

# Risk Factors Associated with Silicosis among Zambian Copper Mine Workers: A Retrospective Case Record Review

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## Research article

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# Abstract

**Background:** Silicosis is the most important occupational disease worldwide and is regarded as a major public health challenge in developing countries. The disease is mainly related to exposure to crystalline silica dust, and once the disease has been established, no treatment exists. There is less focus on other factors that are related to one acquiring the disease among the people at greater risk of developing silicosis. The main aim of this study was to assess the risk factors associated with developing silicosis among Konkola Copper Mine workers in Zambia. **Methods:** A retrospective case review study was used, consisting of 168 Konkola Copper Mine Workers. A data extraction checklist was used to collect data on miners from the occupational hygiene silicosis registers. Data was analyzed using STATA version 12.0; a quantile-quantile plot was used to test for normality of continuous variables such as age and a chi-squared test was used to ascertain association with development of silicosis. Adjustment for the effect of other factors was computed using an investigator led stepwise multiple logistic regression method. **Results:** For each year increase in length of service, Konkola Copper Miners are 1.95 times more likely to develop silicosis adjusting for other factors such as business unit, job category (95% CI 1.92-1.99,  $p=0.033$ ). Miners working in the production areas were highly susceptible to developing silicosis compared to those working in other areas. Within the production area, miners working underground represented 38% of silicosics, while those working at open pit only had 10%. Miners belonging to Konkola and Nchanga business unit were 5.42 and 5.96 times more likely to develop silicosis compared to those working in other units respectively. **Conclusions:** As a result of the statistical analysis, our findings suggest that the factors considered best predictors of silicosis were length of service, business unit and the job category to which the miners belonged to (P-values 0.033, 0.001,  $<0.001$  respectively). There is need to reduce the length of service that individuals work underground, strengthen control measures regarding utilization of personal protective equipment, health education programs, frequent job rotations (for unskilled labour) and adherence to periodical medical examinations.

## Background

Silicosis is regarded one of the oldest occupational health disease. It is one of the most important occupational disease worldwide and it is regarded as a major public health challenge in developing countries such as those found in Southern Africa (Leung, 2012). These include countries like Zambia where this study was conducted. The World Health Organization/WHO (WHO, 2000) ranked China to have the largest number of cases of silicosis worldwide with over 24,000 deaths annually.

The risk of disease is mainly associated to the amount of crystalline silica dust inhaled during the time one worked in areas prone to this dust. Silica has been known to cause silicosis for centuries (Gómez-Puerta *et al.*, 2013; Steenland and Ward, 2014) and plays an important role in autoimmune diseases (Pollard and Kono, 2013). Once one acquires the disease, no proven effective treatment measures presently exist (Li *et al.*, 2013). However, patients are given supportive care and are taken for lung transplantation in waste case scenarios (Bang *et al.*, 2015).

It is estimated that approximately 65 million people had moderate to severe chronic obstructive pulmonary disease (COPD) and 3 million deaths related to it occurred in 2005 (WHO, 2005). The number of deaths represented five percent of the total deaths that were recorded worldwide. Developed and high income countries provided much of the information on COPD. Despite that, precise epidemiological data on COPD are hard and costly to obtain. Records indicate that about 90% of people who die from COPD are from low and middle-income countries (WHO, 2005).

Among the leading causes of death in 2002, COPD came out number five and people dying from COPD are expected to increase by 30 percent ten years from now if appropriate measures are not put in place to combat the disease or reduce the predisposing factors like tobacco use. Furthermore, it is projected that COPD will become number three leading cause of death by 2030 (WHO, 2005). Silica dust and other occupational exposures such as chemicals (vapours, irritants and fumes) are among the predisposing factors which can cause COPD (WHO, 2010).

Respiratory diseases associated with mining have been major international concern, with silicosis at the forefront, leading to the Global Programme for the Elimination of Silicosis (Lehtinen and Goldstein, 2002). It is projected that pneumoconiosis accounts for 30, 000 deaths yearly, with an estimation of 1.3 disability-adjusted life years (Lehtinen and Goldstein, 2002). The prevalence rates in Zambia are equally of major concern: the studies of ex-miners from Botswana, Transkei, and Lesotho, suggested prevalence rates of pneumoconiosis ranged from 26 percent to 36 percent among former mineworkers (Girdler-Brown *et al.*, 2008).

Tuberculosis, chronic obstructive pulmonary disease (COPD) and lung cancer are severe health outcomes linked to occupational exposure to crystalline silica dust (WHO, 2007). Silicosis is a devitalizing and mostly deadly lung disease of persistent worldwide concern whose progressive estimates go above one million cases in third world countries (WHO, 2007). Silicosis is a progressive disease and belongs to a group of lung disorders called pneumoconiosis and it is marked by the formation of nodules and fibrous scar tissue in the lungs (Haggerty, 2006).

Silicosis is the oldest known occupational lung disorder, and is caused by inhalation of particles of silica, mostly from quartz in rocks, sand, and similar substances (Haggerty, 2006). Miners are considered to be at high risk of developing silicosis. Haggerty (2006) attests that silicosis is mostly seen in adults over 40 years and has four forms: (a) Chronic - Chronic silicosis takes about 15 or more years of exposure to manifest. During this period, there is only mild impairment of lung functioning. This form of silicosis can progress to more advanced forms; (b) Complicated—Individuals with complicated silicosis have noticeable shortness of breath, weight loss, and have fibrosis in the lungs. These patients are highly at risk of developing tuberculosis (TB). This condition can further progress to a more severe form; (c) Accelerated - This type or form of silicosis surfaces after five to ten years of intense exposure to crystalline silica dust. Complicated and accelerated forms of silicosis have similar symptoms. Patients who advance to this form often develop rheumatoid arthritis and other autoimmune disorders; (d) Acute - Acute silicosis appears within six months to two years of intense exposure to silica dust. The patient

loses weight significantly, is constantly experiencing dyspnea and is at severe risk of developing tuberculosis (Haggerty, 2006).

Experimental studies indicate that the toxic and fibrogenic potentials of silica dusts vary depending on the innate features of the silica dust (Donaldson and Borm, 1998). This means that people exposed to different environments containing silica dust have different levels of developing silicosis. Miners are among the people at greater risk of developing silicosis hence this study was conducted to assess risk factors associated with developing silicosis among Copper Mine Workers in Zambia.

The study had three objectives: firstly to determine miners at which work sites are at greater risk of developing silicosis, secondly to determine miners at which business unit are more likely to develop silicosis and lastly to assess the major risk factors associated with developing silicosis among copper mine workers.

## Methods

The purpose of this study was to assess the risk factors associated with developing silicosis among copper mine workers in Zambia. A retrospective case record review study design was used in this study. Copper Mine workers with silicosis were followed up retrospectively to assess whether length of service and other risk factors are associated with developing silicosis.

Nchanga, Konkola, Nkana and Nampundwe business units were included in this study and these have been in existence for more than 15 years (long induction period of silicosis diseases criteria met). These mines are owned by Vedanta Resources PLC and operate under the company name called Konkola Copper Mine (KCM) in Zambia. The major product produced is copper with pyrite, cobalt, anode slimes and acid as by - products.

The study population included all Konkola Copper Mines workers diagnosed with silicosis from 2000 to 2015. These should have attended medical examination from Occupational Health Management Bureau (OHMB) on a yearly basis.

The sample size was determined using the 95 percent confidence interval for comparison of proportion, at 80% power, 5% significance level. Hundred and sixty eight participants were included in the study (56 silicotics and 112 non-silicotics). For each silicotic, two non-silicotics were selected.

The researchers used a simple random sampling (probability sampling method), to select the participating copper mine employees from the study population. This procedure was used because it gives equal chance to every participant from the population to be selected. The participants were drawn from records of employees at KCM occupational health section; and who attended medical examinations at the OHMB in the period from 1st January, 2000 to 2015.

The study included participants who had valid silicosis certificates and attended silicosis medical examinations annually. The study excluded participants diagnosed with silicosis but had no valid

certificates.

Silicotics included a sample of Konkola Copper Miners diagnosed (both clinically and radiological examination) with silicosis. These had valid medical certificates. Non-silicotics included a sample of workers with similar characteristics as the silicotics, except they did not have the outcome of interest (clinically and radiological diagnosed silicosis).

Data collection was done through the review of Konkola Copper Mine PLC mineworkers' files (records) at the corporate occupational health office. A data extraction checklist was used to collect data which was later entered directly into STATA for data cleaning (checking for completeness, coding).

Data from the data collection checklist was entered directly onto the computer in coded form using STATA. However, before proceeding with the analysis, raw data was checked for completeness and accuracy.

All analyses were performed using STATA software, version 12.0 SE (Stata Corporation, College Station, TX, USA). The distributions of continuous variables were not symmetric. To test for normality, the q-q plot was used to investigate normality graphically (results not shown). There was no evidence to suggest that data were normally distributed, hence in the descriptive statistics for continuous variables, we report median and inter-quartile range.

To prevent inflation of type-I error, loss of power, residual confounding, and bias, continuous explanatory variables such as age and length of service were not categorised as articulated by Del Priore *et al* (1997); Austin and Brunner (2004) and Royston *et al*, (2006). To test any differences in age and length of service, a non-parametric Wilcoxon rank sum (Mann–Whitney) test was used as opposed to a two sample t-test as these continuous variables were not symmetric. Categorical variables such as sex, are first reported as numbers, percentages; Chi-squared test was used to ascertain association with development of silicosis.

An investigator led step wise multiple regression best model selection approach was used to select the best predictors of developing silicosis in the multiple logistic regression model as opposed to machine-led step-wise regression, which is not advisable by scholars such as Hurvich and Tsai (1990; Derksen and Keselman, (1992). Adding of variables in the model was influenced by literature review. Selection of predictor or explanatory variables was performed by using the likelihood ratio test after estimation of the nested models by adding and eliminating variables one at a time.

## Results

The population of the study comprised only miners working at Konkola copper mine. During the 15 year period, 168 miners were investigated for risk factors associated with developing silicosis. Table 1 shows the demographic characteristics of the participants. Age distribution ranged from 40 to 51 with a median of 46 years and 34 to 53 with a median of 48 among the silicotics and non-silicotics respectively. A total of 29 (17% of total) were females and 139 (83% of total) were males. Only one (3% of total) female was a

silicotic and 28 (97% of total) were non-silicotics and 55(40% of total) males were silicotics and 85(60% of total) were non-silicotics. There was a significant difference between females and males who were silicotics ( $P < 0.001$ ). However, there was no significant difference in marital status and education status between the silicotics and non-silicotics ( $P = 0.081$  and  $0.925$  respectively).

## Risk factors

The results of univariate analysis to assess for correlation between individual risk factors and development of silicosis are given in table 1. There was no significant difference in age between Konkola Copper miners in the silicotic and non-silicotic group (median age of 46 versus 48,  $P = 0.7463$ ) and no difference in the period they have worked in mine or length of service (median period of 11 versus 19 years,  $P = 0.1813$ ). There was a significant difference between the silicotics and non-silicotics in relation to the business unit and job category they belonged ( $P < 0.001$ ).

## Distribution of Silicotics according to Job Category

Figure 1 below shows the distribution of silicotics according to job categories, while Figure 2 shows the distribution of silicotics according to the production areas:

*Figure 1: Distribution of silicotics*

The figure above shows that a majority of silicotics belonged to the production unit and there was a significant difference between the job categories ( $P < 0.001$ ).

*Figure 2: Distribution of silicotics according to production areas*

As shown in figure 2 above, within the production unit, most silicotics were from underground section and the least were from smelter.

## Risk Factors Associated with Silicosis

Table 2 below shows how each predictor variable related with the outcome variable (bivariate analysis) and how all the predictor variables were affected with the outcome variable (adjusted analysis). As a result of statistical analysis, the investigators determined that the factors considered best predictors of silicosis from this study were length of service or the period worked in the mining industry, business unit and job category to which the copper miners belonged to ( $P$ -values  $0.033$ ,  $0.001$  and  $< 0.001$  respectively) as shown in table 3.

## Discussion

The findings of this study showed that the risk factors associated with silicosis were length of service, the business unit and job category to which mineworkers belonged to. Length of service was defined as the number of years one has been working in the mining sector. The longer one works, the more they are exposed to crystalline silica dust and hence increasing the chances of developing silicosis. Length of service was statistically significant in relation to mineworkers developing silicosis. This is consistent with the study done by (Churchyard *et al.*, 1999), who found that for each year increase working in the mining industry, miners were 11 percent more likely to develop silicosis adjusting for other factors such as cumulative exposure to respirable dust; and for every five years increase in working in the mining sector, miners were 1.69 times more likely to develop silicosis (Churchyard *et al.*, 1999).

Konkola Copper Mine has six business units and these include, Corporate, Nchanga, Konkola, Nchanga Smelter, Nkana and Nampundwe. We found that mineworkers at Nchanga and Konkola were more likely to develop silicosis compared to those working in other business units and this was statistically significant. Nchanga and Konkola house many business operations of this company (where many mining activities take place from). Hence they have a large number of workforce exposed to crystalline silica dust compared to the other business units. Nampundwe business unit is mainly associated with pyrite mining than copper mining. No silicotic was present in Nampundwe during the study period. This may suggest that pyrite mining is less likely to be associated with silicosis compared to copper mining. However, there is need for further study on this.

Our aim was to determine the risk factors associated with developing silicosis among Konkola Copper Mine workers. We also evaluated which work site and business unit is more associated with developing silicosis. We found that the average age range for one to develop silicosis was between 46 and 48 which is close to 44 years and 48 which Bang *et al.*, (2015) and Chen *et al.*, (2001) respectively found in their studies.

Furthermore, we found that males are more likely to develop silicosis compared to female counterparts and this was statistically significant. However, this would also be attributed to the nature of the population under study. There are more males employed in the mining sector than females. Varkey *et al.*, (2015) attested to the fact that silicosis mainly affects male workers, reflecting the occupations at risk. Selection of occupations is highly influenced by societal norms regarding gender roles. Manual work is more associated to males than females.

Miners working in the production areas were highly susceptible to developing silicosis compared to those working in other areas. Within the production area, miners working underground represented 38% of the total silicotics and were more likely to develop silicosis compared to those working at open pit and other areas. This is consistent with other studies which showed that miners working as lashers (production area) are more likely to develop silicosis (Sitembo, 2012).

Mineworkers belonging to Konkola and Nchanga business unit were more likely to develop silicosis compared to those working in other units respectively. A study conducted by Sitembo (Sitembo, 2012), equally showed that the percentage of silicotics at Nchanga is higher than those at Konkola. Unlike other

business units, Nchanga has most mining operations, for instance, smelting, underground, tailing leach plant, to mention but a few.

As a result of the statistical analysis, the researchers determined that the factors considered best predictors of silicosis were length of service, business unit and the job category to which the miners belonged to (P-values 0.033, 0.001, <0.001 respectively). Length of service was defined as the period one has worked in the mining industry. Mannelje *et al* (2002) established a similar predictive association between duration of exposure to crystalline silica and eventual development of silicosis which is also consistent with Varkey *et al.*, (2015) also confirmed that the risk of developing silicosis increased as the duration of exposure increased. The longer one works in the mining industry, the more they are exposed to crystalline silica dust hence increasing the chances of developing silicosis.

## Conclusion

Silicosis was well associated with long years of service in the mining industry, the business unit and the job category to which the participants belonged to besides other hypothesized factors. Males are more likely to develop silicosis compared to females as most mining operations are associated to male counterparts as opposed to females. Long years of service usually influence other factors such as cumulative exposure to crystalline silica dust. Different business units and job categories have varying operations and hence differences to exposure levels. The findings are consistent with other studies which looked at risk factors associated with developing silicosis.

There is need for more prospective studies to investigate why other departments are at greater risk of developing silicosis within Konkola Copper Mines Plc operational areas. The findings of this study show the significance of engaging and informing miners at and their employers regarding the effects of exposure to respirable crystalline silica in the workplace. Comprehensive silicosis prevention programs have been suggested by Bang (2015) and these include imploring less hazardous non-crystalline silica options whenever possible, applying engineering controls such as putting up local exhaust ventilation systems, avoiding the use of compressed air for cleaning surfaces, using water sprays to suppress airborne dust, and using surface wetting to prevent dust from becoming airborne when cutting, drilling and grinding. To add on that administrative and work practice controls such as job rotations, personal respiratory protective equipment must be utilized at all times, strict pneumoconiosis medical examination of employees, and training of workers. Due to serious health and socioeconomic effects of silicosis, operations and tasks placing workers at risk for silicosis, and the continuing occurrence of silicosis deaths among workers, effective primary or source prevention through elimination of exposure to respirable crystalline silica dust is critical.

At the same time, due to long latency of silicosis, with cases diagnosed years after exposure and often in retirement, continuous silicosis surveillance is needed to track its prevalence in all risk areas. There is need to rotate employees across different job categories and business units within the mining companies. Results of this study may not be generalized to other mines as it was a case review study.

However, they provide a baseline for further research and measures which can be applied in the affected mining industry. We started off with a case control study but because of lack of information, we ended up doing a case review which has also provided much needed knowledge on the risk factors associated with silicosis. Data on smoking status was not available on records, as a result the investigators did not measure this variable.

## List Of Abbreviations

COPD:Chronic Obstructive Pulmonary Disease, ID:Identity Number, KCM: Konkola Copper Mine, MOH: Ministry of Health, NCM: Nchanga Copper Mine, NkCM: Nkana Copper Mine, OHMB: Occupational Health Management Bureau, SD: Standard Deviation, TB: Tuberculosis, UNZA: University of Zambia, UNZA BREC: University of Zambia Biomedical Research Ethics Committee, WHO: World Health Organization

## Declarations

### Ethics approval and consent to participate

This study received ethical approval from the University of Zambia Biomedical Research Ethics Committee. Permission to use the miners' records was sought from Konkola Copper Mine Plc.

Participants' data (name, silicosis status, etc) was de-identified using IDs. The results of the study will only be circulated to affected mine to uphold confidentiality and minimize risk to company.

### Consent for publication

Not applicable

### Availability of data and material

The datasets generated and/or analysed during the current study are available at Konkola Copper Mine Occupational Health Silicosis Registers

### Competing interests

The authors declare that they have no competing interests

### Funding

The corresponding author funded the study

# Authors' contributions

JZ: Contributed in writing of the manuscript, PM: Provided guidance on statistical analyses and interpretation, RD: Provided guidance on the layout of the manuscript, YS: Provided contextual knowledge on the topic under study

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## Tables

### Table 1 Demographic Characteristics and Associated Risk Factors of Participants

Factors	Silicotics, n=56	Non-silicotics, n=112	P-Value
Age (years)	46(40-51)	48(34-53)	0.7463 <sup>a</sup>
Length of service(years)	11(8-27)	19(8-31)	0.1813 <sup>a</sup>
Sex:			
Female	1(3%)	28(97%)	<0.001 <sup>b</sup>
Male	55(40%)	84(60%)	
Marital status:			
Married	52(36%)	93(64%)	0.081 <sup>b</sup>
Single	4(17%)	19(83%)	
Divorced	0	0	
Education Status:			
Primary	4(29%)	10(71%)	0.925 <sup>b</sup>
Secondary	29(34%)	57(66%)	
Tertiary	23(34%)	45(66%)	
Business Unit:			
Corporate	7(11%)	55(89%)	<0.001 <sup>b</sup>
Konkola	12(48%)	13(52%)	
Nchanga	35(47%)	39(53%)	
Nchanga smelter	1(33%)	2(67%)	
Nkana	1(25%)	3(75%)	

Job category:

Technical services	29(63%)	17(37%)	<0.001 <sup>b</sup>
Support services	7(54%)	6(46%)	
Production	8(12%)	61(88%)	
Engineering services	12(30%)	28(70%)	

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<sup>a</sup>Two-sample Wilcoxon rank sum test (Mann –Whitney test). <sup>b</sup>Chi-square-Test.

## Table 2 Unadjusted and Aadjusted Analysis of Predictor Variables

Variable	Unadjusted OR(95% CI)	P-value	Adjusted OR(95% CI)	P-value
Sex:				
Female	1		1	
Male	18.33(2.42-138.68)	0.05	*16.83(1.93-146.87)	0.011
Age	1.01(0.98-1.05)	0.561	1.02(0.94-1.12)	0.622
Marital status:				
Married	1		1	
Single	0.38(0.12-1.67)	0.090	0.16(0.03-0.02)	0.022
Education status:				
Primary	1		1	
Secondary	1.27(0.37-4.41)		1.50(0.34-6.71)	
Tertiary	1.28(0.36-4.52)	0.704	1.39(0.28-6.80)	0.595
		0.704		0.686
Length of service	0.99(0.96-1.10)		0.93(0.86-0.90)	
		0.347		0.041
Business unit:				
Corporate	1		1	

Konkola	7.25(2.39-22.03)		2.97(0.71-12.35)	
Nchanga	7.05(2.84-17.51)	<0.001	4.68(1.51-14.48)	0.135
Nchanga smelter	3.93(0.31-49.12)	<0.001	3.54(0.19-67.21)	0.007
Nkana	2.62(0.23-28.75)	0.288	1.12(0.07-19.14)	0.399
		0.431		0.935
Job category:				
Technical/Admin	1		1	
Support services	0.68(0.20-2.37)		0.48(0.12-1.89)	
Production	0.77(0.03-0.20)	0.549	0.71(0.02-0.23)	0.295
Engineering	0.25(0.10-0.62)	<0.001	0.19(0.06-0.58)	<0.001
		0.003		0.003

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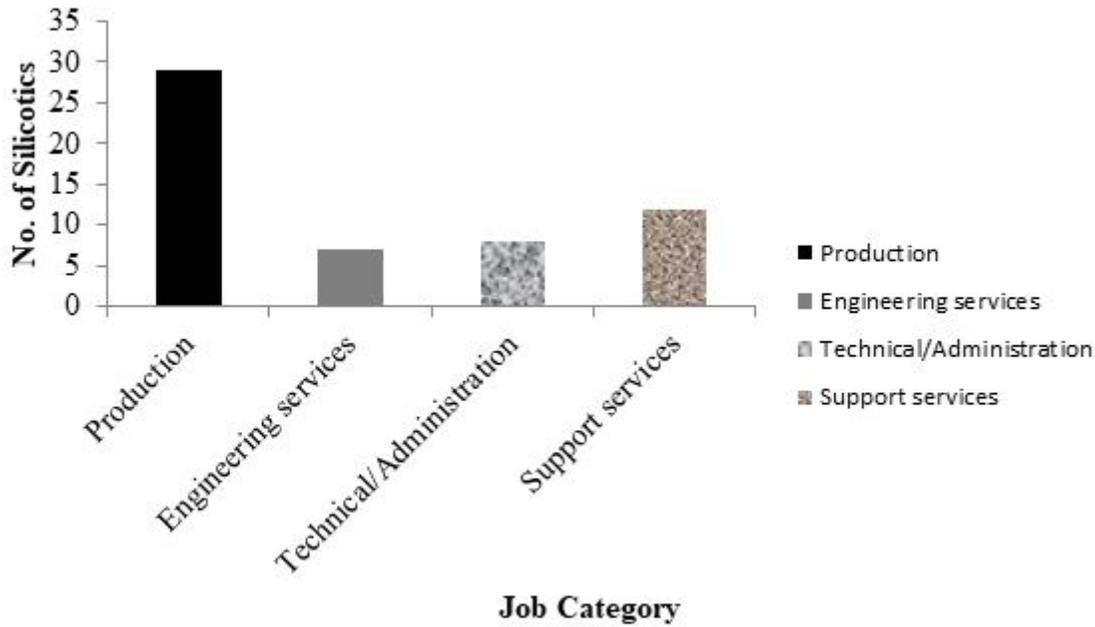
\*Males were 16.8 times more likely to develop silicosis compared to females and this was statistically significant (95% CI 1.93-146.87, P=0.011).

### **Table 3 Adjusted Predictors of Silicosis from the best model that fits the data well**

Variable	OR(95% CI)	P-value
Length of service	*1.95(1.92-1.99)	0.033
Business unit		
Corporate	1	
Konkola	5.42(1.48-19.84)	0.011
Nchanga	5.96(2.11-16.79)	0.001
Nchanga smelter	4.23(0.29-61.21)	0.290
Nkana	1.15(0.08-16.48)	0.920
Job category:		
Technical/Admin	1	
Support services	1.65(0.18-2.41)	0.522
Production	1.09(1.03-1.26)	<0.001
Engineering	1.21(1.08-1.58)	0.002

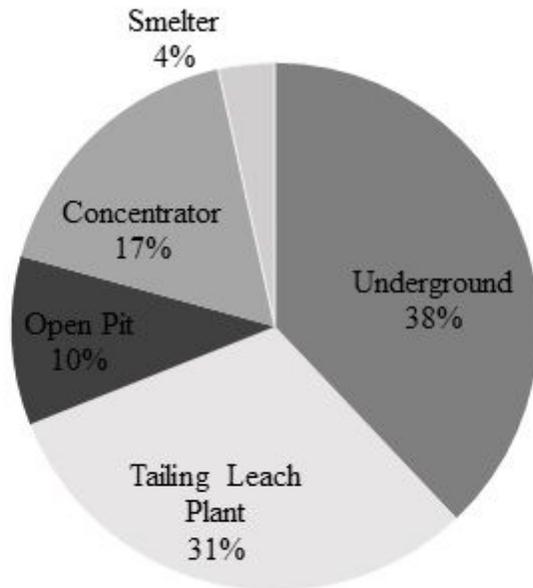
\*For each year increase in length of service, konkola copper miners are 1.95 times more likely to develop silicosis.

## Figures



**Figure 1**

Figure 1: Distribution of silicotics The figure above shows that a majority of silicotics belonged to the production unit and there was a significant difference between the job categories ( $P < 0.001$ ).



**Figure 2**

Figure 2: Distribution of silicotics according to production areas