CN 006

AMBIENT CONCENTRATIONS OF MINERAL FIBERS IN AIR AND WATER IN NORTHEAST MINNESOTA

Minnesota Environmental Quality Board

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Date: September, 1978

Final Draft

INTRODUCTION TO THE REGIONAL COPPER-NICKEL STUDY

The Regional Copper-Nickel Environmental Impact Study is a comprehensive examination of the potential cumulative environmental, social, and economic impacts of copper-nickel mineral development in northeastern Minnesota. This study is being conducted for the Minnesota Legislature and state Executive Branch agencies, under the direction of the Minnesota Environmental Quality Board (MEQB) and with the funding, review, and concurrence of the Legislative Commission on Minnesota Resources.

A region along the surface contact of the Duluth Complex in St. Louis and Lake counties in northeastern Minnesota contains a major domestic resource of copper-nickel sulfide mineralization. This region has been explored by several mineral resource development companies for more than twenty years, and recently two firms, AMAX and International Nickel Company, have considered commercial operations. These exploration and mine planning activities indicate the potential establishment of a new mining and processing industry in Minnesota. In addition, these activities indicate the need for a comprehensive environmental, social, and economic analysis by the state in order to consider the cumulative regional implications of this new industry and to provide adequate information for future state policy review and development. In January, 1976, the MEQB organized and initiated the Regional Copper-Nickel Study.

The major objectives of the Regional Copper-Nickel Study are: 1) to characterize the region in its pre-copper-nickel development state; 2) to identify and describe the probable technologies which may be used to exploit the mineral resource and to convert it into salable commodities; 3) to identify and assess the impacts of primary copper-nickel development and secondary regional growth; 4) to conceptualize alternative degrees of regional copper-nickel development; and 5) to assess the cumulative environmental, social, and economic impacts of such hypothetical developments. The Regional Study is a scientific information gathering and analysis effort and will not present subjective social judgements on whether, where, when, or how copper-nickel development should or should not proceed. In addition, the Study will not make or propose state policy pertaining to copper-nickel development.

The Minnesota Environmental Quality Board is a state agency responsible for the implementation of the Minnesota Environmental Policy Act and promotes cooperation between state agencies on environmental matters. The Regional Copper-Nickel Study is an ad hoc effort of the MEQB and future regulatory and site specific environmental impact studies will most likely be the responsibility of the Minnesota Department of Natural Resources and the Minnesota Pollution Control Agency.

ABSTRACT

The Regional Copper-Nickel Study extensively monitored the area along the Duluth Gabbro Complex of northeast Minnesota for mineral fibers in 1977. Air samples were collected from six sites. One sample to determine size distribution of fibers was collected using a cascade impactor. Stream samples were collected from fourteen sites. Samples were also collected from snow, a lake, a mine shaft, city tap water and gravel road dust. All samples were analyzed by the Minnesota Department of Health using standard methods.

Total fiber levels in air averaged 10-40 thousand fibers/m^3 with chrysotile and 7.5-35 thousand fibers/m3 without chrysotile. Chrysotile fibers may have come from the filters rather than the sampled medium. Amphibole fiber levels appeared to be highest at the Erie Mining office. Approximately half the fibers in the cascade impactor were found in the one to two micrometer stage. Sixty percent of the amphibole fibers were also found in this stage. Amphibole fiber levels varied depending on wind direction and were consistent with a source of amphiboles coming from the vicinity of the eastern end of the Mesabi Iron Range.

Total fiber levels in streams ranged from 0.4 to 7.9 million fibers/liter with chrysotile and 0.2 to 5 million fibers/liter without chrysotile. Median levels were 3.3 and 1.5 million fibers/liter, respectively. These levels appear to be similar to levels reported elsewhere in the literature for rivers, lakes, beer, wine and soft drinks. Fiber levels in streams receiving minewater discharge from Reserve or Erie were not different from streams that did not receive such discharges. A snow sample had fiber levels similar to those in streams and similar to a previous report. Mineshaft water from the Amax shaft near Babbitt contained four billion fibers/liter of which 700 million were amphibole fibers. These levels are at least three orders of magnitude below estimates of levels discharged by Reserve into Lake Superior.

Approximately four-five percent of the particles from a gravel road dust sample, consisting of gravel from a gravel pit five miles west of Reserve's Peter Mitchell mine, was composed of fibers. Many of these fibers had a length-to-width ratio greater than ten. Approximately one-third of these fibers were amphiboles. A similar sample collected from an Erie haul road five miles north of Hoyt Lakes had less than one-two percent fibers.

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INTRODUCTION

Mineral fibers present a potentially serious, but presently poorly understood, environmental health hazard for the non-occupational population in both Minnesota, as evidenced by the Reserve Mining controversy, and nationwide (Carter, 1977). This poor understanding can be attributed partly to confusion over and misuse of terminology, and incomplete knowledge of the mechanism by which fibers affect health.

Asbestos is used as a collective mineralogical term encompassing the asbestiform varieties of various silicate minerals and is applied to a commercial product obtained by mining primarily asbestiform minerals (Campbell, et al. 1977). Five minerals fit this definition: chrysotile (a member of the serpentine group), and the asbestiform varieties of actinolite-tremolite, anthophyllite, cummingtonite-grunerite, and riebeckite (members of the amphibole group). Chrysotile always occurs in the asbestiform habit, amphiboles usually occur in non-asbestiform habits, with the exception of riebeckite, which usually occurs in the asbestiform habit as crocidolite. Asbestiform minerals occur as fibers, which display some resemblances to organic fibers in terms of circular cross section, flexibility, silky surface luster, and other characteristics. Cleavage fragments, such as those produced from crushing and processing non-asbestiform minerals, do not satisfy this definition of fibers and should be considered "fiber-like." When asbestiform and non-asbestiform minerals are subjected to crushing and processing, the resulting fragments have minor differences in morphology and physical properties that are very difficult to distinguish under a transmission electron microscope. For this reason, when the transmission electron microscope is used, fibers are defined as fragments with aspect (length to width) ratio of 3:1 or greater, even though many of these fragments may not meet the mineralogic definition of a fiber. In this paper the term "mineral fiber" will be used to denote both asbestos fibers and cleavage fragments of non-asbestiform minerals because ambient levels of mineral fibers were determined by transmission electron microscopy, which did not distinguish between these two classifications.

Mineral fibers have a number of possible sources. Fragments can be generated from both asbestiform and non-asbestiform minerals by both human activities, such as mining and processing ore, construction, blasting, and drilling, and by natural processes such as mechanical effects from wind and water. Asbestos fibers may occur naturally; however, they are uncommon in northeast Minnesota. Mineral fibers may also be introduced to this region through sources such as insulation materials, foods, and brake linings in motor vehicles.

Asbestos fiber and non-asbestiform cleavage fragments have different characteristics in terms of tensile strength, flexibility, durability, and surface properties. The extent to which these differences are related to the harmful properties of asbestos is uncertain at this time. Occupational health standards of asbestos exposure are based upon fibers greater than five micrometers in width and a length-to-width (aspect) ratio of at least three. However, there is widespread belief that this definition of fibers is inadequate for health standards. Several theories have been proposed as to how asbestos causes disease: the fiber theory, the trace metal theory, the organic material theory and the multifunctional theory (Regional Copper-Nickel Study 1977). Briefly, some believe that the physical characteristics of asbestos (such as aspect ratio or fiber diameter) are responsible for disease; others believe that trace metals associated with fibers cause disease; others believe that fibers serve as carriers for organic materials, which in turn cause disease; and still others believe that several or all three of these theories may be operating concurrently.

The Regional Copper-Nickel Study conducted a general survey of ambient fiber levels in water and air to characterize existing levels and to try to correlate these levels with suspected fiber sources near the Duluth Gabbro Contact. Ambient levels found in northeast Minnesota are compared to levels reported by other investigators.

METHODS

Samples were collected throughout 1977 in conjunction with the rest of the air and water sampling program. The sampling scheme is illustrated in Appendix I. Air samples consisted of 24-hour membrane air filter samples from six sites and a cascade impactor sample from Hoyt Lakes. Membrane air filters were cut up into pieces and each piece underwent a different analysis. Five days were chosen as the sample days based upon varying meteorological conditions and availability of filters for analysis. Methodology for fiber analysis appears in Appendix II. A special cascade impactor sample for fiber analysis was collected in Hoyt Lakes using a Delron Cascade Impactor Model DCI-6. Air was drawn under vacuum through the cascade impactor at a critical flow rate of approximately 12.5 liters/minute. Nuclepore filters (37 mm diameter, 0.6μm pore-size) were coated with Apiezon L grease and placed on the glass slides at each impaction surface (Regional Copper-Nickel Study 1978). Air monitoring sites are illustrated in Figure 1.

Water samples consisted of stream samples, a snow sample, a lake sample, an Ely tap water sample, and a sample from the Amax shaft water. Depending on the sample, five to 500 ml of water were filtered through either a Nuclepore or Millipore filter. Analysis of surface waters for mineral fibers is extremely difficult because of the large amounts of intervening materials.

Diatoms and other non-fiber particulates not only prevent large amounts of water from being filtered but obscure and confuse the final preparation. Little sample to sample comparison is justified. Road dust samples were collected from St. Louis County Road 620 (T60N, R13W, Sec. 19, SW¼, NW¼) and from an Erie haul road (T50N, R14W, Sec. 17). A sample was collected from the center of each road. Water and road dust sample sites are illustrated in Figure 2.

All air and water samples were analyzed by the Minnesota Department of Health according to the methodologies appearing in Appendix II. Road dust samples were analyzed qualitatively. These samples were prepared by placing a portion of the gravel in filtered distilled water and shaking it. The suspension settled for a few seconds and a sample was removed from near the top with a micropipette. This was placed on a parlodion coated TEM grid and dried with a heat lamp (Ring 1978).

Fiber levels are reported in four catergories. Amphibole fibers are defined as those fibers which give electron diffraction patterns characteristic of amphibole minerals. A fiber which clearly has a chrysotile diffraction pattern is classified as chrysotile. A mineral with a clearly non-amphibole, non-chrysotile diffraction pattern is classified as non-amphibole, non-chrysotile. Mineral fibers classified as ambiguous have diffraction patterns or chemical ratios which cannot be used to place the fiber in one of the three previous categories.

Total fiber levels are given with and without chrysotile because the Minnesota Department of Health was uncertain whether the observed chrysotile fibers were artifacts from the filters or were actually present in the medium sampled. Analyses of blank filters by the Minnesota Department of Health have suggested that Millipore filters contain significant levels of chrysotile and Nuclepore filters sometimes contain amphibole fibers. Mean aspect ratios for each category were calculated by dividing the mean length by the mean width of all the fibers observed in the category.

RESULTS

Air: Results of the membrane air filter sampling are presented in Table 1. Fiber levels varied greatly over the days of sampling at each site. In general, total fiber levels averaged between 10,000 and 40,000 fibers per cubic meter. If chrysotile is excluded from the counts, total fiber levels generally range from 7,500 to 35,000 fibers/m^3. Six blank samples had an average of 1.66 chrysotile fibers per grid square compared to an average of 1.77 chrysotile fibers per grid square for the 25 air samples. Because fiber levels are calculated directly from fibers per grid square, these data suggest that most, if not all, of the chrysotile found in the air samples can be attributed to the filters.

Based upon median values for the sampling period, amphibole fiber counts were highest at the Erie Mining Office; non-amphibole, non-chrysotile fiber levels were highest at the Environmental Learning Center; and ambiguous fiber counts were highest at the Erie Mining Office and Babbitt. The highest individual reading (92,300 fibers/m^3) was at Bear Head Lake State Park on June 12, 1977; the lowest level (5,730 fibers/m^3--without chrysotile) was measured at the Fernberg Road site also on June 12. Meteorological data for the five sampling days are shown in Table 2.

Results for the cascade impactor analysis are presented in Table 3. In this sample, 60 percent of the amphibole fibers were found in the one micrometer stage. Overall, roughly half the total fibers (with or without chrysotile) also were found in the one micrometer stage. Total fibers for all stages added up to 126,000/m^3 with chrysotile and 78,000/m^3 without chrysotile.

Water: Fiber levels in various types of water are shown in Table 4. Total fiber counts among stream samples ranged from 380,000 to 7,920,000 fibers per liter with a median of 3,310,000. Excluding chrysotile, total fiber levels ranged from 231,000 to 5,040,000 fibers per liter with a median of 1,540,000. Fiber levels in the Filson Creek snow sample, Ely tap water sample and Bear Island Lake sample were similar to those in stream samples. A water sample from the AMAX mine shaft near Babbitt contained approximately four billion fibers (both with and without chrysotile). Half of these fibers were classified as non-amphibole, non-chrysotile, and thirty percent were ambiguous.

Amphibole and chrysotile concentrations are compared to mean blank levels in Table 5. In 9 of the 25 samples, the amphibole blank fiber level was higher than the corresponding sample amphibole concentrations. Similarly 12 of 25 chrysotile sample concentrations were less than their corresponding blank fiber level. These results suggest that, with the exception of the mine shaft sample, most of the fibers found in these samples were due to blank levels. Therefore the fiber levels presented in Table 4 should be considered upper limits for the probable fiber concentrations in northeast Minnesota.

Road Dust: Two samples of road dust from St. Louis County Road 620 gave similar results. Approximately five percent of the particles on the TEM grid appeared to be fibers. Many of these fibers had a high aspect ratio (greater than 10). About one-third of the fibers were amphiboles. Less than two percent of the particles in the Erie Mining Company haul road dust were fibers. None of the fibers observed had aspect ratios above ten.

DISCUSSION

Air: There are very few reports about ambient levels of fibers in air. Silver Bay, Minnesota was studied because of an industrial source of fibers from a taconite processing plant. Fiber levels found in Silver Bay are shown in Table 6. Examination of these fiber levels with the median levels found at the six sites reported in Table 1 shows that there are one to two orders of magnitude more amphibole fibers in Silver Bay, about the same number of chrysotile fibers, and about ten times as many fiber in the other fiber categories in Silver Bay as compared to the six sites studied for this report. The current occupational standard set by OSHA of 2,000,000 fibers/m^3 (fibers greater than 5 μm) is not of much use for comparative purposes because almost all of the fibers observed in northeast Minnesota were less than five μm and the occupational standard is based upon measurement by a light microscope as opposed to the transmission electron microscope (TEM) used for this study.

Particles in the respirable range (1-2μm) are of most concern from the public health perspective. In the cascade impactor sample, sixty percent of the amphibole fibers and approximately half of all fibers observed were in the respirable range. Although they may not be directly comparable, total fiber levels for all of the cascade impactor stages combined were higher than almost all of those found in the membrane air samples.

Amphibole fiber levels were found to vary with wind direction consistent with a source of amphiboles coming from the general area of the eastern end of the Mesabi Iron Range. Other types of fibers and total fibers did not appear to be related to wind direction. Wind direction on the dates of the highest and lowest mphibole fiber levels are illustrated in Figure 3.

Highest amphibole levels at Bear Head Lake State Park, Babbitt, and Fernberg Road occurred when winds were from the south or south-southeast, while the lowest levels were found when the winds were from the northwest or north-northwest. At the other three sites, the lowest amphibole levels were found during the iron mineworkers' strike (August-December, 1977) when there was no mining activity. The highest amphibole fiber levels at the Erie Mining Office were found when the wind was from the north-northwest. It is interesting to note that this site is due south of the Erie processing plant. Unfortunately, no samples were available for the Erie site on the two days when the wind was from the south. At Toimi, the highest amphibole fiber levels were found when the wind was from the north-northwest. Highest amphibole levels at the Environmental Learning Center occurred when the wind was from the south-southeast. This observation initially appears inconsistent with a source of amphibole fibers coming from the eastern end of the Iron Range; however, the wind was never from the direction of the eastern end of the Iron Range, except during the strike. The south-southeast wind direction on the day of the highest levels suggest the possibility that the fibers came from Reserve's Silver Bay processing plant, which processes ore from the eastern end of the Iron Range.

Water: Stream sampling stations receiving direct minewater discharge from taconite mines are Partridge-5 (from Reserve), Dunka-1 (from Reserve), and Bob Bay-1 (from Erie). Several stations downstream from these three stations, which may also be considered impacted, include Kawishiwi-4 and 5, Partridge-1 and 2, and St. Louis-1 (see map in Figure 2). Fiber levels for both impacted and non-impacted streams showed large variations with little difference between the two stream groups. Amphibole fiber levels in the Partridge River appeared to decrease as the distance from the Reserve pit increased; however, this observation may be due to natural variation. The two highest amphibole levels were found in non-impacted streams. Very high amphibole fiber aspect ratios were found in the Dunka sample (average of 54.0) and the Kawishiwi-5 and 4 samples (30.2 and 37.1, respectively), which are downstream from the Dunka.

Total fiber levels in streams and snow in northeast Minnesota are slightly higher than the reported levels of 0.14-3.9 million fibers per liter in Canadian drinking water supplies drawn from lakes and rivers (Kay 1974). Amphibole fiber levels in Duluth drinking water, which is drawn from Lake Superior, were conservately estimated to be 1-30 million amphibole fibers per liter (Cook et al. 1974). Cook et al. (1976) later estimated this level to be 1-1,000 million amphibole fibers per liter with an average of 45-100 million. Reported chrysotile fiber levels in the drinking water of Midland and Bay City, Michigan, averaged 0.6 and 1.2 million fibers per liter, respectively (Beaman and File 1976). Kramer (1976) reported fiber levels of 5-20 million fibers per liter in western Lake Superior, 1-3 million fibers per liter in the rest of the lake, and less than two million fibers per liter in streams entering Lake Superior. McMillan et al. (1977) found 0.5-4.5 million fibers per liter in raw water (drawn from Lake Michigan) and 0.1-0.6 million fibers per liter in the treated drinking water for the city of Chicago. Samples of beer, wine, and soft drinks from Canada, the United States, Europe, and South Africa reportedly contained 1-12 million fiber per liter (Cunningham and Pontefract 1971). Cunningham and Pontefract (1971) found 33.5 million fibers per liter in a melted snow sample from Ottawa and 9.5 million fibers per liter in the Ottawa River at Ottawa.

Some of the preceeding studies were condicted using sample preparation methods that are now known to result in the significant loss of fibers. Few of these studies give any blank data so it is difficult to interpret their results.

Thus, one should be careful not to draw unwarranted conclusions from comparisons between this study and those cited above.

Based upon reports that there are at least 1 X 10^{21} amphibole fibers discharged daily by Reserve Mining (Cook et al. 1976) in two million tons of water (Ember 1977), the estimated concentration of at least 5.5 X 10^{11} amphibole fibers per liter discharged by the taconite plant at Silver Bay is approximately three orders of magnitude higher than that in a water sample from the AMAX test shaft near Babbitt.

Fiber levels in tap water samples from Canadian cities generally ranged from 2-10 million fibers per liter. At Thetford Mines, which is near a chrysotile asbestos mine in eastern Quebec, asbestos fiber levels were found to be 172.7 million fibers per liter (Cunningham and Pontefract 1971).

Road Dust: Gravel used for St. Louis County Road 620 is believed to have come from a gravel pit off County Road 615 located in the southeast quarter of the northeast quarter of Township 60 north, range 14 west, section 22, between Babbitt and Embarrass (Beauclair 1978). This gravel pit is about five miles west of Reserve's Peter Mitchell Mine. Whether the observed fibers come from the gravel pit, the Peter Mitchell Mine, or some other source is unclear at this time.

CONCLUSIONS

Ambient air levels of fibers in northeast Minnesota near the Duluth Gabbro Contact were found to be one-to-two orders of magnitude below those found in Silver Bay (Table 7). Amphibole fiber levels appeared to be related to wind direction and to come from a source in the eastern end of the Mesabi Iron Range. Other types of fiber categories showed no such correlation. A single cascade impactor sample in Hoyt Lakes found 60 percent of the amphibole fibers and half of all fibers in the stage with a 1-2 μm aerodynamic diameter (the respirable range).

Ambient water levels of fibers found in the streams of northeast Minnesota are similar to previous literature reports of other streams and rivers. Mine shaft water from the AMAX site near Babbitt has fiber levels two-to three orders of magnitude above those for nearby streams, but are almost three orders of magnitude below those estimated for tailings from Reserve Mining in Silver Bay. These and other comparisons are illustrated in Table 8. Fiber levels in streams receiving mine water discharges appear to be similar to streams not receiving such discharges.

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Table 1.

Ambient concentration and mean aspect ratio for fibers found on membrane air samples in 1977.

6 FEBRUARY

Fibers/m^3 (aspect ratio)

SITE		Amphibole	Chrysotile	Non-Amphibole Non-Chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Rd.	(7001)	336* (14.7)	9,400 (12.7)	10,400 (4.9)	1,680 (10.2)	21,800	12,400
Environmental Learning Center	(7004)	1,460 (4.7)	5,840 (19.0)	33,600 (6.4)	3,650 (6.0)	44,500	38,700
Bearhead Lake State Park	(7005)	1,320 (7.8)	7,940 (17.8)	4,630 (5.1)	882 (10.6)	14,800	6,840
Toimi	(7009)	16,700 (5.2)	3,580 (11.5)	875 (6.1)	2,390 (5.4)	31,400	27,800
Erie Mining Office	(7008)	23,400 (6.2)	6,780 (10.0)	3,770 (5.0)	10,500 (7.2)	44,400	37,700
Babbitt	(7013)	--	--	--	--	--	--

*Detection limit, based on one fiber observed

Note: Counting error limits are shown in Appendix III.

Table 1. continued

Ambient concentration and mean aspect ratio for fibers found on membrane air samples in 1977.

8 MARCH

Fibers/m^3 (aspect ratio)

SITE		Amphibole	Chrysotile	Non-Amphibole Non-Chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Rd.	(7001)	3,840 (7.5)	7,670 (13.8)	6,490 (4.1)	2,360 (8.0)	20,400	12,700
Environmental Learning Center	(7004)	--	--	--	--	--	--
Bearhead Lake State Park	(7005)	2,910 (4.1)	2,380 (18.7)	980 (17.2)	2,120 (4.8)	17,200	14,800
Toimi	(7009)	971 (18.5)	5,580 (15.2)	6,800 (10.0)	971 (14.3)	14,300	8,740
Erie Mining Office	(7008)	--	--	--	--	--	--
Babbitt	(7013)	--	--	--	--	--	--

*Detection limit, based on one fiber observed

Note: Counting error limits are shown in Appendix III.

Table 1. continued

Ambient concentration and mean aspect ratio for fibers found on membrane air samples in 1977.

Fibers/m^3 (aspect ratio) 1 May

SITE		Amphibole	Chrysotile	Non-amphibole Non-chysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Rd.	(7001)	2,940 (6.9)	<368** (--)	10,300 (6.5)	1,840 (8.4)	15,100	15,100
Environmental Learning Center	(7004)	3,940 (3.9)	<986** (--)	16,800 (6.0)	19,700 (16.3)	40,400	40,400
Bearhead Lake State Park	(7005)	3,640 (4.0)	<728** (--)	16,000 (5.2)	8,010 (5.3)	27,700	27,700
Toimi	(7009)	15,400 (9.5)	<770** (--)	11,600 (5.5)	10,000 (6.3)	37,000	37,000
Erie Mining Office	(7008)	14,200 (5.6)	947* (10.0)	10,400 (6.1)	10,400 (4.5)	36,000	35,000
Babbitt	(7013)	3,350 (6.6)	<837** (--)	10,900 (4.1)	10,000 (6.2)	24,300	24,300

* Detection limit, based on one fiber observed

** No fibers observed

Note: Counting error limits are shown in Appendix III.

Table 1. continued

Ambient concentration and mean aspect ratio for fibers found on membrane air samples in 1977.

Fibers/m^3
(aspect ratio) 12 June

SITE		Amphibole	Chrysotile	Non-amphibole Non-chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Rd.	(7001)	716 (5.5)	3,220 (23.8)	3,580 (5.4)	1,430 (3.9)	8,950	5,730
Environmental Learning Center	(7004)	5,550 (5.4)	26,400 (50.3)	19,400 (9.7)	5,550 (8.1)	56,900	30,500
Bearhead Lake State Park	(7005)	42,400 (5.6)	<1,850** (--)	40,600 (5.4)	9,230 (6.2)	92,300	92,300
Toimi	(7009)	3,590 (4.8)	5,980 (17.5)	8,730 (6.0)	7,780 (8.3)	25,700	19,700
Erie Mining Office	(7008)	--	--	--	--	--	--
Babbitt	(7013)	5,290 (5.4)	9,400 (16.6)	1,180 (13.4)	9,400 (7.1)	25,300	15,900

*Detection limit, based on one fiber observed

**No fibers observed

Note: Counting error limits are shown in Appendix III.

Table 1. continued

Ambient concentration and mean aspect ratio for fibers found on membrane air samples in 1977.

5 August

Fibers/m^3
(aspect ratio)

SITE		Amphibole	Chrysotile	Non-amphibole Non-chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Rd.	(7001)	1,520 (31.8)	10,600 (24.2)	9,120 (6.2)	1,820 (9.6)	23,100	12,500
Environmental Learning Center	(7004)	372* (14.3)	5,210 (25.4)	7,080 (4.7)	372* (3.0)	13,400	8,190
Bearhead Lake State Park	(7005)	8,170 (5.5)	21,200 (14.0)	7,350 (5.6)	817* (3.2)	37,600	16,300
Toimi	(7009)	902 (5.1)	2,480 (16.7)	5,410 (4.3)	1,130 (17.4)	9,920	7,440
Erie Mining Office	(7008)	4,360 (6.8)	4,850 (16.7)	4,360 (8.8)	3,390 (13.0)	17,000	12,100
Babbitt	(7013)	4,750 (10.5)	19,000 (30.6)	8,550 (5.5)	4,750 (17.4)	37,100	18,100

*Detection limit, based on one fiber observed.

Note: Counting error limits are shown in Appendix III.

Table 1. continued

Ambient concentration and mean aspect ratio for fibers found on membrane air samples in 1977.

Fibers/m^3 (aspect ratio) — Medians for Sampling Period

SITE		Amphibole	Chrysotile	Non-amphibole Non-chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Rd.	(7001)	1,520 (7.5)	7,670 (18.8)	9,120 (5.4)	1,820 (8.4)	20,400	12,500
Environmental Learning Center	(7004)	2,700 (5.2)	5,640 (25.4)	26,500 (6.2)	4,600 (7.3)	42,500	34,600
Bearhead Lake State Park	(7005)	3,640 (5.5)	2,380 (17.8)	7,350 (5.4)	2,120 (5.3)	17,200	16,300
Toimi	(7009)	3,590 (9.5)	3,580 (16.0)	6,800 (6.0)	2,390 (8.3)	25,700	19,700
Erie Mining Office	(7008)	14,200 (6.2)	6,780 (10.0)	4,360 (6.1)	10,400 (7.2)	36,000	35,000
Babbitt	(7013)	4,750 (6.6)	9,400 (23.6)	8,550 (5.5)	9,400 (7.1)	25,300	18,100

*Detection limit, based on one fiber observed.

Table 2

Hibbing Weather Data

Date	Average Wind Direction	Average Wind Speed	Average Temperature (^{o}F)	Precipitation (inches)	Noon Snow Depth(inches)	Previous Day
Feb. 6, 1977	NNW	6	-2	None	14	Wind NNW No precip.
March 8, 1977	S	4	19	None	5	Wind:S to SW No precip.
May 1, 1977	NW	12	53	0.01	--	Wind:Strong from SW No precip.
June 12, 1977	SSE	7	52	None	--	Wind:mostly NE No precip.
Aug. 5, 1977 (No mining activity)	WNW	8	62	None	--	Wind: SW 0.28 inches of rain
Oct. 14, 1977 (No mining activity)	NNW	9	50	None	--	Wind:Strong from SSW No precip.

Table 3. Cascade Impactor Data from Hoyt Lakes (October 14, 1977)
fibers/m^3
(aspect ratio)

	Amphibole	Chrysotile	Non-amphibole Non-chrysotile	Ambiguous	Total Fibers	Total without chrysotile
Stage 3 (4μm)***	670* (9.4)	10,000 (28.3)	9,380 (6.1)	4,690 (8.3)	24,800	14,700
Stage 4 (2μm)	<536** (--)	4,820 (32.2)	2,140 (8.4)	536* (36.6)	7,500	2,680
Stage 5 (1μm)	15,000 (6.2)	8,740 (12.0)	21,200 (5.0)	6,240 (8.5)	51,200	42,500
Stage 6 (0.5μm)	<1,790** (--)	16,100 (8.8)	<1,790** (--)	1,790* (7.4)	17,900	1,790*
Stage BL (<0.5μm)	5,360 (3.6)	8,570 (20.2)	6,430 (7.2)	4,290 (6.6)	24,600	16,100
Total-All stages	21,000	48,200	39,200	17,500	126,000	78,000

*Detection limit, based on one fiber observed
**No fibers observed
***50% cut-off for aerodynamic diameter

Note: Counting error limits are shown in Appendix III.

Table 4. Ambient concentration and mean aspect ratio for fibers found in water samples

Location	Type of sample	Date collected	Thousands of fibers/liter (mean aspect ratio): Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without chrysotile
Partridge-1 (04015490)	stream	8/30/77	110* (3.2)	6,380 (14.9)	110* (7.4)	1,320 (15.8)	7,920	1,540
Partridge-2 (04015471)	stream	5/5/77	427 (16.7)	107* (0.0)	640 (5.4)	320 (4.4)	1,490	1,390
"	stream	7/25/77	232 (6.8)	929 (8.9)	77.4* (7.4)	77.4* (17.3)	1,320	387
"	stream	8/30/77	448 (9.3)	1,340 (26.2)	336 (8.7)	448 (7.6)	2,570	1,230
"	stream	11/21/77	40.7 (16.7)	149 (13.9)	81.4 (7.7)	108 (10.1)	380	231
Partridge-5 (04015447)	stream	8/18/77	711 (7.1)	4,270 (17.2)	711 (13.2)	178* (4.3)	5,870	1,600
Stoney River-2 (05125550)	stream	5/5/77	213* (4.0)	<213** (--)	1,280 (4.9)	640 (10.9)	2,130	2,130
"	stream	7/25/77	<88.7** (--)	1,240 (19.4)	<88.7** (--)	266 (6.8)	1,510	266
"	stream	8/30/77	102* (5.5)	3,170 (16.8)	716 (7.9)	511 (8.8)	4,500	1,330
"	stream	11/21/77	264 (24.8)	926 (17.4)	793 (10.7)	1,320 (14.9)	3,310	2,380
Stoney River-5 (05125450)	stream	9/26/77	1,430 (7.9)	715 (17.0)	238* (3.4)	238* (6.0)	2,620	1,910

*Detection limit, based on one fiber observed
**No fibers observed.
Note: Counting error limits are shown in Appendix III.

Table 4. Ambient concentration and mean aspect ratio for fibers found in water samples (continued)

Location	Type of sample	Date collected	Thousands of fibers/liter (mean aspect ratio) Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without chrysotile
Dunka-1 (05126000)	stream	8/18/77	582 (54.0)	1,940 (19.7)	388 (5.6)	1,360 (8.1)	4,270	2,330
Kawishiwi-4 (05126620)	stream	11/21/77	900 (37.1)	1,100 (33.5)	500 (8.3)	600 (22.0)	3,100	2,000
Kawishiwi-5 (05126210)	stream	7/25/77	256 (6.6)	3,860 (15.8)	386 (4.4)	256 (29.3)	4,760	900
"	stream	8/15/77	356 (15.0)	3,020 (27.8)	533 (9.0)	356 (8.5)	4,270	1,240
"	stream	11/21/77	919 (30.2)	1,840 (12.8)	1,100 (5.6)	827 (12.3)	4,690	2,850
Kawishiwi-7 (05125000	stream	8/15/77	<125** (--)	502 (9.0)	1,130 (4.6)	251 (3.6)	1,880	1,380
Bob Bay-1 (05125730)	stream	9/27/77	420 (7.2)	2,760 (15.0)	840 (11.2)	240 (12.8)	4,260	1,500
St. Louis-1 (04016500)	stream	8/30/77	580 (6.4)	1,740 (7.6)	483 (5.6)	483 (8.0)	3,290	1,550
St. Louis-3 (04015430)	stream	9/26/77	1,110 (6.9)	3,330 (14.5)	222 (4.6)	889 (6.0)	5,560	2,220
Whiteface-2	stream	9/26/77	1,920 (5.4)	1,200 (17.6)	2,400 (5.8)	720 (8.4)	6,240	5,040
Filson Creek Area	snow	11/21/77	495 (7.7)	1,130 (13.8)	2,190 (5.9)	354 (13.5)	4,170	3,040

*Detection limit, based on one fiber observed

**No fibers observed.

Note:Counting error limits are shown in Appendix III.

Table 4. Ambient concentration and mean aspect ratio for fibers found in water samples (continued)

Location	Type of sample	Date collected	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without chrysotile
			Thousands of fibers/liter (mean aspect ratio)					
Bear Island Lake	Lake	11/21/77	212 (38.6)	636 (31.4)	1,700 (8.4)	636 (7.9)	3,180	2,550
Ely	tap water	11/21/77	244 (45.6)	610 (21.6)	1,200 (10.6)	244 (37)	2,230	1,710
Amax-Babbitt	mine shaft	11/21/77	712,000	89,000	2,050,000	1,250,000	4,100,000	4,010,000

*Detection limit, based on one fiber observed

**No Fibers observed

Note: Counting error limits are shown in Appendix III.

DEPARTMENT OF HEALTH
DIVISION OF ENVIRONMENTAL HEALTH
SECTION OF ANALYTICAL SERVICES

Table 6

AIR SAMPLING PROGRAM AT SILVER BAY, MINNESOTA

		MINNESOTA DEPARTMENT OF HEALTH					NERL Lab. Duluth	Mount Sinai
Sample Number	School	Total Fibers per m^3	Ambiguous Fibers per m^3	Non-amphibole (Not Classified) per m^3	Chrysotile Fibers per m^3	Amphibole Fibers per m^3	Amphibole Fibers per m^3	Amphibole Fibers per m^3
4221	Campton	335,000	104,000	92,000	0	138,000	158,000	252,000
4222	McDonald	143,000	19,000	25,000	1,000	96,000	99,000	100,000
4223	Kelly	472,000	106,000	145,000	0	221,000	230,000	394,000
9061	Campton	135,000	26,000	35,000	3,000	67,000	33,000	53,000
9062	McDonald	234,000	45,000	50,000	25,000	112,000	71,000	358,000
9063	Kelly	213,000	43,000	38,000	11,000	120,000	76,000	240,000
9040	Campton	848,000	238,000	148,000	5,000	450,000	513,000	384,000
9041	McDonald	719,000	196,000	172,000	0	351,000	448,000	502,000
9042	Kelly	1,048,000	239,000	239,000	0	569,000	516,000	533,000
7144a	Campton	614,000	109,000	88,000	26,000	390,000	262,000	335,000
7144b	McDonald	238,000	24,000	30,000	5,000	177,000	235,000	154,000
7144c	Kelly	250,000	36,000	29,000	12,000	174,000	178,000	323,000

* All Minnesota Department of Health values are shown with numbers below 1,000 dropped. All mean values are rounded off to the nearest thousands.

Table 5

AMPHIBOLE AND CHRYSOTILE FIBER CONCENTRATIONS COMPARED TO MEAN BLANK LEVELS FOR WATER SAMPLES

(FIBER CONCENTRATIONS IN FIBERS/LITER x 1000)

LOCATION	DATE COLLECTED	SAMPLE TYPE	FILTER TYPE	FILTER AREA ASHED (mm^2)	FILTER AREA(mm^2)/ VOL.FILTERED(ml)	AMPHIBOLE	MEAN BLANK LEVEL	CHRYSOTILE	MEAN BLANK LEVEL
Partridge-1	8/30/77	Stream	Millipore	453	8.69	110*	89	6,380	692
Partridge-2	5/05/77	"	Not Recorded ***	1735	34.72	427	357	107	2760
Partridge-2	7/25/77	"	Millipore	613	8.69	232	89	929	690
Partridge-2	8/30/77	"	Nuclepore	867	17.24	448	416	1340	745
Partridge-2	11/21/77	"	Millipore	1735	34.72	40.7	357	149	2760
Partridge-5	8/18/77	"	Not Recorded ***	1735	34.72	711	357	4270	2760
Stoney River-2	5/05/77	"	Not Recorded ***	1735	34.72	213*	351	<213**	2760
Stoney River-2	7/25/77	"	Millipore	231	3.47	<88.7	36	1240	276
Stoney River-2	8/30/77	"	Millipore	1735	34.72	102*	357	3170	2760
Stoney River-2	11/21/77	"	Millipore	1735	34.72	264	357	926	2760
Stoney River-5	9/26/77	"	Nuclepore	1735	71.42	1430	1721	715	3085
Dunka-1	8/18/77	"	Not Recorded ***	1735	34.72	582	357	1940	2760
Kawishiwi-4	11/21/77	"	Millipore	1735	34.72	900	357	1100	2760
Kawishiwi-5	7/25/77	"	Millipore	220	3.5	256	36	3860	279
Kawishiwi-5	8/15/77	"	Not Recorded ***	1735	34.72	356	357	3020	2760
Kawishiwi-5	11/21/77	"	Millipore	1735	34.72	919	357	1840	2760
Kawishiwi-7	8/15/77	"	Millipore	1735	34.72	<125**	357	502	2760
Bob Bay-1	9/27/77	"	Nuclepore	1735	17.54	420	423	2760	758
St. Louis-1	8/30/77	"	Millipore	525	8.7	580	90	1740	692
St. Louis-3	9/26/77	"	Nuclepore	433	17.24	1110	416	3330	745
Whiteface-2	9/26/77	"	Nuclepore	1735	69.44	1920	1674	1200	3000
Filson Creek	11/21/77	Snow	Millipore	1735	5.78	495	59.5	1130	460
Bear Island Lake	11/21/77	Lake Water	Millipore	1735	34.72	212	357	636	2760
Ely	11/21/77	Tap Water	Millipore	1735	17.36	244	178	610	1382
AMAX,Babbitt	11/21/77	Mine Shaft	Millipore	154.7	333	712000	3430	89100	26507

*Detection Limit, Based on One Fiber Observed
**No Fibers Observed
*** Assumed to be Millipore

Source: Steven Ring, Minnesota Department of Health

Table 7 Comparison of fiber levels* found in air.

Location	Amphibole	Chrysotile	Non-amphibole non chrysotile	Ambiguous	Total	Total without Chrysotile	Comments	Source
Babbitt	4,750	9,400	8,550	9,400	25,300	18,100	Median values found in Cu-Ni sampling program	Table 1
Bearhead Lake State Park	3,640	2,380	7,350	2,120	17,200	16,300		
Environmental Learning Center	2,700	5,640	26,500	4,600	42,500	34,600		
Erie Mining Office	14,200	6,780	4,360	10,400	36,000	35,000		
Fernberg Rd.	1,520	7,670	9,120	1,820	20,400	12,500		
Toimi	3,590	3,580	6,800	2,390	25,700	19,700		
Hoyt Lakes	21,000	48,200	39,200	17,500	126,000	78,000	Total--all stages of Cascade impactor sample	Table 3
Silver Bay:								
Compton School	264,000	4,000	90,000	207,000	475,000	--	Median values of four samples	Table 5
Kelly School	198,000	6,000	92,000	75,000	361,000	--		
McDonald School	145,000	3,000	40,000	35,000	236,000	--		

* Fibers/m^3

Table 8. Comparison of fiber levels* in water samples.

Type of Sample	Location	Amphibole	Chrysotile		Source
Streams and Rivers	NE Minnesota	<88,700-1,920,000	107 - 6,380,000	380,000-7,920,000	Table 4
	Streams entering Lake Superior	--	--	<2,000,000	Kramer (1976)
	Ottawa River (Canada)	--	--	9,500,000	Cunningham and Pontefract (1971)
Snow	Filson Creek	495,000	1,130,000	4,170,000	Table 4
	Ottawa, Canada	--	--	33,500,000	Cunningham and Pontefract
Lakes	Bear Island Lake	212,000	626,000	3,180,000	Table 4
	Western Lake Superior	--	--	5,000,000-20,000,000	Kramer (1976)
	Eastern Lake Superior	--	--	1,000,000-3,000,000	"
Tap Water	Ely	244,000	610,000	2,320,000	Table 4
	Duluth	45,000,000-100,000,000	--	--	Cook et al. (1976)
	Midland and Bay City, Mich.	--	600,000-1,200,000	--	Beaman and File (1976)

Table 8 cont'd

	Chicago: raw water	--	--	500,000-4,500,000	McMillan et al. 1977
	treated	--	--	100,000-600,000	"
	Canadian cities	--	--	2,000,000-9,500,000	Cunningham and Pontefract 1971
	Thetford Mines, Quebec (near chrysotile asbestos mine)	--	--	172,700,000	"
Beer, wine and soft drinks	Canada, U.S., Europe South Africa	--	--	1,100,000 12,200,000	Cunningham and Pontefract 1971
Mine shaft water	Amax-Babbitt	7.12×10^{8}	8.91×10^{7}	4.1×10^{9}	Table 4
Tailings	Reserve-Silver Bay	at least 5.5×10^{11}	--	--	See text

* Fibers/liter

Figure 1. Location of Air Quality Monitoring Sites.

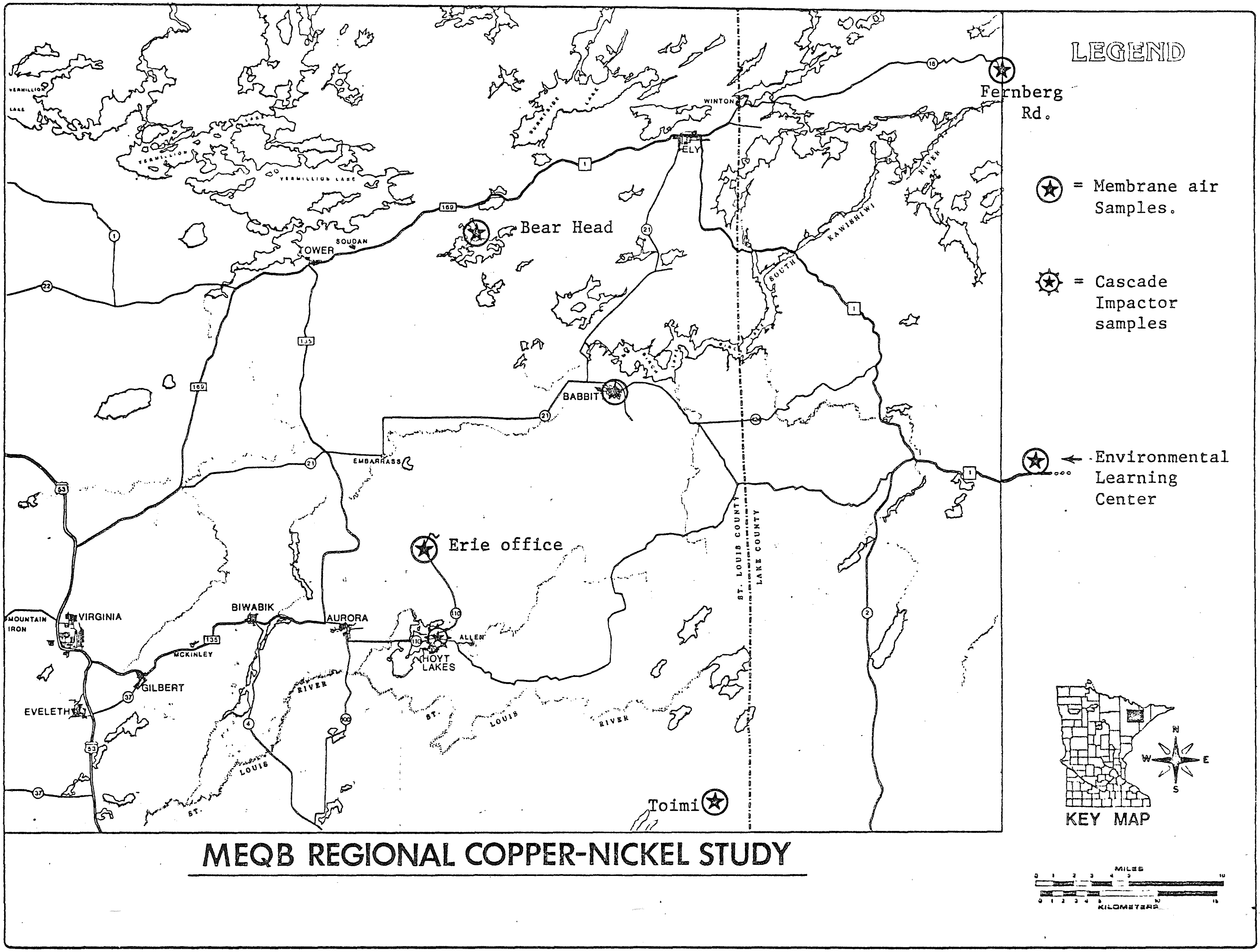


Figure 2. Location of Water Quality and Road Dust Monitoring Sites.

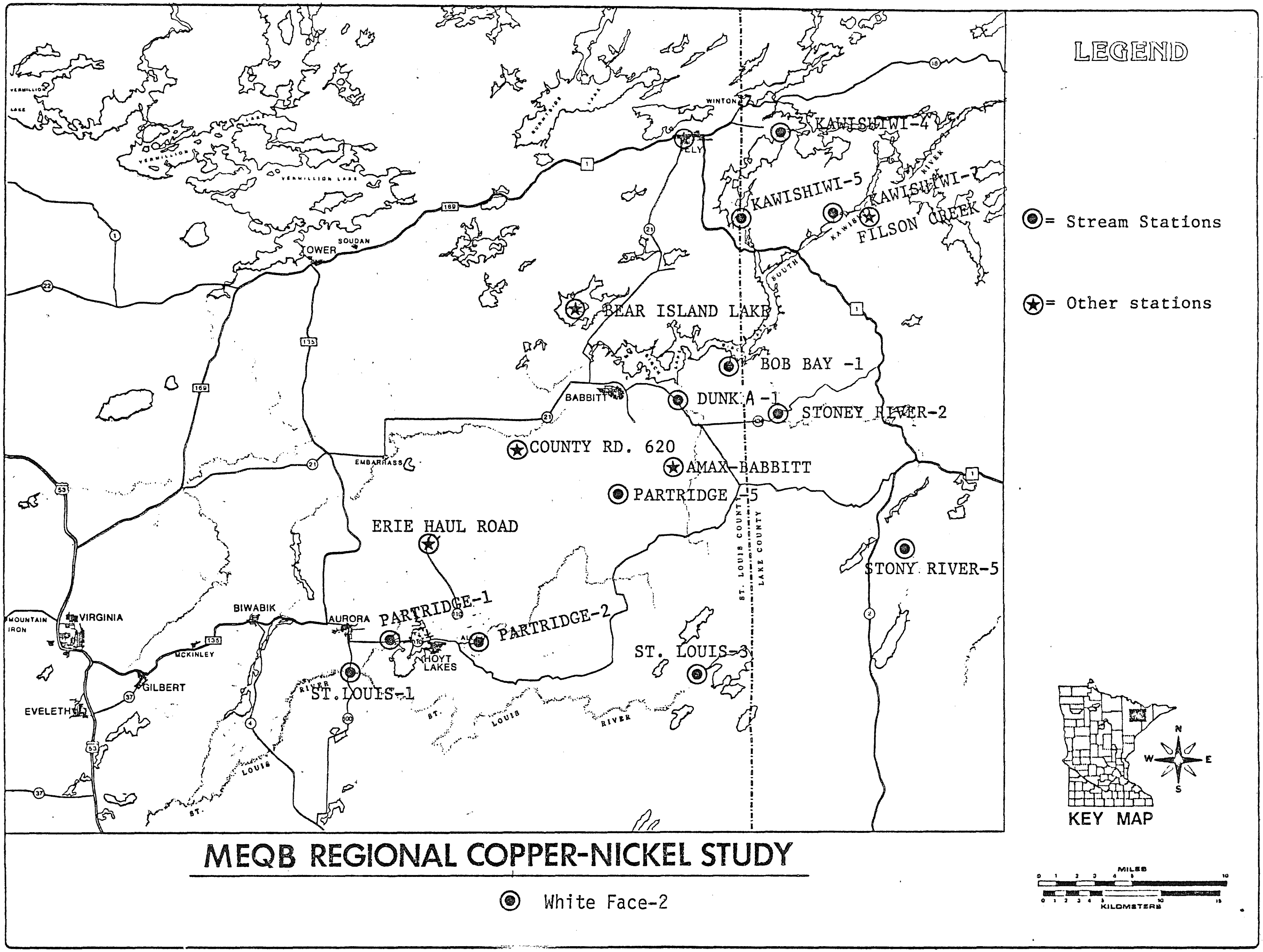
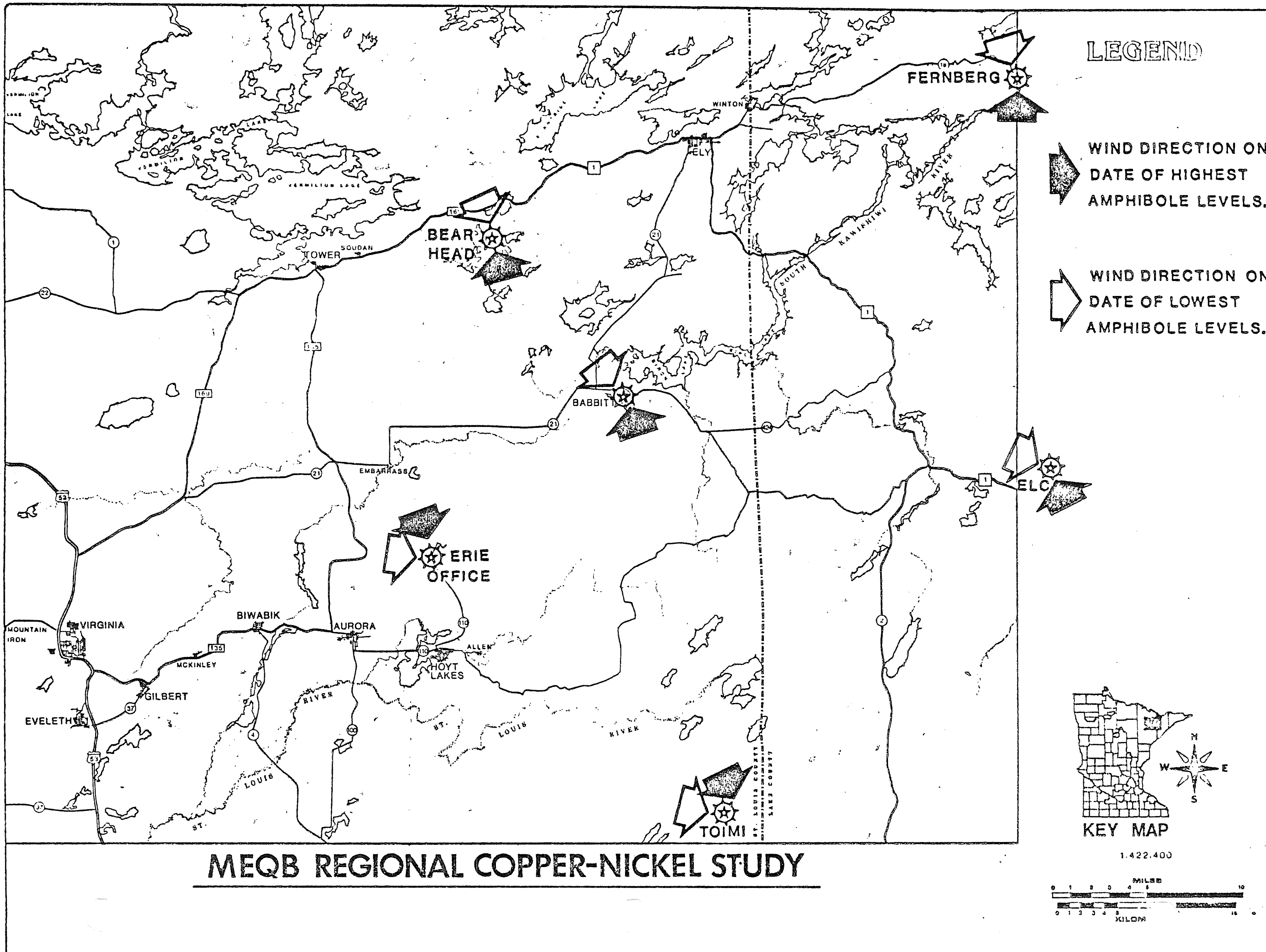


Figure 3 Wind Direction on Days of Highest and Lowest Fiber Levels



APPENDIX I.

Site Location and Dates of Sample Collection for Asbesto Fibers

(1977)

Membrane Filter Air Samples

SITE	6 February	8 March	1 May	12 June	5 August
Fernberg Road (7001)	x	x	x	x	x
Environmental Learning Center (7004)	x	NA	x	x	x
Bear Head Lake State Park (7005)	x	x	x	x	x
Erie Mining Office Building (7008)	x	NA	x	NA	x
Toimi (7007)	x	x	x	x	x
Babbitt (70013)	NA	NA	x	x	x

Cascade Impactor Sample

Hoyt Lakes (7010)	14 October

Stream Samples

Month and Date

	May	July	Aug.	Sept.	Nov.
Partridge-1			30		
Partridge-2	5	25	30		21
Partridge-5			18		
Stoney River-2	5	25	30		21
Stoney River-5				26	
Dunka-1			16		
Kawishiwi-4					21

NA = Not Available

APPENDIX I.. continued

<u>Stream Samples</u>

<u>Month and Date</u>

	May	July	Aug.	Sept.	Nov.
Kawishiwi-5		25	15		21
Kawishiwi-7			15		
Bob Bay-1				27	
St. Louis-1			30		
St. Louis-3				26	
Embarrass-1				26	
Whiteface-2				26	

<u>Snow Sample</u>

Filson Creek Area	21 November

<u>Lake Sample</u>

Bear Island	21 November

<u>City Tap Water</u>

Ely, Minnesota	21 November

<u>Mine Shaft</u>

Amax-Babbitt	21 November

<u>Road Material</u>

St. Louis County Road 620	26 July
Erie Haul Road	27 July

APPENDIX II.

PREPARATION AND ANALYSIS OF CU-NI AIR WATER, AND FLOTATION SAMPLES FOR MINERAL FIBERS*

Preparation of Flotation Samples.

Each sample consisting of 30 ml of suspension was delivered in a small plastic bottle which had previously been cleaned and rinsed in filtered-distilled water.

In order to estimate the mineral fiber concentration of each sample, 2 to 4μl of sample was micropipetted and evaporated on parlodion coated TEM grids. A rough fiber count was made from which the concentration could be calculated. This concentration was used to estimate the volume of sample that when filtered resulted in a total count of 5-20 fibers per grid square. This is important because a loading which is too heavy (too many particles per grid square) will make fiber identification difficult due to interference from nearby particles. A loading which is too light may mean longer analysis time because large areas of the grid must be examined for fibers. This estimate of concentration was performed for every sample at the begining of the program. Later, the estimate was made by examination of a few samples which were compared with previous samples of similar flotation fractions.

After the estimate of fiber concentration was made, a portion of the suspension was was filtered onto 47 mm diameter Nuclepore filters (0.1 μm pore size) with a Millipore filter as backing (HAWP Millipore). The filtration was accomplished by 1) vigorously shaking the sample in its plastic bottle with the cover on, 2) quickly removing the cover and withdrawing a portion of the sample by pipette while swirling the suspension in the bottle, 3) transferring the portion to filtered-distilled water in a crystallization dish, 4) squirting filtered-distilled water into the crystallization dish to stir the suspension, 5) quickly pouring the dilute suspension into the glass filter funnel to begin

*This document was prepared by Steven Ring and Robert Suchanek of the Minnesota Department of Health.

filtration. Three filtrations were done for each sample, a low volume (.05 - 2.0 ml), a high volume (0.15 -5.0 ml), and a filtration to preserve the sample (25 ml). The twenty-five milliliter filtration was pipetted directly to the filtration funnel without the addition of filtered-distilled water.

The Nuclepore filters were transferred to plastic petri dishes and held in place with double-backed tape along the margins of the filter. The filters were dried under a heat lamp for five minutes and then covered with the dish top. The sample material on the filters is quite susceptible to rough handling, especially the 25 ml samples. No suitable compound has been located with which the filters can be treated to stabilize the particles.

AX9002-200 Feed and Tailings.

A sample of feed and tailings material was analyzed to determine the fibers per gram of dry material. These samples had been preserved in a suspension in a plastic bag. The preparation of the samples follows:

1. The mass of the suspension, including the plastic bag, was recorded.
2. The suspension was transferred to a graduated cylinder. Filtered-distilled water was used to rinse the plastic bag.
3. A portion (1 ml) was pipetted from the suspension to make a 100:1 dilution.
4. This dilution was micropipetted onto the parlodion coated TEM grids in 2 μl portions.
5. The TEM grids were carbon-coated and placed on a sponge soaked in acetone for 30 seconds. This removes the parlodion film leaving the sample imbedded in the carbon film.
6. The original suspension was placed in a crucible, and the liquid evaporated so the dry mass could be obtained.

7. The fiber counts were for total fibers (no identification of individual fibers).

The table on the following page summarizes the data and results obtained.

Preparation of Water Samples.

The water samples were collected in large (two liter) plastic bottles and delivered within 24 hours for filtration onto membrane filters. Rapid delivery of the water samples was necessary in order to avoid possible fiber adherence to the collecting vessel wall. Filtration of the samples onto 47 mm diameter membrane filters was done shortly after they were received.

The procedure for filtering the water samples can be summarized as follows:

1. Each sample bottle was shaken vigorously just before an aliquot was poured into a graduated cylinder.
2. The sample aliquot was quickly poured into a filter funnel and drawn through a Nuclepore or Millipore filter. At least one Nuclepore and two Millipore filters were prepared for most samples.
3. Each filter was removed from the filter apparatus, placed in a small plastic petri dish, dried, and covered tightly.

The amount filtered onto each filter varied, but in all cases we attempted to obtain a range of volumes that encompassed a low particle density that might be directly counted (on the Nuclepore) and a high particle density that was near the maximum that could be filtered. Sensitivity limits for the volumes filtered are shown in the table below.

ml H_2O Filtered	Sensivity Limits (Fibers/Liters)
25	400,000
50	200,000
75	133,000
100	100,000
150	67,000
300	33,000
500	20,000

VOLUME, MASS AND FIBER DATA FOR AX9002-200T AND AX9002-200F

	AX9002-200T TAILS	AX9002-200F FEED
Mass of Suspension in Bag (Includes Bag)	52.12g	55.3g
Volume of Suspension After Transfer to Graduate Cylinder (Wash Water Used)	82.0 ml	99.0 ml
Mass of Contents of Graduate	87.93g	101.35g
Mass of Wash Water Added to Graduate	35.81g	46.05g
Volume of Suspension in Bag Assuming Density of 1.0 (82ml - 35.81ml)	46.19 ml	52.95 ml
Tailing Volume Removed for Dilutions	3.0 ml	4.0 ml
Volume of Tailing Before Drying (82-3)	79.0 ml	95.0 ml
Dry Mass of Tailings (79ml dried)	10.48g	7.53g
Total Fiber Concentration (for Graduate Suspension)	2.62×10^{11} fibers/liter	2.02×10^{11} fibers/liter
Total Fiber Concentration (For Plastic Bag Suspension)	4.65×10^{11} fibers/liter	3.78×10^{11} fibers/liter
Fibers Per Gram Dry Material	1.975×10^{9} fibers/g	2.55×10^{9} fibers/g

Sensitivity limits were calculated using the following values and assumptions.

1. Assume 1 fiber was found per 10 grid squares.
2. Assume a filter area (actual area containing sample) of 960 sq. mm.
3. Assume a grid opening area of .0096 mm^2.

EXAMPLE:

$$\frac{.1 \text{ fibers/grid opening} \times 960 \text{ mm}^2}{.0096 \text{ mm}^2 \times 50 \text{ ml Filtered}} \times 1000 \text{ ml/Liter} = 200{,}000 \text{ Fibers/Liter}$$

An attempt was made to directly prepare the Nuclepore filters (see description elsewhere). This attempt was not successful due to the high levels of organic material on the filters. An ashed, organic matter free, preparation technique was used (see Ashing Preparation Technique). The samples were counted and the fibers identified as described under Fiber Counting Procedure.

Preparation of Air Samples.

The air samples were collected on 102 mm diameter Millipore membrane filters (4.5 μm pore size). While methods do exist for direct transfer of a portion of Millipore filter to a TEM grid for analysis, there are serious questions concerning sample loss associated with these procedures. In addition, environmental samples often are too heavily loaded or contain too many organic particles to allow a direct transfer technique. For these reasons a method which removes the filter material and organics was used (see Ashing Technique).

Ashing Preparation Technique.

The ashing procedure uses a low temperature asher, sometimes called a plasma asher, to remove the filter material and organics from the sample. The sample is placed in a chamber with ionized oxygen which is highly reactive. The organics are oxidized at a low temperature, leaving the minerals and other non-combustibles.

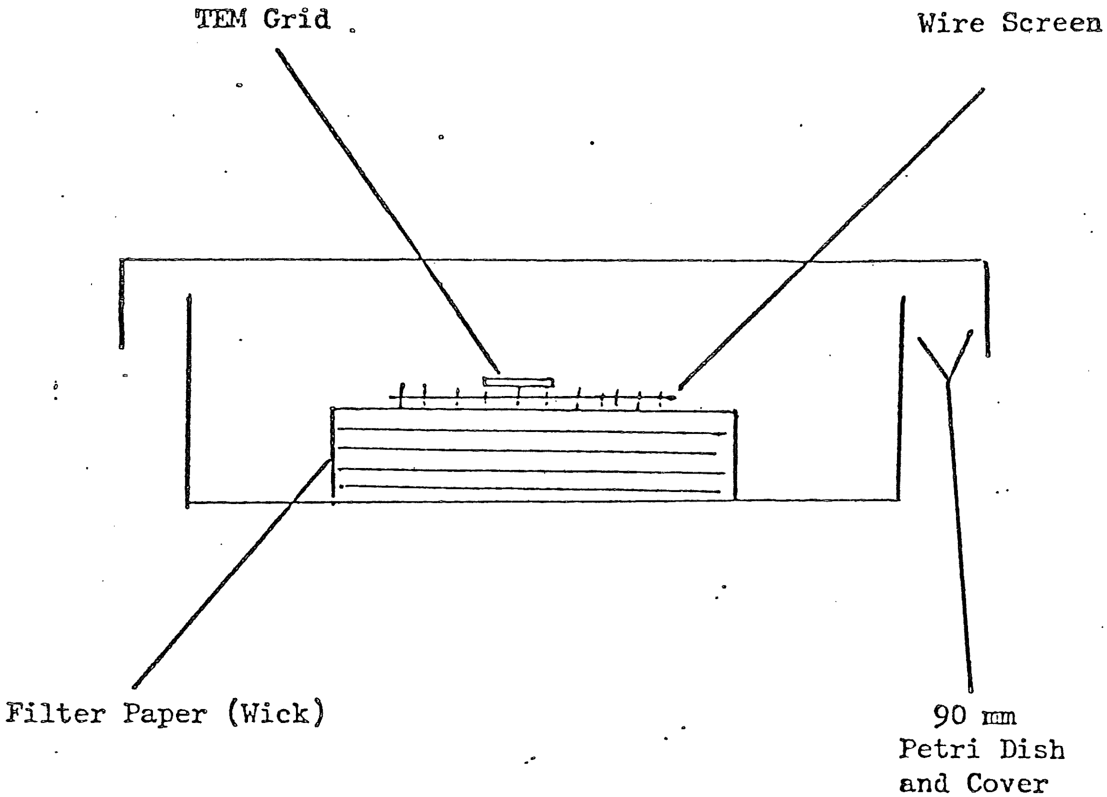
To prepare a sample for ashing, a piece of membrane filter (either Millipore or Nuclepore) containing the sample was cut and carefully measured. In some cases, the whole membrane filter was ashed. The amount of filter which was ashed for air and water samples was determined by experience and trial and error. The area of the piece of air sample filter which was ashed ranged from 9.36 cm^2 to 19.32 cm^2 (the whole filtration area was 67.2 cm^2). For water samples where the original filtration area was 9.60 cm^2, the whole filter was often ashed. The sample was placed sample side down in a crystallization dish (50 mm diameter). The sample was ashed for approximately two hours at 25 watts. During the last 5 to 15 minutes, the power was increased to 75 watts. When the sample was throughly ashed, the low temperature asher was allowed to cool for about 45 minutes before removing the sample. The crystallization dishes were covered immediately upon removal from the low temperature asher.

The ash was resuspended in filtered-distilled water (about 25 ml) using an ultrasonic probe for 30 seconds. The suspension was filtered onto 47 mm diameter Nuclepore (0.1 μm pore size) filters. These filters were removed from the filtration apparatus and placed in plastic petri dishes (50 mm diameter) with double-backed tape arranged to adhere to the filter margins and prevent the filter from clinging to the dish cover or flapping about during coating and storage. The direct technique was used to prepare these filters for TEM analysis.

<u>Direct Preparation Technique</u>.

1. Coat the Nuclepore filter with carbon and gold (4 mm of gold wire evaporated from a tungsten wire about 8 inches above the sample).
2. Mount 3 mm square section of the coated filter on the shiney side of 200 mesh general copper TEM grids which have been placed on the wire screen of a modified Jaffe-Wick washer (see illustration).

Modified Jaffe-Wick Washer



3. Add a drop of chloroform to each filter square and fill the washer with enough chloroform to saturate the wick and bring the level to about 1/2 the height of the screen. Cover with the top of the petri dish.
4. Allow the sample filter to dissolve for 5 to 16 hours.
5. Remove the grids from the washer, allow them to air dry and store them in a clean grid box.

Carbon and Gold Coating Technique.

Nuclepore filters and other samples are coated prior to TEM examination. All of the Nuclepore filters used in this study were carbon and gold coated to provide a support film for the fibers (carbon) and an internal standard for the interpretation of diffraction images (gold). Coating was done in an Edwards vacuum evaporator.

Carbon coating is done by mounting a sharpened, spectroscopically pure, rod of carbon above the samples to be coated and then passing an electric current through the carbon rod. The electric current heats the rod and causes the carbon to evaporate into the vacuum of the coater chamber and onto the samples below.

Gold coating is done in a manner similar to the carbon coating except that a small piece of gold wire is mounted on a tungsten filament through which an electric current is passed to heat and evaporate the gold. The gold coating was always done after the carbon coating, but the sample was not disturbed between coatings since it was possible to simply switch from the carbon to the gold electrically. A gold coating which is too heavy reduces illumination, and the gold crystals impair resolution of fine detail in the sample. The amount of gold which was evaporated was adjusted so that only the strongest gold ring [(111) plane in gold crystal] was suitable for measurement on the diffraction pattern negative.

During preparation of the first flotation sample it was discovered that some materials was being lost when the carbon film was too thin. For this reason, an especially heavy film was used in the preparation of these samples.

Fiber Counting Procedures.

The grid to which the sample was transferred was a circular, 3 mm diameter, 200 mesh copper support. The grid openings were approximately .00784 mm^2 in area.

Grid openings were selected on a random basis from among 25 grid openings in the area of the grid that produces the best x-ray spectra (least amount of scattering) on our microscope. Each grid was completely scanned for fibers using a binocular viewing scope at 21,000X magnification.

For each sample, a minimum of 40 total fibers of 3:1 or greater aspect ratio were counted. At forty fibers the count was considered complete (confidence intervals for 40 fibers based on the Poisson distribution -28.5%, + 36.2%). However, since the entire grid square area was used to arrive at a mean fiber/unit figure, it was necessary to count the remainder of the fibers on the grid square after forty fibers had been counted. On some samples, which were lightly loaded, the count was stopped after 20 grid squares were counted, even though forty fibers had not been reached.

Each fiber was measured for length and width at the time of counting by means of etched gratings on the large TEM screen.

Fiber Identification Procedure.

The general classification of each fiber was made at the time of counting by the microscope operator. This was accomplished in the following manner:

1. Fiber morphology was examined for mineral characteristics.
2. A selected area electron diffraction pattern was obtained for each fiber. This method allows a specific area of the sample (as small as .4 μm) to be examined for crystal structure. After the tilting stage for the microscope was installed, some fibers were tilted into certain crystallographic orientations to allow for a more complete characterization.
3. Energy dispersive x-ray analysis was obtained by focusing the electron beam on each fiber. The x-rays which result are characteristic of elements in the sample. This gives information about the chemical composition of the fiber.

Each of these methods may be obscured by interfering material on the sample, and occasionally the only information obtained is the fiber dimensions.

Each fiber was analyzed in the microscope and determined to be in one of four categories: amphibole, chrysotile, non-asbestos (non-amphibole, non-chrysotile), ambiguous (unknown). In some cases, electron diffraction and x-ray energy dispersive spectroscopy (EDS) provide more specific identification of a mineral. Chrysotile is relatively easy to identfy since its diffraction pattern and morphology are unique. Because of its tubular or scrool-like structure, certain spots in the diffraction pattern are streaked, and the hollow core is visible in the TEM at high magnifications. There are few possible confusing minerals.

In contrast to chrysotile, there are many minerals which have diffraction patterns or chemical composition and morphology similar to the amphiboles. Amphibole minerals are also the primary minerals of concern on these samples since most of the chrysotile which was found can be attributed to the contamination of filters, samplers, and laboratory equipment.

A discussion of the use of each method to categorize mineral fibers follows.

Morphology.

Morphology is often used to identify chrysotile fibers. These fibers have a tubular or scroll-like structure, and the hollow core is easily visible at high magnifications in the electron microscope. Other minerals may be separated from non-mineral fibers (for example, silicate structures characteristic of some types of algae) since the mineral fibers are generally smooth sided. It was necessary, however to use electron diffraction to positively separate mineral from non-mineral fibers in many cases since the morphology was inconclusive.

A particular cleavage can also provide evidence that the mineral is not amphibole (i.e. conchoidal fracture).

Energy Dispersive X-Ray Spectroscopy (EDS).

The x-rays which resulted from the excitation of the atoms in the minerals subjected to electron beam bombardment were emitted in a spectrum of enery levels. Each energy level was characteristic of a given element in the mineral. By examination the energy spectrum from 1000 to 8000 electron volts, it was possible to identify most of the common elemental components of the minerals found in the rocks of northern Minnesota.

Most fibers were analyzed until the peak height of the largest peak was 800 counts. Smaller fibers were often analyzed for fewer counts because their count rate was so low that a full nalysis would have been too time consuming. X-ray analysis time for each fiber was about one minute.

In the microscope, EDS analysis was used in a qualitative way to confirm or reject the operator's classification of the diffraction pattern. Many fibers may quickly be identified as non-amphibole on the basis of EDS. But it is impossible to make a positive identification of an amphibole on the basis of qualitative EDS alone.

For the final identification of a fiber, the EDS spectra was used quantitatively to separate the fibers into several mineral categories based on their chemical compositions. This did not identify specific minerals; it merely indicates possible minerals with a certain composition.

Peaks were integrated over fixed channel widths which represent an average full peak width for most of the elements in these samples. A background channel was obtained in part of the spectrum free of peaks. A background area of the grid, where no fiber or other particles were present, was analyzed on many samples to help eliminate system and sample substrate peaks from the analysis. Background system peaks were subtracted from the raw integrals, and the resulting integrals were divided by the silicon integral to give a ratio for each peak. These ratios were compared to ratios obtained from standard minerals and published ratios for different minerals to place a fiber in a particular chemical composition category.

Many of these groups had compositions which no amphibole mineral could have. Fibers in these groups were classified as non-amphibole. Fibers in categories which might contain amphibole minerals were identified on the basis of electron diffraction analysis.

Electron Diffraction Analysis.

An attempt was made to obtain an electron diffraction pattern from each fiber. In some instances, this was impossible. Very thin fibers have too few diffracting planes to give adequate brightness to the pattern. Extremely dense fibers do not allow enough beam penetration to obtain a good diffraction pattern unless there is a thin area at one end or edge which may be used. The presence of interfering material may also make interpretation of a pattern impossible because it may be difficult to determine which particle is producing the pattern. Some material produces no diffraction pattern since there is no crystal structure in the material. All of these patterns would be classified as "ambiguous" or "no pattern".

Fibers which do produce with the grid in the untilted position are not usually oriented for easy diffraction pattern interpretation. A wide assortment of crystal planes which happen to fulfill the Bragg condition will diffract and no regular array of spots with uniform intensity will be produced. Occasionally the crystal will be oriented so that the electron beam is parallel to the zone axis of a set of crystal planes. This will produce a regular array of uniformly intense spots in the diffraction pattern.

Patterns which are not in this zone axis condition may be very difficult to interpret. Overlapping lave zones, double diffraction, and "screening in", may make it impossible to relate distances and angles between spots in the pattern to the structure of the crystal. There are, however, some characteristics which may identify a diffraction pattern as amphibole even when the pattern is less than ideal.

An amphibole fiber which lies on a TEM grid usually has its C dimension oriented approximately perpendicular to the beam. As a result, most amphibole diffraction patterns exhibit a spacing which represents about 5.2 Å in the crystal structure [the spacing of the (001) planes]. By defocusing the projector lens it is possible to examine the orientation of the fiber with respect to its diffraction pattern. The 5.2 Å spacing should occur along the length of the fiber. Perpendicular to the fiber the spacing between diffraction spots is highly variable, depending on the fiber orientation. One common orientation occurs when the fiber is lying on or nearly on the (100) plane. Spacings in the pattern then represent the b and c dimensions in the crystal. Since the b dimension is the largest in the monoclinic amphiboles, this is the smallest dimension which will occur in the diffraction patterns. This dimension is quickly recognized with the aid of the gold rings [Au (111) has d = 2.355, amphibole (080) has d $\approx$ 2.28]. Many of the patterns which are seen in amphibole asbestos standards exhibit this spacing. There are other spacings which may be recognized, but they are extremely difficult to determine unless the crystal is oriented near a zone axis. Thus microscope identification of amphibole diffraction patterns with the grid not tilted, depends on comparing patterns in the scope to patterns obtained from amphibole mineral standards, estimating some interplanar spacings, and observing the orientation of the fiber to the pattern.

This method works well but is not positive. There are some minerals (i.e., some pyroxenes, talcs, magnetite, etc.) which are not amphibole but may be identified as such. For this reason, many of the fibers were tilted to a zone axis orientation. A micrograph of the diffraction pattern was taken. The distances from the central transmitted spot to five spots on the diffraction pattern (five reciprocal lattice vectors) were measured using a light microscope stage. The angles between the first vector and the other four were also measured. A camera constant was obtained from the diameter of the (111) plane of gold. An attempt was made using a computer to match the interplanar spacing of different mineral standards to the spacings represented by the five distances. The five spots were selected on two lines so that the indexing of each spot by comparing distances, could be checked by vector addition. Finally, the four angles were compared to the interplanar angles for those planes in the mineral standard for a match.

The mineral cell constants which the pattern was compared to were selected by the EDS categorization of the fiber (see Table 1). Some patterns had more than one matching mineral, but usually one could be selected when both the pattern and chemistry were considered. Some patterns had no match, indicating that the mineral standards list may not be complete. The number of fibers in a sample which were tilted varied from zero - 80% of the fibers. Usually 10-20% of the fibers had patterns which were measured.

Final Identification.

The final identification of a fiber was determined by:

1. Positively identifying the measured diffraction pattern.
2. Using these identifications to confirm and characterize the EDS mineral groups.
3. The information on each fiber (EDS and diffraction) was examined, and the filter was classified (amphibole, chrysotile, non-amphibole-non-chrysotile, or ambiguous).

An example of the final identification procedure for sample IP9003-200T-1A follows (see Table 2). In this sample, six of the thirteen fibers in actinolite hedenbergite group were identified as amphibole on the basis of diffraction pattern. Two of these were tilted onto a zone axis and the diffraction patterns were matched. These measurements matched those that would have been obtained from an actinolite.

Table 1.

EDS MINERAL CATAGORIES AND MINERALS USED
FOR IDENTIFICATION OF ELECTRON DIFFRACTION PATTERNS

X-RAY I.D.	MINERAL GROUP	MINERALS USED FOR DIFFRACTION
1	Non-Silicates	
2	Epidote-Biotite-Chlorite	Epidote, Biotite, Chlorite, Plagioclose, Albite, Orthoclase, Hornblende
3	Hornblende-Augite	Hornblende, Grunerite, Hedenbergite, Augite, Chlorite, Pigeonite, Actinolite
4	Chrysotile, Talc, Enstatite	
5	Fiberglass	
6	Ferroactinolite-Actinolite-Hedenbergite	Actinolite, Hedenbergite, Tremolite, Hornblende, Augite, Pigeonite
7	Ambiguous	Minerals from ID No. 3,6,9,and 10
8	Feldspar	Plagioclase, Orthoclase, Albite, Epidote, Biotite, Hornblende, Augite
9	Tremolite-Diopside	Tremolite, Diopside, Augite, Pigeonite, Actinolite
10	Cummingtonite-Grunerite-Hypersthene-Minnesotaite-Olivine	Cummingtonite, Grunerite, Hypersthene, Minnesotaite, Hornblende, Orthoferrosilite, Clinoferrosilite, Anthophyllite
11	Ambiguous High Element/Si Ratio	
12	No X-Ray Data	
13	Quartz-Diatom-Silicon ONLY	

Table 2.

TABLE OF EDS MINERAL GROUPS AND ELECTRON DIFFRACTION IDENTIFICATION FOR SAMPLE IP9003-200T-1A

EDS Mineral Group	X-Ray ID No.	No. of Fibers	No. Identified by Diffraction as Amphibole in TEM	No. of Patterns Measured	Identification of Patterns	No. of Amphibole Identified by Diffraction	Final ID
Non Silicate	1	0					
Epidote-Biotite Chlorite	2	5		1	Hornblende (Amphibole)	1	1-Amphibole 4-Non-Amphibole
Hornblende-Augite	3	4	1	1	Hornblende (Amphibole)	2	3-Amphibole
Chrysotile-Talc	4	0					
Fiberglass	5	0					
Ferroactinolite-Actinolite Hedenbergite	6	13	4	2	2-Actinolite (Amphibole)	6	13-Amphibole
Ambiguous	7	1					1- Ambiguous
Feldspar	8	7		1	Plagioclase (Non-Amphibole)		7- Non-Amphibole
Tremolite-Diopside	9	1					1- Non-Amphibole
Cummingtonite-Grunerite Hypersthene	10	2					2- Ambiguous
High Element/Si	11	0					
No X-Ray Data	12	5					5- Ambiguous
Silicon Only	13	0					

fiber (in the (101) zone axis for both of these fibers), but no other minerals with which the patterns were compared. In addition, the Mg/Si, Fe/Si, and Ca/Si ratios from the other seven fibers in this group agreed with the ratios for those with amphibole diffraction patterns. On this basis, all the fibers in the chemical composition group were classified as amphibole (actinolite is an amphibole mineral).

The epidote-biotite-chlorite group had one fiber with a measured pattern that matched hornblende. This fiber was very thin (.03 μm wide), and the EDS integrals were small (<250 counts in Si integral). Therefore, the counting error was high and small inaccuracies in the background subtraction or other integrals could greatly affect the ratios. This fiber was classified as amphibole, but the others in this group were called non-amphibole since no amphibole mineral has a chemical composition which matches this group's composition.

The feldspars were all classified as non-amphibole. These fibers contained calcium, and probably they were all plagioclase as the one measured pattern suggests.

The one tremolite-diopside chemical group fiber was classified as non-amphibole on the basis of the diffraction pattern in the electron microscope.

The two fibers with x-ray ID number 10 were both classified as ambiguous. Although this group contains amphibole minerals, there was no information available to indicate they were present in this sample.

No x-ray data was obtained for five fibers. The diffraction patterns were also inconclusive so all of these fibers we classified as ambiguous.

Of the three types of samples (flotation, air, and water), the counting and identification of minerals in the flotation samples was the most thorough. An attempt was made to tilt every fiber to a zone axis on sample AX9002-200T-1A. A large percentage of these fibers were identified and this ore sample was well characterized for mineral fibers. Compared to the air and water samples, there was little interference from different particulates on the flotation.

The air samples were also free of interference, but some remnants of the filter material remained. Many chrysotile fibers were found in the air samples which can be attributed primarily to contamination of the filters.

Many of the water samples were extremely difficult to count. Diatom fragments, unashed organics, and many unidentified particulates often obscured or confused fibers to be counted. Even when small amounts of the sample were filtered, resulting in high sensitivity limits, fiber counting was achieved with extreme difficulty. The chrysotile level found in the water samples can be accounted for by the chrysotile level in the blanks. Some of the water samples were collected on Nuclepore filters which may be contaminated with amphibole fibers. As a result, a few of the blanks show amphibole fibers present.

Appendix III.

95 Percent confidence intervals* for fibers found on membrane air samples. February 6, 1977

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Road	8.40- 1,870**	6,250- 13,600	7,070- 14,800	544- 3,910	16,900- 27,800	8,750- 17,100
Environmental Learning Center	177- 5,270	2,520- 11,500	24,600- 44,800	1,180- 8,500	34,100- 57,200	29,000- 50,600
Bearhead Lake State Park	486- 2,880	5,560- 11,000	2,870- 7,080	240- 2,260	11,400- 18,800	4,640- 9,700
Toimi	12,000- 22,600	1,640- 6,790	5,480- 13,200	875- 5,200	24,900- 39,100	21,700- 35,100
Erie Mining Office	15,900- 33,100	3,100- 12,900	1,220- 8,780	5,760- 17,700	33,800- 57,300	27,900- 49,600
Babbitt	--	--	--	--	--	--

* These include only counting errors. Other sources of error are not included.

** Fibers/m^3

95 percent confidence intervals* for fibers found

on membrane air samples. March 8, 1977.

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Fernberg Road	2,040- 6,560**	5,010- 11,200	4,070- 9,830	1,020- 4,650	15,800- 25,800	9,190- 17,100
Environmental Learning Center	--	--	--	--	--	--
Bearhead Lake State Park	1,450- 5,210	1,090- 4,530	6,900- 13,500	916- 4,180	13,300 22,000	11,200- 19,300
Toimi	264- 2,490	3,540- 8,380	4,520- 9,820	264- 2,490	10,900- 18,500	6,120- 12,100
Erie Mining Office	--	--	--	--	--	--
Babbitt	--	--	--	--	--	--

* These include only counting errors. Other sources of error are not included.
** Fibers/m^3

95 percent confidence intervals* for fibers

found on membrane air samples. May 1, 1977.

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total fibers	Total without Chrysotile
Fernberg Road	1,270- 5,790**	0- 1,360	6,850- 14,900	596- 4,280	10,800- 20,500	10,800- 20,500
Environmental Learning Center	1,070 10,100	0- 3,640	9,750- 26,800	12,000- 30,400	29,000- 54,900	29,000- 54,900
Bearhead Lake State Park	1,180 8,490	0- 2,690	10,000- 24,300	4,000- 14,300	19,600- 38,000	19,600- 38,000
Toimi	9,410- 23,800	0- 2,840	6,470- 19,100	5,330- 17,100	27,300- 49,000	27,300- 49,000
Erie Mining Office	7,950- 23,400	23.7- 5,270	5,200- 18,600	5,200- 18,600	25,500- 49,400	24,700- 48,300
Babbitt	911- 8,570	0- 3,090	5,790- 18,600	5,190- 17,500	16,300- 34,900	16,300- 34,900

* These include only counting errors. Other sources of error are not included.
** Fibers/m^3

95 percent confidence intervals* for fibers found on membrane air samples, June 12, 1977.

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total fibers	Total without Chrysotile
Fernberg Road	86.6- 2,580**	1,480- 6,110	1,720- 6,580	389- 3,670	5,790- 13,200	3,280- 9,300
Environmental Learning Center	1,510- 14,200	15,900- 41,200	10,600- 32,600	1,510- 14,200	40,800- 77,200	19,100- 46,200
Bearhead Lake State Park	26,900- 63,700	0- 6,810	25,500- 61,500	2,990- 21,500	68,500- 122,000	68,500- 122,000
Toimi	1,320- 7,820	2,870- 11,000	4,570- 14,100	4,140- 13,300	18,600- 34,600	13,600- 27,700
Erie Mining Office	--	--	--	--	--	--
Babbitt	2,420- 10,000	5,380- 15,300	142- 4,240	5,380- 15,300	1,830- 3,400	1,050- 2,310

* These include only counting errors. Other sources of error are not included.
** Fibers/m^3

95 percent confidence intervals* for fibers found on membrane air samples, August 5, 1977.

Site	Amphibole	Chrysotile	Non-amphibole Non-chrysotile	Ambiguous	Total fibers	Total without Chrysotile
Fernberg Road	492-3,540**	7,420-14,800	6,160-13,000	669-3,980	18,200-28,900	8,950-16,900
Environmental Learning Center	9.31-2,070	2,850-8,750	4,260-11,100	9.31-2,070	9,390-18,600	5,140-12,400
Bearhead Lake State Park	3,920-15,000	13,900-31,100	3,370-13,900	20.4-4,550	27,500-50,100	9,980-25,200
Toimi	245-2,310	1,240-4,440	3,470-8,030	365-2,630	7,210-13,300	5,120-10,400
Erie Mining Office	2,000-8,280	2,330-8,910	2,000-8,280	1,360-6,990	11,800-23,600	7,840-17,900
Babbitt	1,540-11,100	11,600-29,300	3,920-16,200	1,540-11,100	26,300-50,700	10,900-28,200

* These include only counting errors. Other sources of error are not included.
** Fibers/m^3

95 percent confidence intervals* for fibers in cascade impactor sample from Hoyt Lakes, October 14, 1977.

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Stage 3	16.7-3,730**	5,630-16,600	5,120-15,700	1,880-9,660	17,400-34,100	9,240-22,300
Stage 4	0-1,980	2,210-9,150	583-5,490	13.4-2,980	4,100-12,600	868-6,240
Stage 5	7,750-26,200	3,510-18,000	12,400-34,000	2,020-14,500	36,800-69,500	29,400-59,300
Stage 6	0-6,590	7,360-30,500	0-6,590	44.6-9,950	8,570-32,800	44.6-9,950
Stage BL	1,740-12,500	3,700-16,900	2,360-14,000	1,170-11,000	15,600-37,000	9,000-26,500

* These include only counting errors. Other sources of error are not included.

** Fibers/m^3

95 percent confidence intervals* for fibers found in water samples

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without Chrysotile
Partridge-1 (8/30/77)	2.75- 613**	4,850- 8,250	2.75- 613	683- 2,310	6,200- 9,980	841- 2,590
Partridge-2 (5/5/77)	116- 1,090	2.67- 594	235- 1,400	65.9- 934	815- 2,510	738- 2,370
Partridge-2 (7/25/77	47.8 678	480- 1,620	1.94- 431	1.94- 431	766- 2,110	125- 902
Partridge-2 (8/30/77)	122- 1,150	694- 2,350	69.1- 980	122- 1,150	1,630- 3,860	614- 2,200
Partridge-2 (11/21/77	14.9- 88.7	93.5- 226	42.1- 142	6.20- 176	287- 493	160- 322
Partridge-5 (8/18/77	193- 1,820	2,730- 6,330	193- 1,820	4.44- 990	4,040- 8,240	733- 3,040
Stoney River-2 (5/5/77)	5.33- 1,190	0- 787	470- 2,790	132- 1,870	1,020- 3,920	1,020- 3,920

* These include only counting errors. Other sources of error are not included.
** Thousands of fibers/liter.

95 percent confidence intervals* for fibers found in water samples

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without chrysotile
Stoney River-2 (7/25/77)	0- 327**	678- 2,080	0- 327	54.8- 777	877- 2,410	54.8- 777
Stoney River-2 (8/30/77)	2.56- 569	2,150- 4,500	287- 1,470	166- 1,190	3,270- 6,040	707- 2,270
Stoney River-2 (11/21/77)	32.0- 955	371- 1,910	291- 1,730	635- 2,430	2,140- 4,880	1,410- 3,760
Stoney River-5 (9/26/77	525- 3,120	147- 2,090	5.96- 1,330	5.96- 1,330	1,310- 4,690	823- 3,750
Dunka-1 (8/18/77)	120- 1,700	931- 3,570	46.9- 1,400	544- 2,800	2,680- 6,460	1,200- 4,070
Kawishiwi-4 (11/21/77)	412- 1,710	549- 1,970	162- 1,160	220- 1,310	2,100- 4,400	1,220- 3,090
Kawishiwi-5 (7/25/77)	31- 928	2,600 5,500	80 1,130	31- 928	3,340 6,560	360- 1,850

* These include only counting errors. Other sources of error are not included.
** Thousands of fibers/liter

95 percent confidence intervals* for fibers found in water samples

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total Fibers	Total without chrysotile
Kawishiwi-5 (8/15/77)	43.0 1,280**	1,760- 4,840	110- 1,560	43.0- 1,280	2,730- 6,330	499- 2,560
Kawishiwi-5 (11/21/77)	441- 1,690	1,120- 2,840	570- 1,930	379- 1,570	3,490- 6,160	1,930- 4,040
Kawishiwi-7 (8/15/77	0- 463	137- 1,290	517- 2,140	30.4- 906	1,050- 3,100	689- 2,470
Bob Bay-1 (9/27/77)	168- 865	2,020- 3,680	459- 1,410	65.3 614	3,330- 5,370	970- 2,210
St. Louis-1 (8/30/77	213- 1,260	1,030- 2,750	157- 1,130	157- 1,130	2,270- 4,590	885- 2,510
St. Louis-3 (9/26/77)	360- 2,590	1,870- 5,500	5.56- 1,240	242- 2,280	3,590- 8,200	1,070- 4,090
Whiteface-2 (9/26/77)	829- 3,780	389- 2,800	1,150- 4,410	148- 2,100	4,070- 9,140	3,120- 7,710

* These include only counting errors. Other sources of error are not included.
** Thousands of fibers/liter

95 percent confidence* intervals for fibers found in water samples

Site	Amphibole	Chrysotile	Non-amphibole non-chrysotile	Ambiguous	Total fibers	Total without chrysotile
Filson Creek Area Snow (11/21/77)	199- 1,020**	647- 1,840	1,490- 3,110	115- 824	3,180- 5,380	2,200- 4,100
Bear Island Lake (11/21/77)	26- 760	234- 1,400	970- 2,700	230- 1,400	2,150 4,500	1,630 3,780
Ely-tap water (11/21/77)	60- 630	290- 1,100	740- 1,800	60- 620	1,600- 3,200	1,100- 2,500
Amax-Babbitt-Mine Shaft (11/21/77)	308,000- 1,400,000	2,320 496,000	1,300,000- 3,070,000	681,000- 2,090,000	3,000,000 5,460,000	2,930,000- 5,360,000

*These include only counting errors. Other sources of error are not included.

**Thousands of fibers/liters.