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Asbestos Lung Fibre Concentrations in South African Chrysotile Mine Workers

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Mesothelioma has not been found in South African chrysotile miners and millers despite decades of producing about 100 000 tons of the mineral per year. One possible explanation for the scarcity or absence of the cancer may be a relative lack of contaminating fibrous tremolite, an amphibole that variably occurs with chrysotile ores. The fibre content in the lungs of nine former chrysotile mine workers was ascertained by transmission electron microscopy. Despite fairly long service in most cases (median 9.5 yr; range 32-4 yr) the concentrations of chrysotile fibres were relatively low: only two cases exceeded 1.14 million fibres/g dried lung. Tremolite fibre levels were even lower: less than 1 million fibres/g dried lung in all but one case. Tremolite fibre concentrations exceeded those of chrysotile in only two cases. These results support the contention that South African chrysotile is not heavily contaminated by tremolite. © 2001 British Occupational Hygiene Society. Published by Elsevier Science Ltd. All rights reserved

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INTRODUCTION

Chrysotile mining began in the eastern Transvaal region of South Africa, now Mpumalanga Province, in about 1920. African Chrysotile Asbestos (ACA), the most significant mine and mill, started in 1937 near Msauli. ACA has been by far the largest operation but over the decades many smaller mines produced the fibre. Today, ACA is the only active mine, but Stella and Kaapsche Hoop extract small amounts of asbestos from tailings dumps. From 1975 to 1992 chrysotile production was near 100 000 tons per annum (Harington and McGlashan, 1998), with ACA's contribution well over 95% in later years. From 1992 ACA's output has declined quite dramatically from 101 892 to the 20 000 tons expected in 2000. Stella and Kaapsche Hoop now contribute only a couple of tons per annum. [Personal communication. Hart P, Johannesburg 2000]. The number of

employees on chrysotile mines was about 2600 in the 1960s and then settled around 1500-2000 from 1975 to the mid-1990s (Rees *et al.*, 1992). ACA's falling production in later years led to reduced labour needs: 1811 in 1990; 1720 in 1994; 1131 in 1996; and 254 employees now. [Personal communication. Hart P, Johannesburg 2000].

South African research on asbestos induced diseases and fibre concentrations has concentrated on the amphiboles with surprisingly little work on South African chrysotile; in the past few decades there has been no scientific publication on disease rates and fibre exposure in chrysotile mines. Of interest is that mesothelioma has not been found in miners and millers of the South African fibre. For example, no cases with exclusively chrysotile exposure were identified during a case-control study involving 123 cases of mesothelioma selected without prior knowledge of asbestos exposure (Rees *et al.*, 1999). The study did enrol 24 crocidolite, 3 amosite and 3 mixed amosite and crocidolite mine workers. It may be that a relative paucity of tremolite in South African chrysotile is the explanation for the scarcity or absence of chrysotile mesotheliomas. The biopersistent amphibole, tremo-

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lite, variably contaminates chrysotile ores, and may explain the genesis of mesothelioma. The case for the hypothesis that the contaminating tremolite rather than chrysotile is the cause of the cancer has been summarised by Churg (1994) and McDonald and McDonald (1997), although this view is not universally held (Landrigan *et al.*, 1999). Little is known about the tremolite content of South African chrysotile ore. The industry has not determined the tremolite content [P. Hart, Personal communication Johannesburg 2000], but preliminary work by South Africa's National Centre for Occupational Health (NCOH) suggests that it is low. Tremolite fibres were sought in the lungs of four individuals with service exceeding 20 years on chrysotile mines (Rees *et al.*, 1992). Fibres most likely to be tremolite were not observed under optical microscopy, but scanning electron microscopy (SEM) demonstrated tremolite in two. These fibres were scanty, one fibre appearing in approximately 20 fields at 1000 times magnification. In 1992, the NCOH examined 20 rock samples, two bulk samples of dust from the mill and seven samples of airborne fibres from ACA (RSJ du Toit, NCOH, Johannesburg, RdT 4.13.16 1992). X-ray diffractometry revealed tremolite in one of the rock samples and possible tremolite in the bulk dust samples. No tremolite was found under phase contrast microscopy of the airborne samples, but under SEM one fibre was found in one sample from the mill and one fibre in a sample taken underground (out of 100 fibres examined one was tremolite).

The paucity of chrysotile mesothelioma cases and the preliminary data on tremolite in chrysotile ores and in the lungs of miners was the motivation for this study which aimed to characterise the fibre content of the lungs of South African chrysotile mine workers and examine the chrysotile:tremolite ratio.

MATERIALS AND METHODS

South African miners have a statutory right to an autopsy examination of the cardio-respiratory organs for compensation purposes. All of the autopsies are done at the National Centre for Occupational Health (NCOH), Johannesburg, and the organs are received with an occupational history of variable comprehensiveness. This means that deceased miners with a particular exposure can be identified. For this study, over a period of 18 months, deceased chrysotile mine workers were selected, resulting in the formalin fixed lungs from nine chrysotile mine workers being available for study. The lungs were examined macroscopically and microscopically by a pathologist. Tissue samples from the upper, middle and lower zones of each lung were taken and pooled. They were sent to the University of Wales for fibre counting and analysis.

The tissue samples were prepared for examination by extracting their dust content utilising a standard

preparation procedure and instrumentation technique (Mitha and Poolcy, 1993) that is recognised by the International Agency for Research on Cancer.

The instrument employed was a Philips 400T analytical transmission electron microscope (ATEM) fitted with an energy dispersive X-ray analysis system. This ATEM is capable of resolving and providing analysis of all particulates detected.

The analysis of the tissue specimen was performed so that all fibrous particles detected were analysed and recorded. The definition of a fibre employed for analytical purposes in the examination was any particle with a 3:1 axial ratio and parallel sides with no minimum length.

RESULTS

A total of 343 fibres were analysed in the nine cases, and the average detection level was calculated as 80 000 fibres/g dry lung tissue.

The levels of tremolite found in the lungs of these chrysotile mine workers were unremarkable, as shown in Table 1, despite fairly long service in most. Case 6 was a boilermaker, an occupation associated with asbestos use, so some of the lung fibre burden may be accounted for by non-mining work. Case 9 was a despatch clerk with offices near the mills; the absence of direct occupational exposure may explain the non detection of fibres.

There was a suggestive association between tremolite concentrations and duration of work at ACA. Two cases, 1 and 3, had underground asbestos exposure only at ACA. Case 1 had 11 yr of exposure versus the 4 yr of case 3, and had double the tremolite concentration. Similarly, in the ACA heavy duty drivers, cases 2 and 5, the tremolite concentration was higher in the driver with the longer service: 18 and 8 yr respectively.

Tables 1 and 2 show that there was no obvious relation between duration of chrysotile mine work and chrysotile fibre concentrations in the lung of these cases — differential clearance of chrysotile from the lung and their varied occupations may partly explain this. Tremolite fibres made up a fairly low proportion of the total fibre concentration and were not numerous, under 1 million fibres/g of dried lung in all but Case 1 (Table 2). Tremolite fibre concentrations exceeded those of chrysotile in only Cases 2 and 5.

DISCUSSION

The main findings of this study are the relatively low fibre content in the lungs of the nine mine workers and the low levels of both chrysotile and tremolite.

The laboratory that did the fibre analyses has examined lungs of control subjects without known asbestos exposure or asbestos related diseases. Controls, taken from several different areas in different countries,

Table 1. Tremolite fibre concentration in lungs, exposure history and histologic diagnosis in 9 South African chrysotile asbestos workers

Case no.	Tremolite fibres $\times 10^6/\text{g}$ dried lung tissue	Age at death	Mining history	Year of first and last chrysotile exposure	Chrysotile mines and occupation	Years between last chrysotile exposure and death	Pathologic findings
1.	1.86	42	Chrysotile: 11 yr	1981-1992	ACA ^a Underground worker — unspecified ACA	0	No abnormality
2.	0.98	58	Chrysotile: 18 yr	1976-1994	Driver (heavy duty transport)	0	No abnormality
3.	0.9	40	Chrysotile: 4 yr; Coal: 6 yr	Unknown	ACA Miner	Unknown	No abnormality
4.	0.74	63	Chrysotile: 2 yr	Unknown	ACA	Unknown	Ferruginous bodies in air spaces. Small cell bronchiogenic carcinoma
5.	0.44	56	Chrysotile: 8 yr	1984-1992	ACA Driver (heavy duty transport)	0	Ferruginous bodies in air spaces. Small cell bronchiogenic carcinoma
6.	0.1	60	Chrysotile: 9 yr; Gold: 9 yr; Platinum: 2 yr	1983-1992	ACA Boilermaker — surface	0	Ferruginous bodies in air (heavy duty spaces transport)
7.	0.07	54	Chrysotile: 32 yr	1960-1992	Marbestos ACA Stella mine, mill foreman, estate foreman	0	Ferruginous bodies in air spaces Pulmonary tuberculosis and slight degree of asbestosis
8.	0.04	66	Chrysotile: 13 yr; Gold: 11 yr; Lime: 13 yr; Coal: 1 yr	1952-1978	ACA Barberton chrysotile Havelock miner	14	Silicotic pleural plaque formation
9.	ND ^b	59	Chrysotile: 8 yr; Amosite: 10 yr	1984-1991	ACA Despatch clerk — office near mills	1	Epidemioid bronchiogenic carcinoma

^aACA=Asbestos Chrysotile Asbestos Mine, also known as Msaudi^bND=not detected.

Table 2. Fibre concentrations (millions/g dried lung) by asbestos type in nine South African chrysotile mine workers

Case	Total fibre	Chrysotile	Amosite	Crocidolite	Tremolite	Tremolite/chrysotile
1	10.4	7.20	ND	ND	1.86	0.26
2	4.08	0.18	0.18	0.18	0.96	5.3
3	49.1	48.2	ND	ND	0.04	0
4	2.1	1.14	0.06	ND	0.74	0.65
5	2.29	ND ^a	0.11	ND	0.44	—
6	3.2	1.01	0.25	0.1	0.9	0.89
7	2.39	0.07	ND	ND	0.07	1
8	1.03	0.36	0.13	ND	0.1	0.28
9	0.67	0.03	0.16	ND	ND	0
Mean ^b	3.35	0.69	0.14	0.13	0.33	0.48

^aND=Not detected^bGeometric mean

including rural ones, have shown a crocidolite range and an amosite range from undetectable to 1 million fibres/g dried lung, and a chrysotile range from undetectable to 50 million fibres/g dried lung (Edward *et al.*, 1996). One of these sets of controls was 31 women with no known history of exposure to dusts, and no mesothelioma or lung cancer. The geometric mean (and range) for tremolite was 0.02 (0–0.8) million fibres/g of dried lung, and for chrysotile 4.4 (0–20.1) million fibres/g dried lung (Dawson *et al.*, 1993). The fibre concentrations found in the lungs of the South African chrysotile workers were thus relatively low.

Canadian chrysotile miners and millers usually have a much higher concentration of tremolite fibres than found in this group of South African chrysotile mine workers. Becklake has summarised the work of Churg and colleagues on chrysotile miners and millers (Becklake, 1994): six miners and millers without disease had a geometric mean of 2 and 9 chrysotile and tremolite fibres/g of lung tissue respectively; and 23 with asbestosis 30 and 140 million fibres. Patients with mesothelioma seeking compensation in Quebec have geometric mean lung concentrations of tremolite fibres well above our subjects: 12 Asbestos Township cases had tremolite concentrations of 2.2 million and 8.1 million for fibres >5 and <5 µm respectively; and 11 Thetford Mines cases had concentrations of 8.4 million and 57.6 million. As in many other studies the concentrations of tremolite far exceeded those of chrysotile (Dufresne *et al.*, 1996). The preponderance of tremolite over chrysotile fibres is usual in Canadian chrysotile miners (Churg, 1994).

The difficulties in interlaboratory comparisons of lung fibre levels are protean as many factors have to be considered (Gibbs and Poolley, 1976). Nevertheless, it is striking that in this series of chrysotile mine workers the tremolite concentration was well below that usually reported and the tremolite:chrysotile ratio exceeded one in only one case. This tremolite chrysotile relation contrasts with that found by the same laboratory in the early studies on Canadian chrysotile miners (Poolley, 1976): of 20 cases of asbestosis

examined eight had tremolite as the only amphibole and in five of the eight tremolite exceeded chrysotile. In 11 of the 20 cases, amphibole fibres were more numerous than chrysotile.

Some of our subjects were not miners (e.g. heavy duty drivers and a despatch clerk) and most did not have asbestos related disease (thus lowering the expected fibre concentrations). It is unfortunate that we do not have data on the asbestos levels in the ACA mine and mill in the 1980s and 90s when most of our subjects were exposed, but their lung fibre contents suggest that fibre levels were relatively low. The management of ACA mine has stated that fibre levels were consistently below 1 fibre per ml in the 1980s and 90s, and provided average fibre levels (personal sampling) for the stope, mill and mill surrounding for 1984–1999 (personal communication P Hart Johannsburg, 2000). The stope average ranged from 0.17 to 0.54 fibres/ml; the mill average was 0.17–0.7; and the mill surrounding 0.1–0.89 fibres/ml. Of interest is that although fibre levels were low in general, in the lungs of cases 1 and 3, with the highest chrysotile fibres counts of 7.2 and 48.2 million fibres/g dry lung, the tremolite:chrysotile ratio was 0.26 and 0 respectively. Despite the limitation of examining cases likely to have had moderate or low exposure, these results support the contention that South African chrysotile is not heavily contaminated with tremolite.

Lung fibre concentrations in South African chrysotile miners or millers with mesothelioma, if these cases exist, would add to our understanding of the role of tremolite in the genesis of mesothelioma.

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