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Environmental exposure to asbestos and other inorganic fibres using animal lung model

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Abstract

Professional exposure to asbestos fibres is widely recognized as very dangerous to human health and for this reason many countries have banned their commercial uses. People, nevertheless, continue to be exposed to low dose of asbestos from natural and anthropogenic sources still in loco, for which the potential hazard is unknown.

The aim of this research is to assess environmental exposure in an area with outcropping serpentinite rocks, which bear asbestos mineralizations, using sentinel animals which are a non-experimental animal model. We studied the burden of inorganic fibres in cattle lungs which come from two valleys in Italy's Western Alps bearing serpentinitic outcrops: Susa Valley with a heavy anthropization and Lanzo Valleys, with a minor human impact. The identification and quantification of inorganic fibres was performed by scanning electron microscope (SEM) and energy dispersive spectrometer (EDS). In comparison to humans, studies of animals have some advantages, such as no occupational exposure or history of smoking and, in the case of cattle, a sedentary life restricted to one region.

Results spotlight that over than 35% of inorganic fibres found both in Susa and Lanzo valleys, belong to asbestos mineralogical species (asbestos tremolite/actinolite, chrysotile s.s., asbestos grunerite, crocidolite). We also observed a higher concentration of artificial fibrous products in Susa samples showing a correlation with the level of anthropization.

These results confirm sentinel animals are an excellent model to assess breathable environmental background because it is possible to eliminate some variables, such as unknown occupational exposure.

Key words: asbestos, inorganic fibres, sentinel animals, environmental exposure, SEM-EDS

Introduction

According to International law six fibrous silicates, with length > 5 μm, diameter < 3 μm, aspect ratio > 3:1, belong to the asbestos group: asbestos actinolite, asbestos tremolite, asbestos anthophyllite, asbestos grunerite, crocidolite and chrysotile (the first five are amphiboles, chrysotile is a serpentine). -Directive CEE 18/2003. In the last century asbestos has been widely used in many countries: asbestos grunerite, chrysotile and crocidolite have been exploited for several industrial products (i.e. building materials, heat and noise insulators), asbestos anthophyllite was also used, but not in significant amounts (its mineralization are quite rare), asbestos tremolite and asbestos actinolite have not been commercially used but are found as contaminants in mining areas and in some products, such as talc powder. Over this time people have experienced intense exposure to asbestos fibres and a correlation between exposure and some pathologies like asbestosis and mesothelioma, has been found for occupational exposure to high levels of fibre burden. As a result, commercial use of asbestos has been banned by many countries, but nevertheless, fibres are continuously airborne from both anthropogenic sources (e.g. asbestos- cement roof) and natural one (e.g. outcropping serpentinite rocks, bearing asbestos). Therefore low levels of asbestos are present everywhere and can be inhaled and deposited in the deepest parts of lungs.

In addition, other non-asbestos minerals can crystallize with fibrous habit and epidemiological evidence of mesothelioma clusters have been associated also to low level exposure to non-asbestos fibres (Skinner et al., 1988; Hillerdal, 1999). To date it has been impossible to define a threshold below which there is no risk for asbestos and fibrous mineral exposure (WHO, 1986).

The Western Alps of Italy in the region of Piedmont are very rich in serpentine rocks (Fig. 1), many of them outcropping, and some of which have been exploited in the past for the quarrying of asbestos (i.e. the mine at Balangero, closed in the 1990). In recent decades many researchers have aimed to identify other fibrous species in these outcropping rocks, and altogether, 11 have been described. In decreasing order of frequency, these are: chrysotile (with polygonal serpentine), antigorite, asbestos tremolite, asbestos actinolite, diopside, carlosturanite, forsterite, balangeroite, sepiolite, brugnatellite and brucite. These fibrous species are intergrown at sub-micrometric scale to form fibrous bundles (Belluso and Ferraris, 1991).

The Piedmont Region, because of extensive industrialization, also has many anthropogenic sources of asbestos such as roofs in public and private buildings, and shell flues.

In many Italian areas as in Piedmont Region, natural and anthropogenic contexts occur which interact. In fact many buildings are constructed on serpentinitic rocks and, at the same time, manufactured materials containing asbestos are placed in loco. The asbestos species commonly found in natural sources (i.e. rocks) is asbestos tremolite and asbestos actinolite, whereas from anthropogenic materials we commonly find crocidolite and asbestos grunerite; chrysotile fibres can have either origin. Inorganic fibres are continuously airborne from both natural and anthropogenic sources due to weather and/or human activities. Thus in areas as such as Piedmont, everyone is exposed to low doses of airborne asbestos, even if not professionally exposed.

The study of mineralogical burden in lung tissues is a useful tool to understand the natural background of the airborne breathable fibres, as well to monitor its fluctuations. For this kind of investigation a non-experimental animal model, defined as “sentinel animals” (De Nardo et al., 2004), is preferred to a human one. Animals are also exposed to airborne and potentially toxic pollutants, including asbestos, but they have some advantages like non-occupational exposure and/or habit to smoke and, in the case of cattle, they are sedentary and live their lives in a small region.

The aim of the present study is to evaluate the environmental background of breathable inorganic fibres and distinguish between fibres from natural and anthropogenic sources in two different areas of Western Alps in the Piedmont region: the Susa Valley and the Lanzo Valleys.

Materials and Methods

In collaboration with the Veterinary Services of Susa and Lanzo valleys, 39 cattle's lung samples have been collected: 20 from Susa Valley and 19 from the Lanzo Valleys - both in Piedmont Region of North Western Italy - Fig. 2. In order to analyse the same part of the lung, the specimens were always taken from the right lower lobe. All animals were females, except two males from Susa cluster; the average age was 6 (range: 2-15) and 9 (range: 3-16) years for Susa and Lanzo samples respectively. The details of the cattle – sex, age and origin – are reported in Table 1. The distribution map of the 21 localities of where the cattle come from is shown in Figure 2.

Lung samples were examined for count asbestos bodies (Ab) by Optical Microscope (OM, Leica DMLB at the Pathological Service of Giovanni Bosco Hospital – Torino). The identification and quantification of inorganic fibres was carried out by Scanning Electron Microscope (SEM, Cambridge Stereoscan S-360) equipped with an Energy Dispersive Spectrometer (EDS, Link-Oxford Pentafet ATW2, Si(Li) detector), located in the Mineralogical and Petrological Department of the University of Turin.

To quantify Ab by OM and/or inorganic fibres by SEM-EDS, a mass of 1500 mg of lung tissues previously preserved in formalin to 10 %, was used. Two portions of 500 mg were digested each in 30 mL of NaClO in order to eliminate the organic matrix and to produce a suspension of inorganic material. The first portion was filtered on a mixed cellulose esters membrane with a diameter of 25 mm and pore size of 3 μm for OM examination. The second one was filtered on a mixed cellulose esters membrane with a diameter of 25 mm with pore size of 0.45 μm for SEM-EDS observations. During the filtering step, all membranes were washed with warm, distilled water to accelerate the dissolution of micrometric crystals of NaCl, grown during the chemical digestion. This step is necessary since NaCl precipitated on the membranes could hide the inorganic particles and/or it could be included in the analyzed volume thus disturbing the chemical analyses. The filters were then dried.

All membranes prepared for analysis of Ab by OM were attached to a glass slide using acetone vapour (clarification); the filters used for SEM-EDS observation were glued onto the SEM aluminium pin stub by adhesive type. These last filters were also made conductive by carbon sputter coating prior to the SEM-EDS study.

The third portion of 500 mg was dehydrated in a drying oven at 60° C, in order to measure its dry weight, which was used to determine the concentration of fibres expressed as the number of fibres per gram of dry lung tissue (Belluso et al., 2006).

Ab counting by OM was carried out observing the whole membrane at 400 magnifications (Karjalainen et al., 1996).

Identification and quantification of inorganic fibres was carried out by SEM-EDS at 2000 magnification and, to minimize both time and costs, observing a portion of filter according to Belluso et al. (2006). Each inorganic fibre found was measured in length and diameter and only the particles with an aspect ratio ≥ 3 were considered. A chemical analysis was conducted after the observations were completed. The number of Ab and the inorganic fibres was normalized to 1 gram of dry weight, according to the international standard (De Vuyst et al., 1998).

Results

OM observation shows a rare presence of Ab in cattle lungs. In fact, they have been found in only 7 of the 39 samples - 4 from the Susa Valley and 3 from the

Lanzo Valleys as shown in Table 2, where the age of cattle is reported as well. In all samples Ab concentrations were always below 200 Ab/g_{dw}, a value clearly less than 1000 Ab/g_{dw} usually considered as indicative of occupational exposure (De Vuyst et al., 1998).

In the cattle lung samples from Susa Valley 16 different groups of inorganic fibrous species have been determined by SEM-EDS investigation (Fig. 3). Among these, 5 were identified as asbestos: asbestos actinolite, asbestos tremolite, chrysotile s.s., asbestos grunerite and crocidolite. Tremolite and actinolite were grouped together because their chemical characterization can not be determined by qualitative EDS-SEM analyses. For these minerals we distinguished between fibres with asbestos morphology (called ASBESTOS) and fibrous particles without these parameters (with length < 5 μm and aspect ratio $> 3:1$, reported as NAC: Not Asbestos Classified). We included chrysotile in the cluster of asbestos (chrysotile s.s.) when the fibres presented the elemental analyses of serpentine and, at the same time, a flexible morphology, typically of chrysotile only (Fig 4). Alternatively, we put together chrysotile (an asbestos) and antigorite (a not asbestos) under the label “fibrous serpentine” (Fig 5) because of the difficulty in distinguishing them correctly using EDS-SEM technique.

Among the asbestos species found, asbestos tremolite/actinolite comes from natural sources in the studied area, asbestos grunerite and crocidolite may come from anthropogenic sources only - because they are not present in the local outcropping rocks (Compagnoni et al., 1983); chrysotile may have both origins.

Among the fibres not classified as asbestos we determined both mineral phases (not asbestos tremolite/actinolite, clay and micaceous phyllosilicates, fibrous serpentine, feldspars, edenite, diopside, balangeroite), and artificial fibrous products: TiO_2, silicatic man-made, Fe-Cr rich (Dodis et al., 1982; Uljanova et al., 1999). Fibres of SiO_2 were also found. A very low quantity of fibres was not identified (N.R. in Fig. 3).

The average concentration of total fibres was 100347 ff/g_{dw} (0.1 x 10^6 ff/g_{dw}) and considering only the asbestos fibres the average concentration is 36623 ff/g_{dw} (0.04 x 10^6 ff/g_{dw}). The most abundant fibrous species found were TiO_2 (33%) and asbestos tremolite/actinolite (32%); altogether asbestos represents 36% of the fibres.

Inorganic fibres were found in most samples from the Lanzo Valleys. In these samples we found 4 asbestos species: asbestos tremolite/actinolite, asbestos grunerite and chrysotile s.s.. Fibres not classified as asbestos included the minerals fibrous serpentinite, clay/micaceous phyllosilicates, not asbestos tremolite/actinolite and edenite, whereas TiO_2, silicatic man-made and Fe-Cr rich were classified as artificial fibrous products. The Lanzo Valleys samples also contained fibres of SiO_2 (Fig. 6).

The average concentration of all inorganic fibres was 92626 ff/g_{dw} (0.1 x 10^6 ff/g_{dw}) with the average concentration of asbestos fibres of 34543 ff/g_{dw} (0.03 x 10^6 ff/g_{dw}). The most abundant fibrous species are asbestos tremolite/actinolite (35%) and fibrous serpentine group (21%); the asbestos group represents 37% of all fibres. A very low quantity of fibres was not identified (N.R. in Fig. 6).

Inorganic fibres were detected in all samples apart within one from the Lanzo Valleys (VL09). At the moment it is not possible to give an exhaustive explanation for this sample because the lack of fibres might depend on cattle age, its location or perhaps both.

Examining the average concentrations in the two valleys, we found similar amounts of total inorganic fibres: 100347 ff/g_{dw} (0.1 x 10^6 ff/g_{dw}) in Susa Valley and 92626 ff/g_{dw} (0.1 x 10^6 ff/g_{dw}) in Lanzo ones.

Asbestos fibres were found in 29 of the 39 samples: 14 from Susa Valley and 15 from the Lanzo Valleys. We detected the presence of 5 asbestos types in Susa Valley samples (asbestos tremolite/actinolite, asbestos grunerite, crocidolite and chrysotile s.s.) and 4 in those from the Lanzo Valleys (asbestos tremolite/actinolite, asbestos grunerite and chrysotile s.s.). Asbestos coming from natural sources (tremolite/actinolite), was present in both groups. Asbestos with anthropogenic origins was rare, detected only in 3 samples (2 from Susa Valley and 1 from Lanzo); asbestos grunerite was found in both valleys, crocidolite only in Susa Valley. Fibrous serpentine was found in both valleys.

Asbestos tremolite/actinolite always represented the most abundant asbestos found, with similar average concentrations: 32076 ff/g_{dw} in samples from Susa and 32667 ff/g_{dw} in Lanzo samples. On the whole, asbestos made up 36% of the total fibres detected in Susa samples and the 37% in Lanzo Valleys.

Of the fibres not classified as asbestos, the most frequent specie was TiO_2 in the Susa Valley and “fibrous serpentine” in the Lanzo Valleys.

Morphological data

In Figures 7 and 8 the length and diameter of total fibres are plotted for the Susa and Lanzo valleys. In the Susa Valley samples the average length (L) is 13.2 µm and the average diameter (d) is 1 µm. Most of fibres (84%) fall within the breathable fibres definition (L > 5 µm and d < 3 µm; WHO, 1986), whilst 16 % of fibres did not meet these parameters, mainly because they were shorter than 5 µm (only one fibre had a diameter greater than 3 µm). One fibre satisfied the Stanton’ definition of carcinogenic fibre (L > 8 µm and d < 0.25 µm; Stanton et al., 1981). With regard to the Lanzo samples the plot is less diverse: the average length is 12.6 µm and the average diameter is 1.1 µm. For this group, most of fibres (82%)

have dimensions which fall within the breathable definition; the 18% of fibres with dimensions outside this definition had a length less than 5 µm. None of the fibres met the Stanton definition parameters.

The data for only the asbestos tremolite/actinolite fibres in the Susa and Lanzo samples are shown in Figures 9-10.

For both groups, these fibres fall within the breathable fibres definition and none of them is in agreement with the Stanton parameters. The two valley samples had different average length: in the Susa samples the asbestos tremolite/actinolite fibres have lengths with an average value of 19.6 µm, whereas in the Lanzo samples the average length is 10.5 µm. The average diameter of fibres was 1.1 µm for the Susa samples and 1.2 µm for Lanzo samples.

Discussion

The study examined 39 lung samples, 20 from the Susa Valley and 19 from the Lanzo Valleys.

Asbestos bodies were found in only 7 samples (4 from Susa and 3 from Lanzo respectively) and always in very low concentrations with respect the limit of 1000 Ab/g_{dw}, the threshold indicating professional exposure (De Vuyst et al., 1998).The inorganic fibre concentrations detected in the two clusters are compared in Figure 11. For a better comprehension the following groups are reported: “natural source asbestos”, “anthropogenic source asbestos”, “chrysotile s.s.”, “fibrous serpentine” and “artificial fibrous products” (TiO_2, silicatic man-made, Fe-Cr rich), in order to show differences between natural and anthropogenic fibres found in the two clusters.

Similar concentrations of asbestos from natural sources (tremolite/actinolite) and asbestos from anthropogenic sources (crocidolite, asbestos grunerite) were found. Fibres of chrysotile s.s. are almost absent in both valleys. It is very interesting to note that instead, a significant difference between the concentrations of the fibrous serpentine group and artificial fibrous products (TiO_2, silicatic man-made, Fe-Cr rich). The fibrous serpentine is much more abundant in the Lanzo Valleys (21%) with respect to the Susa Valley (3%), whereas artificial fibrous products are higher in Susa samples (45%) than in Lanzo ones (20%). This result emphasizes the different anthropization of two valleys, showing clearly the higher human impact in Susa Valley. A correlation between natural source mineral phases (asbestos tremolite/actinolite, non asbestos tremolite/actinolite) and outcropping serpentine rocks was also found. For this, the average concentrations of these two mineral groups were split between the upper and lower valleys (see Table 3) because the outcropping rocks (matrix of tremolite/actinolite fibres) are more widespread in the Lower Susa Valley (LSV) and in the Upper Lanzo Valleys (ULV). By these comparisons, we can see that animals from Upper Susa Valley (USV) and Lower Lanzo Valleys (LLV) show less amounts ($0.01x10^6$ ff/g_{dw} and $0.01x10^6$ ff/g_{dw} respectively) than Lower Susa Valley and Upper Lanzo Valleys ($0.06x10^6$ff/g_{dw} and $0.13x10^6$ ff/g_{dw} respectively), in agreement with the lower quantities of serpentinite outcrops.

When we compare only the concentration of asbestos tremolite/actinolite from natural sources in the Susa and Lanzo samples with similar studies (i. e. Dumortier et al. 2002; Abraham et al., 2005) we note that in comparison with Corsican goats (Dumortier et al. 2002) we found lower concentrations in USV and LLV, similar amounts of LSV and higher quantities of ULV. Our concentrations were all lower than the California data (Abraham et al., 2005) - Table 3. Nevertheless, these papers don't report precisely the same research conditions because the animals are different and the environmental context as well, but they are the only data available in the scientific literature.

We found a similar morphology distribution when comparing the average dimensions for the whole inorganic fibres (length 13.2 μm and diameter 1 μm for Susa Valley and length 12.6 μm and diameter 1.1 μm for Lanzo ones).

When the sizes of only asbestos tremolite/actinolite was compared, we found similar average values for the diameters (1.1 μm and 1.2 μm respectively for Susa and Lanzo Valleys), whereas for the lengths we found different average values. In fact, in the Susa Valley the average length was 19.6 μm and in the Lanzo Valleys it was only 10.5 μm. This difference may be correlated to the size of fibres in the natural source (i.e. into matrix rocks), because the same animal species with similar range-ages were sampled.

Conclusions

Analyzing cattle lung samples for the research of asbestos and inorganic fibres can be useful in order to shed light on the typology and amounts of inorganic breathable airborne fibres in the environment. The presence of asbestos and inorganic fibres in sentinel animals can provide information about "environmental background", a term used here to indicate the average exposure to airborne fibres, according to the topographic, geological, anemometric, and anthropogenic characteristics in specific areas. In this experimental model it has been possible to evaluate the environmental background for natural and anthropogenic inorganic fibres in the two valleys.

A very low concentration of asbestos bodies were detected in only 7 samples (4 from Susa Valley and 3 from Lanzo Valleys respectively) and no correlation with the age or localities is found.

Moreover, results show higher concentrations of artificial fibrous products

(45%) in the Susa Valley, which is more industrialized than the Lanzo Valleys (20% of artificial fibrous products). In addition, we found a correlation between the concentration of natural source mineral phases (asbestos tremolite/actinolite, non asbestos tremolite/actinolite) in lungs and the higher distribution of outcropping serpentine rocks in Upper Lanzo Valleys and the Lower Susa Valley.

The low concentration of chrysotile s.s., also abundantly present in the outcropping serpentine rocks, probably depends upon its low biopersistence in the lungs (Bernstein and Hoskins, 2006).

The limited number of samples does not allow a correlation between age of animals and inorganic fibres burden. Moreover for this purpose, it would be better to analyses older animals – which more closely simulates human exposure– but for commercial reasons the cattle are slaughtered while young.

These results show that there is a significant local environmental exposure for the human population living in the studied areas. And that the study of inorganic fibres in animals is important in order to better understand the morphological characteristics of breathable inorganic fibrous particles and correlate this data to potential carcinogenic effects for humans.

The sentinel animals are an excellent model to assess breathable environmental background because it is possible to eliminate some variables, such as unknown occupational exposure.

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Tables

Table 1: List of the samples analysed both in Susa and Lanzo valleys. For each of them the sex, the age and the locality are reported.

SUSA Valley				LANZO Valleys			
SAMPLE code	**SEX**	**AGE (years)**	**LOCALITY**	**SAMPLE code**	**SEX**	**AGE (years)**	**LOCALITY**
VS65	♀	2	Bardonecchia	VL05	♀	9	Ala di Stura
VS66	♀	4		VL07	♀	16	
VS08	♀	6	Bruzolo	VL02	♀	4	Balangero
VS22	♀	12	Bussoleno	VL16	♀	12	
VS67	♀	7	Cesana	VL17	♀	9	
VS36	♀	4	Chiomonte	VL18	♀	10	
VS40	♀	3		VL12	♀	8	Cafasse
VS64	♀	10	Exilles	VL09	♀	3	Ceres
VS15	♀	11	Mompantero	VL14	♀	7	
VS11	♀	4	Novalesa	VL03	♀	7	Coassolo
VS34	♀	5	Oulx	VL06	♀	12	
VS39	♀	4		VL04	♀	7	Corio
VS58	♀	8		VL13	♀	5	
VS62	♀	7		VL19	♀	3	
VS45	♀	5	Salbertrand	VL20	♀	15	
VS01	♀	11	Susa	VL21	♀	12	
VS14	♂	2		VL11	♀	13	Groscavallo
VS02	♀	15	Venaus	VL15	♀	9	Monastero
VS21	♂	3		VL01	♀	12	S. Gillio
VS72	♀	9					

Table 2: Concentrations of Ab found in 7 samples (4 from Susa and 3 from Lanzo valleys).

SUSA Valley			**LANZO Valleys**		
SAMPLE and LOCALITY	**AGE (years)**	**Ab/g$_{dw}$**	**SAMPLE and LOCALITY**	**AGE (years)**	**Ab/g$_{dw}$**
VS66 Bardonecchia	4	43	VL03 Coassolo	7	13
VS39 Oulx	5	50	VL16 Balangero	12	183
VS45 Salbertrand	5	25	VL07 Ala di Stura	16	33
VS64 Exilles	10	50			

Table 3: Comparison between the average concentration and the range of fibres from natural source found in animals from Susa and Lanzo Valleys

	SUSA Valley		**LANZO Valleys**		**Corsica[1]**	**California[2]**	
	cattle		cattle		goats	cats	dogs
	Upper	Lower	Upper	Lower			
Asb tr/act + non Asb tr/act	0.01	0.06	0.13	0.01			
range	0-0.06	0-0.3	0-0.5	0.04			
Asb tr/act	0.01	0.06	0.09	0.01	0.04	0.12	2.98
range	0-0.05	0-0.3	0-0.4	0-0.4	0-0.15		

Corsica[1] (Dumortier et al., 2002) and California[2] (Abraham et al., 2005). tr: tremolite, act: actinolite

Figure captions

Figure.1: Lithological map of Piedmont Region (Regione Piemonte, 1990).

1. Terraced, recent and present day fluvial deposits, mainly consisting of coarse-grained sand bodies with clayey intercalations (Olocene-Middle Pleistocene)
2. Complexes of morainic ridges and intermorainic depressions (Upper Pleistocene-Middle Pleistocene)
3. Yellow sands with gravel lenses or silty-clayey coastal sediments; sandy, sandy-gravelly or loamy-clayey alluvial deposits ("Villafranchian", Middle Pliocene-Lower Pleistocene)
4. Sands richly marine molluscs bearing with sandstones lenses (Middle Pliocene)
5. Pelites, clayey marls, marls, gypsarenites and evaporites (Middle Pliocene-Messinian)
6. Marls with interbedded sand or sandstone levels (Miocene)
7. Marly siltstones, with locally interbedded sandstone levels or conglomerate lenses (Miocene-Upper Oligocene)
8. Sandstone and conglomerate levels, with interbedded marls and sandy marls (Oligocene)
9. Clays, marls, limestones and chaotic clayey complex (Cretaceous-Eocene)
10. Ophiolites: peridotites, gabbros, basalts, serpentinites and ophiolitic breccias, with various grade metamorphism (Piedmont-type units, Jurassic-Cretaceous)
11. Quartzites, schists, marbles, phyllites ("Schistes Lustrées" Auctt., Piedmont-type units, Jurassic-Cretaceous)
12. Crystalline dolostones and limestones, dolomitic limestones, sandy-marly limestones (Cretaceous-Triassic)
13. Micaschists and gneisses, with subordinate phyllites, quartzites, eclogites, slates and marbles (Hercynian and Pre-Hercynian crystalline massifs)
14. Gneisses and migmatites, with subordinate schists, porphyries and amphibolitic lenses (Hercynian and Pre-Hercynian crystalline massifs)
15. Plutonic and volcanic Alpine or Pre-Alpine rocks

Figure 2: Distribution map of the 21 localities of where the cattle come from; ● localities in Lanzo Valleys, * localities in Susa Valley.

Figure 3: Concentrations of fibres in cattle from Susa Valley, expressed both as ff/g_{dw} and percent. ASBESTOS and Not Asbestos Classified (NAC). Tremolite/actinolite are divided according to dimension of breathability; tr: tremolite, act: actinolite. N.R. = Not Recognized.

Figure 4: Secondary electron image SEM of a chrysotile fibre (2000M).

Figure 5: Backscattered electron SEM image of serpentine fibres: chrysotile and/or antigorite (2000M).

Figure 6: Concentrations of fibres in cattle from Lanzo Valleys, expressed both as ff/g_{dw} and percent. ASBESTOS and Not Asbestos Classified (NAC). Tremolite/actinolite are divided according to dimension of breathability; tr: tremolite, act: actinolite. N.R. = Not Recognized.

Figure 7: Plot of length and diameter of total inorganic fibres found in Susa samples.

- . - . - mineralogical fibres;

▬▬ area ascribed to breathable fibres;

…….. area for fibres according to Stanton definition

Figure 8: Plot of length and diameter of total inorganic fibres found in Lanzo samples;

- . - . - mineralogical fibres

▬▬ area ascribed to breathable fibres

…….. area for fibres according to Stanton definition

Figure 9: Plot of length and diameter of asbestos tremolite/actinolite fibres found in Susa samples;

- . - . - mineralogical fibres

▬▬ area ascribed to breathable fibres

…….. area for fibres according to Stanton definition

Figure 10: Plot of length and diameter of asbestos tremolite/actinolite fibres found in Lanzo samples;

- . - . - mineralogical fibres;

▬▬ area ascribed to breathable fibres;

…….. area for fibres according to Stanton definition

Figure 11: Comparison between average concentrations of inorganic fibres found in cattle lung tissue from Susa and Lanzo Valleys; N.S.= natural sources (asbestos tremolite/actinolite); A.S. = anthropogenic sources (for crocidolite and asbestos grunerite).

Figure

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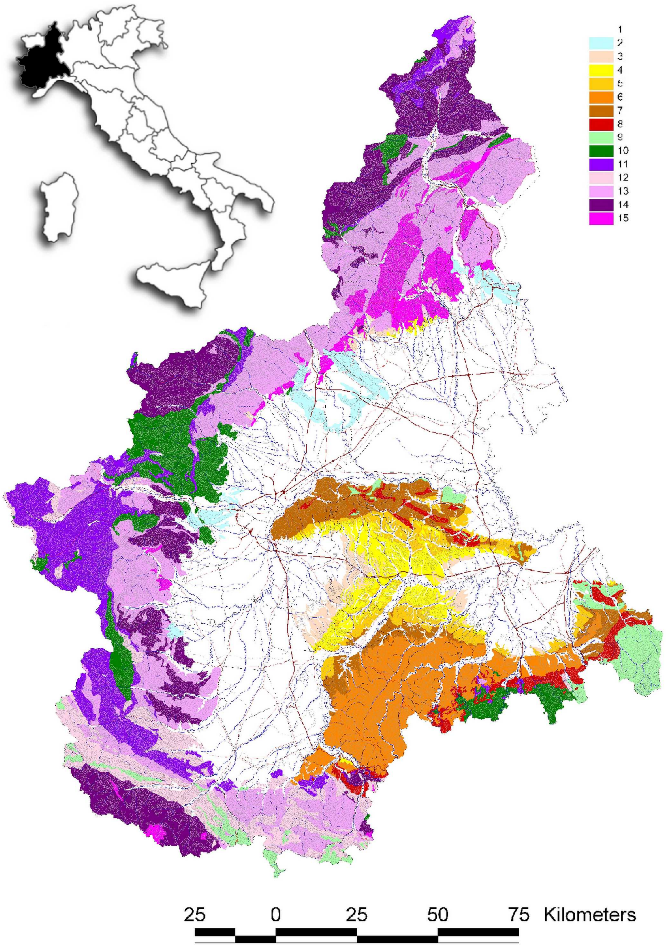
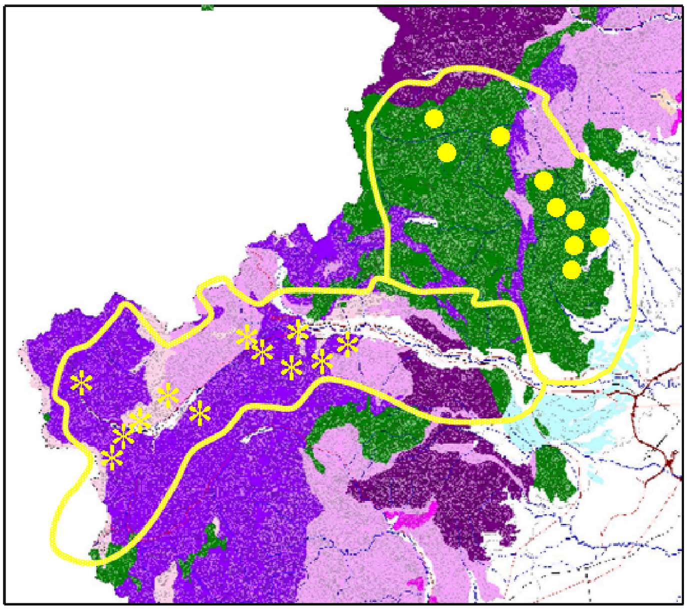


Fig. 1



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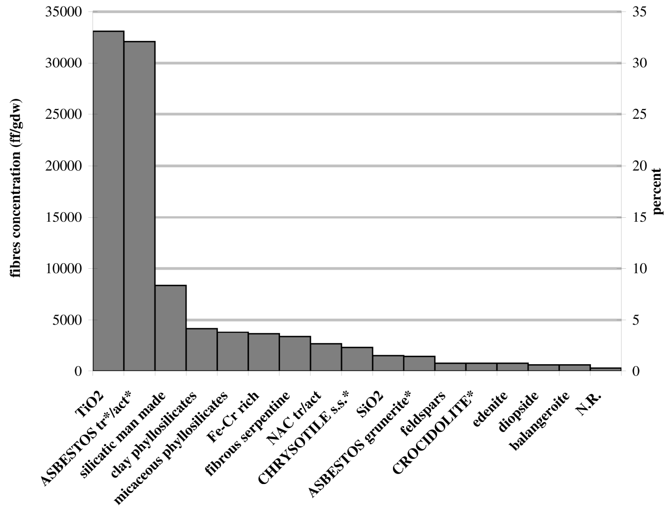

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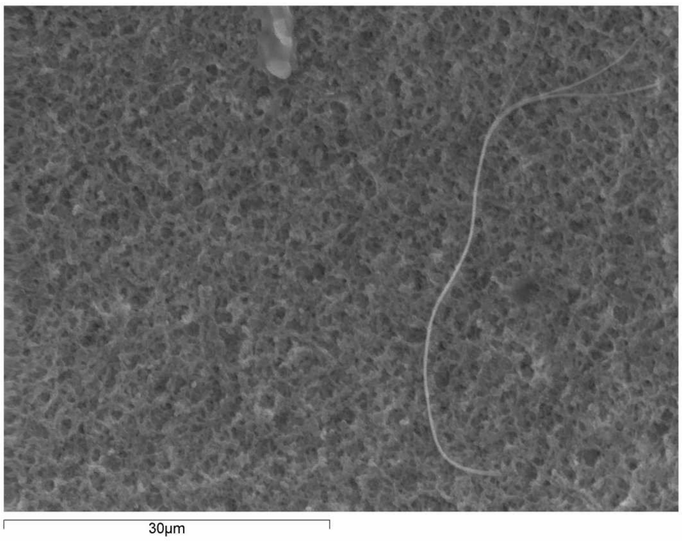
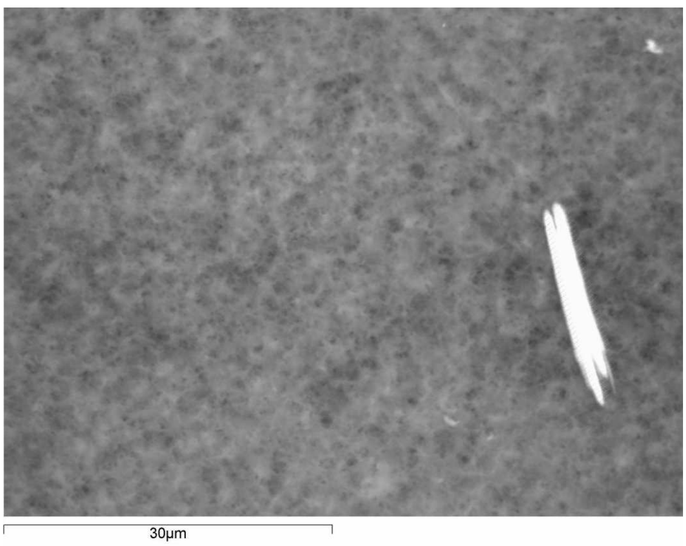


Fig 4



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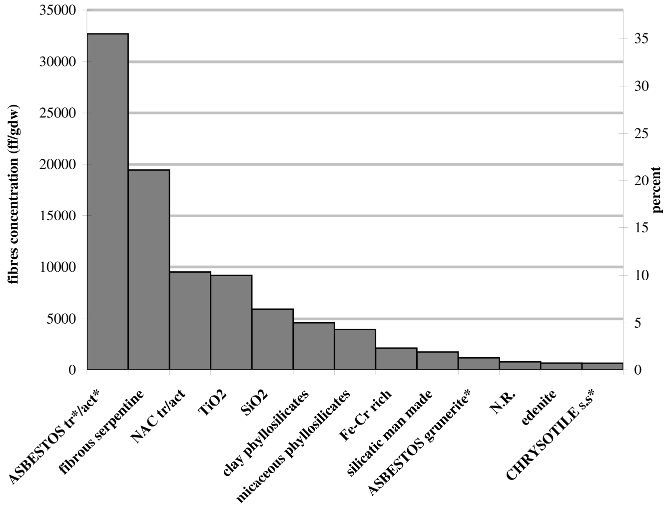
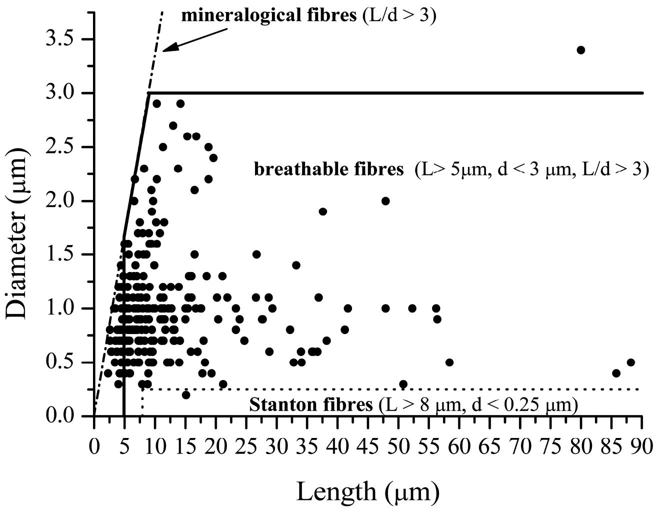


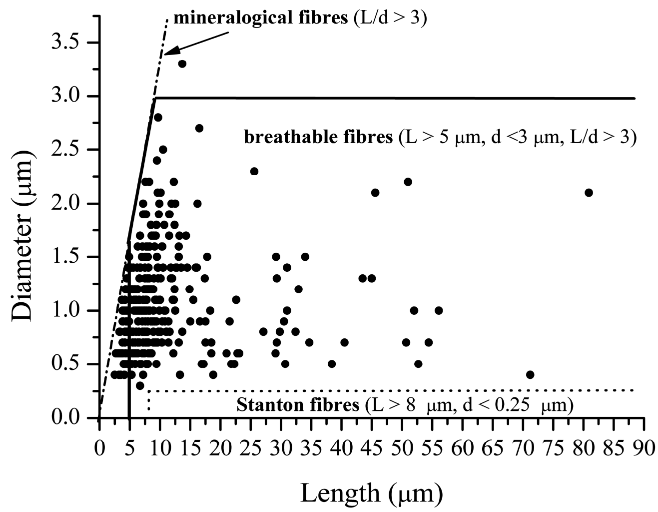
fibres concentration (ff/gdw)
percent
ASBESTOS tr*/act*
fibrous serpentine
NAC tr/act
TiO2
SiO2
clay phyllosilicates
micaceous phyllosilicates
Fe-Cr rich
silicatic man made
ASBESTOS grunerite*
N.R.
edenite
CHRYSOTILE s.s*

Fig. 6



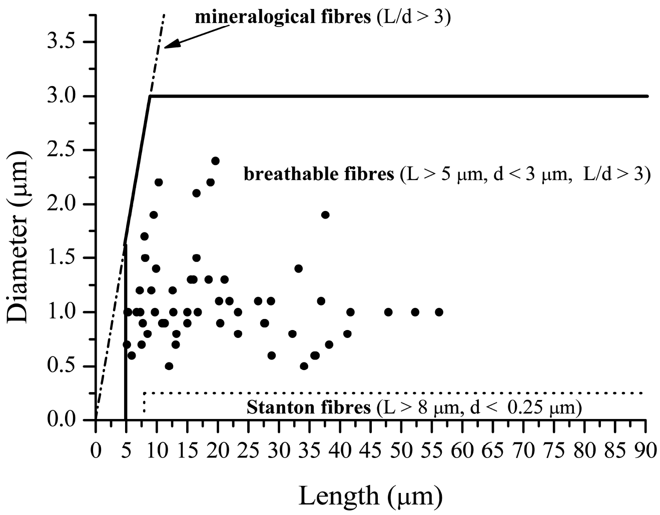
mineralogical fibres (L/d > 3)
breathable fibres (L> 5μm, d < 3 μm, L/d > 3)
Stanton fibres (L > 8 μm, d < 0.25 μm)
Diameter (μm)
Length (μm)

Fig. 7



mineralogical fibres (L/d > 3)
breathable fibres (L > 5 μm, d <3 μm, L/d > 3)
Stanton fibres (L > 8 μm, d < 0.25 μm)
Diameter (μm)
Length (μm)

Fig. 8



mineralogical fibres (L/d > 3)
breathable fibres (L > 5 μm, d < 3 μm, L/d > 3)
Stanton fibres (L > 8 μm, d < 0.25 μm)
Diameter (μm)
Length (μm)

Fig. 9

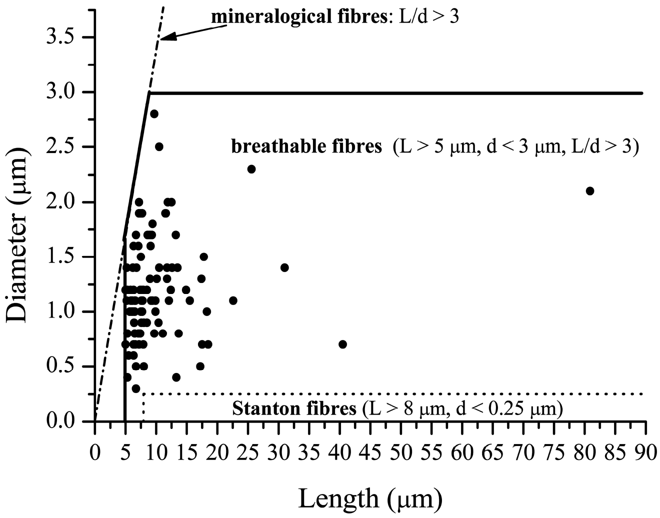

mineralogical fibres: L/d > 3
breathable fibres (L > 5 µm, d < 3 µm, L/d > 3)
Stanton fibres (L > 8 µm, d < 0.25 µm)
Diameter (µm)
Length (µm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90

Fig. 10

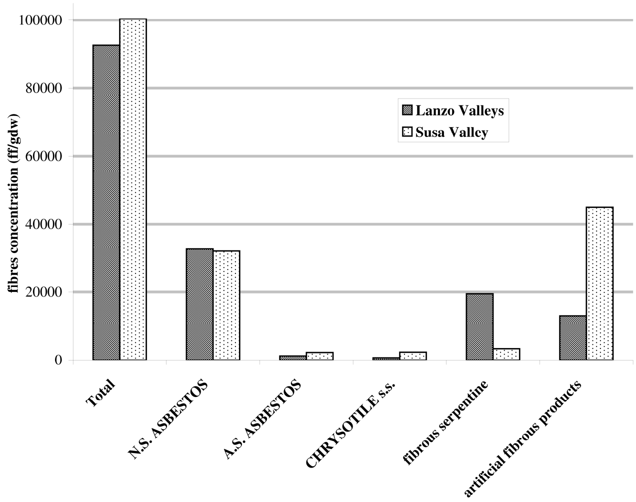

Lanzo Valleys
Susa Valley
fibres concentration (ff/gdw)
0
20000
40000
60000
80000
100000
Total
N.S. ASBESTOS
A.S. ASBESTOS
CHRYSOTILE s.s.
fibrous serpentine
artificial fibrous products

Fig. 11