Period. Mineral. (2010), 79, 3, 21-35

doi: 10.2451/2010PM0015
http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment*, *Archeometry* and *Cultural Heritage*

Fibrous mineral detection in natural soil and risk mitigation (1st paper)

Francesco Burragato[1], Giovanni Gaglianone[1], Giovanni Gerbasi[1], Simona Mazziotti-Tagliani[1]*, Luciano Papacchini[2], Francesco Rossini[3] and Bruno Sperduto[4]

[1]Dipartimento di Scienze della Terra, Sapienza Università di Roma, P.le A. Moro, 5 - I-00185 Rome, Italy
[2]USPP Ufficio Speciale Prevenzione e Protezione, Sapienza Università di Roma, P.le A. Moro, 5 - I-00185 Rome, Italy
[3]Dipartimento Produzione Vegetale, Università della Tuscia, Via S. Camillo de Lellis, I-01100 Viterbo, Italy
[4]Istituto di Medicina del Lavoro, Università Cattolica del S.Cuore, Largo F. Vito,1 - I-00168 Rome, Italy

Submitted, July 2010- Accepted, November 2010

Abstract - The paper describes a fibrous mineral detection methodology, which is based on the use of alternating rotary motion sieving equipment. The equipment was redesigned to meet additional requirements with respect to initial ones. Under this methodology, the fine fraction passing through the sieves was recovered and analysed to determine the sedimentology, mineralogy and morphology of the potentially particulating fraction. Reliance was made on the following analytical techniques: laser granulometry, scanning electron microscopy/energy dispersive spectrometry (SEM/EDS) and polarised and phase contrast light microscopy (PLM, PCLM) for fibrous mineral identification and Walton-Beckett / whole field fibre counting. The samples for the analyses came from known areas with fibrous minerals, e.g. Lauria (Basilicata), and less known areas, e.g. the Natural Reserve of Mt. Rufeno (Latium) and Biancavilla (Sicily). With this methodology, fibres may be directly detected in both farmed and unfarmed soil with fibrous minerals and the process may be repeated in the various stages of farming or during works for creation of fire barriers or lanes, hydrogeological restoration etc. The goal is to identify risks arising from the natural occurrence of asbestos upon atypical activities, such as farming and forestry. With regard to exposure, consideration was given to fibrous minerals not currently classified in the relevant legislation, thus going beyond the search for asbestiform minerals in quarry sites located in ophiolite outcrop areas.

Riassunto - Il presente lavoro descrive un metodo per individuare le fibre minerali presenti nei suoli attraverso l'uso del setaccio a rotazione alternata. Tale dispositivo, modificato per questo studio, permette di raccogliere ed analizzare la frazione fine di materiale che passa attraverso il setaccio e di studiarne la sedimentologia, la mineralogia e la morfologia.

I campioni di suolo scelti per questo studio provengono da aree con presenza di minerali fibrosi, come ad esempio Lauria (Basilicata), la riserva naturale di Monte Rufeno (Lazio) e il paese di Biancavilla (Sicilia). I dati riportati sono stati ottenuti tramite tecniche analitiche: analisi granulometrica attraverso il laser, microscopio elettronico a scansione (SEM) dotato di microanalisi EDS, microscopia ottica e a contrasto di fase (PLM, PCLM). L'osservazione attraverso la microscopia ottica a contrasto di fase è stata effettuata sia attraverso il campo intero sia attraverso l'uso del Walton-Beckett.

L'obiettivo di questo lavoro è identificare i rischi che emergono durante le attività atipiche, come l'agricoltura e la silvicoltura, legati alla naturale presenza

*Corresponding author, E-mail: mazziottitagliani@gmail.com

di amianto. Il metodo sviluppato tramite l'uso del setaccio a rotazione alternata permette di trovare nei suoli agricoli e non agricoli le fibre. Il processo può esser ripetuto nei diversi stadi dell'agricoltura o durante i lavori per la creazione di barriere di fuoco, strade, ripristino idrogeologico, etc. Riguardo l'esposizione, è stata affrontata una discussione relativa ai minerali fibrosi che non possono essere classificati amianto, come nel caso della presenza di minerali asbestiformi nelle cave localizzate su affioramenti ofiolitici.

Key Words: *tremolite; soil; exposure.*

Introduction

Soil contains many types of inorganic and organic particles with at least one dimension in the nanoscale range. This study is focused on fibrous[1] minerals that are present in soil.

Apparently, only a small proportion of the inorganic nanoparticles contained in soil occur as discrete entities. For different reasons, individual nanoparticles are difficult to separate and detect in soil. The characterisation of soil nanoparticles often requires advanced analytical methods.

In recent years, attention has been focused on the nanofibres of asbestos minerals contained in soil, given their impact on environmental pollution. The US EPA has developed protocols and procedures to collect samples from and study the soil contaminated by fibrous minerals (EPA R8, 2000; EPA 540-R-97-028, 2007).

In Italy, interest in this topic has arisen only recently owing to some of diseases (Bernardini *et al.*, 2003; Comba *et al.*, 2003) connected with exposure to minerals classified (e.g. tremolite and chrysotile) and non-classified (e.g. fluoro-edenite) in the relevant legislation. Numerous investigations were conducted over time, but using ground lithoid samples (Paoletti *et al.*, 1999) or comminuted green rocks (Cazzola *et al.*, 2005). Addison *et al.* (1988) proposed a methodology for the study of contaminated natural soils, but using standardised mixtures and not as-is soil; moreover, Swartjes *et al.* (2003) suggested a methodology based on a tiered approach to enable site-specific assessment of risk soil contamination with asbestos. It was only lately that, after reports of lung diseases, procedures have been developed to assess the risk of rock outcrops and soils containing fibrous minerals (Burragato *et al.*, 2004) in one area of Basilicata. Based on these reports, investigations were proposed to monitor airborne fibres (Burragato *et al.*, 2005b, 2006; Fiore *et al.*, 2008) from lithotypes containing these fibrous minerals and to more accurately identify their location (Giordano *et al.*, 2008).

Hence, the naturally contaminated soils were studied with a view to formulating criteria to improve the understanding of and assess the dispersion proneness of asbestiform fibres in areas with or without human activities (Burragato *et al.*, 2005c, 2006).

Considering that pleural mesothelioma was classified in the National Registry of Tumours (Bernardini *et al.*, 2003; Pasetto *et al.*, 2004; Musti *et al.*, 2006), the study reconsidered some areas where naturally contaminated soils had not been officially reported.

[1]Fibers (Harris et al., 2007): fibers are thin particles (width ≤ 0.5 μm) with very high (20:1 to 100:1, or higher) aspect ratios, parallel sides, smooth surface, and no discernable crystal face (i.e., an apparently round cross section).

Analytical methodologies used to study naturally contaminated soils

Samples were collected from areas that have long been known to have asbestiform minerals, such as Seluci di Lauria (Basilicata), and from less known areas, such as the Natural Reserve of Mt. Rufeno (Latium) and Biancavilla (Sicily). Use was made of different techniques to detect the soil fibre content, such as fractionation/polishing, polarised light microscopy (PLM), phase contrast light microscopy (PCLM) and X-ray powder diffractometry (XRD).

The fractionation/polishing technique derives from the use of alternating rotary motion sieving equipment ("metodo del setaccio a rotazione alternata", Pagliai, 2007), (Fig. 1). This equipment was redesigned to meet additional requirements with respect to initial ones. Indeed, the fine fraction passing through the sieves (250 µm) was recovered to conduct sedimentological, mineralogical, compositional and morphological analyses on the fraction prone to being particulated and airborne (Fig. 2) and to perform laser granulometry on the fraction passing through the rotary sieve (250 µm).

PLM was used for mineralogical characterisation; PCLM was used for detecting fibrous minerals and for Walton-Beckett graticule or whole field fibre counting (Cherrie, 1984; Burragato *et al*., 2005b, 2006). Scanning electron microscopy (SEM) with energy dispersive spectrometry (EDS) was used to identify the asbestiform fibres.

Soil sampling and sampling sites

Usually, the fibrous minerals of asbestos classified under the relevant legislation come from rocky formations (ophiolites, serpentines, calc-schists, etc.), but also from formations embedding them, such as argilloschists. The deposits of these minerals are discontinuous and inhomogeneous: veins, veneers, small dikes, stockwork (complex system of veins) and, at times, nodules and very thin intercalations like surface smears. Frequently, these formations are intensely tectonised and brittle, just as asbestos minerals. They may break up under weak mechanical stresses and turn into incoherent material, which may easily be geo-pedogenised (Fig. 3). In the subsequent process of geo-pedogenesis and then pedogenesis, the fibrous minerals (chrysotile, tremolite) carefully investigated with light and electron microscopy

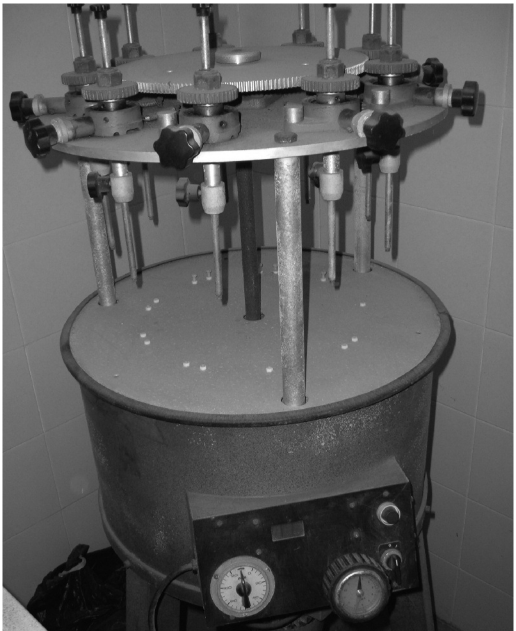


Fig.1 - Photograph illustrating the old instrument.

Fig. 2 - Photograph illustrating the new instrument redesigned for this work.

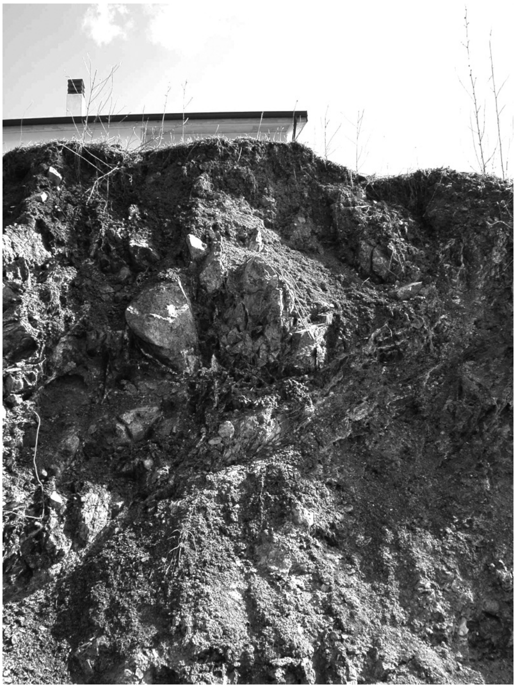


Fig. 3 - Photograph showing a road scarp in the Seluci di Lauria.

do not appear to undergo significant leaching or alteration, but only a morphological change with strong comminution due to exogenous or anthropogenic factors (Fig. 4).

Based on the above considerations, the fine fraction of soil samples is more homogeneous than the one of rock samples, as this fraction is already dispersed in as-is samples.

At Seluci di Lauria (Basilicata) and Mt Rufeno (Latium), samples were collected from soils whereas, at Biancavilla (Sicily), samples were taken from areas close to the Mt. Calvario quarry. The latter samples were collected from volcanic formations, called autobrecciated lavas (originally incoherent) and the nature of their fibrous minerals was only marginally affected by exogenous agents.

As is known, any soil originates from a parent rock. In the cases under review, the soils belong to highly differentiated geological formations. Therefore, it may be useful to concisely describe them. The formations (parent rocks) involved are summarised below.

The area of Seluci di Lauria (with reported fibrous minerals) has an alternation of more or less competent horizons; these horizons are composed of polydeformed metamorphites (bearing argilloschists, calc-schists, phyllites, metarenites, quartzites, rare marbles, etc.), associated with ophiolitic rocks. The outcrops of these rocks consist of highly fractured serpentinites usually having black-bluish translucid surfaces, greasy when touched owing to the presence of talc; only in rare cases do they have a massive structure.

The metamorphites also embody blocks of basic igneous rocks, in part metasomatised, with a thickness of few metres to hundreds of metres, a massive structure and a more or less dark green colour. Fibrous tremolite and sporadic chrysotile mineralisations are encountered in the points of transition between the blocks and poorly competent formations. For this study, the samples from Seluci di Lauria are no. 149 and no. 91.

From a geological viewpoint, the area of Mt. Rufeno is made up of sedimentary formations,

Fig. 4 - Photograph showing the presence of the tremolite in the soil (Seluci di Lauria area).

lying in the immediate vicinity of the northernmost products from the Vulsini volcanic complex.

Flysch facies are dominant (Buonasorte *et al*., 1988) and consist of clays and marly clays, argilloschists, marly limestones and marls, interbedded with siliceous limestones, calcarenites and sandstones.

Basic magmatic rocks, which underwent metamorphic processes, are found among the flysch facies. These are ophiolitic formations of secondary deposition with respect to the flysch and at times associated with euphotites. The latter developed as result of low-grade metamorphism of serpentinous breccias with carbonate cement of marine sedimentary origin (Brotzu *et al*., 1973). Based on the paragenetic talc-tremolite-calcite assemblage of the ophicalcites, the intensity of the metamorphic-metasomatic event may attributed to the green schist facies. Asbestiform materials are observed within the serpentinites and ophicalcites (Burragato *et al*., 2001). The samples from Mt. Rufeno are no. 1 and no. 5. In the Biancavilla area (Sicily), widespread contamination by fibrous amphiboles is related to the volcanic materials outcropping in the quarry of Mt. Calvario (Burragato *et al*., 2005a; Comba *et al*., 2003), on the south-western flanks of the Mt. Etna volcano. Volcanological research identified this area as a locally metasomatised benmoreitic lava dome and as a dyke complex with associated autoclastic breccia. The autoclastic benmoreitic lava body, named "autobreccia lava" in the geological map of Mt. Etna (Romano *et al*., 1982), belongs to the Ancient Mongibello phase of activity and represents the host rock type for the fluoro-edenite mineralisation. In particular, fibrous amphiboles are abundantly present as loose fibres within the friable and fine material of the autoclastic breccia. The fine materials include a mineralogical assemblage dominantly consisting of fibrous amphiboles, alkali-feldspars, clinopyroxenes, fluoroapatite Fe-Ti oxides. The fibrous samples used for this study are labelled no. 19 (taken inside the quarry of Mt. Calvario) and MOB (taken outside the quarry) (Mazziotti-Tagliani *et al*., 2009).

The use of soils considered in this study is reported below.

At Seluci di Lauria, the agrosilvipastoral use of land is chiefly based on: i) crops grown on natural meadows-pastures (evolved from farmland in the recent past), generally at high altitude; and ii) crops typical of valley floors and slopes. In addition to horticultural crops to meet the needs of the farming families, the most common crops are: autumn-winter cereals, some brassicaceans, maize and potato. These annual crops increase the vulnerability of the soil to erosion, in particular water erosion. Generally, with autumn-winter crops, the soil is more subject to erosion in autumn and winter, because: i) it is poorly protected by the crop at its early stages of growth or not yet emerged; and ii) it has been recently stirred up by mechanical working. All the annual crops, especially those whose early stages of growth coincide with high precipitation, are responsible for soil loss. Also spring-summer crops are not fully compatible with environmental conservation, unless crop rotation practices can guarantee full coverage of the soil in periods of higher risk of erosion.

The loss of soil cover is extremely dangerous, because the risk of dispersion of fibres contained in a soil unprotected from erosion (factor "C" of the well-known USLE equation¸ Wischmeier *et al*., 1978) is higher. In the past, natural vegetation covers were mowed in spring and then used for grazing. Now, they are mostly used for free grazing in a non-uniform and irrational way, showing clear patches of overgrazed and undergrazed land.

Land uses are as follows: crops (22%), meadows and pastures (17%), forests (46%), bush and shrub areas (12%), urban areas and infrastructures (1%). The remaining land is occupied by rock outcrops without soil cover.

Crops are grown on small plots of land, generally located in the immediate proximity of forests or meadows-pastures. This type of farming, albeit family-based and localised, is an important mainstay of the local landscape. Given their size, these plots of land are cultivated with small agricultural machinery and a high share of manual work.

The investigated soils of Mt. Rufeno are generally poorly evolved owing to strong erosion. The area is almost entirely forested (*Acer obtusatum-Quercetum cerridis*) with isolated clearings (*Phalarido-Dactyletum glomeratae*), mostly remnants of old autumn-winter cereal crops or of meadows-pastures, at times associated with olive-trees.

Also the old olive groves, apart from a few exceptions, are no longer productive and invaded by nitrophylic herbaceous species and shrubs, such as *Prunus spinosa* and *Rubus umilifolius* in wetter areas and *Spartium junceum* in dryer areas.

The Cava del Bianchi quarry yard wedges into a tendentially mesophylic *Quercus cerris* forest, whose shrub cover includes *Ligustrum vulgare*, *Cornus sanguinea*, *Prunus spinosa* and some thermophylic species (*Phillyrea latifolia*, *Ruscus aculeatus*, *Rubia peregrina* and *Rosa sempervirens*). Orographically, the area is fairly irregular, with slight changes in its slope gradient. The prevailing vegetation is a fairly sparse, small, pioneer bush, which is dominated by *Spartium junceum* and associated with a cover of *Prunus spinosa* and *Fraxinus ornus*. In contrast, the herbaceous component mainly consists of gramineans: *Bromus erectus* subsp., *Brachypodium sylvaticum* subsp. *sylvaticum* (near the forest and under the most mesophylic conditions), *Brachypodium rupestre*, *Elytrigia atherica, Agrostis stolonifera* (in depressions and areas of more persistent soil moisture), *Dactylis glomerata* subsp. *glomerata*. *Cistus creticus* subsp. *eriocephalus* and *Teucrium chamaedrys* (remnants of garrigue, probably more common in the past) are encountered in the more insolated areas. Finally, most of the soils of the investigated are classified as brown andic soils with good agronomic fertility (Fierotti G., 1988). Their mountainous to submountainous locations with gentle to steep slopes and the availability of water for irrigation have always affected their use for farming. In areas of steep slopes and low water supply, citrus groves give way to olive groves, pastures and crops of prickly pears. In the past, the farmland of Biancavilla rested on clayey and volcanic formations and had an important production of citrus fruits. Nowadays, this production has sharply decreased owing to: difficulty of finding water for irrigation, poor conditions of terraces and limited economic resources. This situation has led to the complete abandonment of volcanic soils, except where they are sporadically used as domestic orchards or marginal crops, such as prickly pears, wine grapes, olive-trees and pastures. If these uses are not adequately managed, especially in the drier summer period, they will provide limited coverage of the soil, making it easily erodible.The following table shows the numbering of the investigated soil samples and their origin (Table 1).

As is known, soil fibres are generally analysed with conventional methods, such as x-rays, total carbon analysis, FTIR, MNR, SEM, HTEM and others.

However, only some of these methods were used in this study, whose purpose was to detect fibrous minerals in the soils and then count the fibres in order to determine their concentration.

Moreover, the tendency of particles below 250 µm to aggregate and to form patinas increases when particles are below 50-100 µm. The patinas are generally due to clayey minerals, iron hydroxides, organic soil particles (Bemmy *et al.*, 2009). The soil samples were pre-treated as explained in the following paragraphs (the pre-treatment was not drastic to avoid changes in the mineralogical composition of the investigated

TABLE 1
List of samples.

Numbering	Origin	Parent rock	Remarks
149	Seluci di Lauria (PZ)	in argilloschists	Domestic orchard
91	Seluci di Lauria (PZ)	in argilloschists	Clearing
1	Monte Rufeno (VT)	Serpentine	Clearing
5	Monte Rufeno (VT)	Calc-schists	Forest
MOB	Biancavilla (CT)	Benmoreitic autobrecciated lavas	Urban courtyard
19	Biancavilla (CT)	Benmoreitic autobrecciated lavas	Quarry yard

soils). In spite of this, counting fibres was not always easy, as can be seen in the images enclosed hereto, because of the difficulty of identifying fibres and their frequency (PLM; PCLM). In order to assess the reliable respirable fracition directly connetcted to the risk, we study the samples derived from the suspension.

METHODOLOGIES OF PREPARATION OF THE SAMPLED SOILS

Before being treated in the alternating rotary motion sieving equipment, the as-is soil samples were put into a muffle furnace for 72 hours at 40°C. Then, they were weighed and put into the muffle furnace for another 24 hour to further check possible changes in their weight.

The samples were left under ambient conditions for 2 hours. Then, the portion of debris having an average diameter of more than 2 cm was removed from the samples and the remaining material was quartered and used. One aliquot of the quartered material was weighed and put into cylindrical sieves with a mesh of 250 µm (Fig. 2). The sieves with the weighed content were plunged into a beaker with 500 ml of distilled water. The sieves containing the soil samples were rotated for 1 hour, alternating the direction of rotation every minute. The fractions passing through the sieves were directly stored in the beakers. Then, they were drip-dried for 5 minutes and put into the muffle furnace using the previous procedure for both drying and weighing.

At predefined intervals (10 min), one aliquot (10 ml) of the material contained in the beaker was placed onto a cellulose acetate filter. After being dried in a salt dryer, the material was diaphanised with the acetone/triacetine method and analysed under the transmitted polarised light microscope (PLM) and the phase contrast light microscope (PCLM) with a view to searching, identifying and counting fibrous minerals, if any.

Weight fractions passing through the sieves - treated and untreated soils

Based on the previous considerations, a sedimentological analysis was carried out in order to determine variations, if any, in the grain size distribution of the fine fraction (Wentworth, 1922) passing through the sieve, collected and treated with hydrogen peroxide.

The grain size of the sediment from each sample, tested with the rotary sieve and collected in the beakers, was determined with a laser Sympatec Helos granulometer, equipped with a liquid suspension cell.

The sediment was shaken for 3 hours and wet quartered with an automatic quartering machine (mod. Retsch), equipped with a shaker cylinder (mod. IKA RW20). One portion of each sample was taken from the beakers and divided into 3 identical aliquots, which were brought to a volume of 500 cc: one as-is and one etched with 25-volume H_2O_2.

The resulting data were processed with the Granulgraf software (release 1.1.2), which gave the percentages of grain size classes at a level of detail of ¼ Phi.

The range investigated by the instrument has a total of 30 classes, from the coarsest one (above 2 Phi - 250 micron) to the last and finest one (below 9 Phi - about 1.95 micron).

Based on simple and cumulative distribution percentages, the program builds a simple frequency histogram and a cumulative curve on a bilogarithmic probability diagram. In both cases, diameters are expressed in sedimentological Phi units. From the data of the cumulative curve, the software program obtains the percentiles (graphic method) necessary to compute statistical indexes according to the method of Folk and Ward (1957). Then, the program returns the percentages belonging to the various populations under Wentworth's classification (Folk, 1954), reporting them on a ternary diagram under the classifications of Folk and Tortora (Wentworth, 1922; Tortora, 1999).

The ternary diagrams, the grain size curves and the tables pertaining to the treated aliquots (Figs. 5 and 6) infer that, in some cases, the sandy fraction decreases and the 16-micron fine clayey fraction: i) sharply increases in the Seluci di Lauria samples no. 149 and no. 91 and in the Mt. Rufeno sample no. 5; ii) is poorly significant in the Mt. Rufeno sample no. 1; and iii) equal to zero in the Biancavilla samples MOB and no. 19.

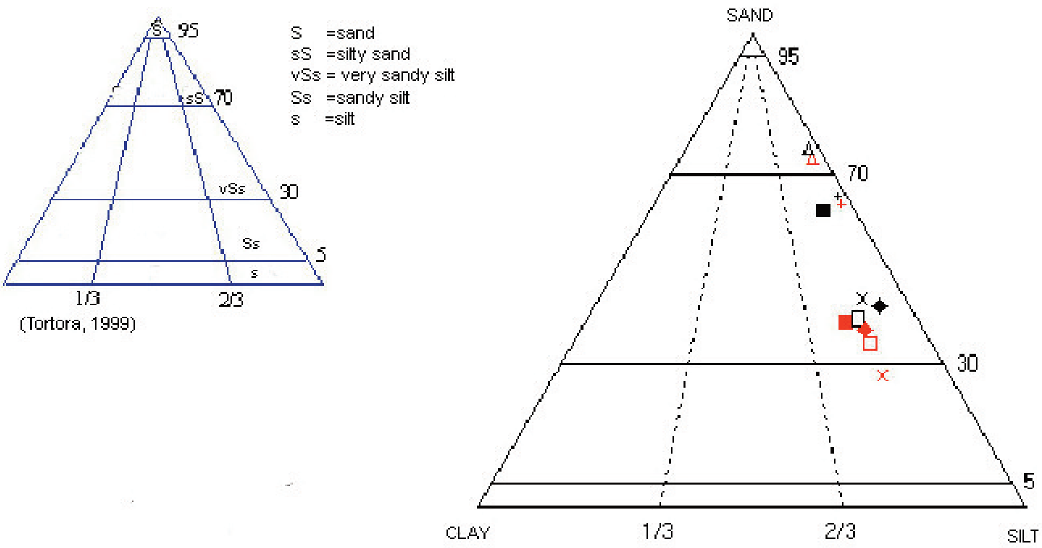
This finding suggested the use of hydrogen peroxide-treated samples for subsequent macro and micro morphological analyses. Indeed, this treatment only destroys the organic component, where present, of the soil samples (e.g. as organic lumps, vegetal frustules, roots, hyphas of submicroscopic size) without altering the inorganic component used for analyses and fibre counting (PLM, PCLM and SEM). Light microscopy was used to estimate the fibrous minerals contained in the treated soil samples. The examination of the slides with the fractions passing through the sieve and treated with hydrogen peroxide validated the results of sedimentological analyses. As shown in Fig. 7 (a,b,c,d - SEM image), when the clayey fraction increases, the treatment favours dispersion of fibres and elimination of clayey lumps.

Light microscopy

For detecting asbestiform minerals via light microscopy, reliance was made on an automatic system for counting fibres and determining their size (ARKON 32 software program). The fibres were counted both on the Walton Bechett graticule (WB) and on the whole field (WF) (Burragato et al., 2006) (diameter: 500 microns). Rufeno (5), Biancavilla (Mob) and Seluci di Lauria (149, 91) samples were slightly shorter than Rufeno (1) and Biancavilla (19) samples (fiber mean length 15 μm versus 40 μm) (Table 2). When estimating low concentrations (e.g. in case of natural outcrops), the expected fibre count was low. The soil samples from Seluci di Lauria had a fairly high fibre count (Fig. 8a) vs. those from Mt. Rufeno. In contrast, the Biancavilla samples had different fibre counts: low in sample MOB and high in sample no. 19.

Conclusions, risk assessment and mitigation

In conclusion, it is worth pointing out that the methodology used in the study has only recently been tested and applied. Before the study described in this paper, a project of environmental and morphological restoration was implemented in an area including a disused quarry yard (Cava



Origin	Sample		Sand	Silt	Clay	M_z (phi)	σ_I (phi)	D_{50} (mm)
Seluci di Lauria (PZ)	91 H_2O	×	44,44	48,15	7,41	4,66	2,00	0,050
Seluci di Lauria (PZ)	91 H_2O_2	× (red)	28,16	59,98	11,86	5,38	2,20	0,021
Seluci di Lauria (PZ)	149 A H_2O	◆	42,23	52,07	5,70	4,57	1,77	0,048
Seluci di Lauria (PZ)	149 A H_2O_2	◆ (red)	37,32	52,08	10,60	5,08	2,06	0,036
Monte Rufeno (VT)	1R H_2O	□	39,81	49,39	10,80	4,93	2,04	0,046
Monte Rufeno (VT)	1R H_2O_2	□ (red)	34,59	54,05	11,36	5,10	2,00	0,041
Monte Rufeno (VT)	5R H_2O	■	62,72	31,69	5,59	3,90	1,72	0,091
Monte Rufeno (VT)	5R H_2O_2	■ (red)	39,04	47,55	13,41	5,08	2,26	0,038
Biancavilla (CT)	19 H_2O	+	65,33	33,15	1,52	3,62	1,25	0,093
Biancavilla (CT)	19 H_2O_2	+ (red)	64,08	34,31	1,61	3,65	1,25	0,090
Biancavilla (CT)	MOB H_2O	Δ	75,73	23,02	1,25	3,32	1,15	0,118
Biancavilla (CT)	MOB H_2O_2	Δ (red)	73,70	24,68	1,62	3,40	1,19	0,112

Fig. 5 - Triangular classification of the analysed samples (Tortora, 1999).

del Bianchi). An interesting lithotype, similar to the "Rosso Levanto", was extracted from the quarry. This site, located in the present Natural Reserve of Mt. Rufeno (Acquapendente, province of Viterbo), has been recognised as the only geosite of ophiolitic rocks in the Latium region (Cresta *et al.*, 2005). The project also involved a training course for the personnel in charge of environmental rehabilitation of the area, as well as a safety plan to be implemented in an appropriately demarcated area (quarry yard and surrounding area). The safety plan included the

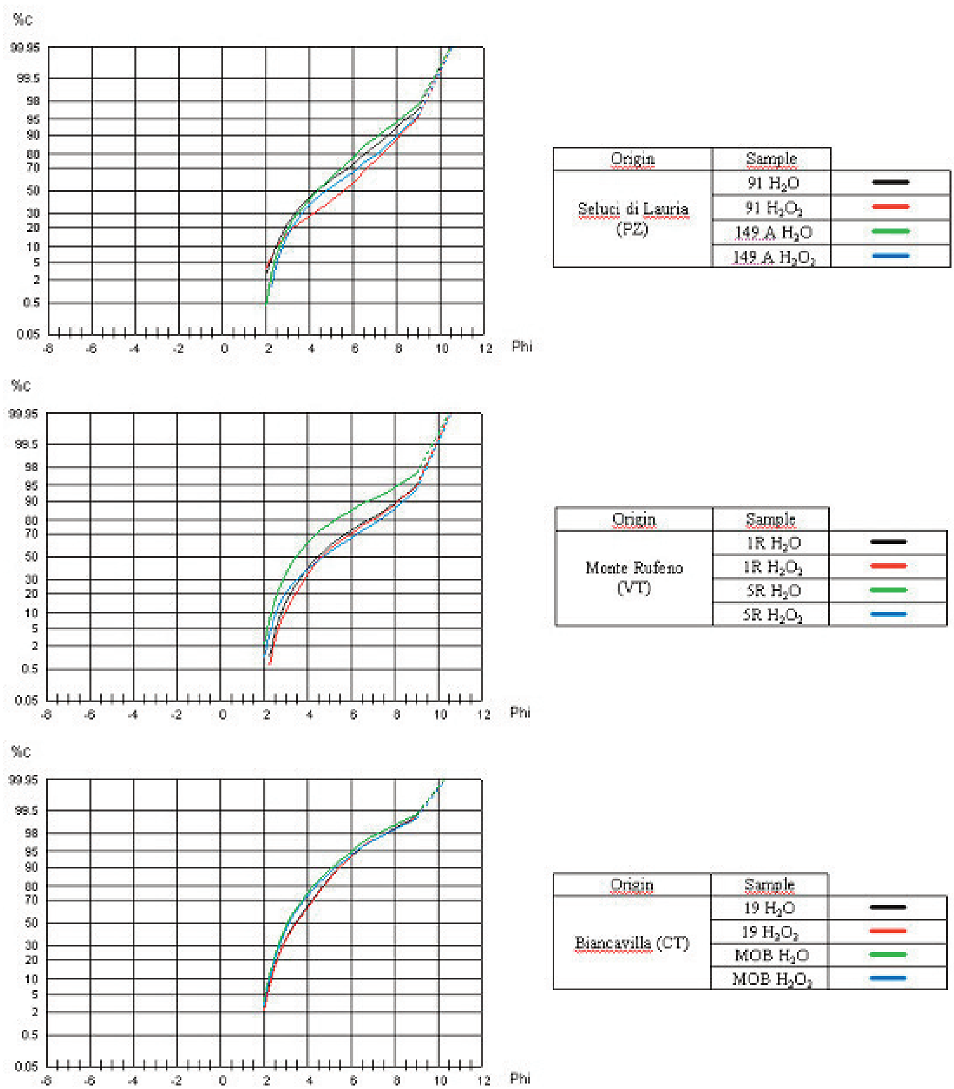


Fig. 6 - Graphs showing the grain size curves of the Seluci di lauria, Mt. Rufeno and Biancavilla samples.

pre- and post-restoration monitoring of airborne fibres and the use of the analytical method reported here to detect tremolite and chrysotile in the soil mobilised during the restoration project. In effect, as these soils belonged to formations suspected to contain asbestos, they might potentially release fibrous minerals (Burragato *et al.*, *personal communication*).

The morphology of the quarry area was restored by using compatible agricultural soils from the Reserve, but examined with the same methodology so as to ensure that did not contain

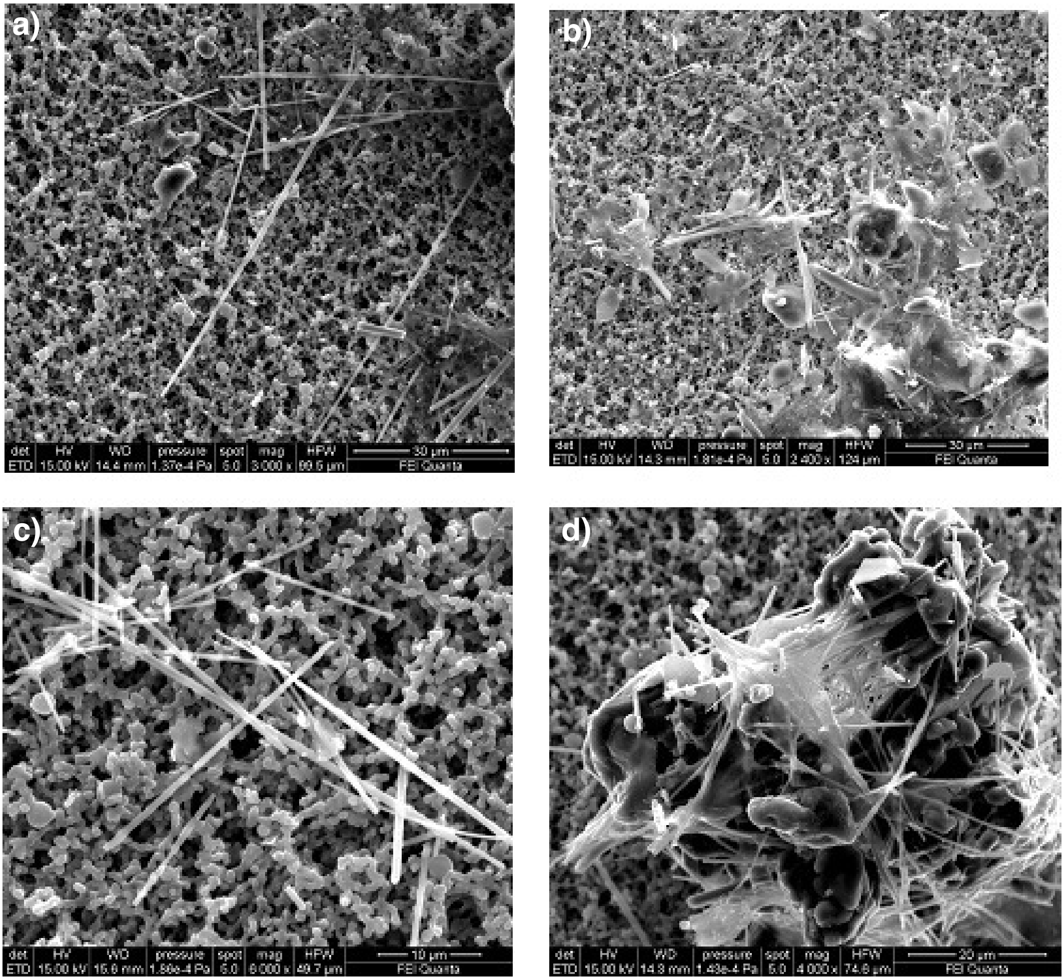


Fig. 7 - SEM images showing the presence of the fibres.

any nanoparticles of fibrous minerals. By using this methodology, fibrous minerals in both farmed and non-farmed land may be directly monitored and controlled. The goal is to identify risks due to air dispersion of naturally occurring asbestos upon agrosilvipastoral activities or hydraulic works for morphological restoration, without neglecting the fibrous minerals that are not currently classified in the relevant legislation (e.g. those present at Biancavilla).

This monitoring and control activity may be repeated upon the various farming cycles and works in areas with naturally occurring fibrous minerals, such as digging, trenching, creation of fire barriers or lanes, hydrogeological restoration, deforestation, aqueducts, etc. Research on direct exposure of the population to these minerals, not confined to ophiolitic quarry sites, as has been the case so far (Bernardini *et al*., 2003; Comba *et al*., 2003; Burragato *et al*., 2005c; Burragato

TABLE 2
Results of light microscopy.

Sample	Origin	WB (total fibres on filter*)	WF (total fibres on filter*)
149	Seluci di Lauria (PZ)	141	3196
91	Seluci di Lauria (PZ)	663	13874
1	Monte Rufeno (VT)	47	415
5	Monte Rufeno (VT)	94	792
MOB	Biancavilla (CT)	49	605
19	Biancavilla (CT)	230	4389

* *mean values*

et al., 2006) is justified, among others, by an improved understanding of ascertained cases of pleural mesothelioma.

Proposed mitigation measures

A variety of measures may be envisaged to mitigate the risk of periodical human activities on these soils, because their uses are very different.

The area of Mt. Rufeno is almost entirely forested. Its herbaceous cover, including serpentinophytic species, is sufficient, except in small areas having very steep slopes, where the growth of the herbaceous cover depends on efficient control of surplus water flows. The activities at risk are thus not farming, but projects of flood control or water diversion, creation and maintenance of dirt roads and of fire barriers or lanes and forest uses. These activities require on-site inspections and investigations, after mapping the location of exposed rocks potentially containing asbestos. It goes without saying that, under these conditions, hydraulic and agricultural water control structures should always be perfectly efficient. Moreover, in areas denuded of vegetal cover (landslides, soil failures, eroded areas), revegetation projects

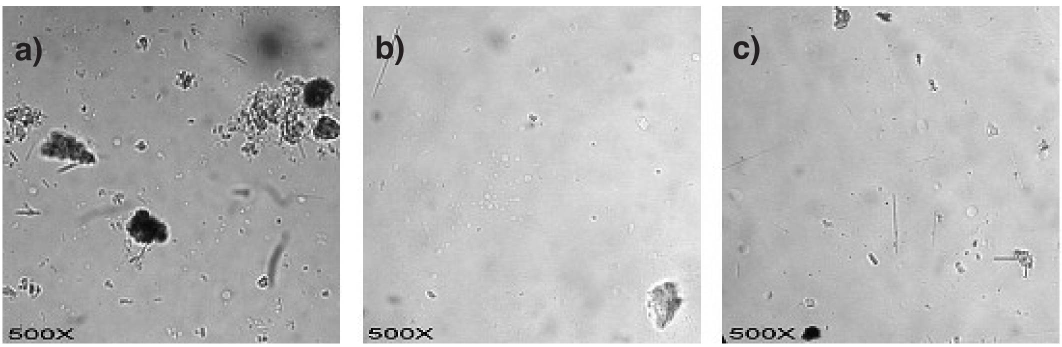


Fig. 8 - PLM image illustrating the presence of the fibres in the 149-Seluci di Lauria, 19-Biancavilla (b) and 5-Mt. Rufeno samples.

should be promptly implemented in order to rapidly restore the herbaceous cover.

In areas of more intense agricultural and pastoral activity, agronomic practices should be focused not only on crop rotation, but also the management of non-farmed land deprived of vegetation, such as waste land and dirt service roads. Indeed, the occurrence of fibrous minerals in some areas of Seluci di Lauria and Biancavilla (domestic orchards, gardens, unvegetated areas near urban and rural buildings, e.g. road scarps, courtyards and other open areas) has been confirmed. This situation is observed not only in the site of national interest - whose boundaries are only of an administrative nature and not related to the geological formation responsible for the above-mentioned minerals - but also in more or less neighbouring areas.

With regard to farm crops, particular emphasis should be placed on: i) rotation of crops, selecting the crops which ensure prolonged coverage of the soil throughout the year; and ii) non-cropped soil working practices. Soil working practices are an extremely critical issue. By eliminating the vegetal cover, they enhance the erodibility of the soil in the drier summer periods (wind erosion of the fine fraction) and in autumn-winter periods (water erosion) (Klein et al., 1993). Measures to mitigate these processes of soil ablation may only be proposed on an experimental basis by: i) adopting farming techniques that minimise soil mobilisation and dispersion of dusts containing nanoparticles and asbestiform fibres (Baker *et al*., 2005; Lopez *et al*., 1998); and ii) introducing cover crops so as to protect the soil in all the seasons of the year.

Acknowlwdgements

Particular thanks are due to the reviewers J. Addison and S. Maliconico for the improvement of the paper.

REFERENCES

Addison J., Davies L.S.T., Robertson A. and Willey R.J. (1988) - *The release of dispersed asbestos fibres from soils*. Edinburgh: institute of Occupational Medicine (IOM Report TM88/14).

Baker J.B., Southard R.J., and Mitchell J.P. (2005) - *Agricultural dust production in standard and conservative tillage systems in the San Joaquin Valley*. J. Environ. Qual., **34**, 1260-1269.

Bemmy K.C.T. and Guodong Y. (2009) - *Nanoparticles in the soil environment*. Elements, **4**, 395-399.

Bernardini P., Schettino B., Sperduto B., Giannandrea F., Burragato F. and Castellino N. (2003) - *Tre casi di mesotelioma pleurico ed inquinamento ambientale da rocce affioranti di tremolite in Lucania*. G. Ital. Med. Lav. Erg, **25** (3), 408-411.

Buonasorte G., Cataldi R., Ceccarelli A., Costantini A., D'Offizi S., Lazzarotto A., Ridolfi A., Baldi P., Barelli A., Bertini S., Bertrami R., Calamai A., Cameli G., Corsi R., D'Acquino C., Fiordelisi A., Ghezzo C. and Lovari F. (1988) - *Ricerca ed esplorazione geotermica dell'area di Torre Alfina*. Boll. Soc. Geol. It., **107**, 265-337.

Brotzu P., Ferrini V., Masi U., Morbidelli L. and Turi B. (1973) - *La composizione isotopica della calcite presente in alcuni affioramenti di oficalciti del F. 129 (S. Fiora) e sue implicazioni metrologiche*. Period. Mineral., **62**, 3, 591-619.

Burragato F., Crispino M., Monti A., Monti F., Montagano G., Papacchini L., Rossini F., Schettino B. and Sperduto B. (2006) - *Environmental pollution from airborne asbestiform fibres: Development of fibre propagation maps (final paper)*. ARAM, Asbestos risk and management, Dec. 2006, Rome, Italy.

Burragato F., Comba P., Baiocchi V., Palladino D.M., Simei S., Gianfagna A., Paoletti L. and Pasetto R. (2005a) - *Geo-volcanological, mineralogical and environmental aspects of quarry materials related to pleural neoplasm in the area of Biancavilla, Mount Etna (Eastern Sicily, Italy)*. Environ. Geol., **47**, 855-868.

Burragato F., Crispino M., Monti A. & F., Papacchini L., Rossini F., Schettino B. and Sperduto B. (2005b) - *Environmental pollution* *from airborne asbestiform fibres: Development of fibre propagation maps (1st paper)*. AMAM, Asbestos monitoring and analytical methods, Dec 2005, Venice, Italy.

Burragato F., Papacchini L., Rossini F., Sperduto B., Crispino M., Schettino B. and Monti F. (2005) - *Le rocce verdi di Seluci di Lauria e Castelluccio Superiore, presenza insolita di minerali fibrosi in alcune formazioni litoidi: esempio di analisi del rischio connesso all'uso del suolo*. Atti del 23° Congresso Nazionale AIDII Bologna, Giugno 2005, 185-190.

Burragato F., Mastacchi R., Papacchini L., Rossini F. and Sperduto B. (2004) - *Mapping of risk due to particulates of natural origin containing fibrous tremolite: the case of Seluci di Lauria (Basilicata, Italy). Modelling, computer assisted simulation and mapping of natural phenomena for hazard assessment*. Geophys. Res., Abstracts Volume 6.

Burragato F., Ballirano P., Fiori S., Papacchini L. and Sonno M. (2001) - *Segnalazione di tremolite asbestiforme nel Lazio*. Il Cercapietre, Notiziario del Gruppo Mineralogico Romano, **1-2,** 33-35.

Cazzola C., Clerici C., Zanetti G., Lauria E. and Wojtowicz M. (2005) - *Sperimentazione di una metodica basata su di un apparecchio di sedimentazione per l'analisi dell'amianto nelle rocce*. Atti del 23 Congresso Nazionale AIDII-Bologna, 22-24 giugno 2005.

Cherrie J.W. (1984) - *The effect of microscope graticule size and counting rules on the estimation of airborne fibre numbers using the membrane filter technique*. Ann. occup. Hyg., **28**, No. 2, pp. 229-236.

Comba P., Gianfagna A. and Paoletti L. (2003) - *The pleural mesothelioma cases in Biancavilla are related to the new fibrous amphibole fluoro-edenite*. Arch. Environm. Health, **58**, 229-232.

Cresta S., Fattori C., Mancinella D. and Basilici S. (2005) - *La geodiversità del Lazio. Geositi e geoconservazione nel Sistema delle Aree protette*. Regione Lazio, Agenzia Regionale Parchi.

EPA R8 (2000) - Multimedia Asbestos Sampling: Libby, MT, pages 1-33.

EPA 540-R-97-028 (1997) - "Superfund Method for the Determination of Releasable Asbestos in Soils and Bulk Material".

Fierotti G. (1988) - Carta dei Suoli della Sicilia. Regione Siciliana.

Fiore S., Giordano F. and Perniola D. (2008) - *Monitoraggio outdoor di asbesto aerodisperso da litologie contenenti amianto. Metodi di campionamento*. 3° Convegno nazionale sul particolato atmosferico PM. Bari 2008, pp. 208,.

Folk R.L. and Ward W.C. (1957) - *Brazos River bar (Texas): a study in the significance of grain size parameters*. J. Sedim. Petrol., **27,** 3-26.

Folk R.L. (1954) - *The distinction between grain size and mineral composition in sedimentary rock nomenclature*. J. Geol., **62**, 344-359.

Giordano F., Fiore S. and Perniola D. (2008) - *Procedura di valutazione della pericolosità degli affioramenti contenenti amianto: un caso di studio*. 3° Convegno nazionale sul particolato atmosferico PM. Bari 2008, pag 64.

Harris K.E., Bunker K.L., Strohmeier B.R., Hock R. and Lee R.J. (2007) - D*iscovering the true morphology of amphibole minerals: complementary TEM and FESEM characterization of particles in mineral dust*. Modern Research and Educational Topic in Mycroscopy, 643-650.

Klein C. (1993) - *Rocks minerals and a dusty word. From Health effects of mineral dusts*. In G.D. Guthrie Jr, B.T. Mossman, Editors. Reviews in Mineralogy, **28**, 7-59.

Lopez M.V., Sabre M., Gracia R., Arrúe J.L. and Gomez L. (1998) - *Tillage effects on soil surface conditions and dust emission by wind erosion in semiarid Aragón (NE Spain)*. Soil and Tillage Research, **45**, 91-105.

Mazziotti-Tagliani S., Andreozzi G.B., Bruni B.M., Gianfagna A., Pacella A. and Paoletti L. (2009) - *Quantitative chemistry and compositional variability of fluorine fibrous amphiboles from Biancavilla (Sicily, Italy)*. Period. Mineral.,**78**, 1, 65-74.

Musti M., Convertini L., Cavone D., Montagano G. and Cauzillo G. (2006) - *Tremolite: environmental exposure in Basilicata region. Asbestos risk and management.* ARAM, December 2006, Rome, Italy.

Pagliai M. (2007) - *Metodi di analisi fisica del suolo*. Ed. Franco Angeli, Collana di metodi analitici per l' agricoltura. Paolo Sequi, 7a edizione.

Paoletti L., Puledda S. and Ferdinandi M. (1999) - *Comminuzione di tremolite ad abito fibroso e ad abito prismatico: effetto sulla risposta diffrattometrica.* Ann. Ist. Super. Sanità, **33**, 3603-3611.

Pasetto R., Bruni B., Bruno C., Cauzillo G., Cavone D., Convertini L., De Mei B., Marconi A., Montagano G., Musti M., Paoletti L. and Comba P. (2004) - *Mesotelioma pleurico ed esposizione ambientale a fibre minerali: il caso di un'area rurale in Basilicata*. Ann. Ist. Super. Sanità, **40**(2), 251-265.

Romano R. (1982) - *Succession of the volcanic activity in the Etnean area*. Mem. Soc. Geol. It., **23**, 27-48.

Tortora P. (1999) - *Una classificazione ternaria su base granulometrica per la descrizione del sedimento sui fondali marini*. Boll. Soc. Geol. It., **118**, 65-73.

Swartjes F.A., Tromp P.C. and Wezenbeek J.M. (2003) - *Assessing risks of soil contamination with asbestos (Beoordeling van de risico's van bodemverontreiniging met asbest)*. RIVM report 711701034.

Wischmeier W.H. and Smith D.D. (1978) - *Predicting rainfall erosion losses: A guide to conservation planning*. USDA, U.S. Gov. Print. Office.

Wentworth C.K. (1922) - *A scale of grade and class terms for clastic sediments*. J. Geol., **30**, 377-392.