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Anthophyllite Asbestos: The Role of Fiber Width in Mesothelioma Induction

Part 1: Epidemiological Studies of Finnish Anthophyllite Asbestos

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Abstract

Anthophyllite asbestos only occurs in a few parts of the world in sufficient quantities to be mined. The largest deposits of anthophyllite asbestos occur in Finland where it was mined for more than 75 years and very extensively used and distributed, anciently, for more than six millennia. Anthophyllite is one of the five minerals known collectively as amphibole asbestos. Studies of the effect of these five mineral fibre types when inhaled have shown that fibre width is an important determinant of mesothelioma induction. Only the “thinner” fibres or those with fiber diameter dimensional profiles predominantly less than 0.25 – 0.30 µm, are clearly mesotheliogenic. The “thicker” ones or those whose predominant widths are greater than these diameters do not appear to show an observable attendant risk of mesothelioma. Observations based on studies of at least, two “thick” forms of amphibole asbestos support these hypotheses. The one is Bolivian crocidolite; the other Finnish anthophyllite. The Finnish anthophyllite industry presents an important opportunity to study the robustness of the theory that fibre width is key to mesothelioma genesis as vast numbers of people in all sectors of the Finnish industry and their families have historically incurred massive fiber exposures sufficient to cause a gross excess of asbestosis. Nonetheless, in spite of these long term, high dose exposures clear evidence for a mesothelioma risk due to anthophyllite asbestos is still lacking.

Keywords: Anthophyllite, fibre width, mesothelioma, epidemiology, Finland

1. Introduction

Anthophyllite asbestos only occurs in a few parts of the world in sufficient quantities to be mined. It is therefore regarded as a ‘non-commercial form’ of asbestos distributed, nonetheless, in many parts of the world in small non-workable deposits. The largest quantities of anthophyllite asbestos have been mined in Finland; much lesser amounts in the United States, Japan, Russian and Mozambique (Hodgson, 1986). Either through its natural occurrence and – or commercial development at the mine, mill, production factory and distribution as raw fibre and – or its use in numerous anthophyllite asbestos containing products, many thousands of people have been exposed to levels of anthophyllite asbestos significantly above background in Finland, the United States and Japan and those countries to which they exported their anthophyllite asbestos. Nonetheless, despite these widespread occupational, para-occupational and environmental exposures, a proven attendant attributable mesothelioma response has not been proven. The prevailing explanation for this is fibre width which is now regarded as an important determinant of mesothelioma induction (see Wylie et al., 1993 for review). Fibre width is also regarded as an important factor in adjudging the toxicity of other materials which some classify as cleavage fragments and a variety of other similarly ubiquitous materials known as elongated mineral particles (EMP). Neither has demonstrable pathogenic effects (Ilgren, 2004).

Fibre width as an explanation for anthophyllite’s lack of mesothelioma potential was first proposed by Timbrell (1972a,b,c) over 45 years ago. He related this to a concomitant reduction in respirability, retention and pleural translocation (also see Van Orden et al., 2014). Twenty years later, Meurman et al. (1994) concurred with Timbrell (1972) saying that "the thickness of the (anthophyllite) fibres is systematically different between the amphibolic asbestoses. Anthophyllite asbestos is more crude than crocidolite asbestos" making it "…likely that the carcinogenic properties of different asbestos types depend on fibre structure". Karjlenen (1994a) noted that whilst his three alleged cases of mesothelioma were "heavily exposed and had asbestosis", "the high level of exposure was needed for a sufficient amount of (anthophyllite) fibres of adequate dimensions to be deposited in the lungs" … "to induce mesothelioma". Scientists have believed anthophyllite's increased fibre width could be due to specific geological (Aureola & Vesalo, 1954) mineralogical (Neathery, 1968) and microstructural features (Veblen, 1980) for many years and this will be discussed in subsequent parts of this series of reports.

1.1 State of the Art Observations supportive of the Fibre Width Theory

Epidemiologically, the state of the art mesothelioma experience between 'thin' South African crocidolite and 'thick' Finnish anthophyllite could not be more different. Thus, in 1960, there was irrefutable evidence that crocidolite could cause mesothelioma and by 1994, crocidolite related mesotheliomas had been reported in every segment of the asbestos industry, on almost every continent, and in situations not associated with asbestosis. By contrast, in 1974, Meurman et al. (1974) said "mesothelioma cases are rare in Finland", "being too early to draw far-reaching conclusions on the association of malignancy and anthophyllite asbestos exposure in Finland". Huuskonen (1980) said that "it is noteworthy that not yet a single case of mesothelioma has been found in workers exposed almost exclusively to anthophyllite". The first alleged mesothelioma in anthophyllite miners and millers was seen in 1986 nearly 70 years after the Paakila cohort began working (Meurman, 1994) though Meurman et al. (1994) still doubted an association for anthophyllite with mesothelioma stating: **"**The main purpose of this study was to find out whether the biological effects of anthophyllite asbestos dust differ from the effect of other asbestos types and whether earlier reports that it does not cause mesothelioma in humans are still valid after an extended follow up period." Lemen (2015) even said that "anthophyllite is exceptionally common in the lungs of the Finnish population when compared to other countries its potency in producing mesothelioma has been considered low and not observed until the 1990s." Therefore, as of 1994, thousands of crocidolite mesotheliomas had been found where the issue of anthophyllite's potential to produce mesothelioma was still under debate. Indeed, the findings of this report indicate that for anthophyllite the potential for it to produce mesotheliomas is still in question on the basis of epidemiological observation and detailed case specific analysis.

1.2 More Recent Evidence for the Fibre Width Theory

The US Bureau of Mines (Shedd, 1985) studied four types of crocidolite. Two, one from South Africa and the other from Western Australia**,** were called "thin" having fiber diameter dimensional profiles predominantly less than 0.25 – 0.30 µm. Conversely, two, one from Bolivia and the other from the Transvaal, were called thick with predominant widths greater than these diameters. The US BUM report said the "thin" were clearly mesotheliomagenic but the other two appeared to lack the ability to induce mesotheliomas. Our detailed studies of the 'thick' Bolivian crocidolite demonstrated demographically a lack of attributable mesotheliomas despite long term heavy usage (Ilgren et al. 2012a) whilst our comparative summary of the Finnish and Japanese anthophyllite experience (Ilgren et al., 2012b) provided further evidence for a lack of an attendant risk of mesothelioma. The findings of the present report strongly suggest that Finnish anthophyllite asbestos has not produced an attributable risk of mesothelioma. This conclusion is greatly strengthened by the finding of crocidolite – chrysotile cement board in the construction of the Paakila mill facility.

2. Materials and Methods

This report, and the three which follow, are based on a ten-year effort to understand the mesothelioma potential of anthophyllite asbestos. The information on which these three papers are based incorporates geo-mineralogical, industrial hygiene, ethnological, and epidemiological data. Since the vast majority of anthophyllite asbestos ever mined has come from Finland, this first report is on the Finnish epidemiology of occupationally exposed individuals.

To gather the information used in this particular report, the first author not only did an ongoing literature search but also discussed various aspects of the Finnish endemic pleural plaque story with Prof. Emeritus Gunnar Hillerdal of the Karolinska Institute in Stockholm in August, 2015; met with the scientists who oversaw much of the most recent epidemiological studies of the Paakilla miners and millers (Drs. Oksa, Timo, Pukkala and Wolf) in Helsinki in September, October and November 2015; and interviewed the pulmonologists, radiologists and pathologists at the regional medical centre in Kuopio and ethnologists in Joensuu and Helsinki in 2015. The senior author also interviewed the geological experts at the Finnish Geological Service in Kuopio and Helsinki in this same year. The senior author visited Paakila in 2015 with the Professor of Oncology at the Kuopio medical centre and her husband to interview various residents and medical personnel familiar with the area. Her husband also had been borne and raised in Paakilla village so the trip included visits to the nearby mine, mill and factory and the surrounding area by car and on foot. Professor Emeritus Matti Huuskonen, formerly Director of the FIOH and his wife also very kindly took the senior author to their home near Paakilla and Helsinki for additional highly informative discussions. Mr. Keijo Halonen, formerly senior archivist of the FIOH also spent many hours researching the archives and discussing documents and certain aspects of the Paakilla story with the first author.

Part of the factory mill in Paakilla appear to be covered with asbestos cement board and the same material was used on the original living quarters of the Paakilla workers. A section of broken board (fig 1) was taken along with some samples of anthophyllite ore (fig 2,3) abandoned in boxes in the mill nearby and sent to Dr. Drew van Orden of the RJ Lee Group in Pittsburgh on 4 Jan 17. The board was analysed for asbestos using EPA Bulk Method (EPA/600/R-93/116) (Data available on request).

3. Epidemiological Findings

3.1 Epidemiological Studies

3.1.1 The Finnish Epidemiological Studies - Occupational Studies of the Finnish Anthophyllite Miners and Millers

The Finnish epidemiology must be considered in terms of the ancient use and distribution of anthophyllite in Finland and its 'modern' use, development and distribution.

3.1.2 The Ancient Finnish Anthophyllite Asbestos Ceramic "Combware" Industry

Finland is one of the oldest asbestos producing centres in the world known for the production of anthophyllite asbestos containing ceramic wares since Neolithic times (more than 6,000 years ago). The Finns are thus known as the first 'asbestos merchants'. The historical centre for the production of anthophyllite ceramic ware was based around Paakilla in central Karelia (figs 4,5). The people were known as 'asbestos blenders' since they took anthophyllite fibres from myriad lake shores and blended them with clay to make comparatively, light weight ceramic ware. The anthophyllite asbestos ceramic pottery industry spread from Karalia over the ensuing 4,500 years through Finland, neighboring Scandanavia, and Russia (Lavento, 2015, pers. comm.; Europaeus – Ayrapaa, 1930). Extensive historical 'occupational', 'para-occupational', and 'environmental' exposures to anthophyllite occurred since it was "mined", processed, distributed, used and repaired for millenia. Millions of people of all ages were thus endemically exposed occupationally, domestically and environmentally for more than 4,500 years (also see Noro, 1968a,b). Despite the anciency of these exposures that pre-dated the diagnosis of mesothelioma (1960), had these exposures been to a potent mesotheliomagenic fibre, indications similar to those recognized in the Turkish erionite villages would have been recognized through the stigmatization of the populations thus exposed (Baris, 1981, 2006).

3.2 The Modern Finnish Anthophyllite Asbestos Industry

3.2.1 Introduction and History

The exploitation of the asbestos occurrences of anthophyllite in the area of Paakilla (also known as the Tuusniemi commune) with more modern methods began in the late 1800s following the foundation of Suomen Asbesti Oy. The regulations of the firm were ratified in 1900 by the Finnish Imperial Senate. Mining operations were, however, unprofitable. In 1907 the quarries were leased to the Danish firm I. L. Smith & Co. but after three years, this firm also ceased mining. At the end of the first World War the quarries were taken over by Suomen Mineraali Oy. Besides the production plant operated in the immediate vicinity of the quarries, this firm also owned a modern factory at Tapanila (near Helsinki) "for turning out asbestos products." (Aureola & Vesalo, 1954).

3.2.2 Industrial Hygiene

The early operations at Paakilla and Tapanila were characterised by uncontrolled dust conditions that produced much morbidity and death. The rate of turnover was therefore very high. Thus, whilst the formal "modern" Finnish epidemiological studies included at least 1645 Finnish miners and millers (Ahlman et al, 1973), the number who worked at Paakilla and Majsami for over 60 years (for Paakillia from1918 to 1975) could very well have been twice that high. The extraordinarily high concentrations of anthophyllite asbestos to which the miners and millers were exposed, under largely unregulated conditions resulted in very high levels of asbestosis in up to 50% of all workers, men and women) at very young, median ages (ca. 54 years). The mining extraction and milling processing methods produced large dust clouds of thin and thick anthophyllite fibres (including those of a "Stanton size" fraction). Various authors stressed the very severe exposures. Noro (1968a,b) thus calculated that the fibre levels in the mill and mine could have averaged 100 f/ml historically with mass dose levels as high as

100mg/m^3. Noro (1968a,b) went on to say "Twenty years, ago, before the management of the quarry and mill changed, the dustiness was, especially in the mill, rather great. One could only see a few meters ahead. The level of dust was surely many times higher than what our threshold limits indicate it should be. This great exposure reflects in the frequency and severity of our asbestosis cases". … "Unfortunately, the exposure levels at plants have been systematically measured only during recent years." …" The level of industrial hygiene in Finland is not yet satisfactory, and unfortunately we must expect still more asbestosis cases."

Huuskonen (1980) said "The Finnish who worked in the Paakkila anthophyllite asbestos quarry or mill were heavily exposed to asbestos dust in these operations. …The mine and mill had been continuously in operation from 1918 to 1975; however, not until the late 1960s was attention paid to working conditions. The first industrial hygiene surveys of workplace air were performed in the 1960s. The average fibre concentration was 50 fibres/cc (range 1 to 300) in three consecutive surveys, 1969, 1970 and 1973. The corresponding total dust figure was 6 mg/m^3 (range 1 to 170) (Table 1)."

Meurman (1994) reckoned the average fibre concentration was still 50 fibres/ml in the late 1960s. Not surprisingly, as Hillerdal et al. (1984) mention, "Paakkila in the Tuusniemi commune, closed down in 1975 because of the dust problem"

In October 20015, at his home in Helsinki, Prof. Matti Huuskonen also showed the first author a film entitled "Paakkila Asbestos village" first aired on YLE television (formerly the Finnish Broadcasting Company) in 1977 two years after the closure of Asbestos mine and mill commercial activities (http://yle.fi/aihe/artikkeli/2010/08/26/paakkilan-asbestikyla). Various points emphasized the horrific dust conditions. Thus, Prof. Huuskonen translated the film that noted at the time of filming a total number of around 40 houses built mainly in the 1940s and 50s. Only retired people were said to be there. The commentators said that most of workers died of lung cancer and asbestosis and in the beginning, workers did not know about asbestos health hazards, but started to suspect asbestos as a cause of deaths because so many asbestos workers died of lung cancer and asbestosis. Asbestos was also said to have been used in the materials of houses. Suomen Mineral operated the mine and mill to 1959 and after that Partek Company continued until 1975. The interviews with the women who worked in the mills shown in the film said the dust was so heavy they could not see one another short distances apart and also remarked on the poor to non-existent ventilation, poor use of masks, and a general resistance of management to improve working conditions resulting in asbestosis cases in workers in their 40s. (Huuskonen to Ilgren Sept 27, "Paakkilan asbestikylä | Elävä arkisto | yle.fi").

Table 1. The results of Hygienic Measurements of the Pakkila Mine from 1969 to 1973

	No. of Measurements	Average No. of Fibres/cc (over 5 μm)
Drilling	3	56
Loading	2	73
Crushing	4	31
Drying	2	36
Dressing	4	260
Milling	2	24
Supervision	2	7
Others	20	22

3.2.3 Chronological Summary of the Literature on the Health Experience of the Finnish Anthophyllite Miners and Millers

The modern industrial exposure of workers at Paakilla began at the end of the first World War (in 1918) when the quarries were taken over by Suomen Mineraali Oy (Noro, 1968a; Aurola & Nieminen, 1954**)**. The health experience of the Finnish anthophyllite miners and millers has been described in the scientific peer reviewed literature over a span of 70 years from 1946 to 2016. By 2015, the epidemiological experience of the Paakilla anthophyllite asbestos miners and millers had been presented in seven formal, peer-reviewed publications and one conference presentation. The salient findings are summarised below:

Wegelius (1946) did the first medical survey of the anthophyllite asbestos industry (1918 to 1938). The radiological results "told about the health effects of rather heavy exposure demonstrating 126 cases (26.5%) of asbestosis" in 476 asbestos workers (industry included). No mesotheliomas were reported.

Noro (1968a) reported the findings of regular radiological studies of the workers from 1954 to 1967 that included 144 cases of asbestosis in approximately 500 workers. No mesotheliomas were reported.

Kiviluoto and Meurman (1966 op cite Nurimen, 1972) studied the Paakilla miners and millers who worked more than ten years had many cases of asbestosis but no mesotheliomas were reported.

Nurimen (1972*)* conducted the first cohort study of the Paakilla asbestos miners and millers (n=1,495: 80% male). This was funded by the Quebec Asbestos Mining Association (QAMA). It covered the period from 1936 to 1967. Nearly 50% of the workers got asbestosis but no mesotheliomas were reported (also see Huuskonen, 1980)

Ahlman et al (1973*)* conducted a cohort study of the Paakilla asbestos miners and millers largely for asbestosis. They said 1,676 persons were registered since 1936 but 423 were excluded with exposures times less than 3 months leaving 1,044 men and 205 women. The turnover rate was considerable and at the end of 1971, 121 workers were employed. Of the 105 cases of asbestosis, 89 were in men, 16 in women. In total, of 286 workers with more than 6 years' employment, one third had asbestosis. No mesotheliomas were recorded even though they said "anthophyllite dust gave rise to pleural changes at a very early stage of exposure". This is particularly important regarding the women since historically, hundreds of women worked at Paakilla under extraordinarily dusty, 'asbestotic' conditions. Whilst their true numbers are probably significantly underestimated (e.g. see above per Nurimen, 1972: ca 300 women: Ahlman et al., 1973: 205 women; Meurman et al., 1994: 167 women) due to high turnover, it is remarkable that no mesotheliomas were reported in women, thus further strengthening the low mesotheliomagenic potential of anthophyllite.

Meurman et al. (1974*)* conducted the first cancer mortality cohort study of the anthothophyllite miners and millers (N=1,092). The men worked from 1936 to 1967. No case of mesothelioma was found.

Meurman et al. (1994) conducted the second cancer mortality cohort study of the anthothophyllite miners and millers (N=1,003: 736 men, 167 women) who worked for at least three months from 1953 to 1967. Follow up ended in 1991. The mean duration of follow up was 28 years. There were no losses to follow up. Four mesotheliomas were reported. These were the first to be noted in the cohort since it was first studied. The first was found in 1986 (case 3) and the second in 1987 (case 2). Both were sarcomatoid. Each was the subject of diagnostic debate. Case 2 was thus taken out of the series by the authors latterly as not being a mesothelioma. Case 3, as indicated below, was also in diagnostically in doubt but kept in the series even though the diagnostic stains were not felt to be sufficiently discriminatory at the time as discussed below (Wolff, pers. comm. 2015).

Karjlenen et al. (1994a*)* studied 999 anthophyllite miners and millers. Their study was aimed at providing the case specific details of the four mesotheliomas reported by Meurman et al. (1994). It covered all workers who worked from 1936 to 1967. Follow up also ended in 1991. None of the four cases reported are attributable.

Oksa (2013) presented a cursory update of the Paakilla anthophyllite miner and miller study at a conference in Helsinki in 2011 (see fig. 6). There was only group level data; no case specific information. Diagnostic specifics, case names, work histories at and outside of Paakilla, information regarding concomitant asbestosis, and lung burden data were not presented. This update was not published in a peer reviewed scientific publication. Oksa (2013) included Paakilla workers (n=752) studied from 1967 to 2009. By that time, 99% of the cohort was deceased. The number of workers studied (752) was significantly less than earlier studies. However, its similarity to the number of male workers studied by Meurman (1994) suggests Oksa (2013) may have only studied men. Oksa claimed there were five (5) new cases of mesothelioma beyond those reported by Karjlenen et al. (1994) thus allegedly bringing the total to eight (8). The 8 cases were taken from the Cancer Registry via a 'simple register linkage' method. Since Oksa (2013) was only based on group level data, one or more of the five might be the same as one or more of the four reported by Meurman et al. (1994). (Oksa, pers. comm.).

Oksa (2015). The first author met with Oksa and his colleagues including Dr. Timo Tuomi, the lung burden electron microscopist; Dr. Eero Puukala, the Finnish Cancer Registry epidemiologist; and Dr. Henrik Wolff, the FIOH pathologist to discuss the mesothelioma findings in the updated 2013 conference presentation in September 2015. Oksa was the Chief medical officer of the FIOH or Finnish Institute of Occupational Health at the time. Originally, only three of the four cases reported by Karjlenen et al. (1994) were analyzed for lung burden content. However, the electron microscopic methods applied were not, according to Tuomi, 2015 pers. comm.) sufficient to exclude the presence of fine amphibole asbestos fibres. Moreover, such fibres could have been from natural sources locally and – or from commercial sources such as the construction industry where significant amounts of crocidolite and or amosite have been encountered (as suggested by Nynas et al., 2017) and as noted by the finding of crocidolite in the cement board of the Paakilla factory (see below). Dr Tuomi confirmed he could not exclude the presence of thin commercial amphibole asbestos fibres in the three diagnostically confirmed cases reported by Karjalenen et al. (1994) and also said he had no intention of doing any further lung burden studies on the five allegedly new ones. At the meeting, Oksa (pers. comm., 2015) also confirmed the absence of detailed work histories for the five new cases making it impossible to exclude work in other dusty trades that could have included crocidolite and – or amosite use and exposure from worker exchange in other asbestos containing facilities near the mine and / or the mill. The finding of asbestos cement board used in the construction of part of the Paakilla factory mill containing 5% crocidolite and 40% chrysotile greatly strengthens the possibility of such exposure. Such materials would have been drilled, sawed and put in place thus causing exposures to those working with them. Oksa 2015 (pers. comm.) also confirmed one of the two sarcomatoid variant cases had been thrown out (also see Nynas et al. 2017) on diagnostic grounds. The other sarcomatoid variant was also queried since, according to Dr. Wolff (2015, pers. comm.) the immunohistochemical stains used to differentiate these from metastatic sarcomas were not totally adequate to do so when the study was conducted before 1994. Dr. Wolff also said the pathology materials could be retrieved with permissions from the authorities but this would be difficult to do and rather time consuming. Dr. Puukalla said detailed work histories could also be obtained but he also had no intention of doing so at that time. Therefore, even though Oksa (pers. comm. 2015) said the five alleged new cases, based solely upon group level data and the three remaining cases described by Karjalenin et al. (1994) allegedly demonstrated anthophyllite asbestos could cause mesotheliomas in man, they were not willing to perform a case specific analysis in a manner similar to Karajllenin et al., 1994 to confirm the diagnoses, lung burden status, dose relationships, and other possible sources of exposure for the five new cases. Because one of the primary rate limiting steps of doing a case specific analysis of the alleged five new cases and repeat the lung burden studies using TEM, the first author arranged outside funding for Oksa and his colleagues to carry out these studies but they decided not to accept the offer to do so.

Nynas et al. (2017*)* published additional data that had only been presented in cursory form by Oksa (2013) at the 2011 Helsinki conference. The data were however only group level data so all of the criticisms applied above to Oksa's study also apply here. Nynas et al. (2017) only examined workers who worked from 1953 to 1967 for at least three months in a manner similar to Meurman et al. (1994). Since the Maljami mine closed in 1953 and Nynas et al. (2017) only started to study workers in 1953, their study will not have studied anyone actively mining at Malsamji. This is important since Malsamji was potentially contaminated by tremolite from other nearby sources. This is in contrast to Karjalainen et al. (1994) who examined workers from both mines and mills. This does not exclude the possibility that once Malsamji closed, workers from Malsamji went to Paakilla either before or after it closed causing those workers to bring their potential risk factors with them.

3.2.4 Other Comments and Criticisms

Inclusion Criteria: There are exclusions in the data. Nynas et al. (2017) apparently excluded all deaths from 1936 to 1966. If so, all of the data upon which Nurimen (1972) is based would have been excluded.

Denominator Issues: There are also denominator issues and related confounders such as worker turnover, worker exchange and immigration associated with recognized risks of mesothelioma. Nynas et al. (2017) studied 734 workers which was approximately the same number of workers as Oksa (2013) (N=752) and identical to the number of men studied by Meurman et al. (1994). However, since Nynas et al. (2017) said the 477 heavily exposed workers worked in the mine and the refinery whilst the remaining 257 were the "rest of the personnel", it would appear that the authors are suggesting that the denominator of their miner miller study was not 752, but 477.

Meurman (1994) created more confusion since his study suggests all of the workers studied by Nynas et al. (2017) were men and also raised the broader question: who were the "rest of the personnel". It is difficult to believe the company needed to have more than one third of their personnel working outside the mine and the mill. It would be more common for some personnel to rotate in and out of the mine and the mill. a possibility that should have been considered.

Five earlier studies (Nurimen, 1972; Ahlman, 1973; Meurman 1974, 1994; Karjalainin, 1994) of the Paakilla workers (including Malsamji) reported denominators ranging from 999 to 1645. All but one (Meurman, 1994) studied workers who had worked from 1936 to 1967 for 31 years. Oksa, as reported by Nynas et al. (2017), only included those who worked from 1953 to 1967 for 14 years. This may explain some of the denominator differences in the earlier and later studies. However, it seems hard to justify eliminating 17 years of workers or ca one half the time workers worked in earlier studies. Nynas et al. (2017) might have done this for ease of analysis since the first time the tracing system could be done automatically was in 1967. By contrast, tracing that started at 1953 was done manually. Nonetheless, failure to study men working in the earlier years eliminates a large number of historically heavily exposed workers and thus introduces a significant source of bias making Nynas et al. (2017) difficult to compare with the other studies.

3.2.5 Migration and Its Potential Effect on Mesothelioma Causation Determination

Finnish ethnology enabled studies of industrial workers and their occupational histories to be conducted in great detail. The interviews involved detailed biographical questions and this information was added to the demographic statistics that enabled the migratory patterns of Finns to be very carefully traced. This has made Finland famous for its ability to trace migratory movements. For the purpose of understanding the role of anthophyllite asbestos in mesothelioma production in Finland, it is important to be able to trace the such migratory patterns. Many Finns left Finland to work abroad at different periods in Finnish history. Whilst abroad, many worked in industries associated with recognized risks of mesothelioma. Snellman's (2005) outstanding work on the migration of the Finnish people sheds considerable light on this subject, albeit influenced by Partek (Snellman pers. comm., Dec 2015).

The forest is to the Finns their "Green Oil". Vast proportions of the wood processing industry in the Nordic countries including Finland, could only have been established with the acquisition of the steam saw mill (ca. 1870s). With the great increase in the wood industry, the country became more dependent upon migrant workers and thus population shifts occurred and, for the purpose of increasing steam mill construction, asbestos use also increased. Finns also went to the United States and Canada to learn new logging methods and steam mill technologies. As these newly skilled workers were in great demand in Finland to implement those new technologies, they returned sometimes bringing the asbestos exposure risk factors they acquired abroad back to Finland.

The decades after WWII represent one of the most important transition periods in Finnish history as they involved rapid industrial mechanization. During this period, massive emigration occurred from villages in the north and eastern parts of Finland to the factories of Southern Finland and Sweden where there was a new burst of job opportunities. Many young people were persuaded there was no longer any future in Finnish agriculture, and emigrated by the thousands to take well – paid industrial jobs in the South of Sweden. The new Alien's Act of Sweden passed in 1954 made it far easier than before for Finns to obtain such employment. With the reformation of Finland's agricultural policy in the mid – 1960s, former subsidies to unprofitable small farms also ceased to exist and thousands suddenly found themselves unemployed in rural regions. Karaelia was one such region. Tax reforms in the late – 1960s put even more pressure on farmers to leave the countryside. Moreover, the "austere and powerful work ethic that pervades Finnish rural society" (Snellman, 2005) further fueled the migration as the Finns believed that the "only road to a good life was through unremitting physical and mental toil" … "to honor work above all else in life". It was only until the mid – 1970s that the attraction of the Swedish labor markets began to weaken. Then, as Snellman said: "The years of great migration were over". In total, some estimated that up to 800,000 Finns immigrated to Sweden between 1945 and 1994, yet only some of them took up permanent residence there. However, they were not lost to the Finnish demographer since the Nordic tracing system was able to earmark their moves and consequently their health status after they had moved. Many young girls also emigrated as early as 14 years old to take jobs in Sweden as babysitters. They "would stay long enough to get a better – paid job in a factory". Nonetheless, the dream of returning to Finland was always alive despite their resettlement. Many families also emigrated together and, to the extent, one or more may have worked in a dusty trade, the possibility of domestic exposure was also a significant possibility. Ethnological study also detailed the hardships the Finns faced in Sweden despite their allegiance to work in diverse and dangerous occupations such as metal factories, shipyards, mining and the rubber, textile, clothing and paper industries. As Snellman (2005) wrote: "Homesickness comes in many guises one of which is a longing for the native countryside". Their sense was that they had to get back to Finland even after decades had passed. However, as this occurred, many would bring the asbestos risk factors they acquired abroad back to their homeland. It is therefore particularly germane to look at these patterns of migration and re-emigration as potential explanations for some of the mesotheliomas recognized in Finland.

3.2.6 Worker Turnover and Study Inclusion Duration their Potential Effect on Mesothelioma Causation Determination

A high worker turnover rate can cause a significant underestimation of the true denominator. Whilst the precise level of turnover cannot be determined without the underlying work records, Ahlman (1973) said 423 out of the

1645, or nearly 25% of the workforce, were eliminated from study since they worked less than 3 months. Nynas et al. (2017) also said only 25% of the workforce worked for more than 5 years again suggesting a very high rate of turnover. Indeed, Nynas et al. (2017) may only have examined one-quarter of the original workforce. Nynas et al. (2017) also claimed that 'those who had worked for a shorter time … were less exposed'. This is not correct. New workers commonly start work in the dustiest jobs hence the high turnover in short term workers. Therefore, even though they may have incurred shorter exposures, those exposures, particularly historical ones were exceptionally high and largely absent dust controls.

3.2.7 Worker Exchange and Its Potential Effect on Mesothelioma Causation Determination

The effect of worker exchange from different asbestos using factories near Paakilla is also confounding. Nyas et al (2017) only followed up those who emigrated from 1967 to 1994. Immediately after WWII, Sweden began recruiting labour for its fast-expanding industry and "the 1960s in Finland went down in the Finnish research literature as the decade of migration from rural regions" (Snellman, 2005). "As the immigrants usually had a low level of education and were young, most worked in industry, particularly construction and shipbuilding. Indeed, between 1945 and 1994, an estimated quarter of a million Finns took up residence in Sweden" (Snellman, 2005). A high percentage also returned and brought their asbestos exposure job related risk factors back with them largely from working in jobs associated with the use of crocidolite and amosite. Therefore, if Nynas et al. (2017) missed a significant number who emigrated and then re-immigrated particularly back to Karelia, they may also have not recognised the risk factors thus acquired.

3.2.8 Measures used to Estimate Risk and Their Potential Effect on Mesothelioma Causation Determination

Nynas et al. (2017) presented risk estimates as SIRs or Standard Incident Ratios but these are misleadingly high. The large SIRs for mesothelioma are, as Nynas et al. (2017) stated, high because the number of incident cases per year is small, not because the risk is high.

3.2.9 Numerator Issues Their Potential Effect on Mesothelioma Causation Determination

Nynas et al. (2017) relegate two of the mesothelioma cases to the moderate exposure group. This group was said to be "other personnel" that did not include the miners and millers. Therefore, if these were not miners and millers, these two mesothelioma cases should not be included in the "miner and miller cohort". In addition, as noted above, one of the four mesotheliomas in Karjalenin (1994) was eliminated on diagnostic grounds.

3.2.10 Surveillance Issues

Nynas et al. (2017) said the first periodic health screening for asbestosis was in 1977. However, according to Huuskonen (1978) and Huuskonen & Tossavainen (1978), between 1964 and 1976, 229 cases of asbestosis had already been notified to the Finnish Register of Occupational Diseases, whilst asbestosis patients from 1938 to 1963 had been gathered from published reports and unofficial registers at the FIOH. Also, according to Answers to Interrogatories (22 Mar 96) (Note 1) "the FIOH studied the health of workers at Paakkila during the 1950s, 1960s and 1970s; at Muijala during the 1960s and 1970s; at Tapanila during the 1940s, 1950s, 1960s and 1970s and at Pargas during the 1960s and 1970s". Therefore, health screening for asbestosis and, of course, mesotheliomas, started long before 1977. Therefore, the FIOH and other leading Finnish physicians were apparently aware of the level of disease and the horrific hygiene conditions largely without regulation that were responsible for this. Scientifically, this is important since the Finnish Register and the FIOH recorded large numbers of cases of asbestosis but no mesotheliomas due to anthophyllite as late as 1978 (Huuskonen, pers. comm., 2015). The Finnish Institute was also apparently responsible for overseeing the medical follow up of the Finnish asbestos workers from 1954 to the present day, its activities paid very largely by the Partek company on a fee for service basis (Halonen pers. comm., 2015).

4. Conclusion

Personal detailed review of the epidemiological literature of occupationally exposed workers along with many first-hand discussions with the scientists and physicians who had studied the Paakilla miner miller cohort in detail for many years failed to provide credible evidence that anthophyllite had produced attributable mesotheliomas in those exposed. In addition, failure to undertake a case specific analysis of the allegedly attributable Paakilla mesothelioma cases using, in particular, state of the art TEM based lung burden methods, and now, with the finding of the use of crocidolite containing asbestos cement mill board at Paakkila, leaves open the distinct possibility that the few mesotheliomas alleged to be due to anthophyllite were in fact due to crocidolite. This would be consistent overall with the Finnish lung burden literature published to date particularly by Professor Tim Tuuomi.

Figure 1. Crocidolite cement board used in construction of the factory

Figure 2. Storeroom

Figure 3. Box of Anthophyllite samples

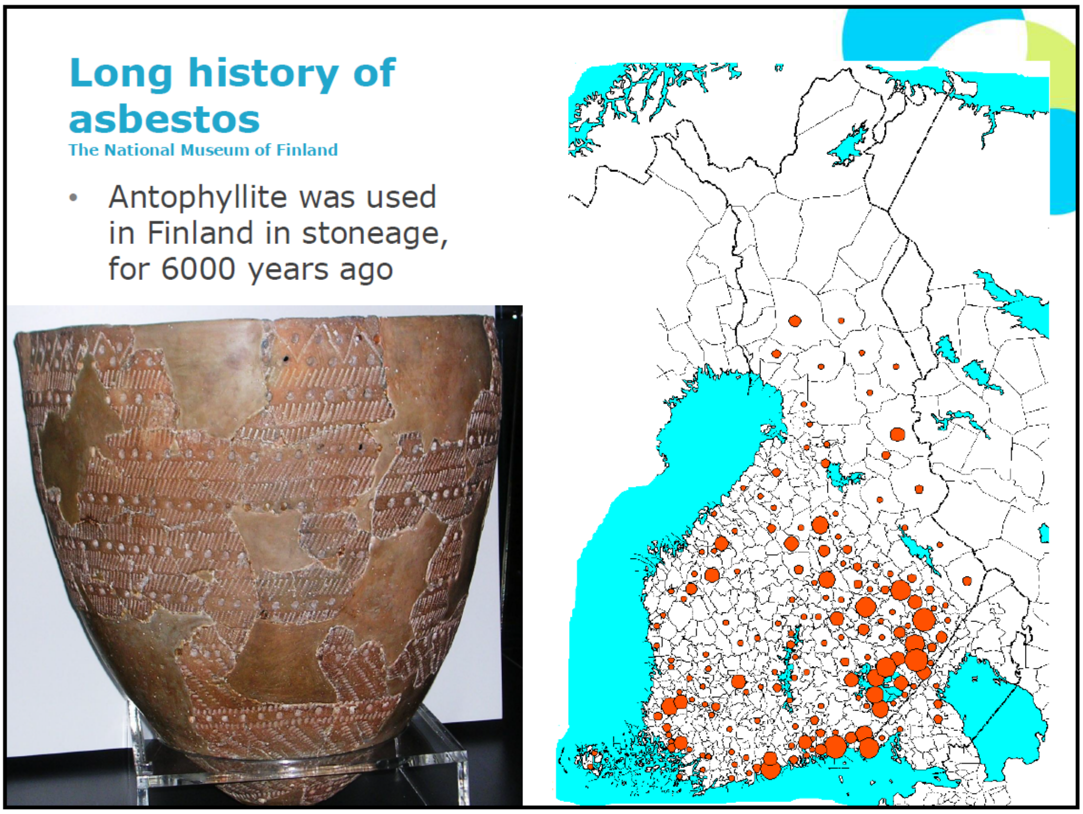

Figure 4. (ex. Oksa 2013)

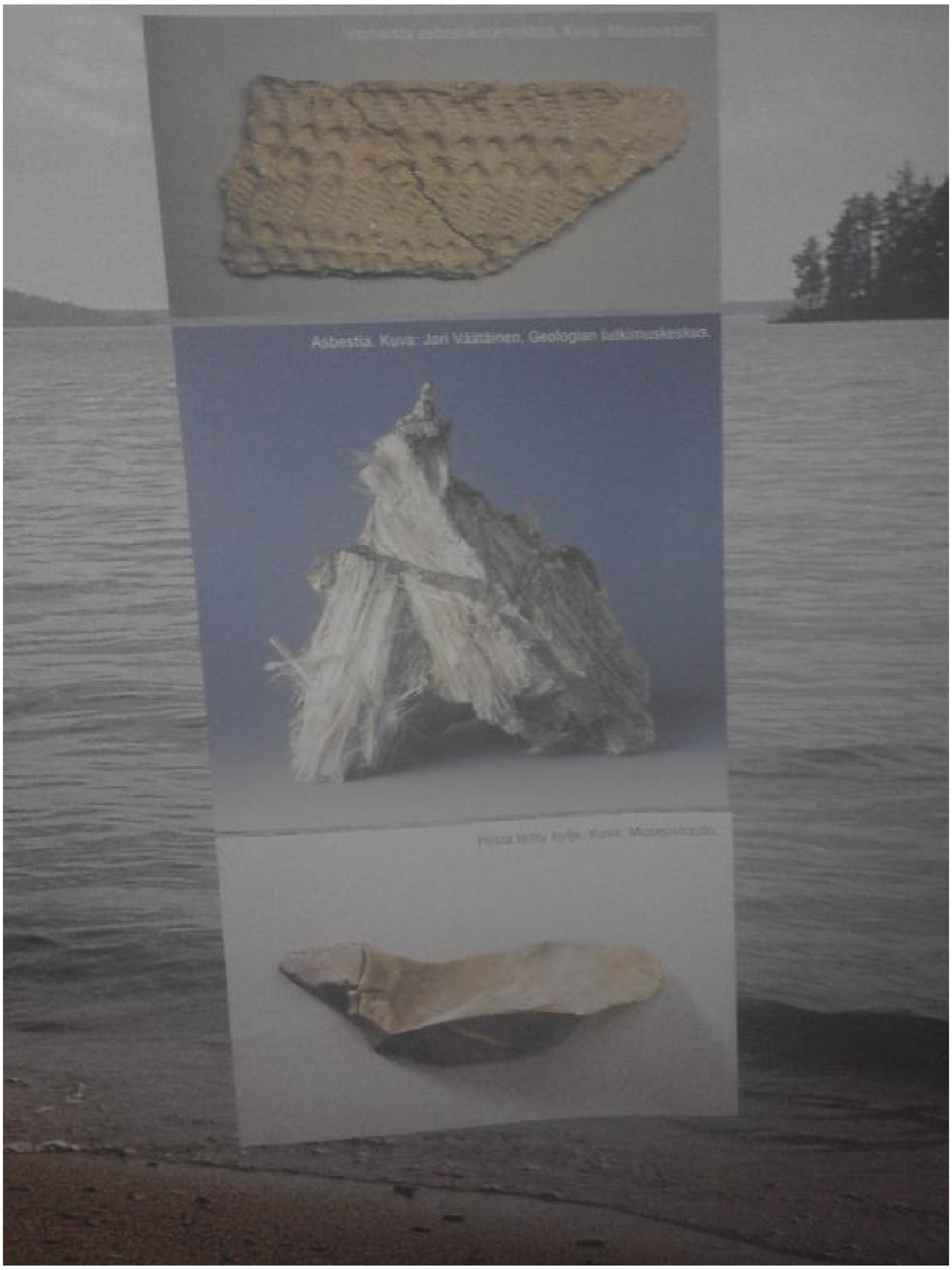

Figure 5. Anthophyllite found by Lake Shore

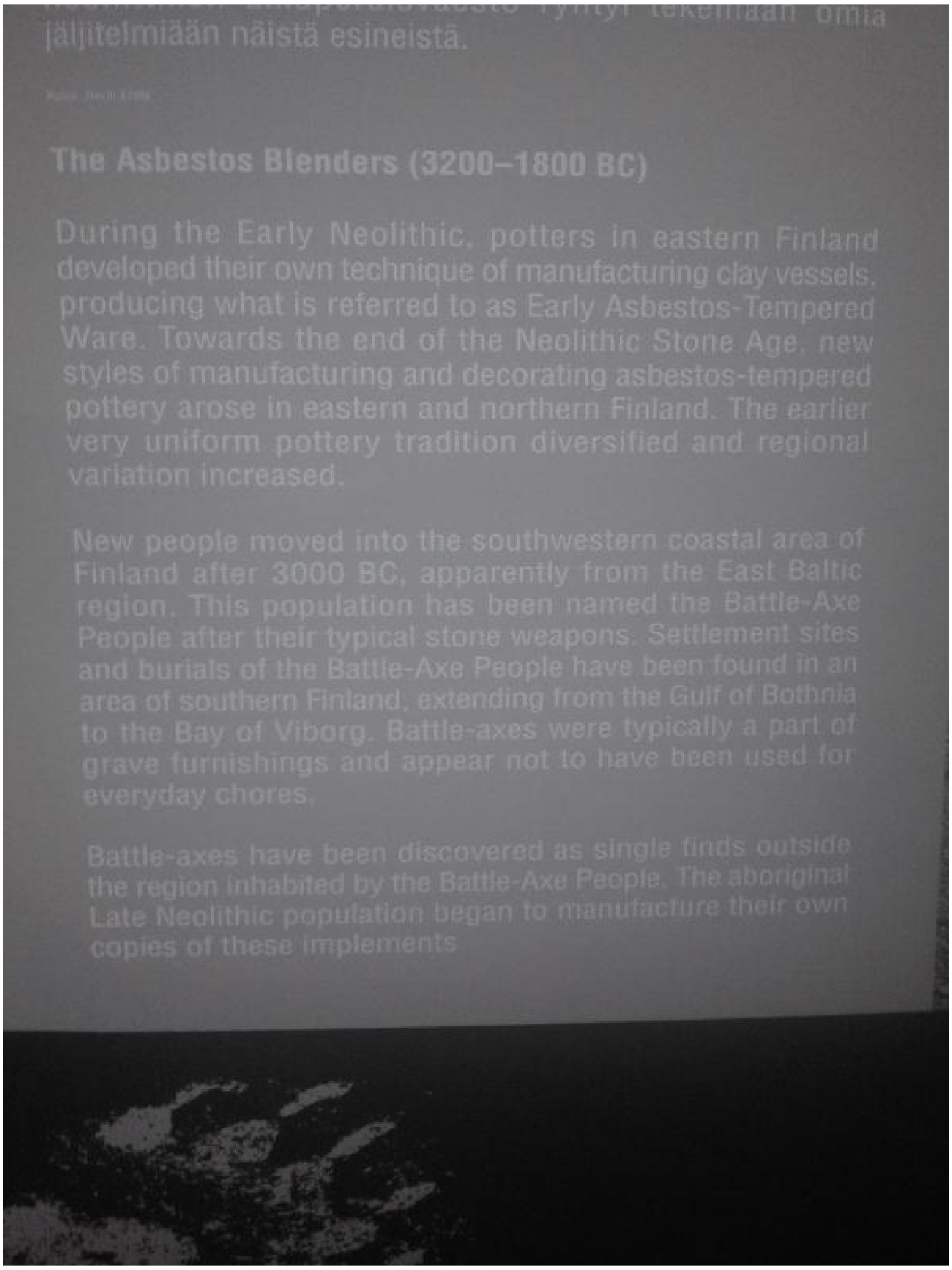

Figure 6. Asbestos Blenders

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Note

Note 1. In the Superior Court of the State of Delaware in and for Newcastle County. C. A. No. 77C-ASB-2.