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INTERNATIONAL VIEWPOINT AND NEWS

The emerging field of medical geology in brief: some examples

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Abstract Emerging medical problems present medical practitioners with many difficult challenges. Emergent disciplines may offer the medical community new opportunities to address a range of these diseases. One such emerging discipline is *medical geology*, a science that is dealing with the influence of natural environmental factors on the geographical distribution of health in humans and animals. It involves the study of the processes and causes of diseases and also the use research findings to present solutions to health problems.

Medical geology—introduction

Medical geology is a rapidly growing discipline that has the potential to help medical and public health communities all over the world pursue a wide range of environmentally- and naturally-induced health issues. Health problems caused by geologic material and processes occur quite frequently and are generally chronic. These problems are caused by long-term, low-level exposures to, for instance, trace, elements including fluorine, arsenic, radon, mineral dust and naturally occurring organic compounds in drinking water.

Geographical variation of occurrence of certain non-communicable diseases has been reported in all countries worldwide. Goiter, dental caries, multiple sclerosis, cardiovascular diseases, diabetes and Parkinson's disease among others are such examples. The etiology of diseases is usually multifactorial resulting from several biologic, behavioral, genetic and also environmental risk factors. For example, certain geological risk factors, which are fairly stable, may have a meaningful role in the etiology and regional variation of certain non-communicable diseases.

In 1996, the first steps of an international network in medical geology started in Uppsala, Sweden, which was financed by UNESCO and the International Council of Science. In 2001, short courses in medical geology were developed and since then have been presented in almost 60 countries. In 2006, the International Medical Geology Association (IMGA) was established, which has now about 400 members from all around the world with many national groups (http://www.medicalgeology.org). In addition to regular courses and an international biannual conference, many papers and books have been published in this field during the last 10 years, (e.g. Selinus et al. 2013; Rapant et al. 2014; Applied Geochemistry 2014; Centeno et al. 2016). In 2008, "medical geology" was declared as one of the ten themes in the United Nations' International Year of Planet Earth.

It is clear that the field of medical geology is growing considerably and is gaining interest during the last few years by postgraduate students and researchers. The following selected PhD theses have been completed and illustrate the diversity of the research: *Mineral element*

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contents in drinking water—aspects and potential links to human health (Rosborg 2005), *Metals in Urban Playground soils* (Ljung 2006), *The regional association of the hardness in well water and the incidence of acute myocardial infarction in rural Finland* (Kousa 2008), *Hydrogeological and geochemical assessment of aquifer systems with geogenic arsenic in southeastern Bangladesh* (Brömsen 2012), *Studies on metals in motor neuron disease* (Roos 2013), *Iodine in Danish ground and drinking water* (Voutchkova 2014). A new dissertation will be: Clays and Health by Sandra Londono, Arizona State University in 2016.

In addition, a new book on *Practical Applications of Medical Geology* by Malcolm Siegel et al. is planned for publication by Springer in 2018 and a number of distinguished lecturers and more short courses are considered for the years ahead arranged and announced by IMGA.

Arsenic

Awareness of the health problems associated with arsenic in drinking water and the environment has grown significantly over the last two decades and today there is an enormous amount of literature documenting its occurrence, behaviour and impacts in many places across the globe. The mobilization of arsenic in the environment occurs through a complex combination of natural biogeochemical reactions and human interactions. Most recognized problems are generated by mobilization and transport under natural conditions, but mobilization has also been caused, or exacerbated, by mining, fossil-fuel combustion and use of synthetic arsenical compounds (pesticides, herbicides, crop desiccants and arsenic-based additives in livestock feed). Arsenical pesticides and herbicides have been used much less over the last few decades, and more recent restrictions have been imposed on the use of arsenic in wood preservation (e.g. European Communities' Directive 2003/2/EC), but the legacy of such sources may still pose a localised threat to the environment (Plant et al. 2014; Sharma et al. 2014).

Human exposure to arsenic occurs through a number of pathways, including air, food, water and soil. The relative impacts of these vary depending on local circumstances but of the potential pathways, drinking water poses one of the greatest threats to human health as borne out by the large number of documented case histories from around the world. The concentrations of arsenic in drinking water are very variable, depending on nature of source (surface water, groundwater, rainwater) and local conditions, and observed ranges vary over several orders of magnitude. Excepting local sources of anthropogenic contamination, the highest aqueous arsenic concentrations are usually found in groundwaters because of the high solid/solution ratios found in aquifers. Groundwaters, therefore, pose the greatest overall threat to health. Groundwaters with arsenic concentrations sufficiently high to be detrimental to humans or with already detectable health impacts have been reported in Argentina, Bangladesh (Edmunds et al. 2015), Burkina Faso, Cambodia, Chile, China, India, Hungary, Laos, Mexico, Nepal, Romania, Spain, Taiwan, Thailand and Vietnam and occasional problems are found in many other countries.

Drinking water

In the early 21st century, drinking water security is a global concern as hundreds of millions of people still lack daily access to clean and safe drinking water. The increasing risks of climate change have brought us to the awareness that in many regions of the world, water security is under increasing threat and cannot be taken for granted (Stearman et al. 2014). In more and more locations, people are drinking water that has been treated and recycled from lower-quality water or seawater, while conversely the sales of bottled mineral water are skyrocketing.

It is not only the water itself that is crucial to our well-being, the minerals it contains are also vitally important. Over time, the dangers of high levels of certain elements in water have also become apparent, with tragedies such as the arsenic present in the drinking water wells of Bangladesh causing widespread illness and death. Arsenic toxicity in drinking water is now declared by the World Health Organization (WHO) to be a public health emergency, which has affected more that 130 million people worldwide. Guidelines on maximum recommended levels for a range of minerals in water have been developed. In general, toxicity levels of minerals with regard to human health are now quite well known. However, the beneficial health aspects of elements in water have not been investigated to the same extent. Broadly, many elements may be beneficial and even essential to health in smaller quantities, and yet harmful in large quantities (Rosborg 2005, 2014; Schaerström et al. 2014).

The interaction between elements is crucial to determining their health benefits and harmful effects. For instance, many people are aware that calcium is the most abundant element in the human body and is essential for building healthy, strong bones and teeth. Yet how many know that it acts as an antagonist to magnesium that is essential for a healthy heart? Too much calcium prevents the uptake of magnesium. Hence, the optimum balance of these two minerals in the water that we drink is vital to our health. Bicarbonate ions are the body's most important buffer against acidity. Bicarbonate ions in water help to reduce osteoporosis and have a strong association with increased longevity in areas where the water is hard (and bicarbonate alkalinity is high). There is a great deal of evidence with regard to health impacts of sodium, potassium and sulfate (macro-elements). The micro-elements or trace elements, such as selenium, lithium, zinc, fluorine, chromium, silicon, copper and boron, are less well understood and there is so far less evidence regarding the roles that they play. Selenium deficiency has been implicated in a range of diseases including some cancers. Zinc is essential for healthy growth and a well-functioning immune system. Lithium (Li) is protective against several mental health disorders, while boron has been shown to play an important role in joint functioning and so an optimal level of boron can be helpful against arthritis. The essential role of fluoride in protecting teeth is of course well known. However, much more research and subsequent regulation are needed regarding the other micro-elements.

Other studies indicate that areas with elevated Li in drinking water have lower suicidal behavior in people with mood disorders and less severe crime rate (Voutchkova et al. 2015). Figure 1 shows interesting facts on Li in streams/groundwater in Europe. The Li concentrations are much higher in Southern Europe, while mental disorders are more common in Northern Europe. Compare also with the map on Li in agricultural soils (Fig. 3).

Ca and Mg are key to the hydrochemical make up of all groundwaters (Razowska-Jaworek 2014). They are also critical components of drinking water, satisfying essential element requirements of the human system that also protect it from illness. There are optimum ranges of concentrations in potable water, particularly for Ca, with too little and too much both being detrimental to human health. This importance, however, contrasts starkly with the scarcity of regulation recommending such a range and the general public is left in ignorance of any guideline levels towards healthy consumption. Although the average Ca and Mg contents are printed on the labels of bottled drinking waters in Europe and elsewhere, there is again no guideline information provided on whether the stated concentrations are too high or too low for human wellbeing.

Three new books have been published on health issues of drinking water: Rosborg (2014), Schaerström et al. (2014) and Razowska-Jaworek (2014). These give excellent overviews of the most recent research on drinking water. The first book gives a broad view of the whole topic, the second book looks into the geographical distribution while the third book concentrates on Ca and Mg in water.

Fluorine

The element fluorine has long been recognized to have benefits for dental health: low-fluoride intake has been linked to development of dental caries and the use of fluoride toothpastes and mouthwashes is widely advocated in mitigating dental health problems. Fluoridation of water supplies to augment naturally low fluoride concentrations is also undertaken in some countries. However, despite the benefits, optimal doses of fluoride appear to fall within a narrow range. The detrimental effects of ingestion of excessive doses of fluoride are also well documented. Chronic ingestion of high doses has been linked to the development of dental fluorosis, and in extreme cases, skeletal fluorosis. High doses have also been linked to cancer (Edmunds and Smedley 2013).

Many high-fluoride groundwater provinces have been recognized in various parts of the world, particularly northern China, India, Sri Lanka, Mexico, western USA, Argentina and many countries in Africa. Large populations throughout parts of the developing world suffer the effects of chronic endemic fluorosis. Estimates are not well established, but more than 200 million people worldwide are thought to be drinking water with fluoride in excess of the WHO guideline value.

Environmental guideline values or health criteria are given for various potentially harmful substances, in various contact media. They are routinely used by authorities and decision makers to assess the levels of these substances. Finding optimal guideline values to use in health risk assessments is a delicate task for toxicologists and risk analysts. A straightforward way to determine which level of a certain substance that can be considered safe is to evaluate the results from epidemiologic surveys, which focus on the correlation between a certain negative health effect and some environmental variable, for example the concentration of a specific substance in tap water. A critical problem here is that the total exposure seldom is a function of only one exposure pathway. In addition, people differ in physiology and consumption patterns, meaning that the exposure varies substantially from one person to another. All in all, the variability in exposure as well as in sensitivity sum up to a highly variable and inconsistent picture of the tolerable level when focusing only on acceptable concentrations in a single environmental media. For drinking water, guideline values can be derived following that the daily dose of a certain substance is a function of water consumption and concentration in the water. However, the drawback is that several exposure pathways often contribute to the total dose, which makes the assessment complicated.

The overall conclusion is that the risk of an excess fluoride intake may be best judged after having quantified all relevant exposure pathways, and that evaluations of the variability found in these pathways suggest that a drinking-water guideline of 1.5 mg/L alone may not be conservative enough.

There has been much debate over the alleged benefits of fluoridation of drinking-water supplies and the issue is still

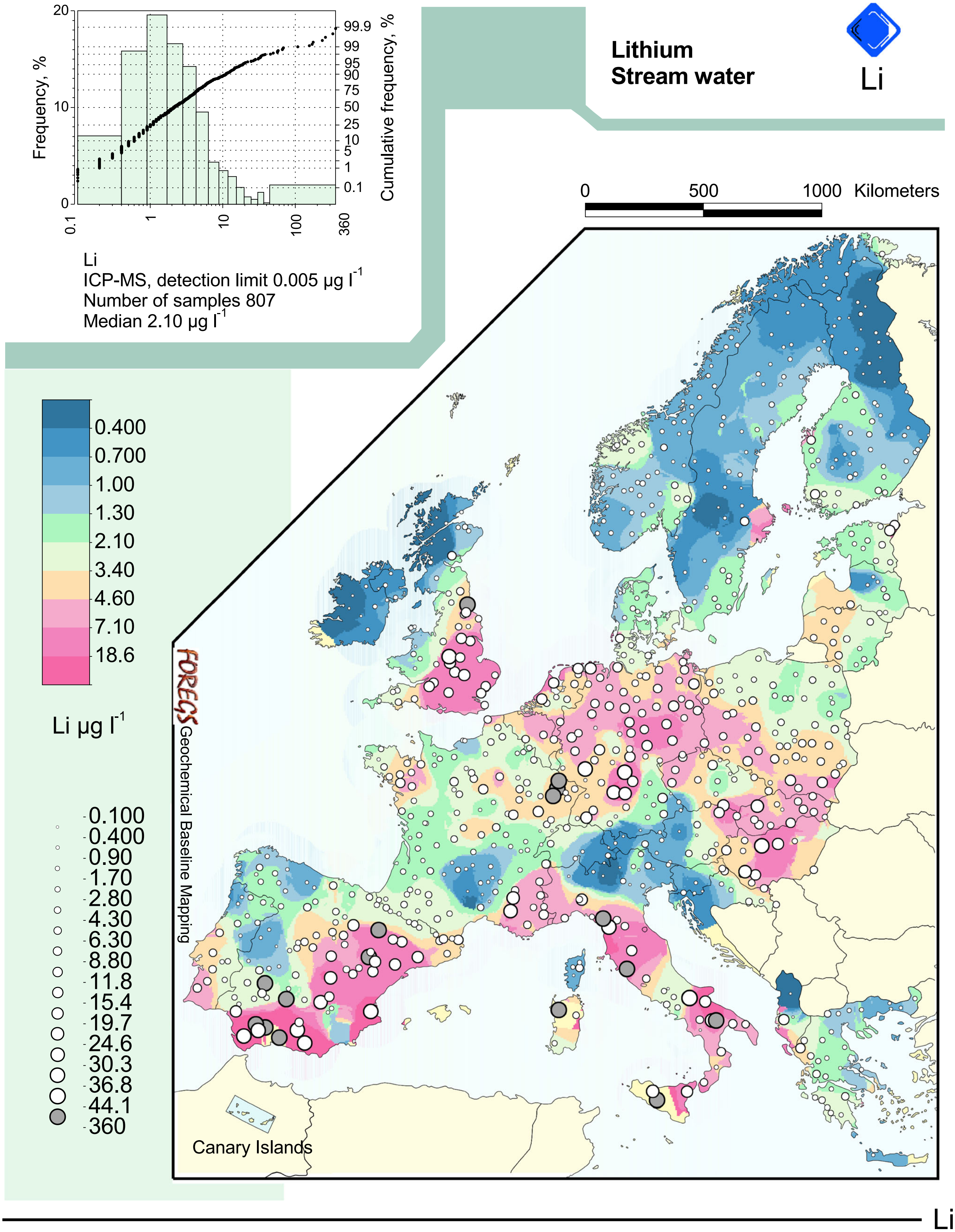

Fig. 1 Lithium in stream water in Europe based on the FOREGS Geochemical Atlas of Europe, Salminen et al. (2005)

strongly contentious. Despite the uncertain consequences of fluoride in drinking water at low concentrations (≤0.7 mg/L), the chronic effects of exposure to excessive fluoride in drinking water are well established. The most common symptom is dental fluorosis (‘mottled enamel’), a condition involving interaction of fluoride with tooth enamel, which involves staining or blackening, weakening and possible eventual loss of teeth. With higher exposure to fluoride, skeletal fluorosis can result. This manifests in the early stages as osteosclerosis, involving hardening and calcifying of bones and causes pain, stiffness and irregular bone growth. At its worst, the condition results in severe bone deformation and debilitation. Long-term exposure to fluoride in drinking water at concentrations above about 1.5 mg/L can result in dental fluorosis while values above 4 mg/L can result in skeletal fluorosis and above about 10 mg/L, crippling fluorosis can result.

In both Sweden and Denmark there seem to be problems with fluoride. In Sweden for example, a significant proportion of wells with drinking water have contents of fluoride exceeding the safety values.

Fluoride is a substance where it is often considered that the intake of drinking water is the predominant route of exposure. The intake of this substance is thus often evaluated by comparing levels in drinking water with available drinking-water criteria. The problem is that fluoride in low doses has beneficial health effects, but there is a narrow line between the intake that optimizes these positive effects and the intake that is detrimental. Establishment of guideline values is thus problematic. The issue is exacerbated by the fact that water consumption is not the only exposure pathway: fluoride is also present in food and beverage, as an additive to various dental products, and it exists in soil particles that can be ingested or inhaled. Thus, the assessment of the risks associated with fluoride intake can be better judged by comparing the total intake via all relevant routes of exposure with a toxicological measure of the tolerable daily intake. In this context, also the variability that is associated with the different exposure pathways should be characterized. Certainly, one could assume that the levels deemed tolerable in drinking water in epidemiological studies should indirectly take into account that the study population experiences a *background exposure* also from other sources, but when these other sources play a major role for the total intake, and indeed a highly variable role, it is not certain that the groundwater concentration that is eventually given as a drinking-water guideline value will give the same result when used in a risk assessment as would a comparison with a measure of tolerable daily intake.

In an interesting study by Augustsson and Berger (2014), the following conclusions were drawn: first, the intake of drinking water is in less than 50 % of the scenarios dominating the exposure of fluoride, even though the calculations in the present study were applied on a region where the geological environment is rich in this element. With high fluoride concentrations in the water and a larger water consumption and a lower body weight than average, this source dominates the total intake, but in other circumstances the ingestion of tooth paste and intake of food and beverages is of greater importance. Intake through water consumption was, however, found to be by far the most variable route of exposure. Second, the risk characterization that was based on the drinking-water guideline showed that 24 % of the children were assessed to be “at risk” for an excess fluoride intake, that is, they had a water source with a fluoride content above 1.5 mg/L. When the risk assessment instead focused on comparing the calculated fluoride intake via water consumption with the maximum tolerable intake of 0.06 mg/kg-day, it was found that the number at risk almost doubled to 43 %, and when all exposure pathways were included, the proportion increased to 79 %. Hence, the outcome of the risk characterization strongly depends on the basis for evaluation even though both the WHO drinking-water guideline and the US EPA RfC value are widely accepted and used tools for this purpose.

Naturally occurring asbestos: public health and geology

Naturally occurring asbestos (NOA) is a term used to describe fibrous minerals that include regulated asbestos minerals as well as other fibrous minerals that do not meet the regulatory definition of asbestos. These minerals occur as a natural component of rocks and soils, and often may go unrecognized because they occur in low concentrations. However, these lower concentrations do represent a potential health risk. Soils that have asbestos concentrations below the limit of detection (<0.001 %) can still produce airborne dust with unacceptable levels of fibers (>0.1 f/mL).

In North Dakota USA, sediment from the Arikaree Formation contains the zeolite mineral erionite. Erionite is a group 1 human carcinogen and is best known from the epidemic of mesothelioma in Cappadocia, Turkey. In North Dakota, erionite-bearing sediments were used as road gravel, causing inhalation exposures to people performing road maintenance, driving on these roads, or those downwind (e.g. Pratt 2012; North Dakota Department of Health 2005; US EPA 2010; Carbone et al. 2011; Ryan et al. 2011).

Recently, NOA in the form of fibrous amphibole minerals was found in rock, soil, and dust samples in and around the Las Vegas metropolitan area in southern

Nevada, USA (Buck et al. 2013; Metcalf and Buck 2015). The finding of NOA postponed building of a major highway: the Boulder City Bypass—a portion of the planned Interstate 11 that will connect Las Vegas, NV to Phoenix, AZ. Construction activities were halted in order to confirm the findings of NOA, to re-evaluate and complete a new environmental impact statement, and to develop appropriate mitigation measures.

The sources of the NOA in southern Nevada are unusual and they likely never would have been found except for a somewhat unlikely set of circumstances. Research on the health effects of mineral dust at an off-road-vehicle (ORV) recreation area, just 6 km north of the Las Vegas metropolitan area found exceptionally high arsenic concentrations, which were being studied as part of a human health risk assessment. Brenda J. Buck, the lead researcher on that project, also found a fibrous clay mineral, palygorskite, which is regulated in the state of California and has shown mixed results in regards to its carcinogenicity. She was concerned about citizens breathing these fibers, so she asked researchers at the University of Hawaii Cancer Center to look into data from the Nevada Cancer Registry. It turns out that those same researchers were also looking for a geologist to help them because they had concerns based on young cases of mesothelioma. Francine Baumann, an epidemiologist at the University of Hawaii examined the data and concluded that it was very likely that people were being environmentally exposed to carcinogenic fibrous minerals that cause mesothelioma. Buck then realized that she needed to find minerals other than palygorskite to explain these data. In particular, she searched for natural occurrences of asbestos minerals and erionite. However, there were no published occurrences of any of these fibrous minerals in Clark County—an area over 20,000 km^2, where the Las Vegas metropolitan area is located. It was then that she remembered talking to a friend and colleague, Rod Metcalf, a petrologist in the UNLV Geoscience Department. He had mentioned fibrous amphibole minerals a few years previously in a remote part of Arizona. Her concern was that those minerals were likely too remote to be causing the results in Baumann's dataset. So could they also be occurring closer to the population center? They put together a team of researchers and found fibrous amphibole minerals south of Henderson, NV.

However, when they planned to present these preliminary data at the Annual Geological Society of America (GSA) meeting in the fall of 2012, the State of Nevada Health and Human Services issued a cease and desist order, preventing the research team from using any of the data from the Nevada Cancer Registry and demanding that the abstracts for the GSA meeting be retracted. The Nevada State Health Officer and the State Epidemiologist disagreed with the research team's interpretations of the Nevada Cancer Registry's data and prevented any scientific discussion from occurring. For the cease and desist order, they used a clause in the agreement Baumann had signed that required her to acquire permission from them to publish the abstracts. Sadly, the State Health officials never once asked about the asbestos minerals. These actions resulted in several news media publications, radio and TV broadcasts (New York Times 2015; Desert Companion 2015; Pratt 2015; The TakeAway 2015; KNPR 2015a, b; Channel 8 Las Vegas 2015). After the cease and desist order, the geologic research team quietly continued their work, eventually publishing their first paper in the fall of 2013 (Buck et al. 2013).

What the geologists found was that the NOA occurred in a geologic setting where NOA would not have been predicted based on current models (Metcalf and Buck 2015). The fibrous amphiboles occur in Neogene-age granitic plutons that outcrop in and around Boulder City, Black Hill, the McCullough Range in Nevada, and across the Colorado River in the Wilson Ridge area of northwestern Arizona (Fig. 2). The fibrous amphiboles have formed in the granitic rocks as a result of hydrothermal alteration. On the Arizona side of the Colorado River, sodic fluids likely from dissolution of nearby sedimentary halite deposits caused the formation of more sodic amphiboles: fibrous winchite, magnesioriebeckite, richterite and actinolite (Metcalf and Buck 2015). These minerals are similar to those found in Libby Montana, a major USA superfund site. In contrast, on the Nevada side of the Colorado River, they hypothesize that the hydrothermal fluids have less sodium, and mostly calcic amphiboles are found: the regulated asbestos mineral actinolite, and non-regulated magnesiohorneblende (Buck et al. 2013). Baumann eventually published the work using data obtained from the Centers for Disease Control and Prevention, since the State of Nevada refused to remove their cease and desist order (Baumann et al. 2015).

Erosion of these plutons has distributed the NOA into surrounding alluvial fan deposits and soils. These alluvial deposits can range in age from the late Miocene to Pliocene Black Mountain conglomerate in Arizona (Metcalf and Buck 2015) to modern alluvium in drainages emanating from any NOA-containing materials in Nevada or Arizona. Unfortunately, Boulder City, with a population of approximately 15,000 was built directly upon deposits containing NOA (Fig. 2).

The primary NOA exposure route is through inhalation of fibers when either natural erosional processes or human disturbance cause them to become airborne. Dust emissions are a common occurrence in this region due primarily to the arid climate of the Mojave Desert. Annual precipitation in the region is approximately 10 cm/year and

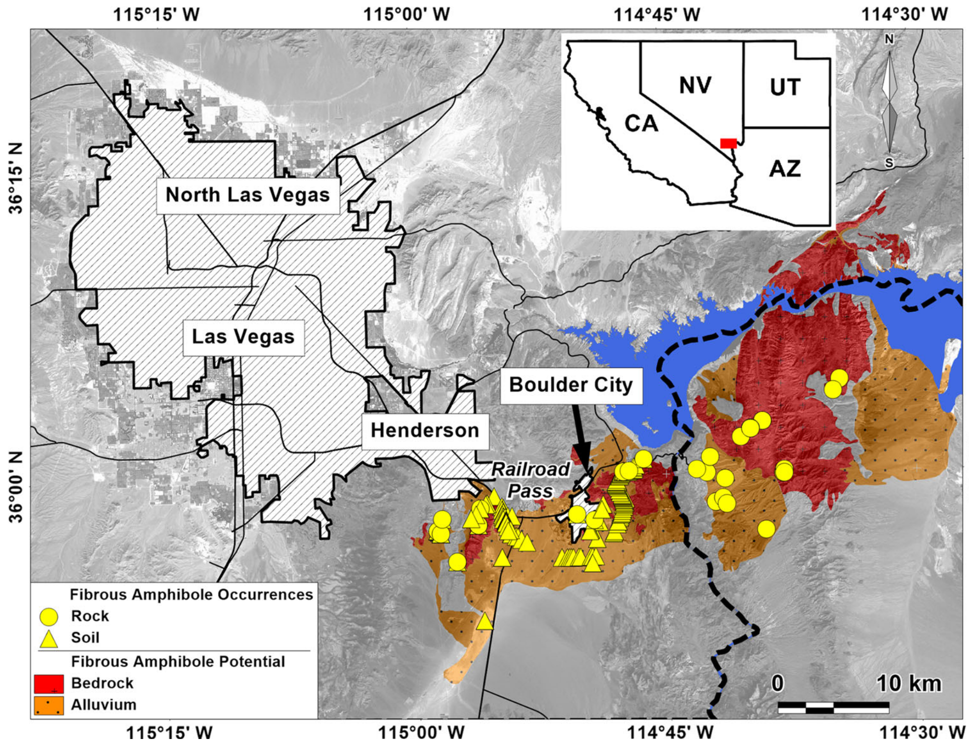

Fig. 2 *Map* showing measured fibrous amphibole occurrences and the geologic units that are permissive for naturally occurring amphibole asbestos in southern Nevada and northwestern Arizona (data from Buck et al. 2013; Metcalf and Buck 2015 and references in Baumann et al. 2015)

temperatures are in excess of 40 °C in the summer with average annual temperatures of 19.5 °C. Vegetation is sparse and large areas of the lower elevations are commonly devoid of vegetation and are covered by desert pavements and vesicular soil horizons. When these desert pavements are disturbed by activities such as off-road driving, large quantities of the sediment in the vesicular horizon are released into the air by wind erosion. Other low elevation bare soil surfaces are the dry lake beds, which are dry year-round except for brief rainy periods. Impressive dust clouds resulting from local wind erosion can be observed at any time during the year. The increased dust emissions from both natural wind and anthropogenic activities, greatly increases the potential for human exposure.

There are very little data on the concentrations of mineral fibers in the air. However, as part of the work done for the Boulder City Bypass, ambient air was measured in the area of Railroad Pass near the southernmost extent of Henderson (Tetra Tech 2014; Fig. 2). Reported values from May 8 to August 10, 2014 vary from non-detect to 0.0014 s/cc with an average of 0.00021 s/cc. The average is 2.3 times higher than the new inhalation reference concentration for non-cancer just released by the EPA: 0.00009 f/cc (US EPA 2014). Much more work needs to be done before risks to the population can be calculated. Seasonal changes in wind direction, speed, precipitation, and human activities all contribute to ambient air concentrations. In particular, many people enjoy numerous recreational activities in areas that contain NOA, such as horseback riding, ORV driving, running, hiking, bicycling, and camping that will increase their risk of exposure. These activities not only increase dust emissions but also will cause fibrous minerals to attach to clothing, cars, and equipment that when brought home can cause additional secondary exposures. Activity-based sampling, in addition to long-term ambient air monitoring is needed to better understand human exposures.

In addition, much more mapping is needed, not only regionally but expanding these findings worldwide. In southern NV, similar granitic plutons exist further south and currently only water-laid deposits have been preliminarily mapped to predict NOA occurrences (Fig. 2). Eolian processes are a significant factor in the Mojave Desert and they may redistribute NOA to soils at great distances from the source. Dust deposition controls the formation of desert pavements with associated vesicular horizons. Similarly, fragile biological crusts trap dust and also can also form vesicular horizons. Many of these vesicular horizons may contain NOA fibers and therefore, soils great distances from the source materials may also be sources for NOA exposure.

The Las Vegas metropolitan area, with over 1.9 million people may be affected, and if similar geologic processes have occurred elsewhere many other areas may find themselves in a similar situation.

Clays: friend or foe?—turning clays into allies and guarding against threats for human health

Clays have been called 'the mutants of the mineral world' (Thorez 2003) because they change their chemical makeup via ion exchange and readjust to the environment due to their small particle size (<2 μm) and large reactive surface area (>100 m^2/g). Similar to the changing chemistry of clays, medicinal uses of clay have evolved and adapted to cultures over time. Exhumed from ancient traditions and modified in new and exciting products, clays can help us meet current environmental and health challenges. However, clays can also pose a threat for humans. Researchers from multiple disciplines are investigating the pathogenic or beneficial character of natural clays (e.g. Williams and Hillier 2014; Sánchez-Espejo et al. 2014). Understanding what differentiates beneficial from toxic clays is key to producing new clay-based medicines and therapies, and to addressing safety concerns. The harm or benefit of clays depends on the dose, route of exposure and composition of exchangeable ions.

Recent research on some hazardous clays focuses on the links between foot skin exposure to red clay soils and *podoconiosis*, a severe inflammation of the feet and legs. Using statistical analysis, Molla et al. (2014) showed a positive correlation between smectite, quartz and mica and the prevalence of podoconiosis in Northern Ethiopia. The disease begins when mineral particles enter the skin and invade the lymphatic system. Presumably, the particles block the water absorption, and infect or damage the cells. Ultimately, the disease deforms the lower legs and the patient suffers from physical disability and social stigma. Jones et al. (2015) assayed the bioreactivity of 'red clays' from the volcanic island of Madeira, Portugal that have been shown to produce podoconiosis. The clays are mostly composed of kaolinite and contain oxidized Fe from basalts. They assessed the reaction of the red clays against DNA and different types of human cells and found that the red clays damaged DNA, attacked immune cells, and lysed human blood cells (haemolysis).

While volcanic red clays are enemies of human cells, some clays are allies to fight infections: the antibacterial clays. To inhibit or halt bacterial growth, antibacterial clays buffer the pH outside of the near-neutral environment that suits human pathogens, where mineral-microbe interactions are affected by ion exchange. We have found different *modus operandi* for the antibacterial actions of certain clays (Londono and Williams 2015). Certain metal species supplied by clays are bactericidal due to production of reactive oxygen species. Morrison et al. (2014) tested different alteration zones of a hydrothermal antibacterial clay deposit, from the Oregon Cascades, USA. The altered high sulfidation zones contained reduced Fe-rich blue clays, which proved most effective in killing human pathogens, including antibacterial-resistant strains, while oxidized zones (red clays) were not. The mechanism of action involves the dissolution of minerals that supply Fe^{2+} and Al^{3+}, which synergistically compromise the bacterial envelope. An excess of Fe^{2+} then penetrates the bacterial cell where reactive oxygen species form and oxidize intracellular proteins (Morrison and Williams 2015).

Another antibacterial clay from the NW Colombian Amazon (AMZ) is a time-honored healing clay used by the Uitoto tribe, a native culture of the region. They have used it to treat stomach pain, indigestion and fever. With tribal permission to collect clay samples and investigate the antibacterial action of the AMZ clay (Londono and Williams 2014, 2015), it was found that the ingested clays are primarily composed of kaolinite and smectite, containing a range of transition metals. The AMZ clay inhibits bacterial growth of Gram-positive and Gram-negative model bacteria: *Escherichia coli* and *Bacillus subtilis*. However, metal toxicity does not cause growth inhibition in this case because individual concentrations of metals are too low to be toxic. Rather, chemical analyses of *E. coli* before and after reaction with AMZ indicated that this clay deprives bacteria of essential nutrients (Mg and P). Current research aims to understand the geobiochemical interactions between the clay and phosphate. Withholding essential nutrients imperative for bacterial metabolism is effective but less aggressive than metal-induced toxicity, which could make this type of mineral more suitable for treatment of internal infections.

The pathogenesis or medicinal character of clay cannot be unequivocally linked to a particular clay mineral or element. While certain kaolins or smectites may disinfect wounds, the same components with a mutant chemistry might also irritate the lymphatic or immune system. It is the goal of our research to understand the nuances of the clay-cell interactions to be able to use them effectively to benefit human health.

Medical geology in Africa—an example from South Africa

Medical geology in Africa is a relatively new discipline. Although interest in the subject is growing, Africa is still to make visible strides in medical geology. Few data are available or published on geological health problems in Africa in general and in South Africa in particular. With recent developments and exposure of new knowledge of such problems elsewhere in the world, thorough studies of these problems in South Africa have become urgent. A few initiatives however, have been made such as the publication of Davies (2010) and the 1st International Symposium on Medical Geology in Africa at the University of Johannesburg in 2014 to promote this field of science. More still needs to be done. Geological problems have been present for a long time in Africa and some examples of the well-known health effects are: asbestosis, silicosis, thyroid disorder including goiter development, as well as dental and skeletal fluorosis.

South Africa has several natural and anthropogenic geological problems that affect the environment and the health of its inhabitants. The semi-arid area immediately west of the Pilanesberg Complex is located approximately 210 km west of the city of Johannesburg. An investigation conducted in 11 villages focused on the health problems that are occurring due to the groundwater contaminated by the Pilanesberg Complex and the Rustenburg Layered Suite (McCaffrey and Willis 2001). The alkaline Pilanesberg Complex contains high concentrations of zirconium (Zr), fluoride (F), sodium (Na), uranium (U), thorium (Th), hafnium (Hf), niobium (Nb), and tantalum (Ta). The Rustenburg Layered Suite is the world's largest mafic intrusion and hosts the largest reserves of platinum-group elements (PGE), chromium (Cr) and vanadium (V), but also contains rock formations that are rich in calcium and magnesium (Mg).

Nearly all communities in this locality heavily depend on groundwater for domestic use. Although villages have several community taps, some individuals often drill holes in their own yards. The water from these groundwater boreholes is often untested for harmful trace elements. Water in this area is hard and dominated by HCO_3^- anion and Ca and Mg cations. The water also forms limescale in kettles or pots immediately upon boiling and may clog the water distribution pipes. Data from previous reports as well as preliminary results from this study indicate high concentrations in F, Ca, U, Na, Mg, Ca and total dissolved solids (TDS), consistent with the chemical composition of surrounding rocks. These concentrations are higher than the allowable safe limits of the WHO and the South African Department of Water Affairs (DWA). Analyses show that some concentrations are about 10 times greater than the allowable limits (Table 1).

Dental fluorosis cases are common in Southern Africa (Thole 2013) even at concentrations that are similar to the recommended DWA fluoride limit in water for the NW Province. Radioactivity emitted by uranium from the Pilanesberg Complex is low and therefore immediate health risks may be negligible. However, it is the long-term effects from ingestion and inhalation that are of concern. The mortality profile reports by Bradshaw et al. (2006) and Statistical Release (2013) for the North West Province show significant mortality rates from diseases prevalent in this province. These reports also show that diseases such as skeletal fluorosis, cardiovascular related diseases, renal diseases and diarrhoea are prevalent in the NW Province.

Preliminary investigations from recent fieldwork in the study area show a significant amount of hypertension, cardiac failures, diarrhoea, irregular menstrual cycle disorders, mental illnesses and musculoskeletal problems. This is partly in line with the NW Province mortality profile report and studies elsewhere in the world. In many cases, patients with hypertension also had one of the following disorders: musculoskeletal diseases, diabetes, psychosis, stomach ulcers, and other mental illness problems. In addition, aggression is a prominent problem in some villages in the study area.

Apart from natural geological problems, this area also has a compromised distribution of water, municipal safety plans, non-compliance on sanitation efficiency and incident management protocols. The NW Province faces the most critical risk. This is according to the 2013 Blue Drop Progress Report by the DWA that will be generated from this type of investigation may help prevent serious health risks and even loss of life in future generations.

Databases in medical geology

What high quality databases can be used in studies in medical geology? Especially in Europe there exist big quality controlled databases for use in medical geology research. Almost all data can be used for free and much is available on the web. The main organizer of these is EuroGeoSurveys (EGS) in Brussels, which consists of all geological surveys of Europe.

In 2005, the *Geochemical Atlas of Europe* was published. The European programme was carried out by government institutions from 26 countries under the auspices of the Forum of European Geological Surveys (FOREGS) The main objectives of this European survey were to apply standardized methods of sampling, chemical analysis and data management to prepare a geochemical baseline across Europe, and to use this reference network to level national baseline datasets. Samples of stream water, stream sediment and three types of soil (organic top layer, minerogenic top and sub soil) have been collected at 900 stations, each representing a catchment area of 100 km^2, corresponding to a sampling density of about one sample per 4700 km^2. In addition, the uppermost 25 cm of floodplain sediment was sampled from 790 sites each representing a catchment area of 1000 km^2. All soil and sediment samples were prepared at the same laboratory, and all samples of particular sample types were analyzed by the same method at the same laboratory. More than 50 elements, both total and aqua regia extractable concentrations, and other

Table 1 Comparison of element concentrations measured in the groundwater (in mg/L) of the study area west of the Pilanesberg Complex, South Africa (Shelembe) to the recommended concentration limits set by the South African Department of Water Affairs (DWA) and World Health Organization (WHO)

Element	Moses Kotane local municipality	Study area west of Pilanesberg complex	DWA	WHO/World mean
F	1–10 (75[a])	0.1–9.0 (74[a])	0.75	0.5–1.0
Na	Not measured/published	Up to 370 000	400	500
TDS	590–850	160–1750	200	0–450[b]
U	Not measured/published	1–54	0.07–0.284	0.0004
Th	Not measured/published	Not measured yet	3.642×10^{-8}	0.03

[a] Data close the Pilanesberg complex

[b] South African standard

parameters (such as pH and grain size) were determined on the <2 mm grain size fraction of minerogenic samples, and total concentrations of organic soil samples were measured after using a strong acid digestion. Altogether, 360 geochemical maps showing the distribution of elements across Europe have been prepared. All the results and field observations are organized in a common database and the maps are published as the *Geochemical Atlas of Europe*. Initial results show that the distribution patterns of both water and solid samples are related to such factors as large-scale tectonic provinces, geochemical variation of large lithological units, extension of the glaciation, and contamination reflecting industrialized areas and regions of intensive agriculture.

EuroGeoSurveys has also published a European atlas of bottled water that examines around 1800 bottles. The scientists have found an enormous natural variation of many elements, including arsenic and uranium. The new comprehensive guide to European groundwater prepared on the basis of analyses of bottled water will allow consumers to make a conscious choice of the best product for their health and taste. The new atlas, *Geochemistry of European Bottled Water*, provides the chemical composition of 1785 bottled water samples from 38 European countries altogether. The samples were purchased in supermarkets during 2008 and subsequently analyzed in one single laboratory. The survey is important, since more than 1900 brands of bottled water are currently registered in Europe and the market is rapidly expanding. The published book contains a CD with all analytical results as Excel® files, which can be used in medical geology. (Banks et al. 2015; Flem et al. 2015).

Urban areas are of increasing importance in environment and health. Therefore, EuroGeoSurveys has also done an extensive mapping of larger urban areas all over Europe and published this in 2011. *Chemical Environment of Urban Areas* focuses on the increasingly important issues of urban geochemical mapping with key coverage of the distribution and behaviour of chemicals and compounds in the urban environment. Clearly structured throughout, the first part of the book covers general aspects of urban chemical mapping with an overview of current practice and reviews of different aspects of the component methodologies. The second part includes case histories from different urban areas around Europe. Most of all these described big databases are freely accessible and can be used in research and studies in medical geography. In some cases, data are provided on a CD at the end of the book or are freely accessible on the web.

Food production and quality depend on the properties of agricultural and grazing land soil. The fact that the natural variability of chemical elements in soil at the continental scale spans several orders of magnitude is widely neglected. In agricultural sciences, the focus is on the major nutrients in soil, while trace elements and especially contaminants (e.g., the heavy metals) are mostly overlooked. In environmental sciences today, much of the political attention focuses on 'too high' toxic element concentrations in soil. For a number of elements, maximum admissible concentrations have been defined for agricultural soil or sewage sludge used as fertilizer. It is not realized, however, that even 'too low' deficient element concentrations may commonly have a more severe influence on productivity and on plant, animal and human health. A sound documentation of element concentrations and their variation in agricultural and grazing land soil at the continental scale is needed before political actions are taken. Such data are also urgently needed at the continental scale in forensic chemistry. For example, regional differences can be used to trace the origin of food.

Therefore, a new project GEMAS, Geochemical Mapping of Agricultural and Grazing Land Soil covers the whole of Europe. The GEMAS project delivered comparable data on metals in agricultural and grazing land soil, in addition to soil properties known to influence the bioavailability and toxicity of metals. 2211 samples of agricultural soil (0–20 cm) and 2118 samples of grazing land soil (0–10 cm) were collected. The aim

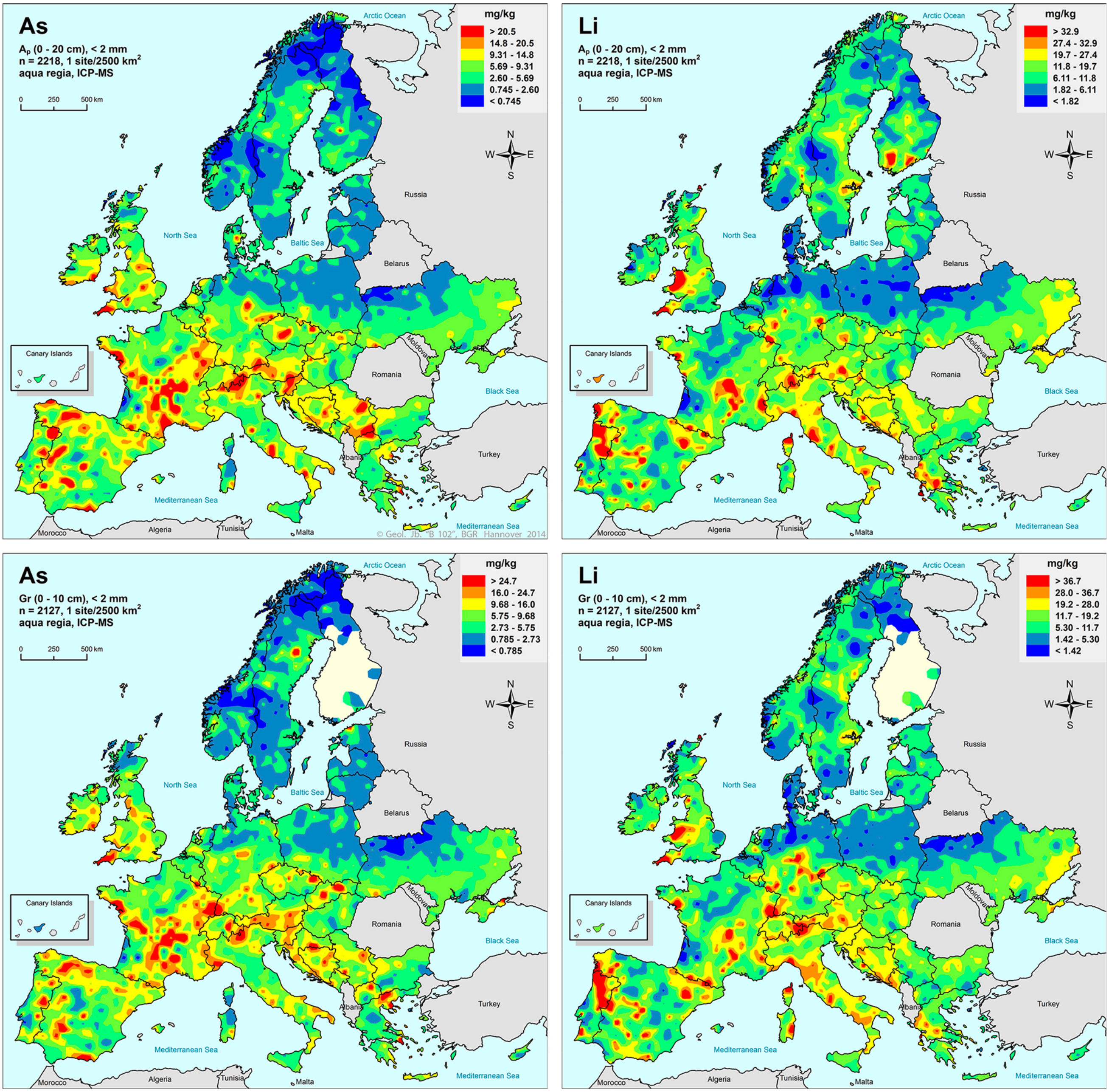

Fig. 3 As and Li in agricultural soils (*upper*) and grazing lands (*lower*) in Europe. (Reimann et al. 2014a)

was to produce one of the best harmonized and directly comparable datasets on soil quality and metals in soils that exists at the EU scale. This is very important for health reasons because crops and the subsequent uptake through food are dependent on the agricultural soils. The GEMAS project delivers good quality and comparable exposure data of metals on agricultural and grazing land soil; in addition, soil properties that are known to influence the bioavailability and toxicity of metals (and other elements) were determined in soil at the European scale (Fig. 3).

All GEMAS project samples were analyzed for (1) 53 chemical elements following an aqua regia extraction, (2) pH in $CaCl_2$, TOC, LOI, grain size (on a selection of samples), total C and S, (3) total concentrations of 39 elements by X-ray fluorescence, (4) Pb and Sr isotopes, (5) prediction of soil properties by mid infrared (MIR) measurements, and (6) determination of Kd values for selected elements on selected samples. GEMAS is a cooperation project between the Eurogeosurveys Geochemistry Expert Group and Eurometaux. The results of the GEMAS project were released in April 2014 as a set of two volumes, accompanied by a DVD with all the analytical data, maps, diagrams and tables. The maps show interesting details on As and Li in the soils of agricultural land and grazing land—especially the great difference between northern and southern Europe is mainly due to the geology (Fabian et al. 2014; Ottesen et al. 2013; Reimann et al. 2014a, b).

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