British Journal of Industrial Medicine 1980;37:152-162

Effects of exposure to slate dust in North Wales

J R GLOVER,[1] CAROL BEVAN,[2] J E COTES,[2] P C ELWOOD,[3] N G HODGES,[4] R L KELL,[1] C R LOWE,[1] MARGERY McDERMOTT,[2] AND P D OLDHAM[2]

From the Department of Community Medicine,[1] Welsh National School of Medicine, the MRC Pneumoconiosis Unit,[2] the MRC Epidemiology Unit,[3] Cardiff, and the Gwynedd Area Health Authority,[4] North Wales, UK

ABSTRACT In a study of slate workers in four areas in North Wales 725 workers and ex-workers who had been exposed to slate and to no other dust were seen, together with 530 men from the same area who had never been exposed to any dust. Evidence of pneumoconiosis was found in one-third of the slate workers, and 10% had degrees of pneumoconiosis that would attract compensation (category 2 or higher). The prevalence of respiratory symptoms was high, and there was evidence of an effect of both simple and complicated pneumoconiosis on lung function additional to that of age. There was a high prevalence (40-50%) of radiological lesions suggestive of healed tuberculosis in men aged over 55. Either pneumoconiosis or old tubercular lesions (or both together) could account for the current symptomatology and disability of the men.

Slate has been quarried and mined in North Wales for over 200 years. At the turn of the century there were about 18 000 men in the industry; this fell to 2500 in 1950 and by 1975 only about 400 were employed. Interest in slate for architectural and domestic purposes is reviving, however, and slate souvenirs are now being produced for the tourist trade. Thus there are in North Wales many older men who have had a heavy exposure to slate dust in the past, and a smaller number of men whose exposure continues to the present day.

Three previous surveys of pneumoconiosis in North Wales have been reported. Sutherland and Bryson[1] conducted a study for the Mines Department based on 120 selected slate workers heavily exposed to dust. They estimated that 15% of the mill men who worked indoors had pneumoconiosis. Davies[2] examined 117 slate workers and, as a result, silicosis in underground slate workers became recognised as a scheduled disease, and, later, pneumoconiosis became a prescribed disease for all quarrymen. Jarman *et al*[3] surveyed 90% of working slate quarrymen and found a prevalence of 8·3% of pneumoconiosis of category 2 or above, and 20% in ex-quarry workers. They compared slate and coal workers in Wales and found that, while slate workers showed less pneumoconiosis, they had a very much higher prevalence of tuberculosis. In fact several studies[3-5] have reported very high prevalence rates of tuberculosis in North-west Wales, and death rates have consistently been about three times the overall rate for England and Wales. Two of these reports comment on the frequent association of tuberculosis and work in slate.

It was also suggested to us that slate workers suffer from respiratory disability additional to that which could be attributed to pneumoconiosis and tuberculosis. A preliminary study, conducted by one of us to explore this possibility, established that the proportional mortality ratio from respiratory conditions other than pneumoconiosis was larger than unity (1·6, 1·9, and 1·9 for men in the age groups 55-64, 65-74, and 75-84 respectively). We proceeded therefore to conduct a survey of respiratory symptoms, lung function, and *x*-ray category of pneumoconiosis in slate workers and ex-workers in North-west Wales.

In this paper the term pneumoconiosis is used where previous authors have applied the word silicosis, to avoid the assumption that true silicosis is concerned. Respirable slate dust contains between 13% and 32% of respirable quartz (HM Inspectorate of Mines and Quarries, 1977, personal communication).

Method

Four areas of slate mining and quarrying were selected—Blaenau Ffestiniog, Penygroes, Bethesda, and Llanberis.

Received 27 October 1978
Accepted 14 May 1979

A pilot study established that rather more than half the men aged over 30 residing in these areas had worked in slate for at least three months. From the electoral roll for each area, a random sample of about 400 men was chosen. These were visited and two groups identified; firstly, men of any age over 18 who had worked in slate for three months or more, and secondly, men who had never worked in slate, or had worked for a total of less than three months, and who were aged 30 or more and had lived in the area for all their lives except for, at most, 20 years, which might have been spent in a polluted conurbation. All these men, together with all those employed in the industry at the time of the survey, were invited to attend a special clinic.

The following data were collected for each man:

(1) Age.

(2) Height without shoes, and weight.

(3) Tobacco consumption.

(4) Respiratory symptoms: a Welsh translation of the MRC questionnaire on respiratory symptoms (1974)* was used, and to this were added questions about attendance at a pneumoconiosis medical panel or chest clinic, and about possible exposure to mouldy hay or domestic birds.

(5) Occupational history: an expanded classification of jobs in the slate industry is given in the appendix. For most of the analyses that follow, jobs were grouped by apparent dustiness into 11 subgroups (appendix 1). In this report all men who had had occupational exposure to any other dust—for example, coal, granite, etc, as listed in appendix 2—are omitted. The analyses presented therefore relate only to men who had been exposed to slate, but to none of the other dusts listed, and men who had never been exposed for as much as three months to slate or to any other dust. We refer to them later as "slate workers" and "non-exposed men".

(6) Pneumoconiosis category: posteroanterior and lateral radiographs for each man were read separately by each of three experienced readers, using the ILO-U/C (1971) classification.[6] Agreement among readers on individual radiographs was found to be excellent for the profusion of pneumoconiosis but not for whether small opacities were rounded or irregular (appendix 2). The former greatly predominated, and the convention was adopted that a film on which rounded opacities were recorded by one or more observers should be taken as of rounded opacities. A numerical score for simple pneumoconiosis was then derived by the method of Oldham.[7] The formula for a transformed score was, for rounded opacities,

$$y = (85 + 11x^2 - 36/x^2)/60$$

where x is the category 0, 1, 2, or 3 plus a fraction within a category: for example an x of 1·5 represents the mid-point of category 1. A similar formula was used for irregular opacities.

(7) Lung function: FEV_1, FVC, and a flow-volume curve on air were estimated on all subjects using the McDermott dry spirometer;[8] flow-volume curves on helium, to give V-iso-V and closing volumes, were estimated on subsamples of men.

The radiograph and questionnaires were examined (NGH) immediately so that any abnormalities could be dealt with clinically. In those patients in whom the *x*-ray appearance raised the possibility of tuberculosis, including all those subjects with large shadows, sputum specimens were examined with microscopy and culture. Two cases of active tuberculosis were detected in the entire survey.

*Obtainable from the MRC, 20 Park Crescent, London W1N 4AL.

Analysis and results

The numbers of men seen are shown in table 1. In table 2 the smoking habits of slate workers and the non-exposed men are compared. They are closely similar. Further analyses, however, indicated that the lighter smokers were less healthy than the heavier smokers in the younger men, and more healthy in the older men, suggesting that self-selection into these classes had occurred. This

Table 1 *Details of population surveyed*

Samples drawn from electoral registers		1731
Exclusions—never worked in slate, under 30 years of age	311	
—never worked in slate, out of area >20 years	150	
Effective sample drawn from electoral registers		1270
Current slate workers		392
Total population sample		1662 (100%)
Refused to co-operate, etc	100	
Total seen in clinic etc		1562 (94%)
Exclusions—mixed dust exposure	307	
Total on which report is based		1255
Slate workers		725
Non-exposed men		530

Table 2 *Smoking habits of the slate workers and the non-exposed men*

	Slate workers		*Non-exposed men*	
Smokers				
<15 g/day	212 (48%)		138 (44%)	
15 g/day or more	228 (52%)		173 (56%)	
Total	(100%)	440 (61%)	(100%)	311 (59%)
Ex-smokers				
≥10 years	70 (41%)		49 (40%)	
<10 years	102 (59%)		73 (60%)	
Total	(100%)	172 (24%)	(100%)	122 (23%)
Non-smokers		107 (15%)		91 (17%)
Total		719 (100%)		524 (100%)
Incomplete smoking history		6		6
Total		725		530

complex pattern, however, has no major effect on our general conclusions, although in some cases it may have reduced the statistical significance of the positive findings; consequently all cigarette smokers are treated as one group (which includes smokers of cigarettes and pipes or cigars).

RADIOLOGICAL FINDING

Figure 1 shows the distribution of the radiological scores in the slate workers, using whichever is the higher of the scores for either rounded or irregular opacities. There were 23% of the men with films in category 1, just over 8% in category 2, and just under 2% in category 3. Thus 10% of the men had pneumoconiosis severe enough to attract compensation. Less than half of the men with category 2

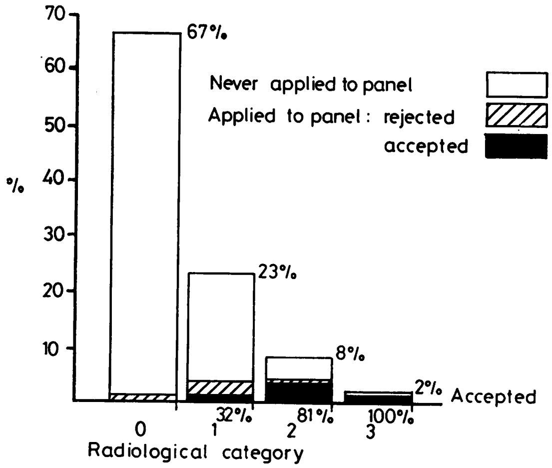

Fig 1 *Distribution of slate workers by category of simple pneumoconiosis, showing proportions of men who had never applied to pneumoconiosis panel for compensation, and outcome of those who had.*

pneumoconiosis had ever applied to the pneumoconiosis medical panel, and of the 27 who had, 22 had been compensated. Only eight of the 12 men in category 3 had ever applied for compensation, and all of them had been accepted. Twenty-five (16%) of those in category 1 had applied, and eight had been accepted.

Small irregular opacities of category 1 or more were recorded in 8% of the slate workers—7% in category 1 and 1% in category 2. In addition there were 12·5% in subcategory 0/1.

Table 3 shows the distributions of radiological scores by smoking habits omitting the 175 who had stopped smoking less than 10 years previously. No pronounced association is apparent, although the proportion with rounded opacities among the non-exposed men appears to be higher in the smokers and ex-smokers than in the others. In many cases the small opacities in the non-exposed men could be attributed to a pathology other than pneumoconiosis—for example, the one man read as more than mid-category 3 was diagnosed as cryptogenic fibrosing alveolitis.

To discover the rate of production of pneumoconiosis the radiological score for small rounded opacities was related to age, and to years of different types of exposure to slate dust, by regression methods. Initially, it was hoped to include both years of exposure and years of exposure weighted by elapsed time in the equations to allow for radiological changes developing in the period after an increment of dust exposure. It was found, however, that these two indices of exposure were so highly correlated ($r = 0·9$ for slate makers) that their relative importance could not be distinguished, and only the simpler index, total years of exposure, was therefore included. This was correlated with age to the extent of 0·68, and thus the separate effects of age and exposure could be unravelled. The transformed radiological score "y" was used as the independent

Table 3 *Number and percentage of men by smoking classes and x-ray category*

		Slate workers			Non-exposed men		
		Non-smokers	*10 y or more ex-smokers*	*Smokers*	*Non-smokers*	*10 y or more ex-smokers*	*Smokers*
Small rounded opacities	0/0	48 (49·0)	31 (47·0)	215 (53·1)	64 (82·1)	31 (67·4)	195 (70·1)
	>0/0–	16 (16·3)	12 (18·2)	65 (16·0)	10 (12·8)	12 (26·2)	51 (18·3)
	1 –	16 (16·3)	9 (13·6)	61 (15·1)	3 (3·8)	2 (4·3)	21 (7·6)
	1·5–	6 (6·1)	5 (7·6)	30 (7·4)	—	1 (2·2)	9 (3·2)
	2 –	4 (4·1)	4 (6·1)	15 (3·7)	—	—	1 (0·4)
	2·5–	4 (4·1)	2 (3·0)	16 (4·0)	—	—	1 (0·4)
	3 –	2 (2·0)	3 (4·5)	2 (0·5)	—	—	—
	3·5–	2 (2·0)	—	1 (0·2)	1 (1·3)	—	—
No *x*-ray		9	4	35	13	3	33
Total		107	70	440	91	49	311
Small irregular opacities	0/0	83 (84·7)	49 (74·2)	318 (78·5)	69 (88·5)	39 (84·8)	227 (81·7)
	>0/0	5 (5·1)	10 (15·2)	56 (13·8)	9 (11·5)	6 (13·0)	45 (16·2)
	1 –	6 (6·1)	5 (7·6)	24 (5·9)	—	1 (2·2)	5 (1·8)
	1·5–	3 (3·1)	—	4 (1·0)	—	—	1 (0·4)
	2 –	1 (1·0)	1 (1·5)	2 (0·5)	—	—	—
	2·5–	—	1 (1·5)	1 (0·2)	—	—	—
No *x*-ray		9	4	35	13	3	33
Total		107	70	440	91	49	311

variable to improve the normality of the distribution of deviations, and to allow for the uncertain numerical values of the many films read as 0/0 by all readers, these were taken as censored (less than 0/1) values, known only to be less than the upper limit of category 0/0. The regression equations were fitted by maximum likelihood, using the formulation devised by Glasser.[9]

Table 4 shows the estimates of the parameters of the regression equation for radiological score on the years of exposure in each of the 11 job groups recognised. The effects of all jobs except office work were estimated as positive, though only four groups differed significantly from zero—miners, underground rockmen, quarry rockmen, and slate makers. The score also increased significantly with age (by 0·021 a year), either because of the effects of unrecorded dust exposure or because some of the radiological features read as pneumoconiosis were really associated with any aging lung.

Table 4 *Relationship of transformed x-ray score to years of exposure and age**

	Job code	*Regression coefficients ± SE*
Underground workers		
Miners	A	+0·224 ± 0·063†
Rockmen	B	+0·034 ± 0·008†
Assistants	C	+0·013 ± 0·008
Quarry workers		
Rockmen	D	+0·016 ± 0·005†
Slate producers		
Sawyers	E	+0·015 ± 0·008
Slate makers	F	+0·031 ± 0·004†
Finishers I	G	+0·122 ± 0·097
Finishers II	H	+0·006 ± 0·017
Crushers	I	+0·008 ± 0·027
General workers		
General workers	J	+0·007 ± 0·004
Office and managerial staff		
Office workers	K	−0·006 ± 0·008
Age only		+0·021 ± 0·004†
Standard deviation of score about multiple regression		0·868 ± 0·037
Constant term		−0·850 ± 0·150

* Regression equations: transformed score.
$y = -0{\cdot}850 + 0{\cdot}224x_A + 0{\cdot}034x_B + \ldots\ldots -0{\cdot}006x_K + 0{\cdot}021$ age
where x_A = years in job A, etc.
Thus for slate mining (job A) alone:
$y = -0{\cdot}850 + 0{\cdot}224x_A + 0{\cdot}021$ age, all other x values being, in this case, zero.
† Significantly different from zero.

The coefficients in table 4 can be used to give a dose-response curve for the average amount of pneumoconiosis—that is, for miners

$$y = 0{\cdot}224 \times \text{years mining} + 0{\cdot}021 \times \text{years of age} - 0{\cdot}850$$

By assuming, however, that y is normally distributed about the regression line, the response curves can be used to calculate the proportion of men reaching the level that would attract compensation—that is, category 2 or above. Figure 2 shows these curves for the 11 occupation groups defined in appendix 1, but these must be carefully assessed in relation to the coefficients and their standard errors given in table 4.

Two curves merit special comment because they are based on very few observations. The three miners had had 12, 6, and 4½ years' exposure and had *x*-ray scores of 3·54, 1·22, and 0·57 respectively. The two finishers in the group judged to have been severely exposed to dust (finishers I in appendix 1) had had nine and one years' exposure and had scores of 1·05 and 0·57 respectively.

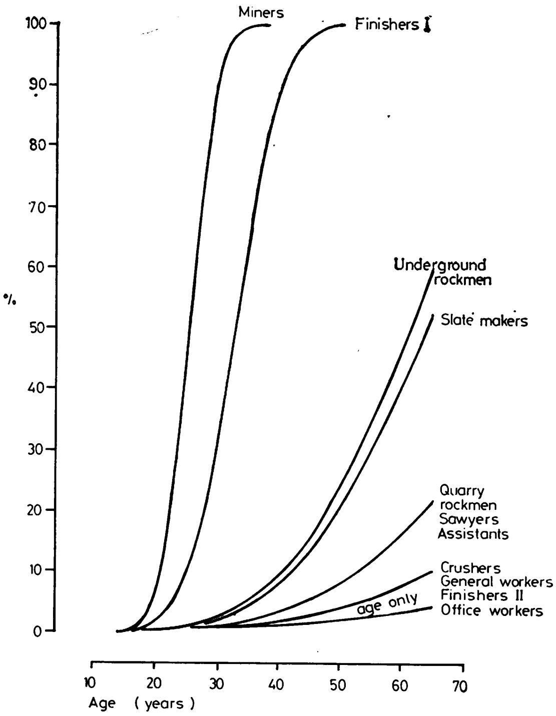

Fig 2 *Curves showing estimated proportions of slate workers reaching category 2 or more after continuous employment in each of 11 occupation groups from age 15.*

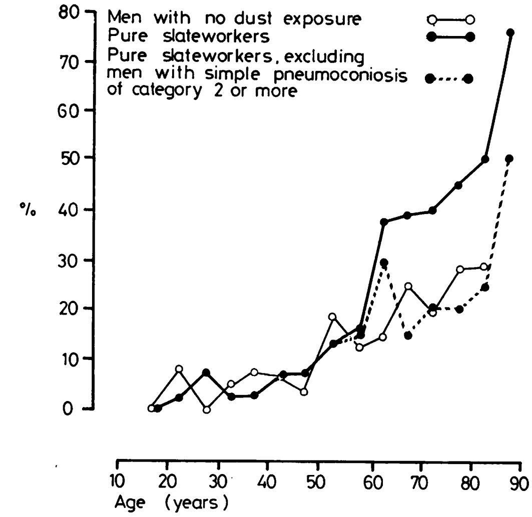

Fig 3 *Prevalence of radiological large shadows by years of age, for slate workers and non-exposed men.*

The curves in fig 2 suggest that after 20-30 years' work slate miners would probably have category 2 pneumoconiosis or worse. After a lifetime's work by underground rockmen or slate makers about 50-60% would have this amount of the disease, while 15-20% of quarry rockmen, sawyers, and underground assistants would be at this risk. Other jobs in the industry appear to carry a much smaller risk.

Apart from simple pneumoconiosis, a high proportion of the radiographs showed large shadows classed as healed tuberculosis or complicated pneumoconiosis. There was considerable inconsistency between the readers as to which of these names was used, so these terms are treated impartially in this presentation. Figure 3 shows the prevalence by age of large shadows seen by one or more observers, and it is clear that above age 55 there is a pronounced excess in the slate workers compared with non-exposed men. In the absence of simple pneumoconiosis this would imply a link between slate work and damage to the lung which resembles tuberculosis. If, however, all men with category 2 or more pneumoconiosis are removed (fig 3) the prevalence becomes closely similar in the two groups. It appears therefore that exposure to slate dust is not specifically associated with large shadows unless it also produces simple pneumoconiosis, and that older slate workers with pneumoconiosis are very likely to show such changes.

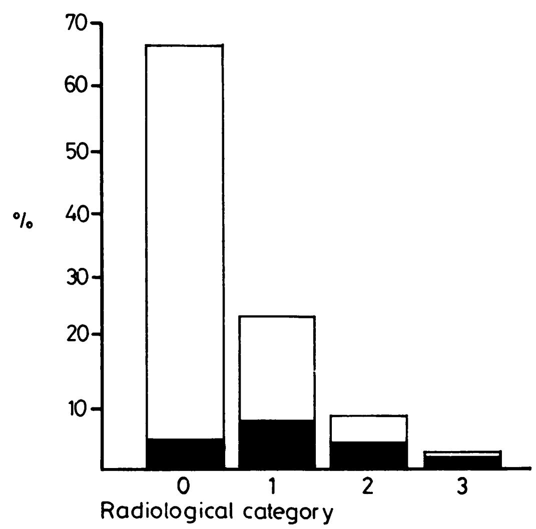

Fig 4 *Distribution of large shadows (in black) by radiological category of simple pneumoconiosis in slate workers.*

Table 5 *Dependence of various symptoms etc, on age, category of pneumoconiosis, and years of slate work*

Symptom		*Slate workers*				*Non-exposed men*	
		% with symptom	*1000 × regression coefficient of probit on:*			*% with symptom*	*1000 × regression coefficient of probit*
			Age	*Pneumoconiosis*	*Years of slate work*		*Age*
Chronic cough	S	38·9	+ 9 ± 6	+358 ± 136*	− 3 ± 6	27·5	+13 ± 6*
with or without	NS	19·4	+21 ± 13	− 86 ± 225	+25 ± 13	5·2	+14 ± 16
phlegm	Ex-S	31·8	+ 6 ± 19	+317 ± 234	+12 ± 13	9·8	−59 ± 31
Chronic phlegm	S	30·3	− 3 ± 6	+355 ± 137*	+ 3 ± 7	20·0	+17 ± 7
with or without	NS	17·3	− 2 ± 13	− 48 ± 241	+28 ± 14*	3·9	−38 ± 33
cough	Ex-S	30·3	+ 1 ± 19	+173 ± 233	+ 9 ± 13	4·9	—
Periods of	S	26·8	+ 1 ± 6	+298 ± 138*	+ 1 ± 7	17·1	+19 ± 7*
increased cough	NS	13·3	+17 ± 14	−144 ± 252	+26 ± 15	2·6	—
and phlegm	Ex-S	27·3	− 4 ± 20	+289 ± 236	+10 ± 13	4·9	—
Chest illness	S	15·3	+ 7 ± 7	+243 ± 149	+ 2 ± 7	13·3	+11 ± 7
with increased	NS	14·3	+10 ± 13	+130 ± 226	+ 7 ± 14	5·2	+24 ± 17
cough and phlegm	Ex-S	22·7	+ 0 ± 19	+ 82 ± 249	− 2 ± 13	9·8	+29 ± 23
Dyspnoea of	S	17·7	+22 ± 7*	+425 ± 146*	+ 2 ± 7	12·5	+42 ± 8*
grade 2 or	NS	17·3	+11 ± 13	+472 ± 222*	+ 7 ± 13	3·9	+ 7 ± 18
more	Ex-S	37·9	+22 ± 19	+269 ± 234	+ 2 ± 12	9·8	+17 ± 21

S = Smokers, NS = Non-smokers, Ex-S = Ex-smokers.
*Significantly different from zero.

Figure 4 shows the proportions of slate workers with large shadows, by category of simple pneumoconiosis. Using the prevalence of these shadows by age in the non-exposed men to estimate those shadows that are likely to be due to tuberculosis suggests that the proportions of slate workers with complicated pneumoconiosis are 0%, 18%, 33%, and 52% in categories 0, 1, 2, and 3 respectively.

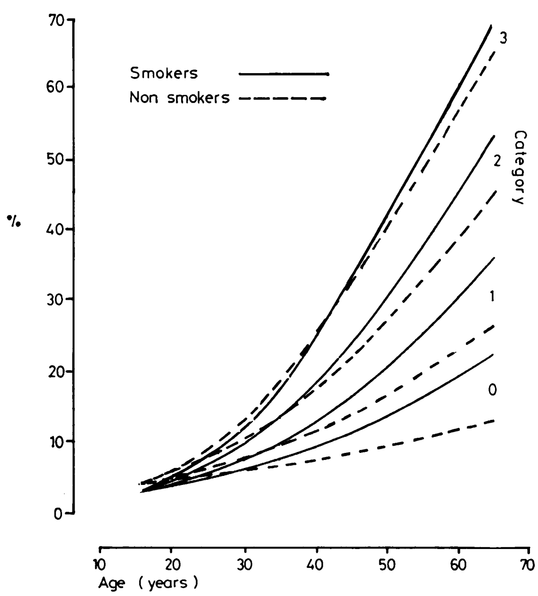

Fig 5 *Curves showing estimated prevalence of dyspnoea of grade 2 or more in slate workers, by age, smoking habits, and category of simple pneumoconiosis reached at age 65 after uniform progression from category 0 at age 15.*

SYMPTOMS AND RESPIRATORY HISTORY

To determine the relation between the presence or absence of symptoms and measures of exposure or of evidence of exposure (such as radiological pneumoconiosis) probit analysis was used. In this, the proportion with a symptom is expressed as the equivalent area of a normal curve, and multiple regression is used to relate this to the measure of exposure, using a succession of cycles of fitting that converge on the maximum likelihood solution.

Table 5 shows the regression coefficients determined for five groups of symptoms in slate workers and in the non-exposed men, according to smoking habit. In the slate workers there are two distinct patterns of these coefficients. For cough and phlegm and for periods of increased cough and phlegm smokers show an increased prevalence with increasing amount of pneumoconiosis. Ex-smokers are similar, though in this case the coefficients are not significantly different from zero. In neither group is there any suggestion of a relation either to age or to years of exposure to slate dust in men with the same amount of pneumoconiosis.

The second pattern applies to dyspnoea and to a history of chest illness with increased cough and phlegm. For these there is an increased prevalence with both age and the amount of pneumoconiosis in smokers and non-smokers, but again no sign of any independent effect of years of exposure. Figure 5 illustrates these findings for the prevalence of dyspnoea of grades 2 or more, assuming a steady increase of amount of pneumoconiosis from the middle of category 0 at age 15 to the middle of categories 1, 2, or 3 at age 65.

Non-smokers, however, show no sign of a dependence of cough and phlegm on amount of pneumoconiosis, but an increase in prevalence, of borderline significance, with years of exposure. In a further exploration of this relationship it was noted that these symptoms were very frequent in men whose radiographs were read as showing healed tuberculosis or complicated pneumoconiosis. If these men were excluded the dependence of these symptoms on years of exposure disappeared. For example, for cough the coefficients were as follows:

	Age	*x-ray*	*Years of exposure*	*% with cough*
All non-smokers	+0·021	−0·086	+0·025	19·4
Non-smokers without large shadows	+0·016	+0·021	−0·110	15·9

50% of the men with large shadows reported a chronic cough. The apparent link with years of exposure in non-smokers is a consequence of the high prevalence of tuberculosis in North Wales 30 or more years ago, an association between being in slate work at this time and having a history of long employment, a tendency for healed tuberculosis to be associated with chronic cough and sputum subsequently, and for men with cough and phlegm to abstain from smoking. Some of the noticeable differences between the groups are listed in table 6.

Among the non-exposed men symptoms were uncommon in the non-smokers and the number of 10-year ex-smokers was small. Table 5 gives the proportions with each symptom or history and, at least for the smokers, the regression coefficient on age.

Table 6 *Average characteristics of different smoking classes*

	Mean age in years	*Mean years of slate work*	*% with healed tuberculosis*
Smokers	45·5	16·2	14·0
Non-smokers	47·1	20·3	15·0
10 years or more ex-smokers	60·2	27·3	20·6
Other ex-smokers	49·4	18·7	22·0

FORCED EXPIRATORY VOLUME AND VITAL CAPACITY

Tables 7 and 8 show the regression coefficients for these indices on age, amount of pneumoconiosis, and years of exposure. The effect of height on both indices has been eliminated by standardising each man's results to a stature of 1·7 m by the method of Cole.[10] For neither index was there an additional effect with years of exposure when amount of pneumoconiosis was allowed for. Smokers appeared to be less affected by amount of pneumoconiosis than non-smokers; but this could be an effect of self-selection, those smokers who lose FEV and FVC through pneumoconiosis tending to join the ex-smokers, so that only those less affected remained among the smokers.

Figure 6 gives a general picture of the relative effects on FEV of age, amount of pneumoconiosis, and smoking habits, again assuming a steady progression of pneumoconiosis with age.

In coal workers material loss of FEV and FVC is mainly associated with complicated pneumoconiosis. In the slate workers this was not so: when the men with large shadows were removed the regression coefficients on amount of pneumoconiosis were not greatly reduced:

Non-smokers − 0·234 compared with − 0·264
Smokers − 0·109 compared with − 0·154

Table 7 *Dependence of FEV_1 on age, category of pneumoconiosis, and years of slate work. For slate workers partial regression coefficients are shown*

	Mean FEV_1	*Regression coefficients of FEV_1 on*		
		Age (yr)	*Pneumoconiosis category*	*Slate work (yr)*
Slate workers				
Smokers	3·06	−0·040 ± 0·003*	−0·154 ± 0·062*	−0·001 ± 0·003
Non-smokers	3·23	−0·038 ± 0·004*	−0·264 ± 0·083*	−0·001 ± 0·005
Ex-smokers	2·62	−0·049 ± 0·010*	−0·138 ± 0·139	+0·006 ± 0·007
Non-exposed men				
Smokers	3·04	−0·046 ± 0·003*		
Non-smokers	3·53	−0·020 ± 0·003*		
Ex-smokers	3·15	−0·038 ± 0·008*		

*Significantly different from zero.

Table 8 *Dependence of FEV on age, category of pneumoconiosis, and years of slate work. For slate workers partial regression coefficients are shown*

	Mean FVC	*Regression coefficients of FVC on:*		
		Age (yr)	*Pneumoconiosis category*	*Slate work (yr)*
Slate workers				
Smokers	4·18	−0·034 ± 0·003*	−0·178 ± 0·064*	−0·003 ± 0·003
Non-smokers	4·20	−0·034 ± 0·004*	−0·422 ± 0·088*	+0·007 ± 0·005
Ex-smokers	3·63	−0·042 ± 0·011*	−0·129 ± 0·151	+0·001 ± 0·008
Non-exposed men				
Smokers	4·18	−0·044 ± 0·003*		
Non-smokers	4·47	−0·031 ± 0·005*		
Ex-smokers	4·05	−0·039 ± 0·009*		

*Significantly different from zero.

although with reduced numbers they ceased to be significant. Some indication of the effect of *x*-ray category can be obtained by looking at the regression lines of FEV on age for each category separately (fig 7) although this groups together films read as just in category 2 and films read as almost in category 3, as well as films read as quite normal, and films almost in category 1. For men without large shadows the main appearance is of a difference between category 0 and categories 1 and 2, which are indistinguishable. When large shadows are present, categories 1 and 2 are separated, but category 0, in which the large shadows are probably purely tuberculous, show a totally distinct pattern.

Indices from the flow-volume curves, which together with more detailed tests, will be reported elsewhere, showed a relationship to age and height, but, unlike the FEV_1 and FVC, were not significantly related to the category of pneumoconiosis.

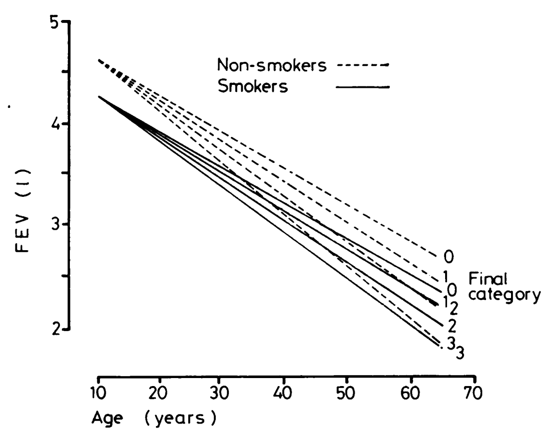

Fig 6 *Estimates of linear regression of FEV_1 (adjusted to height 1·7 m) on age in slate workers by smoking class and category of simple pneumoconiosis reached at age 65 after uniform progression from category 0 at age 15.*

Discussion

This study suffers from the usual limitations of a cross-sectional survey—for example, the men seen represent a survivor population. As there is evidence of a heavy burden of respiratory disease in these, selection through death is likely to have been considerable. A less serious limitation is that although over 94% of the defined population was investigated, those who failed to co-operate probably included some of the men most severely affected by respiratory disease. Because of these limitations we are likely to have underestimated the full effect of exposure to slate dust.

This survey showed a high prevalence of respiratory disease. Tuberculosis must have been very common in the past. Healed lesions are common in men aged over 50, and the association of these lesions with pneumoconiosis suggests that prevalence was particularly high within the industry. Old tubercular lesions appeared to contribute substantially to the present disability of the older men.

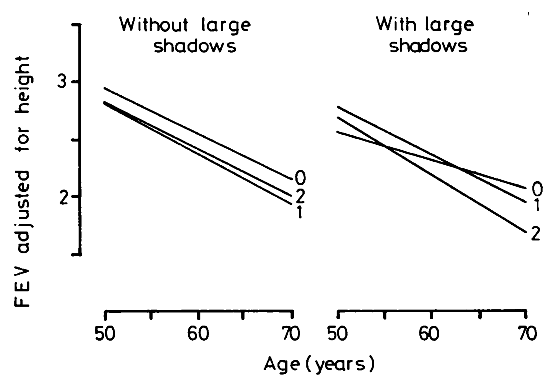

Fig 7 *Regression lines of FEV_1 (adjusted to height 1·7 m) on age in smoking slate workers for different categories of simple pneumoconiosis, with and without large shadows.*

The prevalence of pneumoconiosis was high. One-third of all the slate workers had some evidence of this condition, and 10% had a degree which would attract compensation—that is, category 2 or greater. The prevalence of pneumoconiosis within subgroups of men defined by occupation accorded well with our impressions of dustiness.

Unfortunately, HM Inspectorate of Mines and Quarries was unable to supply reliable measurements of past or present dust levels, and we were not permitted to make these measurements ourselves. Those dust levels we do have, however, suggest that some occupations may be very dusty indeed. Certain of them have contributed disproportionately to the present case load of pneumoconiosis, probably because dust levels in these trades were very high.

The estimation of the prevalence of progressive massive fibrosis (PMF) is difficult because similar shadows were seen in the non-exposed men, and some of them probably were tuberculous lesions. Comparison, however, of the corrected prevalence estimates for the slate workers with estimates of the prevalence of PMF in coal miners in South Wales[11] indicates that, within both categories 2 and 3 of simple pneumoconiosis, PMF has, in slate workers, a rather lower prevalence at all ages.

The prevalence of respiratory symptoms is high. The usual excess in smokers is shown, but overall about one-third of the slate workers reported cough, a similar proportion have phlegm, and about 17% complained of dyspnoea of grade 2 or more. These rates are considerably higher than those which apply to the non-exposed men. Multiple regression analyses show a dependence of symptoms on pneumoconiosis category that is consistent for all symptoms in smokers and ex-smokers and is present for some symptoms in non-smokers. Once pneumoconiosis category has been taken into account, there is little evidence of any further dependence on length of employment in the industry. In other words, the amount of pneumoconiosis is a good measure of the clinical effects of exposure to dust.

One exception to this broad pattern is, however, of special interest. Among the non-smoking slate workers there was evidence of an association between duration of employment in the industry and cough and phlegm. This appeared, however, to be largely due to an excess of these symptoms in men with healed tubercular lesions, which were commoner in men with long service, suggesting that this disease had a high prevalence in slate workers about 30 years ago.

FEV and FVC also show a significant association with pneumoconiosis category, and within both smokers and non-smokers the fall with age is greater with increasing category of simple pneumoconiosis. This fall is consistent with a disabling effect of simple pneumoconiosis in these workers, and this implies that the effect of slate dust on the lung differs from that of coal, because no effect on lung function is demonstrable in coal workers.[12] The pattern we detected was complicated, however, by smoking habit and by a probable self-selection over the years into the lighter and ex-smoking groups. The picture was further complicated by the large radiographic shadows, presumed to be tuberculous, the loss of lung function being greater and the relationship with category of pneumoconiosis being more pronounced in men with both types of lesion than in those without large shadows. Pneumoconiosis and old tubercular lesions appear to account for both the respiratory symptoms and the disability of these slate workers.

One of the origins of this study was the claim that an unrecognised occupational lung disease was causing disability in slate workers but did not attract compensation. Information was obtained from the subjects of this survey about their attendance at a pneumoconiosis medical panel and about receipt of compensation. This showed that the radiographic assessment of the panels accorded closely with the opinion of the three expert readers (fig 1). Part of the small discrepancy between their grading of pneumoconiosis and that implied by the decisions of the panels could have arisen because the panels had assessed most of the men some years earlier, progression of disease having occurred in the interval. On the other hand, the observation that compensation had been awarded to almost one-third of those men in category 1 who had applied suggests that the panels tend to err on the generous side.

Thus there is no evidence of an unrecognised occupational lung disease, but we have found that many men with pneumoconiosis have never applied for compensation. In fact just under half of those who are eligible for compensation according to our findings had never applied to a panel, while almost all who had applied had received compensation. Symptoms in the older men, however, were quite often due to the effects of previous tuberculosis, which does not attract compensation. For example, 11 men out of about 30 with evidence of old tubercular disease who had applied to the panel had been rejected and might feel that they had been unfairly treated. Perhaps it was this experience which gave rise to the belief that a disabling but unrecognised lung disease was occurring in slate workers.

This study suggests that effective dust control is needed. Both monitoring of the working environment and regular radiological surveillance of employed men should be undertaken. Help should be given to this industry because it is in an area of high unemployment, and its current revival should be encouraged.

Finally, this population sample will be reviewed at a later date.

We thank the Gwynedd Area Health Authority and Dr Gareth Crompton, chief medical officer for Wales, but at that time area medical officer for Gwynedd, for the use of health centres and for generously seconding some of their staff; Drs J C Gilson and G Sheers for reading the radiographs; Dr Evan Richards, specialist in community medicine, for local organisation and support; Dr E H Kinsey, former medical officer of health to the Gwyrfai District Council, for extracting the original mortality data; Miss Avril Thomas, area nurse (child health) and the four Welsh-speaking health visitors, Mrs G Evans, Miss C M Owen, Miss M Roberts, and Mrs J C Williams, on whose diligent visiting and interviewing the success of the work depended; and Mr Tom Benjamin, of the MRC Epidemiology Unit, who organised the home visiting and transport of the volunteers. The study was supported by a grant from the Medical Research Council to Dr J R Glover.

Appendix 1

Classification of occupations

A WORKERS IN THE SLATE INDUSTRY

Nearly 100 job titles were recorded. Help from experts in the slate industry was obtained and the following broad classifications were devised. Many men interchanged their skilled work within their team over the years; this was allowed for in the analysis.

Underground workers in slate mines

Miners—
: An almost redundant group who opened up new extraction areas.

Underground rockmen—
: Skilled slate production workers including drillers.

Underground assistants—
: All other men who work underground—for instance, transport, loaders, maintenance men, etc.

Skilled quarry workers

Quarry rockmen—
: Skilled drillers and slate extractors in open quarries.

Slate producers (usually working inside buildings)

Sawyers—
: Saw-bench operators.

Slate makers—
: Splitters and dressers—the major employment group within the industry.

Finishers I and II—
: Grinders and polishers, often using high-speed rotary tools. These workers were divided by the apparent dust level in the shed in which they worked, I being the higher.

Crushing plant operators—
: Workers who produce slate dust from waste material.

General workers

General workers—
: All other workers not separately detailed—for instance, labourers, loaders, transport, maintenance, etc.

Office and managerial staff

Office workers—
: Men exposed to negligible dust levels.

B WORKERS IN NON-DUSTY JOBS

Men who had had jobs with no known dust exposure or exposure to dusts with no known inhalation health risk—for instance, workers in building and construction, or those exposed to roadmaking, wood dust, and dirt dusts.

C WORKERS IN OTHER DUSTY JOBS

Men in the following jobs and industries were considered to have had a mixed dust exposure:
Quarrying and granite work, iron and steel foundries, flour, kaolin, talc, coal mining, asbestos, potteries, tunnelling, gold, lead, copper and manganese mining, farming, cotton, cable jointing, refrigeration engineering, jobs exposed to toluene di-isocyanate, tin, welding and the burning of metals, and jobs using jewellers' rouge.

Appendix 2

X-RAY READING

Each film was read, in a randomised sequence, using the ILO-U/C classification,[6] by three readers (G, S, and H) working independently. A preliminary reading of 100 films was followed by discussion and an agreed reading for each of them. During the main reading sessions 60 of these 100, chosen as "trigger" films, were interpolated one by one at intervals of about 10 films, and after each was read the reader was told its agreed classification. It was hoped by these means to reduce drift in the standard of classification.

Table 9 *Indices of repeatability (inter-observer). Maximum profusion of small opacities*

	Gilson/Sheers	*Gilson/Hodges*	*Sheers/Hodges*
Agreement within one subcategory	85·8%	85·2%	87·6%
Agreement within two subcategories	95·2%	95·6%	96·9%
Agreement within one subcategory standardised to 30% abnormal	64·9%	67·0%	72·8%
Bias $\left(\frac{\text{below diagonal} - \text{above diagonal}}{\text{total}}\right)$	−11·7%	−3·1%	10·9%
Consistency $\left(\frac{\text{No within one subcategory}}{\text{No showing abnormality}}\right)$	68·7%	69·4%	73·2%

Table 10 *Table of repeatability (intra-observer). Maximum profusion of small opacities*

	Observers		
	G	*S*	*H*
Agreement within one subcategory	87·3%	88·2%	84·2%
Agreement within two subcategories	96·1%	98·0%	95·C%
Agreement within one subcategory standardised to 30% abnormal	83·0%	80·4%	80·9%
Bias $\left(\frac{\text{below diagonal} - \text{above diagonal}}{\text{total}}\right)$	—8·8%	2·9%	—2·0%
Consistency $\left(\frac{\text{No within one subcategory}}{\text{No showing abnormality}}\right)$	81·2%	78·6%	78·1%
Correlation of first and second readings counting the subcategories as equally spaced	0·87	0·90	0·84

From the repeated readings of the trigger films various indices of intra-observer agreement can be calculated, while the complete series of readings can give indices of inter-observer agreement (tables 9 and 10). Since agreement will tend to be good when all films are nearly normal, a standardised index is provided in which agreement over films with average category within category 0 and over films with average category above 0 are averaged with weights 70:30.

No recent studies in which observer agreement has been measured in this way have been published, but in a sequence of studies by the HSE/MRC Panel on Survey Radiology the results were very similar to the present ones. Generally, the disagreement between observers were such as to suggest variation in judgment rather than lapses of judgment, so that averaging of readings rather than selection of readings should give results of greater relevance and closer accord with what other readers might have obtained.

References

1 Sutherland CL, Bryson S. *A report on the inquiry into the occurrence of disease of the lungs from dust inhalation in the slate industry in the Gwyrfai district*. London: HMSO, 1930. (Mines Department.)

2 Davies TW. Silicosis in slate quarry miners. *Tubercle* 1939;**20**:543-55.

3 Jarman TF, Glyn Jones J, Phillips JH, Seingry HE. Radiological surveys of working quarrymen and quarrying communities in Caernarvonshire. *Br J Ind Med* 1957;**14**:95-104.

4 Wade TW. *Reports on public health and medical subjects*. London: HMSO, 1927. (Ministry of Health, Welsh Board of Health, No 38.)

5 Jones JG, Owen TE, Corrado JA. Respiratory tuberculosis and pneumoconiosis in slate workers. *Br J Dis Chest* 1967;**61**:138-43.

6 International Labour Office. *ILO-U/C International classification of radiographs of pneumoconiosis*. Geneva: ILO, 1971.

7 Oldham PD. Numerical scoring of radiological pneumoconiosis. In: Walton WH (ed). *Inhaled particles III*. Old Woking, Surrey: Unwin, 1971:621-30.

8 McDermott M, McDermott TJ. Digital incremental techniques applied to spirometry. *Proc R Soc Med* 1977;**70**:169-71.

9 Glasser M. Regression analysis with dependent variables censored. *Biometrics* 1965;**21**:300-7.

10 Cole TJ. Linear and proportional regression models in the prediction of ventilatory function (with discussion). *J R Stat Soc. Series A*. 1975;**138**:297-338.

11 Cochrane AL, Davies I, Chapman PJ, Ray S. The prevalence of coalworkers' pneumoconiosis: its measurement and significance. *Br J Ind Med* 1956;**13**:231-50.

12 Cochrane AL. An epidemiologists' view of the relationship between simple pneumoconiosis and morbidity and mortality. *Proc R Soc Med* 1976;**69**:12-4.