ASBESTOS EXPOSURE AND MESOTHELIOMA IN SOUTH AFRICA

David Rees, Kim Goodman, Elize Fourie, Ronald Chapman, Charlmé Blignaut, Max O Bachmann, Jonny Myers

Objectives. To describe the exposure experiences of South African mesothelioma cases, with emphasis on the contribution made to the caseload by different fibre types, the proportion of subjects with no recall of asbestos exposure and only environmental contact, and the importance of putative causes other than asbestos.

Design. A multicentred case-control study.

Subjects and setting. 123 patients with mesothelioma interviewed by trained interviewers in study centres established in Johannesburg, Kimberley, Pretoria, Bloemfontein, Cape Town and Port Elizabeth.

Results. A convincing history of asbestos exposure was obtained in the overwhelming majority of cases (only 5 cases had unlikely asbestos exposure). Twenty-three subjects had worked on Cape crocidolite mines, 3 at Penge (an amosite mine), 3 on mines producing amosite and Transvaal crocidolite and 1 on a Transvaal crocidolite mine. Exclusively environmental exposure accounted for at least 18% of cases; 91% of these cases (20/22 subjects) had had contact with Cape crocidolite. There was a relative paucity of cases linked to amosite and no convincing chrysotile case. Non-asbestos causes occur rarely, if at all, in South Africa.

Conclusion. The preponderance of crocidolite cases, followed by amosite and then chrysotile cases, is consistent with the view that there is a fibre gradient of mesotheliomagenic potential for South African asbestos (crocidolite > amosite > chrysotile).

S Afr Med J 1999; **89**: 627-634.

National Centre for Occupational Health and Department of Community Health, University of the Witwatersrand, Johannesburg
David Rees, MB BCh, DOH, MSc, PhD, MFOM
National Centre for Occupational Health, Johannesburg
Kim Goodman, RNRM, MBA
Department of Health, Welfare and Environmental Affairs, Kimberley, Northern Cape
Elize Fourie, MB ChB, MMed (Rad T)
Department of Community Health, University of the Orange Free State, Bloemfontein
Ronald Chapman, BSc, MB BCh, MMed (CH)
Department of Community Health, University of Pretoria
Charlmé Blignaut, MB ChB, DOH, MMed (CH)
Department of Community Health, University of Cape Town
Max O Bachmann, MB ChB, DOH, MSc, FFCH, MFPHM
Jonny Myers, MB ChB, BSc, MD, MFOM

In the course of a case-control study of mesothelioma in South Africa, detailed exposure information was obtained from 123 subjects. This exposure information is of interest in that it shows the contribution different fibre types (crocidolite, amosite and chrysotile) make to the caseload (the chrysotile caseload is of particular interest as chrysotile is still mined in South Africa), the proportion of subjects with no recall of asbestos exposure, the occupations to look out for when taking an occupational history, the proportion of cases with exclusively environmental exposure (who are not eligible for workers' compensation and therefore require special consideration), the importance of putative causes other than asbestos, and the danger of incidental exposure (e.g. use of panel heaters or living in asbestos-cement structures).

Despite decades of asbestos mining and the attendant mesothelioma epidemic, the above issues have not been thoroughly studied in this country. South African case series have been published but all were from one geographical region, one occupation (mining), or a single clinic. The only incidence study[1] and the South African registry data share the flaw of incomplete exposure data provided by surrogate informants. These limitations are reduced in large measure by the detailed exposure data presented in this article. The analytical data are reported elsewhere; this article focuses on the details of asbestos exposure reported in person by a relatively large number of subjects.

METHODS AND SUBJECTS

Study centres and research teams

The study was conducted in the six major industrial centres of South Africa, with each centre including all hospitals within 50 km of the city centre. Greater Bloemfontein, Cape Town, Durban, Johannesburg, Kimberley, Port Elizabeth and Pretoria were selected as study centres because they are the major industrial cities and are geographically placed so that their tertiary hospitals serve much of South Africa, including the asbestos mining regions (without being in asbestos mining districts themselves). Durban was later abandoned as a study centre as it did not operate successfully. A research team comprising a co-ordinator and two interviewers, between them fluent in English and the predominant vernaculars, was established in each study centre. Each team was trained using a detailed interactive instruction manual as pre-reading, followed by a day-long training session. Research teams operated for approximately 16 months, from late 1988 through early 1990.

Cases

Our intention was to include all cases treated or diagnosed in the study centres over the study period. To achieve this all pathologists, oncologists, cardiothoracic surgeons and respiratory physicians registered in the study centres were invited by mail and telephone to refer new cases to the research

teams. In addition, to encourage participation, key practitioners most likely to encounter cases were visited by research teams. All these medical practitioners were reminded regularly of the study and were sent brightly coloured reminder cards at intervals for display in their rooms.

To increase the specificity of diagnosis, cases were only entered into the study if a specialist pathologist diagnosed mesothelioma, the histological diagnosis was supported on review by a member of the South African Asbestos Tumour Reference Panel (a panel of experienced specialist pathologists established to standardise the histological diagnosis of mesothelioma), and immunohistochemical staining supported the diagnosis with a minimum requirement of negative staining for carcino-embryonic antigen (CEA).

Exposure information

Exposure information was obtained directly from subjects by means of a structured questionnaire after written informed consent had been obtained. The questionnaire was administered in the preferred language of the subject and in a standard manner.

The questionnaire included a residential history (town and magisterial district); time spent near dockyards, mines, mills, asbestos-using factories or stores of asbestos; parents' occupation; domestic and leisure-time exposure to dust; and a complete occupational history, with detailed questioning regarding asbestos exposure. Two components of the questionnaire were developed as 'memory joggers' to aid recall of particularly important potential sources of asbestos exposure. One section enumerated districts in which asbestos had been mined and the other listed important industries, occupations and activities with a known risk of asbestos exposure. The industry and occupation lists were compiled by collating information from three sources, namely the literature, consultation with experienced occupational health practitioners, and the patient database of the Occupational Medicine Clinic of the National Centre for Occupational Health (NCOH). General references[2-5] were used to compile an initial list. To this was added the important exposure settings reported by patients who had attended the clinic, with patients cross-filed according to exposure category. The list was then refined by two experienced occupational hygienists who together produced the final 31 primary memory joggers or occupational risk settings (Appendix I).

Asbestos exposure categories

Subjects were grouped according to probability of exposure to asbestos (exposure class), the likely fibre type and the nature of this exposure (e.g. occupational or environmental).

Exposure classes

Table I shows the criteria for allocation of subjects to definite, probable, possible or unlikely asbestos exposure classes.

Table I. Criteria for asbestos exposure classes

Definite
1. Direct or indirect occupational exposure reported
2. Contact with asbestos while spending time in an asbestos mining district (contact included playing on tailings dumps, living near a mine or mill, parent working on a mine or mill, asbestos fibre contaminating work or domestic environment)
3. Domestic exposure reported

Probable
1. Worked in high-risk occupation or activity with no recall of occupational exposure
2. Spent 12 months or longer in an asbestos mining district of NW Cape, NE Transvaal or E Transvaal with no reported contact with asbestos
3. Co-resident worked with asbestos products in the residence

Possible
1. Worked in a risk occupation with no recall of occupational exposure
2. Spent less than 12 months in NW Cape, NE Transvaal or E Transvaal district with no recall of contact
3. Domestic use of asbestos cement products or heating panels
4. Lived or worked in an asbestos cement structure
5. Lived or worked within 1 km of a dockyard or asbestos product manufacturing factory
6. Uncertain direct or indirect occupational exposure reported

Unlikely
1. No recall of exposure
2. No risk or high-risk occupation or activities
3. Lived in 'other' district with no reported contact

The magisterial districts of South Africa were divided into five groups: Northern Cape and North West (Cape crocidolite mining, previously the NW Cape asbestos fields); Northern Province (amosite and/or Transvaal crocidolite mining, previously the NE Transvaal mining region); Mpumalanga (chrysotile mining); 'other' districts (minor asbestos deposits — anthophillite, chrysotile or tremolite mined in a small locality for a short period in some districts); and non-asbestos districts (no asbestos deposits). The period spent in any of the asbestos districts was recorded for each subject using the questionnaire data.

Living 'near' an asbestos mine or mill was not restricted to a specified distance, since it is well known that extensive areas around mines and mills were contaminated, particularly in the Northern Cape[6] and Northern Province.[7] 'High-risk' occupations or activities are those for which asbestos exposure was thought to be probable even if the subject did not actually recall exposure. In Appendix I those work activities described in A1, 3, 6, 12, 13, 16, 18, 19, 21 and 22 were labelled high risk, while all other activities described in A (excluding sugar-cane) and B were labelled 'risk' occupations.

'Other' districts mined asbestos in limited quantities and in a small section of the district, often only for a relatively short period of time. Consequently asbestos exposure was

considered unlikely in these areas — unless there was also reported contact with asbestos, in which case the subject would be classified as definitely exposed.

Nature of exposure

Exposure was categorised as occupational, environmental, domestic, or incidental. The category 'direct occupational' included subjects who worked with asbestos, while 'indirect occupational' referred to exposure due to the use of asbestos by co-workers. 'Environmental-mining' referred to exposure due to contamination of the general environment by asbestos mining, milling and related activities, while the category 'environmental-other' included those living within a kilometre of an asbestos-using factory, store of asbestos or dockyard. Domestic exposure involved exposure incurred at home, either due to contaminated work clothes (domestic-clothes), or to work with asbestos products (domestic-use), for instance hobbies and the servicing of motor vehicle brakes. Incidental exposure involved use of asbestos cement garden furniture, spending time in asbestos cement structures and use of asbestos heating panels.

RESULTS

One hundred and twenty-three cases were accepted into the study. Table II shows that 94% had pleural mesothelioma, and that the mean age for each region was in the 50 - 60-year age group.

Ninety-four (76%), 14 (11%), 12 (10%) and 5 (4%) cases were classed as definite, probable, possible and unlikely exposure, respectively; 17 cases were therefore classed as possible or unlikely. A fairly convincing case could be made for asbestos exposure even in most of the possible cases. One subject had visited the Northern Cape town of Prieska (for seven 1-week visits) and another Koegas (for nine 10-day visits). Five subjects had worked in jobs associated with asbestos exposure: an electrician in a dockyard, a plumber and construction site worker, a moulder in a foundry, a sailor with ship maintenance experience and work on a construction site, and a production foreman in alcohol production where filters were made of asbestos. Less convincing but suggestive histories were obtained in 4 of the remaining 5 cases. Here 1 subject was a winch driver on a goldmine (possible exposure from brake shoes); 1 spent time on construction sites as a pay clerk; 1 had been a shoemaker for 36 months, a construction site worker for 6 months and had worked in an asbestos cement building for 120 months; the 5th, who had been a metal grinder for 456 months, was found to have coated fibres in his sputum. The 12th possible case is intriguing. She had been an office worker in a factory making body filler, which has chrysotile as a component. She had had her first contact with the body filler 4 years before diagnosis, too short a latent period to lend itself to causal interpretation. Her only other possible contact was the use of asbestos panel heaters for an unspecified length of time.

Two of the 5 subjects classed as unlikely provided information weakly suggestive of some asbestos contact. Subject 1 worked on the north-western Cape diamond fields. It has been suggested that crocidolite fibres may have been carried to these alluvial fields by the Orange River, which passes through the Cape crocidolite fields on its way to the Atlantic Ocean (JCA Davies, NCOH — personal communication). The subject also worked in a foundry but did not recall being exposed to asbestos, did not work near the furnaces and had never worn heat-protective clothing. For compensation purposes a thorough exposure history was obtained from the patient by an experienced occupational

Table II. Characteristics of 123 South African mesothelioma cases

	Site*		Sex		Age (mean (SD))	
	Pleura	Peritoneum	Male	Female		
Johannesburg ($N = 48$)	44	3	43	5	55.8	(13)
Pretoria ($N = 21$)	20	1	15	6	58.2	(11)
Kimberley ($N = 22$)	20	2	16	6	52.6	(12)
Bloemfontein ($N = 19$)	18	1	16	3	52.3	(10)
Cape Town ($N = 10$)	10	0	9	1	58.9	(15)
Port Elizabeth ($N = 3$)	3	0	3	0	57.3	(7)
Total	115 (94%)	7 (6%)	102 (83%)	21 (17%)	55.4	(12)

* Excludes pericardium: Johannesburg = 1 case.

medicine physician. No additional evidence to support exposure could be obtained and no coated fibres were present in his sputum. Subject 2 reported that her father worked at the Koegas asbestos mine. She did not recall having lived in a mining district herself and could recall no contamination of the home by work clothes; she also did not know whether she had been born before or after this employment. The other 3 had no recall of asbestos exposure, and had been a goldminer, a domestic worker and a security guard on a platinum mine, respectively. Four of these 5 'unlikely' subjects provided sputum, and no coated fibres (ferruginous bodies) were detected.

The nature of asbestos exposure is shown in Table III. Only 3 cases were categorised 'none' — these 3 plus the 2 cases categorised 'other district' make up the 'unlikely' class discussed above. Fifty-eight per cent of the cases had had occupational exposure to asbestos. No subject had been exposed exclusively as a consequence of contaminated work clothes (domestic-clothes), but this was nevertheless an important source of exposure as 13 subjects (11%) reported contact with asbestos in this way. All of them had either worked with asbestos or lived in a mining district and were therefore not allocated to the 'domestic-clothes' category. Two cases had 'domestic-use' as the major source of exposure: one built his own house and cut asbestos ceilings, and the other was exposed while her husband insulated their house. This woman had another possible source of exposure as she had worked as a pay clerk and had visited construction sites for approximately 30 minutes per week for many years.

Table III. Nature of asbestos exposure in 123 South African cases of mesothelioma

	Cases		Female cases	
Nature	*N*	(%)	*N*	(%)
Occupational				
Direct	63	51	1	5
Indirect	9	7	1	5
High risk	0		0	
Risk	8	7	0	
Uncertain	2	2	0	
Environmental				
Mining	22	18	15	71
Other	0		0	
+ Uncertain occupational	4	3	1	5
+ Risk	8	6	0	
'Other' district only	2	2	1	5
Domestic				
Clothes	0			
Use	2	2	1	5
Incidental	0			
None	3	2	1	5
Total	123		21	

Occupational asbestos exposure

Table IV lists all subjects who reported occupational asbestos exposure next to the industry in which they had worked and the occupation of the exposed subject. These data are presented as they may be useful in taking an exposure history. Data from both cases and controls are presented, as the industry or occupation in which exposure occurred in South Africa is of interest irrespective of the case/control status of the subject. A number of unexpected occupations are represented. For example, the policeman was a detective responsible for criminal investigations on the asbestos mines in the district where he worked. The farmer worked with asbestos cement products in building and maintenance on the farm. Of the 123 cases, 23 had worked on Cape crocidolite mines; 3 subjects reported employment at Penge, an amosite mine in the Northern Province; 3 had worked in a mixture of amosite and Transvaal crocidolite mines; and 1 subject had worked in a Transvaal crocidolite mine. It is notable that no subject has worked on a chrysotile mine.

District-specific exposure and crocidolite exposure

A proportion of cases had had no asbestos exposure other than that which may have occurred due to living in or visiting an asbestos mining district or from occupational or other contact with asbestos mined in the particular district. In these individuals asbestos fibre type could be identified confidently as the exposure had occurred exclusively in a mining district. The numbers of such cases were: Cape crocidolite only — 44, amosite with or without Northern Province crocidolite — 7, chrysotile — 0, and slight possibility of exposure to unspecified asbestos in 'other' district — 2. No subject reported exclusively Mpumalanga exposure, but 1 had spent 369 months in chrysotile mining districts and only 3 months in Northern Province mining districts. He was a policeman who conducted criminal investigations on chrysotile mines and on an asbestos mine in the Northern Province (amosite and/or crocidolite). Strong evidence of exposure to crocidolite was reported in 68 of the 123 cases (55.3%). Clear evidence of exposure to this fibre occurred in subjects exposed in the Northern Cape mining districts, those with occupational crocidolite mining exposure (Northern Cape, except for 1 Northern Province case), occupational contact with large-diameter asbestos cement pipes (2 cases), battery casings (2 cases) or as reported by the subject (1 case). Some cases not included as crocidolite-exposed may well have had substantial contact with this agent, for example 3 subjects mined asbestos in the Pietersburg asbestos fields and were therefore probably exposed to both Transvaal crocidolite and amosite. These cases were not included in the crocidolite group in order to limit this group to cases with almost incontestable crocidolite exposure.

Exclusively environmental exposure

Table V shows the exposure details of 22 cases with exclusively

Table IV. Occupational asbestos exposure in study subjects according to industry and occupation

Industry

Mining or milling asbestos
Construction
Transport
Asbestos product manufacture
- Asbestos cement
- Friction materials
- Floor tiles

Engineering
- Heavy
- Light

Power
Battery manufacture
Foundry
Chemical
Law enforcement
Fire control
Navy

Goldmining
Dry cleaning
Agriculture
Rubber
Commercial
Public service

Occupation (number of subjects in each occupation)

Asbestos mining and milling
- Underground (14)
- Surface (12)
- Mill (6)
- Transport (3)

Fitter and turner (11)
Machine operator (6)
Construction
- Carpenter (5)
- General labour (4)
- Other (4)
- Railway line (1)

Driver (4)
Boilermaker (4)
Electrician (4)
General maintenance (2)
Office administrator (2)
Boiler operator (2)
Foreman (3)
Welder (2)
Laboratory supervisor (2)
Sailor (1)
Steam locomotive maintenance (1)
Furnace mason (1)
Factory manager (1)
Turbine maintenance (1)
Engineer
- Marine (1)
- Unspecified (1)

Motor vehicle mechanic (1)
Farmer (1)
Upholsterer (1)
Toolmaker (1)
Crane driver (1)
Cleaner (1)
Building inspector (1)
Policeman (1)
Salesman (1)
Painter (1)
Storeman (1)
Missing data (1)

environmental asbestos exposure. Two subjects (Northern Cape No. 5 and Northern Province No. 1) spent years in asbestos cement structures; as the relevance of this contact is unclear, these 2 cases were categorised as 'exclusively environmental'. Fifteen of the 22 cases (68.2%) were documented as having exposure beyond mere residence in a district. It is notable that this was directly related to mining and related activity.

Exposure to non-asbestos agents

Thirty subjects reported exposure to non-asbestos agents putatively associated with mesothelioma, namely glass fibre (21 cases), other manufactured mineral fibres (3 cases), radioactive material (2 cases), nickel (3 cases), and sugar-cane (1 case). No subject reported exposure to X-rays, radiotherapy before current illness or beryllium. Twenty of the 21 subjects with exposure to glass fibre were classed as having had definite or probable asbestos exposure. The remaining subject, who had worked on construction sites as a pay clerk for 54 months, was classed as having had possible exposure. Nine subjects reported exposure to an agent other than glass fibre: 8 of them

Table V. Twenty-two cases with exclusively environmental exposure

Region	Case No.	Months spent in district	Nature of asbestos contact or potential contact	Year of first entering district
Northern Cape	1	1.5	Stayed < 5 km from Danielskuil mine	1948
	2	2	None recalled. 3 visits x 3 weeks each	1932
	3	12	None recalled	1953
	4	30	Stayed < 5 km from Riries mine. Father a miner	1958
	5	84	Lived in asbestos cement building 1964 - 1969	1929
	6	192	Father a miner — clothes contaminated home	1927
	7	192	1944 - 1957 lived < 500 m from store of asbestos at Prieska station	1941
	8	228	Farmer: asbestos mill on farm boundary	1927
	9	228	Missing information	1920
	10	312	Spouse a miner: clothes contaminated home	1942
	11	360	Brother a miner: clothes contaminated home	1944
	12	384	Lived within 1 km of an asbestos mine	1956
	13	384	Lived within 5 km of Bretby mine	1950
	14	396	Lived within 0.5 km of Riries mine	1953
	15	480	Lived near Prieska railway station	1958
	16	528	None recalled	1935
	17	588	Father a miner. Lived within 5 km of an asbestos mill	1939
	18	708	Asbestos transported past his home — broken bags contaminated area	1930
	19	720	Mother worked at Pomfret mine	1929
	20	780	None recalled	1924
Northern Province	1	228	Taught in asbestos cement classrooms 1934 - 1975	1923
Mpumalanga + Northern Province	1	372	Policeman — regular trips to asbestos mines	1958

had had definite or probable asbestos exposure, the remaining case was classed as having had possible asbestos exposure due to nine visits to Koegas, a crocidolite asbestos mining district in the Northern Cape province. None of the 5 unlikely asbestos exposure cases reported exposure to one of the agents listed above.

No subject reported purely incidental exposure, e.g. use of asbestos cement furniture or heating panels. However, 1 subject reported contact with chrysotile 4 years before diagnosis (a very short period between exposure and disease manifestation), but had used asbestos panel healers for an unspecified length of time.

Discussion

This study confirms that a history of asbestos exposure can be obtained in the overwhelming majority of South African mesothelioma cases; that environmental exposure in the crocidolite mining areas of the Northern Cape accounts for a significant proportion of cases; that there is a relative paucity of diagnosed cases linked to amosite or chrysotile; and that other causes of mesothelioma occur rarely, if at all, in this country.

In the main, limitations of this study relate to the representativeness of cases. The number of subjects who could potentially have entered the study is not known, but indirect evidence suggests that ascertainment of diagnosed cases was reasonable: the only incidence study in South Africa[1] registered on average 169 cases per year for 1980 - 1984. (This was for the whole of South Africa and histological confirmation of the diagnosis was not necessary.) More important, there is evidence that in some respects the 123 cases who entered our study were not representative of South African cases. Fifty-five per cent of the cases were white, yet this group only makes up approximately 20% of South Africa's population. A likely explanation is that black South Africans have poorer access to health care,[1] but the effect of underrepresentation of black subjects is not known. No study team was successfully established in Durban (KwaZulu-Natal), but Durban has a major harbour that exports asbestos (mainly chrysotile). The proportion of cases collected in Kimberley (22/123) was not as large as expected, given the historic importance of this region. In summary, although it cannot be quantified, it is possible that this series of cases underrepresents cases with environmental

exposure to Cape crocidolite and those with harbour-related exposure.

Putative non-asbestos agents

This study showed that putative non-asbestos agents together with a possible background rate could make a very small contribution to the mesothelioma caseload in South Africa. This is important, as an assumption of asbestos exposure is likely to be correct in the overwhelming majority of cases. It would seem reasonable to provide some form of compensation to all diagnosed cases since the cause is almost certainly direct or indirect industrial activity. The current system of restricting compensation to only those people with a history of occupational exposure should be revised.

Environmental cases

The large proportion of cases due to purely environmental exposure is unique to South Africa. Australia is the only other country to have mined crocidolite in significant amounts and it is also the only other country to have documented environmental cases in any number. Australia has maintained a mesothelioma surveillance programme since 1979. Ferguson *et al.*[8] presented exposure data on 726 cases collected from 1 January 1980 to 31 December 1985. Environmental exposure had occurred in 43 of these cases (6%), but in only 6 of the 726 (less than 1%) was environmental exposure a consequence of living in an asbestos mining region (Wittenoom, the crocidolite district). This is about 1 case per year — in sharp contrast to the findings of our study. Here 22 cases were found to have been exposed environmentally and a further 8 had experienced environmental exposure and had been employed in a risk occupation with no recall of asbestos exposure. None of the South African environmental cases was eligible for financial compensation or for payment of medical expenses related to the disease.

Fibre-specific data — the relative importance of the Northern Cape and paucity of chrysotile cases

The majority of subjects who had mined asbestos had mined Cape crocidolite, and the majority of subjects with asbestos exposure exclusively in an asbestos-mining district had incurred this exposure in the Northern Cape province. Of the 22 subjects with only environmental exposure, 20 (91%) had been exposed in the Northern Cape.

Besides a greater risk following crocodilite exposure, explanations for the preponderance of cases with Northern Cape mining district experience are that these districts mined much more asbestos than the other districts; that the nature of the mining operations led to contamination of a much larger area; and that they generated much more dust, thereby exposing more people to contamination.

The first suggestion is difficult to support. It was only in about 1960 that crocidolite production exceeded that of amosite. Amosite and chrysotile production were substantial throughout the 1960s and early to mid-1970s. (Given the long latent period for mesothelioma more recent data are not of real interest.) Twenty-seven, 53 and 100 metric kilotons of chrysotile were produced in 1960, 1970 and 1975, respectively.[9]

It is true that Cape crocidolite mining took place over a wide geographical area, but extensive contamination of the Northern Province has been well documented.[7] Asbestos pollution of surrounding villages and the environs was extensive, for example at least nine mills operated in the Mafefe district, each with a large asbestos waste dump. Disease due to environmental exposure was common in mining areas, for example 389 of 611 randomly selected adults from Mafefe had a history of environmental asbestos exposure, and 34% of these 389 individuals had pleural disease. Mpumulanga (chrysotile) communities have not been studied, and the extent of environmental pollution experienced by these communities and of asbestos-related disease in this area is not known.

Dust levels in and around Northern Province mines and mills were very high (dust counts taken in the Penge mill remained well above 12 fibres/ml until after the second half of the 1970s).[7] There are very few published studies of fibre levels in Mpumalanga chrysotile mines, with the only readily available data taken from Slade's 1931 thesis.[10]

Given the contamination of mining regions in the Northern Province and the fact that the Northern Cape is a sparsely populated region, it is untenable that the preponderance of Cape crocidolite cases can be explained solely on the basis of a preponderance of individuals exposed to this fibre. South African data suggesting that amosite is less dangerous than Cape crocidolite, at least as far as mesothelioma is concerned, have been presented by Sluis-Cremer and co-workers.[11] They found the incidence of mesothelioma per 100 000 subject-years to be 7.8 and 44.6 for amosite and crocidolite miners, respectively, and the proportional mortality ratio in men followed up from 20 years after first employment to be 1.7% and 11.9%, respectively.

Paucity of chrysotile cases

No case with a history of chrysotile mining entered the study, and there was no case involving exclusively environmental exposure to chrysotile. Although no case could be said to have shown good evidence of exclusively chrysotile occupational exposure, 2 subjects reported having had contact with this material and little if any contact with amphiboles. One of these subjects spent 369 months in chrysotile mining districts and 3 months on an asbestos mine in the Northern Province, and the other had been exposed to chrysotile only 4 years before diagnosis. This is a very short latent period and does not lend itself to causal interpretation.

The absence of South African chrysotile cases is not an

isolated finding. No mesothelioma cases have been recorded from South African chrysotile mines.[12]

One explanation for the absence of exclusively chrysotile cases is that production and use of the material in South Africa was so limited that only a small number of individuals were exposed, resulting in very few cases. This seems unlikely. Hart[9] estimates that chrysotile production constituted approximately 30% of total asbestos production by the end of the 1970s; in the early 60s, production was closer to 20%. Substantial numbers of miners worked in chrysotile production — from the 1930s to mid-1980 roughly 1 000 - 2 000 workers were employed in chrysotile mining at any one time (RSJ du Toit, NCOH — personal communication), and in 1960 there were approximately 2 600 workers, constituting 17% of all asbestos miners. From these data it seems unlikely that scarcity of exposed workers is an adequate explanation for the absence of cases.

In summary, the great preponderance of crocidolite cases, followed by amosite and chrysotile (in this study no convincing case was identified), is consistent with the view that there is a fibre gradient in mesotheliomagenic potential of South African asbestos (crocidolite > amosite > chrysotile).

Dr Erica Jansen was the co-ordinator of the Port Elizabeth study centre. Cases were referred to this study by a large number of South African practitioners, notably pathologists. We thank them for their goodwill and co-operation. The South African Asbestos Tumour Reference Panel members supported the project by reviewing the diagnoses of mesothelioma. Financial support came from the South African Medical Research Council, the Anglo-American and De Beers Chairman's Fund and the National Cancer Association of South Africa. The paper is based on a PhD thesis awarded by the University of Cape Town.

References

1. Zwi AB, Reid G, Landau SP, Kielkowski D, Sitas F, Becklake MR. Mesothelioma in South Africa, 1976 - 84: Incidence and case characteristics. *Int J Epidemiol* 1989; **18:** 320-329.
2. Health and Safety Commission. *Asbestos.* Vol. 1. Final report of the Advisory Committee. London: HMSO, 1979.
3. Health and Safety Commission. *Asbestos.* Vol. 2. Final Report of the Advisory Committee. London: HMSO, 1979.
4. Michaels L, Chissick SS. *Asbestos.* Vol. 1. Properties, Application and Hazards. Belfast: John Wiley & Sons, 1979.
5. International Labour Office. *Encyclopaedia of Occupational Health and Safety.* 3rd ed. rev. Parmeggiani L, ed. Geneva: ILO, 1983.
6. Marchand PE. The discovery of mesothelioma in Northwestern Cape Province in the Republic of South Africa. *Am J Ind Med* 1991; **19:** 241-246.
7. Felix MA, Leger JP, Ehrlich RI. Three minerals, three epidemics — asbestos mining and disease in South Africa. In: Mehlam MA, Upton A, eds. *The Identification and Control of Environmental and Occupational Diseases.* Princeton: Princeton Scientific Publishing Company, 1994.
8. Ferguson DA, Berry G, Jelihovsky T, *et al.* The Australian mesothelioma surveillance program 1979 - 1985. *Med J Aust* 1987; **147:** 166-172.
9. Hart HP. Asbestos in South Africa. *Journal of the South African Institute of Mining and Metallurgy* 1988; **88:** 185-198.
10. Slade GF. The incidence of respiratory disability in workers employed in asbestos mining, with special reference to the type of disability caused by the inhalation of asbestos dust. MD thesis, University of the Witwatersrand, 1931.
11. Sluis-Cremer GK, Liddell FDK, Logan WPD, Bezuidenhout BN. The mortality of amphibole miners in South Africa, 1946 - 80. *Br J Ind Med* 1992; **49:** 566-575.
12. Wagner JC. Mesothelioma and mineral fibers. *Cancer* 1986; **57:** 1905-1911.

Accepted 15 Nov 1998.

APPENDIX I. MEMORY 'JOGGERS' READ OUT TO STUDY SUBJECTS

A. Have you ever been involved in any of the following?

1. Insulation work
2. Working with furnaces
3. Manufacturing asbestos cement products
4. Working with boilers
5. Wearing heat-protective clothing
6. Selling asbestos
7. Construction site work
8. Demolishing buildings
9. Working in a factory using asbestos
10. Working for the navy/merchant navy
11. Repairing/servicing motor vehicles more than once a month
12. Helping manufacture asbestos-containing articles
13. Working in a power station
14. Working with the manufacture of batteries
15. Working in the plastic industry
16. Using asbestos rope or asbestos gaskets
17. Working in the rubber industry
18. Manufacturing brake linings or clutch plates
19. Transporting asbestos
20. Working for a railway company
21. Insulation of hot-water pipes
22. Working with steam locomotives (train engines)
23. Working with sugar-cane

B. Did you ever work as a ...

1. Boiler maker
2. Fitter and/or turner
3. Stevedore
4. Marine/civil engineer
5. Plumber/plumber's assistant
6. Welder/welder's assistant
7. Building carpenter/building carpenter's assistant
8. Electrician/electrician's assistant
9. Paint manufacturer