

Mortality Experience of Vermont Granite Workers

Letitia K. Davis, MS, ScD, David H. Wegman, MD, Richard R. Monson, MD, ScD, and John Froines, PhD

The proportional mortality experience (1952-1978) of 969 deceased white male granite workers was compared with that of United States white males. Industrial hygiene information was combined with work histories to develop an estimate of lifetime granite dust exposure for each individual. Subjects were grouped into four cumulative exposure categories, and exposure-response relationships were examined. Trends of increasing silicosis and tuberculosis with increasing lifetime exposure were observed. These are consistent with earlier findings. With the exception of excess suicide among granite workers dying before 1970, there was little evidence of association between other causes of death and employment in the granite industry.

Key words: granite dust, silica, proportional mortality, silicosis

INTRODUCTION

Vermont's granite industry consists of several quarries and a number of small manufacturing plants called "sheds" where the stone is cut, polished, and finished into monuments. The granite contains approximately 30% free silica, and the dust generated in processing the stone has been recognized as a cause of silicosis among exposed workers since the 1920s. The high prevalence of respiratory disease among workers at that time led to a series of early epidemiologic investigations [Hoffman, 1922; Russell et al, 1929; Russell, 1941]. On the basis of these early studies, it was recommended that dust exposures be reduced to 10 million particles per cubic foot (mppcf).

Dust controls were installed in the granite sheds between 1937 and 1940 and were in place in the quarries by 1950. Subsequent environmental surveys indicate that dust exposures generally have been maintained below 10 mppcf since that time

Occupational Health Program, Harvard School of Public Health, Boston.

John Froines is now at the School of Public Health, University of California at Los Angeles.

Address reprint requests to Dr. Wegman, Occupational Health Program, Harvard School of Public Health, 665 Huntington Avenue, Boston, MA 02115.

Accepted for publication March 8, 1983.

[Bloomfield et al, 1934; Urban, 1939; Hosey et al, 1957; Ashe et al, 1964; Theriault et al, 1974a]. No cases of silicosis or silicotuberculosis have been reported among men who began employment after controls were instituted. The question remains as to whether or not low levels of dust are damaging to workers' health in other ways.

The respiratory function of granite workers has been the subject of several recent investigations [Theriault et al, 1974b,c; Musk et al, 1977; Graham et al, 1981; Eisen, 1982]. The overall mortality of granite workers, however, has not been reported since 1929 [Russell et al, 1929]. The purpose of the present study is to investigate the recent mortality experience of Vermont granite workers; in particular, it is to evaluate causes of death, other than silicosis and silicotuberculosis, that may be associated with employment in the granite industry. The long-term efficacy of controls in eliminating fatal silicosis is also examined.

MATERIALS AND METHODS

In 1937, a medical surveillance program was established whereby periodic chest X-ray examinations were made available to all workers in the industry through the Division of Industrial Hygiene (DIH) of the Vermont Department of Health. From 1937 to 1951, DIH held X-ray clinics at their office in Barre. Participation in the program was voluntary, and it is estimated that fewer than half of the workers took part. In 1951, a mobile van was purchased, and X-ray equipment taken around to the worksites. A systematic effort was made to X-ray all workers in the granite industry. While participation remained voluntary, 85% of those employed on clinic day were X-rayed in 1952. By 1963, 98% of employees had been X-rayed by DIH at least once [Ashe et al, 1964].

DIH maintains a record for each person who was X-rayed. The record includes a comprehensive work history together with the dates and results of the individual's X-rays.

Population

DIH records were used to identify 1,387 white men who had been employed for at least 1 year in the industry and who had died prior to July, 1978. The use of a volunteer population as the study group raised the potential of biased selection. To address this problem, the study population was limited to 1,023 deceased who had work experience in the industry during the period when DIH made a systematic effort to X-ray all the workers (January 1, 1952–July 1, 1978). It is estimated that these 1,023 deaths constitute over 90% of all deaths among men employed during this period. The potential for bias introduced by self-initiated participation in the X-ray program is therefore small.

Work Histories

Work histories were obtained for each subject from DIH records. Information on jobs held in the industry and dates during which the man remained at those jobs was abstracted. The work histories were complete except for dates of retirement. These were obtained from records maintained by the unions, the local tuberculosis clinic, and the granite workers' pension fund.¹ When a subject's retirement date could

¹Quarry workers and shed workers involved in moving stone are members of the United Steelworkers of America. Shed workers employed in cutting and shaping stone are represented by the Granite Cutters International Association.

not be found in any of these records, it was assumed that he left the industry on the date last contacted by DIH.

Over 90 different job titles were cited in the work histories. Granite manufacturers and workers were interviewed to obtain a better understanding of changes in the work process and in job titles over time. This information together with job descriptions contained in the literature were used to condense the job titles into 20 major job classifications. Jobs that could not be assigned to any of these 20 classifications were assigned to one of two broad classifications entitled "other quarry" and "other shed."

Exposure

Summary results of six different environmental surveys were available for use in this study [Russell et al, 1929; Bloomfield et al, 1934; Urban, 1939; Hosey et al, 1957; Theriault et al, 1974a; Eisen, 1982]. These surveys provide estimates of granite dust exposures for a period of over 50 years (1924–1977), which corresponds approximately to the years the subjects worked in the industry.

Data from these surveys were used to define an average predust control and postdust control exposure for each of the 22 job classifications (Table I). Average dust levels were combined with individual work histories to develop an estimate of lifetime granite dust exposure for each subject. The calendar time of a subject's work experience was considered to determine whether predust control or postdust control

TABLE I. Granite Dust Concentration by Job Classification and Dust Control Period

Job classification	Average exposure (MPPCF)	
	Pre-dust control	Post-dust control
SHED JOBS		
Cutter	48.8	8.8
Surfacer	35.4	9.2
Toolgrinder	22.2	6.9
Boxer	18.1	3.9
Craneman	18.1	3.6
Grouter	18.1	4.6
Maintenance	18.1	4.7
Foreman	18.1	5.1
Laborer	18.1	5.6
Lumper	18.1	5.3
Polisher	15.6	9.3
Other shed	10.0	3.2
Sandblaster	7.5	5.2
Sawyer	6.4	5.8
Contour planer	—*	6.3
Blacksmith	2.5	—*
Office worker	1.9	.8
QUARRY JOBS		
Channel bar operator	142.8	1.1
Jackhammer operator	121.0	1.4
Plugdrill operator	87.0	2.7
Other quarry	7.7	1.7
Office worker	1.9	.8

*Job non-existent during period.

levels applied. Work experience prior to 1940 in the sheds and 1950 in the quarries was defined as precontrol work.

Lifetime exposure estimates were calculated as follows:

$$\text{Lifetime exposure} = (T_i \times E_i)$$

where T_i = years in job i and E_i = estimates of granite dust exposure in job i during that time, as read from Table I. Thus, if a subject worked from 1935 to 1945 as a lumper, from 1945 to 1955 as a polisher, and from 1955 to 1960 as a grouter, his lifetime dust exposure would be $(5 \times 18.1) + (5 \times 5.3) + (10 \times 9.3) + (5 \times 4.6) = 233$ mppcf years.

Lifetime exposures were classified into the following exposure categories: very high, lifetime exposures greater than or equal to 800 mppcf years; high, lifetime exposures between 399 and 800 mppcf years; medium, lifetime exposures between 199 and 400 mppcf years; and low, lifetime exposures less than 200 mppcf years.

The above categories were based on the following rationale. Assuming a working lifetime of 40 years, a lifetime exposure of 800 mppcf years corresponds to an average annual work exposure of 20 mppcf. Likewise, the lower limits of the "high" and "medium" exposure categories correspond to average annual work exposures of 10 and 5 mppcf, respectively. Each of these figures, 20, 10, and 5 mppcf, represents a "threshold limit value" for granite dust that has been proposed in the literature [Russell, 1941 ; US Department of Health, Education, and Welfare, 1974].

Conversion of Mass Measures into Particle Counts

In the early environmental surveys, impinger samples were collected, and the results were expressed in million particles per cubic foot. In the last two studies, mass respirable samples measuring milligrams per cubic meter were taken. To utilize all the available environmental information, it was necessary to convert respirable mass measures into particle counts, or vice versa. Since most of the data were expressed in mppcf, mass measures were converted into particle counts.

The recommended method for converting mass measures of granite dust into particle counts equates 10 mppcf granite dust to 0.1 mg/m^3 respirable quartz [American Conference of Governmental Hygienists, 1971]. This equation is based on the results of a 1965–1966 unpublished study in which simultaneous impinger and gravimetric samplings were carried out in the Vermont granite sheds [Sutton et al, 1968]. In 1972 simultaneous mass respirable and impinger samples were again collected in the sheds by this research program. These data were analyzed together with those from the earlier survey using a similar technique. The following conversion equation was derived (as explained in the Appendix) and used to convert mass respirable measures into particle counts:

$$10 \text{ mppcf} = .075 \text{ mg/m}^3 \text{ respirable free silica.}$$

While there was an extensive amount of historical exposure information, there were also data limitations. Job titles contained in the work histories did not exactly correspond with those in the environmental surveys. The conversion equation is

necessarily imprecise. Pre- and postdust control exposure levels were not constant over time, although variation within control period is small in comparison to that between periods. There is also evidence that dust levels for any single job classification varied between sheds [Eisen, 1982]. While the average levels reported in Table I cannot be considered as precise estimates, they are believed to reflect basic patterns of job-specific granite dust exposures during the period that the subjects worked in the industry.

Other Exposures

In addition to granite dust, men working in the quarries and sheds are exposed to a number of other known or potential health hazards including noise, vibration, and a variety of abrasives. Job classifications were also used to allow for investigation of job-specific hazards independent of granite dust.

Cause of Death

Death certificates were requested from State and Provincial (Quebec) health departments. Certificates were obtained for 95% of the subjects, and the underlying cause of death was abstracted as coded by the states' nosologists according to the revision of the "International Classification of Disease" in use at time of death [World Health Organization, 1968]. Seventh Revision codes were transformed into Eighth Revision codes for the analysis.

The personal and employment characteristics of subjects with and without death certificates were compared. The two groups were similar with respect to average age and year of entry into the industry, length of time in the industry, age, and year of death. Those without certificates retired slightly earlier. No adjustment was made in the analysis to account for subjects whose death certificates could not be located.

Proportional Mortality Analysis

Observed numbers of cause-specific deaths among granite workers were compared with numbers expected based on the proportional mortality experience of United States white males [Monson, 1974]. United States white male mortality rates were similar to Vermont white male mortality rates during the study period [Grove et al, 1968; U.S. Department of Health, Education, and Welfare, 1960-1978]. Expected numbers were derived by categorizing the observed number of cause specific deaths into 5-year, age-time-specific groups, and multiplying these numbers by the age-, time-, and cause-specific proportional mortality of United States white males. Observed to expected ratios (OER) were calculated for all causes of death in the total and various subgroupings of the subject population. Due to the unusual number of deaths due to silicosis and tuberculosis, OERs in which all tuberculosis and silicosis deaths are removed from the study population were also computed (OER II). Statistical significance was calculated using a modification of the Mantel Haenszel summary chi-square test, and 95% confidence intervals were derived.

OERs calculated in the above manner are not mutually comparable if disease rates vary by age and if the age distributions of the groups being compared are different. To allow for the direct comparison of mortality in the four exposure groups, age-adjusted proportions of cause-specific mortality were derived by direct standardization, using the following age groups: less than 50 years, 50-59 years, and greater than 59 years. The entire subject population was selected as the standard. The age-

adjusted proportions of cause-specific mortality in each higher exposure category were compared with those in the lowest exposure group and expressed as standardized relative risks.

RESULTS

Overall Mortality

There are 969 granite workers included in the analysis. The average man in the study began work in 1934, worked 31 years, and died at the age of 62; 73% of the men worked in the sheds only, whereas 24% were either quarry workers or had experience in both quarries and sheds. An additional 26 men worked in the sawplants or gritmill, minor sectors of the industry.

Causes of death among the 969 deceased are presented in Table II. Two sets of expected numbers, both based on the proportional mortality experience of United States white males, are shown. The expected numbers in column I were derived with all causes of death included in the study population. Those in column II were derived after excluding the 93 tuberculosis and silicosis deaths among granite workers. The relationship between the observed numbers and the expected numbers in column II is expressed as an observed-to-expected ratio.

The observed number of tuberculosis deaths is 10 times that predicted by the United States white male experience (65 observed, 6.5 expected). There is also a notable excess of deaths due to all respiratory disease (89 observed, 57.3 expected). Of these, 28 deaths are due to silicosis. With the removal of silicosis and tuberculosis deaths from the study population, a small excess of respiratory disease remains (OER 1.2). This is accounted for almost entirely by excess deaths due to emphysema (22 observed, 15.2 expected).

The OER is slightly greater than 1.0 for all cancer, as well as several site-specific cancers; cancer of the digestive system, the respiratory system, and the prostate. Other causes of death for which the OER exceeds 1.0 include diseases of the genitourinary system and suicide. The OER for diseases of the skin is high (4.9) but is based on only three observed deaths.

Of the 65 observed tuberculosis deaths, 48 were due to silicotuberculosis, 16 were due to pulmonary tuberculosis, and 1 was due to the late effects of tuberculosis. The X-ray records of these men were examined. Of the 17 tuberculosis deaths not specified as silica-related, 15 had evidence of preexisting silicosis in their X-ray records.² Tuberculosis is therefore interpreted in this study as evidence of silicotuberculosis.

The X-ray records of the deceased in the respiratory disease category were also examined. Of the 25 men who did not die of silicosis, 10 had evidence of silicosis in their X-ray records suggesting the possibility that some of the other respiratory disease deaths were misdiagnosed cases of silicosis.

Mortality by Time of Entry

The subjects were divided into two groups on the basis of entry into the industry before or after the institution of dust controls. These were defined as the pre- and

²Five different readers had been hired by DIH to read the X-rays, and they did not use a consistent system for classifying their findings. Diagnosis on last X-ray, as recorded by the reader of that X-ray, was taken as evidence of silicosis status.

TABLE II. Observed and Expected^a Deaths Among Granite Workers, 1952-1978

ICD NO. ^b	Cause of death	Observed	Expected I ^c	Expected II ^d	OER II ^c	95% Confidence
						intervals of the
	All deaths	969	969	876	—	—
010-019	Tuberculosis	65	6.5	—	—	—
140-209	All cancers	189	188.1	170.1	1.1	1.0-1.3
150-159	Digestive organs	57	55.4	49.6	1.2	0.9-1.5
160-163	Respiratory	70	61.6	56.0	1.3	1.0-1.6
161	larynx	5	3.0	2.3	1.9	0.8-4.4
162	lung	62	57.9	52.6	1.2	0.9-1.5
185	Prostate	15	12.7	11.4	1.3	0.8-2.2
200-209	Lymphatic	11	18.5	16.9	0.7	0.1-1.7
390-458	Diseases of circulatory system	444	521.6	468.4	1.0	0.9-1.0
430-438	Vascular lesions of CNS	61	70.8	63.3	1.0	0.8-1.2
460-519	All respiratory diseases	89	57.3	51.9	1.2 ^f	0.9-1.5
480	All pneumonia	15	20.4	18.4	0.8	0.5-1.3
492	Emphysema	22	16.9	15.2	1.5	1.0-2.2
515	Silicosis	28	—	—	—	—
520-577	Diseases of digestive system	30	45.6	41.4	0.7	0.5-1.0
580-629	Diseases of genito-urinary system	15	13.3	12.0	1.3	0.8-2.1
680-709	Diseases of skin and cellular tissue	3	.7	.6	4.9	—
710-739	Diseases of bones and organs of movement	1	1.6	1.5	.7	—
800-829	Accidents	60	59	55.3	1.0	0.9-1.4
950-959	Suicide	34	19.0	18.3	1.9	1.3-2.7
	Other causes	39	53.8	50.6	.7	—

^aExpected numbers based on calendar time, age specific proportional mortality experience of U.S. white males.

^bInternational Classification of Disease, Eighth Revision.

^cExpected number of deaths derived with all causes of death included in the study population.

^dExpected number of deaths derived after silicosis and tuberculosis deaths have been excluded from the study population.

^eOERII = Observed deaths/Expected II deaths.

^f61 respiratory disease deaths observed in this category after the exclusion of silicosis deaths.

postcontrol groups, respectively. All observed tuberculosis deaths occurred among men who started work before dust controls. Of the 28 observed silicosis deaths, one man started work in the postcontrol period. His work history offers no explanation for the development of silicosis.³ His X-ray record, updated 2 months prior to his death, presents no evidence of silicosis, but indicates that he had considerable emphysema, suggesting a likely death certificate misdiagnosis.

Table III includes observed and expected deaths and OERs for other select causes of death in the pre- and postcontrol groups. Expected numbers in this and subsequent tables were derived after excluding silicosis and tuberculosis deaths from the study population.

³He worked as a farmer from 1938 to 1940, was in the army from 1941 to 1945, and started work as a lumper in the granite sheds in 1945. He continued in this job until he died in 1969 at the age of 49.

TABLE III. Observed and Expected Deaths According to Entry Into the Industry Before or After the Installation of Dust Controls^a

ICD No.	Cause of death	Pre-dust controls			Post-dust controls		
		Observed	EXP ^b	OER II	Observed	Expected	OER II
	All causes	650	650.0	1.0	226	226	1.0
140-209	All cancers	143	128.6	1.1	46	41.5	1.1
150-159	Digestive	45	38.9	1.2	12	10.1	1.1
160-163	Respiratory	50	42.1	1.2	20	13.8	1.5
162	Lung	44	39.6	1.1	18	13.0	1.4
185	Prostate	11	9.7	1.1	4	1.7	2.4
390-458	Diseases of circulatory system	354	366.9	1.0	90	101.5	.9
460-519	All respiratory diseases	49	40.7	1.2	12	11.1	1.1
492	Emphysema	19	12.2	1.6	3	2.9	1.0
520-577	Diseases of digestive system	21	29.0	.7	9	12.4	.7
580-629	Diseases of genito-urinary system	13	9.0	1.4	2	2.9	.7
950-959	Suicide	18	9.9	1.8	16	8.4	1.9

^aTuberculosis and silicosis deaths are not reported in the table. All 65 of the observed tuberculosis and 27 of the 28 observed silicosis deaths occurred among men who started work before dust controls were instituted.

^bExpected number of deaths derived after silicosis and tuberculosis deaths have been excluded from the study population.

The OERs are similar in the two groups with few exceptions. The OER for prostate cancer is elevated (OER = 2.4) in the postcontrol group, but it is based on only four observed deaths. There is a moderate excess of emphysema in the precontrol group consistent with the suggestion that some emphysema deaths are misdiagnosed silicosis deaths. There is an excess of suicide in both groups.

The postcontrol group worked an average of 14 years, and only nine had more than 25 years of experience in the industry. It should be noted, therefore, that this group provides limited opportunity to explore the potential effects of full working lifetime exposures to postcontrol dust levels.

Mortality by Exposure Level

The average age and employment characteristics of the four exposure groups are shown in Table IV. Lifetime exposures could not be computed for the 26 men with sawplant and gritmill experience, since no environmental measures were available for these sectors. These men are excluded from this table and the following analysis by exposure group.

In interpreting Table IV, it is important to recognize that there are correlations between exposure groups and characteristics, and between characteristics themselves. For example, men in the high exposure group, on the average, worked longer than men in the lower exposure groups. Men who started work after 1940 and died, did so at a younger age than men who started work earlier. While there are trends in characteristics with exposure group, only the low exposure group is notably different from the others. Men in this group, on the average, started work later, worked fewer years, and died at an earlier age than men in the other groups.

Adjusted proportions and relative risks of tuberculosis and silicosis according to exposure category are shown in Table V. Observed deaths in the "low" and "medium" categories were combined to provide observed numbers large enough for the calculation of directly adjusted proportions.

There is a marked increase in adjusted proportions and relative risks for both causes with increasing exposure. These trends suggest an exposure-response relationship consistent with earlier findings. They also suggest that the lifetime exposure estimates computed in this study are reasonable approximations of true exposures.

Adjusted proportions and relative risks of other select causes of death according to exposure group are shown in Table VI. Adjusted proportions were derived after the exclusion of tuberculosis and silicosis deaths. There is no evidence of a positive exposure-response relationship for any other cause of death. The proportion of prostate cancer was highest in the low exposed group. The highest proportions of emphysema and lung cancer deaths are found in the medium exposed group. The proportions of suicide deaths are higher among men with both very high and low exposures.

TABLE IV. Average Personal and Employment Characteristics by Exposure Category^a

Exposure category	Number of men	% Men with pre-dust control experience	Average age started	Average year started	Average years worked	Average years between entry and death	Average age at death
Very high	199	100	21	1918	40	46	67
High	199	100	23	1922	38	44	66
Medium	190	89	23	1926	35	42	64
Low	355	39	31	1942	19	25	56

^a26 men with sawplant or gritmill exposures excluded.

TABLE V. Crude and Adjusted^a Percentage of Tuberculosis and Silicosis Deaths According to Exposure Category^b

Exposure Category	OBS #	Crude %	ADJ %	Relative risk
TUBERCULOSIS				
Very High	35	17.6	15.6	7.4
High	19	9.5	7.2	3.4
Medium/Low	9	2.0	2.1	1.0
SILICOSIS				
Very High	17	8.5	10.2	12.8
High	8	4.0	3.5	4.4
Medium/Low	3	.6	.8	1.0

^aAdjusted to the age distribution of the entire study population.

^bMedium and low exposure subjects combined to form one exposure group.

TABLE VI. Adjusted^a Percent^b of Deaths According to Exposure Category

Exposure category	OBS number	ADJ %	Relative risk
ALL CANCERS			
Very high	33	18.8	0.8
High	41	21.1	0.9
Medium	41	21.9	1.0
Low	72	22.6	1.0
DIGESTIVE CANCER			
Very high	10	5.5	0.9
High	15	7.7	1.3
Medium	11	5.6	0.9
Low	20	6.0	1.0
RESPIRATORY DISEASE			
Very high	13	6.5	0.9
High	14	8.5	1.2
Medium	15	6.9	1.0
Low	18	6.9	1.0
LUNG CANCER			
Very high	10	5.8	0.8
High	13	6.5	0.9
Medium	16	8.6	1.2
Low	23	7.2	1.0
PROSTATE CANCER			
Very high	2	1.0	0.4
High	2	1.2	0.4
Medium	4	2.1	0.8
Low	7	2.8	1.0
EMPHYSEMA			
Very high	3	1.6	0.8
High	4	2.1	1.1
Medium	9	4.7	2.5
Low	5	1.9	1.0
DISEASES OF THE GENITO-URINARY SYSTEM			
Very High	2	1.2	0.9
High	3	1.6	1.2
Medium	5	2.6	2.0
Low	4	1.3	1.0
SUICIDE			
Very High	6	3.9	1.0
High	3	2.2	0.6
Medium	3	2.7	0.7
Low	22	3.8	1.0

^aAdjusted to the age distribution of the entire study population.

^bPercentages calculated after silicosis and tuberculosis deaths excluded from the study population.

In Table VII, OERs and observed deaths are presented for select causes according to five personal and employment characteristics. With the exception of suicide deaths, OERs within each characteristic do not differ greatly. Similar findings were noted for other causes of death not shown in the table.

The excess of suicide deaths is greatest among young men who worked fewer than 15 years, or who died before 1960. Suicides are also elevated among men with both long and short latency periods, whereas they are not elevated among men with 20–29 years between entry and death. No suicides were found among men 70 years of age or older, and the excess seen in earlier years is not found after 1970.

Mortality by Job Classification

Mortality by job classification was next examined to explore the effect of job-related exposures other than granite dust. The subjects were grouped by jobs ever worked and jobs usually worked. Several of the original 22 job classifications were condensed to provide sufficient numbers for the analysis. The results summarized here pertain only to those causes for which 5 or more deaths were observed within job category.

While in general, OERs did not differ greatly from 1.0, several were notably elevated (equal to or greater than 2.0). When subjects were grouped according to jobs usually worked, excess suicide was observed among cutters (8 observed, 3.7 expected), polishers (6 observed, 1.7 expected), and a miscellaneous shed group (5 observed, 1.8 expected). Lung cancer was elevated among sawyers (5 observed, 2.4 expected) and emphysema in the shed group (5 observed, 1.8 expected). When subjects were categorized by jobs ever worked, digestive cancer among sandblasters (11 observed, 5.3 expected) and prostate cancer (5 observed, 1.6 expected) and

TABLE VII. Observed to Expected Ratios (OER II) and (Observed Deaths) for Select Causes According to Personal and Employment Characteristics

Characteristics	Category (years)	All cancers	Lung cancer	Suicide
Year started working	< 1930	1.1 (101)	1.2 (33)	1.8 (10)
	1930–1949	1.1 (68)	1.2 (24)	2.0 (15)
	≥ 1950	1.2 (20)	1.0 (5)	1.7 (9)
Age started working (yrs)	< 20	1.2 (57)	1.2 (17)	1.4 (7)
	30–39	1.1 (111)	1.2 (39)	2.2 (27)
	≥ 40	1.2 (21)	1.1 (6)	- (0)
Years worked	< 15	1.1 (28)	.9 (7)	2.3 (16)
	15–34	1.2 (78)	1.5 (32)	1.8 (13)
	≥ 35	1.1 (83)	1.1 (23)	1.2 (5)
Time between entry and death (yrs)	< 20	1.0 (23)	.8 (5)	2.7 (19)
	20–29	1.1 (31)	1.4 (14)	.8 (3)
	≥ 30	1.1 (135)	1.2 (43)	1.7 (12)
Age at death	< 60	1.1 (67)	1.2 (24)	2.2 (30)
	60–69	1.2 (73)	1.4 (29)	2.2 (4)
	≥ 70	1.1 (49)	.8 (9)	- (0)
Year of death	< 1960	1.3 (30)	1.2 (7)	3.9 (16)
	1960–1969	1.1 (80)	1.3 (29)	1.7 (15)
	≥ 1970	1.1 (79)	1.0 (26)	.5 (3)

genitourinary disease (5 observed, 1.8 expected) among other quarry workers became apparent. The large number of OERs calculated and the small numbers on which the elevated OERs are based make it difficult to draw conclusions about job-related health risks.

The excess of lung cancer among those usually employed as sawyers and polishers (8 observed, 4.9 expected) did raise questions about the possible effects of abrasive exposures, since all polishers use abrasives as do some of the sawyers depending upon the type of saw operated. The work histories of sawyers were reexamined to identify those likely using abrasives. These men were combined with polishers to form groups of men usually and ever exposed to abrasives.⁴ The OERs for the usual abrasives group (8 observed, 5.0 expected) and the ever abrasives group (18 observed, 13.0 expected) were less than that for either the sawyers or polishers considered separately.

Excesses of laryngeal cancer and skin diseases seen in Table II have not been further documented because of the small numbers of observed deaths. The job and lifetime exposure experiences of men dying of these causes were examined. No common exposure or job experience was found among those dying of either cause. Of the three skin disease deaths, two were due to cellulitis and one was due to boils and carbuncles.

DISCUSSION

In this study we used proportional mortality methods to examine causes of death among granite workers in relation to lifetime dust exposure and job classification. We observed trends in silicosis and tuberculosis consistent with reports of earlier investigators. With the exception of excess suicide deaths among those dying before 1970, the data provided little consistent evidence of association between other causes of death and exposures in the granite industry.

Silicosis and Silicotuberculosis Mortality

The association between silicosis and silicotuberculosis and exposure to Vermont granite dust is well documented [Russell et al, 1929; Russell, 1941; Hosey et al, 1957; Ashe et al, 1964]. The trend of increasing silicosis and tuberculosis with increasing lifetime exposure observed in the present study is consistent with these earlier findings. Investigators in 1955 and 1964 reviewed DIH X-ray records and reported the absence of silicosis among shed workers who started work after the installation of dust controls [Hosey et al, 1957; Ashe et al, 1964]. However, chronic silicosis is a slowly developing disease; the lower the silica exposure, the longer it should take the disease to become manifest. In neither study had sufficient time elapsed to allow for the evaluation of the dust control program in eliminating silicosis among men with full working lives in the industry after controls were introduced. In the 1964 study, for example, the average postcontrol subject worked 14 years.

The present investigation allows for 14 additional years of observation. While mortality data are not optimal for evaluating the impact of dust controls on silicosis

⁴Sandblasters also use abrasives, but in an enclosed process. Excess lung cancer was not observed among sandblasters, and these men were not included in the abrasives groups.

incidence, it does provide some insight into the efficacy of the control program. No tuberculosis deaths were observed among men who started work in the postcontrol period. The single silicotic death reported is believed to be misclassified emphysema, given the individual's X-ray reading 2 months prior to death.

These findings strongly suggest that the dust control program has been effective in eliminating fatal silicosis; yet in this study as in the earlier investigations, an insufficient number of postcontrol subjects worked long enough to allow for a complete evaluation of long-term exposures to low dust levels. Postcontrol results cannot be generalized to men with full working lifetime exposures to less than 10 mppcf. The long-term efficacy of the dust control program in eliminating silicosis remains to be documented.

Other Causes of Death

Hoffman [1922] reported a deficit of cancer deaths among all New England granite cutters. Russell et al [1929] reported a proportional excess of all cancer deaths among Vermont granite shed workers exposed to 20 mppcf or less of dust (14.8 observed, 7.4 expected). No other references to the association between cancer and granite dust have been found in the literature to date. There are conflicting reports on the association between silica exposure and pulmonary carcinoma [Maillard, 1980; Westerholm, 1980; Finkelstein et al, 1982].

In the present investigation, small excesses of digestive, respiratory, and prostate cancer were seen in the total population and several subgroups. There was, however, no evidence of an exposure-response relationship for all or any cancers when the data were analyzed by exposure category.

Given conflicting reports on the association between silica exposure and pulmonary carcinoma, factors potentially obscuring a positive association must be considered. First, the presence of silicosis or pulmonary tuberculosis is known to complicate the diagnosis of lung cancer [Pendergrass, 1958]. Not only may the history of dust exposure bias the diagnostician, but also the X-ray picture can make diagnosis difficult. Perhaps some lung cancer cases were misdiagnosed. While it is true that the presence of silicosis or tuberculosis in the lung may hinder the early detection of lung cancer, the particular course of lung cancer makes continued misdiagnosis unlikely.

Second, there is the possibility that knowledge of the silica hazard led granite workers to smoke less than the United States white male population. Data on the smoking habits of the subject population were not available. There is, however, information on the smoking habits of granite shed workers actively employed during the 1970s [Graham et al, 1981; Eisen, 1982]. This information indicates that the active granite workers, on the average, smoke slightly more than United States white males smoked in 1970 [Sterling et al, 1976]. Interviews with older granite workers likewise suggest that the men did not reduce their cigarette consumption because of the silica hazard. Other investigators have reported that dust-exposed workers do not necessarily smoke less than workers not exposed to dust [Goldman, 1975; Vidal et al, 1969].

Third, it should be noted that fewer than 10% of the total population and fewer than 27% of the high exposed group died of silicosis or tuberculosis. The extent of silicosis and tuberculosis in the study population does not, therefore, explain the absence of an observed association between lung cancer and granite dust exposure.

Finally, most epidemiologic studies demonstrating a positive association between lung cancer and silica have looked at workers with mixed occupational exposures. Silica exposures in the granite industry are comparatively uncontaminated. This difference may account for the inconsistency between reports. The association between lung cancer and silica should be further investigated in various exposure environments.

Hoffman [1922] reported elevated rates of pneumonia, bronchitis, and tubercular respiratory diseases among New England granite cutters. Russell et al [1929] found excesses of the same diseases among the granite cutters of Barre. No notable excesses of bronchitis and pneumonia were found in this study. There was a slight excess of emphysema deaths (OER 1.6) limited to men who started work before the installation of dust controls. This finding together with X-ray records of men dying of emphysema suggests that some of these deaths may have been misdiagnosed cases of silicosis.

Elevated rates of suicide among granite cutters was first reported by Hoffman [1922]. The reasons for the excess observed in the present investigation are not apparent. Physical illness has been reported as associated with suicide, and the diagnosis of silicosis might possibly be related to several of the deaths among the older men with more than 30 years of work experience [Pisetsky et al, 1979]⁵. It cannot, however, account for the excess found in the younger, less experienced group. Vermont white male suicide rates were slightly higher than the United States white male rates during the study period, but this difference also is not large enough to explain the observed excess. Whatever the risk factors, they do not appear to be operating in recent years, as no suicide deaths were reported in this group after 1970.

GRANITE DUST: THE CONVERSION OF GRAVIMETRIC MEASURES INTO PARTICLE COUNTS (APPENDIX)

In order to utilize the industrial hygiene information contained in the six available environmental surveys, it was necessary to convert respirable mass measures into particle counts [Russell et al, 1929; Bloomfield et al, 1934; Urban, 1939; Hosey et al, 1957; Theriault et al, 1974a; Eisen 1982]. In this appendix, we review the data on which the commonly accepted conversion equation is based. The results of a reanalysis of this together with an additional set of data are presented, and a revised equation for converting mass measures of silica-containing dust into particle counts is derived.

The Sutton Data

In 1969, Ayer recommended a mass respirable "threshold limit value" (TLV) of:

$$10 \div (\% \text{ respirable free silica} + 3 \text{ mg/m}^3) \text{ respirable dust [Ayer, 1969]}$$

This TLV was subsequently adopted by the American Conference of Governmental Industrial Hygienists and by the Occupational Health and Safety Administration [American Conference of Governmental Hygienists, 1971; Code of Federal Regulations, 1975]. Ayer based his recommendation on environmental studies of the Vermont granite sheds by Sutton and Reno [1968]. In both of these studies simultaneous, fixed location sampling with several mass respirable instruments (two elutriators, one cyclone) and with Greenburg Smith impingers was carried

⁵Of the 34 suicide cases, 5 had evidence of silicosis in their X-ray records. One had been identified as also having active tuberculosis.

out to determine a gravimetric equivalent to the particle count TLV of 10 million particles per cubic foot (mppcf).

The previously unpublished results of the two studies are summarized in Table VIII. On the basis of elutriator and impinger values, Sutton concluded that 10 mppcf = 0.1 mg/m³ respirable free silica. This equation describes the mean impinger value as a function of the mean value of the respirable free silica elutriator samples.

TABLE VIII. Dust Concentrations and Composition in the Vermont Granite Shed (1965-1966)*

Sample No.	Impinger (mppcf)	1 pm Elutriator		mre Elutriator		Cyclone	
		(mg/m ³)	(%RFS) ^a	(mg/m ³)	(%RFS)	(mg/m ³)	(%RFS)
1	1.4	.40				.10	
2	2.7	.39	4	.83	3	.32	3
3	3.9	.47	5	.69	5	.27	5
4	4.9	.46	6	1.04	5	.26	
5	1.6	.28		.77	3	.20	
6	2.0	.27		.23	2	.17	
7	4.3	.60	6	.87	7	.25	5
8	8.9	.99	8	1.45	4	.53	4
9	4.3	.61	7	.85	6	.33	8
10	5.8	.71		.94	7	.35	
11	2.1	.30				.17	
12	2.4	.31	4	.71	4	.17	
13	2.7	.25		.78	3	.11	
14	2.9	.46	10	.25	1	.25	11
15	4.3	.63		1.10	3	.35	
16	7.4	.69	10	2.03	2	.34	5
17	7.0	.65	9	.98	4	.33	10
18	5.6	.63		.86	4	.38	
19	0.8	.44	4	.54	7	.23	3
20	5.3	.12		.77	9	.39	
21	2.6	.37	9			.19	8
22	1.2	.48	3			.55	1
23	2.6	.34	10				
24						1.12	1
25	1.1	.40	1			.11	3
26	1.0	.28	5			.41	4
27	5.2	.79	6				
28	1.1					.16	3
29	1.5	.27	9			.15	8
30	1.8	.18	14			.28	6
31	3.1	.40	7				
32	0.6					.28	4
33	2.8	.54	9			.14	5
34	0.5	.36	3			.22	13
35	2.6	.60	7				
36	1.0					.33	7
37	4.4	.68				.26	6
38	4.0	.49	9			.29	8
39	3.9	.50	13				
40	4.0						
Average	3.2	.47	7.1	.81	4.4	.29	5.7
RFS equivalent to 3.2 mppcf			.034			.036	.017 mg/m ³
RFS equivalent to 10 mppcf			.11			.09	.05 mg/m ³

*From Sutton.

^aRFS: respirable free silica.

A reexamination of the data reveals two fundamental problems. First, the proposed equation is based on simple averages of all the data collected rather than of the paired data only. Second, the cyclone data, in which we are most interested, was problematic because the sampling flow rate was believed to be incorrect. Sutton excluded the cyclone data in deriving his conversion equation. If the task is to convert mass respirable measures based on cyclone samples into particle counts, one can question the reliance on elutriator data given that the elutriator and cyclone have different size selective criteria.

The Harvard Data

In 1972, simultaneous mass respirable (cyclone) and impinger samples were again collected in the granite sheds by DiBeradinis of the Harvard School of Public Health (DiBeradinis, personal communication). This provided a second data set with more reliable cyclone values. These sampling results are presented in Table IX. Using the same method of relating mean impinger and mass respirable values but limiting the analysis to paired data only, the following equation was derived.

$$10 \text{ mppcf} = 0.071 \text{ mg/m}^3 \text{ respirable free silica}$$

A reanalysis of the original Sutton data using paired data only and including the cyclone data yielded a similar equation:

$$10 \text{ mppcf} = 0.078 \text{ mg/m}^3 \text{ respirable free silica}$$

The two data sets provided consistent results and were combined to derive a conversion factor slightly lower than the commonly accepted value:

$$10 \text{ mppcf} = 0.075 \text{ mg/m}^3 \text{ respirable free silica}$$

Regression Analysis of the Sutton and Harvard Data

Simple linear regression techniques were used to reanalyze both the Sutton and Harvard data. Separate regression models were used to describe particle count measures in terms of respirable free silica and total respirable dust for each data set and for both data sets combined. Both raw and log transformed data were analyzed separately. In general the r^2 's were low, and the two data sets did not yield consistent regression coefficients. When the data sets were combined, the model accounted for only 6% of the variability in particle count values.

Conclusion

Any equation for converting mass measures of dust into particle counts is necessarily approximate. The use of a single conversion factor assumes a constant particle size distribution over samples. This assumption does not necessarily hold over time nor within any one sampling period. The particle size distribution of dust samples may differ with variations in job process, in raw materials used, and in methods of dust control.

Regression analysis of the data presented in this paper indicate that the conversion of weights to counts is, in fact, problematic. Weights are not good predictors of particle count values. Sutton's method of relating mean values did yield consistent results when applied to the two available data sets. However, the inadequacy of this method, which ignores the paired nature of the data, should be noted.

TABLE IX. Dust Concentrations and Composition in the Vermont Granite Shed (1972)*

Sample No.	Impinger (mppcf)	Dust (mg/m ³)	Cyclone (mg/RFS/m ³) ^a
1	3.7	.29	.010
1	2.5	.45	.035
3	2.2	.20	.014
4	5.6	.34	.009
5	3.2	.40	.018
6	2.9	.16	.003
7	2.9	.81	.088
8	3.7	1.17	.031
9	4.1	.51	.020
10	2.2	.47	.021
11	3.0	.33	.009
12	3.7	.58	.043
13	2.4	.29	.027
14	1.8	.18	.011
15	4.0	.93	.173
16	1.7	.15	.005
17	1.1	.57	.048
18	2.3	.31	.010
19	2.5	.60	.018
20	2.7	.21	.026
21	2.8	.24	.004
22	1.0	.24	.011
23	1.8	.20	.011
24	2.8	.24	.020
25	4.0	2.04	.079
26	2.5	.27	.027
27	1.0	.13	.002
28	4.0	.14	.002
29	5.5	.20	.009
30	2.8	.46	.008
31	6.2	.35	.006
32	8.7	.82	.032
33	7.6	.31	.011
34	1.4	.20	.004
35	1.7	.16	.009
36	11.3	.97	.036
37	1.8	.29	.003
Average	3.4	.439	.024
RFS equivalent to 3.4 mppcf		.024 mg/m ³	
RFS equivalent to 10 mppcf		.071 mg/m ³	

*From DiBeradinis. [Personal communication].

^aRFS: respirable free silica.

The combined Sutton-Harvard equation, which takes advantage of all the available conversion data, was selected as the best means of conversion available for use in this study. In using this equation, we emphasize that the derivation of a cumulative exposure variable in this study is a qualitative undertaking. For this purpose, the application of an approximate conversion factor is appropriate. The gravimetric

measures that have been converted to particle counts in this investigation all fall on the lower end of the range of possible exposures, and the opportunity for gross misclassification of lifetime exposures due to inaccurate conversion is small.

ACKNOWLEDGMENTS

The writers thank Lena Bizazero and Louis DeBeradinis for their assistance in data collection and Donna Speigleman for her technical advice. We also thank the Barre Granite Employees Pension Association, the Granite Cutters International Association of America, the United Steelworkers of America, Local 4, and the Barre Chest Clinic for their cooperation.

This work was supported by Grants 5 T OHO70-6 from the National Institute for Occupational Safety and Health and SS 5 P30 E50002 from the National Institute of Environmental Health Sciences.

REFERENCES

- American Conference of Governmental Hygienists (1971): Documentation of the threshold limit values for substances in workroom air. American Conference of Governmental Hygienists, Cincinnati, Ohio.
- Ashe HB, Bergstrom DE (1964): Twenty-six years' experience with dust control in the Vermont granite industry. *Ind Med Surg* 33:73-78.
- Ayer HE (1969): The proposed ACGIH mass limits for quartz: Review and evaluation. *Am Ind Hyg Assoc J* 30:117-125.
- Bloomfield JJ, Waldemar CD (1934): Silicosis among granite quarriers. *Public Health Rep* 49:679-684.
- Code of Federal Regulations (1975): Part 1910, Title 29, paragraph 100(c).
- Eisen EA (1982): A longitudinal study of pulmonary function among Vermont granite workers. Doctoral Thesis, Harvard School of Public Health, Boston, Massachusetts.
- Finkelstein M, Kusiak R, Suranyi G (1982): Mortality among miners receiving workmen's compensation for silicosis in Ontario: 1940-1975. *J Occup Med* 24:663-667.
- Goldman KP (1965): Mortality of coal miners from carcinoma of the lung. *Br J Ind Med* 22:72-77.
- Graham WGB, O'Grady RV, Dubuc B (1981): Pulmonary function loss in Vermont granite workers: A long-term follow-up and critical reappraisal. *Am Rev Respir Dis* 123:25-28.
- Grove R, Hetzel A (1968): Vital Statistics Rates in the U.S., 1940-1960, USDHEW PHS, Washington, DC, National Center for Health Statistics, PHS Publication No. 1677.
- Hoffman FL (1922): The problem of dust phthisis in the granite stone industry. *Bulletin of the Bureau of Labor Statistics* No. 293.
- Hosey AD, Ashe HB, Trasko VM (1957): Control of silicosis in the Vermont granite industry. Washington, DC, USHEW, PHS Publication No. 557.
- Maillard LM (1980): Silicose et cancer bronchique. *Poumon Coeur* 36:41-48.
- McMichael AJ (1976): Standardized mortality ratios and "The Healthy Worker Effect": Scratching beneath the surface. *J Occup Med* 18:165-168.
- Monson RR (1974): Analysis of relative survival and proportional mortality. *Comput Biomed Res* 7:325-332.
- Musk AW, Peters JM, Wegman DH, Fine LJ (1977): Pulmonary function in granite dust exposures: A four year follow-up. *Am Rev Respir Dis* 115:769-776.
- Pendergrass EP (1958): Silicosis and a few other pneumoconioses. Caldwell Lecture 1957. *Am J Roentgen* 80:1-41.
- Pisetsky JE, Brown W (1979): The general hospital patient. In Harkoff LD, Einsidler B (eds): "Suicide, Theory and Clinical Aspects." Littleman MA: PSG Publishing, pp. 279-284.
- Russell AE, Britten RH, Thompson LR, Bloomfield JJ (1929): The health of workers in the dusty trades. II. Exposure to siliceous dust (granite industry). *Public Health Bulletin*, No. 187, US Public Health Service.
- Russell AE (1941): The health of workers in the dusty trades. Restudy of a group of granite workers. *Public Health Bulletin*, No. 269, US Public Health Service.

- Sterling TD, Weinkham JJ (1976): Smoking characteristics by type of employment. *J Occup Med* 18:743-754.
- Sutton GW, Reno SJ (1968): Respirable mass concentrations equivalent to impinger data. Barre Vermont granite sheds. Read before the annual meeting of the American Industrial Hygiene Association, St. Louis, Missouri.
- Theriault GP, Burgess WA, DiBeradinis LJ, Peters JM (1974a): Dust exposure in the Vermont granite sheds. *Arch Environ Health* 28:12-17.
- Theriault GP, Peters JM, Fine LJ (1974b): Pulmonary function in granite shed workers of Vermont. *Arch Environ Health* 28:18-22.
- Theriault GP, Peters JM, Johnson WM (1974c): Pulmonary function and roentgenographic changes in granite dust exposure. *Arch Environ Health* 28:23-27.
- U.S. Department of Health, Education and Welfare: Vital Statistics of the United States 1960-1978.
- U.S. Department of Health, Education and Welfare (1974): Center for Disease Control, National Institute for Occupational Safety and Health, Criteria Document: Recommendations for an occupational exposure standard for crystalline silica, HEW Publication.
- Urban DJ (1939): Ventilation in the granite industry. *J Ind Hyg Toxicol* 21:57-67.
- Vidal J, Michel FB (1969): Incidence de cancer bronchique chez les mineurs de carbon. Resultants d'une enquete sur la consommation de tabac. *J Frac Med Chir Thor* 23:49-62.
- Westerholm P (1980): Silicosis, observations on a case register. *Scand J Work Environ Health* 2:1-86.
- World Health Organization (1968): International Classification of Diseases, Adapted for Use in the United States, Vol. 1 and 2. USDHEW PHS No 1693, December, 1968.