CEGEMI-UCB
CENTRE D'EXPERTISE EN GESTION DU SECTEUR MINIER

vliruos SHARING MINDS, CHANGING LIVES

Les mines, l'environnement et la santé : recherches et perspectives
Bukavu, 16-17 décembre 2019

La santé des mineurs

Benoit NEMERY, MD, PhD
Centre for Environment and Health
Department of Public Health and Primary Care
KU Leuven – Belgium

ben.nemery@kuleuven.be

Impact des mines sur la santé

- Un peu d'histoire …
- Impact sur la santé des mineurs
  - Effets de l'inhalation de poussières
  - Comment mesurer l'exposition
  - Quelques résultats de nos études au Katanga
- Impact sur la santé des populations

  → Prof. Banza Lubaba

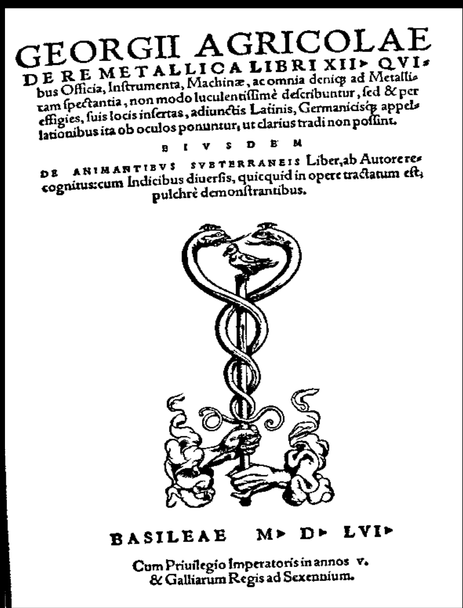
Acknowledgements:

Prof. BANZA LUBABA NKULU Célestin, PhD
and colleagues
Unité de Toxicologie et Environnement
Ecole de Santé Publique – UNILU
Lubumbashi – DR Congo

Un peu d'histoire

Lucas Gassel, De Kopermijn – La Mine de Cuivre (1544) [Musées Royaux des Beaux-Arts, Bruxelles]

see McKiernan M. *Occupational Medicine* 2008, 58, 159-160



GEORGII AGRICOLAE
DE RE METALLICA LIBRI XII. QVIbus Officia, Instrumenta, Machinae, ac omnia denique ad Metallicam spectantia, non modo luculentissimè describuntur, sed & per effigies, suis locis insertas, adiunctis Latinis, Germanicisque appellationibus ita ob oculos ponuntur, ut clarius tradi non possint.

EIVSDEM

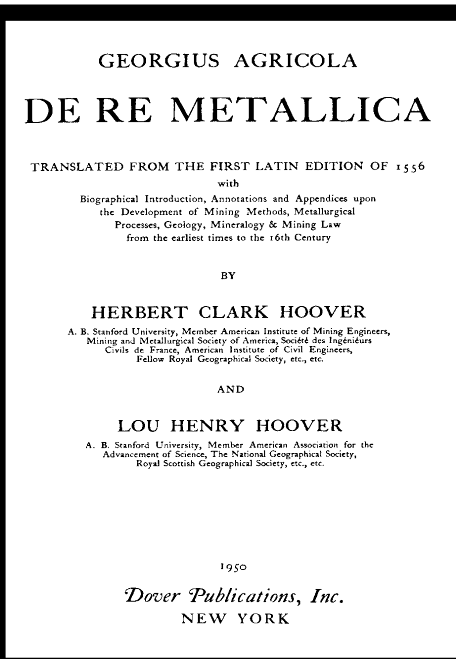
DE ANIMANTIBVS SVBTERRANEIS Liber, ab Autore recognitus: cum Indicibus diversis, quicquid in opere tractatum est, pulchrè demonstrantibus.

BASILEAE M. D. LVI.

Cum Privilegio Imperatoris in annos v. & Galliarum Regis ad Sexennium.

Georg Bauer
Georgius AGRICOLA
(Glauchau, Sachsen, 1494
–
Chemnitz, 1555)

Herbert C. Hoover
(1874-1964)
President USA (1929-1933)



GEORGIUS AGRICOLA

DE RE METALLICA

TRANSLATED FROM THE FIRST LATIN EDITION OF 1556
with
Biographical Introduction, Annotations and Appendices upon the Development of Mining Methods, Metallurgical Processes, Geology, Mineralogy & Mining Law from the earliest times to the 16th Century

BY

HERBERT CLARK HOOVER

A. B. Stanford University, Member American Institute of Mining Engineers, Mining and Metallurgical Society of America, Société des Ingénieurs Civils de France, American Institute of Civil Engineers, Fellow Royal Geographical Society, etc., etc.

AND

LOU HENRY HOOVER

A. B. Stanford University, Member American Association for the Advancement of Science, The National Geographical Society, Royal Scottish Geographical Society, etc., etc.

1950

Dover Publications, Inc.
NEW YORK

Agricola - De Re Metallica

Agricola - De Re Metallica

Book VI (Hoover, p.214): mines

- *Certaines [maladies] affectent les articulations, d'autres attaquent les poumons ou les yeux, et enfin certaines sont fatales pour les hommes*

Agricola - De Re Metallica

Book VI (Hoover, p.214): mines

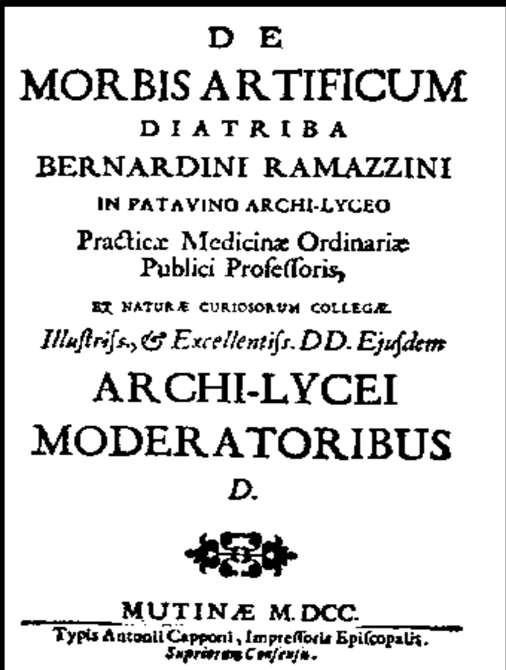
[dans certaines mines] la poussière produite par les creuseurs pénètre dans la trachée et les poumons et cela cause des difficultés pour respirer et une maladie que les Grecs appellent $\alpha\sigma\theta\mu\alpha$. Si cette poussière a des propriétés corrosives, les poumons et le corps sont détruits; par conséquent, dans certaines mines des Carpathes on connaît des femmes qui ont marié sept maris, car cette terrible maladie les a tous menés à une mort prématurée

Agricola - De Re Metallica

Book VI (Hoover, p.214): mines

- *Il faudrait toujours accorder plus d’attention à notre santé plutôt que de faire du profit*

Bernardino Ramazzini
(Carpi, Modena, 4 Oct.1633 - Padova, 5 Nov.1714)



DE
MORBIS ARTIFICUM
DIATRIBA
BERNARDINI RAMAZZINI
IN PATAVINO ARCHI-LYCEO
Practicæ Medicinæ Ordinariæ
Publici Professoris,
EX NATURÆ CURIOSORUM COLLEGÆ
Illustriss., & Excellentiss. DD. Ejusdem
ARCHI-LYCEI
MODERATORIBUS
D.

MUTINÆ M.DCC.
Typis Antonii Capponi, Impressoris Episcopalis.
Superiorum Consensu.

Ramazzini - De Morbis Artificum CAPUT PRIMUM

De Morbis quibus obnoxii sunt Metallorum Fossores

Varia et multiplex morborum seges, quam non raro artifices quidam extrema sui pernicie ex iis artibus quas exercent, pro lucro referunt, ex duabus praecipue causis, ut reor, progerminat; quarum prior, ac potissima, est prava materiae conditio quam tractant, quae noxios halitus ac tenues particulas humanae naturae infensas exspirans, particulares morbos invehit

Diseases to which miners of metals are exposed

Various and manifold is the harvest of diseases reaped by certain workers from the crafts and trades that they pursue; all the profit that they get is fatal injury to their health. That crop germinates mostly, I think, from two causes. The first and most potent is the harmful character of the materials that they handle, for these emit noxious vapours and very fine particles inimical to human beings and induce particular diseases.

Ramazzini - De Morbis Artificum CAPUT PRIMUM

Morbi autem, quibus obnoxii sunt metallorum fossores, aliique id genus artifices, sunt ut plurimum dyspnoea, phthisis, apoplexia, paralysis, cachexia, pedum tumores, dentium casus, gingivarum ulcera, artuum dolores ac tremores. Pulmones itaque, et cerebrum in hujusmodi artificibus male plectuntur, magis tamen pulmones; hi etenim simul cum aëre minerales spiritus hauriunt, et prima noxam persentiunt,

Now the diseases to which miners and other workers of that sort are exposed are chiefly dyspnoea, phthisis, …

Hence the lungs … are badly affected …

since they take in with the air mineral spirits and are the first to be keenly aware of injury.

Ramazzini - De Morbis Artificum
CAPUT PRIMUM

Neque vero fossores tantum in fodinis a metallicis pestibus mactantur, verum etiam multi alii artifices, qui circa fodinas operantur, graves noxas accersunt, ut metallurgi omnes qui effossam materiam versant, exquocuunt, fundunt, ac repurgant

Non solum ergo fossores, sed degentes et operantes circa fodinas male plectuntur a metallicis exhalationibus, quae vitales et animales spiritus, quorum natura aetherea est et pellucida, obfuscant, et totius corporis naturalem oeconomiam pervertunt.

Not only the miners in mines are severely punished by metallic pests, but many others too whose work is near the mines invite serious injury, I mean all the metal workers who shovel, smelt, cast and refine.

Also those living close to the mines are affected by metal exhalations that obscure the vital spirits … and alter the natural economy of the body.

Les mines et la santé publique

Les mines et la santé publique

- Impacts positifs:
  - Emploi
  - Création de richesse
  - Développement des infrastructures (transport, hopitaux, …)
- Impacts négatifs:
  - ➢ pour les mineurs et travailleurs en aval
  - ➢ pour les populations vivant à proximité des mines & industries de transformation

Travailleurs

Large scale organized mines ↔ small scale artisanal mines

Extraction ↔ refining ↔ processing

- ➢ Risques spécifiques
- ➢ Conditions de vie
  - Camps (alcool, drogues, prostitution → HIV, ...)
  - Environnements inhospitaliers (jungle, montagnes, déserts)
- ➢ Populations vulnérables (migrants; femmes, enfants)

Risques pour la santé des travailleurs

Risques pour la santé des mineurs

Indépendemment du minerai extrait, les risques principaux pour la santé sont

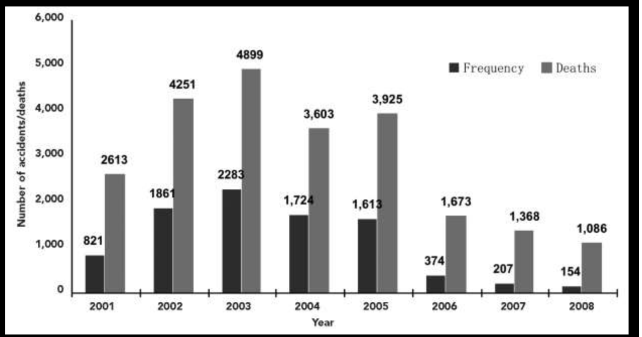
- Les accidents
- Les affections musculo-squelettiques
- La chaleur excessive
- Les maladies respiratoires


Katondo 2017


Katondo 2017

Ming-Xiao et al. Analysis of national coal-mining accident data in China, 2001-2008. Public Health Rep. 2011;126:270-5.

- China:
  - 2005: 28,000 coal mines
  - 2008: 12,777 coal mines
- 2001-2008:
  - 9,037 accidents
  - 23,418 deaths

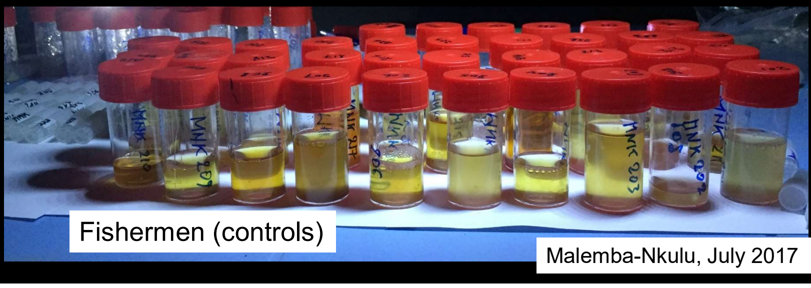


Heat strain in mining

- Hunt *et al*. Heat strain and hydration status of surface mine blast crew workers. *JOEM* 2014, 56, 409-414
  - Australia,15 blast crew personnel, 12 h shift
  - Heart rate: mean 86 bpm, max 127 bpm
  - Core body temp.: mean 37.46°C

    → max 37.98°C (47% >38°C)
  - Specific urine gravity: 1.024 (79% above 1.020)
  - Fluid consumed during shift: 4.4 ± 2.1 L
  - 73% report symptoms of heat illness

Adjusting for urine concentration ?



Exposition à la poussière

Poussières minérales et poumons

Les effets de l’inhalation des particules de poussière dépendent de

1. La quantité totale de poussière inhalée
2. La taille des particules
3. La nature de la poussière

Poussières minérales et poumons

Les effets de l’inhalation des particules de poussière dépendent de

1. La quantité totale de poussière inhalée

concentration dans l’air (mg/m^3) x durée

- Mines souterraines > carrières à ciel ouvert

Inhaled dose

- Quantity of material

  concentration in air (mg/m^3)

  x amount of air inhaled (L)

  minute ventilation

  8-10 L/min at rest → 50 L/min during exercise

  x duration of exposure (min)

  ➢ 12 – 15 m^3 air/day

Poussières minérales et poumons

Les effets de l'inhalation des particules de poussière dépendent de

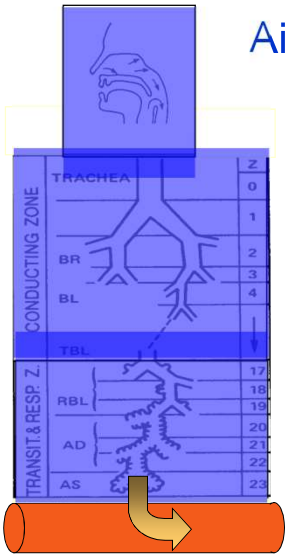
1. La quantité totale de poussière inhalée

   concentration dans l'air (mg/m^3) x durée

2. La taille des particules

   ➢ site de déposition dans l'arbre respiratoire

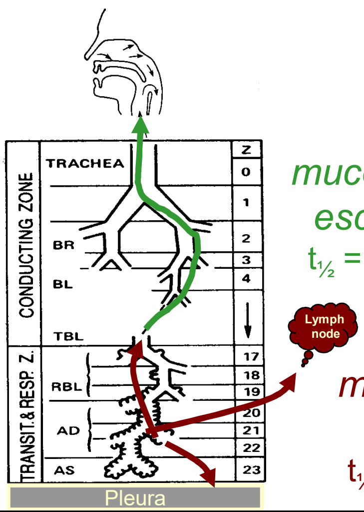
Respiratory uptake of particles



Air velocity		Particle size
+++	impaction	> 5 µm
++ / +	sedimentation	1 - 5 µm
0	diffusion	< 0.2 µm
		<< 0.1µm

Particle deposition & clearance

	v_{air}
impaction > 5 µm	+++
sedimentation 1 - 5 µm	++ / +
diffusion < 0.2 µm	0



mucociliary escalator
$t_{1/2}$ = 1h-15d

macrophages + lymph
$t_{1/2}$ = 60 - 300 d

Poussières minérales et poumons

Les effets de l'inhalation des particules de poussière dépendent de

1. La quantité totale de poussière inhalée
2. La taille des particules

- ➢ Plus les particules sont petites, plus elles pénètrent profondément dans le poumon
- ➢ La mécanisation produit plus de particules et des particules plus petites → danger ↑↑

Poussières minérales et poumons

Les effets de l'inhalation des particules de poussière dépendent de

1. La quantité totale de poussière inhalée
2. La taille des particules
3. La nature des particules

Dust-induced respiratory disease

- Pneumoconioses
- Chronic rhinitis & sinusitis
- Chronic bronchitis & chronic obstructive pulmonary disease (COPD; emphysema)
- Lung cancer (radon, …)

Radon daughters

- $^{238}U \rightarrow$ ^{222}Rn (gas) $\rightarrow$ Rn progeny (particles)

  α-irradiation

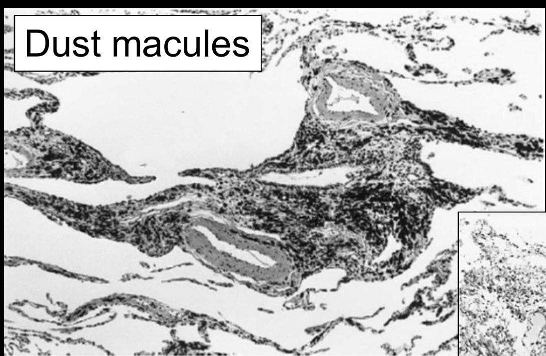
- uranium mines
- other mines (Fe, ...)

  not in coal mines (high ventilation)
- domestic contamination

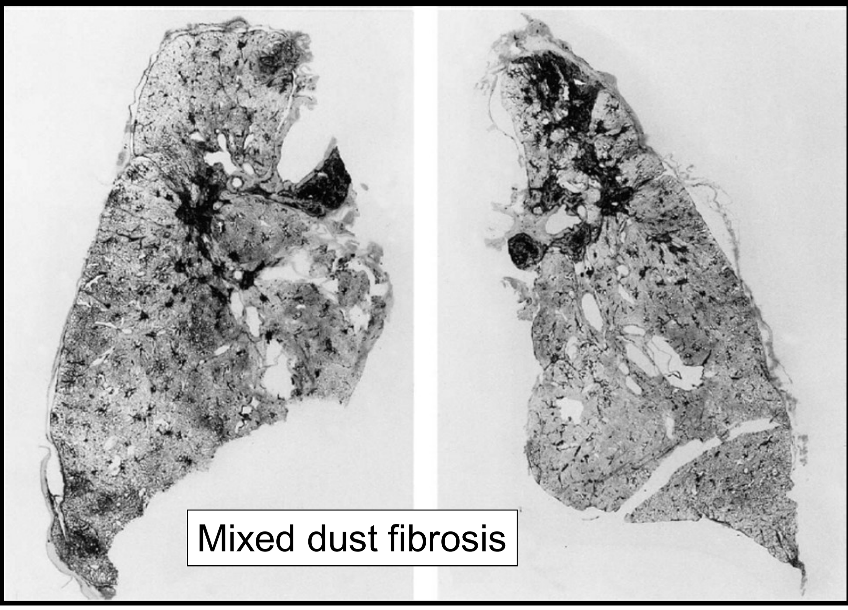
Pneumoconiosis

- Fibrotic disease of the lung parenchyma (focal or diffuse) caused mainly by accumulation of mineral dust or fibres (+ host reaction)
  - Silicosis
  - Coal worker's pneumoconiosis (CWP)
  - Asbestosis
  - Other pneumoconioses (talcosis, ...)
  - "Mixed dust fibrosis"

Honma K. *et al. Hum Pathol*, 2004, 35, 1515-23



Honma K. *et al*. *Hum Pathol*, 2004, 35, 1515-23



Poussières minérales et poumons

Les effets de l'inhalation des particules de poussière dépendent de

1. La quantité totale de poussière inhalée
2. La taille des particules
3. La nature des particules
   - concentration en silice cristalline libre (SiO_2)

Silicosis

Causes

Clinical Presentation

Complications

Silicosis

- Caused by free crystalline SiO_2 (quartz, …)
  - mining, quarrying, tunnelling
  - stone cutting, polishing, cleaning
  - sandblasting
  - abrasive & scouring powders
  - foundries
  - ceramics, refractory bricks, enamels
  - construction, demolition
  - …

Sandblasting jeans

Courtesy Dr. Akgün, Erzurum, Turkey

“New materials”
Kitchen and bathroom countertops, ...

caesarstone®

Hayumbu *et al*. Cross-sectional silica exposure measurements at two Zambian copper mines of Nkana and Mufulira. *Int J Environ Res Public Health* 2008, 5, 86-90

Table 2: Some descriptive statistical parameters for Mufulira and Nkana respirable dust samples

Descriptive	*Crystalline SiO_2 content quartz (%)*		*Total respirable dust (mg/m^3)*	*Respirable crystalline SiO_2 quartz (mg/m^3)*
	Mufulira	*Nkana*		
Count	87	85		
Mean	17.5	13.6		
Stdev	12.0	12.4		
Minimum	1.5	0.9		
Maximum	82.5	62.5		
Percentile 5th	3.8	2.1		
Percentile 10th	5.8	2.8		
Percentile 25th	9.6	4.7		
Median	16.8	9.0		
Percentile 75th	20.3	20.0		
Percentile 90th	25.8	29.7		
Percentile 95th	40.9	37.1		

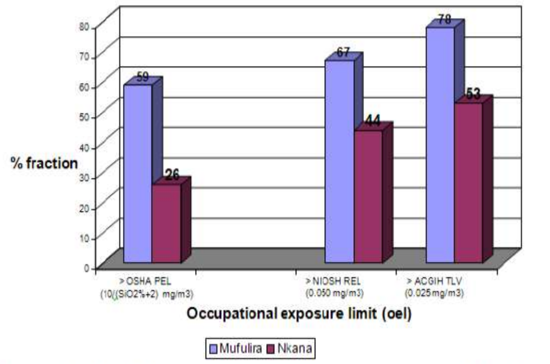


Figure1: MCM personal samples of respirable dust containing crystalline silica higher than specified U.S. OEL

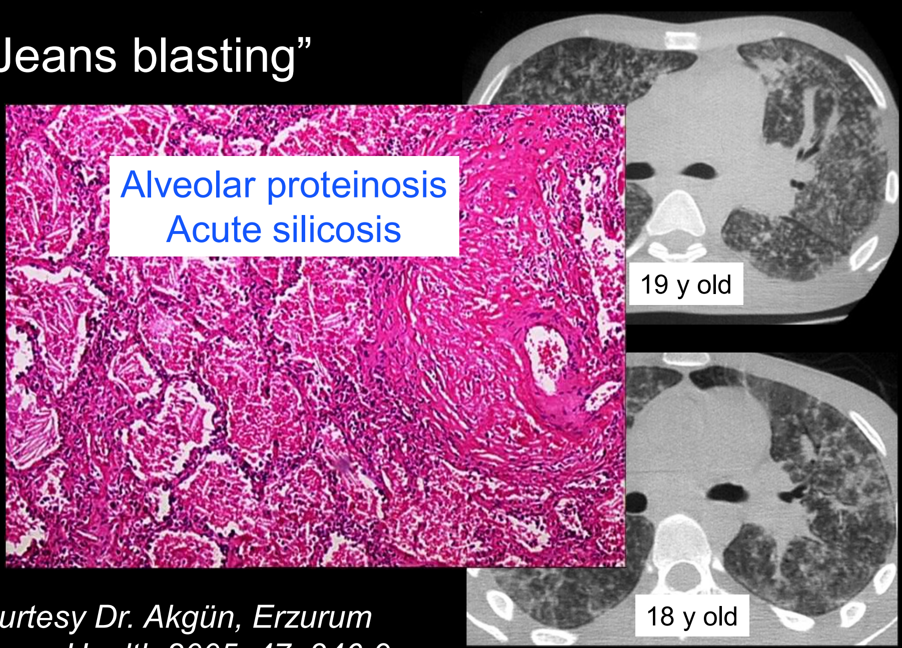
Silicosis

Clinical presentations

Acute silicosis

- Alveolar proteinosis, silico-lipoproteinosis
  - ➢ intense exposure to very fine & freshly fractured silica particles (sandblasting, silica flour)
  - ➢ within weeks to months
  - poor prognosis → death

“Jeans blasting”



Courtesy Dr. Akgün, Erzurum
J Occup Health 2005, 47, 346-9

Silicosis

- Chronic simple silicosis
  - discrete silicotic hyaline nodules in lung
  - little or no functional consequences
  - may progress, sometimes rapidly ["accelerated (or galloping) silicosis"]

Silicosis

- Chronic simple silicosis
  - discrete silicotic hyaline nodules in lung
  - little or no functional consequences
  - may progress, even after exposure cessation, to
- Complicated silicosis (Progressive Massive Fibrosis = PMF)
  - confluent noduli (> 1 cm)
  - often + emphysematous changes
  - evolution to cor pulmonale → death

Akgun *et al.* ERJ 2008, 32, 1295-1303

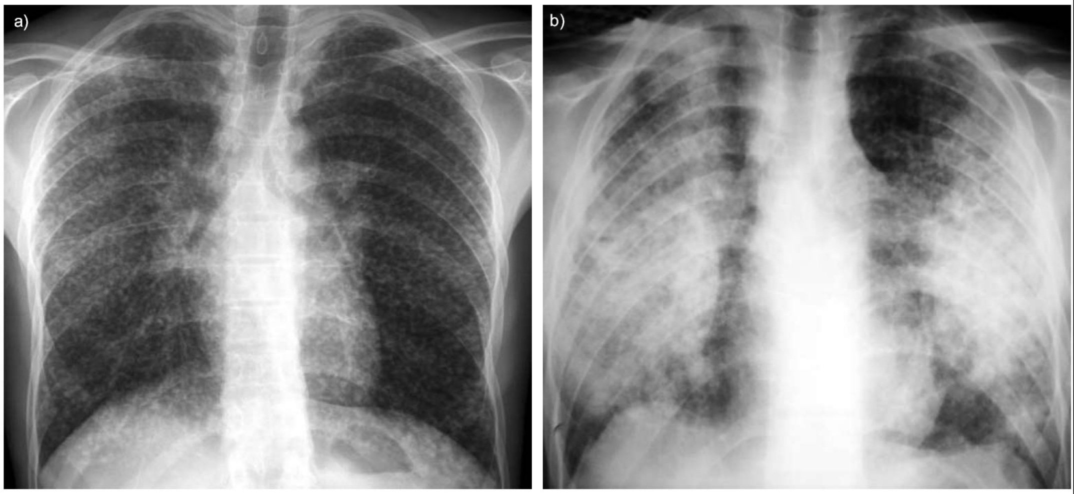


FIGURE 4. Chest radiographs belonging to two different ex-denim sandblasters showing a) bilateral small, widespread nodules and b) large type C opacities.

Churchyard *et al*. Silicosis prevalence and exposure-response relations in South African goldminers. *Occup Environ Med* 2004, 61, 811-6

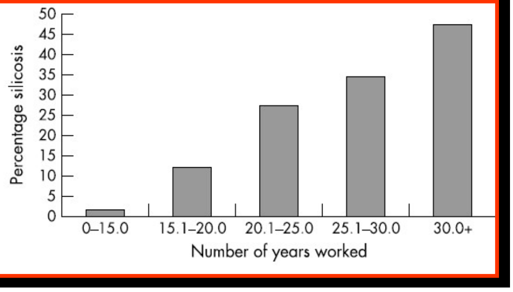
520 goldminers: employed (migrant) contract workers > 37y

- Age: 46.7 y [37.1-59.9]; 51% ever-smokers; 19% TB history
- Length of service: 21.8 y [6.3-34.5]
- Respirable dust: 0.37 mg/m^3 [0-0.70]
- α-Quartz: 12% [0-21.3] ; 0.053 mg/m^3 [0-0.095]

35% TB by history or CXR
teWaterNaude *et a*l.
OEM 2006, 63, 187-92

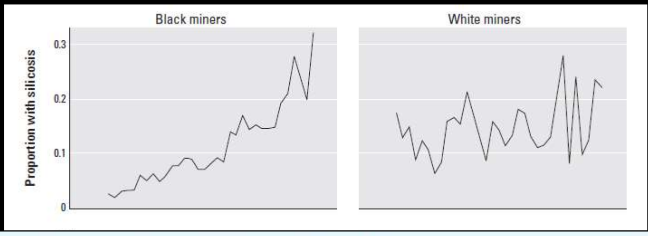
➢ Silicosis (ILO ≥ 1/1): 18-20%

ILO category	Reader 1 n	Reader 1 %	Reader 2 n	Reader 2 %
0, 0/1	392	76.1	394	76.8
1/0	29	5.6	17	3.3
1/1, 1/2	45	8.7	49	9.5
2	42	8.2	47	9.2
3	7	1.3	6	1.2
Subtotal ≥1/1	94	18.3	102	19.9
Total	515	100.0	513	100.0



Nelson *et al*. Three decades of silicosis: disease trends at autopsy in South African gold miners. *EHP* 2010, 118, 421-6

NIOH (Johannesburg) autopsy data base (PATHAUT)



RESULTS: The crude proportion of silicosis for white miners was six times that of black miners in 1975. By 2007, it was 1.5 times higher for black miners. The proportion of miners with silicosis increased from 0.03 to 0.32 for black miners and from 0.18 to 0.22 for white miners. The increase can be explained by increasing age and employment duration for white miners. For black miners, it can be only partly explained by these two factors.

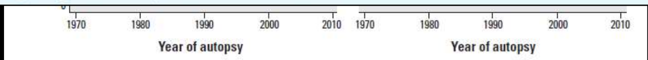


Figure 1. Crude population group-specific proportions of gold miners with silicosis (external causes of death): mean ages and mean employment durations from 1975 to 2007 (n = 16,411 for black miners and n = 2,732 for white miners).

Complications of silicosis

- Tuberculosis *(especially if HIV+)*
- Bronchopulmonary cancer (IARC group 1)
- Autoimmune disease
  - Systemic sclerosis (Erasmus syndrome)
  - Rheumatoid arthritis (Caplan syndrome)
  - Lupus erythematosus
- Renal disease

! Also without pulmonary silicosis

Silicosis, HIV and tuberculosis

Corbett *et al*. HIV infection and silicosis: the impact of two potent risk factors on the incidence of mycobacterial disease in South African miners. *AIDS* 2000, 14, 2759-68

- 1374 HIV+ *vs* 2648 HIV- miners
- TB in 135 (4.9/100 person-years) *vs* 78 (1.1 person-years)

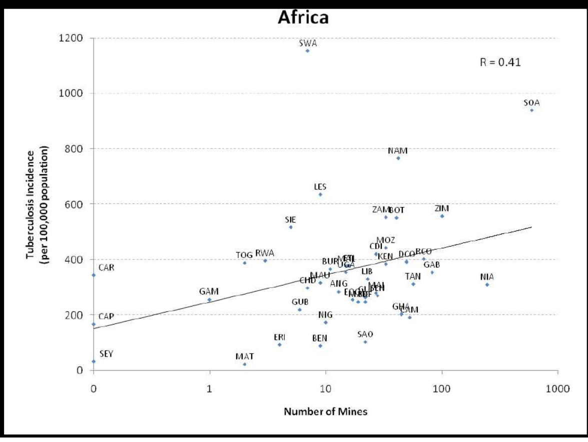
➢ TB incidence rate ratio (IRR): 4.5 [3.4-6.0]

• Multivariate analysis:	TB IRR
• No silicosis (78/1031 *vs* 40/1893)	1
• Possible silicosis (19/146 *vs* 11/314)	1.4 [1.0-2.2]
• Probable silicosis (11/58 *vs* 6/154)	1.8 [1.0-3.0]
• Early silicosis (15/52 *vs* 5/104)	2.2 [1.3-3.7]
• Advanced silicosis (12/62 *vs* 15/135)	2.5 [1.6-4.0]

➢ Risks of silicosis and HIV combine multiplicatively for TB

Mining and tuberculosis

Basu *et al*. The production of consumption: addressing the impact of mineral mining on tuberculosis in southern Africa. *Globalization and Health* 2009, 5, 11



Mining and tuberculosis

- Stuckler *et al.* Mining and risk of tuberculosis in Sub-Saharan Africa. *Am J Publ Health* 2011, 101, 524-30

➢ "mining is a significant determinant of countrywide variation of TB in sub-Saharan African nations" (i.e. not only among miners)

TABLE 1—Associations Between Mining and Tuberculosis Incidence Rates: Sub-Saharan Africa, 2001–2005

	Mining Production, 2001–2005			No. of Mines, 2005		
Covariate	Unadjusted Model	All Countries	Mining Countries	Unadjusted Model	All Countries	Mining Countries
Mining production, B (SE)	0.068*** (0.009)	0.093*** (0.013)	0.123*** (0.019)	. . .	. . .	. . .
No. of mines, B (SE)	. . .	. . .	. . .	0.197** (0.058)	0.446*** (0.115)	0.406** (0.133)
GDP per capita, B (SE)	. . .	-0.074 (0.065)	-0.050 (0.068)	. . .	-0.180 (0.147)	-0.179 (0.165)
Exports as % of GDP, B (SE)	. . .	0.007* (0.003)	0.005 (0.003)	. . .	0.003 (0.007)	0.007 (0.008)
Urbanization rates, B (SE)	. . .	-0.017*** (0.004)	-0.019*** (0.004)	. . .	-0.017 (0.009)	-0.019* (0.009)
Population size, B (SE)	. . .	0.011 (0.049)	-0.049 (0.050)	. . .	-0.226 (0.149)	-0.272 (0.160)
No. of countries[a]	44	36	33	44	34	31
R^2	0.20	0.34	0.27	0.22	0.44	0.32

Note. GDP = gross domestic product. Tuberculosis incidence, mining production, number of mines, GDP per capita, and population size are in log form to adjust for positive skew. Ellipses indicate not applicable.
Source. Tuberculosis incidence data are from the World Health Organization Global Tuberculosis Database 2009 edition.[2] Mining data are from the British Geological Survey Map 2009 edition.[32]
[a]Number of country-years in models using mining production is 220 country-years for unadjusted, 175 country-years for adjusted, and 158 country-years for mining countries.
*$P < .05$; **$P < .01$; ***$P < .001$.

Prévention des maladies causées par l'inhalation de poussières

- Lutte contre la génération de poussières (eau)
- Ventilation + aspiration des poussières
- Equipements de protection personnelle (masques)
- Surveillance médicale
  - Radiographies annuelles du thorax
  - Spirométries annuelles
  - Prévention du tabagisme

Blackley DJ *et al*. Resurgence of a debilitating and entirely preventable respiratory disease among working coal miners. *AJRCCM* 2014, 190, 708-9.

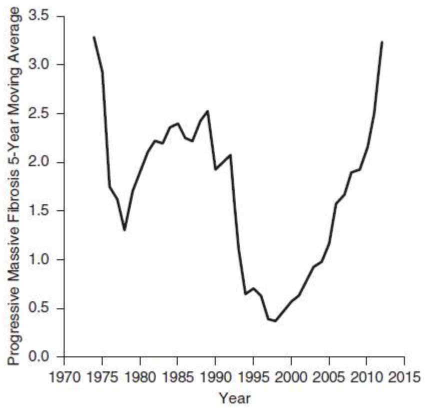


Figure 1. Prevalence of progressive massive fibrosis among working underground coal miners with 25 or more years of underground mining tenure (1974–2012) in Kentucky, Virginia, and West Virginia, according to the Coal Workers' Health Surveillance Program. Data are 5-year moving average

Blackley DJ *et al*. Small mine size is associated with lung function abnormality and pneumoconiosis among underground coal miners in Kentucky, Virginia and West Virginia. *OEM* 2014, 71, 690-4.

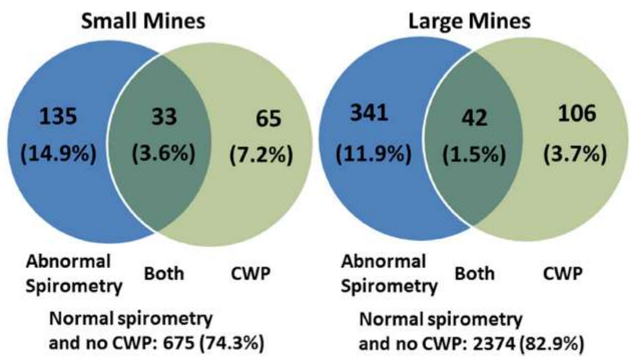


Figure 1 The relationship between abnormal spirometry and radiographic evidence of coal workers' pneumoconiosis among Kentucky, Virginia, and West Virginia underground coal miners, by mine size, Enhanced Coal Workers' Health Surveillance Program (ECWHSP), September 2005–December 2012.

Podoconiosis

Podoconiosis, also known as **nonfilarial elephantiasis**, is a disease of the lymphatic vessels of the lower extremities that is caused by chronic exposure to irritant [volcanic] soils. It is the second most common cause of tropical lymphedema after lymphatic filariasis, and it is characterized by prominent swelling of the lower extremities, which leads to disfigurement and disability. Methods of prevention include wearing shoes and using floor coverings.

Wikipedia

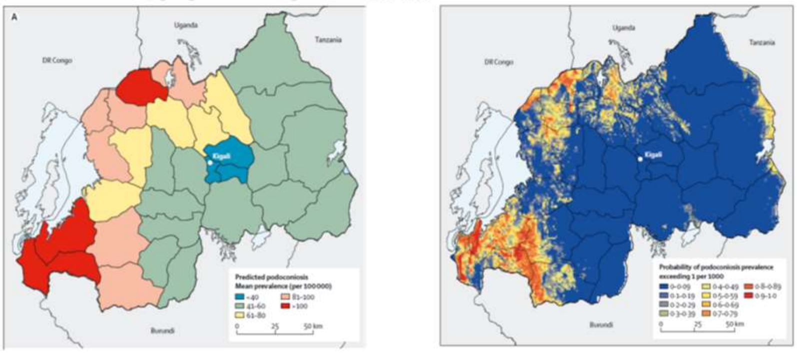
Mousley *et al*. The impact of podoconiosis on quality of life in Northern Ethiopia. *Health and Quality of Life Outcomes* 2013; 11:122

Geographical distribution and prevalence of podoconiosis in Rwanda: a cross-sectional country-wide survey

Lancet Glob Health 2019; 7: e671–80

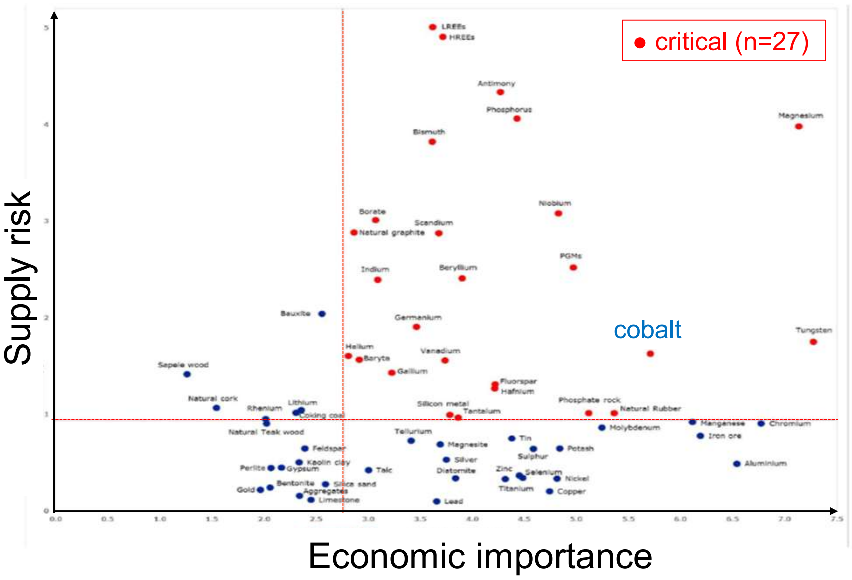
Kebede Deribe, Aimable Mbituyumuremyi, Jorge Cano, Mbonigaba Jean Bosco, Emanuele Giorgi, Eugene Ruberanziza, Ursin Bayisenge,

Findings Between June 12, and July 28, 2017, 1 360 612 individuals—719 730 (53%) women and 640 882 (47%) men—were screened from 80 clusters in 30 districts across Rwanda. 1143 individuals with lymphoedema were identified, of whom 914 (80%) had confirmed podoconiosis, based on the standardised diagnostic algorithm. The overall prevalence of podoconiosis was 68·5 per 100 000 people (95% CI 41·0–109·7). Podoconiosis was found to be widespread in Rwanda. District-level prevalence ranged from 28·3 per 100 000 people (16·8–45·5, Nyarugenge, Kigali province) to 119·2 per 100 000 people (59·9–216·2, Nyamasheke, West province). Prevalence was highest in districts in the North and West provinces: Nyamasheke, Rusizi, Musanze, Nyabihu, Nyaruguru, Burera, and Rubavu. We estimate that 6429 (95% CI 3938–10 088) people live with podoconiosis across Rwanda.



Exposition aux métaux

“Critical raw materials” (EU 2017)



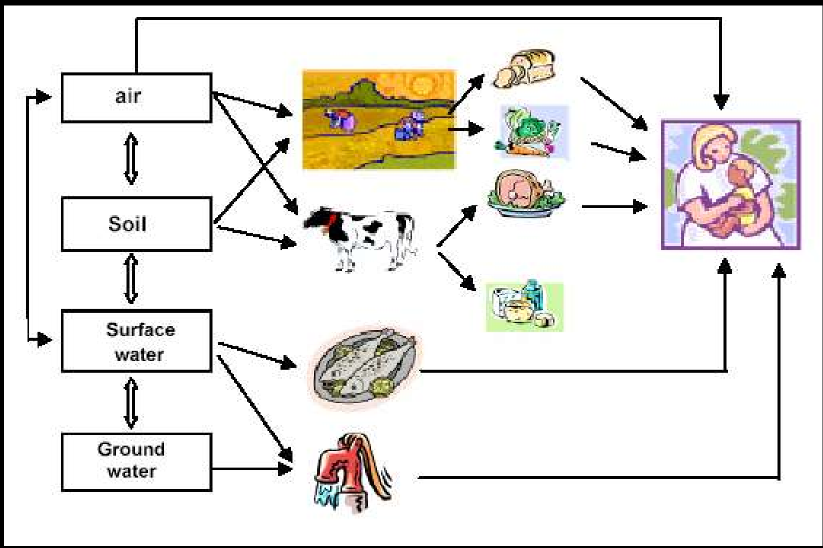
How to assess human exposure to metals?

- Measure concentration of metals in air, water, food, soil ..., and estimate (daily) intake
- Measure concentration of metals in body fluids = biological monitoring (= biomonitoring)
  - Blood
  - Urine
  - Sputum
  - ...

Biological monitoring

- integration of exposure by all routes
  - inhalation
  - ingestion
  - dermal
- all types of exposures (diet, smoking, work, …)
- effect of past exposures (hours, weeks, months, years) depending on toxicokinetics of agent (elimination T½)

Biomonitoring



Slow excretion

- Cd : accumulation in liver/kidney (metallothionein)
  → elimination T½ ~ 20 years
  - Cd-B mainly reflects recent exposure
  - Cd-U mainly reflects body burden
- Pb : accumulation in soft tissues & bones
  → elimination T½ ~ 1-3 months (blood, soft tissues)
  ~ 5-20 years (bone)
  - Pb-U mainly reflects recent exposure
  - Pb-B mainly reflects recent exposure and body burden

Rapid excretion

- As, Co, Hg : no (major) accumulation
  - As-B and As-U
  - Co-B and Co-U
  - Hg-B and Hg-U

  reflect ongoing (background) and recent exposure (days/weeks)

2009

Environmental Research 109 (2009) 745–752

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

ELSEVIER

High human exposure to cobalt and other metals in Katanga, a mining area of the Democratic Republic of Congo ☆

Célestin Lubaba Nkulu Banza [a], Tim S. Nawrot [b], Vincent Haufroid [c], Sophie Decrée [d,e], Thierry De Putter [e], Erik Smolders [f], Benjamin Ilunga Kabyla [a], Oscar Numbi Luboya [a], Augustin Ndala Ilunga [a], Alain Mwanza Mutombo [a], Benoit Nemery [b,*]

[a] Unité de Toxicologie et Environnement, Ecole de Santé Publique, Université de Lubumbashi, Democratic Republic of Congo
[b] Occupational & Environmental Medicine, Unit of Lung Toxicology, Katholieke Universiteit Leuven, Herestraat 49 (O&N 706), B-3000 Leuven, Belgium
[c] Industrial Toxicology and Occupational Medicine Unit, Université catholique de Louvain, Brussels, Belgium
[d] Geology Department, Royal Museum for Central Africa, Tervuren, Belgium
[e] Geology Department, Facultés Universitaires Notre-Dame de la Paix, Namur, Belgium
[f] Division of Soil and Water Management, K.U. Leuven, Belgium

2014

Science of the Total Environment 490 (2014) 313–321

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

ELSEVIER

CrossMark

Pathways of human exposure to cobalt in Katanga, a mining area of the D.R. Congo

Karlien Cheyns [a,h], Célestin Banza Lubaba Nkulu [b], Léon Kabamba Ngombe [b,c], Jimmy Ngoy Asosa [b], Vincent Haufroid [d], Thierry De Putter [e], Tim Nawrot [f,g], Célestin Muleka Kimpanga [c], Oscar Luboya Numbi [b], Benjamin Kabyla Ilunga [b], Benoit Nemery [f], Erik Smolders [h]

A further study in a community affected by artisanal mining

nature sustainability

ANALYSIS

https://doi.org/10.1038/s41893-018-0139-4

NATURE SUSTAINABILITY | VOL 1 | SEPTEMBER 2018 | 495–504 | www.nature.com/natsustain

Sustainability of artisanal mining of cobalt in DR Congo

Célestin Banza Lubaba Nkulu[1], Lidia Casas[2,3], Vincent Haufroid[4], Thierry De Putter[5], Nelly D. Saenen[6], Tony Kayembe-Kitenge[1], Paul Musa Obadia[1], Daniel Kyanika Wa Mukoma[1], Jean-Marie Lunda Ilunga[7], Tim S. Nawrot[2,6], Oscar Luboya Numbi[1], Erik Smolders[8] and Benoit Nemery[2*]

Artisanal gold mine
(Kimpese 2015-2016)

(unpublished data)

Photographs: Th. De Putter


Kimpese 2016

Kimpese 2016

Kimpese 2016


Kimpese 2016


Kimpese 2016


Kimpese 2016


Kimpese 2016


EXO
Kimpese 2016


Kimpese 2016

Kimpese 2016

Crushing of gold ore

Kimpese, April 2016

Crushing of gold ore

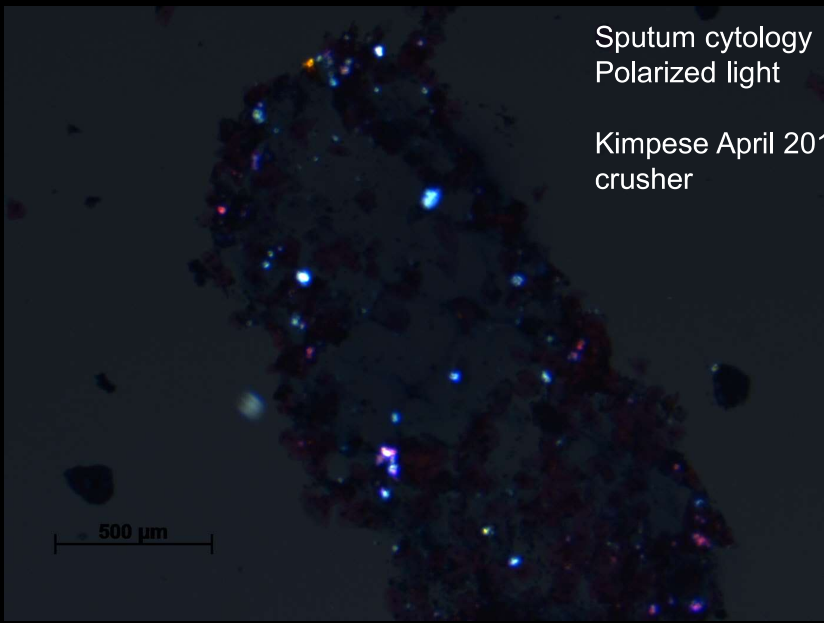
INHALABLE DUST
Inside: 41.6 / 70.5 / 15.4 mg/m^3
Outside: 2.40 mg/m^3

Control: 0.29 mg/m^3

11.2 mg/m^3

Kimpese, April 2016

Kimpese, April 2016



Kimpese Gold Mine (2015): sputum

+ variable volume of fixative

	K	V	Cr	Mn	Fe	Co	Ni	Cu	As	Mo	Pb	U
	mg/l	µg/l	µg/l	µg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
Control	*16*	<LOQ	<LOQ	<LOQ	<LOQ	0,8	<LOQ	54	20	<LOQ	14	<LOQ
Control	*18*	0,9	<LOQ	<LOQ	<LOQ	10	<LOQ	63	16	<LOQ	13	0,6
MEAN	***17***	**<1**	**<7**	**<26**	**<185**	**6**	**<5**	**58**	**18**	**<2**	**13**	**<1**
Crusher	*18*	32	13	331	<LOQ	726	149	292	25	4	104	28
Crusher	*19*	66	12	530	<LOQ	1160	313	687	29	17	301	77
Crusher	*20*	138	28	949	<LOQ	2873	628	1698	39	17	679	142
Crusher	*12*	103	17	1160	<LOQ	4172	683	1867	71	21	631	195
Crusher	*11*	50	12	500	<LOQ	1042	186	434	28	8	161	41
MEAN	***16***	**78**	**16**	**694**	**<185**	**1995**	**392**	**996**	**38**	**14**	**375**	**97**

Kimpese 2016

Kimpese 2015

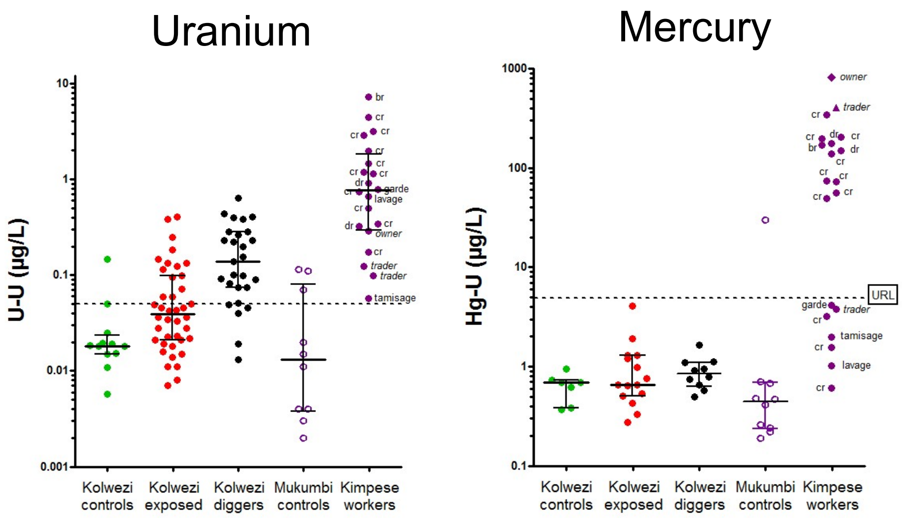

Hg
Kimpese 2016


Likasi – Shituru (DRCongo)
August 2010

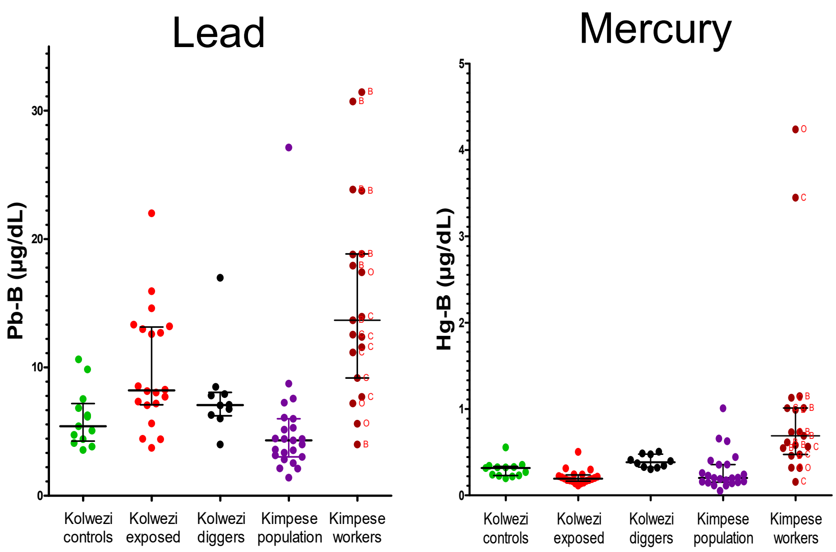

Kimpese 2016


Kimpese (DRCongo)
May 2015

Kimpese Gold Mine (2015): urine



Kimpese Gold Mine (2016): blood



Outbreak of Fatal Childhood Lead Poisoning Related to Artisanal Gold Mining in Northwestern Nigeria, 2010

Carrie A. Dooyema,[1,2] Antonio Neri,[1] Yi-Chun Lo,[2] James Durant,[3] Paul I. Dargan,[4] Todd Swarthout,[5] Oladayo Biya,[6] Saheed O. Gidado,[6] Suleiman Haladu,[6] Nasir Sani-Gwarzo,[7] Patrick M. Nguku,[6] Henry Akpan,[8] Sa'ad Idris,[9] Abdullahi M. Bashir,[9] and Mary Jean Brown[1]

[1]Healthy Homes and Lead Poisoning Prevention Branch, National Center for Environmental Health, Centers for Disease Control and Prevention, Atlanta, Georgia, USA; [2]Epidemic Intelligence Service, Centers for Disease Control and Prevention, Atlanta, Georgia, USA; [3]Agency for Toxic Substances and Disease Registry, Atlanta, Georgia, USA; [4]Guy's and St Thomas' NHS Foundation Trust and King's Health Partners, London, United Kingdom; [5]Médecins Sans Frontières, Amsterdam, the Netherlands; [6]Nigerian Field Epidemiology and Laboratory Training Program, Abuja, Nigeria; [7]Centers for Disease Control and Prevention, Abuja, Nigeria; [8]Nigerian Federal Ministry of Health, Abuja, Nigeria; [9]Zamfara State Ministry of Health, Gusau, Nigeria

Background: In May 2010, a team of national and international organizations was assembled to investigate children's deaths due to lead poisoning in villages in northwestern Nigeria.

Objectives: Our goal was to determine the cause of the childhood lead poisoning outbreak, investigate risk factors for child mortality, and identify children < 5 years of age in need of emergency chelation therapy for lead poisoning.

Methods: We administered a cross-sectional, door-to-door questionnaire in two affected villages, collected blood from children 2–59 months of age, and obtained soil samples from family compounds. Descriptive and bivariate analyses were performed with survey, blood lead, and environmental data. Multivariate logistic regression techniques were used to determine risk factors for childhood mortality.

Results: We surveyed 119 family compounds. Of 463 children < 5 years of age, 118 (25%) had died in the previous year. We tested 59% (204/345) of children < 5 years of age, and all were lead poisoned (≥ 10 µg/dL); 97% (198/204) of children had blood lead levels (BLLs) ≥ 45 µg/dL, the threshold for initiating chelation therapy. Gold ore was processed inside two-thirds of the family compounds surveyed. In multivariate modeling, significant risk factors for death in the previous year from suspected lead poisoning included the age of the child, the mother's work at ore-processing activities, community well as primary water source, and the soil lead concentration in the compound.

Conclusion: The high levels of environmental contamination, percentage of children < 5 years of age with elevated BLLs (97%, > 45 µg/dL), and incidence of convulsions among children before death (82%) suggest that most of the recent childhood deaths in the two surveyed villages were caused by acute lead poisoning from gold ore–processing activities. Control measures included environmental remediation, chelation therapy, public health education, and control of mining activities.

Key words: artisanal gold mining, childhood, environmental health, lead poisoning, nervous system. *Environ Health Perspect* 120:601–607 (2012). http://dx.doi.org/10.1289/ehp.1103965 [Online 20 December 2011]

et al. 2008). Lead poisoning is of specific concern for children in developing countries (Falk 2003). The World Health Organization (WHO) estimates that lead poisoning causes 0.6% of the global burden of disease and contributes to approximately 600,000 cases of intellectual disability in children annually (WHO 2010). During the past 20 years, moderate to high elevations of BLLs have been documented globally in clusters of children living in mining and smelting communities or areas where lead batteries are reclaimed (Brown et al. 2010; Garcia Vargas et al. 2001; Kaul et al. 1999; Lalor et al. 2006). However, only one report found in recent literature documents fatalities from childhood lead poisoning; in 2008 in Senegal, informal battery recycling was determined to be the likely cause of death of 18 children (Haefliger et al. 2009).

Description of the outbreak. During meningitis surveillance activities conducted February–April 2010, Médecins Sans Frontières (MSF) and local Nigerian public health officials observed higher than expected numbers of childhood illnesses and deaths in four villages in rural northwestern Nigeria. Most of the illnesses and deaths occurred in

Health impact?

Health effects of metals

- Many metals are "essential"
  Fe, Cu, Co, Zn, Mn, Mo, ...
  - ➢ deficiencies lead to disease
  - ➢ excesses lead to disease
- Some metals are non-essential
  Pb, Cd, Hg, As, Sn, U, ...
  - ➢ low levels of exposure may lead to disease

Toxicity of Cu

- Cu is an essential element = relatively non-toxic
- High exposure to CuO fumes
  → metal fume fever (~ malaria or flu)
- Exposure to high Cu in drinking water
  → gastrointestinal disturbances
- Chronic overexposure
  → possibly liver damage

Toxicity of Co

- Non-respiratory effects
  - polycythemia
  - cardiomyopathy *(beer + $CoSO_4$)*
  - thyroid hyperplasia
  - allergic contact dermatitis
- Respiratory effects
  - airway irritation
  - bronchial asthma *(all forms of Co)*
  - interstitial lung disease *(Co+WC or diamond)*
  - bronchopulmonary cancer *(Co+WC)*

Toxicity of As

- Skin toxicity
  - Hyperpigmentation
  - Hyperkeratosis
  - Skin cancer
- Lung and sinonasal cancer
- Liver damage and liver cancer
- Bladder cancer
- Peripheral neuropathy
- Heart and cardiovascular disease

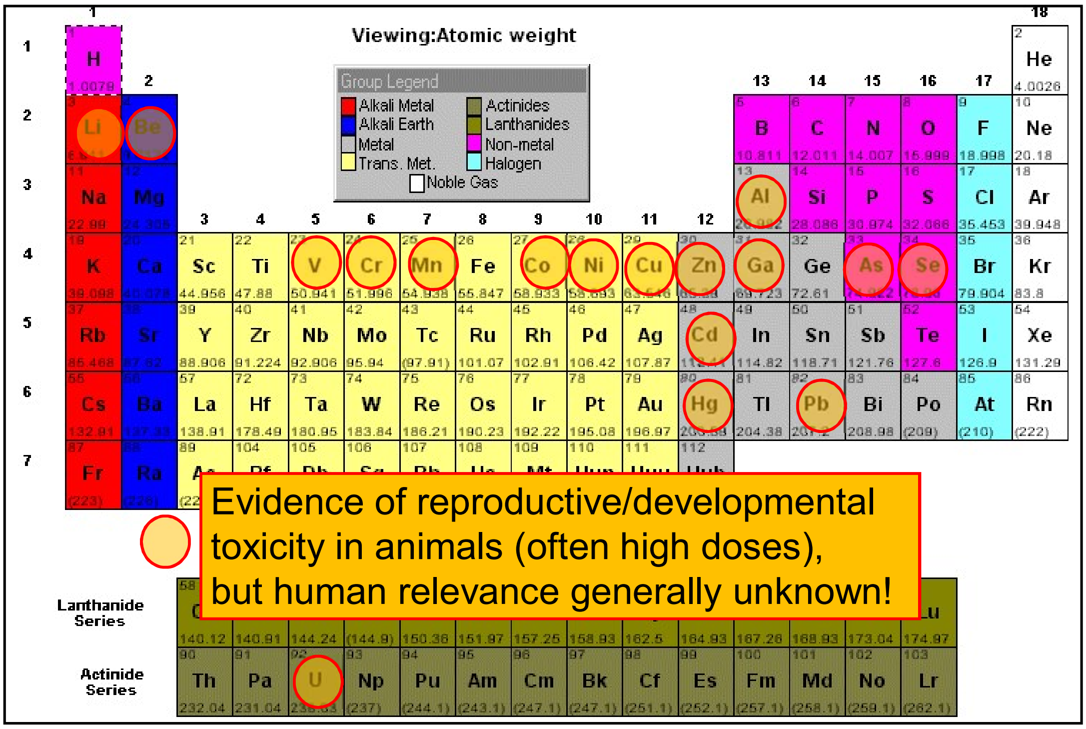
Main toxicity of Mn, Cd, Hg, Pb, U

- Mn: central nervous system (“Parkinson”)
- Cd: kidney, bone, lung
- Hg: central nervous system and kidney
- Pb: central (children) & peripheral nervous system; blood; kidney; hypertension
- U: kidney

- Sn, Nb, Ta, W, …: little (known) toxicity

Concerns expressed by doctors, NGOs, authorities, media, …

“more babies born with severe birth defects, especially among creuseurs”



Case-control study (KMC)

- Cases: infants born with visible birth defects
- Controls: infants without birth defects born from mother of similar age
- ➢ Hypothesis: different exposure to metals
  - ➢ comprehensive history
  - ➢ cord blood or placenta
  - ➢ blood, urine, hair of mother (& father)
  - ➢ exposure at home

KMC

- 2009: start proposal and requests of funding (2xVLIR. Belspo. ...), unsuccessful !
- 02/08/2012: final preparatory meeting with various stakeholders; official support from Lubumbashi health authorities & Provincial Ministry of Health
- 11.11.11 (Belgian NGO) agrees to fund local operational costs for one year @ 18.000 € (based on estimated 50 cases + 50 controls)
- Ethical approval from UNILU Faculty of Medicine

KMC

- Notification system for all hospitals/maternities in Lubumbashi: each newborn born with visible birth defects (except isolated polydactyly, club foot) to be notified to a central telephone number (+ back-up)
  - 4 MDs (T. Kayembe, L. Kabamba, S. Mbuyi, T. Lubala)

➢ MD at hospital within 24h of notification
  - detailed questionnaire
  - diagnosis (photographs)
  - sampling from mother and child (+ father)

  + same procedure with healthy control newborn

Questionnaire

- administrative data
- medical & obstetrical history
- medication, geophagy, diet, cosmetics during pregnancy
- educational level, socioeconomic status
- residence (location, characteristics)
- occupation (also of husband/partner)

- if possible: also questionnaire to child's father

KMC

- after ~ 2 weeks: visit to mother's residence for environmental assessment and dust/water sampling (B. Kyanika)
- later: follow-up visit at hospital (CUL)
  - to assess health status of cases and controls
  - + obtain complementary information (e.g. pedigree)

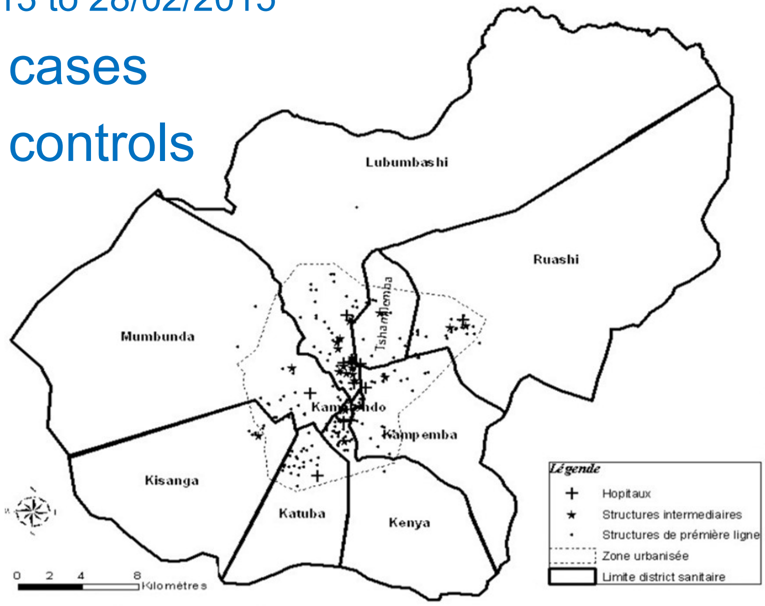
KMC study: methods

- Recruitment: 01/03/2013 to 28/02/2015
- Final diagnosis of type of birth defect (photos)
  - Prof. K. Devriendt
- Analysis of samples by ICP-MS
  - April 2015: funding received from VLIR (250,000 €; 4 y)
  - Prof. E. Smolders
- Statistical analysis (2017-2018)
  - Dr. Daan Van Brusselen, Dr. Tony Kayembe

01/03/2013 to 28/02/2015

LUBUMBASHI

- 138 cases
- 108 controls



KMC study: results

- Cases (n=138)
  - Clinically recognizable genetic syndromes (n=12)
  - Acquired malformations (n=5) (amniotic bands, …)
  - Malformations of unknown origin (n=118)
  - Multiple defects (n=45)
  - Neural tube defects (spina bifida, encephalocele, anencephaly) (n=21)
  - Orofacial defects (cleft lip/palate) (n=21)
  - Other (n=48)
- Controls (n=108)

Holoprosencephaly

Kayembe-Kitenge T *et al. Birth Defects Research* 2019 DOI: 10 1002/bdr2.1583

KMC study: results

	CASES (n=138)		CONTROLS (n=108)		p-value (t-test)
	mean	SD	mean	SD	
Age mother	28.5	7.0	26.5	6.8	0.03
Parity	3.7	2.8	3.0	2.6	0.08
Gestational age	38.2	3.4	38.3	3.7	0.84
Birth weight	2816	92	3084	70	0.03
Age father	35.1	8.2	33.7	7.8	0.21
Adults in household	2.9	1.5	2.8	1.5	0.52
Children in household	3.2	2.0	3.2	2.5	0.84

KMC study: results

- Questionnaire data:
  - No significant differences for most factors
    - Vitamins during pregnancy: higher among controls
  - Job of mother: more “paid job” among cases (not mining)
  - Job of father: more “mining-related jobs” among cases (17%) than among controls (8%), p<0.05
- Trace metals:
  - High levels in both cases and controls
  - Generally, no significant differences between cases and controls
    - Mn higher in cord blood and fetal placenta in cases

KMC study: results

Multivariate model

	aOR (95%CI)
Vitamins during pregnancy	0.3 (0.1 - 0.5), p=0.001
Mother with paid job	2.5 (1.2 – 6.9), p=0.02
Father with mining-related job	5.6 (1.2 – 25), p=0.025
Doubling of Mn in cord blood	1.7 (1.1 – 2.7), p=0.026

KMC study: discussion

- Unique investigation of association between environmental pollution and birth defects
- Effect appears to be mediated mainly by paternal occupational exposure to mining (epigenetic effect ?)
- Exposure to Mn ?
- Limitations:
  - Possible overmatching of cases and controls
  - Biomonitoring at delivery (toxicokinetics!)
  - No/limited biomonitoring of fathers

Erectile dysfunction and mining-related jobs: an explorative study in Lubumbashi, Democratic Republic of Congo

Occup Environ Med 2020;**77**:19–21. doi:10.1136/oemed-2019-105771

Paul Musa Obadia,[1,2] Tony Kayembe-Kitenge,[1,2] Célestin Banza Lubaba Nkulu,[1] Paul Enzlin,[3] Benoit Nemery [2]

UNILU Université de Lubumbashi
TOXICOLOGIE ET ENVIRONNEMENT

ARES ACADÉMIE DE RECHERCHE ET D'ENSEIGNEMENT SUPÉRIEUR

KU LEUVEN

Aims

- To investigate the possible association between erectile dysfunction and working in mining-related jobs.

Research question

Among clients of a pharmacy (UKIMIA) in a popular neighborhood (Ruashi) in Lubumbashi : are (young) men purchasing sildenafil (« Viagra », …) more likely to work in mining than young people buying pain killers ?

Methods

- Case-control study **:** 2017, men 18 to 40 years old.
- In a popular pharmacy (Ukimia) inclusion of:
  - 42 men purchasing sildenafil (Kifaru, Davigra, etc…) = CASES
  - 42 men buying pain killers (Ibuprofen, paracetamol) = CONTROLS
- Questionnaire (face-to-face, Swahili):
  - Demographics & lifestyle
  - International Index of Erectile Function (IIEF-6) = standardized questionnaire to evaluate erectile dysfunction (max score = 30)
  - Occupation: current, occasional and former occupations
- Anthropometric measures
- Blood pressure

Sociodemographic characteristics

		Men purchasing sildenafil (“cases”) (n = 42)	Men purchasing pain killers (“controls”) (n = 42)
Age (y)		33.7 (3.8) [22-40]	33.6 (3.5) [21-38]
Marital state	Married/cohabiting	38 (90%)	35 (83%)
	Single/divorced	4 (10%)	7 (17%)
Number of children		3 (2) [0-7]	3 (2) [0-6]
Body Mass Index (kg/m^2)		25.0 (2.1) [20.5-29.0]	26.3 (1.2) [23.1-28.1]
Current tobacco smoking		11 (26%)	10 (24%)
Cannabis use		2 (5%)	2 (5%)
Alcohol drinking		27 (64%)	22 (52%)
Arterial Blood Pressure	Systolic (mmHg)	123 (11)	125 (13)
	Diastolic (mmHg)	76 (7)	78 (6)

		Men purchasing sildenafil (n=42)	Men purchasing painkillers (n=42)
Age (years)*		33.7 (3.8) (22–40)	33.6 (3.5) (21–38)
IIEF6 score†		17 (8) (8–30)	30 (6) (17–30)
Current occupation	**Mining-related job**	**19 (45%)**	**7 (17%)**
	Artisanal mineworker	*3 (7%)*	*2 (5%)*
	Downstream of mining‡	*13 (31%)*	*5 (12%)*
	Other (security, trader)	*3 (7%)*	*0 (0%)*
	Non-mining-related job	**23 (55%)**	**35 (83%)**
	White collar job	*2 (5%)*	*8 (19%)*
	Petty trader	*5 (12%)*	*10 (24%)*
	Transportation	*5 (12%)*	*5 (12%)*
	Construction	*8 (19%)*	*8 (19%)*
	Charcoal preparation	*2 (5%)*	*0 (0%)*
	Food preparation	*0 (0%)*	*2 (5%)*
	Army or police	*1 (2%)*	*2 (5%)*

All data were obtained at the time of interviews; current occupation stands for current main job [recently (<1 year) held job for one artisanal mineworker among sildenafil-buyers]. The prevalence of mining-related jobs is significantly higher among sildenafil-buyers than among painkiller-buyers (χ^2 8.02, $p<0.005$).
*Data are means (SD) and (range),
†Data are median (IQR) and (range); other data are n (percentage).
‡Transporting, washing, sieving, crushing ores; smelter operator.
IIEF6, International Index of Erectile Function.

OR = 4.1
(95%CI 1.5 – 11.3
P<0.009)

Conclusion

- ❑ First explorative study on erectile function in mining related jobs in Katanga,
- ❑ Confirmation of higher risk of erectile dysfunction among men with metal-related jobs.
- ❑ Epidemiological studies of the possible role of occupational exposure to specific metals in the pathogenesis of male sexual dysfunction among miners and workers in the copper and cobalt industry are needed.

Merci pour votre attention

ben.nemery@kuleuven.be