

A COMPARATIVE ANALYSIS OF THE ELEMENTAL COMPOSITION OF MINING-GENERATED AND LABORATORY-GENERATED COAL MINE DUST

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ABSTRACT

The occurrence of Coal Worker's Pneumoconiosis (CWP) has been potentially linked with several characteristics of coal such as rank, volatility, percent content of ash and non-coal components, quartz content, and the presence of several trace elements. According to the National Research Council, numerous epidemiological studies indicate that the incidence of CWP varies significantly with the composition and/or the concentration of the coal mine dust.⁴

Although advances in dust-suppression techniques have markedly reduced respirable-dust levels in underground coal mines, the National Research Council has concluded that chemical characteristics of respirable dust from different coal seams should be studied. With this objective in mind, research has been conducted in underground coal mines located in the eastern and midwestern United States, and in the laboratory to characterize the elemental composition of mining-generated airborne dust and laboratory-generated dust derived from samples taken from these mines. The goal of the research is to determine if a relationship exists between mining-generated and laboratory-generated dust from the same mine.

INTRODUCTION

The Federal Coal Mine Health and Safety Act of 1969 was enacted to ensure healthier and safer working conditions for miners. In 1970, it provided for an underground respirable dust standard of 3.0 mg/m³ in active coal mine workings and was subsequently lowered, in 1972, to 2.0 mg/m³ as long as the mine dust contained less than five percent quartz. Despite the current respirable-dust standard, coal miners are continually being diagnosed as developing CWP. The amounts of black-lung compensation payments continue to rise and are approaching two billion dollars annually. The compensation payments are partially funded by an excise tax on coal. Currently, the tax amounts to \$1.10 per ton for coal mined underground and \$0.55 per ton for surface-mined coal.

Coal extraction by a continuous mining machine (CMM) is the most common underground method in the U.S. industry today and accounts for slightly more than two-thirds of the nation's deep-mining production (Figure 1).¹ Even if longwall mining should become more commonplace, it can proceed only after ventilation and access entries have been driven by CMMs.

The Mine Safety and Health Administration (MSHA) is required to inspect all underground coal mines four times each year and collect dust samples twice each year. MSHA inspectors also sample specific occupations in a mining operation that are typically exposed to the highest respirable-dust concentrations and which create potential hazards to the in-

dividuals assigned to these worksites. Such occupations are referred to as designated occupations (DO). Examples of DO would include the continuous-miner operator and the continuous-miner-operator helper. Additionally, the MSHA inspectors sample other underground occupations suspected to have high dust exposures such as roof bolters. These are referred to as nondesignated occupations (NDO).⁸

Thus, since a CMM operator and helper have DO, and other personnel such as the section foreman and the shuttle-car operators may be exposed to dust generated by the CMM as well, the purpose of this paper will be to discuss the relationship between the elemental composition of mining-generated airborne dust sampled from the immediate ventilation return of a CMM and laboratory-generated dust derived from channel samples taken from the mines. The elemental composition of the dust in the immediate ventilation return was chosen to be compared to the laboratory-generated respirable dust because it is close to the dust generating source, which is the CMM, and samples can be safely taken from this area.

The potential contributions of this research to the coal mining industry are: 1) after more fundamental knowledge of the cause(s) of CWP is learned, in particular certain trace elements, the laboratory-generated respirable dust could be used to identify a potentially hazardous coal seam. Also, this research could possibly aid in understanding the fundamental causes of CWP by producing mining-simulated samples of coal dust which could be used in epidemiological studies,

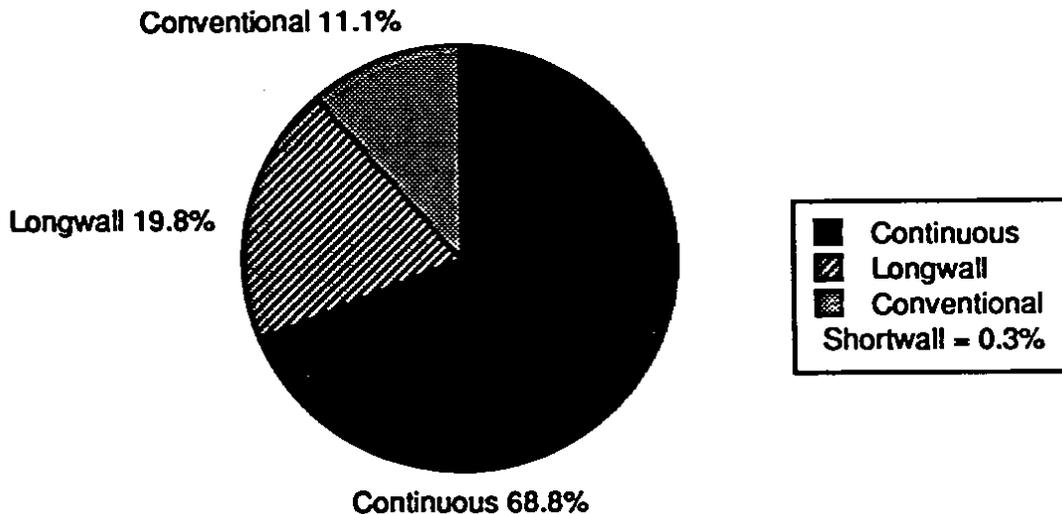


Figure 1. Underground coal production by type of mining for 1983.

and 2) assuming there is no difference in the elemental composition of a drill-core sample and a channel sample from the same location, a mining company could predict a new mine's respirable dust elemental composition in the immediate ventilation return by using exploratory drill-core samples of the roof, coal, and floor rock to prepare the laboratory dust. Ventilation engineers could then use engineering design and control measures during pre-mine planning to reduce the incidence and severity of CWP by better ventilating the potentially hazardous coal seam. If this proper planning prevented any future changes to the ventilation equipment and mine design, much time and money could be saved.

SCOPE OF WORK

To investigate the variability of the chemical characteristics of respirable dust, airborne dust samples from eight underground coal mines located in the eastern and midwestern United States were collected with eight-stage Sierra Model 298 Marple cascade impactors marketed by Andersen Samplers, Inc. as well as twenty-five channel samples of mined material. Each channel sample was removed from the middle of the coal face before mining occurred. Sampling of the mining-generated dust was conducted by Lee.³ He sampled the entire working sections, primarily for characterization purposes, to obtain information on the locational variability of dust characteristics. Research performed for this study used the elemental analyses of the mining-generated dusts he sampled in the immediate ventilation returns of CMMs.

The procedure that was used to produce the laboratory-generated respirable dust was based on the Hardgrove grindability test, a test which reflects the pulverizing characteristics of coal. This test was chosen for several reasons. First, it is repeatable and reproducible; a consistent amount of input energy is used as well as a specified size range of feed material to be crushed (the channel samples). Secondly, it is thought to generate secondary dust in a way similar to that of the crushing and grinding of the coal and rock as they

pass through the arc-shaped cutting path of the CMM's cutter head. The potential effect on dust generation by this secondary grinding mechanism may be at least as much as that produced by primary fragmentation, which is dust produced by the cutting action of the bit against the coal or rock.⁵ Finally, the Hardgrove grindability test is well known and is used in the coal industry to guide mineral-processing engineers in estimating the capacity of mills used to grind coal.

One hypothesis of dust researchers in the Generic Technology Center for Respirable Dust is that the elemental as well as the physical characteristics of coal-mine dust will make a difference in the incidence and severity of the Black-Lung disease. Coal-mine dust is generated not only from coal, but also from any rock partings contained within the seam or any roof or floor material mined with the coal. Thus, coal-mine dust may not have the same elemental characteristics as the coal being mined.

Given that hypothesis, mixtures proportional to each thickness mined of roof, coal, and floor rock derived from the channel samples of the face areas from which the respirable dusts were generated by the CMMs were used to produce the feed material which was pulverized in the Hardgrove machine. The minus 400-mesh fraction ($<37 \mu\text{m}$) (U.S. series standard test sieve) that was collected after pulverization was placed in a fluidized-bed aerosol generator manufactured by TSI, Incorporated and dispersed in an aerosol test chamber manufactured by Elpram Systems, Inc. While the minus 400-mesh fraction was being dispersed in the aerosol test chamber, it was also being sampled with the eight-stage cascade impactors in the same manner as the dust in the immediate ventilation return of the CMM was sampled.

The elemental composition of the mining-generated dust and the laboratory-generated dust were determined from stages 3, 5, and 7 ($10 \mu\text{m}$, $3.5 \mu\text{m}$, and $1.0 \mu\text{m}$ aerodynamic diameter, respectively) of a cascade impactor by the Proton induced X-Ray Emission (PIXE) method by the Element Analysis Corporation of Tallahassee, Florida. To perform

a PIXE analysis, a beam of protons is used to excite the atoms in the dust mass of a particular impactor stage. The X-rays emitted as a result of this excitation are analyzed to determine the elements that originated the various wave lengths. The number of X-rays that are emitted in a particular range are counted and the amount of each element in the dust can be calculated with an error that can be determined statistically for each element.

The PIXE method quantifies the mass of all elements simultaneously but had one limitation: the commercially available analysis is set up to determine only those elements that have an atomic number greater than or equal to sodium. The PIXE analysis is also a nondestructive method; therefore, any elements contained in the volatile material of the dust samples are not lost by an ashing procedure and dust samples can be archived for future use. The PIXE method easily gives a multi-element analysis from small dust masses which ranged from 5 to 120 μg .

DESCRIPTION OF THE ANALYSIS

After receiving the elemental analyses from the outside company, the data were grouped by mine, channel-sample location, and stage according to their identification as a laboratory-generated dust or a mining-generated dust. Since each element's weight fraction of the total dust mass had an associated error plus or minus its weight fraction, a range of values occurred for an element's weight fraction. For example, if iron's weight fraction of a dust mass was $2.50\text{E}-3$ (0.00250) with a ± 10 percent error, then the range of iron in the dust mass was from $2.25\text{E}-3$ to $2.75\text{E}-3$. For a few elements in quantities near the PIXE analysis' detection limits, an error of more than 100 percent occurred. This presented no problem when adding more than 100 percent of the original weight fraction to itself, but when subtracting it, the weight fraction of the particular element was entered as zero, since a negative quantity of an element does not physically exist.

After a range of values for a particular element was calculated, all weight-fraction ranges of the mining-generated and the laboratory-generated dust from the same mine and particular impactor stage were sorted for a minimum and a maximum weight fraction value. Once these two values were identified, their average value could be calculated and column graphs drawn. The height of the column represented the average value, and the difference between the maximum value and the average value represented the error bar value. See Figures 2 through 5 for examples of some of the elemental values.

In those cases where the weight fraction of the laboratory-generated dust fell short of or exceeded the range of the mining-generated dust, or did not appear at all as in the cases for Na, Sb, and Ba, they were considered unsuccessful predictors. Thus, for the 32 elements, the laboratory-generated dust was considered a successful predictor 73% of the time for stage 3, 65% of the time for stage 5, and 57% of the time for stage 7. This resulted in an overall predictability of 65% (see Table I).

CONCLUSIONS AND RECOMMENDATIONS

1. By observing Figure 2, the carbon or the organic frac-

tion in the coal dust appears to increase with decreasing dust size.

2. Although different researchers have differing opinions on the elements which they believe have an impact in contracting CWP, evidence indicates that elements such as Pb, Ni, and Zn are contained in greater amounts in bituminous-coal-miner's lungs than normal concentrations of these elements.^{6,7} As such, the standard procedure developed to produce a laboratory-generated dust appears to predict well the concentrations of Pb, Ni, and Zn (with 100%, 85%, and 81% accuracy, respectively) in the immediate ventilation return of a CMM (see Figures 3, 4, and 5). Thus, potential problem mines or coal seams may be identified during planning stages.
3. Ba, Sb, Cd, and Na were the most difficult elements for the laboratory-generated dust to produce in detectable amounts. They were detected in the mining-generated dust in mines where roof and floor rock were mined with the coal seam. Poor detection of these elements in the laboratory-generated dust may be due to inadequate grinding of the rock component during sample pulverization. It is recommended that a refined procedure of the one used in this research be developed to better predict the mining-generated dust when rock is concurrently mined with the coal seam.

An important contribution of this research was that it developed and described a standard procedure, or a tool, which has shown promise for measuring the variability of the elemental composition of coal mine dust in the immediate ventilation return of a CMM through the use of a laboratory-based process.²

To make the successful technology transfer in which a coal mining company is able to predict a proposed mine's airborne dust elemental characteristics in the immediate ventilation return of a CMM by using the standard procedure presented in this paper, it is recommended that core samples of a coal property be used to prepare the laboratory-generated dust which would be compared to the mining-generated dust sampled as close as possible to the core location after mine development. This would allow verification of the assumption that a core sample could successfully be used in place of a channel sample to produce laboratory-generated dust that has elemental characteristics similar to those of dust sampled in the immediate ventilation return of a CMM.

Finally, it is recommended that researchers investigating the significance of elements and chemical variations on cell cultures and live animals use a laboratory-generated dust which is similar in composition to actual mine dust to perform their studies. This would better represent the dust that miners actually breathe.

As medical investigations continue to find the cause(s) of CWP, and if a portion of the cause(s) is found to be certain elements or particular concentrations of those elements in the mine dust, then the successful application of this research will contribute to the reduction in incidence and severity of CWP and reduce the cost of attaining that goal.

Table I
 Lab Dust in the Same Concentration Range as Mine Dust

Element	Stage 3	Stage 5	Stage 7	Totals
C	hypothetical	hypothetical	hypothetical	-
O	hypothetical	hypothetical	hypothetical	-
Na	0/3 = 0%	0/2 = 0%	0/1 = 0%	0/6 = 0%
Mg	6/8 = 75%	5/9 = 56%	1/8 = 13%	12/25 = 48%
Al	5/9 = 56%	5/9 = 56%	5/9 = 56%	15/27 = 56%
Si	6/9 = 67%	4/9 = 44%	3/9 = 33%	13/27 = 48%
P	9/9 = 100%	8/9 = 89%	7/9 = 78%	24/27 = 89%
S	6/9 = 67%	7/9 = 78%	6/9 = 67%	19/27 = 70%
Cl	8/9 = 89%	5/9 = 56%	7/9 = 78%	20/27 = 74%
K	4/9 = 44%	3/9 = 33%	1/9 = 11%	8/27 = 30%
Ca	4/9 = 44%	3/9 = 33%	0/9 = 0%	7/27 = 26%
Ti	6/9 = 67%	5/9 = 56%	6/9 = 67%	17/27 = 63%
V	4/6 = 67%	4/7 = 57%	0/6 = 0%	8/19 = 42%
Cr	2/7 = 29%	5/8 = 63%	1/8 = 13%	8/23 = 35%
Mn	6/9 = 67%	5/9 = 56%	4/9 = 44%	15/27 = 56%
Fe	5/9 = 56%	3/9 = 33%	3/9 = 33%	11/27 = 41%
Ni	7/9 = 78%	7/9 = 78%	9/9 = 100%	23/27 = 85%
Cu	data suspect	data suspect	data suspect	-
Zn	8/9 = 89%	8/9 = 89%	6/9 = 67%	22/27 = 81%
Ga	9/9 = 100%	9/9 = 100%	8/8 = 100%	26/26 = 100%
Ge	7/7 = 100%	6/6 = 100%	5/6 = 83%	18/19 = 95%
As	6/6 = 100%	4/4 = 100%	5/5 = 100%	15/15 = 100%
Se	6/6 = 100%	4/5 = 80%	5/6 = 83%	15/17 = 88%
Br	6/9 = 67%	5/9 = 56%	8/9 = 89%	19/27 = 70%
Rb	8/9 = 89%	5/8 = 63%	6/9 = 67%	19/26 = 73%
Sr	9/9 = 100%	7/9 = 78%	6/9 = 67%	22/27 = 81%
Zr	9/9 = 100%	7/8 = 88%	7/8 = 88%	23/25 = 92%
Mo	7/7 = 100%	7/8 = 88%	3/6 = 50%	17/21 = 81%
Cd	1/6 = 17%	0/2 = 0%	0/1 = 0%	1/9 = 11%
Sb	0/3 = 0%	0/3 = 0%	0/3 = 0%	0/9 = 0%
Ba	0/1 = 0%	0/1 = 0%	0/1 = 0%	0/3 = 0%
Pb	9/9 = 100%	9/9 = 100%	9/9 = 100%	27/27 = 100%
Totals	163/222 = 73%	140/215 = 65%	121/211 = 57%	424/648 = 65%

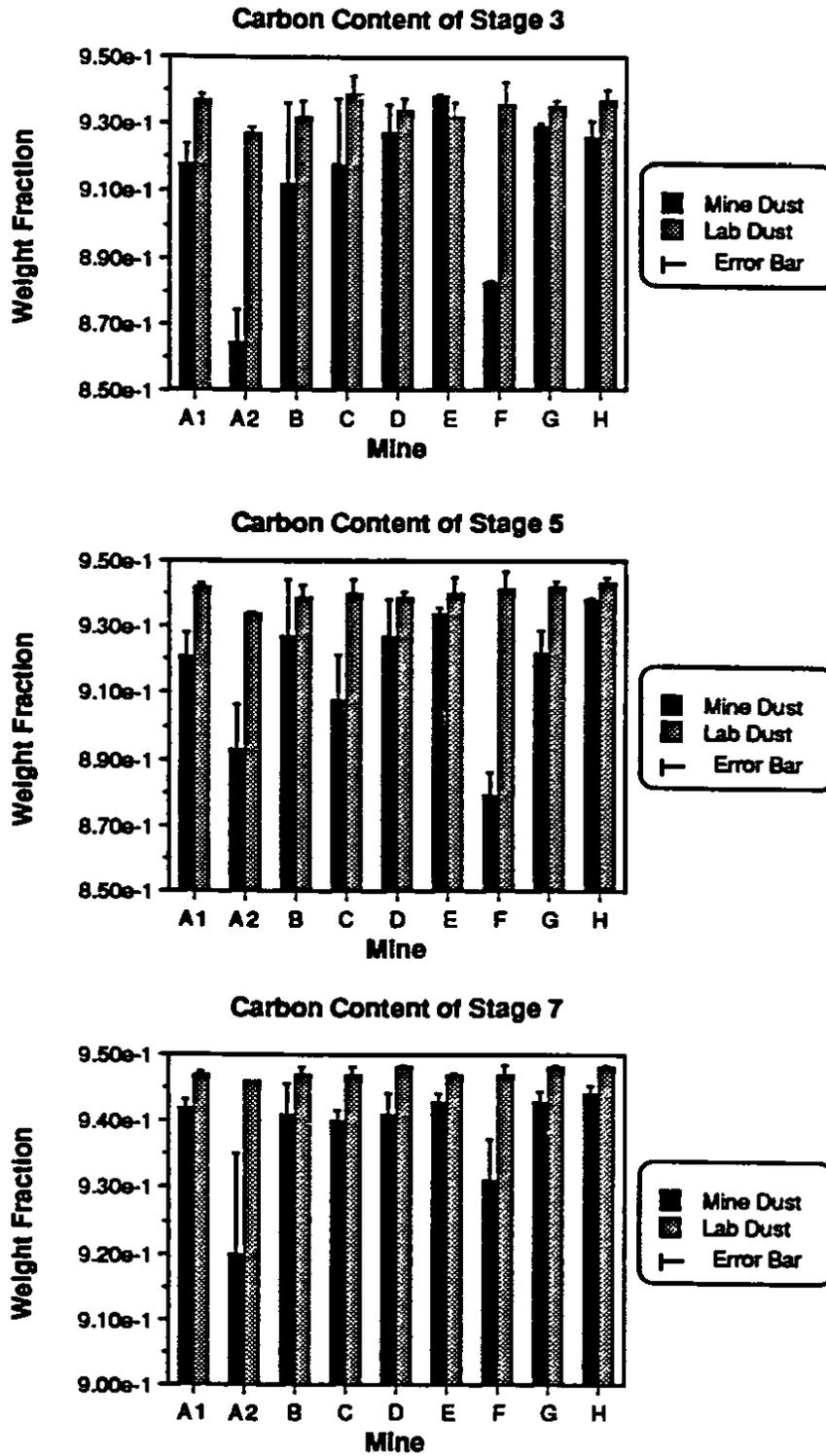


Figure 2. Carbon content by stage and mine.

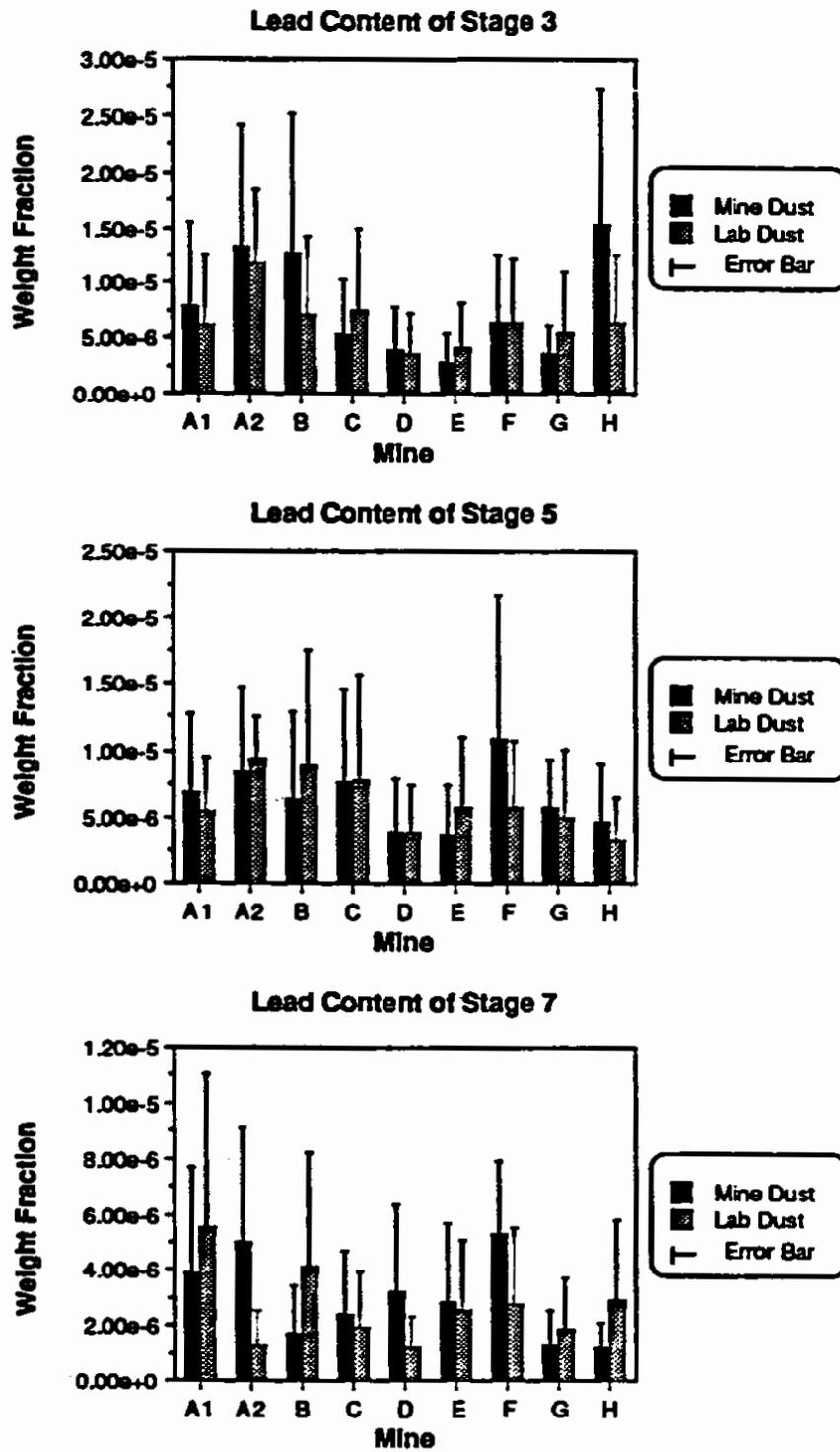


Figure 3. Lead content by stage and mine.

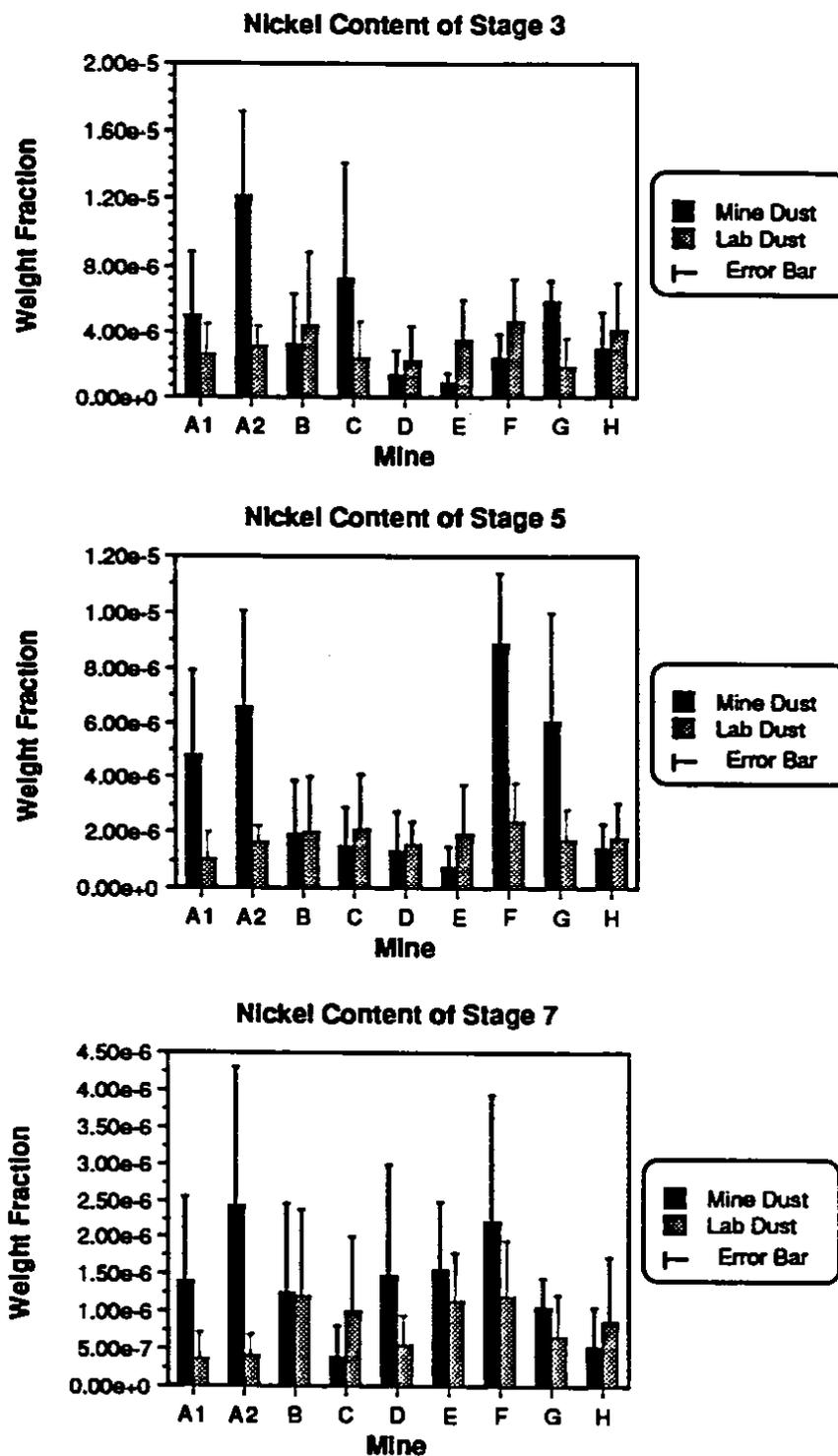


Figure 4. Nickel content by stage and mine.

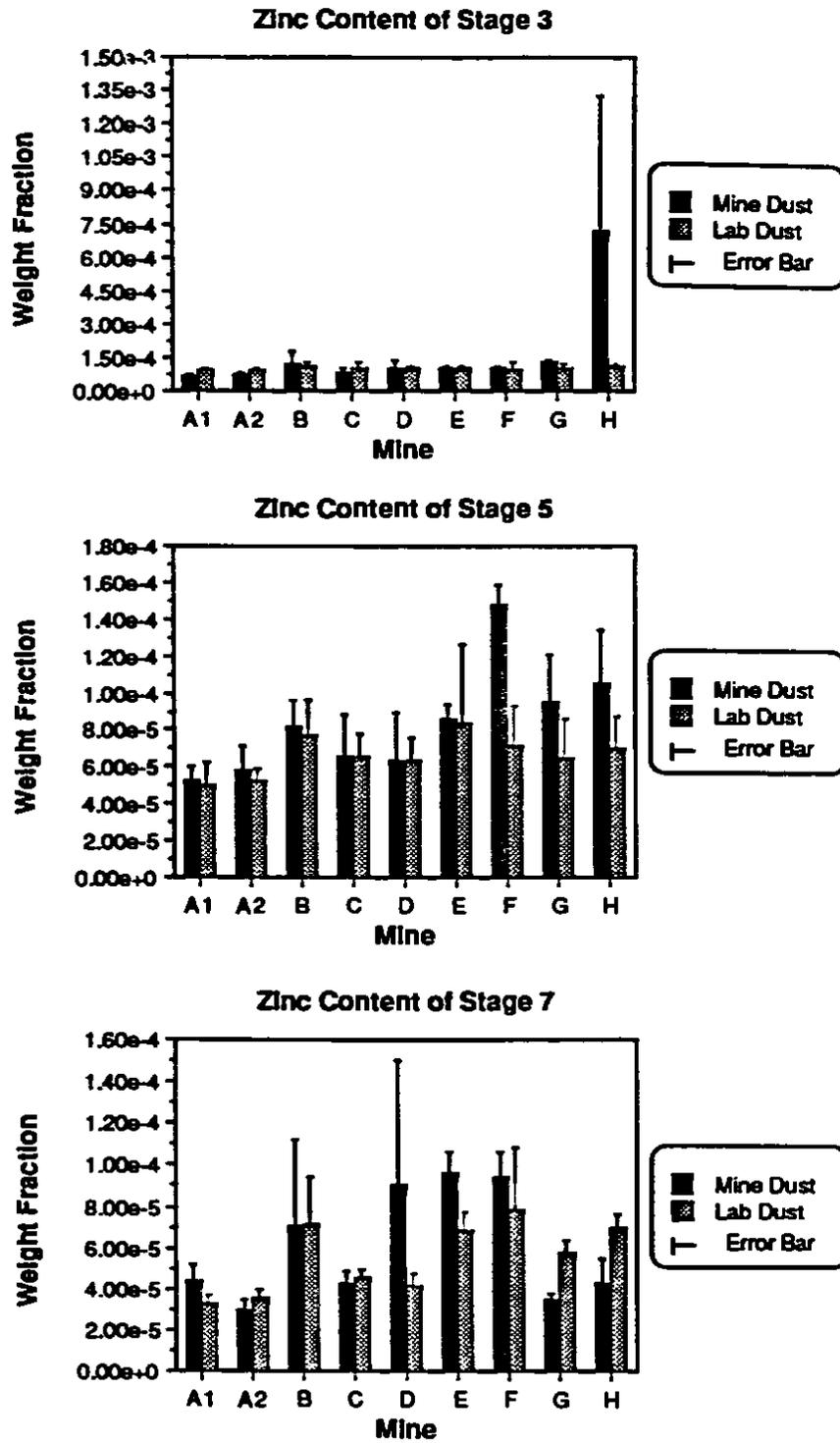


Figure 5. Zinc content by stage and mine.

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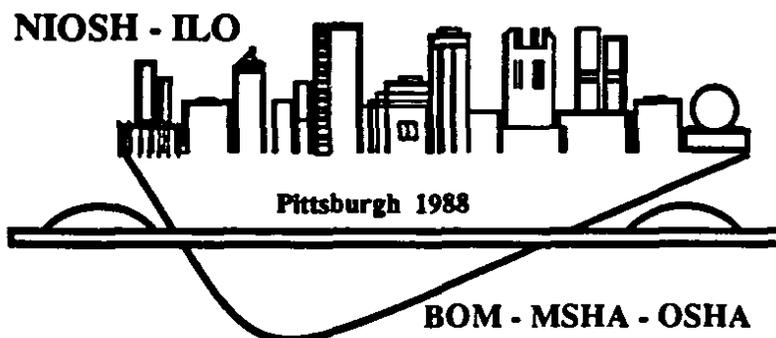
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