <sup>(416)</sup> For a particular data set an interpolation method may work best because of the study's objectives, the characteristics of data, the type of surfaces to be generated, and the tolerance of estimation errors. The best interpolation method is found through understanding the data set and through selecting the most appropriate interpolation method based on comparative evaluation to other methods. The best

interpolation technique for a chosen data set is based on values of the statistical parameters. Common statistical indicators are Root Mean Square Error (RMSE), Mean Error (ME), Mean Absolute Error (MAE) and Mean Square Error (MSE). These computed statistical parameters are calculated, and the best predictive concentration models are chosen based on these values.

(412)

Inverse Distance Weighted (IDW) is an exact, quick, deterministic interpolator. <sup>(417)</sup> Sample points values are weighted during interpolation calculations so that the influence of one point to another point drops off with distance from a new point. The weighting power controls the weighting factors decline as the distance from a new point increases. Its main weakness is that equal weight is assigned to all of the data points even if they are inside a cluster of uneven distribution. The EPA uses the Inverse Distance Weighting modeling technique to trace contaminants or other elements in soils. <sup>(413)</sup>

Ordinary Kriging is a stochastic interpolator and is somewhat unique among the interpolation methods because it provides a very simple method for characterizing the variance of predictions. <sup>(418)</sup> In kriging, modeled data are considered homogeneous across the surface and the pattern of variation is the same at all locations on the surface. The basis of this technique is the rate at which the variance between points changes over space. The major disadvantage of kriging is that the original input data points are rarely at the value introduced because as a smooth interpolation method the main objective is to avoid spatial blunders by following spatial trends.

(419)

Global Polynomial is an inexact/smooth quick deterministic method, fitting one polynomial through an entire dataset. It has the strength of creating very smooth surfaces and assumes a homogenous behavior (model) of the dataset. <sup>(420)</sup> Its weaknesses are that higher-order polynomials can extend to ridiculously large or small values outside of data area while the model itself is susceptible to outliers in the data set.

### **4.3 Results**

A cluster of samples was identified visually and (also detected geostatistically in) the interpolation model. Five samplings of soil data, which were very close to each other in the Pine Hills area and at great distance from the area of interest Slim Buttes, were deemed irrelevant to the area of interest and were not used in the interpolators calculations. (See Annex 1).

#### **4.3.1 Geostatistical Methods**

The GIS modeling methods were assessed for their quality of predictions based on the Root-Mean-Square of Prediction Error (RMSE). Table 13 reports the RMSE value for each geostatistical method and on Annex 2 shows the prediction errors for each sampling location using the IDW method. Inverse Distance Weighting yields the lowest RMSE value and was chosen as the best fit prediction model for this study.

Table 13: GIS modeling methods studied

Geostatistical Methods	Root-Mean-Square of Prediction Error
<b>Inverse Distance Weighting (IDW)</b>	<b>0.0033</b>
<b>Global Polynomial Interpolation</b>	0.0036
<b>Local Polynomial Interpolation</b>	0.0034
<b>Kriging</b>	0.0034

#### 4.3.2 Histogram

As shown in the figure 44, the distribution of data shows two distinct distributions of erionite soil concentration within the soil samples. The first distribution contain values varying from 0.009% to 0.39% for samples outside the erionite-containing geological layers. The second has a range of, 1.03% to 22.9% for samples inside the erionite-containing geological layers. Histogram statistics for erionite log data are found in table 14.

Based on these findings, a map symbology classification for prediction map was done using the geometric interval method with 10 classes.



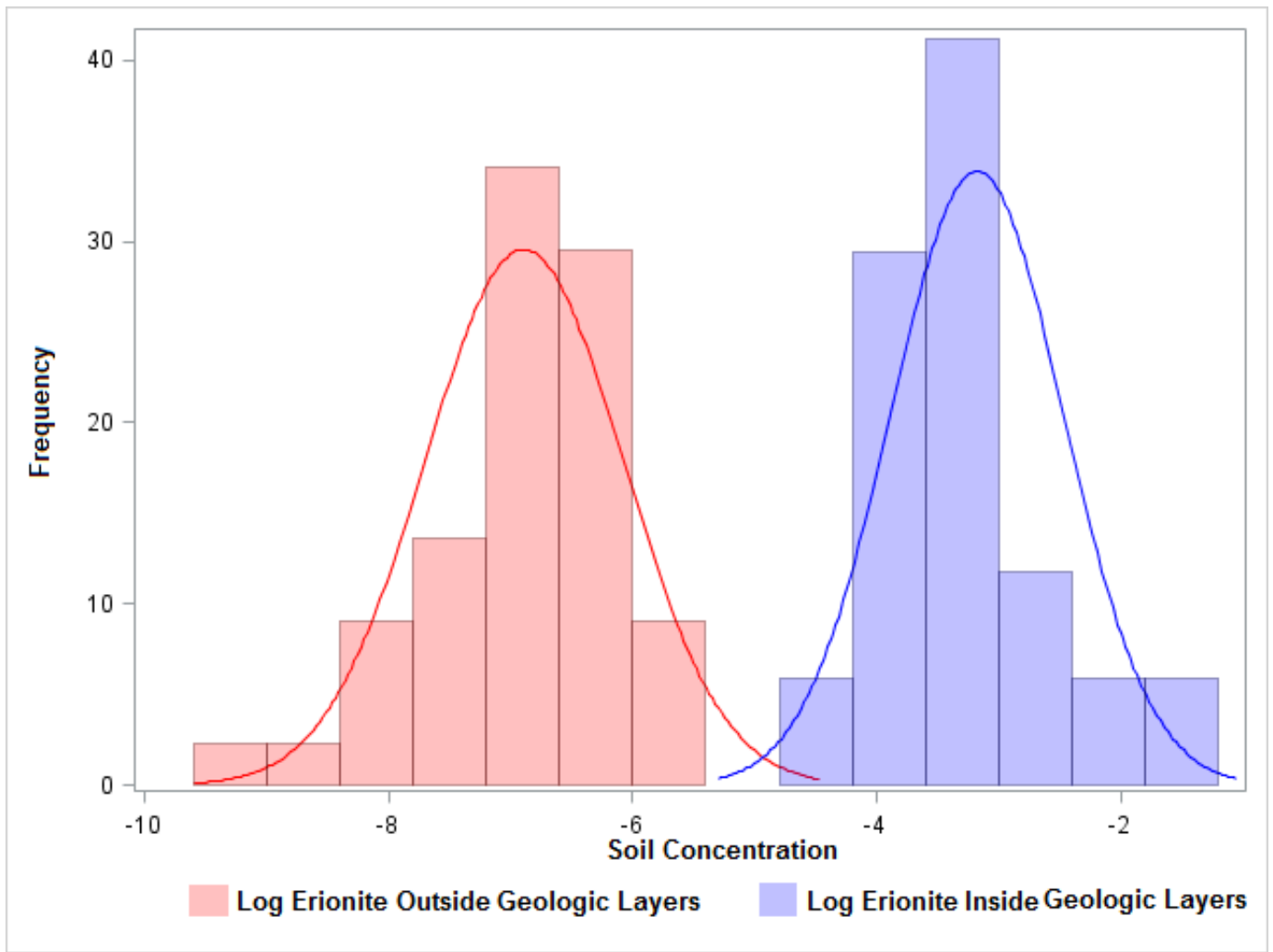


Figure 44: Histograms of erionite soil concentration data

Table 14: Histograms statistics for log data

Outside Geological Layers		Inside Geological Layers	
N	44	N	17
MEAN	-6.89	MEAN	-3.17
SD	0.80	SD	0.70
Skewness	-0.90	Skewness	0.65
Kurtosis	0.76	Kurtosis	1.49
Min	-9.31	Min	-4.57
Max	-5.52	Max	-1.47

### 4.3.3 Prediction Map

Figure 45 shows an area of 129.52 square miles was predicted to contain erionite levels of at least 1% or above. As observed, erionite-containing geologic formations occur both within and on lands adjacent to CNF boundaries. The high levels of erionite soil concentrations (above 2.8%) overlap substantially with the erionite-containing geologic formations, particularly inside the CNF boundaries. Outside the CNF boundaries, soil concentrations of erionite are predicted by the interpolation method to be low. However, the actual values are expected to be higher because the interpolation model did not account for the spatial variability of the two distinct soil sample distributions (figure 44) and the inside-outside classification of erionite-containing geological layers.

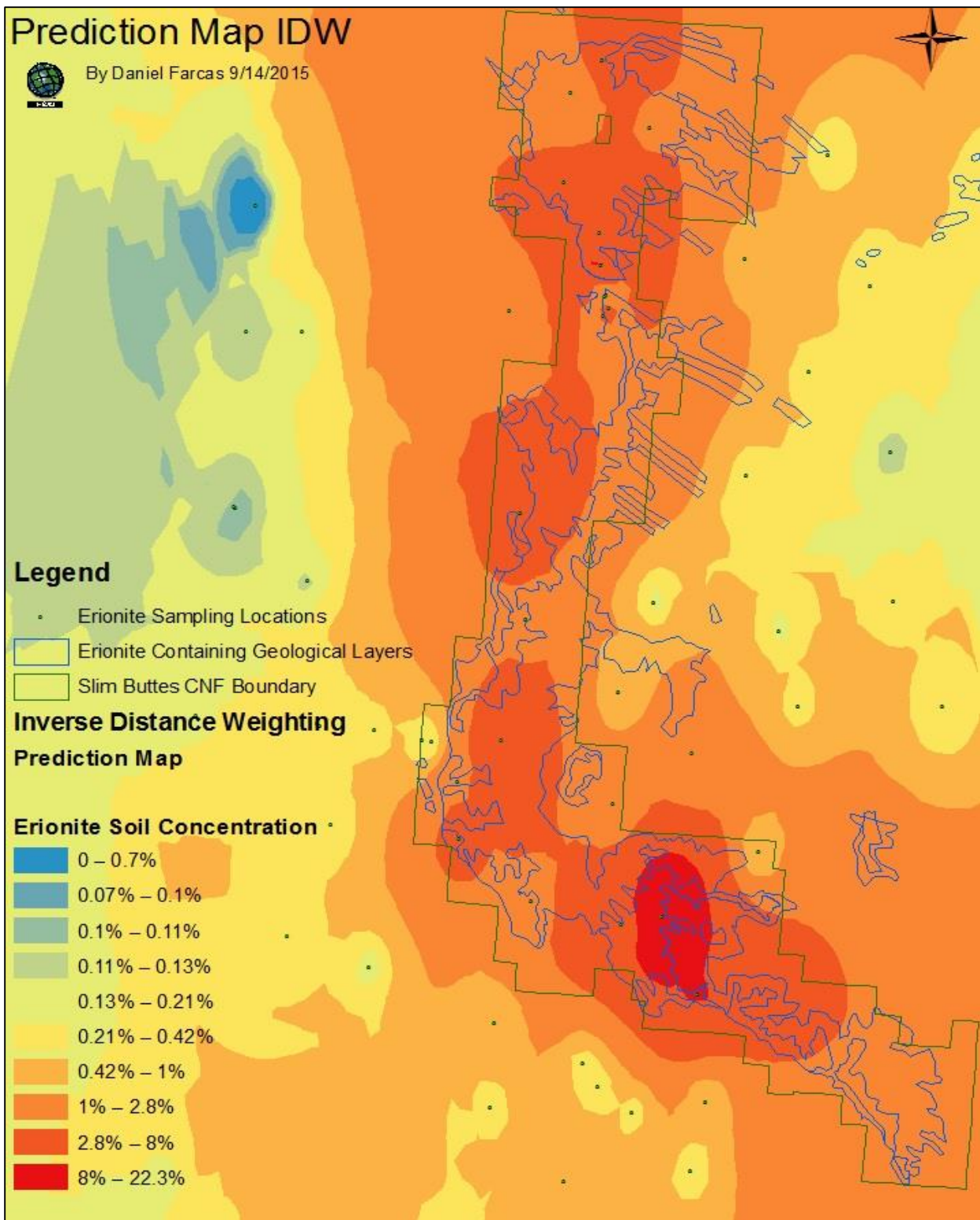


Figure 45: Prediction Map of Erionite Soil Concentration

Although the accuracy of the prediction map can be improved in some sections by obtaining and analyzing more soil samples, the overall reliability of this map should allow government officials to correctly identify the areas within Slim Buttes of the CNF which should be of the most concern for the region.

#### **4.4 Discussion**

Based on the prediction map we can state with confidence that there is an area where erionite is at or above 1% soil concentration in Sioux Ranger District. The accumulation of erionite in the Sioux Ranger District was found to be significantly higher in the surface soils where the erionite occurs naturally, reaching 22.9%, compared to background soils where the concentration was less than 0.01%.

Micro-scale variability in the prediction model may be due to structural soil factors, such as parent material, water table, as well as random factors, such as soil management were not taken in account in this study. Further studies should include a larger number of soil samples with detailed diagnoses based on topography features and anthropological activity inputs.

The erionite deposits are hosted by specific geologic layers and formations that experienced a specific geologic environment that lead to the formation of erionite. It is also important to recognize that although the erionite-bearing sites contain soils contaminated with erionite, which may constitute a health hazard, the erionite itself is coming from geologic units that are located in the proximity of the sampled soil. The readers should not view the reported erionite occurrence in the soil as just site-specific but also as an indication to the regional geologic conditions and rock formation. Thus, identifying erionite-bearing/forming rocks units across the contaminated area and stopping future erosion should be the priority. The erionite soil concentration prediction map seen in figure 45 is useful for an overview of preliminary data. Its intended use is to justify

and help prioritize soil sampling for a larger, more detailed research study in the area in order to should improve the mapping accuracy of erionite-containing soils.

Recent studies advocate for interactive map-mediated risk communication to the public. In this case an aerial image can be used as the background layer while risk ladders could be represented against the standard acceptable risks. A dedicated website page with interactive clickable icons in specific areas of the map may allow the server to offer more information to the end-user and allow him/her to upload additional data or pictures. <sup>(414)</sup>

Symbolic risk colors and shapes can express an inappropriate risk message while topographies choices can ease or hardship the orientation on the map and its accuracy. Risk perception is easily manipulated by the choice of map features. <sup>(415)</sup>

#### **4.5 Conclusions**

This section of the dissertation forecasts the erionite soil concentration landscape using ArcGIS IDW modeling map to describe the spatial distribution and to produce graphical outputs that will aid scientists and decision makers in developing a public health risk mitigation plan. The state authorities should continue to monitor erionite soil concentrations in the Sioux Ranger District area and identify unforeseen elevations.

Since erionite is almost never used in industrial application, it is not a cause for concern in occupational settings. Erionite in U.S. is not commonly used as residential or commercial building material, and as a naturally-occurring mineral is known to be found in soils that are mostly undisturbed which should made it easily manageable from the public health perspective. Erionite should be known to the public as a mineral with strong carcinogenic potential, and the public should be aware of its locations that unnecessary exposure may be avoided.

## Chapter 5

### Risk Communication

#### Abstract

Risk communication involves government authorities involving local people impacted by exposure to risks. As residential proximity to the naturally occurring asbestos (NOA) has been related to mesothelioma cases, communities across U.S. have become more concerned about their children health, property values and liability. The purpose of this fifth chapter is to present ideas and recommendations on how to start a risk communication dialogue with the Harding County community by exchanging information about the nature, magnitude, significance, and control of risk from natural occurring erionite (NOE) exposure. Exposure risk calculations from chapter 2 are used to show an amplified risk of mesothelioma from NOE, although each risk calculation has significant uncertainty associated with it, both calculations are based on equations developed for asbestos and not erionite,.

This last essay provides an outline for developing a risk communication plan that could be used by the local officials to formulate and convey risk messages to Harding County residents, USFS employees, and CNF visitors. Based on an extensive review of risk literature research, demographic and epidemiological data along with risk assessment calculations from chapter 2, a framework for dialogue between community and authorities is developed. The communication techniques explored include visual displays in the form of numerical data, log scale presentation, and persuasive graphic images. Several simple actions are suggested to minimize NOE exposure for occupational, residential, and recreational activities where geological sources are present in order to minimize the risk of exposure. NOA and NOE is generally considered safe if it is undisturbed and encapsulated by soil and/or vegetation. There is currently very little evidence that living above or near geology that includes mineral fibers is a hazard.

## 5.1. Introduction

Risk is defined by the Merriam-Webster dictionary as “the possibility that something bad or unpleasant will happen”, but different disciplines interpret and express the concept of risk in many different contexts and quantify it differently. <sup>(501)</sup> Measurement of risk in the workplace is commonly carried out objectively, due to the convenience of statistics, while subjective risk which is personalized to the individual takes in the account psychosocial work characteristics, workers' particular characteristics and work load. <sup>(502)</sup> The risk estimates generated in Chapter 2 are examples of objectively measured and calculation based risk using previously conducted risk assessments from the EPA based upon a very large pool of workers exposed to different asbestos fiber concentrations for the last century.

Perceived risk can be different from the objectively measured risk because it is subjective and is therefore biased by emotions, religious belief, etc. Experts and the general public often disagree when it comes to risk assessment. <sup>(503)</sup> People often distrust experts due to their government/political association while experts argue they are challenging the population to rationally let go of their irrational fears and beliefs. These ongoing disagreements unavoidably lead to the need for developing an effective strategy of risk communication by government officials where both parties can find a common ground by gaining trust and respect for each other.

Risk communication became recognized starting in mid-1980s as a necessary component in risk management and community decision making as the concern over toxic waste, nuclear power plants, and hazardous materials gained public attention and interest. The first national conference on risk communication was in 1986. At this conference, EPA Administrator William

Ruckelshaus addressed the difficulty of translating scientific information to the general public and advocated for the government to accommodate the will of the people and involve the local population in decision making process. <sup>(504)</sup>

For the last three decades risk communication has been mainly associated with community dialogue regarding environmental health decision-making about community issues such as air pollution, hazardous waste management, lead, pesticides, drinking water quality, and asbestos. <sup>(505)</sup> As the “legacy” exposure of job related asbestos starts to decline worldwide due to new environmental and work regulations and also the use of personal protection equipment, “future” exposures may increasing be due to NOA via the disturbance of the material in *situ*. <sup>(506)</sup>

The objective of this last chapter is to present ideas and recommendations on how to start a dialogue with a community at risk by exchanging information about the nature, magnitude, significance, and control of risk from natural occurring asbestos (NOA). In this Chapter, the focus will be on Harding County residents and their exposure to erionite, a newly discovered NOA-like material in their community.

## **5.2. Background on NOA Exposure**

Residential proximity to NOA has been found to account for mesothelioma cases. <sup>(503)</sup> Workers who were exposed to asbestos products previously used in construction materials, (examples include asbestos used in cement products, wall, attic and pipe insulation, ceiling and floor tiles, mastics, grout, spackle and asphalt) could have also be exposed to NOA in the ground in the same time, as shown in figure 46.





Figure 46: NOA or Asbestos?

Prospecting for asbestos began in the mid-1800s due to the demand for asbestos-based products. The United States Geological Survey (USGS) has identified 35 out of 50 U.S. American states as containing NOA including South Dakota (Figure 47). There are two areas: the first area begins in Eastern Canada and extends down to the eastern coastal and inland states, and the second area stretches from Alaska through British Columbia, Washington State, Oregon and ending in California. USGS counted a total of 60 former asbestos mines and 331 “natural asbestos occurrences.”<sup>(507)</sup> Although several studies have tried to find patterns of geographical distribution of mesothelioma cases based on NOA, given the long latency for mesothelioma and the small exposed population the data was deemed insufficient for detecting trends.<sup>(508)</sup>

## The distribution of natural occurrences of asbestos in the continental United States

Bradley S. Van Gosen, USGS, and John Clinkenbeard, California Geological Survey

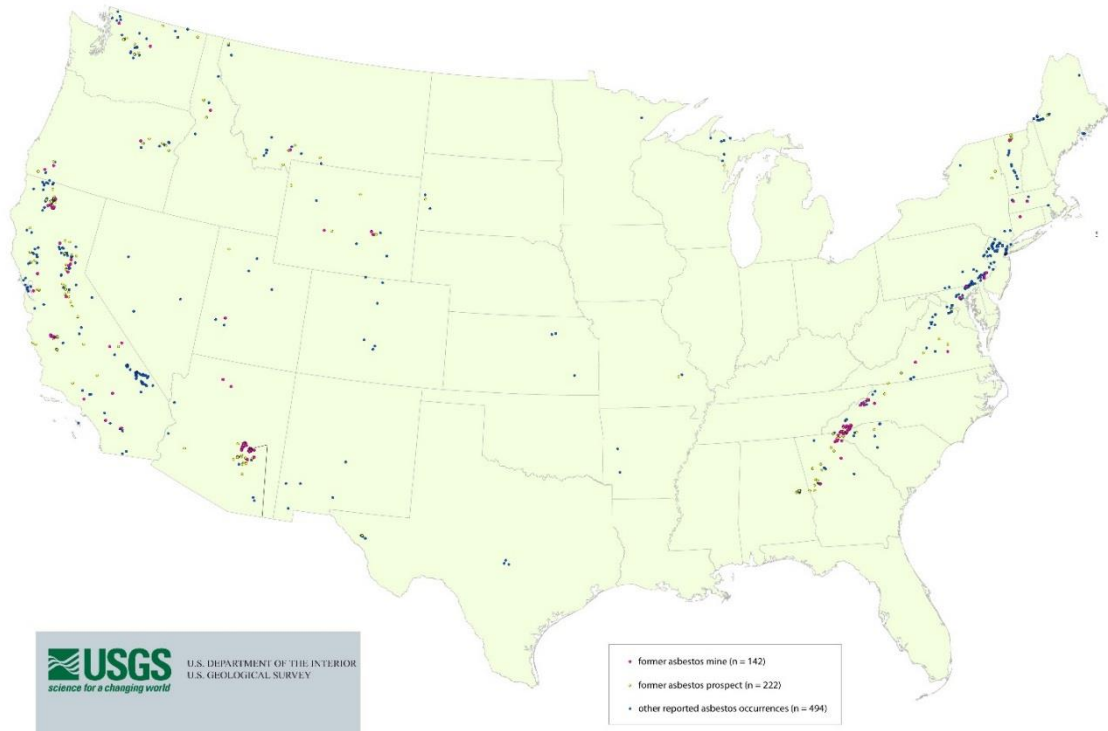


Figure 47: The distribution of natural occurrence of asbestos in the continental U.S.

Generally, cancer clusters garnish considerable public, press and legislative attention but rarely, if ever, produced important findings. <sup>(509)</sup> CDC's 1990 Guidelines for Investigating Clusters of Health Events stated that "the perception of a cluster in a community may be as important as, or more important than, an actual cluster" and defines a cancer cluster as a "greater-than-expected number of cancer cases that occurs within a group of people in a geographic area over a period of time." <sup>(510)</sup> Currently, as observed in the figure 48, there are no mesothelioma deaths in Harding County according to CDC's National Program of Cancer Registries (NPCR).

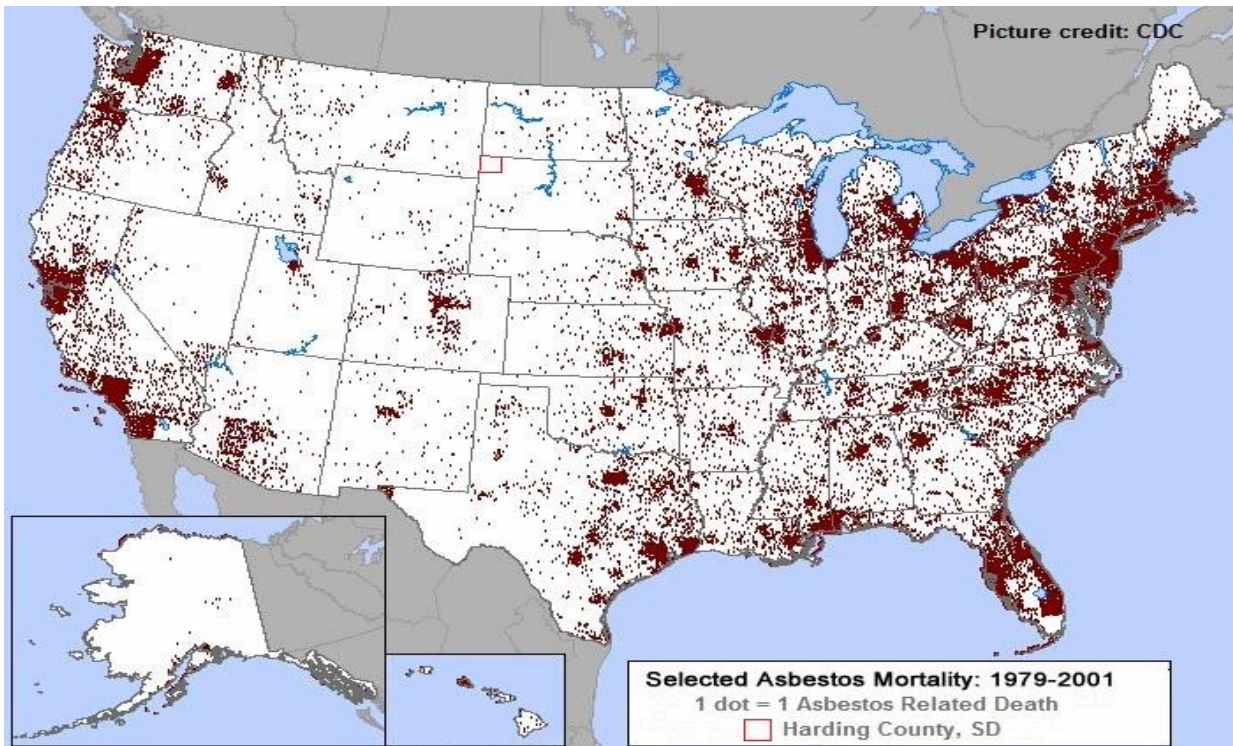


Figure 48: Asbestos mortality due to mesothelioma in U.S.

### 5.3. Risk Communication Principles

Dr. Peter Sandman is known for his unique and effective approach to managing risk controversies. He created the formula “Risk = Hazard + Outrage” for risk communication. In his book, *Responding to Community Outrage: Strategies for Effective Risk Communication*, Dr. Sandman advocates handling situations where the “hazard” is virtually perceived as unknown and the “outrage” is high <sup>(511)</sup>. In cases like these, the core task is outrage management.

Using Sandman’s perspective, erionite presents a natural risk, midway between voluntary risk and coerced risk. Some people might perceive it as “God’s coerced” risk so that the general public is less likely to be outraged by God than human created institutions, like a multinational

corporation. Also, people usually underestimate familiar risks so that, locals residents who have grown up in an area with erionite will most likely be less frightened than new residents or tourists.

In “Living and Dying from Asbestos,” Linda Waldman describes communities in newly-industrializing and developing countries where people's understandings of their illness, risk and compensation may be surprising to the western world. Locals understand that asbestos is already in their lungs and they grow up assisting relatives and other members in their community that are suffering and dying from asbestos related diseases. They still choose to remain in town and start families, while “caring for each other” and “being patient with one another.” Social support made them feel happy although they knew they are very likely to die of asbestos related diseases. Early death is considered an acceptable risk to take by the inhabitants in exchange for living in that community <sup>(512)</sup>.

In a good risk communication strategy, the general public has to be involved early, before any state or federal decisions are made. All available information should be released with in communication media as soon as it becomes available. People's trust for government officials has to be earned in an honest and compassionate way while motivating individuals to act to lessen their potential exposure <sup>(513)</sup>.

An effective risk communication for naturally-occurring erionite exposure is likely to be achieved if risk is explained in a culturally sensitive and caring manner supported by scientific evidence. Selective comprehension bias, where information is interpreted in a way that is congruent <sup>(514)</sup> with peoples' own existing values and beliefs, may be very influential in understanding risk perceptions and specific concerns of a population. Distrust of government, contradictory messages from different sources and community conflicts can lead to inaction and resistance to the local authorities' efforts to address risk.

## A. Residential Risk Communication

Long-term residential exposure to NOA is commonly associated with an increased risk of developing mesothelioma and each individual has its own acceptable risk level. It is common for individual jurisdictions to develop a personalized information package for distribution to their residents containing data on risk, identification, handling of asbestos-containing materials.

Although it may be cumbersome to explain to the general public risk numbers that are unfamiliar, they still easily understand risk messages that are presented visually or by sound. Appropriate visual aids dramatically improve comprehension as long as “people have moderate levels of graph literacy”.<sup>(515)</sup> As shown in the figure 49, 92% of the Harding County residents have high school degrees or above, while the average for South Dakota is 82.7%, and 81.4% in U.S.A.<sup>(516)</sup> This higher level of education in Harding County should allow them to readily comprehend graphical communication which should ease the risk communication.

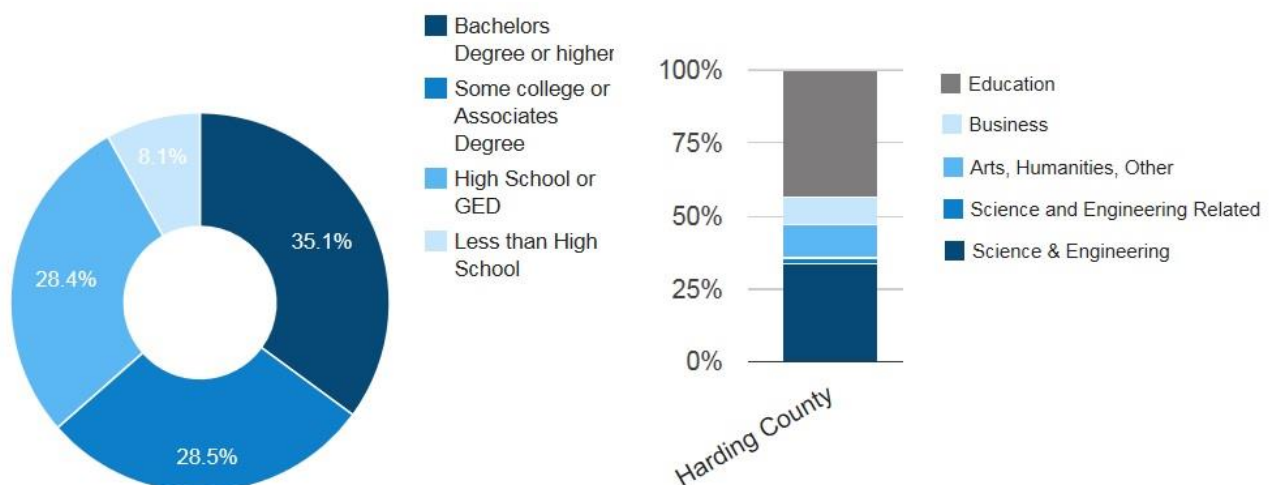


Figure data source: United States Census Bureau

Figure 49: Education Attainment Breakdown and Bachelor's Degrees Field of Study

## B. Occupational Risk Communication

Numerous research agencies, including the National Institute for Occupational Safety and Health (NIOSH), World Health Organization (WHO) and International Agency for Research on Cancer (IARC), have produced various safety document conveying risk and safety information to workers.

In the U.S.A. the four major federal health and safety regulatory agencies that enforce exposure limits to hazardous materials for workers are:

1. Occupational Safety and Health Administration (OSHA) through policies found in the U.S. Code of Federal Regulations (CFR) Title 29—Labor, parts 1900-1910.
2. Mine Safety and Health Administration (MSHA) by policies found in the U.S. Code of Federal Regulations (CFR) Title 30.
3. Environmental Protection Agency (EPA) through policies described in the U.S. Code of Federal Regulations (CFR) Title 40.
4. Department of Transportation (DOT) in the U.S. Code of Federal Regulations (CFR) Title 49.

These agencies enforce laws that minimize exposure and offer protection against hazardous substances, however, they do not reduce exposure risk to zero. The factors that may influence acceptance of risk varies from worker to worker based on their personal experiences, intellect and physical attributes. <sup>(517)</sup> If the risk is of a voluntary

nature, people feel that they are more “in control” of voluntary risks than involuntary risks. Some people accept higher risk in exchange for higher earnings. Examples include, healthcare workers accept their risk of exposure to blood borne pathogens and police officers choose to take the risk and expose themselves to dangerous situations and criminals. These risks are compensated by what the worker himself considers to be an appropriate amount of benefits that can be financial, social or personal gratification. <sup>(518)</sup> In Harding County, most occupational exposures to erionite will take place during forest maintenance and firefighting activities.

### C. Recreational Risk Communication

Risk-seeking recreational enthusiasts, like bungee jumpers or rock climbers have an extreme sport culture that gratifies risk-taking activities. Organized recreational activities that involve risk, like zip lining, commonly require recreational users to sign a release of liability or waiver of claims. <sup>(519)</sup> However, family oriented recreational activities occurring in the Custer National Forest of Harding County may have unexpected risks that the visitors are unaware of in terms of exposure to erionite. Thus, tourists hiking the hills of Slim Buttes are presently uninformed of the inherent potential hazards and risks associated with visitation of the recreational site.

There is a wide variety of risk communication strategies that can be used to efficiently inform the public. Communication experts in risk communication generally agree that there are three important elements in risk communication: <sup>(520)</sup>

1. The Message: The message should inform local communities about erionite health effects and where erionite can be found in their community.
2. The Medium: The medium could be brochures, billboards, or local television infomercials.

3. The Audience: The targeted audience should be the local community and the Sioux Ranger District visitors.

Addressing peoples' perceptions is the most common way to change a hazardous behavior with long-term adverse consequences. Hazards originated and transmitted through the natural environment with cumulative effect also require persuasion to change receivers' perceptions of the natural environment and their behaviors relating to this environment. <sup>(521)</sup>

#### **5.4. Risk Perceptions**

Risk perceptions are subjective judgements that people use to interpret the characteristics and severity of a risk by their own set of values and understandings (see figure 50). Presenting risk in a rational manner and weighing information before making a decision commonly alters people perceptions of risk. Paul Slovic advocates for the role of emotions and cognition in people conceptions of danger and he argues that experts should also respect these various factors (ranging from cultural to emotional) in their communication with the general public. <sup>(522)</sup>

An individual's perceptions of risk are also commonly decreased by greater familiarity, less dread, and increased personal control. <sup>(523)</sup> As an example, in 2010, there were 33 fatal dog attacks on individuals ranging in age from 4 days old to 87 years old and there were 5 fatal shark attacks (age range of 19 to 57 years). Statistically the chances of getting killed by a shark are 1 to 6.6 compared to the chances of being killed by a dog. However, shark attacks are usually lethal and thus people are more reluctant to expose themselves to risk from sharks because they perceive the magnitude of the danger.



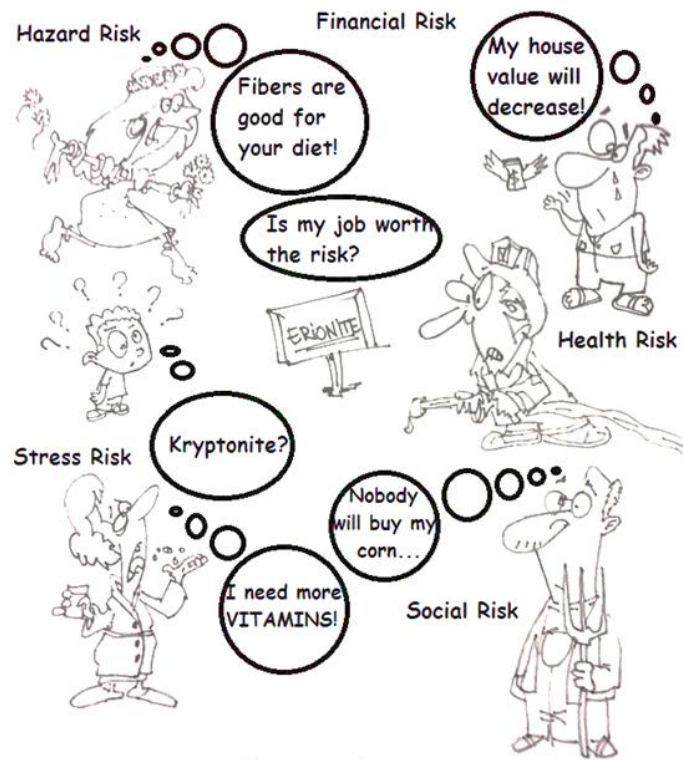


Figure 50: Implications of Risk Communication

### 5.5. Visual Displays of Risk Communication

Visual graphics displays are effective aids to communicate risk because the information is conveyed in forms that can be read or looked upon. Risk is normally expressed numerically on a probability scale with a range of probabilities span from 0 to 1, where 0 means there is completely “no risk” and 1 means the risk is absolutely certain. To understand the magnitude of a specific risk it is useful to compare the risk to other well-known risks

## A. Numerical Displays

Commonly, numbers are used to enhance quantitative risk communication. Graphic risk presentation is preferred by cancer screening patients. <sup>(524)</sup>

As shown in the table 15, lifetime risk of dying of mesothelioma due to erionite based on Chapter 2 calculations are displayed with and compared to lifetime risks of common activities. When compared with the risk of death from a motor vehicle accident according to the National Safety Council <sup>(525)</sup> or being diagnosed of any other forms of cancer according to the National Cancer Institute <sup>(526)</sup>, the lifetime risks from erionite exposure can be regarded as low to moderate. People living in Harding County are four times more likely to die in a car crash than develop mesothelioma or twenty times more likely to die of any other forms of cancer, 1 in 2.5 (0.4). As another example, a person living in Harding County has a chance of developing mesothelioma in his/her lifetime according to the Worst Case Scenario within 50 km of 0.0007, which is about equal to the chance of this person drowning, (0.0009) (Table 15).

Table 15: Lifetime Risks

Risk of being killed/dying	Lifetime Risk out of 10,000
<b>Venomous Animal or Plant</b>	<b>0.3</b>
<b>Acceptable EPA Cancer Risk</b>	<b>1</b>
North Dakota ELCR toddlers	2
Worst Case Scenario within 50 km	7
<b>Drowning</b>	<b>9</b>
North Dakota ELCR children	15
North Dakota ELCR adults	23
North Dakota ELCR seniors (lifetime)	26
<b>Dying in a Motor Vehicle Accident</b>	<b>100</b>
<b>Being Diagnosed with Cancer (all forms)</b>	<b>4000</b>

*Bolded data source: National Safety Council and National Cancer Institute.*

## B. Log Scale Presentations

For asbestos, ambient air concentrations of 0.001 fibers per cubic centimeter (f/cc) are considered “acceptable” by the World Health Organization, <sup>(527)</sup> “not significant” by the Ontario Royal Commission on Asbestos, <sup>(528)</sup> and “further control not justified” by the Royal Society of London. <sup>(529)</sup> This risk is considered as low as that presented by natural background radiation. Given exposure at 0.001 f/cc and at a normal breath rate of 10 liters per minute, 10 fibers are inhaled each minute by a “normal” non-occupationally exposed person depending on small variations such as location and weather conditions.

Current OSHA regulation for asbestos exposure includes a short-term permissible exposure known as Excursion Limit (EL) where exposure to the airborne concentration of asbestos is limited to 1 f/cc for a maximum of 30 minutes and a Permissible Exposure Limit (PEL) of 0.1 f/cc for a 8 hours work in all industries, including construction, shipyards, and asbestos abatement work. The PEL was set in 1971 originally at 10 f/cc.

Figure 51 shows, in log scale, the calculated erionite exposure results from chapter 2. Both results are well above the current PEL limit set by OSHA. This illustration compares early occupational asbestos workers that, until 1971, experienced asbestos concentrations that were ten times higher than 50 meter behind vehicles in normal weather (D class) on an average erionite-containing road. However, this PEL standard also is ten times lower than 50 meter behind vehicles in stable weather (F class) on a high concentration erionite-containing road. Cancer risk from these high levels of erionite exposure are indeterminable because the EPA's IRIS extrapolation curve reaches the value of 1 (certain death) at 4 f/cc.

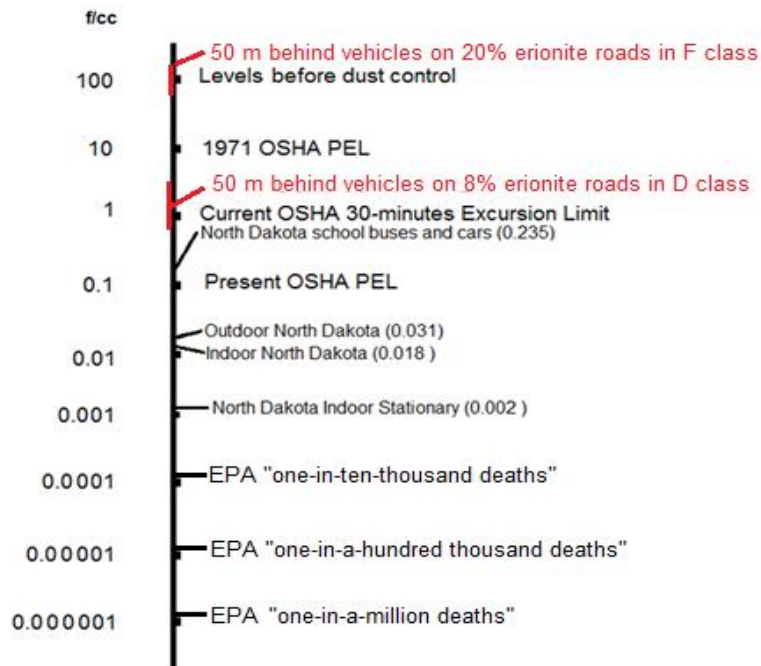


Figure 51: Log scale of fiber concentration per cubic centimeter.

### C. Graphic Images

The best sources of risk recollection and dread remembrance are personal experience, news or fiction. People who lived through the traumatic diagnosis and death of a relative or a friend with mesothelioma tend to take the exposure more seriously. Some well-known powerful pictures that advocate reducing asbestos exposure were first published in the Canadian newsletter "The Globe and Mail," and then republished around the world. In the pictures in figure 52, Blayne Kinart, a former pipe fitter is shown fighting an unwinnable battle with mesothelioma.



*Image source: Louie Palu*

Figure 52: Blayne Kinart a former chemical worker and mesothelioma victim

Another graphic image related to mesothelioma consists of a 9-year-old's letter (Breck grandson of mesothelioma victim Lyle Cassidy, figure 53) to the Canadian Mesothelioma Foundation conference. This letter gathered a lot of attention from the Canadian government which imposed more stringent regulations for asbestos and curbed its use.

I hope doctors will find out  
more about asbestis so it  
won't be so painful. I love my  
papa so pleas help him get  
better and every body els.  
~~who~~ who has aspestis and any  
other cancer. Even thos who  
apnt doctors can rais money  
for it. I am glad that people  
doh't use aspestis any more.

(Courtesy of the Cassidy family)

Figure 53: A 9-year-old's letter to the Canadian Mesothelioma Foundation conference

## 5.6. Frequently Asked Questions in Communities with Asbestos

A number of communities have included in their websites pages dedicated to frequently asked questions about asbestos (see Annex 8 for a listing). Below are some examples of questions and answers concerning NOA.

A. Did asbestos exist in air prior to its extensive use in industry?

Asbestos has been reported to be present in the Greenland ice cap which indicates that airborne asbestos was present in both hemispheres prior to industrial use. <sup>(530)</sup> But recent critiques of this 1977 presentation abstract have shown that there is no indication about who collected samples or where was the exact location. There was no methodology for dating the ice and no subsequent other reports of asbestos fibers found in ice were published since then. Figure 54 details pictures from that presentation.

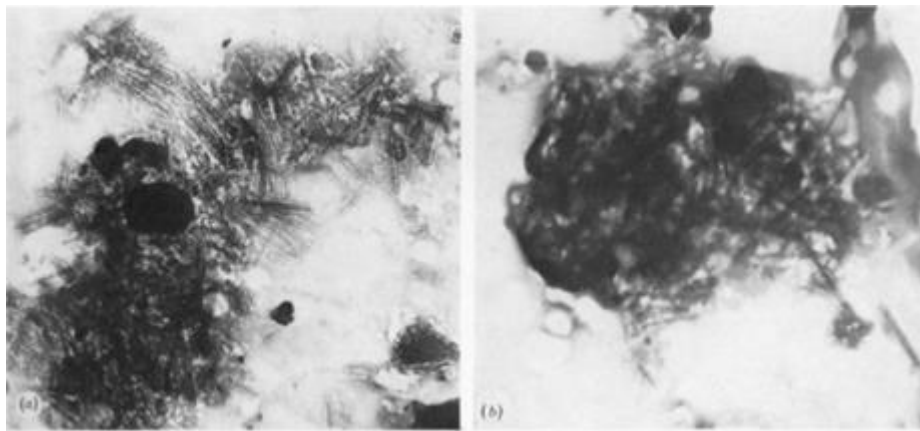


Figure 54: Pictures of asbestos supposedly from old Greenland ice (1977)

B. What is “environmental” asbestos?

The term “environmental” has been used to include occurrences of asbestos minerals in the environment that got there by many different pathways. Four such pathways are listed below:

1. Mine and factory tailings along with subsequent uses of these tailings. Solid waste containing asbestos has been used in gardens, school yards, race tracks and even airports. Such uses have created permanent sources of asbestos dust as demonstrated in figures 56 and 55.





Figure 55: Asbestiform amphibole dispersed by mining and milling activities



Figure 56: Turner Belting factory site, Cheshire, UK in the 1980's

2. Deliberate local use for whitewash. Substantial release and exposure to tremolite-asbestos took place through the lime solution used for whitening in paints all over the world.
3. Roadbase. Asbestos containing materials have been used as road base or as secondary concrete aggregates.



4. Soil excavation. Traditional construction activities have involved excavation into NOA containing rocks and soil throughout human history.

Asbestos has been used for centuries. The first use of asbestos dates as far as 3000 BC, when embalmed bodies of Egyptian pharaohs were bound in asbestos cloths. Through the years, the amount of worldwide use of asbestos has increased, including importing and exporting until the 1980s. In 2012, two million metric tons of asbestos was produced in the world and knowing that just one mg of asbestos can contain more than 100 million respirable fibers, its presence should be expected to be ubiquitous.

C. Is NOA going to affect my property value?

NOA risk perceptions may differ from community to community and even within communities. Logan and Moloch stated that: “Owned homes may provide their residents with an observable indication of their success in society. Thus, perceived threats to home and neighborhood may be experienced as threats to one’s sense of social status and/or self-esteem”. <sup>(531)</sup>

As one example, in the upscale suburb of Washington, DC with the highest median income of any county in US and with more than 1,000,000 residents (Fairfax Co., VA), tremolite and actinolite asbestos were found in rocks and soils that underlain individual properties, but “very little fuss” was made over it.

Fairfax County has an excellent web-site (<http://www.fairfaxcounty.gov/hd/chs/natural-asb.htm>) detailing the 11 mi<sup>2</sup> affected area including the town of Falls Church (Figure 57). Also, the county has an exposure control plan for use in construction projects that excavate

"asbestos containing material". A construction plan is needed for NOA areas and 6 inches of clean soil cover is required after disturbance. The state of Virginia does even not require disclosure for NOA in property sales and housing prices have risen steadily since the discovery of NOA was first made public in 1993.

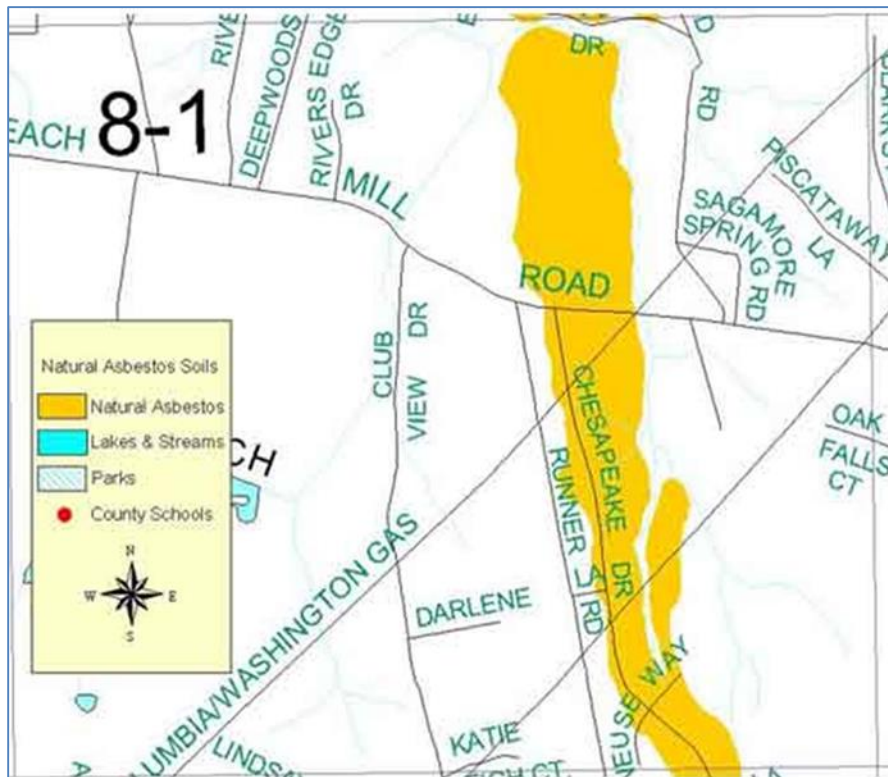


Figure 57: Map detailing NOA from Fairfax Co., VA website

The opposite impact occurred in California with the discovery of NOA under your property comes with more risks than asbestos exposure. Lowered home values have effects on psychological well-being of their owners and families as concluded in a study conducted in 2013: “The central tenet underlying the psychological impacts of housing is that our dwellings can affect what we think and how we feel. If true, then housing can play an important role not only in promoting psychological well-being, but also in reducing the incidence and severity of stress that can lead to psychopathologies and mental illnesses” (532)

As an example of this risk, a home built in the 1980's underlain by tremolite asbestos and valued at \$650,000 was sealed with 1,000 yards of clean soil fill, but construction dust from the home being built next door caused the owners to walk away (Figure 58). The county administrator Laura Gill declared that: "Some people are frightened. Others say they're glad we've got asbestos because maybe it will keep out all the folks who are moving up here." <sup>(539)</sup>



Figure 58: House underlain by tremolite asbestos in suburban county of El Dorado

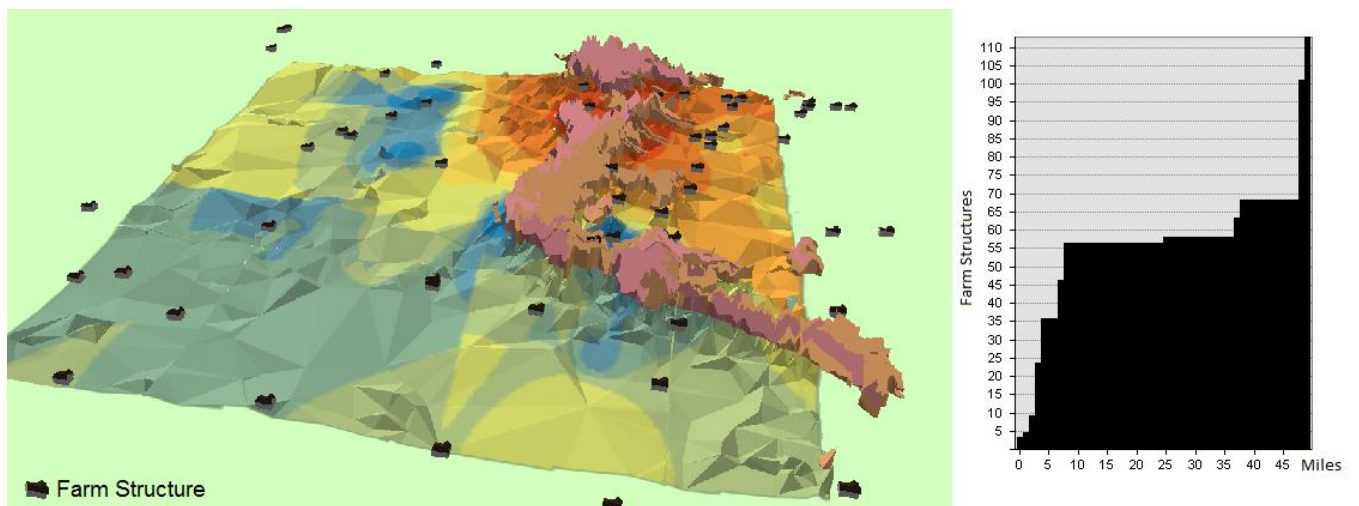
#### D. Is there any dangers for farmers?

Farmers are known to experience possibly unacceptable exposures to silica when tilling dry soils. For example, an increased prevalence of pleural plaques was found among Bulgarian tobacco farmers <sup>(533)</sup> but further research is still necessary (Figure 59). Some soils may serve as capping material for NOA and may require special handling. In Turkey the erionite stigma is so deep that farm products coming from Karain are sold at low prices to middlemen who disguise their origin to sell them, while women deny they grow up there out of fear that no man will marry them <sup>(534)</sup>.



Figure 59: Farmer's potential exposure to NOA

In our study 24 farm structures with potential Harding County inhabitants were found within the area of 1% or above of erionite-containing soil and only 81 farm structures are within areas above 0.1% erionite soil concentration, as shown in figure 60. The local authorities should take steps to inform these farmers about the potential hazard in their soils. Also these farmers may face a stigma attached to their crop.



Data Source: ArcGIS analysis of the data made available by South Dakota State GIS website

Figure 60: Farm structures proximity to the affected area.

## 5.7. Asbestos “Watch Dogs”

The U.S. Great Basin is a cold desert that starts from southern Idaho and ends in southern California while stretching western to the Sierra Nevada Mountains. A project envisioned by the Southern Nevada Water Authority (SNWA) was to construct a pipeline to supply pumped groundwater from Snake River Valley to Las Vegas at the cost \$15 billion dollars.

In 2013, a national educational and scientific organization called Physicians for Social Responsibility (PSR) and the Utah Physicians for a Healthy Environment (UPHE) expressed concerned over erionite particle pollution in the Great Basin area due to frequent dust storms. These organizations sent a joint letter to Nevada’s Governor stating that the risk to the public’s health is too high to allow the project. Dr. Alan Lockwood, a board member of PSR, stated that: "Creation of a significant, new source of particulate pollution is acknowledged by virtually every independent evaluation of the project. The public health impact to the people of Utah would be enormous especially as they already suffer from severe particulate pollution spikes" <sup>(535)</sup>. Ultimately, this project was halted due to these concerns.

In the “Mesothelioma Watch: Will Erionite Be the New Asbestos?” article published by Oncology Report quotes Dr. Michele Carbone statement that: "We have a unique opportunity to implement novel prevention and early detection programs in erionite-rich regions of the United States, similar to what has been done in Turkey" <sup>(536)</sup>. Furthermore, early detection of mesothelioma is associated with better clinical outcomes <sup>(537)</sup>. Professor James Lockey, M.D of University of Cincinnati argues that the states need to identify where the erionite actually is and take precautions to protect people without delay: “We have enough information now to take steps” <sup>(508)</sup>.

## **5.8. Uncertainty Related to NOE Exposure and Potential for Developing Mesothelioma**

As emphasized in Chapter 2, NOE exposure includes a large range of erionite fibers types, shapes, and sizes that are not historically documented. The risk ranges presented in literature today do not include any confidence estimates for individual predicted risks. Specific individuals may have significantly higher or lower exposure to erionite, depending on the areas which have been accessed during a person's lifetime.

Unknown risk quantifications for NOE exposure include:

1. Which characteristics determine higher toxicity (fiber size, shape, composition, and bundle)?
2. Screening for BAP1 gene mutations.
3. Smoker and nonsmoker risk.

## **5.9. Risk Communication Conclusions**

It is safe to say that most of the Harding County residents are currently unaware of the presence of NOE within geological layers of Slim Buttes and surrounding fields. Unlike the villages in Cappadocia Region of Turkey, the communities in Harding County have not been plagued by mesothelioma and the population is not socially stigmatized. Since the Harding County residents are generally unaware, early identification of their potential concerns along with the input from community should set the stage for a clear and comprehensive dialogue minimizing confusion and stress among the community. Perhaps the first step should be an educational campaign to inform the communities about the location of NOE in their proximity as well as help them to understand what NOE is.

Since communicating risk information to the audiences is particularly difficult when the risk is a newly discovered hazardous material and when there are no well-established quantification of the risk yet, authorities in Harding County should emphasize the following:

A. Erionite and other elongate minerals particles are part of the natural environment

Fibers are found naturally in the environment and are presumed to have been present in the atmosphere long before industrial exploitation of the minerals. This presence is due to the natural occurring erosion of geological formations and other asbestos emitted from natural sources like volcanos. High-Level geological sources are present in the area and are of concern. Although the erionite prediction map in figure 45 offers a preliminary overview of Slim Buttes region a more detailed investigation is necessary to produce an improved map that can be released to the public.

Mesothelioma as a consequence of NOE or NOA being present in the environment without overt disturbance is questionable. These materials are generally considered safe if is undisturbed and encapsulated by soil and/or vegetation. There is currently very little evidence that living above or near geology that includes asbestos is a hazard to human health.

B. Evidence is necessary before confirming risks

Evaluating low-level risk for “environmental” versus occupational exposures is very difficult due to numerous variables impacting outcome of a disease and occurring over in a long time span. The risk exposure to erionite calculations in chapter 2, however, clearly demonstrate that NOE exposure in Harding County are above EPA acceptable risk standards and present the potential to result in mesothelioma occurring within the exposed population..

C. There are consequences of fear and dread within the general public on property values, quality of life, and health

The stigma associated with self-esteem depreciation, depression, sense of control or local public health can have a greater impact on the community as a whole that is more powerful than NOA itself. The impacts on homeowners within communities in South Dakota may be different from Cappadocia Region communities as their housing experiences are considerably different. Fear and misinformation about an unfamiliar disease creates distorted and stereotypical risk perceptions. Making the unfamiliar risk familiar through displays at churches, community centers or in schools is one way to break through any possible stigma.

#### **5.10. Exposure Management Principles for Communities with Erionite in Soils**

Although no mesothelioma cases have been currently reported, South Dakota's Harding County authorities should begin to test the local community and visitors to the CNF about their knowledge concerning the presence and associated risk of erionite exposure. In addition, information should be provided on how to manage these risks. For a persistent hazard like erionite, health educators in elementary schools in erionite-containing geographic areas should teach long-term strategies to minimize the exposure and associated health problems because people tend to fear what they don't understand. Local authorities also should develop, with the help of the scientific community, guidelines for managing risk and communicated risk in the recreational settings of CNF.

As the list below indicates, local authorities can take some simple actions to limit NOA and NOE exposure in Harding County:



#### **A. Testing for erionite prior to land disturbance.**

Authorities should test soil samples for erionite concentrations prior to soil disturbance in Slim Buttes of CNF. Exposure to disturbances should be reduced to a minimum and abated quickly to lower possible exposure to erionite, especially the identified areas of concern. Helispots, often a necessity in forest firefighting, should be chosen in the areas with low erionite concentrations in soil. Low altitude flight should also be redirected around the Slim Buttes area.

#### **B. Use of Personal Protection Equipment (PPE).**

USFS employees should use PPE (respirators and protective clothing) in Slim Buttes and surrounding areas, establish decontamination protocols, and limit their exposure time. Although some areas may have been predicted to have relatively low erionite concentrations in the soil (see figure 45), these areas do not necessarily have low exposure if high erionite concentrations are located within their vicinity which increases the risk of exposure through aeolian transport of the fiber released through natural erosion.

#### **C. Use of wetting or binding methods and proper dismissal of erionite containing materials.**

Removal and disposal of erionite-containing materials or equipment used in handling of or exposed to erionite-containing materials should be done according to state and local procedures.

#### **D. Road travel.**

It is recommended that windows on vehicles be closed when traveling throughout the erionite-containing areas of Harding County. In addition, the air recirculating option should be used and travel distance between vehicles should be increased to minimize the exposure to road dust. Road signs like those shown in figure 61 should be put in areas with documented soil concentrations above 8% to provide adequate warnings. Frequent vehicle washing is recommended when traveling on dirt roads in the county.

#### **E. Limiting visitors in areas where erionite fibers may become airborne.**

Limit access of visitors to CNF areas with particularly high levels of erionite in the soils. Provide suggestions that visitors to these areas wash their clothes as soon as possible and knock off excess soil from their boots before they enter their car.

#### **F. Investigate the geological settings before starting any construction / development actions that involve major soil disturbances.**

Maximize the distance between building construction and erionite-containing geological layers in Harding County.

#### **G. Teach community members how to minimize their exposure to NOE while conducting their normal activities.**

Health educators in elementary schools in Harding County should teach long-term strategies to minimize the exposure and associated health problems.



Figure 61: Common warning signs placed in NOA sites (bottom pictures design D. Farcas)

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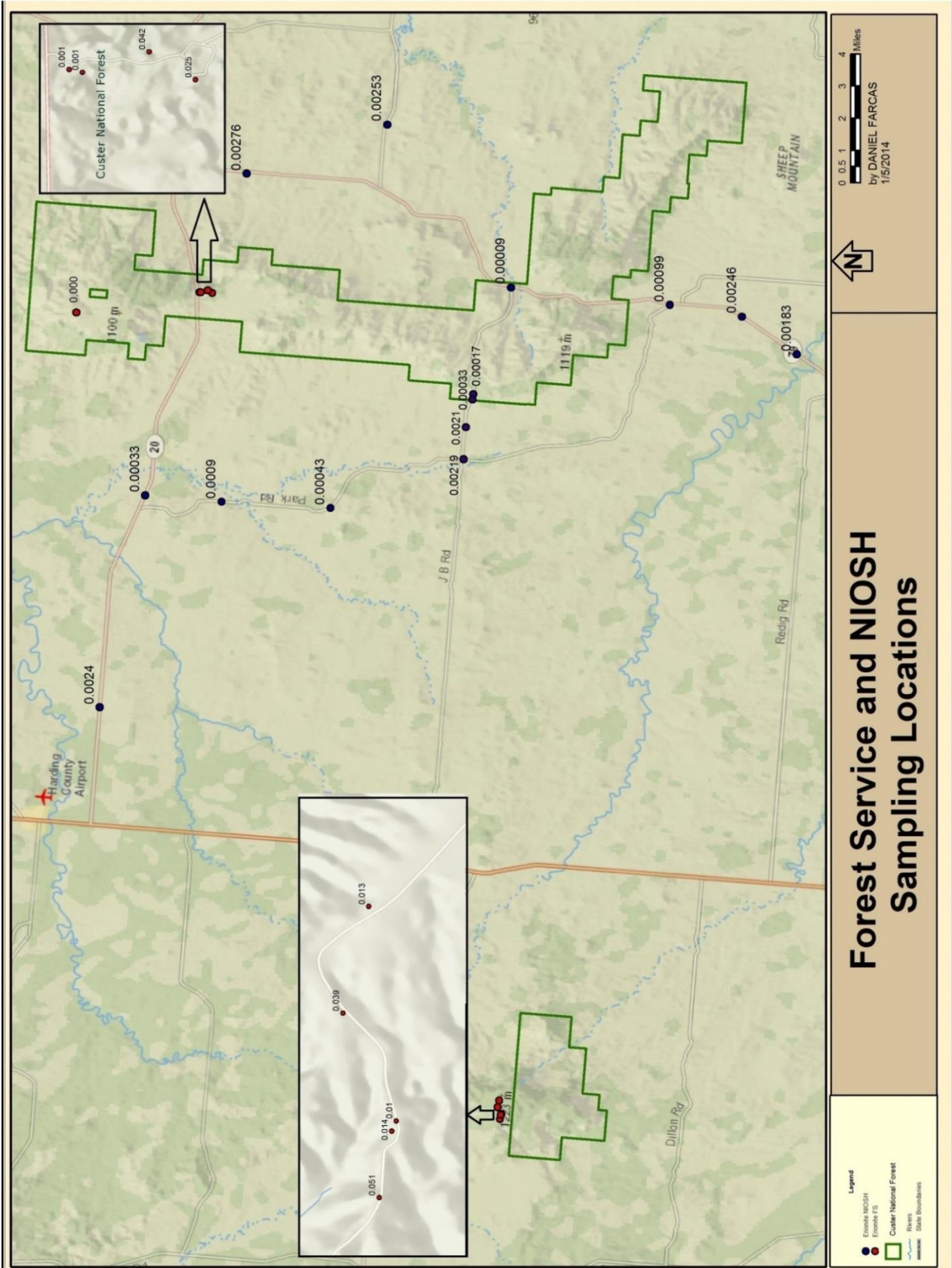
NIOSH/CDC - Exposure Assessment Branch

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304-290-1853

# ANNEX 1.

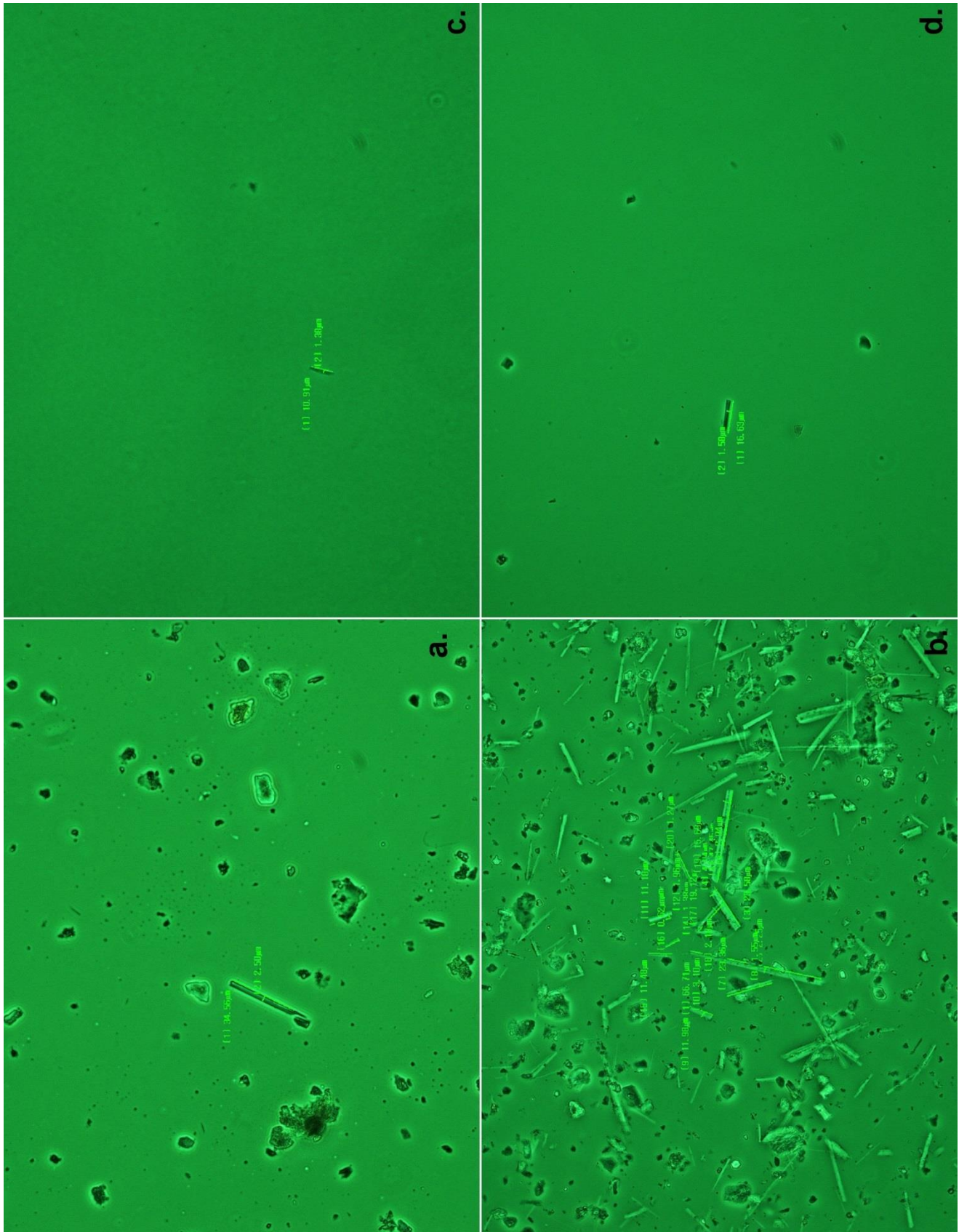


## ANNEX 2: Prediction errors for IDW method.

Inverse Distance Weighting		
Measured	Predicted	Error
0.0024	0.0016147038896985291	-0.00078529611030147065
0.001885	0.0012936099155788298	-0.0005913900844211702
0.0009	0.0012383061877705988	0.0003383061877705988
0.00033	0.0014322738270576268	0.0011022738270576268
0.001561	0.0004314503305027108	-0.0011295496694972893
0.00043	0.0015608579842671566	0.0011308579842671566
0.001279	0.0015879772134383234	0.00030897721343832343
0.001151	0.001477384287787768	0.0003263842877877681
0.0012	0.0012162183516678286	-3.448164833217142e-005
0.001567	0.0021809640593048185	0.0006139640593048185
0.00219	0.0015641056143508593	-0.0006258943856491408
0.001	0.0014393971751949	0.00043939717519490004
0.0021	0.0010236639776408007	-0.0010763360223591991
0.001011	0.001171966371335299	0.00016096637133529912
0.00033	0.0002946441155289288	-3.535588447107119e-005
0.00017	0.0004176397551713322	0.00024763975517133217
0.0004	0.0013354969091349171	0.0009152369091349171
0.00186	0.0009522278291173566	-0.0009077721708826435
0.00183	0.001452606935654067	-0.00037739306434593305
0.00246	0.0009396398541295657	-0.0015203601458704343
0.00099	0.0005486569488270756	-0.00044134305117292437
0.001489	0.0020379770228023397	0.0005489770228023396
9e-005	0.0010302799756770453	0.0009402799756770453
0.000321	0.0010745139131171358	0.0007535139131171358
0.0005	0.0011023794613009878	0.0005842494613009878
0.000528	0.0006461369839516444	0.00011813698395164436
0.000281	0.0007496499617055761	0.0004686499617055761
0.000435	0.0011827165664585904	0.0007477165664585904
0.00232	0.001298724643211484	-0.001021275356788516
0.010341	0.011981745032894498	0.0016407450328944986
0	0.011613811131377546	0.011613811131377546
0.001	0.0026213755810886585	0.0016213755810886585
0.025	0.027358431843380885	0.0023584318433808836
0.001	0.0022798358654528006	0.0012798358654528006
0.042	0.012034332882742634	-0.02996566711725737
0.001055	0.0036489541580348468	0.002593954158034847
0.003999	0.007139672649121863	0.0031406726491218628
0.003104	0.004659556409842793	0.001555556409842793
0.001302	0.0027573639334610594	0.0014553639334610594
0.00276	0.0039180853412395635	0.0011580853412395636
0.001393	0.005064640743410141	0.003671640743410141
0.00124	0.003720459423857628	0.0024804594238576278
0.001125	0.0033140435273078185	0.002189043527307819
0.00253	0.001494684374992466	-0.0010353156250075342
0.0010329	0.0018803620356161006	0.0008474620356161006



Annex 3: Eclipse 50i Microscope field of view a. Soil 1, b: Soil 19, c. Blank, d. Sand.



#### Annex 4: Triplicates subsamples NIOSH/PCM.

SAMPLE	SubSample1	SubSample2	SubSample3	Average	SD	CV
4	0.0003	0.0001	0.0002	<b>0.0002</b>	0.0001	1.4446
5	0.0001	0.0001	0.0000	<b>0.0001</b>	0.0001	1.5563
6	0.0002	0.0004	0.0004	<b>0.0003</b>	0.0001	3.0864
7	0.0004	0.0000	0.0006	<b>0.0003</b>	0.0003	1.2266
8	0.0018	0.0007	0.0030	<b>0.0018</b>	0.0011	1.6130
9	0.0011	0.0008	0.0008	<b>0.0009</b>	0.0002	4.1343
10	0.0008	0.0012	0.0010	<b>0.0010</b>	0.0002	5.5234
11	0.0022	0.0034	0.0020	<b>0.0025</b>	0.0008	3.2947
12	0.0017	0.0023	0.0034	<b>0.0025</b>	0.0009	2.8440
13	0.0044	0.0015	0.0025	<b>0.0028</b>	0.0015	1.8825
14	0.0021	0.0016	0.0028	<b>0.0022</b>	0.0006	3.4503
15	0.0028	0.0030	0.0014	<b>0.0024</b>	0.0009	2.7091
16	0.0017	0.0023	0.0024	<b>0.0021</b>	0.0004	5.6326
17	0.0017	0.0009	0.0017	<b>0.0015</b>	0.0005	3.0748
Sand	0.0000	0.0000	0.0000	<b>0.0000</b>	0.0000	0.0000
Blank	0.0000	0.0000	0.0000	<b>0.0000</b>	0.0000	0.0000
Camp	0.0843	0.0738	0.0919	<b>0.0833</b>	0.0091	9.1859
Mole	0.0425	0.0611	0.0687	<b>0.0575</b>	0.0135	4.2580
Arikaree	0.3254	0.3498	0.1960	<b>0.2904</b>	0.0827	3.5122

#### Triplicates subsamples NIOSH/TEM.

SAMPLE	SubSample1	SubSample2	SubSample3	Average	SD	CV
4	0.00005	0.00006	0.00000	<b>0.00004</b>	0.00003	1.10652
5	0.00045	0.00001	0.00010	<b>0.00019</b>	0.00023	0.79730
6	0.00014	0.00021	0.00014	<b>0.00017</b>	0.00004	4.30743
7	0.00000	0.00000	0.00000	<b>0.00000</b>	0.00000	N/A
8	0.00162	0.00082	0.00488	<b>0.00244</b>	0.00215	1.13280
9	0.00019	0.00000	0.00000	<b>0.00006</b>	0.00011	0.58471
10	0.00000	0.00002	0.00038	<b>0.00013</b>	0.00021	0.62330
11	0.00089	0.00003	0.00207	<b>0.00100</b>	0.00102	0.97420
12	0.00112	0.00053	0.00124	<b>0.00096</b>	0.00038	2.51551
13	0.00000	0.00062	0.00021	<b>0.00028</b>	0.00031	0.88105
14	0.00002	0.00011	0.00015	<b>0.00009</b>	0.00007	1.33835
15	0.00014	0.00025	0.00162	<b>0.00067</b>	0.00082	0.81117
16	0.00044	0.00002	0.00042	<b>0.00029</b>	0.00024	1.22450
17	0.00037	0.00013	0.00003	<b>0.00018</b>	0.00018	0.99922



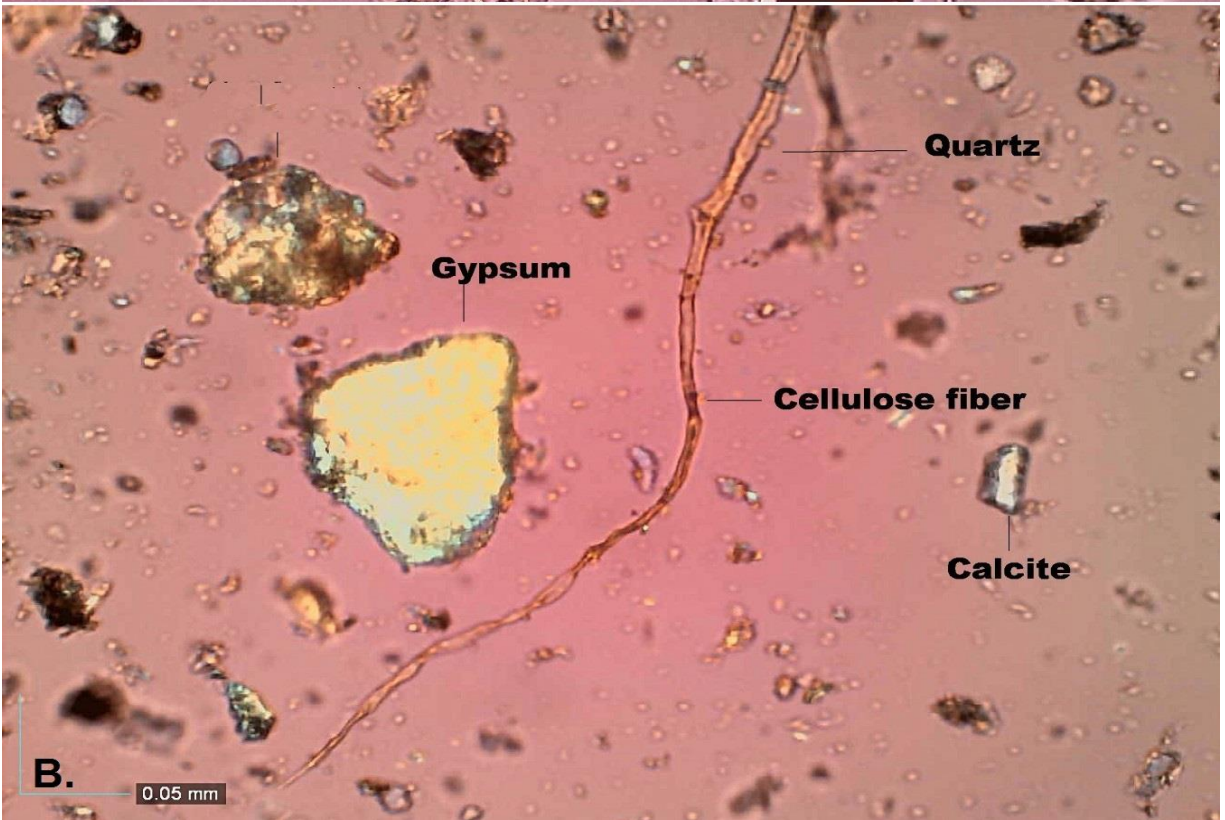
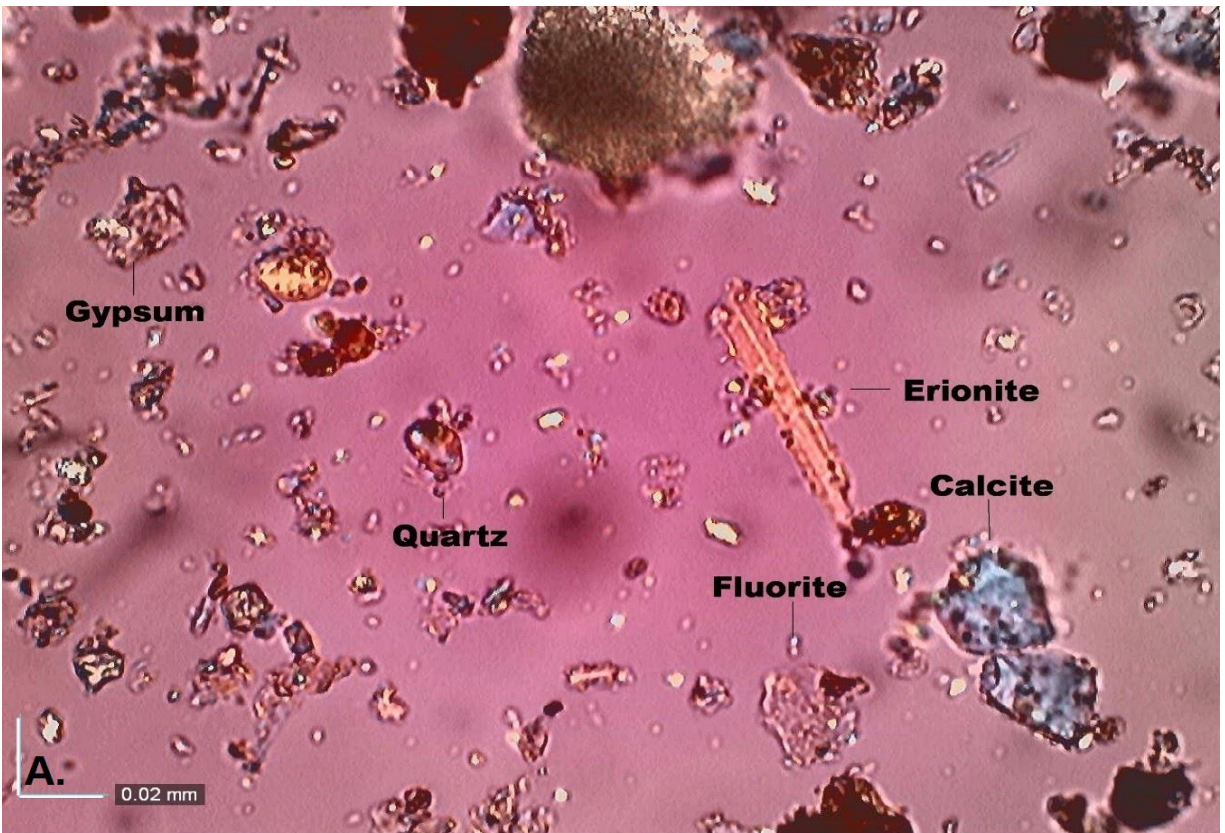
### Annex 5: Triplicates subsamples North Dakota University.

SAMPLE	SubSample1	SubSample2	SubSample3	Average	SD	CV
SB-12-1	0.00208509	0.0020811	0.002806376	0.002324	0.000418	0.179672
SB-26-1	0.00106234	0.00151078	0.000459723	0.001011	0.000527	0.521699
SB-29-1	0.00068846	0.00094623	0.001365486	0.001	0.000342	0.341685
SB-28-1	0.00148889	0.00104891	0.001214166	0.001251	0.000222	0.177705
SB-23-1	0.00104348	0.00103283	0.001376949	0.001151	0.000196	0.169992
SB-22-1	0.00111544	0.00170769	0.001858779	0.001561	0.000393	0.251745
SB-24-1	0.0013326	0.0023384	0.001031325	0.001567	0.000684	0.436667
SB-21-1	0.01189452	0.00937091	0.009756483	0.010341	0.001359	0.131465
SB-14-1	0.00086406	0.00073778	0.001496789	0.001033	0.000407	0.393745
SB-20-1	0.00111619	0.00108789	0.001631695	0.001279	0.000306	0.239422
SB-15-1	0.0030637	0.00246194	0.003787641	0.003104	0.000664	0.213819
SB-25-1	0.00121246	0.00278496	0.001658197	0.001885	0.00081	0.429903
SB-2-1	0.00061336	0.00085982	0.000110199	0.000528	0.000382	0.723893
SB-13-1	0.00115211	0.00207632	0.000677241	0.001302	0.000711	0.546486
SB-11-1	0.00205985	0.00082367	0.001583578	0.001489	0.000623	0.418721
SB-10-1	0.00111538	0.00109139	0.000958778	0.001055	8.43E-05	0.079936
SB-7-1	0.00059993	0.00030528	0.000401009	0.000435	0.00015	0.345209
SB-16-1	0.00144572	0.00089354	0.001035731	0.001125	0.000287	0.254853
SB-5-1	2.1888E-05	0.00021558	0.001023324	0.00042	0.000531	1.263899
SB-8-1	0.00041559	0.00037633	0.000762456	0.000518	0.000213	0.410141
SB-18-1	0.0010256	0.00115779	0.001535855	0.00124	0.000265	0.213605
SB-19-1	0.00132276	0.00184283	0.001012312	0.001393	0.00042	0.301331
SB-3-1	0.00138148	0.00279463	0.00140462	0.00186	0.000809	0.435041
SB-17-1	0.00586779	0.00353975	0.002588621	0.003999	0.001687	0.421904
SB-1-1	0.00036431	0.00029713	0.000182686	0.000281	9.18E-05	0.32637
SB-4-1	0.00021427	0.00022026	0.000527443	0.000321	0.000179	0.558572

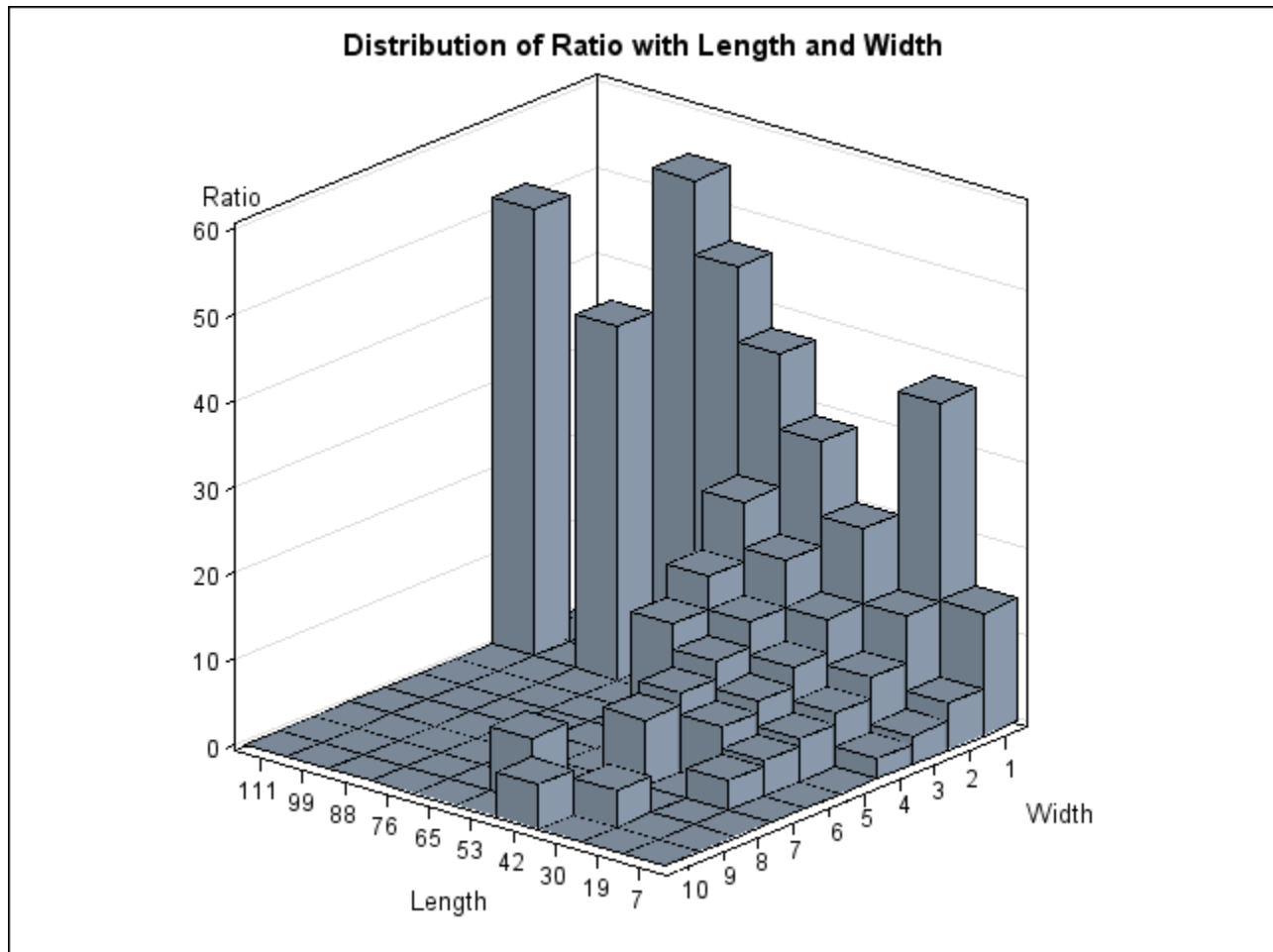
## Annex 6: Samples collected by CDC/NIOSH on Aug 11-12, 2015

SAMPLE	SubSample1	SubSample2	SubSample3	Average	SD	CV
1	0.065099308	0.097038209	0.195368003	<b>0.119169</b>	0.067895	0.569743
2	0.08978928	0.014414064	0.016363851	<b>0.040189</b>	0.042966	1.069099
3	0.072124661	0.01427529	0.019039605	<b>0.035147</b>	0.032112	0.913675
4	0.11251411	0.008655863	0.017555323	<b>0.046242</b>	0.057566	1.244887
5	0.017646407	0.02387499	0.0380438	<b>0.026522</b>	0.010453	0.394133
6	0.018244321	0.025871363	0.03437418	<b>0.026163</b>	0.008069	0.308405
7	0.043208325	0.016649827	0.078724885	<b>0.046194</b>	0.031145	0.674218
8	0.061416582	0.071164417	0.072838721	<b>0.068473</b>	0.006168	0.090084
9	0.039123082	0.02875596	0.013159912	<b>0.027013</b>	0.013069	0.483806
10	0.045270486	0.038268509	0.038105712	<b>0.040548</b>	0.00409	0.100877
11	0.035741985	0.012140855	0.020966856	<b>0.02295</b>	0.011925	0.519605
12	0.038669676	0.041687477	0.0355729	<b>0.038643</b>	0.003057	0.079118
13	0.069620586	0.051347714	0.132450112	<b>0.084473</b>	0.042542	0.50362
14	0.142821911	0.138842564	0.407310303	<b>0.229658</b>	0.153864	0.66997
15	0.000401056	0.000895365	0.000817684	<b>0.000705</b>	0.000266	0.377206
16	0.002799945	0.000379374	0.00108893	<b>0.001423</b>	0.001244	0.874598
17	0.000868182	0.001014812	0.001390317	<b>0.001091</b>	0.000269	0.246812

Annex 7: PLM Microscope field of view A. SOIL 13, B: SOIL 22.



**ANNEX 8: Size distribution by ratio to length and width for Erionite fibers.**



## ANNEX 9: SAS Output Values

The SAS System

June 9, 2015

The FREQ Procedure

WIDTH_CAT	Frequency	Percent	Cumulative Frequency	Cumulative Percent
A:<3	895	80.63	895	80.63
B:3+	215	19.37	1110	100.00

LENGTH_CAT	Frequency	Percent	Cumulative Frequency	Cumulative Percent
A:< 8	3	0.27	3	0.27
B:8-40	988	89.01	991	89.28
C:40+	119	10.72	1110	100.00

Table of WIDTH\_CAT by LENGTH\_CAT

WIDTH_CAT	LENGTH_CAT			Total
	A:< 8	B:8-40	C:40+	
A:<3	3	798	94	895
	0.27	71.89	8.47	80.63
	0.34	89.16	10.50	
	100.00	80.77	78.99	
B:3+	0	190	25	215
	0.00	17.12	2.25	19.37
	0.00	88.37	11.63	
	0.00	19.23	21.01	
Total	3	988	119	1110
	0.27	89.01	10.72	100.00

The SAS System

June 9, 2015

The MEANS Procedure

Variable	Label	N	Mean	Std Dev	Minimum	Maximum
WIDTH		1110	2.1562883	1.0778828	0.4300000	7.8500000
Length	Length	1110	24.8989820	13.0964478	2.4100000	110.5100000
WIDTH_TO_LENGTH		1110	0.1021532	0.0620650	0.0072525	0.8630705

### Annex 10: Worst and Normal Scenarios Dispersion Values

D Neutral 8% Erionite						
Meters Away	25 mph		20 mph		15 mph	
	Light Vehicle	Heavy Vehicle	Light Vehicle	Heavy Vehicle	Light Vehicle	Heavy Vehicle
50	2.59	5.95	2.08	4.76	1.55	3.57
100	0.64	1.47	0.51	1.17	0.38	0.88
150	0.30	0.69	0.24	0.56	0.18	0.42
200	0.18	0.42	0.15	0.33	0.11	0.25
250	0.12	0.28	<b>0.10</b>	0.23	<b>0.07</b>	0.17
300	<b>0.09</b>	0.21	0.07	0.16	0.05	<b>0.12</b>
400	0.05	0.13	0.04	<b>0.10</b>	0.03	0.08
600	0.03	<b>0.06</b>	0.02	0.05	0.02	0.04
800	0.02	0.04	0.01	0.03	0.01	0.02
1000	0.01	0.03	0.01	0.02	0.01	0.02

F Stable 20% Erionite						
Meters Away	25 mph		20 mph		15 mph	
	Light Vehicle	Heavy Vehicle	Light Vehicle	Heavy Vehicle	Light Vehicle	Heavy Vehicle
50	48.98	112.43	39.22	89.94	29.28	67.46
100	14.14	32.47	11.33	25.97	8.46	19.48
150	7.01	16.09	5.61	12.87	4.19	9.66
200	4.29	9.85	3.44	7.88	2.57	5.91
250	2.94	6.75	2.35	5.40	1.76	4.05
300	2.16	4.97	1.73	3.97	1.29	2.98
400	1.34	3.07	1.07	2.45	0.80	1.84
600	0.68	1.56	0.54	1.25	0.41	0.94
800	0.42	0.97	0.34	0.77	0.25	0.58
1000	0.28	0.64	0.22	0.51	0.17	0.38
2 KM	0.10	0.23	0.08	0.18	0.06	0.14
5 KM	0.03	0.06	0.02	0.05	0.02	0.04

Where:  = below PEL level

### Annex 11: Communities websites dedicated to FAQ about asbestos

Community	Website Pages for FAQ Asbestos
Scituate, Massachusetts	<a href="http://www.scituatema.gov/">http://www.scituatema.gov/</a>
Greenburgh, New York	<a href="http://www.greenburghny.com/">http://www.greenburghny.com/</a>
Derry City, UK	<a href="http://www.derrycity.gov.uk/">http://www.derrycity.gov.uk/</a>
Montana State	<a href="http://www.deq.mt.gov/">http://www.deq.mt.gov/</a>
Michigan State	<a href="http://www.michigan.gov/">http://www.michigan.gov/</a>
Community	Website Pages for FAQ NOA
Fairfax County, Virginia	<a href="http://www.fairfaxcounty.gov">http://www.fairfaxcounty.gov</a>
Clark County, Nevada	<a href="http://www.clarkcountynv.gov/">http://www.clarkcountynv.gov/</a>
Mendocino County, Northern CA	<a href="http://www.co.mendocino.ca.us/">http://www.co.mendocino.ca.us/</a>
Skagit County, WA	<a href="http://www.skagitcounty.net/">http://www.skagitcounty.net/</a>
Washington State	<a href="http://www.doh.wa.gov/">http://www.doh.wa.gov/</a>

## ANNEX 12: POSTER and PODIUM PRESENTATIONS

### Poster and Podium Presentations

1. **West Virginia University**, Davis College of Agriculture, Natural Resources and Design Nineteenth Annual Research and Creative Scholarship Conference on April 7, 2015.
2. **Shepherd University**, Division of Graduate Studies, WV Graduate Research Day April 18, 2015

### Erionite Studies in Custer National Forest

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**Abstract:** In the center of each mesothelioma tumor is a mineral fiber, and not all of the cancer-causing fibrous rocks are called asbestos. Although it is the least familiar and least abundant of all the asbestos minerals, erionite is an emerging naturally-occurring carcinogen that through continued and frequent exposure can lead to lung cancer, mesothelioma and other related disease. The erionite samples studied in our research are from the Sioux District of the rocky outcrops of Custer National Forest in the northwestern South Dakota, where the geologic formations have been analyzed and determined to contain erionite. Although there is currently no proof of emerging erionite-related illnesses in the U.S., mesothelioma normally takes 30 to 50 years to develop. For this study, we selected soil collections that were performed by CDC/NIOSH and USDA/USFS, respectively and we further analyze the results using ArcGIS 10.2 software from ESRI. Fluidized Bed Asbestos Segregator (FBAS) was used for its effectiveness and efficient separation of erionite fibers from sampled soils while maintaining the integrity of the erionite fibers so that the true structural characteristics and quantity of erionite fibers in the soils can be determined. The accumulation of erionite in a specific area was found to be significantly higher in the surface soils, reaching 22.9 %, compared to background soils where the concentration was less than 0.01%. An area of 129.52 squared miles was predicted to contain erionite levels at or above EPA's 1% limit soil concentration for asbestos fibers. The concentration of erionite in Sioux Ranger District background soils (<0.2% by mass) is well below the detection limit of traditional PCM/PLM methods, but is reliably detected by FBAS method and detected by TEM analysis according to ISO 10312 due to the high confidence in the fiber discrimination. The results support the conclusion there is a non-zero level of erionite in the soils surrounding Custer National Forest in Sioux Ranger District and that breathing in naturally occurring erionite in the Sioux Ranger District area, over a life time has the potential to harm people's health.



ANNEX 13: WVAGS recognition for outstanding scholarship, research and participation.

