Introduction to Nanopathology

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By

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ACKNOWLEDGEMENTS

Many of the samples we have analyzed and many of those published in the pages of this book were donated by subjects who wanted to know why they had become ill. Our thanks go to them and, we believe, with ours go the thanks of all those who, directly or indirectly, have benefited and will benefit from the knowledge gained from the investigations carried out.

PREFACE

In the years that followed our first discoveries in nanopathology and, later, nanoecotoxicology, we published several scientific books dedicated to professionals and, at the same time, popular books aimed at everyone.

What was missing was a book in some way in an intermediate position: a book dedicated to those who already have solid scientific and medical foundations (it is not the same thing) but who have never delved into such a topic. It is entirely possible that, perhaps having read something on the subject, there are those who have realized that that something could fill some gap in the understanding of cases that have been experienced and that have not had a satisfactory solution.

Here, then, is a book that touches on this new scientific discipline and - at least we hope - stimulates the curiosity to penetrate the subject more deeply.

The book is also, and perhaps above all, dedicated to students who, young as they are, have not had the time to crystallize on certain visions of science, science that – we must never forget – is in continuous evolution and is always open to disputes as the epistemologist Karl Popper warned. Therefore, it is not crystallizable.

What we wanted to do is open a door to a very little explored world, that world that is halfway between what is macro and what is on an atomic scale, hoping to find not only new traveling companions, but independent explorers, capable of traveling alone, with new ideas, curious and enthusiastic like us, who want to penetrate territories whose existence is not rarely unsuspected and which can reserve completely unexpected surprises.

In several chapters there will be images of electronic microscopy accompanied by explanations, sometimes not brief. These are photographs relating to some of the over 5,000 cases, health and environmental in many of their nuances, that we have come across.

If 5,000 cases seem like a lot, it is important to underline that these are just the first steps on the beach taken by those who, for the first time, have landed in an unknown land. Whether there is little else or a continent beyond that beach will be up to the scientists who will dedicate themselves to this study to establish. What we can say, we who arrived on that beach and left from there thirty years ago, is that the beach has been walked and we are entering a continent. And a very vast one.

CHAPTER ONE

INTRODUCTION

What are we talking about?

To understand what we are going to talk about, it is necessary to know its origins, origins that date back, perhaps surprisingly, to several thousand centuries ago.

No one can say with an acceptable approximation when a primate (etymologically from late Latin with the meaning of "he who enjoys the greatest prestige") that can be defined as Man appeared on the planet Earth. What we can say with certainty is that for thousands of centuries this evolving being behaved like any animal, that is, according to the rules of Nature. Then, with enormous temporal differences from place to place on the Planet, what we will call Man for convenience began to use fire: a fire lit by natural causes.

The first (uncertain) evidence dates back approximately to one and a half million years ago (1), and that limited to very simple uses, with great difficulty in preserving the flame which Man was unable to light. Much later, just over 1,000 centuries ago, initially in Africa, Man, then evolved to *Homo erectus*, discovered how to light fire, that is, to "domesticate" it (2). From there begins the social distancing of this primate from the path of Nature: a path which, as circular as it is, where every product of metabolism, be it animal or vegetable, along with ethology falls into a sort of virtuous circle useful for maintaining natural balance. It is a fact that no animal knows how to light a fire and does not even seem to feel the need for this.

With the use of fire, the production begins of increasingly sophisticated objects, objects that, sooner or later, become useless and are thrown away or simply abandoned somewhere. In short, Man introduces the concept of waste into the Planet and, gradually, slowly, increasingly detaches himself from natural circularity by undertaking a linear path where little or often nothing returns to the origin represented by natural benefit.

It may seem strange, but lighting fire was the most significant technological advance in the history of humanity, a history which was heavily and irrevocably conditioned by it.

It is evident that, in a world that is very sparsely populated by human beings (very rough estimates state that the first million inhabitants were reached only around the year 10000 BC) and with waste made up of materials that differed very little from what existed in Nature, the impact of those foreign bodies on the environment was very limited and, therefore, actually irrelevant.

Without wanting to retrace the history of technology, it is precisely thanks to fire that Man, now become *Homo sapiens*, began to produce more and more complex materials and objects increasingly distant from Nature, and an example could be that of glass, whose first production dates to before the fourth millennium BC and whose first written recipe, dictated in the seventh century BC, is preserved on a terracotta tablet in Nineveh (Assyria).

The main problem of that production was certainly not that of getting the raw materials, made largely of sand, and modified over time to achieve better performance, but the need to reach high temperatures obtainable by blowing air into the flame, thus enriching it with oxygen. If this, on the one hand, required the use of a rather demanding workforce to put the bellows into action which, for economic reasons, limited the use of that material, on the other hand, just because of the high temperature, as we will see later, was the origin of non-negligible forms of pollution. And, from the point of view of environmental impact, a similar problem had already arisen when it was discovered how to extract and work metals to be used as they are or to make alloys with to replace stone or wood artifacts, the latter hardened by heat treatment. As for bronze, i.e. copper and tin together, the oldest of metal alloys, the starting time for Europe is around 3400 BC and lasted for over 2000 years. Elsewhere, that technology never arrived, and various populations suddenly found themselves leaping millions of years into the future when they, more or less peacefully, encountered European "visitors."

For a very long time, given the difficulties of production, the artifacts were treated and preserved in the most accurate way possible and considered precious, so much so that in certain medieval inventories, weapons, agricultural tools, and utensils meant for various uses were listed together with the jewelry heritage belonging to the lord of the territory. With all this, waste began to accumulate, and its remains are often still found in ancient sewers or in real hills of earth under which there are large landfills used for a very long time.

Making a leap of several centuries during which the technologies available did not undergo noticeable evolutions at least as far as the subject of this book is concerned, in the second half of the 18th century, apparently almost suddenly, due to a series of very complex circumstances, steam-driven machines began to be used to enhance the results in quantitative terms of mineral extractions and various industrial productions, resorting to a relatively reduced use of manpower. Regardless of the social consequences that followed and characterized that period now known as the First Industrial Revolution, and which cannot be part of this discussion, what interests us is the fact that many objects, once available with comparative ease only to certain social classes, began to be available to growing larger layers of less wealthy people and, consequently, to no longer be considered worthy of the care they had traditionally received.

Therefore, also due to an increase in the population which in the mid-eighteenth century reached almost 800 million across the Planet and just over 160 million in Europe, the quantity and variety of waste grew considerably. Along with all this there was the growing pollution caused by coal burning to produce the steam needed to drive machinery, a pollution to which not much attention was paid at that time.

In the midst of the Industrial Revolution, in 1775, the British surgeon Percival Pott discovered the origin of a disease which, until then, had found neither a solution nor an explanation as to what was its cause. In that period, homes were mainly heated by burning wood, and the fumes were carried outside along often very tortuous chimneys which required periodic cleaning due to the carbon residues that were deposited there. The reason why the chimneys had to be so narrow and tortuous originated from the fire that destroyed a good part of London's houses in 1666. Those built in place of those no longer existing were required to have such chimneys to better control combustion and counteract its dangers. Passing through those chimneys was impossible for an adult and, thus, the chimney sweeps were usually children called “climbing boys”.

To prevent their clothes from getting caught in the twists and turns of the passages, the children crawled naked into the chimneys. It was relatively frequent compared to the rest of the population for those children to get scrotal cancer, a cancer that today we would call squamous cell carcinoma, a cancer that is also referred to as epidermoid carcinoma of the scrotum and epithelioma of the scrotum. It was sufficient to impose a daily bath on the chimney sweeps to solve the problem of that occupational pathology of clearly environmental origin due to direct skin contact with soot, impure carbon particles resulting from the incomplete combustion of hydrocarbons. Because of that, today, with good reason, we could list that disease among the *nanopathologies*, that is, the pathologies caused by inorganic micro- and nanoparticles. Just as a side observation, today it is customary to state that cancer is a multifactorial pathology, i.e. caused by multiple concomitant causes. It is clear that in the case in question, given also the very young age of the affected subjects and the consequent low probability that other factors may be present, there was only one triggering cause. We will see later how there are also other cases in which multifactorial nature in the onset of cancer is excluded, and we will see how the same origin causes very different results depending on how it presents itself.

It may be interesting to observe how such a serious pathology, moreover, having such young people as victims, has not found an explanation and, therefore, a remedy for so many years. However, we should not be surprised: it is not at all uncommon that, even today, potential causes, often obvious, are overlooked for many diseases. And this is also why the knowledge of micro- and nano-dust pathologies is assuming great importance. It is significant to underline that in that case of cancer no therapy was proposed, but it was only prevention, moreover in a very simple form, that solved the problem.

Approximately between 1850 and the outbreak of the First World War, what is currently called the Second Industrial Revolution occurred, a technological acceleration developed at different times depending on the country, which has among its characteristics the more massive introduction of steel, and the use of electricity, chemicals, and oil to produce energy. In short, a variety of new pollutants were beginning to be part of the environment, with all that this entails from a health point of view.

One of the most serious problems of what we call progress, neglecting the obviousness that that progress is often only technological, i.e., partial, is the fact of concentrating efforts to obtain substances, objects, machines, and techniques, caring only for the immediate result, and failing to consider that those novelties may lead to side effects which may become evident even after a relatively long time. Almost as a rule, those products induce the formation of pollutants already when they are being manufactured and, having reached the end of their usable life, they become waste, that is, embarrassing presences which in many cases are hidden as if not seeing them would solve all the inconveniences, starting from health.

An interesting phenomenon is that which affects various hygiene-related pathologies such as, for example, many infectious diseases. Thanks to ongoing technological progress, the quality of everyday life improves and, therefore, life expectancy increases. On the other hand, almost surreptitiously and, initially, without arousing particular attention, pathologies that were once rare or even unknown begin to appear: diseases linked to new working conditions and altered environment. We will see later how syndromes are established, that is, collections of symptoms, apparently inexplicable because, without certain knowledge, their mutual correlation cannot be seen.

Then, here is a new revolution: plastic.

Since ancient times, Man has used natural polymers including amber, tortoise shell and horn. These were completely natural materials that behaved relatively like industrially produced plastic. Plastic as we know it originated in the 19th century when, between 1861 and 1862, the Englishman Alexander Parkes, working on cellulose nitrate, isolated and then patented the first semi-synthetic plastic material, initially called Parkesine and then known commercially as Xylonite. Then, in 1870, the American Hyatt brothers patented the formula of celluloid, a material initially designed to replace ivory in the production of billiard balls. A few decades later, in 1907, the Belgian chemist Leo Baekeland obtained the first thermosetting resin of synthetic origin in the laboratory, patented three years later as Bakelite. In a short time and for several years that was the most widespread and used plastic material.

PVC (polyvinyl chloride), born in 1912, probably remains the most used plastic today. When the numerous artifacts produced with that plastic have reached the end of their life, the first concern is to make them disappear from sight, and, almost normally, they are burned in a waste incinerator. That combustion inevitably leads to the formation of extremely toxic chlorinated dioxins carried in the environment by micro- and nanoparticles. But the toxicity of PVC is already present as an oncogene when the starting monomer, vinyl chloride (C_2H_3Cl), is necessarily used.

From that moment on, the studies on plastic intensified, reaching the peak of enthusiasm between the 1960s and 1970s, when it was common opinion that, thanks to those apparently “miraculous” materials created by Man’s ingenuity, the trees from which wood is obtained would be spared, and it would no longer be necessary to extract substances from the Earth. In short, a panacea for the Planet.

But things went another way. In general, already during manufacturing, as is the case with PVC, plastic polymers produce pollutants, and the immoderate use of the objects compared to those of the past that the new products replace at a much more advantageous price quickly transforms them into gigantic quantities of waste which, as we will see later in this book, are extremely hard to treat. This is how pathologies that were once rare or completely unknown manifest themselves due to interference with substances that human, animal, and plant organisms have never come across.

Unfortunately, a more and more important topic is that linked to wars, events in which there is an increasing use of weapons that explode at very high temperatures, forming particles that are largely non-degradable and nanometric in size. As is obvious, that novel dust attacks anyone in a "democratic" way: the soldiers of each side and the civilian population, and keeps doing so for many years after hostilities have ended.

And, speaking of the temperatures that industry can reach today, plasma well exceeds 10,000 degrees centigrade (18,000 °F), thereby inevitably producing nanometric particulates.

Overcoming, not without difficulty, many clichés that have never been demonstrated and resistance dictated by interests of various kinds, today we realize that many pathologies, including a relevant number of those already known but whose origin was unknown or poorly understood, added to new and completely unusual combinations of pathologies like the so-called Balkan Syndrome which will be discussed later in the book, find explanation in the study of the behaviour of solid micro- and nanoparticles that arise from environmental pollution. That pollution spreads in the air, in water, in food and, in short, in everything that can penetrate the organism in one way or another. These diseases have been called nanopathologies and are the topic of the following pages.

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Chapter Two

How It All Began

In the second half of the 1990s, vena cava filter implants were relatively widespread, a small metal device intended to be inserted into the lumen of the inferior vena cava, just below the outlet of the renal veins, to prevent the migration of any venous thrombi originating distal to the implant towards the pulmonary circulation, a phenomenon called pulmonary thromboembolism which can have fatal outcomes (1).

The filter is normally implanted by radiologists, cardiologists, and vascular surgeons, and it was a surgeon who gave us a sample of a stainless-steel filter that had broken inside the vena cava and which, for this reason, had been removed. As a side note, such an explant is very rarely justified, as those filters, even if broken, are generally harmless, unless there are very particular situations. The question we were asked as biomaterials experts was to find out why a breakdown had occurred. The reason for that failure was very trivial and does not deserve further discussion. What immediately interested us, however, was what we identified on the surface of the device, especially at the breaking point, a particularly rough area.

The observation of the surface of the specimen under an electron microscope equipped with an elemental chemical analysis system (EDS: see the dedicated section of the book) showed the presence of a variety of chemical elements foreign to both the device and the human body. Providing an explanation for the origin of those elements according to the knowledge of the time was in fact impossible. For this reason, we turned to the surgeon again to get his opinion, but we received no response other than "I have no idea." We questioned other doctors from different specialties but got nowhere (2,3).

Not long after we received another explanted filter, this time a plastic one. Even in that case the surface was covered with chemical elements in part similar to and in part different from those of the filter analyzed previously, but, in any case, equally foreign. Once again, those presences were still waiting for an explanation.

It was only a few years later that the answer arrived (4,5).

The opportunity was offered by a patient who was admitted to the university hospital of Modena (Italy). The symptoms he had been experiencing for over eight years without having received any answers elsewhere regarding his problems were moderate and unstable hyperpyrexia, persistent pain in one ear, tearing of the ipsilateral eye and serious problems with liver and kidney functions, so that he was told that he would need relatively quickly to undergo chronic hemodialysis treatment.

Biopsies of the two damaged organs were taken from the patient at the hospital of Modena, and the histopathologist's diagnostic response was of granulomatosis "sine causa", i.e., without a cause. Regardless of the obvious fact that diseases do not exist without something having caused them, in short, an inflammatory form of the tissues was underway without its origin being known. By pure chance the biopsy samples ended up at the Biomaterials Laboratory of which Dr. Gatti, co-author of this book, was responsible, and she observed them under the electron microscope discovering within them, coinciding with the granulomas, a notable quantity of very small ceramic particles. We learned that nine years before admission to the Modena hospital the patient had been implanted with two dental bridges that faced each other between the left mandible and maxilla.

The prostheses had immediately caused discomfort linked to malocclusion problems, so much so that the subject had become a bruxist. A clumsy intervention by the dentist aimed at eliminating the problem consisted of filing down some of the prosthetic teeth, the cause of the malocclusion. Bruxism and mechanical intervention had then worn away the prostheses. Since these were prostheses made of ceramic, a very small sample was taken and analyzed through the EDS system. The result was that it was the same material as we had found in the biopsies.

What had happened was that the patient had ingested the small particles produced by grinding and filing part of the ceramic of which the prosthesis was made. So, we thought that if those foreign bodies had reached the liver and the kidneys, they must have crossed the barrier of the digestive system, entered the circulatory system, and been carried there by the blood. This also accounted for the puzzling findings on the two caval filters: particles carried by the blood that had adhered to the surface of the devices.

If having ingested small particles appeared to be anything but a rare event, what, with knowledge of the time, was hard to accept was that those particles had been captured by organs. The accepted belief was, in fact, that, in such cases, the fragments, evidently non-biodegradable, would have been eliminated in the feces. No demonstration in this regard existed, but the belief was accepted without question as if it were an act of faith.

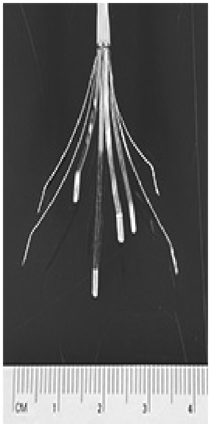

Fig. 2-1 Image of a temporary vena cava filter.

Most pulmonary embolisms result from the detachment of thrombi from the walls of the major veins of the lower limbs and pelvis. For this reason, surgical techniques were experimented with to partially interrupt the inferior vena cava, the preferred passageway for embolizing thrombi.

In the second half of the 1960s, transvenous implantable devices were introduced, of which there are now numerous versions. Their function is to stop blood emboli, preventing them from reaching the pulmonary circulation. The physiological production of plasminogen activators and the mechanical action of blood flow reduce the size of the thrombus to the point, in many circumstances, of dissolving it completely. In addition to metallic vena cava filters that are implanted permanently or semi-permanently (some of them can be removed through special transvenous devices), there are temporary filters connected to a catheter that protrudes from an access point (usually the right jugular vein) and that can be removed after a limited time when there is no longer a need for filtration. The presence of foreign particles has also been found on the surface of these devices.

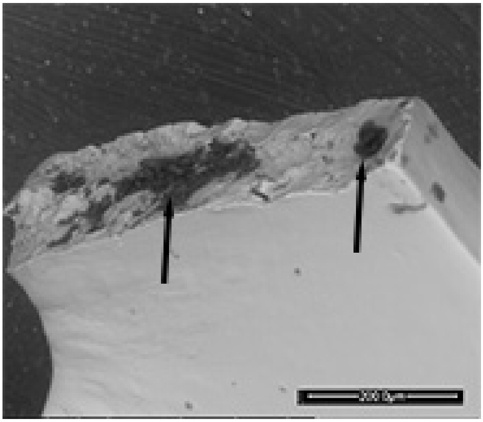

Fig. 2-2 Fractured vena cava filter with organic deposits indicated by arrows.

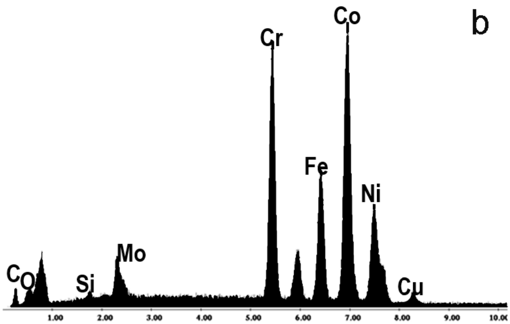

Fig. 2-2b EDS spectrum of the alloy of the filter.

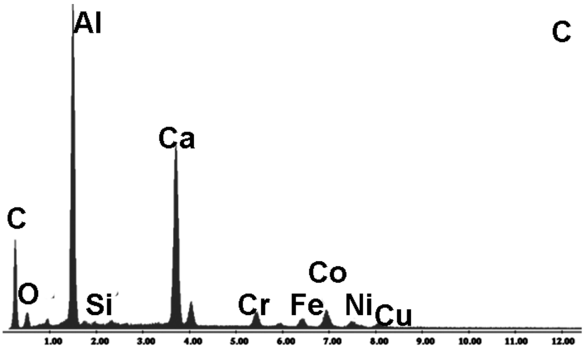

Fig. 2-2a,b,c Image of a part of a broken filter (a, marker 200micron) with the presence of foreign material indicated by the arrows. Fig.2-2 b and c indicate respectively the chemical spectrum of the metallic substrate (chromium, iron, cobalt, nickel, silicon) and 2 areas of a foreign material attached (see arrows) that contains aluminium and calcium.

Very rarely, a vena cava filter fails inside the vessel. This is due to fatigue induced by the movements of the vena cava caused by breathing and Valsalva maneuvers or, less rarely, due to the device slipping distal with one of the prongs penetrating into a renal vein. This can happen if the filter is positioned too cranially. The correct position is with the apex of the device slightly cranial to the outlet of the renal veins. On the rough surface of the filter's breaking point, particles of a composition foreign to the human organism had stopped.

However, in the case of our patient, countermeasures were taken: the two dental bridges were replaced with suitable ones, and the inflammatory and feverish state was resolved by administering cortisone drugs. Even the watery eyes and ear pain, treated for years with antibiotics (!), disappeared immediately. In addition, there was no longer any need for hemodialysis treatment. Yet, despite that clear clinical success, the academy refused to take the fact into consideration.

That dust, when entered in the body, causes diseases was a widely known fact, but this was mostly limited to pneumoconioses, i.e. diseases affecting the respiratory system: silicosis, caused by inhaling stone dust, or sand, containing silica; asbestosis, caused by asbestos; anthracosis, another name for pulmonary fibrosis from carbon inhalation; siderosis (see Fig. 2-3 a,b,c), caused by the accumulation of ferrous dust; berylliosis, caused by beryllium; talcosis, caused by talc; smiridosis, caused by emery; hard-metal lung disease (HMLD), caused by inhalation of hard metal particles (tungsten carbide, cobalt, less frequently tantalum, nickel, chromium and niobium); Shaver-Riddell disease, caused by dust and fumes of aluminium or aluminium oxide-based abrasives. As is evident, these are generally occupational diseases. If inhalation and breathing were accepted as inducers of respiratory pathologies, this was not the case for other pathogenetic mechanisms for which dust could be responsible.

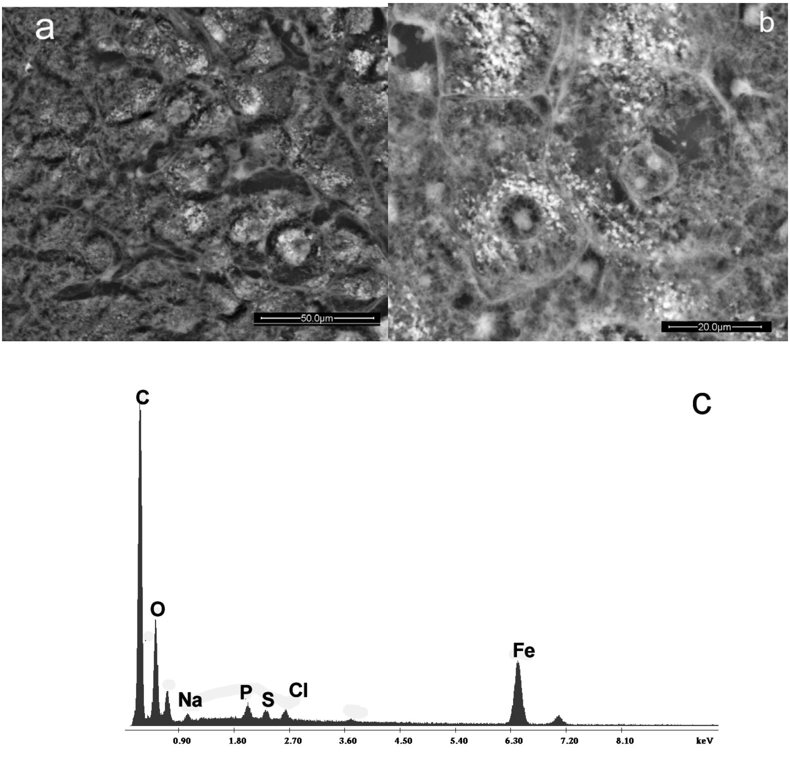

Fig. 2-3a,b,c: the images show a case of siderosis. (a,b), a genetic disease. The liver is invaded by endogenous iron (c) precipitates, mainly intracellular.

Personal research carried out by Dr. Gatti revealed that numerous unresolved cases of granulomatosis labelled "sine causa" were filed in the archives, and that the samples archived in paraffin blocks invariably contained non-biodegradable particulate matter.

In 2002 the European Community granted Dr. Gatti funding to continue her research, research which also involved the universities of Cambridge and Mainz as partners. If the moment in which the study of what are called nanopathologies, i.e. diseases caused by nanoparticles, was born occurred a few years earlier, the impulse to research can be traced back to 2002 (7,8).

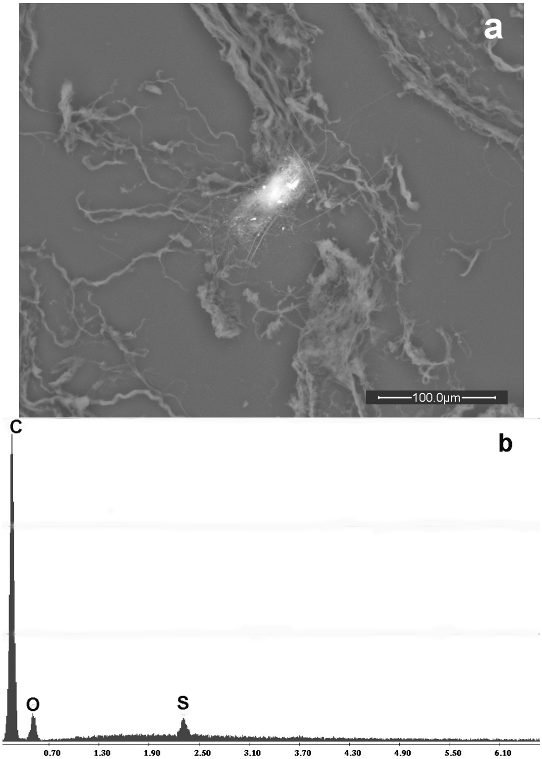

Fig. 2-4 a,b Images of a byssinosis (pathological condition caused by cotton fibers) diagnosed as lung mesothelioma.

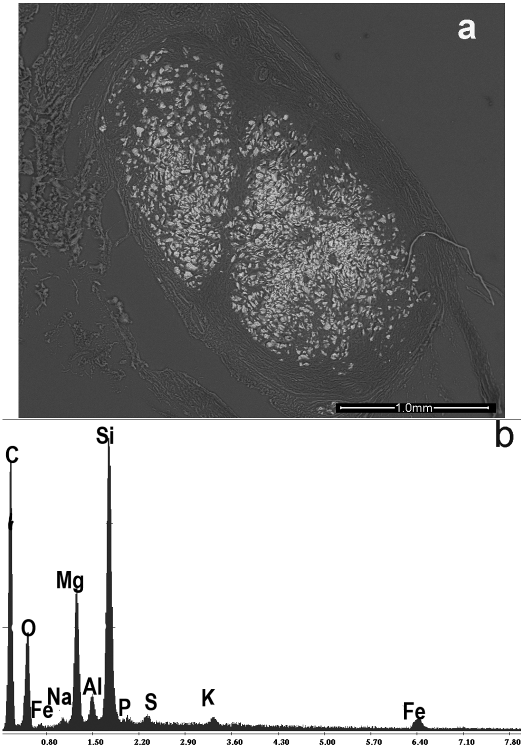

Fig. 2.5 a,b Images of a case of lung with talc particles (talcosis.)

Then, it was a matter of entering uncharted territory.

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CHAPTER THREE

MICRO AND NANOPARTICLES

Ever since Man has been present on this planet, he has always found himself in contact with dust. The wind lifts it from the ground, earth and rocks suffer erosion from temperature differences, rain, snow, frost, and wind; occasionally vegetation catches fire and, where they are present, volcanoes erupt lava and ash, as well as gas.

Those dusts, very different from each other in chemistry, size, and shape, inevitably fall on the plants that Man and animals eat and, when they are in the suspension phase, a phase that is often very long in time, they can penetrate through inhalation and breathing throughout the respiratory system until reaching, if small enough, the pulmonary alveoli.

In the overwhelming majority of cases, these powders are inorganic, and, with rare exceptions, they are not biodegradable nor are they tolerable by the body nor, least of all, are they bio-available, i.e. usable in some way by the body. For this reason, those dusts are perceived by the tissues as foreign bodies, and, since it is something that is not recognized by the organism, it reacts to their presence. This topic will be addressed later in the text.

Generally, with a few exceptions, the inorganic dust we are dealing with has a thermal origin, sometimes very distant in time as happens, for example, to sand formed by erosion of pre-existing rocks, rocks which in turn originate from cooled magma.

We mut note that the sand of Sahara Desert can travel across the oceans. It should be considered that the Sahara Desert extends over 8 million km^2 and its geology is not uniform. In that extension, in fact, different types of landscape can be identified: the hamada, a desert of bare, smooth rock, engraved and worked by the winds that forms sharp and cutting splinters; the serir, formed by a layer of pebbles and gravel, and the erg, in the central Sahara, formed by the characteristic sand dunes. Geological differences must be taken into account when trying to identify the place of origin of a sand sample.

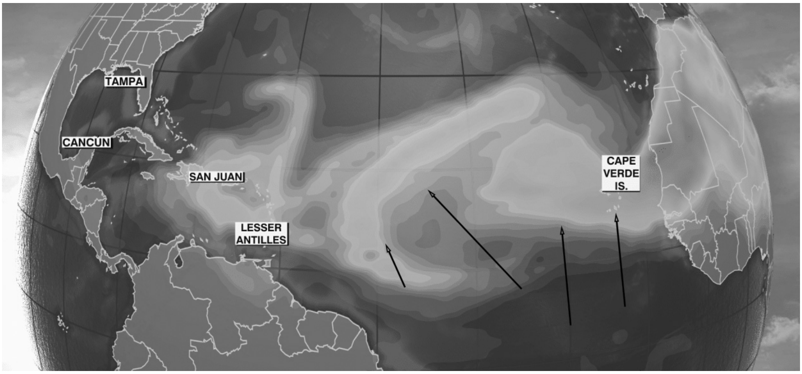

Fig. 3-1 Map of the world as seen from satellite that shows the flux of the sand (indicated by arrows) across the Atlantic Ocean. (1)

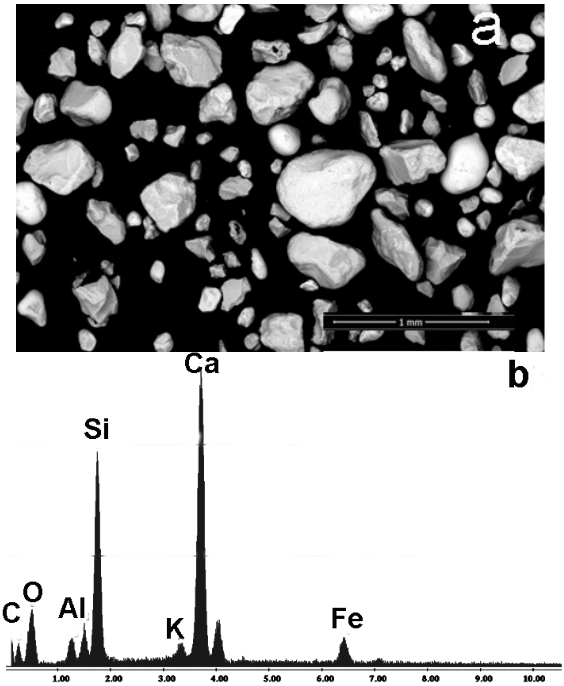

Fig. 3-2 a, b - Sahara Desert Sand with its chemical composition.

A feature that makes this ancient particulate material more recognizable is the blunt appearance of many particles, especially the coarser ones. The spectrum (b) shows its elemental composition of Ca, Si, Al, Mg, Fe and K. C and O are present in the spectrum because they are part of the stub that supports the sample.

In February 2024, a sandy rain fell on Italy. The FEGESEM analysis showed that the solid particles were smaller than those usually found in rainwater that carries sand from the western Sahara. Both for the particular size of the grains and for the presence of diatoms, our assumption is that on that occasion it was sand from the Bodélé, a depression located in northern Chad, which represents the lowest point of the country, located between the Tibesti and Ennedi plateaus. About 9,000 years ago, the depression hosted a lake about 400,000 km^2 in size and 180 meters deep.

The Depression is known to meteorologists because it is one of the largest and most active sources of dust in the world (1).

Sand, however, can form through at least two other mechanisms: by chemical precipitation from waters supersaturated with ions (hypersaline waters), and by the accumulation of skeletons and shells of organisms. Regardless of how it was formed, sand rises and forms suspended dust.

As for particles formed at high temperatures, different chemicals, occasionally close in space, are fused or, if the temperature is high enough, are volatilized. In this regard, see the chapter dedicated to war pollution.

Then, when those substances have reached a colder point in atmospheric space, they come into contact with each other and condense into solid particles. In any case, it must be remembered that the mass balance remains unchanged, according to the Principle of Conservation of Mass ("The mass of any one element at the beginning of a reaction will equal the mass of that element at the end of the reaction") whose scientific demonstration dates to Antoine-Laurent Lavoisier (1743 - 1794).

Depending on the case, always in accordance with the Principle of Conservation of Mass, that condensation can lead to chemical compounds, alloys, crystals, amorphous combinations, or particles in which some or even all those varieties are present in varying degrees.

An example of those formations is offered by waste incinerators.

Materials of the most varied nature, changing in quality and proportions that differ from load to load, enter the furnace. The temperature at which those waste products are treated differs according to the technological project adopted, but, speaking generally and allowing a margin especially for the higher temperatures of the most recent systems, it ranges from a minimum of 850 °C to a maximum of 1,050 °C. At those temperatures, the molecules that make up the waste break down into smaller molecules or into atoms.

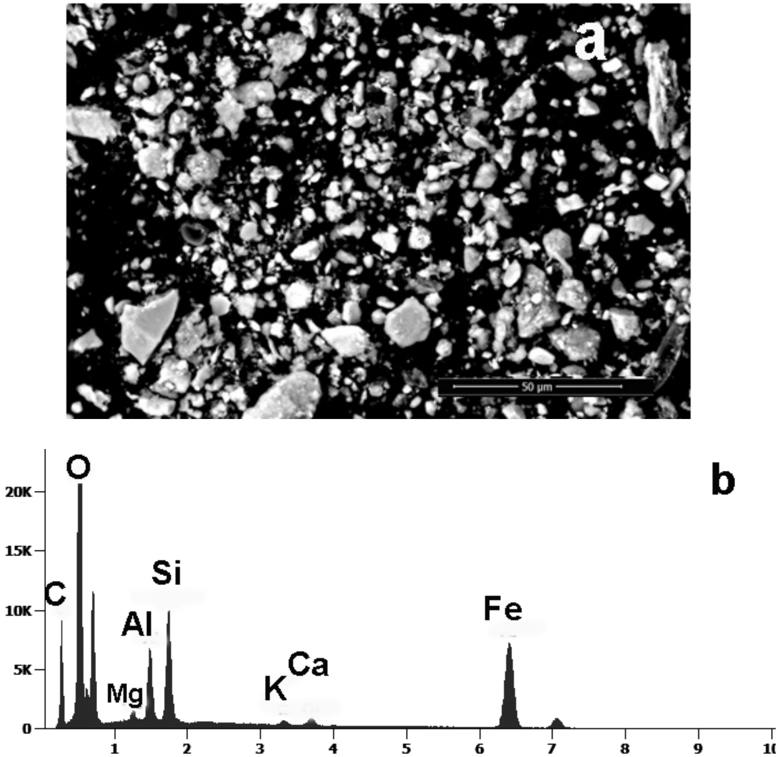

Fig. 3.3 a, b - Rain carrying Saharan sand. The elemental composition is relatively similar to that of Fig. 3, but the proportions are different, since it comes from a different source area. The higher iron content gives the "red" color to the rain.

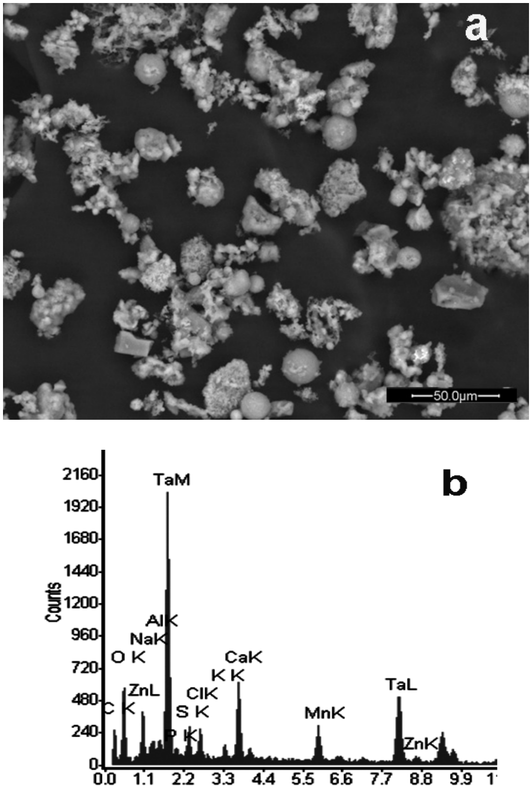

Fig. 3-4 a, b Ashes from the Raibano incinerator (Rimini – Italy) with spectra. Note the elemental composition formed by several different elements (tantalum, zinc, aluminium, manganese, etc.).

When evaluating ashes from a waste incinerator, it is necessary to consider the fact that municipal waste has a composition that is not only very varied, but also extremely variable in quality and proportions. The residues from industrial incineration evaluated in each individual industry are much more constant, generally always coming from the same materials.

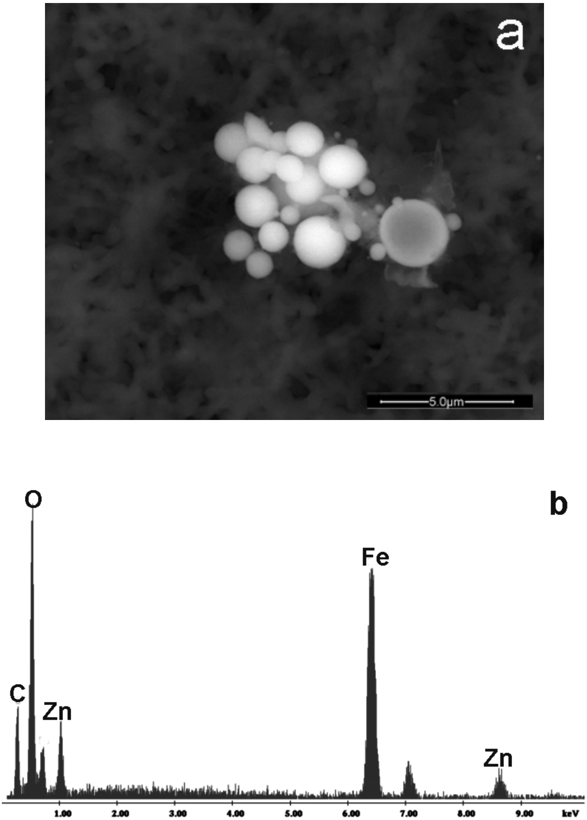

Fig. 3-5 a, b - The image shows small, metallic (b) spherical particles from the waste incineration of Modena (Italy).

Inside the ashes, numerous different morphologies and chemistries can be found as the result of the combustion of different typologies of municipal waste.