History of Toxicology and Environmental Health

Toxicology in Antiquity, Volume II

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CHAPTER 3

Anthropogenic Air Pollution in Ancient Times

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3.1 POLLUTION OF THE ENVIRONMENT IN ANCIENT TIMES

Environmental pollution is coeval with the appearance of humans. When *homo sapiens* first made fire, the resulting smoke was, in effect, an early form of environmental pollution. The burning of fuels for heating and cooking has contributed to indoor air pollution. The walls of caves inhabited several thousands of years ago are covered with thick layers of soot. The presence of smoke in confined spaces must have made breathing difficult and irritated the eyes. In the few mummified bodies remaining from the Palaeolithic Era the lungs have a black tone. In the first inhabited areas, smoke was not driven away (one of the practical reasons might have been protection against mosquitoes) and the people dwelling in these inner areas found shelter in the smoke [1]. Millions of people continue to live this way today. In 1993, when we were in Nepal trekking in Langtang National Park, we visited many small villages and found accommodation at local houses on the southern slopes toward the High Himalayas. Even today, the smoke of fire is not driven away from the buildings. The walls of the houses are built of metamorphic slates with no bonding, and the roofs are covered with rush matting. When there is fire, it produces a thick smoke inside the house, irritating the eyes and making breathing difficult. It is impossible to sleep; one can only stay there for a short time. From the outside, the houses look as if they were on fire; smoke is streaming out through the slits and gaps of the walls. Humans seem to have been living together with this unhealthy form of air pollution for many thousands of years.

Indoor air pollution, especially particulate matter, was a significant problem in antiquity. Animal and vegetable oils were burned to provide light; furthermore, the houses were heated by wood and animal dung. All these materials produced high quantities of soot and toxic gases [2]. Capasso [3] examined skeletons buried by the volcanic eruptions of Vesuvius and found evidence of inflammation of the pulmonary tract.

History of Toxicology and Environmental Health. DOI: http://dx.doi.org/10.1016/B978-0-12-801506-3.00003-0

Histological assessment of the lungs of ancient human mummies has shown that anthracosis (accumulation of carbon in the lungs caused by inhaled smoke or coal dust) was a regular disorder in many ancient societies due to long exposure to the smoke of domestic fires. Smoke protected against mosquitoes and other insects; however, it greatly increased the risk of chronic respiratory diseases [2].

Environmental pollution was responsible for a variety of illnesses. The very first polluting material might have been human feces. Bowel bacteria living in the human body, such as *Escherichia coli*, might have easily gotten into the drinking water, infecting early humans. Even today, this type of environmental pollution causes illnesses affecting millions of people. In China, where a comprehensive system was developed for waste disposal, the use of human feces as a fertilizer was an important component of agricultural practice thousands of years ago. The high productivity of the alluvial plain in eastern China has been maintained in this manner for over 4000 years. This tradition is being followed today in several regions of China. As Han Suyin says, "In Chengtu (the capital of Szechuan Province) those families who owned the city sewers and this way could sell the accumulated feces in the countryside, belonged to the richest ones even in the twentieth century (till 1949)" [4]. The fertilization of rice paddies with feces contributed to the pollution of groundwater, making it unsuitable for drinking in all of tropical Asia. However, boiling the water results in the precipitation of salts, rendering it totally tasteless. The tradition of flavoring boiled water with tea leaves comes from China. It began spreading geographically about 2000 BC and ultimately spread throughout Asia [5].

Dust pollution also appeared in ancient times. Some of this was of natural origin, and Chinese and Korean writers have noted the easterly movement of yellow loess (sometimes called Kosa dust) for thousands of kilometers (e.g., [6]). According to Janssens, in the New Stone Age, people mining flint from the embedding limestone in the stone mines day after day might have suffered from silicosis, (see, for example, Obourg [4]). The all-day inhalation of dust was likely the underlying cause. Sometimes the geographical location of an area was responsible for the outbreak of certain diseases. Investigations revealed that near Broken, in the territory of recent Zambia, hominids that lived about 200,000 years ago suffered from lead poisoning. The reason for this

illness was the transport of lead into the spring located next to the cave of a streak of ore [4].

The harmful activities of ancient civilizations caused long-lasting changes in the environment, the effects of which can be experienced even today. However, these effects appeared only regionally, not globally. Increasing soil alkalinity on the floodplains of the Tiger and Euphrates Rivers between 3500 BC and 1800 BC resulted in a gradual decrease of the productivity of Sumerian agriculture. Water used for irrigation raises the groundwater table, and if the extra water is not driven away by channels, soil becomes saturated with water, resulting in the dissolution of salts and their precipitation on the surface in the form of an impermeable layer. Sumerian people noted this process: "*the soil surface turned white.*" Water used for irrigation gradually made the region more and more unsuitable for agricultural production due to leaching of soil. This phenomenon largely contributed to the decline of the Sumerian culture. [4,7]. Babylonian and Assyrian law included clauses that discussed neighbors' property. Although the earliest laws, those of Hammurabi (twenty-third century BC), related mostly to water [8], smoke was typically treated in the same way in ancient law [9]. Around AD 200, the Hebrew *Mishnah* and its interpretation through the Jerusalem and Babylonian *Talmud* detailed pollution issues [10].

In ancient times, air pollution had substantial consequences only in the cities. The air of these early towns, as in some recent settlements, was filled with the penetrating smell of decaying organic domestic waste, rotting meat, and human feces. During a siege, when there was no chance to remove these waste materials, which emitted aggressive smells, unbearable conditions prevailed in settlements. According to Egyptian historical records, when Nubian troops encircled the city of Hermopolis, which is situated on the left bank of the Nile halfway between Theba and Memphis, the inhabitants surrendered, pleading for mercy, rather than bearing the putrid smell of their town's air [11]. In ancient cities, pollution deriving from unpleasant odors was an important concern. Aristotle (384–322 BC) proposed a rule in his work, *Athenaion Politeia*, according to which manure should be placed outside the town, at least 2 km away from the town walls [12]. Smoke stained marble in antique towns, giving it a grayish tone. This annoyed several classical poets as well (e.g., Horace (65 BC to AD 8) and

motivated ancient Jews, among others, to introduce a list of laws [10]. In ancient times, smoke and soot represented the two major media of air pollution.

There are several examples of environmental pollution in China as well. Prior to the Tang era (618 AD–907 AD), the firs on the mountains of Shantung were logged and burned; later in the Tang era, the slopes of the Taihang mountains, located at the borderline of the Shansi and Hopei provinces, became barren [13]. Also at this time, dynasty forests were cut around Loyang, the capital, in a circle with a radius of 200 miles. The trunks of the trees were mostly used as firewood and partially burned to produce ink for governmental offices [14].

Urban air pollution, especially from the use of traditional fuels, depends on the dimensions of the given settlement and the extent of the built-up territory, as well as on the nature of the industrial activity. As urbanization progressed in China, in the Mediterranean Basin, and in northwestern Africa from about AD 1000, more and more people lived in smoky and sooty surroundings. Maimonides, the philosopher and physicist (1135–1204), who had comprehensive experience of the towns of that era from Cordoba to Cairo, found that urban air is "stuffy, smoky, polluted, obscure, and foggy." Furthermore, he thought that this condition is produced by "dullness preventing understanding, lack of intelligence, and amnesia" of the inhabitants [15].

On the other hand, traffic and transportation difficulties restricted the rate of air pollution within the cities. Industrial activities consuming the most energy (e.g., the production of tiles, glass, pottery, bricks, and cast iron) were located near the forests, since the transportation of fuels in large quantities to the cities would have been too expensive. This way, though air pollutants of industrial origin made the air smelly, only a few people inhaled it. Port cities were partial exceptions, as ships could transport wood and charcoal more economically. Hence, Venice could maintain its glass industry, ensuring its energy supply by the transportation of wood from distant places. However, the majority of urban air pollution derived from household fuels such as manure or wood but sometimes from smokeless charcoal as well [1]. The air of the Chinese cities might have been extremely polluted, too, because the developed water transport system (Big Channel) enabled the use of large quantities of fuel, at least in the Sung capital, Kaifeng. This city, 500 km south of Beijing, was probably the first one in the world to convert its

energy supply from wood to coal. The transition occurred at the end of the eleventh century, when the city had about 1 million inhabitants. However, the coal-heating period was short, because Mongolian troops destroyed Kaifeng in 1126 and those who remained in the city died from plague in the early thirteenth century [16].

Intensive environmental pollution appeared simultaneously with the development of societies. Extensive environmental losses occurred even in the earliest societies. Air and water were polluted, soils were destroyed, and many animal and plant species were exterminated. However, environmental changes caused by the earliest societies were generally minor ones and followed by a rapid restoration of original conditions. Thanks to this, many people are not aware of the environmental losses triggered by the activities of early societies. Consequently, they tend to be more lenient toward these early societies than toward modern societies living in an urban environment. At the same time, there are examples of environmental activities in ancient times that resulted in long-lasting changes, the signs of which are observable even today. The cutting down of forests in large areas for building ships in ancient times might have contributed to the decrease of woodland coverage in the Balkan Peninsula, and in the territory of Greece. However, the drier summers and droughts in the Mediterranean might have contributed to this large-scale reduction of woodland areas as well [17]. Not that this latter fact has no relation to human activities. In Greece, due to the scarce summer precipitation, stunted plants and bushes develop that are suitable only for grazing of sheep and goats. These animals, by overgrazing the slopes of mountains, increase soil erosion. The thin soil layer that becomes loose is transported from the slopes by winter runoff, creating barren limestone surfaces quite rapidly as a final and complete stage of erosion.

There are several examples of deforestation in other regions as well. During the reign of King Solomon, cedar woodlands covered an area of 5000 km^2. Cedar woodlands were first mentioned in the literature between 2500 BC and 2300 BC. However, today very few cedars are found there. In the golden age of the Roman Empire, the whole main road from Baghdad to Damascus was shadowed by cedars. Today, the road between these cities is surrounded by desert [1].

Several cultures emphasize that one should live in harmony with the environment. However, even in those societies where this idea has been

perpetually mentioned (e.g., in Asian societies), environmental ideas frequently lost out to financial demands.

Ancient Romans called air pollution *gravioris caeli* (heavy heaven) or *infamis aer* (infamous air) [2]. Air pollution problems of ancient times are mentioned even in the poems of classical poets. "The smoke, the wealth, the noise of Rome..." held no charms for the Roman poet Horace (65 BC–AD 8), who described the blackening of houses and temples by smoke [18]. He wrote that Roman buildings turned more and more dark from smoke and that this phenomenon might be observed in many other ancient cities as well. Seneca (4 BC–AD 65), the teacher of Emperor Nero (AD 37–68), was in poor health all his life, and his physician frequently advised him to leave Rome. In one of the letters he wrote to Lucilius in AD 61 he mentions that he must escape from the gloomy smoke and kitchen odors of Rome in order to get better [19].

Sextus Julius Frontinus (AD ~30–100), once governor of Britain, who later oversaw water supply to imperial Rome and wrote about it in his book *De Aquaeductu Urbis Romae*, believed his actions also improved Rome's air. Civil claims over smoke pollution were brought before Roman courts almost 2000 years ago [9]. According to the Roman law, cheese-making facilities should be established in such a way so that their smoke would not pollute other houses. Much similar material is available from the very important book *Pan's Travail* [20] and in Brimblecombe [21].

The Roman senate introduced a law about 2000 years ago according to which "Aerem corrumpere non licet" (polluting the air is not allowed). The *Institutes* issued under the Roman emperor Justinian in AD 535 were used as a text in law schools. Under the section "Law of Things," our right to the air is clear: "By the law of nature these things are common to mankind—the air, running water, the sea, and consequently the shores of the sea." (Lib. II, Tit. I: Et quidem naturali iure communia sunt omnium haec: aer et aqua profluens et mare et per hoc litora maris).

3.2 LEAD IN ANCIENT TIMES

3.2.1 Lead Mining and Exploitation

In the ancient Mediterranean, mining and metallurgy played a primary role in the economy. According to Xenophon (434–359 BC) and

Lucretius (98–55 BC), the smoke of lead mines in Attica was harmful to human health [22].

Lead is extracted from its most important ore, galena. The lead content of galena is 86.6%, but it also contains arsenic, tin, antimony, and silver. Most of the silver production in the world comes from galena and not from silver ore, since mining and exploitation of galena is much more significant. A long time after the introduction of silver coin as a currency (about 2700 BC), the primary aim of galena mining was to extract silver, and lead was considered to be only a by-product [23].

The oldest lead object found by archaeologists is a string of beads worn in Anatolia some 8000 years ago. Its use as jewellery suggests that this was a time when lead was still new and rare [24]. At the same time, lead mining started about 4000 BC. Considerable exploitation began about 1000 years later, when a new smelting technology was introduced in order to extract lead (and silver) from sulfide ores of lead. The exploitation of lead ores and use of lead became more and more important during the Copper, Bronze, and Iron Ages [25]. This progress was promoted by the introduction of silver coins and the development of Greek civilization. (During that time lead production was 300 times higher than that of silver.) Lead production reached its maximum of 80,000 metric tons/year—about the same magnitude as that of the Industrial Revolution some 2000 years later [26]—in the golden age of the Roman Empire. The most important lead mines were situated in the Iberian Peninsula, the Balkans, in the territory of ancient Greece, and in Asia Minor [25]. Lead production suddenly decreased after the fall of the Roman Empire and reached its minimum at about AD 900 with a mass of only some 1000 metric tons/year. Then production began to increase again, thanks to the new lead and silver mines opened in Central Europe after about AD 1000.

3.2.2 The Utilization of Lead

Lead mines during the Roman era were a plentiful source of the metal, as Pliny describes lead being found "in the surface stratum of the earth in such abundance that there is a law prohibiting the production of more than a certain amount" [27]. In Roman times, lead was the most popular metal and was widely used in everyday life. It has a number of useful properties that suit it to relatively low levels of technology. It melts at low temperatures, it is malleable and easy to work, it can be

readily cast and joined, and it is resistant to corrosion. Thus it comes as no surprise that it found widespread application in the ancient world [28]. Its compounds were used as face powders, lipstick, and mask paint, as well as a coloring agent in paints. Furthermore, lead was used for preserving foods; it was even added to wine in order to prevent its fermentation. Lead compounds were used as a birth control medicine (for exterminating sperm) and as a kind of a spice, too. Cups, jugs, pots, and frying pans were made of lead alloys. Coins were also made of lead, as well as of alloys of lead with other metals such as copper, silver, and gold. Since it resists corrosion and can be processed easily, lead was extensively used in shipbuilding, house building, and for the construction of water pipes. During house building, hot lead poured between limestone/marble blocks served as a binder. In ancient Rome and in other cities of the Roman Empire, the construction of water pipes was the most important use of lead. Also, in Babylon, a water pipe made of lead was used for watering the hanging gardens built by King Nabu-kudurri-usur (Nebuchadnezzar) (605–562 BC). Because of the above-mentioned facts, lead is frequently referred to as a Roman metal [4,24].

3.2.3 Illnesses Caused by Lead

Both lead and its compounds are poisonous. Thanks to its relatively low volatility (lead vapour), as well as the volatility of some of its compounds [e.g., a petrol additive ($Pb(C_2H_5)_4$)] or solubility [e.g., $Pb(CH_3COO)_2$], it can easily get absorbed in the human body. Symptoms of lead poisoning are headache, nausea, diarrhea, fainting, and cramps.

Romans knew that lead was a dangerous metal, since they noticed the symptoms people who worked in lead mines suffered. Pliny wrote that "red-lead is a deadly poison and should not be used medicinally" and warned that the "exhalations from silver mines (i.e., galena mines) are dangerous to all animals" [27]. Furthermore, the geographer Strabo (3.2.8 C142) described (in about 7 BC) the high chimneys required to disperse the air pollutants during silver production in Spain. However, since lead was used extensively in everyday life, danger was taken out of consideration. Lead was believed to be less dangerous if it got into the body only in small doses. When carbon dioxide dissolved in water interacts with lead in the water pipes, it results in a possible enrichment of these dissolved lead compounds in

the body; this process can easily lead to a so-called lead disease, a consequence of which might be paralysis. Ancient writers Xenophon and Lucretius observed the noxious emissions from metal mines of Greece, and Pliny declared that smelter emissions were dangerous to animals, especially dogs [29,30]. The presence of lead in food and drinking water might have led to infertility or stillbirth [31]. Nevertheless, mineworkers suffered the most from the harmful effects of lead. Hence, Romans generally made slaves work in mines. In Greco-Roman times, according to estimates, several hundred thousand people (mainly slaves) died of acute lead poisoning during the mining and smelting processes [25,26,32]. The credit for the first direct clinical account of lead poisoning has in recent times been accorded to Hippocrates [27].

The use of lead water systems represented a hazard to health, but both the Romans and the Greeks exposed themselves to a far greater risk. They found that coating their bronze or copper cooking pots with lead or lead alloys not only prevented leaching of copper from the pots, thus avoiding spoiling the taste of the food, but was also very useful in preparing wine and grape syrup (sapa), which was used almost exclusively as a sweetening agent. Pliny also advocated this dangerous practice. He writes, "Preference should be given to lead vessels... in boiling defrutum and sapa" [27]. One property of lead is inhibition of enzyme activity. Hence, sapa kept fruit from souring and fermenting and was used extensively as a preservative. In addition, sapa was found to improve the quality of a poor wine and to prolong the length of time for which any wine could be kept [27]. Adoption of the use of lead to sweeten wine in medieval Europe caused widespread illness [33].

Some authors contend the extreme behavior of Emperors Caligula (AD 12–41) and Nero might also have been the consequence of lead poisoning [31]. No aspect of the history of lead is likely to provoke as much interest and controversy as the prevalence of chronic lead disease (deriving from extensive lead mining and the wide-scale usage of devices made of lead) in antiquity and the suggestion that it played an important part in the decline of the Roman Empire [25,26,32]. On the other hand, there are some aspects on which this idea has been largely discredited. First, the lead-related gluttony and other excesses of the Julio-Claudian and Flavian emperors are difficult to reconcile with the loss of appetite and constipation that are among the prominent

symptoms of chronic plumbism (lead poisoning). Second, the Empire attained its greatest wealth, power, and extent under Trajan and other effective emperors, who also consumed foods and drinks prepared in lead-made devices [28]. Third, most of the lead in the bones from citizens of Rome has come from postmortem absorption [34]. It is suggested that gradual depopulation was the main contributor to the failure of the Roman Empire, with lead-induced infertility possibly playing a lesser role [24]. The rise of Christianity might have also been a major reason [35]. The decline of the Roman Empire is a phenomenon of great complexity and it is too simple to ascribe it to a single cause.

3.2.4 Lead Pollution in Ancient Tooth Samples from the United Kingdom

English researchers, co-fellows of the Natural Environment Research Council and the British Geological Survey, studied the concentrations of lead in tooth enamels from Romano-British and early medieval people from various sites in the United Kingdom. Then, they compared the lead concentrations present in these people to that of their prehistoric forebears as well as that of the modern people living in the United Kingdom today. According to an extensive study on the tooth enamel lead concentration of adults living in the United Kingdom carried out in the early 1980s, the concentrations of lead displayed spatial variations with an average of 3 ppm. Some more recent analyses on modern children's teeth found lead concentrations with averages around a few tenths of ppm suggesting, as indicated also by the atmospheric data, that modern lead exposure is decreasing. On the other hand, Neolithic people living before the use of metals had tooth enamel lead concentrations that averaged around 0.3 ppm. These concentrations are only a tenth of the average for modern people and possibly similar to those in modern children.

When analyzing tooth enamels of Roman, Anglo-Saxon, and Viking people from the United Kingdom, researchers found individuals with tooth lead concentrations greater than 10 ppm, and occasionally even higher values. Concentrations of this magnitude among modern people can be associated with occupational or acute exposure, and suggests that lead pollution was a significant problem for both Romans and early medieval ancestors of British citizens.

The explanation may be that England, Scotland, Wales, and Ireland are all rich in natural lead deposits. Furthermore, each of these countries has abundant ores, which have been mined since antiquity. Probably, it was partly the richness of the country's lead ores, with their associated silver, of course, which led to Rome's initial interest in conquest of this most northerly reach of the Empire. It is also known that the Romano-British, Anglo-Saxon, and Viking people inhabiting the area of the United Kingdom were exposed predominantly to lead from ore sources, because of the characteristic isotopic composition of the lead remaining in their teeth.

On the other hand, high exposures were detected not only among people actively involved in lead mining, smelting, or metal working, but in the tooth enamels of children too. Thus high lead concentration was considered to be an environmental rather than occupational problem.

3.2.5 Lead Pollution on Regional and Hemispheric Scales

In 1957–1958, as part of the International Geophysical Year, the first extensive research programs were launched to analyze information stored in snow and ice layers of Greenland and the Antarctic that were hundreds of thousands of years old. The aim of this research was to establish a possible hemispheric scale of air pollution for a time period spanning many thousands of years. Later, the ice cores coming from this area served as substantial evidence of the atmospheric effects of human activities (e.g., [36–38]). In Greenland, the deepest boring corresponds to an interval of 7760 years, which is well before the time when silver was first smelted from galena. We can speak about background levels of the atmospheric lead concentration up to this period [23].

The chemical analysis of an ice core 9000 ft deep from Greenland (1 ft = 30.48 cm) enabled the collection of information on the atmospheric pollution for the past back to 7760 years. According to this, lead concentration in the atmosphere before the beginning of lead production, when atmospheric lead derived only from natural sources, was low. At this time, the enrichment factor of the atmospheric lead was near 1 (0.8), which indicated that this lead derived from soils and rocks. Three thousand years ago, the lead concentration of the atmosphere practically corresponded to the levels measured at the beginning

of lead production. This means that anthropogenic lead emission was still negligible up to this time, considering the amount of lead that went into the atmosphere naturally. The atmospheric concentration of lead started to increase in the fifth century BC, and during Greco-Roman times (between 400 BC and AD 300), the enrichment factor of lead reached the value 4 and remained at the same high level for seven centuries. Four times higher lead concentration was detected for this period in the snow and ice layers of Greenland compared to the earlier, natural values. This is the earliest detected hemispheric-scale air pollution, dating almost 2000 years before the Industrial Revolution and well before any other polluting effect [26].

In the golden age of the Roman Empire, about 2000 years before, 5% of total processed lead (80,000 metric tons) got into the atmosphere, which might have resulted in an atmospheric emission peak of 4000 metric tons/year [26]. Regarding the economic development of the Roman Empire, Scheidel [39] associated the lead pollution level of the atmosphere with the annual number of shipwrecks (trade volume) and meat consumption (animal bones). Lead emission deriving from metal processing caused important local and regional air pollution all over Europe, which can be detected, e.g., in the lacustrine deposits of southern Sweden [40]. Furthermore, these emissions significantly polluted the troposphere over the Arctic [26].

Rosman examined the possible sources of lead pollution in the ancient atmosphere. According to the analysis of lead isotope ratios in ice cores, the mines in the territory of Spain proved to be the main sources of atmospheric lead. These mines were supervised by Carthage between 535 BC and 205 BC, and subsequently by the Romans till AD 410. About 70% of lead in the ice layers of Greenland from the period between 150 BC and AD 50 comes from the mines of Rio Tinto, in the southeastern part of Spain [41].

During the Greco-Roman age, an important part of the fourfold increase of lead concentration in the troposphere over Greenland came from lead/silver mining and processing. During the Roman Empire, 40% of the lead production in the world occurred in Spain, Central Europe, Britain, Greece, and Asia Minor [25]. Lead was smelted in open furnaces, for which the rate of emissions was not checked. The escaping small aerosol particles could have easily reached the Arctic region via routes that have become known only recently [26].

After the fall of the Roman Empire, atmospheric lead concentrations suddenly dropped to the background level that was characteristic 7760 years ago. In the medieval and Renaissance periods, it began to increase again, and 471 years before it reached a concentration double that detected during the Roman Empire [23]. In the seventeenth century, scientists identified widely illnesses in mining areas that were thought to arise from dispersion of the toxic elements [9]. Following the Industrial Revolution, the increase was continuous. From the 1930s till about 1960, snow and ice samples in Greenland indicated a rapid increase. This can be traced back to the antiknock additives of leaded fuels, which were used first in 1923 [29]. On a global scale, two-thirds of the leaded additives were used by the United States in the 1970s, 70% of which went directly into the atmosphere via exhaust gases of vehicles. Atmospheric lead concentrations measured in the 1960s were about 200 times higher than natural values. This is one of the most serious global-scale pollutions of the environment on the Earth ever recorded [23]. The sudden decrease observed after 1970 can be traced to an increasing use of unleaded fuels. In recent years, all petrol sold in the United States, and a gradually increasing ratio of that sold in Europe, has been unleaded [29]. Recently, Eurasia has been responsible for 75% of the atmospheric lead concentration on the Earth [41].

Lead pollution in the atmosphere has been detected over the Antarctic since the beginning of the twentieth century. The use of leaded fuels and then their cutback can also be detected. Furthermore, it can be established that an important part of anthropogenic lead comes from South America [23]. At the same time, natural concentration changes of lead (and other heavy metals) were also considerable over the Antarctic during the past ages. Low concentration values were detected in the Holocene period, while lead concentration was two orders of magnitude higher than this during the last glacial maximum, about 20,000 years ago [42].

3.3 COPPER IN ANCIENT TIMES

3.3.1 Copper Mining and Exploitation

Initially (about 7000 years ago), copper was produced from native copper. This was the main procedure for about 2000 years. Following this period, the discovery and introduction of a new smelting technique

of oxide and carbonate ores as well as the appearance of tin-bronze brought the development of the real Bronze Age. From then on, production increased continuously. In the period 2700–4000 BP (before present), total production was about 500,000 metric tons [43,44].

Copper production suddenly increased in the Roman times. In this period, copper alloys were used more intensively and frequently, both for military and for civil purposes (e.g., minting). The production reached its maximum 2000 years ago with a mass of about 15,000 metric tons/year. In this period, the main copper mines were situated in the territory of Spain (half of total world production of the derived from the regions of Huelva and Rio Tinto) as well as in Cyprus and Central Europe [45]. Total production in the period 2250–1650 BP was about 5 million metric tons [46].

When speaking about any metals, peaks and decreases in production correspond to booms and busts of the production area. This statement is valid for both the Roman Empire and China. A decrease in mining of all metal ores, including copper, started with the weakening of the Roman Empire. After the fall of the Empire, copper production decreased significantly in Europe. World production stagnated at a mass of about 2000 metric tons/year until the eighteenth century and then started to increase again. This increase, from the European side, was especially attributable to the opening of new mines in the ninth century in the territory of Germany, and in the thirteenth century in Sweden (the latter particularly in the region of Falun) [47].

Outside the Roman Empire, important copper production occurred in Southwest Asia and the Far East. When the Han dynasty (206 BC–AD 220) extended its influence over Southwest Asia, copper production in China was about 800 metric tons/year. In the medieval age, most of the world's production came from China (during the rule of the northern Sung dynasty). In this period, Chinese production reached its maximum of 13,000 metric tons/year, and this resulted in peak world production of 15,000 metric tons/year in the AD 1080s. Most of the copper was used for minting [48]. During some hundred centuries after this period, production suddenly dropped to about 2000 metric tons/year in the fourteenth century), and increased again from the Industrial Revolution until recently. (As a comparison, world copper production was 10,000 metric tons/year at the beginning of the Industrial Revolution.) In Japan pollution from the extensive

production of copper used in the manufacture of giant Buddhist statues gave rise to extensive environmental pollution starting in the eighth century [49].

3.3.2 Copper Pollution on Regional and Hemispheric Scales

Before the beginnings of anthropogenic use of copper, about 7000 years ago, all atmospheric copper derived from natural sources. This situation did not change until 2500 years ago. Since 2500 BP, atmospheric copper concentration has increased, which is a consequence of large-scale copper pollution in the northern hemisphere [50].

Copper emissions from ancient times to the recent period have been the results of mining and metallurgical activities. Other anthropogenic activities (e.g., the production of iron and nonferrous metals and wood burning) contribute to these emissions only to a lesser extent.

Emissions from copper production, in connection with a significant technological development, have considerably changed during the past 7000 years. In ancient times, due to the primitive smelting procedures, the emission factor was about 15% [44,45,50]. At the beginning, several steps of processing of sulfide ores (roasting, smelting, oxidation, and cleaning) were performed in open furnaces. Emission has been taken out of consideration until the Industrial Revolution. From that time onward, more sophisticated furnaces and more recent metallurgical procedures started to spread. In the middle of the nineteenth century, the processing procedure was reduced to five steps. These technological developments resulted in a significant decrease in the emission factor. In the twentieth century, this factor was only 1% and later, with the introduction of further modifications, it became a mere 0.25% [45,50].

Since Roman times, the Cu/Al ratio has increased in ice samples, which indicates that considerable copper pollution occurred in the troposphere over the Arctic in this period. This copper might have originated during the high-temperature phase of processing as small-sized aerosol particles, and then entered the atmosphere. These aerosols could easily reach the Arctic region from the middle latitudes where they originated (in Roman times, mainly the Mediterranean Basin, especially Spain; in the medieval period, China).

Changes of the Cu/Al ratio in the ice samples seem to correspond to estimated changes of anthropogenic copper emission. Data derived from

ice cores from Greenland indicate low values until 2500 years before present, medium values from Roman times until the Industrial Revolution and suddenly increasing values near the recent period. Data from Roman times show high variability. This can probably be traced back to the fact that in this period the production of copper occurred over short periods and was dependent on how many copper coins were needed [50].

According to the ice samples from Greenland, when comparing production data with emission factors, atmospheric copper emission peaked twice in the period before the Industrial Revolution. The first peak occurred in the golden age of the Roman Empire, about 2000 years ago, with a mass of some 2300 metric tons/year, when the use of metal coins spread in the ancient Mediterranean. The second peak appeared in the golden age of the northern Sung dynasty in China (AD 960–1279), about AD 1080, with a mass of some 2100 metric tons/year, when the Chinese economy was extensively developing and copper production increased. Since the smelting technology was primitive at that time, about 15% of the smelted copper got into the atmosphere. Though the total copper emission of the Roman and Sung times was about a tenth of that in the 1990s, copper production did not reach even a hundredth of that in the recent period. Hemispheric copper pollution caused by copper emissions has a more-than-2500-year history and copper emissions of the Roman and Sung times were so high than never before the year 1750 AD [45].

3.4 ENVIRONMENTAL AWARENESS IN ANCIENT ISRAEL

The environment is a natural issue of concern in Judaism. Much of the discussions center on the Biblical commandment of *bal taschit*, i.e., not to destroy without purpose any object from which someone might derive pleasure. Trees, fields, and rivers belonged to this circle. Jewish people knew that trees were very important and, for this reason, they prohibited the cutting down of trees around cities. Furthermore, trees were required to be watered and the environment cared for. Any form of luxury was prohibited, because luxury itself is a kind of waste. Beyond the prohibition of actual destruction, an entire series of laws deals with maintaining the general environmental quality of life. The Talmud requires

1. that one must not open a shop in a courtyard if the noise pollution of customers will disturb the neighbors' sleep;

2. that one must put pigeon cotes at least 50 cubits from the town walls, so that the droppings will not damage the town's vegetable gardens;
3. that threshing floors must also be kept at this distance, to prevent the chaff from creating an air pollution problem for the city.

Carrion, graves, and tanneries had the same distance requirement because of the odors they produce.

The fifth book of Moses is the basis of Jewish ecology. It specified, among other things, that soldiers were prohibited to relieve themselves on the field of their camp. They were to leave the camp, dig a hole, and when they are finished, bury their output. It was prohibited to build a latrine near houses because latrines were malodorous. Since stench disseminates in a different way in winter than in summer, open sewer channels were prohibited during the summer. If anybody suffered from the sewage of another person, he or she could claim compensation. Sewage was not allowed to be released near kitchen gardens, because it decreased yields. Nature is natural and basic for Jewish people and they believe, even now, that one should live in the way that is prescribed in the Bible, Torah, and Talmud. The Biblical cities in Israel were surrounded by a *migrash*—an area of 1000 cubits left for public enjoyment in which nothing could intrude. For this reason, trees must be kept 25–50 cubits (depending on the species of tree and the amount of shade each species provides) from the city wall. Furthermore, according to the rabbis, the migrash may not be turned into a field, as that would destroy the beauty of the city. Interestingly, a field cannot be made into a migrash, as that will diminish crop production.

In temple services, olive wood and wood from grape vines are prohibited from use on the altar. One opinion is that this rule arose from concern for the settlement and cultivation of the land of Israel. The second opinion is much more specific. These types of woods burn with a great deal of smoke, and air pollution is to be avoided. Jerusalem, as the holiest of the cities, also had special environmental legislation designed to protect its unique environment for the enjoyment of its inhabitants and visitors. In that regard, all garbage was removed from the city, dunghills were prohibited from the city area, and no kilns were allowed to operate within its border. In this way, vermin and smoke were kept out of the city and the quality of life was improved [12]. Tanning facilities were to be placed at least 60 cubits from the city wall, because they were highly odoriferous. They were prescribed

to be built on the eastern side of the city, since in Israel northerlies and westerlies were generally the most frequent winds; this way, the stench would not get back to the city. Mills had to be built at least 50 cubits from the city wall, because when they were operating much dust got into the air, which was harmful to humans when inhaled. Furthermore, it was said that wheat powder was not only unhealthy, but also harmful for the fields. Accordingly, mills should be built far away from fields. One can read in the Talmud that smoke is not only bad and harmful, but destroys the Garden of Eden of God as well. Hence, the relationship between God and humans becomes worse and they draw away from each other. The Talmud also says that the soul of God lives in everything: in animals, plants, and stones, etc. Therefore, He must not be offended, because if God had wanted a smoky world he would have created it. In the law-book of Tosefta, it was written that it was prohibited to wash in drinking water. Each well should be covered by a roof so that snakes, insects, and vicious souls could not to attack the water in it. Sewage holes were not allowed to be dug near a neighbor's well.

The Jewish law-books dealt with noise pollution, too. Millstones caused loud noise and vibration during work. For this reason, mills were not allowed to be established near the city. The operation of a school (if it was a big one with at least 50 students) depended on the inhabitants of the neighboring houses. Children caused lots of noise, and this could disturb the inhabitants [51].

This raises the question of why rabbis dealt so much with the environment in the past and why this environmental sensitivity was later pushed into the background. The answer might be that Jewish people didn't have farms for a long time, and thus didn't feel close to nature. Therefore, they didn't appreciate the value of a field as much as their ancestors did. Perhaps now that they can go back to their real homes, they will listen to the sounds of nature and their environment more carefully. According to the proverb, "The clean Jewish people take better care of their environment than the dirty Romans" [51].

ACKNOWLEDGMENT

The authors would like to express their gratitude to Claude F. Boutron (Laboratoire de Glaciologie et Géophysique de l'Environment du Centre National de la Recherche

Scientifique, Unité de Formation et de Recherche de Mécanique Université Joseph Fourier, Grenoble, France) for his exceptionally comprehensive contribution, and Noa Feller, Ian Strachan, and Keith Boucher for their useful hints on the topic.

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