Medical Geology: Its Relevance to Mexico

Geología Médica: su relevancia para México

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Abstract

Interest in medical geology issues is rapidly expanding around the world. The objective of this paper is to highlight medical geology issues in Mexico and to discuss the importance of natural resources and its relation to human and animal health. Three Mexico´s zones are discussed; North, Central and Western. In addition, two main concerns are addressed; the arsenic and the flouride levels in ground water. These two trace elements along with others such as uranium and radon are elements that pose a serious threat to human health. The last part is dedicated to Chihuahua where arsenic, fluorine, uranium and radon coming from geogenic or anthropogenic sources present a serious threat to humans. The authors hope to encourage students and professors to participate and engage in medical geology conferences and events in order to improve their knowledge on this topic as well as to improve the health of Mexican citizens and people all over the world.

Keywords: human health, environmental human threat, arsenic, fluorine, uranium, radon.

Resumen

El concepto y la importancia del estudio de la geología médica está creciendo alrededor del mundo. El objetivo de este trabajo es discutir la importancia de diversos aspectos de geología médica en México y señalar la relacion de los recursos naturales con la salud humana y animal. Se discuten tres grandes regiones del país: la región norte, la región central y la región oeste. Además, se analizan dos preocupaciones fundamentales: el arsénico y el flúor. Estos dos elementos, junto con otros como el uranio y radón son elementos que potencialmente representan una amenaza a la salud humana en el país. La última parte del análisis se enfoca en el estado de Chihuahua, que es el más grande de México, y donde el arsénico, flúor, uranio y radón, presentes ya sea de fuentes naturales (geogénicas) o antropogénicas, representan una seria amenaza a la salud humana. Los autores desean motivar tanto a estudiantes como profesores a participar e involucrarse en el tema de la geología médica con el fin de ahondar en sus diferentes aspectos y, como consecuencia, mejorar la salud de los habitantes de México y del mundo.

Palabras clave: salud humana, amenaza, arsénico, flúor, uranio, radón.

Introduction

If you have never heard the term Medical Geology you are not alone. Most people, even many scientists, have not heard of the term. Yet medical geology is a field of knowledge whose roots go back millions of years and whose impacts affect just about everyone on the planet.

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Medical geology is the science dealing with the impacts of the natural environment (geologic materials and geologic processes) on animal and human health. It is concerned with exposure to naturally occurring trace elements, minerals in ambient dust and organic compounds in water and in the atmosphere. Medical geologists study volcanoes, earthquakes, and other natural phenomena to determine how these activities impact health. Medical geology is a discipline that links environmental science, public health, and geoscience in an effort to better understand these issues so that their impacts on public health can be minimized or even eliminated.

As long as 2 million years ago humanoids used minerals to settle upset stomachs likely counteracting the effects of eating rotten fruits and meats (Abrahams, 2005). Certainly long before that humanoids were aware of the potential dangers from volcanic activity and drinking water from certain natural sources. Many ancient civilizations were aware of various ways that rocks, minerals, water, and dust could impact human health. Their scientists and philosophers produced treatises warning readers of these dangers or recommending the use of specific rocks and mineral to counteract various diseases. Much of the valuable knowledge of these ancient indigenous peoples have been ignored by modern society or irretrievably lost.

Despite this long history and the widespread and sometimes severe health impacts, the science of medical geology is relatively new. During this past decade there has been a resurgence of interest in this field that has led to active research projects in many parts of the world including Mexico and the development of a support structure for those active or interested in the field. A number of useful medical geology books have been produced in the past few years including: Geology and Health 2003, edited by Skinner and Berger; Essentials of Medical Geology, 2005, edited by Selinus *et al.* (note: a new edition will be published in late 2012); Introduction to Medical Geology, 2009, by Dissanayake and Chandrajith; and Medical Geology: A Regional Synthesis, 2010, edited by Selinus *et al.* that contains a chapter on medical geology issues in Mexico, Central America and the Caribbean (Armienta *et al*., 2010). Several local and regional organizations have been formed including the International Medical Geology Association (www.medicalgeology.org) which, presently, has a regional chapter in Mexico and the Geological Society of America's Geology and Health Division (http://rock.geosociety.org/GeoHealth/index.html). In addition, it is important to mention that more than 5,000 people have attended the 50 Medical Geology short courses presented in more than 30 countries. In Mexico, courses in this series were presented in Piedras Negras (1995) and Mexico City (1997). Medical Geology short courses were also given in San Luis Potosi (2007) and, most recently (2011 and 2013), at the Universidad Autónoma de Chihuahua.

In this paper, we provide examples of the recent and ongoing medical geology research in Mexico. We hope that these examples will adequately demonstrate the significance of medical geology health issues and illustrate the opportunities that exist for students and researchers to engage in the growing field of medical geology.

Examples of Medical Geology Studies in México (Figure 1)

Arsenic (As) and fluorine (F) are important elements in México from the perspective of medical geology. Their health impacts have resulted mainly from drinking of naturally contaminated groundwater. High fluoride groundwater concentrations have been detected in many areas of the country; many of them coincide with arsenic contaminated zones. Estupiñán-Day *et al.* (2005) considered that about 4 million people live in natural fluoride-rich zones and are at risk from dental and skeletal fluorosis (Figure 2). This is particularly important since groundwater is the main drinking water source in México especially in the Northern part where arid and semiarid ecosystems are common. Indeed, endemic fluorosis was considered as an unrecognized environmental health problem in México in 1997 (Díaz-Barriga *et al*., 1997). A meeting of the National Commission of Water and the Ministry of Health of Mexico (Comisión Nacional del Agua, Secretaría de Salud), the Panamerican Health Organization, and the U. S. Center for Disease Control and Prevention was held in 2004 to deal with fluoride occurrence and fluorosis in México and recommend alternatives to protect the population. The states of Aguascalientes, Sonora, Zacatecas, San Luis Potosí, Baja California and Durango were identified as having the highest prevalence of fluorosis. A review on dental fluorosis in México was written by Soto-Rojas *et al.* (2004). One of the measures to diminish the population exposure was to prohibit selling fluoridated salt (the salt type offered regularly throughout the country) in fluoride-enriched areas.

Arsenic-related health problems due to ingestion of arsenic-rich water were first identified around 1958 in the Comarca Lagunera region, in northern México; about 400,000 people were considered at risk at that time. Various As-enriched groundwater zones have been identified since then, in different parts of the country. Studies have been conducted to assess As concentrations, distribution, and, most recently, As sources. Natural arsenic presence in groundwater has been mainly related to its release from As-bearing minerals, geothermal processes, water interaction with volcanic rocks, clays and Fe-oxyhydroxides as well as evaporation (Armienta and Segovia, 2008). Epidemiological studies to determine the actual effects of chronic As ingestion have also been carried out in some of those areas. These effects include hyperkeratosis, hyper and hypopigmentation, and blackfoot disease (Figure 2). Examples of these studies are included below. Arsenic presence (up to 0.12 mg L^{-1}) in groundwater has been ascribed to sulfide oxidation (Mahlknecht *et al*., 2004) and volcanic rocks dissolution in the fractured aquifer (Ortega-Guerrero, 2009).

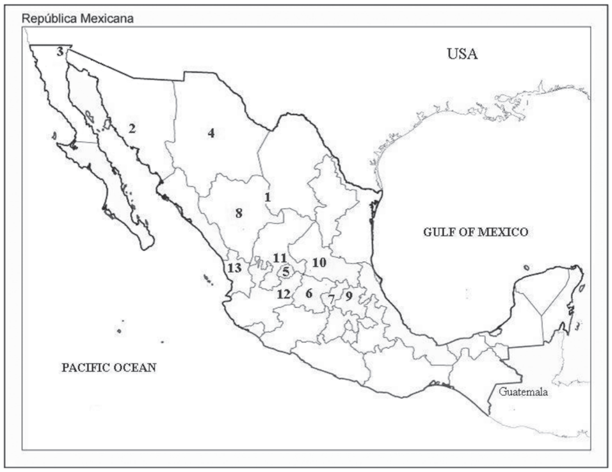


Figure 1. Location of studied zones. 1) Comarca Lagunera, 2) Hermosillo, Sonora 3) Mexicali, Baja California, 4) Chihuahua, Chihuahua, 5) Aguascalientes, Aguascalientes, 6) Acámbaro, Guanajuato, 7) Tequisquiapan, Qurétaro, 8) Guadiana Valley, Durango, 9) Zimapán, Hidalgo, 10) San Luis Potosí, San Luis Potosí, 11) San Ramón, Zacatecas.

Distribution of Medical Geology Problems in Northern México

One of the most studied zones of the country in the field of medical geology has been the Comarca Lagunera (Figure 1). In this zone, which includes the southwest part of Coahuila and the northeast part of Durango states, health problems such as kerathosis, skin pigmentation and black foot disease resulting from chronic As intake were detected in 1958 (Cebrian *et al.*, 1994). Groundwater containing up to 0.718 mg L^{-1} was identified as the source of exposure (Del Razo *et al.*, 1990; Rosas *et al.*,1999; Molina, 2004). The Mexican drinking water standard for arsenic is 0.025 mg L^{-1} (NOM-127-SSA1-1994, 2000). Several research projects in this area have been conducted to unravel the As origin in groundwater, including geological, hydrogeological, and geochemical aspects together with hydrogeological and geochemical modeling. According to those studies As originated from one or several of the following processes: hydrothermal activity, desorption from clays, dissolution and desorption from Fe and Mn oxides, evaporation, and oxidation of sulfides (González-Hita *et al.*, 1991; Ortega-Guerrero, 2003; Molina, 2004; Gutiérrez-Ojeda, 2009). Ingestion of As consumption through cooked food was also revealed as an important source of the contaminant to the inhabitants in the Comarca Lagunera area (Del Razo *et al*., 2002). Research has also been conducted to relate As exposure with health. Del Razo *et al.* (1997) found relationship between As speciation in urine and signs of dermatological affectations. Gonsebatt *et al.* (1997) observed a significant increase in micronuclei of urinary and oral epithelial cells of exposed people as well as an increase in the frequency of chromatide deletions, isochromatides in lymphocytes. Coronado-González *et al.* (2007) detected a relation between diabetes and total As concentrations in urine. Rosales-Castillo *et al*. (2004) found an increase of cancer incidence with As exposure (Armienta *et al*., 2010; Camacho *et al*., 2011).

The presence of high concentrations of fluoride (up to 3.7 mg L^{-1}) in groundwater in As contaminated areas has also been reported at Comarca Lagunera (Del Razo *et al.*,1993).

Figure 2. Fluorosis evidence in a Mexican patient.

In Sonora (Figure 1) studies of arsenic and fluoride in groundwater and population health have also been carried out. Up to 0.305 mg L^{-1} As was measured in wells and storage tanks in 1990; however, concentrations decreased afterwards due to dilution with uncontaminated water (Wyatt *et al*., 1988a). Bearing in mind the absence of possible anthropogenic sources of As, its presence was considered to result from natural processes. Analyses of urine in exposed population at the town of Esperanza in Sonora showed a geometric mean of 65.1 mg L^{-1} As corresponding to a mean As intake of 65.5 mg day^{-1}. A positive correlation between As in urine, As intake and As in water was also found in Hermosillo, Sonora (Wyatt *et al*., 1998b; Meza *et al*., 2004). Besides, at Hermosillo, As concentrations in groundwater correlated with those of fluoride (Wyatt *et al*.,1998b).

Fluoride, from 1.5 to 5.67 mg L^{-1} was reported in groundwater of the Guadiana valley in Durango. Nearly 95% of the population was considered to be exposed to concentrations above 2.0 mg L^{-1} which is higher than the Mexican drinking water standard of 1.5 mg L^{-1} (NOM-127-SSA1-1994, 2000). These people exhibited dental fluorosis and increased bone fractures and children showed a positive correlation between dental fluorosis and fluoride in drinking water (Ortiz *et al*.,1998; Alarcón-Herrera *et al*., 2001)

Radon is another natural health threat causing increased lung cancer risk and linked to alpha radiation exposure from radon in air. High radon concentrations may occur in certain geologic environments. Radon-in-soil levels up to 500 kBq m^{-3} were measured in a uranium-rich zone in Sonora (Segovia *et al*., 2007; Armienta *et al*., 2010). Reyna-Carranza and López-Badilla (2002) determined indoor radon concentrations in 95 houses of Baja California (Figure 1). They found a higher number of deaths in neighbourhoods without pavement in comparison to those paved, as well as a higher number of women deaths relative to men. These researchers explain their results due to the longer time spent in the home by women. Radon concentrations were also higher at homes where a lung cancer death had occurred.

In Chihuahua, arsenic levels from 0.006 to 0.474 mg L^{-1} in 35 sampled locations were measured in 2004 (Junta Central de Agua y

Saneamiento, 2006). In addition to other health problems that have been identified and studied in this State.

Central México

In Aguascalientes (Figure 1), estimation of cancer risk due to ingestion of As in water (average 0.0145 mg L^{-1}) was 9.5 cases per 100,000 inhabitants for the lower water As content, and 1.63 cases per 1000 inhabitants for the highest As concentration (Trejo-Vázquez and Bonilla-Petriciolet, 2002). Fluoride (up to 4 mg L^{-1}) in water supply produced from groundwater interaction with igneous rocks was reported by Rodríguez *et al*. (1997).

In Guanajuato (Figure 1), various studies attempting to explain the occurrence and health affectations of arsenic have been carried out. Arsenic was present in drinking water wells (CODEREG, 2000; ESF, 2006; Rodríguez *et al*., 2006; Martínez-García, 2007; Armienta *et al*., 2010). Fluoride is also present in Guanajuato. Dental fluorosis was observed in Irapuato and Salamanca where groundwater fluoride concentrations varied from 1 to 3 mg L^{-1} (Ovalle, 1996; Rodríguez *et al*., 2000, 2006). Occurrence of fluorosis has also been reported in other cities within Guanajuato (Fragoso *et al*., 1997; Armienta *et al*., 2010). In the Independence aquifer in northeast Guanajuato up to 16 mg L^{-1} of fluoride were measured and related to the presence of acid volcanic rocks (Mahlknecht *et al*., 2004). Dental fluorosis resulting from tainted water ingestion was also reported in Querétaro (Sánchez-García *et al*., 2004).

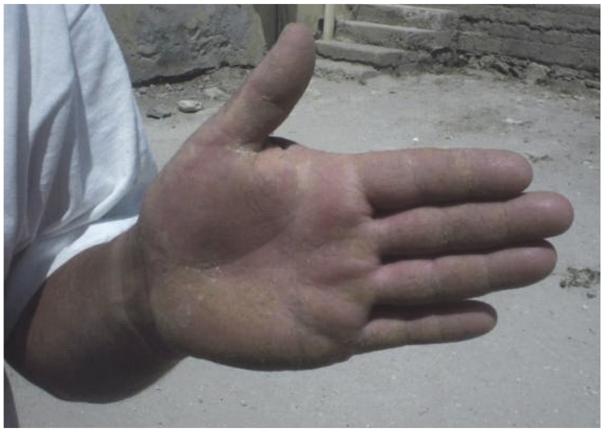
Mineralization is an important source of fluoride and arsenic in Mexican groundwater. Medical geology studies have been conducted for many years at the mining zone of Zimapán, in Hidalgo (Figure 1) to determine concentrations, distribution and origin of As in groundwater and related health effects. Arsenic presence has mainly been linked to dissolution of arsenic minerals, mainly arsenopyrite which is widely distributed in the mineralized zones of the limestone aquifer (Armienta *et al*., 1997a, 2001; Sracek *et al*., 2010). Contaminated water flows through fractures, and As concentration is influenced by rainy periods (Rodríguez *et al*., 2004). Health effects due to As exposure observed in this area, include dermatological affectations (hyper- and hypo-pigmentation, hyperkerathosis), and increment of transforming growth factor alpha (TGF-α) levels in bladder urothelial cells (Armienta *et al*., 1997b; Resendiz and Zúñiga, 2003; Valenzuela *et al*., 2007).

For many years drinking water for Zimapán was only supplied from this contaminated limestone aquifer. At present, As levels have decreased as a result of mixing with low-As water delivered from another area and the instalation of a treatment plant to remove As. However, as is commonly found at other historical mining zones, wastes from ore processing polluted shallow wells that fortunately are not used as drinking water sources.

The adverse influence of mining residues on health was investigated in San Luis Potosí where high concentrations of Pb and As were measured in water, soils and sediments (Castro-Larragoitia *et al*., 1997, Razo *et al*., 2004). Children showed increased DNA damage (Yáñez *et al*., 2003) after. Bioaccessible concentrations of As and Pb also showed they were exposed to concentrations above the maximum criteria (Gamiño and Monroy, 2009).

In San Luis Potosí (Figure 1), widespread fluorosis from groundwater tainted intake has been known for decades. Various studies to determine the source and geochemical processes responsible for concentrations above drinking water standards have been conducted for many years (Carrillo and Armienta, 1989; Carrillo-Rivera *et al*.,1996, 2002). Fluoride is released from the deep volcanic aquifer and transported through fractures in the regional groundwater flow. Health studies showed a correlation between dental fluorosis and drinking water fluoride concentrations in this state and in Aguascalientes (Trejo-Vázquez and Bonilla-Petriciolet, 2002). Children showed neuro-toxicological effects as a result of enriched fluoride water intake (Estupiñán-Day *et al*., 2005). Groundwater contamination by As in Zacatecas (Figure 1) was also reported with levels up to 0.5 mg L^{-1} (Leal-Ascencio and Gelover-Santiago 2006; Armienta *et al*., 2010).

Figure 3. Hyperkeratosis from ingestion of As-polluted water.



Western México

Fluoride (up to 17.77 mg L^{-1}) has been measured in Jalisco (Figure 1). Geothermal processes may be linked with its presence. In addition, arsenic is also higher than the drinking water standard in this area with up to 0.263 mg L^{-1}. Fluoride concentrations represent a potential risk of dental and skeletal fluorosis. Furthermore, skin diseases, gastrointestinal effects, neurological damage, cardiovascular problems, and hematological effects constitute potential health effects from chronic arsenic exposure (Hurtado-Jiménez and Gardea-Torresdey, 2005, 2006).

In Nayarit mean concentrations of arsenic in drinking water provided from three wells were below Mexican standards (0.025 mg L^{-1}) but above WHO limits (0.010 mg L^{-1}) (Mora-Bueno *et al*., 2012).

Medical Geology issues in Chihuahua

The state of Chihuahua is the largest state in Mexico and has three main geological environments. The mountain areas known as the Tarahumara region is located in the western part having elevations ranging from 2,000 to 2,400 meters above sea level (masl) and with mainly settlements of rural villages. The central part of the state is characterized by rangeland valleys known as Chihuahua´s great plains, with elevations from 1,500 to 2,000 masl. This area is dominated by short grass communities where most human settlement can be observed. Lastly, the eastern area is characterized by an arid environment where the precipitation is below 200 mm per year presenting shrub land communities and elevations from 850 to 1,500 masl. Each of these three main environments in the State of Chihuahua exhibits contrasting geology and human health issues that we highlight in this review. It is important to point out that groundwater is the main hydrological resource for drinking water supply.

Chihuahua´s Natural Resources-Water

The most important watershed in the State is associated with the Conchos River which is the main river about 560 km in length. This river originates in the municipality of Bocoyna which is located in the upper part of the Tarahumara region, flows through Chihuahua´s great plains, and joins the Rio Grande/Rio Bravo in a very arid zone. It is important to point out that the Conchos River is the major tributary of the Rio Grande/Rio Bravo and there has been evidence that the water in the upper part of the river is uncontaminated (Rubio *et al*., 2004). In contrast, there is strong support of water contamination, to different degree, in the central part (Gutiérrez and Borrego, 1999; Gutiérrez *et al*., 2008; Rubio-Arias *et al*., 2011) as well as in the lower part of the river before joining the Rio Bravo-Rio Grande (Holguín *et al*., 2006; Rubio-Arias *et al*., 2012) that represents a potential health risk for local residents. Other aquatic ecosystems in the state have been detected as contaminated such as the Laguna de Bustillos (Rubio *et al*., 2004), which in turn, is negatively affecting range and crop land (Rubio *et al*., 2006).

It is well confirmed that aquifers can become contaminated from different elements leaching from urban and rural wastewater (Squillace *et* *al*., 2002) or could contain higher levels of potentially toxic trace elements because of natural cycling. Espino *et al.* (2007) reported that drinking water samples from wells in the central part of the state exceeded the level of 10 mg L^{-1} N-NO_3, established by NOM-127-SSA1-1997 (2000) This study is important when it is observed that in the central part of the state there are many human settlements that depends 100% on the water coming from wells and where less than 50% of the localities have a demineralization treatment system (JCAS, 2006). High levels of nitrate in drinking water have been associated with different diseases (Gulis *et al*., 2002; Volkner *et al*., 2005) and in particular with the blue baby syndrome. The Chihuahua´s nitrate problem has also been detected in the north (Martinez-Rodriguez *et al*., 2006) as well in the south where Rubio *et al.* (2004) noted level of nitrate as high as 10.53 mg L^{-1} in surface water of the Florido River which is a tributary of the Conchos River.

The presence of arsenic in water through natural and anthropogenic sources represents another important issue in Chihuahua. Camacho *et al.* (2011) detected high As concentrations in groundwater while Rubio *et al.* (2004) presented data on high levels of this metalloid in surface water of the Conchos River. At present, there is no information about water consumption patterns in Mexico, nor in Chihuahua, and the local communities or owners of private wells are not required to control the As level, or even other contaminants, from their drinking and cooking water. This is important when it is considered that Chihuahua has about 13,000 wells in the State and some of them are utilized for the families in different activities (CFE, 2011).

Volcanic rocks and lacustrine sediments were proposed as sources of groundwater As in different zones of Chihuahua (Reyes Cortés *et al.*, 2006a, 2006b; Mahlknecht *et al.*, 2008). In the Delicias–Meoqui and Jimenez–Camargo aquifers 50% of the wells were reported with As concentrations higher than 0.05 mg L^{-1} (Camacho *et al.,* 2011). Arsenic has been related to arsenopyrite, ascendant geothermal flow, and high evaporation. Reverse osmosis is currently used to remove As and other toxic elements in Chihuahua (Espino-Valdés *et al*., 2009; Camacho *et al.,* 2011). In fact, about 88 small reverse osmosis treatment plants, partially paid by the consumers were reported to be in operation in 2006 (Calderón-Fernández, 2006).

There are 50 uraniferous areas in the state of Chihuahua; the most important is Sierra Blanca which contains about 60% of Mexico´s uranium reserves (Villalba *et al*., 2011). In fact, about 30 years ago there was established a uranium milling process causing a significant natural hazard. Villalba *et al.* (2011) reported high levels of uranium in water samples with levels in a range of 0.38 to 1.39 Bq L^{-1}. These concentrations are above the maximum levels established for the U.S. Environmental Protection Agency (EPA) which specify a maximum level of 0.78 Bq L^{-1}. In addition, these researchers found high levels of radio and radon in the water samples of the communities of Aldama and the city of Chihuahua which is higher than those values reported in the EPA levels. In Aldama levels of radon in indoor air samples were reported in a range from 29 to 422 Bq m^{-3} (Colmenero *et al*., 2004) which are higher than values established in international norms. The authors estimated an annual effective dose of 3.0 mSv which is higher than the average international norms of 1.2 mSv.

Final Remarks

Different alternatives have been given to Medical Geology problems in some areas of México. Mixing of poor quality water with good quality water has been a widespread option to decrease the contaminant levels. Highly polluted wells have been closed and substituted by safe-water wells or surface water in some places. Household filters were distributed in some As polluted areas. Studies have been carried out to develop new affordable treatment methods. These treatment developments, which offer a promising option to remove As and other contaminants, deserve a special review.

However, many problems are still waiting for solutions. Much is still to be done in México; regular analyses of the most common contaminants: fluoride and arsenic, must be done in every drinking water source. Laboratories must be provided with the adequate analytical equipment to perform these determinations nationwide. Treatment systems must be installed in every place where the presence of arsenic and fluoride concentrations are higher than drinking water standards. Affordable and environmental-sustainable methods suitable for every contaminated location should be promoted by joining efforts between researchers and authorities. Maintenance of current treatment systems (household or municipal) must always be included as a priority in municipal expense programs and supported by all authority levels. Overall, population health must be placed in the first in priority of national and local authorities.

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