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Original scientific paper

ANALYSIS OF ASBESTOS IN BUILDING MATERIALS – CASE IN TOWN SKOPJE

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Asbestos has been extensively researched as one of the most hazardous materials to human health in the past century. Despite its universal recognition as a challenging problem, the topic is unfortunately not widely discussed in our country. However, the city authority of Skopje has undertaken a significant campaign focused on identifying and removing asbestos-containing materials from various buildings in the city. This initiative represents the largest effort of its kind in the country thus far. The campaign involved the development of methodologies and the analysis of samples collected from different buildings in Skopje. A systematic analysis was conducted on 50 samples collected from 21 public buildings in Skopje, utilizing techniques such as optical microscopy, infrared spectroscopy, X-ray diffraction, and scanning electron microscopy (SEM). The results revealed the presence of asbestos in 33 of the analyzed samples. Notably, asbestos was not detected in only two buildings. These findings indicate that asbestos is present in the building materials of practically all the inspected structures, suggesting its likely presence in many other buildings within the city and throughout the country. Of particular concern is the confirmed presence of asbestos in kindergartens, as this exposes the young population to potential asbestos-related health risks.

Key words: asbestos; serpentine asbestos; amphiboles asbestos; building materials; Skopje

INTRODUCTION

Asbestos

The contemporary era of extensive industrialization and globalization has given rise to numerous processes that have severe detrimental effects on human health. The urbanization that followed the industrial revolution inevitably led to the development of various building materials with different origins. However, in the rapid pace of urbanization, many crucial aspects closely tied to long-term human well-being were not adequately anticipated. One prominent example of such prolonged adverse effects is the utilization of asbestos in building materials over an extended period. The health issues associated with the widespread use of asbestos-

containing materials have not been fully resolved and continue to be a significant topic of concern in many urban areas.

It is crucial to emphasize that asbestos has been extensively studied as one of the most hazardous materials to human health in the past century. The scientific and medical literature is replete with hundreds of papers addressing various aspects and questions related to asbestos. Additionally, scientific conferences and debates are held annually, focusing on different facets of asbestos use and associated risks [1–19]. Regrettably, in our country, this topic is not extensively discussed, despite its universal recognition as one of the most challenging issues that require attention. The campaign initiated by the municipal authorities of Skopje, aimed at identifying and eliminating asbestos-containing materials

from various structures in the city, represents the most significant effort of its kind in the country thus far. This initiative involved the implementation of specific methodologies and the presentation of results obtained from the analysis of samples collected from different buildings within the city.

The term "asbestos" encompasses multiple fibrous silicate minerals that can be categorized into two groups: *serpentine asbestos* and *amphibole asbestos*. The serpentine group primarily includes *chrysotile*, commonly known as white asbestos, which is the most prevalent form of asbestos. The amphibole group consists of *amosite* (brown or grey asbestos), *crocidolite* (blue asbestos), *tremolite*, *actinolite*, and *anthophyllite*. Among these, chrysotile has been the most economically significant, accounting for approximately 95 % of the global asbestos production until about two decades ago. Crocidolite and amosite were the predominantly produced types within the amphibole asbestos category, while anthophyllite, tremolite, and actinolite were produced to a lesser extent. It is worth noting that the use of any asbestos-containing products was completely banned in European Union countries in 2005.

Asbestos minerals possess several commercially valuable properties, including high strength, elasticity, thermal resistance, and chemical stability. These characteristics make asbestos particularly suitable for manufacturing textile products and materials that need to withstand heat, fire, and friction. Not all naturally occurring fibrous minerals are classified as asbestos since they do not possess these properties. Asbestos is typically not used or found in its pure form; it is often mixed with other materials. Consequently, visual inspection alone is not conclusive for identifying asbestos due to its stable nature and infrequent occurrence in its native form.

Serpentine minerals have emerged as a captivating subject of research [20, 21] due to several compelling reasons.

- Firstly, they represent the last group of minerals in rocks for which the detailed structural polytypes have not been clearly described.

- Secondly, there is scientific and practical interest in understanding the thermodynamics of their formation.

- Lastly, their significant impact on the living and working environment has drawn considerable attention.

The heightened concern surrounding asbestos, a mineral known to pose serious health risks, has substantially increased interest in its study and contributed to advancements in the field of mineralogy. When materials containing asbestos are

damaged or broken, they can release asbestos fibers into the air, which can be inhaled and lead to adverse health effects. Prolonged exposure to airborne asbestos has been linked to several negative health outcomes, including asbestosis, lung cancer, and mesothelioma [3–6, 9, 12, 14, 16, 17, 19].

Despite the abundance of available data on these diseases, scientists still lack a comprehensive understanding of the underlying mechanisms by which asbestos triggers them. It is worth noting that inhaling *amphibole asbestos* has been proven to pose a significantly higher health hazard compared to inhaling *serpentine asbestos* [3, 12].

Detection of materials containing asbestos

Materials that contain asbestos (referred to as asbestos materials, AM) are classified by the U.S. Occupational Safety and Health Administration (OSHA) and the U.S. Environmental Protection Agency (EPA) as "materials containing more than one percent (1%) asbestos".

Thermal insulation systems (TSI) and flooring materials installed prior to 1980 are highly likely to contain asbestos. Additionally, asphalt and vinyl flooring materials produced before 1980 are also suspected to contain asbestos. Therefore, it is essential to inspect these materials to confirm or eliminate any doubts regarding the presence of asbestos.

When materials are suspected to contain asbestos, it is necessary to conduct thorough checks to confirm its presence. If asbestos is confirmed, the owners of buildings, structures, and equipment are obligated to inform residents and contractors about the presence, location, and asbestos content in their properties. If asbestos-containing materials are damaged or deteriorated, they can release fibers into the surrounding air within the living or working environment, posing a potential risk of inhalation and subsequent health issues. It is important to note that intact asbestos-containing materials do not pose a health hazard.

Review of asbestos regulation in the European Union (EU)

Asbestos and materials containing asbestos are subject to regulation under several EU directives, including the following:

- Regulation (EC) No 1907/2006, known as the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) Regulation. This directive, enacted on 18 December 2006, establishes the European Chemicals Agency and amends various

previous directives. It repeals Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94, as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC, and 2000/21/EC.

Annex XVII of the REACH Regulation (EC) No. 1097/2006, which bans the marketing and use of products containing asbestos in the European Union. This regulation prohibits the use of asbestos in new products.

- Regulation (EC) No 1272/2008, enacted on 16 December 2008, concerning the classification, labelling, and packaging of substances and mixtures. It amends and repeals Directives 67/548/EEC and 1999/45/EC and also amends Regulation (EC) No 1907/2006.

- Directive 2009/148/EC, enacted on 30 November 2009, of the European Parliament and the Council of Europe. This directive aims to protect workers from the risks associated with asbestos exposure in the workplace. It establishes limit values for exposure to asbestos and sets forth specific requirements to prevent and mitigate health risks related to asbestos exposure at work.

The aforementioned directive focuses on safeguarding workers' health and aims to prevent risks arising from exposure to asbestos. It sets limits for acceptable exposure levels and outlines various specific requirements. The most significant requirements are detailed below:

- **Prohibition** of the application of asbestos through spraying processes and working procedures involving the use of low-density insulating or soundproofing materials (with a density less than 1 g/cm³) that contain asbestos.

- **Prohibition** of activities that expose workers to asbestos fibers during asbestos extraction, manufacturing and processing of asbestos products, and manufacturing and processing of products intentionally containing asbestos (excluding products resulting from demolition and asbestos removal).

- **Employers** must ensure that workers are not exposed to an airborne concentration of asbestos exceeding 0.1 fibers per 1 cm³ as an 8-hour time-weighted average.

- Regular measurement of asbestos fibers in the air at the workplace should be conducted, depending on the results of the initial risk assessment, to ensure compliance with the aforementioned limit value.

- Commission Regulation (EU) 2016/1005 of 22 June 2016, amending Annex XVII to Regulation (EC) No 1907/2006, focuses on asbestos fibers (chrysotile).

Furthermore, EU members emphasize the need for an impact assessment and cost-benefit analysis to consider the establishment of action plans for the safe removal of asbestos from public buildings and buildings with regular public access by 2028. They also urge the provision of information and guidelines to encourage private homeowners to conduct effective audits and risk assessments of their premises for asbestos-containing materials (ACMs), following the example of Poland.

In this context, it is important to highlight the statement of the International Commission on Occupational Health (ICOH) advocating for a global ban on the production, sale, and use of all forms of asbestos, as well as the elimination of asbestos-related diseases.

“The ICOH calls on each country to implement a total ban on asbestos production and use, and to pursue primary, secondary, and tertiary prevention of asbestos-related diseases through country-specific “National Programs for the Elimination of Asbestos-Related Diseases,” following guidelines from the International Labor Organization (ILO) and World Health Organization (WHO).”

The current regulatory framework for asbestos in Macedonia, which aims to align with EU standards, is not yet fully completed. The existing regulations pertaining to asbestos treatment are as follows:

- The maximum permissible concentration of asbestos in the air emitted from sources is 0.5 mg/m³ per hour, and the maximum allowable quantity of asbestos in the air is 0.1 mg/m³ per hour (Official Gazette of RM No. 3 in 1990).

- The presence of asbestos in water is regulated by the Water Classification Regulation (Official Gazette of RM No. 18 in 1999), which prohibits the presence of asbestos in any of the IV classes of water.

- Guidelines for handling waste containing asbestos and asbestos materials are outlined in the Law on Waste Management (Official Gazette of RM No. 68/04 and 71/04 in 2004).

- The Rulebook on minimum requirements for workers' health and safety concerning risks related to asbestos exposure at work (Official Gazette of RM No. 50 in 2009) provides specific regulations in this regard.

ACTIVITIES

Considering the aforementioned health hazards associated with asbestos and the timeframe for their manifestation (5–40 years after initial

exposure to airborne asbestos), it is crucial to conduct thorough inspections of all public buildings in the country, particularly those predominantly occupied by the young population who will enter their most productive years in 15–20 years' time. Given the significant risks posed by asbestos to human health and well-being, especially among the young population, it is urgent to establish a schedule for identifying the presence of asbestos materials and their removal from all public institutions in Macedonia.

In this regard, inspections and analyses have been conducted in numerous public institutions in the city of Skopje, including kindergartens and schools, and the results are presented in this article. These findings provide valuable data regarding the incorporation of asbestos-containing materials in public buildings, which necessitates their proper treatment and elimination to mitigate potential health risks associated with asbestos exposure.

EXPERIMENTAL

The collected material was prepared for optical investigation using an optical binocular and the transmission of polarized light. This method only provides an indication of the presence of asbestos in the examined material. Infrared spectroscopy was also utilized as an additional technique to study the collected materials. To confirm the presence of asbestos, X-ray diffraction and scanning electron microscopy (SEM) were employed. There is existing literature on the use of these methods for asbestos analysis in various materials [7, 22–29].

The infrared spectra were recorded using a Perkin-Elmer System 2000 infrared interferometer, with pressed KBr disks, at room temperature (RT). To improve the signal-to-noise ratio, 32 scans were collected and averaged. The instrument had a resolution of 4 cm⁻¹ for all measurements. Spectra acquisition and management were performed using the GRAMS ANALYST 2000 [30] and GRAMS 32 [31] software packages.

The presence of asbestos was initially assessed using optical microscopy after appropriate sample preparation. The AX-IOLAB Carl Zeiss Jena microscope was used for this purpose.

To identify the studied samples, X-ray diffractograms were recorded and analyzed using the SIMENS D 500 system, controlled by a computer. The analysis was conducted with CuK α monochromatic radiation at 40 kV/30 mA. The computer PDP 11/23+ automatically obtained the optimal signal-to-noise ratio. The characterization of the identified phases was performed using the DIFRAC 11 software package, specifically the EVAL and IDR programs. Samples

with minimal orientation were prepared to record an adequate diffraction range of $2\theta = 3\text{--}70^\circ$.

RESULTS AND DISCUSSION

Preliminary monitoring was conducted to detect the presence of asbestos in building materials obtained from various educational and healthcare institutions in Skopje. Multiple samples were collected from different parts and materials of each object, including floors, roofs, walls, and ceilings. In total, fifty samples were analyzed using four different analytical methods: optical microscopy with polarized light, X-ray diffraction, scanning electron microscopy, and infrared spectroscopy.

The results of all the analyses are presented in Table 1, and supplementary material (Figures 1-9) is provided, including infrared spectra, X-ray diffractograms, and SEM images of representative samples containing orthochrysotile, anthophyllite, and both anthophyllite and clinochrysotile. The names and addresses of the public buildings are not disclosed here but can be made available to the relevant authorities in Skopje.

After a systematic analysis of the fifty samples from twenty-one public buildings in Skopje using optical microscopy, infrared spectroscopy, X-ray diffraction, and SEM, it can be concluded **that asbestos is present in 33 of the analyzed samples**. Notably, out of these thirty-three samples with asbestos, twenty-eight contained the serpentine type (chrysotile), while five samples contained the more hazardous amphibole type (anthophyllite), and two samples contained both types of asbestos. It is important to highlight **that asbestos was not detected in only two objects**. These findings suggest that asbestos is present in the building materials of nearly all inspected objects, indicating its likely presence in numerous other buildings throughout the city and the country. The confirmed presence of asbestos in kindergartens is particularly concerning due to the exposure risk it poses to young children. Previous studies have also identified asbestos in the building materials of the Pediatric Clinic in Skopje.

Considering the widespread presence of asbestos in Skopje's buildings, the authors of this study recommend immediate action to safely remove asbestos materials from public buildings. The highest priority should be given to the Pediatric Clinic, kindergartens, primary and secondary schools, and all institutions where children spend a significant amount of time. The second priority should be the removal of asbestos-containing materials from healthcare facilities, followed by sports facilities, and so on.

Table 1. Analysis of asbestos in building materials in different objects in Skopje

No.	Object	Roof	Floor	Wall	Ceiling
1.	Kindergarten			I/29 S Nd*	I/29 T Chrysotile
2.	Elementary school – 1	I/3a K Chrysotile	I/5 n Nd		
3.	Elementary school – 2		I/8 n Nd	I/8 S Chrysotile	I/8 T Chrysotile and Clinochrysotile
4.	Elementary school – 3		I/21 n Chrysotile	I/21 S Chrysotile	I/21 T Anthophyllite
5.	Elementary school – 4	I/28 K Chrysotile	I/28 n RA 17411 Chrysotile	I/28 S Chrysotile	I/28 T RA 17388 Chrysotile (Clinochrysotile)
6.	Elementary school – 5	I/38 K Nd		I/38 S Chrysotile (Clinochrysotile)	
7.	High school – 1	I/3 K Chrysotile (Orthochrysotile)			
8.	High school – 2	II/3 K Chrysotile (Clinochrysotile)			
9.	High school – 3		II/7 n Chrysotile (Clinochrysotile)	II/7 S Chrysotile (Clinochrysotile)	II/7 T Anthophyllite
10.	High school – 4	II/9 K Nd	II/9 n Nd		
11.	High school – 5	II/13 K Anthophyllite and Clinochrysotile	II/13 n Nd		
12.	High school – 6	II/14 K Anthophyllite and Clinochrysotile	II/14 n Nd	II/14 S Chrysotile (Clinochrysotile)	II/14 T RA 17425 Anthophyllite
13.	High school – 7	II/17 K Nd	II/17 n Nd	II/17 S Chrysotile	II/17 T RA 17428 Chrysotile
14.	High school – 8		II/18 n Nd		
15.	High school – 9	II/19 K Nd	II/19 n Chrysotile (Clinochrysotile)	II/19 S Nd	
16.	High school – 10	II/20 K Nd	II/20 n Chrysotile		
17.	Faculty – 1	I/7 K Chrysotile	I/7 n Chrysotile		
18.	Health care center	I/40 K Nd	I/40 n Nd	I/40 S Chrysotile	
19.	Sports association	I/27 K Chrysotile	I/27 n Nd		I/27 T Chrysotile
20.	House of culture	I/22 K Chrysotile			
21.	Public enterprise	I/23 K Chrysotile (Clinochrysotile)		I/23 S Chrysotile	

*Nd – not detected

When planning the removal of asbestos materials, priority should be given to those containing *amphibole asbestos* due to its easier penetration into the human respiratory system. This is primarily because of the dimensions and properties of the fibers in this type of asbestos, as mentioned earlier.

Before initiating the asbestos removal work in any building or structure, it is crucial to conduct a comprehensive inspection and monitoring of the entire premises, following the appropriate guidelines and instructions for asbestos handling and removal. To ensure the safe removal of asbestos-containing materials, it is also essential to differentiate between various types of these materials, such as brittle asbestos, asbestos coatings used for thermal and acoustic insulation in buildings, decorative coatings, asbestos-containing insulation in boilers and other industrial plants, products made of asbestos-containing cement, vinyl-asbestos floors, and various wall coatings.

To facilitate safe removal, a **detailed plan should be prepared for the removal of asbestos-containing materials** from buildings, equipment, factories, and other structures. This plan should include information about the equipment to be used, the techniques for asbestos removal, and the necessary safety and hygiene requirements. It is mandatory to specify a suitable location and method for the safe disposal of asbestos-containing waste. The disposal of asbestos waste must adhere to the regulations outlined in the Rulebook for the methodology of handling waste containing asbestos and waste from asbestos-containing materials, which is based on the Law on Waste Management (Official Gazette of RM No. 68/04 and 71/04 in 2004).

Contractors working with products that may contain asbestos must ensure that all required steps are taken to confirm the presence or absence of asbestos. If there is any doubt about the presence of asbestos, laboratory analysis should be conducted.

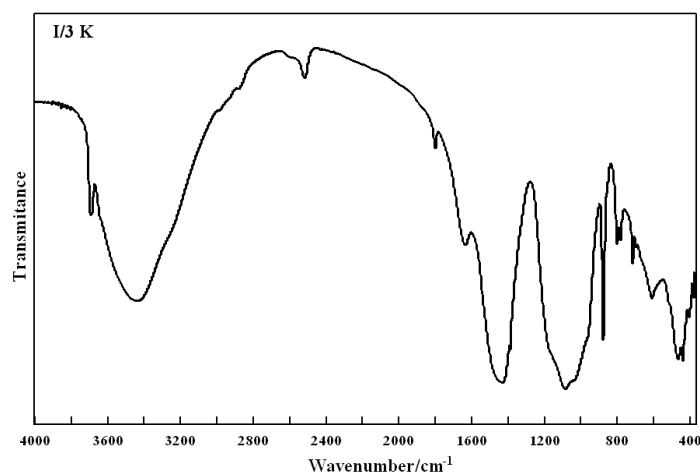


Figure 1. Infrared spectrum of a sample taken from the roof of High school – 1

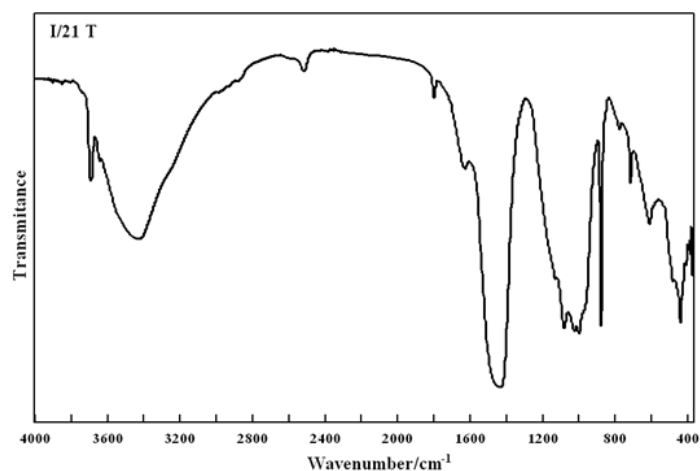


Figure 2. Infrared spectrum of a sample taken from the ceiling of Elementary school – 3

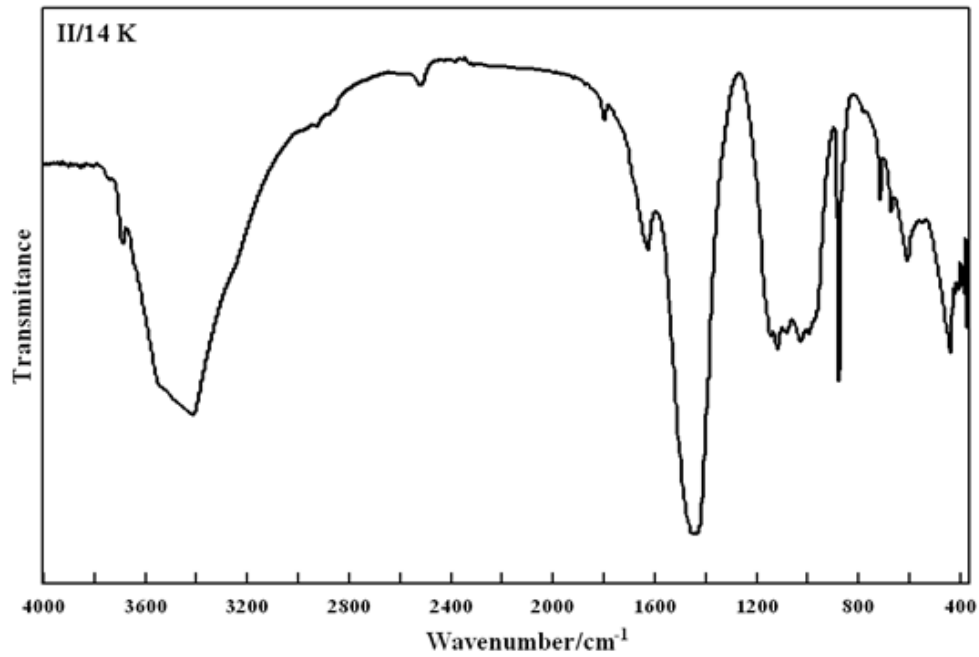


Figure 3. Infrared spectrum of a sample taken from the roof of Elementary school – 6

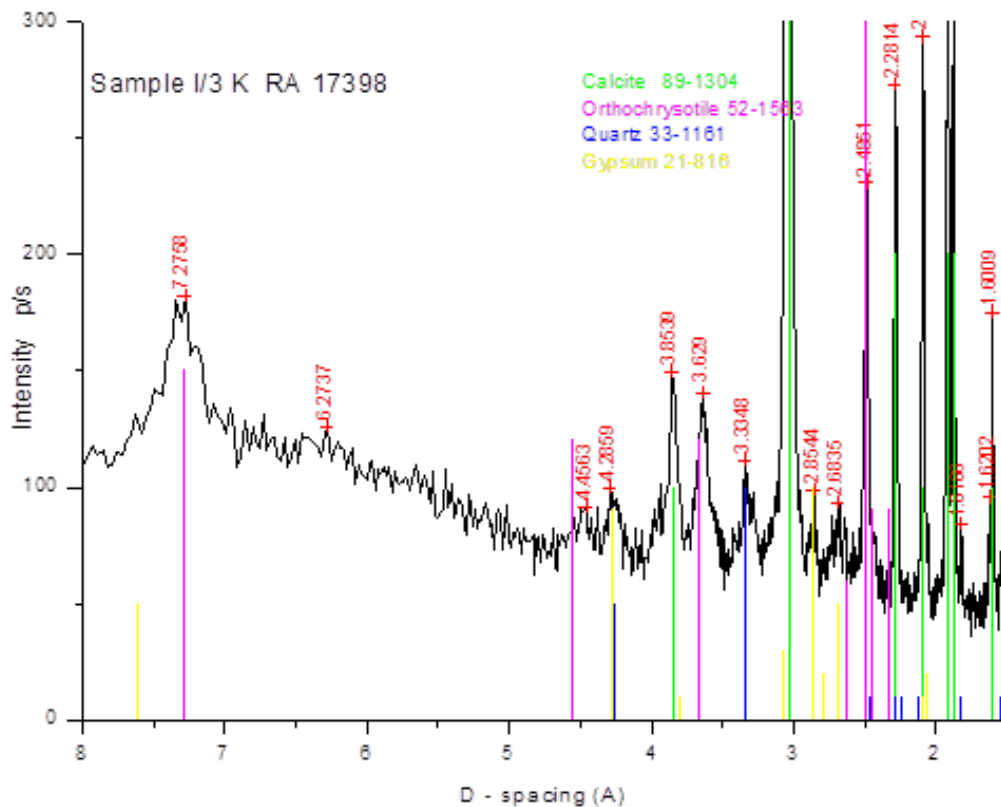


Figure 4. Scattered intensities as a function of the diffraction spacing of a sample taken from the roof of High school – 1

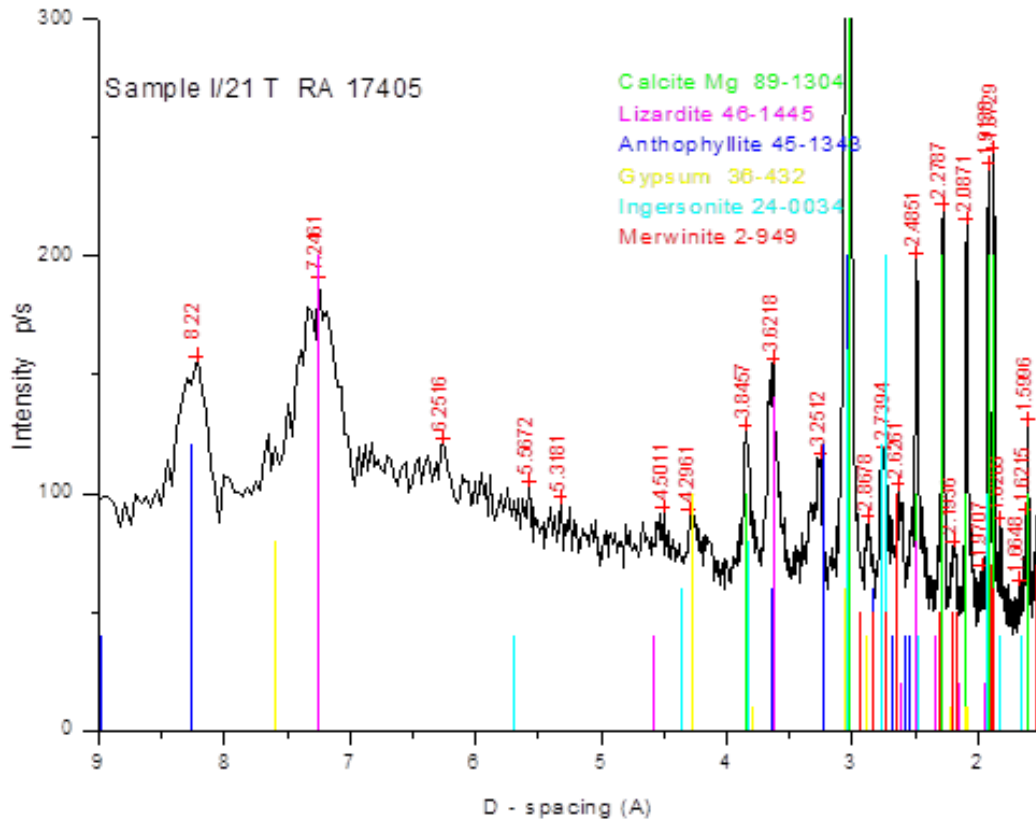


Figure 5. Scattered intensities as a function of the diffraction spacing of a sample taken from the ceiling of Elementary school – 3

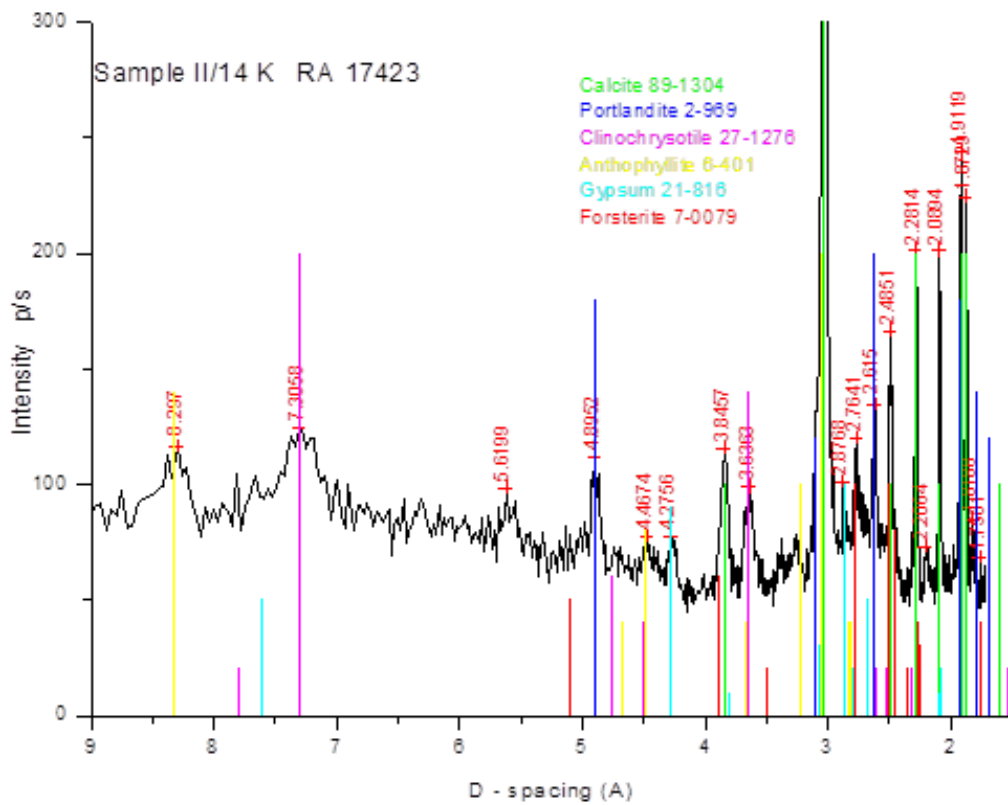


Figure 6. Scattered intensities as a function of the diffraction spacing of a sample taken from the roof of Elementary school – 6

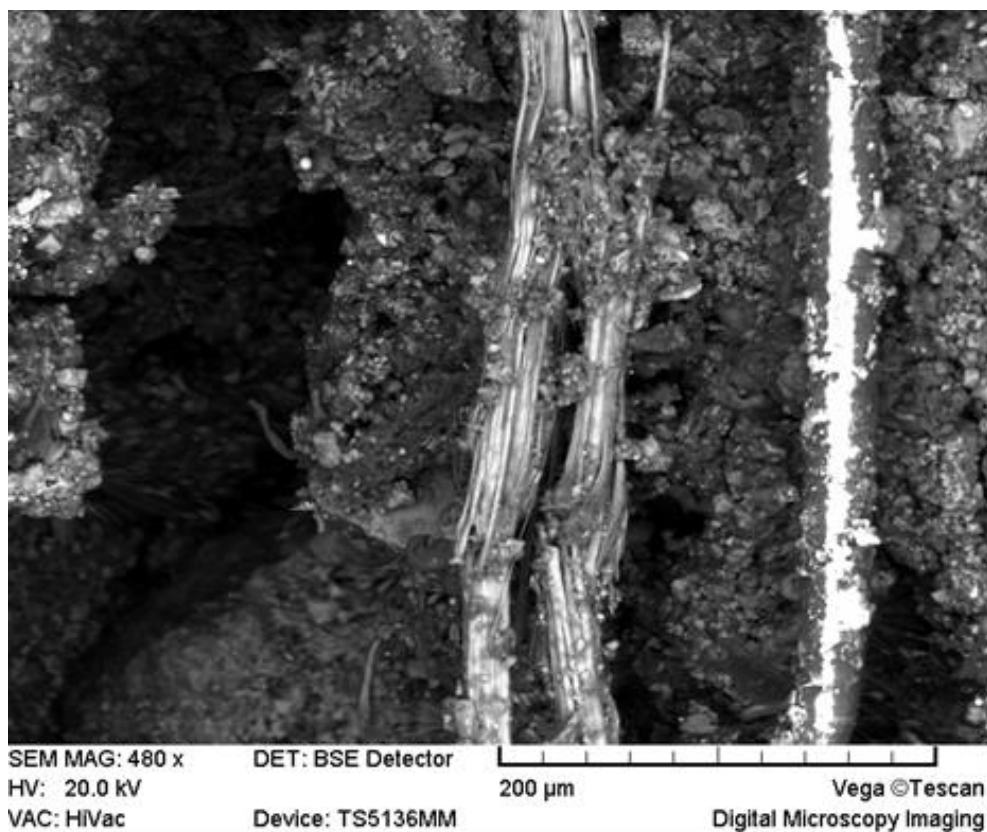


Figure 7. SEM of selected sample that contain asbestos

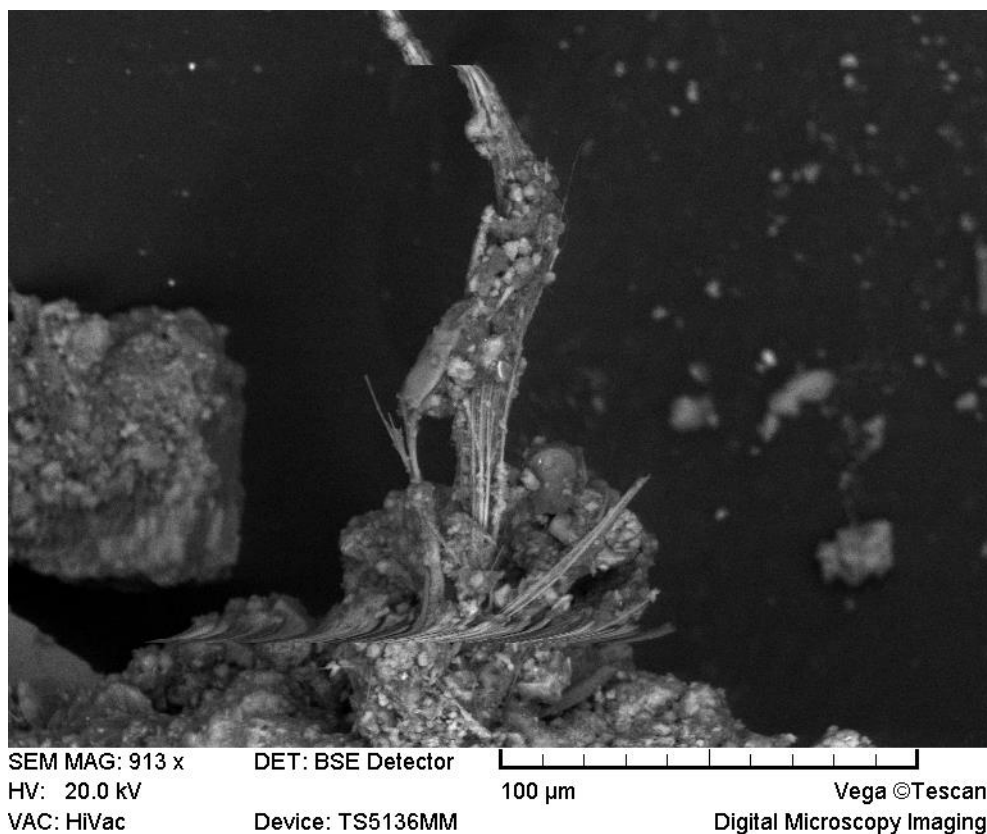


Figure 8. SEM of selected sample that contain asbestos

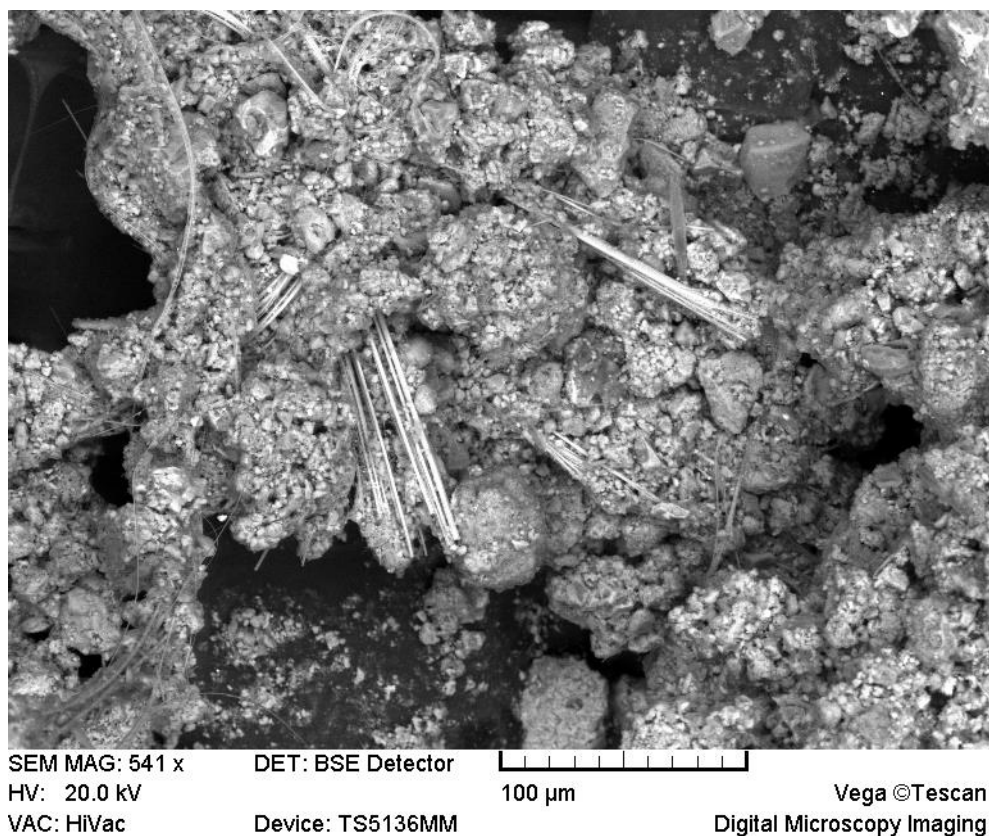


Figure 9. SEM of selected sample that contain asbestos

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АНАЛИЗА НА АЗБЕСТ ВО ГРАДЕЖНИ МАТЕРИЈАЛИ – СЛУЧАЈ ВО ГРАД СКОПЈЕ

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Азбестот е материјал кој е меѓу најтемелно проучуваните од сите материјали опасни за здравјето во минатиот век. Во нашата земја, оваа тема, за жал, не се дискутира многу иако овој проблем во светот се смета за еден од најголемите предизвици со кои треба да се справиме. Кампањата на градските власти на Скопје насочена кон откривање и елиминирање на материјалите што содржат азбест од разни предмети во градот е досега најголемата ваква иницијатива во земјата. Во неа беа опфатени методологија и резултати од анализи на примероци од градежни материјали собрани од разни објекти во градот. По систематска анализа на 50 собрани примероци од 21 јавен објект од регионот на град Скопје, со употреба на оптичка микроскопија, инфрацрвена спектроскопија, дифракција на X-зраци и СЕМ, може да се заклучи дека присуство на азбест има во 33

анализирани примероци. Важно е да се истакне дека азбестот не е идентификуван само во примероците од два објекта. Овие податоци сугерираат дека азбестот е присутен во градежните материјали на практично сите проверени објекти, што дополнително подразбира негово присуство и во многу други објекти во градот и низ земјата. Ситуацијата особено загрижува поради потврдено присуство на азбест во примероци земени од детските градинки, што е поврзано со изложеност на азбест кај младата популација.

Клучни зборови: азбест; серпетински азбест; амфиболски азбест; градежни материјали; Скопје