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Mortality in gold and coal miners in Western Australia with special reference to lung cancer

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ABSTRACT Cohorts of 1974 gold miners and 213 coal miners in Western Australia surveyed for respiratory symptoms, smoking habits, occupational history and radiographic evidence of pneumoconiosis have been followed up for 13–14 years. Overall, neither group had a significantly higher mortality than expected from the experience of Western Australian men in general. Lung cancer mortality was relatively high in the gold miners (59 deaths observed, 40·8 expected) but weakly and inconclusively related to the extent of their underground mining experience. Cigarette smoking may explain the excess of lung cancer in the gold miners because the prevalence of the habit in the latter (66·3%) was higher than in the coal miners (58·7%) or in other men in Western Australia (53·2%). Radiographic evidence of silicosis was present in 21·7% of the gold miners but did not appear to have contributed substantially to their mortality. The coal miners showed a lower than expected rate of lung cancer but an excess of deaths from all other forms of cancer (11 observed, 5·6 expected). This excess was not attributable to any one cancer site and cannot be explained readily.

Miners of uranium, asbestos, underground haematite, fluorspar and some metals are known to have higher than average rates of lung cancer which may be attributable, at least in part, to their mining experience (Peller, 1939; Wagoner *et al.*, 1963; Boyd *et al.*, 1970; Saracci, 1977; Wright and Couves, 1977). In each of these situations, except asbestos mining, inhalation of radon may be an aetiological factor. Gold miners in Rhodesia also appear to have high rates of lung cancer, possibly due to a high concentration of arsenic in the gold-bearing ores (Osburn, 1957, 1969; Cookson *et al.*, 1974). In contrast, coal miners, who have been studied extensively, have either the same or lower rates of lung cancer than men in the general population (Kennaway and Kennaway, 1953; Goldman, 1965; Liddell, 1973; Costello *et al.*, 1974) although contrary observations have been made (Crofton, 1969; Enterline, 1972; Mooney, 1975).

Gold has been mined at Kalgoorlie and nearby areas of Western Australia since 1881, and unpublished studies of lung cancer incidence in Western Australia in 1971 to 1974 have shown rates in men in the Kalgoorlie (Eastern Goldfields) area which are equal to those in the capital city, Perth. Lung cancer rates in all other parts of the State (except the sparsely populated 'frontier' settlements of the North-west) are 30–75% less than in Perth, thus suggesting that men in the Eastern Goldfields, an appreciable proportion of whom are miners or ex-miners, may be at special risk.

Prevalence surveys of respiratory health, smoking habits and occupational history were conducted among gold miners in Kalgoorlie in 1961 and 1962 and, under an identical protocol, among coal miners in Collie, Western Australia where soft coal has been mined since 1889. This report describes a 13–14 yr follow-up study of men included in these surveys, undertaken to test the hypothesis that Kalgoorlie miners have a high incidence of lung cancer which is attributable to their mining experience.

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Methods

Survey records were located for all the Kalgoorlie miners originally studied (1974 men) and 213 of the 531 men originally surveyed in Collie. No other records identifying the original survey populations were available, so these 2187 men only were followed up.

The loss of 318 survey records from Collie cannot be explained adequately. As no previous follow-up had been attempted, it is not thought to relate to the subsequent work, survival or migration status of the men concerned. A possible explanation lies in the fact that the original analyses of the survey (McNulty, 1968) were carried out by hand, involved separate examinations of underground and other miners and concentrated mainly on those aged 40–59 years, thus allowing the possibility of selective loss of records according to these characteristics. All except 8 (3·8%) of the 213 Collie miners in this study worked underground, compared with 47·3% of non-underground miners in the original population. They were also older at the time of the original survey (81·6% aged 40+ years) than those for whom survey records could not be located (67·6% aged 40+ years). The records available for this survey were therefore mainly those of underground miners aged 40–59 years at the original survey and included 174 (82·8%) of the 210 men originally in this group.

Each survey record included responses to the British Medical Research Council's questionnaire on respiratory symptoms (Medical Research Council, 1960), a record of past and present smoking habits, experience in mining and other occupations involving dust exposure and a chest radiograph code taken from the 1959 revision of the International Labour Office Classification of Radiographs of the Pneumoconioses (International Labour Office, 1959).

Retrospective follow-up of the miners for whom records were available was begun in December 1976 with a cut-off date of 31 December 1975. The following sources of follow-up information were used:

THE PUBLIC HEALTH DEPARTMENT OF WESTERN AUSTRALIA MINERS' REGISTER

Gold miners in Western Australia are required to have annual chest radiographs while engaged in the industry and those found to have silicosis are compensated and reviewed from time to time even after retirement. Details of these examinations, together with continuing occupational records, are kept in the Miners' Register. These data were collected for the Kalgoorlie miners and in many cases were sufficient to establish vital status on the cut-off date.

COMMONWEALTH ELECTORAL ROLL FOR WESTERN AUSTRALIA

Miners whose names appeared on the Western Australian electoral roll current at 30 June 1976 were considered to be alive and resident in Western Australia on the cut-off date. This method of follow-up was validated by a direct approach to a random sample of 100 of the men whose names appeared on the electoral roll. All of them proved to be alive and resident in Western Australia on 31 December 1975.

STATE DEATH REGISTER FOR WESTERN AUSTRALIA

The names of all men not found to be alive by the above two methods were searched for both manually and by computer in the Western Australian Death Register. The underlying cause of death (as assigned by the Australian Bureau of Statistics which compiles Australian mortality data) together with all other causes of death was recorded for each man found to have died.

OTHER SOURCES

The vital status at the cut-off date of over 90% of all men in the study cohort was ascertained from the above three sources. Other sources of information which were used included employer, union, pension fund, hospital insurance, and motor vehicle driver's licence records and the Western Australian telephone directories. Agreement on name and date of birth was considered adequate for positive matching and in most cases residential and occupational information was consistent with the match.

The percentage distributions of vital status at the cut-off date are shown in Table 1. Only 1·7% of men remained untraced who, for analytical purposes, have been treated as alive and resident in Western Australia on the cut-off date. This procedure was adopted for the following reasons:

(1) it is conservative with respect to the hypothesis under test;
(2) it is unlikely that any deaths which had occurred in Western Australia would have been missed. (The State Death Register was repeatedly researched with residual lists of names after each other source of follow-up information had been tapped);
(3) those lost to follow-up were on average 3·2 years younger (45·4 yr) than those who were followed to the cut-off date (48·6 yr). Only 10 of them would have been aged 70 years or over on the cut-off date, with the oldest aged 76.

Table 1 *Final follow-up status of the Kalgoorlie and Collie miners at 31 December 1975*

Miners	*Mines*	
	Kalgoorlie	*Collie*
Original number	1974	213
Follow-up status		
Alive	1427	152
Emigrated	13	4
Dead	500	54
Not known	34	3

It is likely that most of those lost to follow-up emigrated from Western Australia during the follow-up period because no certain method of establishing the fact of emigration was available. If it is assumed that these men lived, on average, half of the follow-up period in Western Australia, emigrated and then died at the same rate as those who remained in Western Australia, about six deaths (five in Kalgoorlie miners and less than one in Collie miners) would have been missed.

Computer analysis of the data was undertaken using SPSS (Nie *et al.*, 1975) and Man Years Computer Language (MYCL; Hill, 1972) package programmes.

Results

All results reported here relate to the 2187 men for whom original survey records could be located.

CROSS-SECTIONAL CHARACTERISTICS

At the time of the original surveys the men ranged in age from 24 to 79 years and the majority were in the sixth decade of life (39·3% in Kalgoorlie and 55·4% in Collie). Few had less than 10 years' mining experience (2·6% in Kalgoorlie and 0·5% in Collie) and the majority had worked for more than 10 years underground (57·0% in Kalgoorlie and 83·0% in Collie). Some had not worked underground at all (24·0% in Kalgoorlie and 3·8% in Collie).

The cigarette smoking experiences of the two groups of miners are summarised in Table 2. Most of the men smoked hand-rolled cigarettes and in calculating the number smoked per day a conversion factor of 30 cigarettes to one ounce of cigarette tobacco was applied. Cigarette smoking was current among 66·3% of Kalgoorlie and 58·7% of Collie miners, and 15·7% of Kalgoorlie miners compared with 20·7% of Collie miners had never smoked.

The prevalence of chronic bronchitis (defined as cough and phlegm during the day or night for as much as three months of each year) standardised for age and smoking habits in Kalgoorlie miners was 20·4% compared with 11·8% in Collie miners and the age-standardised prevalence of radiographic evidence of pneumoconiosis (suspected and higher grades) was 21·7% in Kalgoorlie compared with 3·5% in Collie. Of the 429 Kalgoorlie miners with radiographic evidence of silicosis 235 (54·8%) had suspected silicosis only, 140 (32·6%) had opacities up to about 1·5 mm in diameter and 54 (12·6%) opacities exceeding 1·5 mm in diameter, of whom only 4 had opacities exceeding 3 mm in diameter. None had opacities with any diameter exceeding 1 cm.

Table 2 *Percentage distributions of smoking habits in Kalgoorlie and Collie miners at the original surveys*

Miners' smoking habits	*Mines*	
	Kalgoorlie	*Collie*
Never smoked	15·7	20·7
Current cigarette smoker		
<15/day	18·8	18·3
15–25/day	28·4	23·0
25+/day	19·1	17·4
Current pipe or cigar only smoker	2·1	2·8
Ex-cigarette smoker	15·4	17·8
Ex-pipe or cigar only smoker	0·5	0·0

Among the Kalgoorlie miners, 4·4% had also mined coal at some time, 4·9% had worked in other mines and 1·6% had mined or worked with asbestos. Sixteen per cent of the Collie miners had worked in other than coal mines and one only (0·5%) had mined or worked with asbestos.

In the original analyses of the Collie survey (McNulty, 1968) the prevalence of current smoking (all forms) was 64% in underground miners aged 40–59 yr and 55% in other miners of this age, compared with 61·5% in the 213 men in this study. The prevalence of chronic bronchitis in the original analyses was 11·1% in all underground miners, 12·4% in those aged 40–59 yr and 8·8% in all non-underground miners compared with 11·3% in this study. The prevalence of radiographic evidence of silicosis was not recorded in the original report. These comparisons suggest that there was no appreciable selective loss of men at high risk of death, by virtue of their smoking habits or symptoms, from the cohort of Collie miners who were followed up.

MORTALITY

A total of 25 551 man-years of follow-up with 500 deaths were accrued by the Kalgoorlie miners and 2445 man-years with 54 deaths by the Collie miners. Observed and expected numbers of deaths for each of three calendar periods (1961–67, 1968–72, and 1973–75) are shown in Table 3. Expected numbers of deaths were calculated within 5-year age groups by use of the age-specific death rates of Western Australian men in general in the periods 1963–67, 1968–72 and 1973–76. In the Kalgoorlie miners, the ratio of observed to expected deaths increased in each successive calendar period, as would be expected from the healthy worker effect (Fox and Collier, 1976). A similar increase was not seen in Collie miners but this is, perhaps, not surprising in view of their small number. In both groups there was a small overall excess of observed compared with expected deaths.

Observed and expected numbers of deaths for major specific categories and broad groups of cause of death are shown in Table 4. Among Kalgoorlie miners, there were significant excesses of deaths from respiratory cancer (57 of the 59 deaths were from

Table 3 *Overall mortality during follow-up of 1974 Kalgoorlie and 213 Collie miners*

Calendar period of death	Kalgoorlie			Collie		
	Observed deaths	Expected deaths	Ratio O/E	Observed deaths	Expected deaths	Ratio O/E
1961–67	158	165	0·96	15	13	1·15
1968–72	204	186	1·10	27	18	1·52
1973–75	138	120	1·15	12	13	0·95
All periods	500	471	1·06*	54	43	1·24**

*95% confidence limits 0·97–1·16.
**95% confidence limits 0·93–1·62.

Table 4 *Observed and expected numbers of deaths in specific categories and broad groups of causes of death in 1974 Kalgoorlie and 213 Collie miners*

Causes of death	ICD-8 rubrics	Kalgoorlie			Collie		
		Observed	Expected	O/E*	Observed	Expected	O/E
Tuberculosis	010–019	4	1·6	2·5	0	0·1	—
Stomach cancer	151	4	9·8	0·4	2	0·9	2·3
Colorectal cancer	153–154	9	11·0	0·8	3	1·0	3·0
Pancreatic cancer	157	7	5·8	1·2	2	0·6	3·5
Respiratory cancer	161–163	59	40·8	1·4‡	1	4·0	0·2
Melanoma of skin	172	1	2·0	0·5	3	0·2	15·8‡
Bladder cancer	188	2	3·2	0·6	1	0·3	3·6
Lymphoma, leukaemia, etc.	200–209	7	8·1	0·9	1	0·8	1·3
Other cancers		22	21·0	1·0	5	1·8	2·8
Ischaemic heart disease	410–414	178	172·7	1·0	19	16·2	1·2
Other heart disease		17	17·1	1·0	0	1·5	—
Cerebrovascular disease	430–438	40	39·6	1·0	4	3·4	1·2
Bronchitis	490–491	23	23·5	1·0	2	2·1	0·9
Pneumoconiosis	515–516	11	1·7	6·4‡	0	0·2	—
Other respiratory disease		23	38·6	0·6†	0	3·4	—
Industrial accidents and falls	916–921 923–928	13	4·5	2·9‡	0	0·4	—
Other accidents		21	18·9	1·1	3	1·8	1·7
Suicide and homicide	950–969	12	8·9	1·3	2	0·8	2·4
All other causes of death		47	42·3	1·1	6	3·9	1·5

*Ratio of observed to expected deaths. Expected deaths derived from the mortality experience of all Western Australian men.
†O/E ratio significantly different from 1·0, $P < 0·05$ (Bailar and Ederer, 1964).
‡$P < 0·01$.

bronchial cancer), pneumoconiosis (entirely silicosis) and industrial accidents and falls (the categories of accidental death which would be likely to occur in miners). There was a significant deficit of deaths from respiratory disease other than bronchitis and pneumoconiosis.

Among Collie miners, there was a significant excess of deaths from non-respiratory cancer (17 deaths observed, 5·6 expected, $P < 0·01$). Detailed examination of this difference revealed melanoma of the skin as showing the largest relative excess with 3 deaths observed and 0·2 expected, but most other cancer sites showed two to three-fold excesses of observed to expected deaths. A notable exception was respiratory cancer, for which there was an apparent deficit of deaths; only one death was observed, whereas 4·0 would have been expected from the population death rates and 5·5 from the experience of the Kalgoorlie miners.

Standardised mortality rates from all causes and respiratory cancer in Kalgoorlie miners are shown in Table 5, distributed separately by an estimate of lifetime cigarette consumption and duration of underground mining (both as recorded at the initial survey). As would be expected, both mortality from all causes and from respiratory cancer increased in a graded fashion with increasing cigarette consumption.

Overall mortality and mortality from respiratory cancer were also higher in those who had worked underground than in those who had not. However, the rates (standardised for age and cigarette consumption), although increasing in a graded fashion in those with experience of none to 10 to 19 years of underground mining declined again in those with 20 or more years underground and did not, therefore, show a statistically significant linear trend. Comparison of all underground miners with those without underground experience (Ederer and Mantel, 1974) gave a relative risk of death from all causes of

Table 5 *Effect of lifetime cigarette consumption and total duration of underground mining on mortality from respiratory cancer in Kalgoorlie miners*

Variables	*No. of deaths*		*Mortality per 1000*	
	All causes	*Respiratory cancer*	*All causes**	*Respiratory* cancer*
Lifetime cigarette consumption ('000s)				
None	76	1	15·7	0·06
<12·8	76	6	17·8	1·99
12·8–25·6	165	20	21·8	3·20
25·6+	183	32	22·4	4·71
Total duration of underground mining (yr)				
None	110	10	18·3†	2·14†
1–9	81	11	20·2	3·42
10–19	141	19	22·3	3·57
20+	168	19	20·8	2·41

*Rates standardised to the distribution by age and duration of underground mining of all Kalgoorlie miners. χ_1^2 for trend = 8·1 for all causes ($P < 0·01$) and 19·2 for respiratory cancer ($P < 0·001$); Mantel (1963).
†Rates standardised to the distribution by age and lifetime cigarette consumption of all Kalgoorlie miners.

1·09 (95% confidence limits 0·88–1·35), and of death from respiratory cancer of 1·41 (95% confidence limits 0·69–2·96).

Evidence was sought of interaction between cigarette smoking and underground mining in the production of lung cancer in Kalgoorlie miners. Table 6 shows age-standardised mortality from respiratory cancer distributed both by cigarette consumption and underground mining experience. The highest mortality was in those who had both smoked and mined underground: 3·60 per 1000 person-years compared with 2·62 in those who had smoked only; relative risk 1·39 with 95% confidence limits 0·68–2·93. The detailed distribution of the mortality rates is compatible with interaction, although the pattern is by no means fully consistent.

The mortality of Kalgoorlie miners was also examined in relation to radiographic evidence of silicosis. Evidence of silicosis was associated with a relative risk of death from all causes of 1·18 (171 deaths in silicotics; 95% confidence limits about relative risk 0·97–1·42), of death from respiratory cancer of 1·13 (21 deaths in silicotics, 95% confidence limits 0·64–1·98), and of death from non-neoplastic respiratory disease of 1·21 (23 deaths in silicotics; 95% confidence limits 0·70–2·10).

Discussion

This study shows that Kalgoorlie gold miners have a higher mortality from, and probably therefore a higher incidence of, lung cancer than do Western Australian men in general and Collie coal miners in particular. We know of no reason to postulate a higher case-fatality rate for lung cancer in Kalgoorlie miners compared with men in the rest of the State. Medical services in Kalgoorlie are good and most of the men diagnosed there (and elsewhere in the State) would have been treated in Perth. It is perhaps more likely that the Kalgoorlie miners had a slight survival advantage by virtue of the occasional early diagnosis which may have resulted from their regular chest radiographs.

There are two likely explanations for a high relative incidence of lung cancer in Kalgoorlie miners: their cigarette smoking habits and their mining experience.

Respiratory cancer mortality in Kalgoorlie miners was strongly associated with cigarette consumption and the prevalence of current cigarette consumption in Kalgoorlie miners was high (66·3%) compared with Collie miners (58·7%) and with men surveyed in the South-west coastal town of Busselton in 1966 (53·2% standardised to the age distribution of the Kalgoorlie miners (Cullen *et al.*, 1968)). More general data on cigarette consumption in Western Australia are not available but it seems reasonable to conclude that more Kalgoorlie miners were cigarette smokers than were other Western Australian men in the 1960s. It is likely also that Kalgoorlie smokers generally smoked more heavily than other male smokers in Western Australia; 71·6% of them smoked 15 or more cigarettes per day compared with 64·0% of Busselton male smokers surveyed in 1972 (Cullen and Woodings, 1975). Cigarette smoking therefore probably explains at least part of the lung

Table 6 *Interaction between lifetime cigarette consumption and underground mining experience in respiratory cancer mortality in Kalgoorlie miners*

Lifetime cigarette consumption ('000s)	*Duration of underground mining (yr)*							
	None		*1–9*		*10–19*		*20+*	
	No.	*Rate**	*No.*	*Rate**	*No.*	*Rate**	*No.*	*Rate**
None	0	0·00	0	0·00	1	0·19	0	0·00
<12·8	1	0·53	1	1·44	3	5·99	1	0·93
12·8–25·6	5	3·47	5	4·93	5	2·56	5	2·33
25·6+	4	3·52	5	4·51	10	5·62	13	4·58

*Rate per 1000 person-years standardised to the distribution of person-years by age in Kalgoorlie miners.

cancer excess in Kalgoorlie miners.

Evidence that underground experience in Kalgoorlie miners contributed to their lung cancer mortality was inconclusive. Underground miners had a 40% excess of deaths from lung cancer compared with surface miners, but this excess was not statistically significant and there was no consistent tendency for respiratory cancer mortality to increase with increasing duration of underground mining. There was also evidence, although again inconclusive, of interaction between cigarette smoking and underground mining in the production of lung cancer. Interaction with cigarette smoking is characteristic of some other mining-associated lung cancer hazards (Archer *et al.*, 1976; Saracci, 1977).

The absence of a strong association between underground mining experience and lung cancer mortality in this study is consistent with the relative absence of known carcinogenic hazards from the Kalgoorlie miners. Radon and radon daughter isotope levels were surveyed in Kalgoorlie in 1973 by the Australian Radiation Laboratory and the Western Australian X-ray Laboratory (Leith and Hartley, 1974). Maximum levels of 11 pci of radon per litre and 0·045 WL (working levels) of radon daughters were found, with the majority of air samples being far below these levels. Even the maximum levels were much lower than those which have been associated with lung cancer in other studies (De Villiers and Windish, 1964; Boyd *et al.*, 1970; Archer *et al.*, 1976).

Arsenic levels were also determined (molybdenum blue method, Western Australian Government Chemical Laboratories) in samples from the Kalgoorlie lode systems and adjacent country rocks (Western Mining Corporation, personal communication). The highest level in any individual sample was 335 parts per million with average levels at the various sampling sites ranging up to 49 parts per million. How these levels compare with those of the Rhodesian mines (Osburn, 1957; 1969) is not known. It is probable that they are very much lower, given that clinical features of arsenicalism are not seen in Kalgoorlie miners.

It has been suggested that silica itself, or the chronic inflammation associated with its inhalation, may be carcinogenic (Bryson and Bischoff, 1967). Little evidence to support this view was found in this study. Respiratory cancer mortality was only slightly higher (13%, not statistically significant) in Kalgoorlie miners with radiographic evidence of silicosis than in those without. This degree of positive association, if not due solely to chance, might easily have arisen through confounding with some other factor associated with underground mining.

In contrast to the above, lung cancer mortality in the Collie miners was low both in comparison with Kalgoorlie miners and with men in the whole of the State. Although these differences may have occurred by chance, they are consistent with other observations suggesting that coal miners have an unexpectedly low mortality from lung cancer (Kennaway and Kennaway, 1953; Goldman, 1965; Liddell, 1973; Costello *et al.*, 1974).

The mortality rates for causes other than lung cancer in Kalgoorlie miners reveal little that is surprising. There was a high death rate from silicosis, low death rates from other respiratory diseases and a high mortality from industrial accidents and falls. The former observations suggest that, in miners with known silicosis, there may be a tendency for deaths from respiratory diseases to be attributed to silicosis when, in fact, it was not truly the underlying cause of death. The overall death rate from non-malignant respiratory disease in Kalgoorlie miners was, in fact, slightly less than expected (61 deaths observed compared with 65·4 expected).

It is, of course, likely that the 'healthy worker effect' would have affected deaths from non-malignant respiratory disease more than deaths from other conditions, thus rendering mortality from respiratory disease artificially low. Miners who develop radiographic evidence of silicosis or respiratory symptoms are strongly encouraged to leave the industry. Within the Kalgoorlie cohort itself, however, mortality from non-malignant respiratory disease and all causes of death was only some 20% higher in those with radiographic evidence of silicosis than in those without. These excesses were not statistically significant. Silicosis of the degree commonly observed in these men (none had lung opacities greater than 1 cm in diameter at the time of the original surveys) is probably, therefore, associated with less than a 50% increase in mortality and may be associated with no increase in mortality at all. This is consistent with observations on simple pneumoconiosis in coal miners (Cochrane, 1973; Ortmeyer *et al.*, 1974).

Overall mortality in Collie coal miners was greater than that expected (observed to expected ratio, 1·24) although the excess was not statistically significant. The major contributors to this excess were non-respiratory cancers, deaths from which, when taken together, significantly exceeded the expected number. No one cancer site explained this difference. Melanoma of the skin showed the largest relative excess but we had no *a priori* reason to expect such a finding. The high relative mortality from non-respiratory cancer is similar to that which has been described in American coal miners (Enterline, 1972). From our knowledge of the working environment and lifestyle of Collie miners we are unable to offer a firm explanation of this finding.

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