

Geology-Improving Inputs and Outputs

Antonio Polo Sánchez^{1,3,*} and Christian Schaffalitzky de Muckadell^{2,3,*}

¹Université Clermont-Auvergne, Clermont-Ferrand, 63000, France

²Eurasia Mining, Dublin, Ireland

*polosanchezantonio@gmail.com

*cschaffalitzky@icloud.com

³EFG Mentoring Programme, Rue Jenner 13, B-1000 Brussels, eurogeologists.eu

ABSTRACT

I am a geology student doing a master in volcanology in Clermont-Ferrand. Christian is the Executive Chairman of Eurasia Mining plc, an experienced geologist and my mentor. We have decided to write together this abstract as part of our cooperation under the European Federation of Geologists (EFG) Mentoring Programme, a European programme designed to provide help to students or young professionals (mentees) by experienced geologists (mentors). Nowadays, geology has a big “social” problem. Starting in the field of education, the science of geology is less not taught well, so that society learns less about geology and its important role in daily life. For example, we can see on the news many people suffering because of natural phenomena such as volcanic eruptions (e.g. Fuego in Guatemala, Kilauea in Hawaii), landslides or floodings (e.g. Malawi, East Tyrol (Austria)), which could have been minimised or even prevented if society was more aware of the pivotal contribution that the geosciences can provide for such problems. However, we cannot solve this problem, until we have solved our “internal problems”. First of all, Geology has further to evolve, in the manner that Physics did from Classical Physics of Newton to Quantum Physics. Modern geology has only begun to use the ‘Plate Tectonics’ theory and needs more time to evolve and find its “quantum theory”. Our science has been “distracted” by the rest of “earth sciences” which is less interested in pure geological research to improve learning. Consequently our community understands the framework of our science very well, but we have not been able to improve key factors, such as predictability or more precise modelling. The more we are specialised, the less we know about the other geological disciplines. If we want to contribute to this evolution, all disciplines must work together. As many say “the best geologists have seen the most rocks”. Secondly, geology is suffering from a subtle degradation of science education, allowing poor science to be accepted as true by the media. No-one wants to see the policing of science but it is a daily occurrence that emotional issues take precedence over data-driven facts. We have a role to ensure that our own scientific opinions are clear and not subject to the whims of fashionable thought. Once this has been solved, we should be able to transmit more effectively the key role of geosciences in daily life. An obvious start is transmitting geology to those that love the countryside such as artists, walkers, mountain climbers or landscapers, those who appreciate nature and already have wide perspectives on their environment. Geology can help to improve those qualities. If we also use our research to help the economic and social development of an area, we will have advanced our role in optimising the tasks. Combining geological knowledge with other disciplines of science can also help society, e.g. the International Medical Geology Association (IMGA), a good example of applying our expertise to enhance mutually beneficial solutions. During our EFG cooperation, we had the opportunity to get to know H2020, an EU programme destined to improve scientific research and share knowledge between scientists. This project, as well as IMGA, are examples of structures in which geosciences are can be applied to advance sustainable development. Attending the Geoscience and Society Summit will allow us to explain in detail our experience with H2020, our ideas of effective transmission of geosciences to society, as well as learn from other submissions that undoubtedly will help to understand the challenges of our modern society.

Key words: Education, Natural Disasters, Scientific Revolution, Plate Tectonics, Medical Geology.

Introduction

This article represents part of our cooperation under the first edition of the EFG (European Federation of Geologists) Mentoring programme. The aim of this programme is to support students or non-experienced geologists (Antonio) in order to facilitate their entrance into the labour market, as well as to help them to grow their informal networks at an international level. This support is made by more experienced geoscientists (Christian) over a period of 9 months. The cooperation is also coordinated by the EFG office, located in Brussels.

During our cooperation, EFG presented the ‘*Geoscience and Society*’ Challenge. As winners of this challenge, we were allowed to assist the *Horizon Geoscience* dinner debate which was held in Brussels on 26th September 2018. During this debate, we participated in discussing the key role that geosciences have in society and to share some ideas with other professionals. Here we develop all the ideas we have shared in that debate. We invite everyone to share his/her opinion with us.

Nowadays, geology has serious problems. The poor understanding of this scientific discipline has evolved into a loss of knowledge by society, and to make it worse, its important role in daily life. This loss is the main cause of different social and economical disasters associated with natural phenomena such as volcanism or landslides, that could have been avoided if society was more aware about the pivotal role geosciences can play to face these kind of problems. Here we present some of those problems and possible ways of solution.

Problems

Education

In Education, geology is usually taught with Biology but increasingly with diminished emphasis. In 90 per cent of cases, the teacher is a biologist, so geology is not well-taught. Recently, different governments, for example the Spanish government, are considering removing the subject of geology from the official curriculum. This is a **dangerous sign** as it highlights how poorly politicians understand the crucial role of geosciences in daily life. This can result in errors that lead to catastrophic events (e.g. the government of Guatemala could not handle the human disaster during the Fuego eruption that took place last June 2018). However, this problem is not recent.

In the case of Spain, during the early 90's, geology started to disappear as an independent science subject and became diluted in the field of "experimental sciences" (Brusi i Belmonte et al, 1993). At that time, only people related to geology teaching or geology professionals worried about this, some of them resigned, others criticised the government and others proposed the subject of 'Earth Sciences' as a solution (This subject combined 'Environmental Sciences' with 'Geology'). This phenomenon was in part due to the exponential growth of scientific knowledge that looked at all sciences from a multidisciplinary point of view.

In the early 90's, in primary education (schools), earth sciences were established in the area of Natural and Social Environment (Brusi i Belmonte et al, 1993). In this area, there were many disciplines and it was usually focused on biology, climatology or ecology. Teaching geological concepts relied on each education centre's policies and individual teacher's determination (Brusi i Belmonte et al, 1993). In obligatory secondary education (The first four years in high school), geology was covered in the Natural Sciences area with biology, physics and chemistry. Educational policies stated that this area should be taught following the axis of "the study of matter and energy in living beings and in inert materials" without making any reference to science disciplines (Brusi i Belmonte et al, 1993). Moreover, the topics related to geology were the last ones and they represented (at most) around 25 per cent of the complete programme. Sometimes, some geological concepts appeared in social sciences, related to geography, but it depended on the teacher's determination (Brusi i Belmonte et al, 1993).

In baccalaureate (The last two years of high school), geology was only taught in geography and geology subjects (Brusi i Belmonte et al, 1993). Some geological concepts might appear in other subjects, but again, it depended on the teacher's determination and the educational centre policies. Furthermore, inside the subject of geology, some geological disciplines such as paleontology or historical geology were hardly taught at all (Brusi i Belmonte et al, 1993).

As we see, geology teaching depended on educational policies and teacher determination. This determination is strongly influenced by educational policies. The new policies made in Teaching diplomas, where the discipline of sciences completely disappeared, led to a lack of scientific (and geological) knowledge by the new teachers and consequently, they do not have enough determination to give scientific lessons (Brusi i Belmonte et al, 1993), especially in primary education.

Here we are talking of policies that were put in place during the 1990's. New policies made since then have given the same result or have aggravated these phenomena, leading in some cases to the complete disappearance of geology teaching. Furthermore, geology is suffering from the subtle degradation of science education, allowing poor science to be accepted as true by the media. No one wants to see the policing of science but it is a daily occurrence that emotional issues take precedence over data-driven facts. Our collective has a role to ensure that our own scientific opinions are clear and not subject to the whims of fashionable thought, as well as make politicians understand that current educational policies are "killing" geology.

As an example of the trivialization of geological understanding, a recent (peer-reviewed) paper makes statements which are a merger of science and, among other surprises, gender politics (Carey et al., 2016). One statement from the abstract catches the themes: "Merging feminist postcolonial science studies and feminist political ecology, the feminist glaciology framework generates robust analysis of gender, power, and epistemologies in dynamic social-ecological systems, thereby leading to more just and equitable science and human-ice interactions.

Apart from teachers and policies, geology courses have been "dumbed down". Students think that geosciences are too difficult and that it is not worth the risk to take as a course. Consequently, most students decide to choose "easier" subjects, causing the closure of the subject. In order to solve this, the solution is not making the subject easier, but encourage the students by teaching them that life is not easy and that the effort they make now, will be well rewarded in the future.

A final example of a problem that will face the supply of raw materials in the future is the diminishing role field work plays in geological education. Students today do formal field work but do not work on their own. This is due to health and safety concerns at the schools and universities for the individual student. While well meant, the disadvantage is that independent

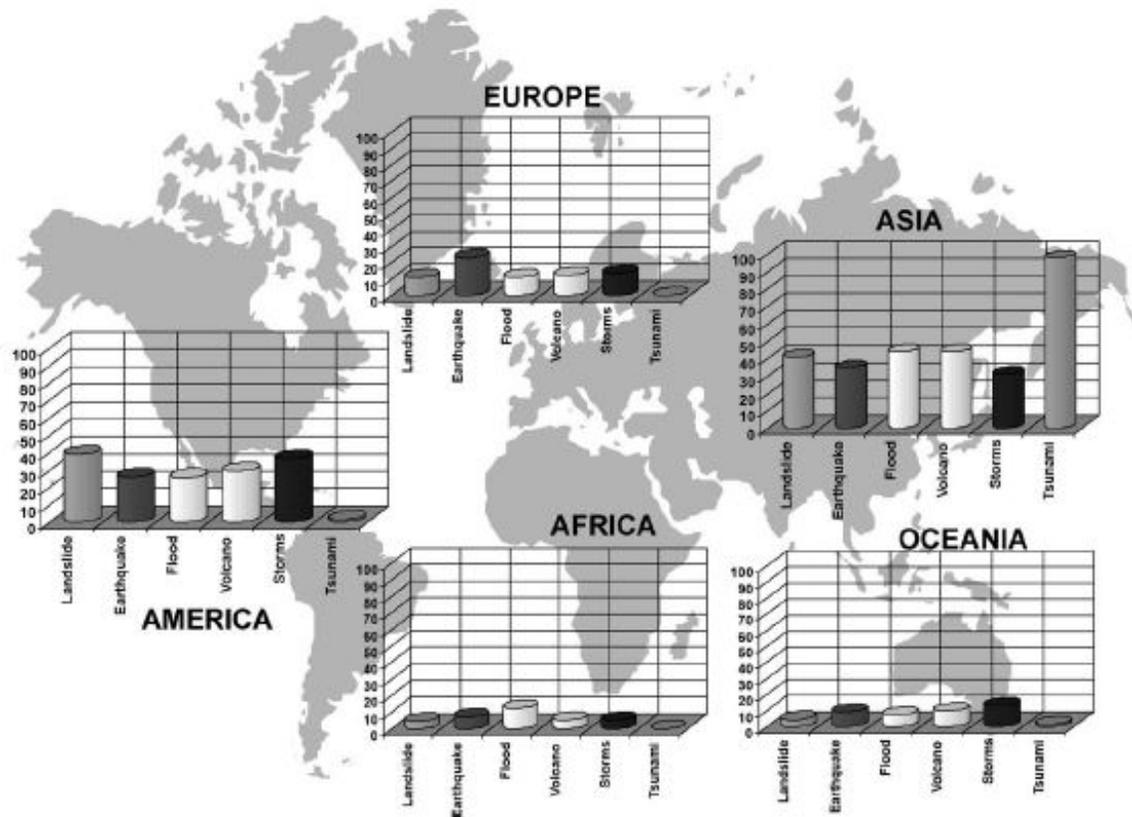


Figure 1. Distribution of natural disasters all around the world (Alcantara Ayala, 2002)

management learnt by working in the field on your own leads to important non-geological experience which is essential when starting work in, for example, mineral exploration. Training of staff for field management is going to be essential as in-work training in the future, delaying programmes. There is also the danger that students will not be prepared for this life, having never experienced it in their training.

Natural Hazards

Geophysical events such as earthquakes, volcanic eruptions or landslides existed long before human appearance. The concept of ‘natural disaster’ appeared simultaneously with human evolution and its socioeconomic system. Natural disaster involves these geophysical events and the socioeconomic network developed through history, as well as the vulnerabilities associated to them (Alcantara Ayala, 2002).

The impact of those phenomena depends on two main factors: The geological setting and the historic and economic development of the location. Unfortunately, the impact of geophysical events are greater in developing countries because of their location in sectors often affected by seismicity, flooding or volcanism (geological setting); and because of their weak economic and social development (historical development) aggravating the ability to respond to such events (Alcantara Ayala, 2002). Asian and South American countries are the most affected by volcanic activity (they are situated in the Circumpacific Volcanic Belt) or landslides (they are situated in sectors where hurricanes or tropical storms often take place) (Figure 1). Furthermore, these continents are located in high susceptibility seismic areas (Alcantara Ayala, 2002).

Natural disasters take place at a certain place in a short period of time. However, their formation is not instantaneous, they are the result of the evolution of different factors. For example, atmospheric perturbations lead to tropical storms that lead in floods (Alcantara Ayala, 2002). Geomorphology plays a crucial rule in prevention of these disasters. Here we present some cases associated particularly to volcanism and landslides/floods we consider interesting to highlight the importance of geology facing these problems.

Volcanism

Different volcanic phenomena (lava flows, ash particles, lahars) may create dangers for the population that live nearby, these dangers on the inhabitants and the economy of the area can be reduced with a good survey system. Unfortunately, some

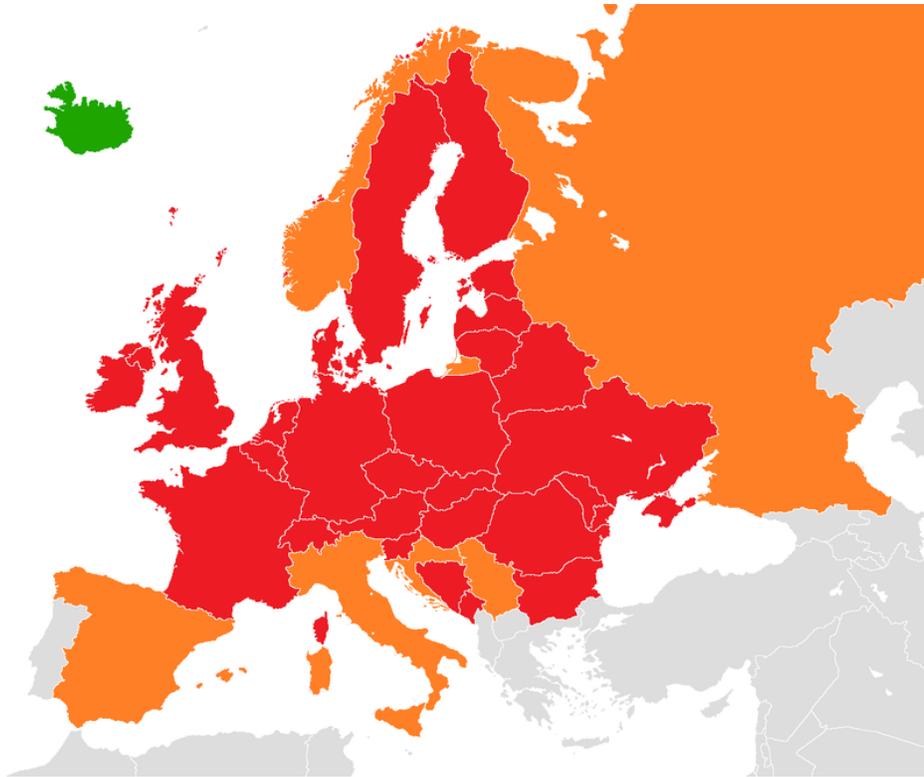


Figure 2. Air space in Europe during Eyjafjallajökull in 2010. Red: Completely Closed. Orange: Partially Closed. Author: DeltaFalcon, Wikipedia (For public use)

important volcanoes do not have a monitoring programme network. Here we present some interesting examples of volcanic activity and their socioeconomical impact.

Eyjafjallajökull (Iceland)

In 2010, the eruption of **Eyjafjallajökull** (Iceland) caused the massive closure of the European air space due to the ash particles emitted by the volcano (Figure 2) since in this case, the particles were finer than usual (Mazzochi et al, 2010). On 17th April 2010, 17 EU members and 6 EU non-members closed completely their air space and 2 EU members closed it partially (Mazzochi et al, 2010) according to a protocol set earlier, based on the experience of a British Airways flight, in which the aircraft engine failed due to ash particles emitted by the Galunggung volcano (Indonesia) in the 1980's (Ellertsdottir, 2014). On 22nd April 2010, the air space was fully operation again (Mazzochi et al, 2010), but at that time, the economic damage was already enormous, not just because of the period of returning to normal flight operations but for the psychological effects on people. For example, tourists decide to cancel their flights and take alternative means of transport, other passengers also preferred alternative ways because of security (Mazzochi et al, 2010).

This closure caused an economic loss of **1500 million euros** (Around 0.1 per cent of GDP) in the European economies. The biggest markets affected were Britain, Germany and France (Mazzochi et al, 2010). The most affected sector was aviation, which suffered losses of circa 1.7 billion US dollars. British Airways and Air France reported losses of 20 million pounds per day (Mazzochi et al, 2010) (See Figure 3 for a more detailed economical description). Unfortunately, this impact expanded beyond European borders affecting imports from Africa with big losses, an example was the case of fruit exportation from Kenya, which suffered losses of some **3 million US dollars** with job losses for **5000 temporary workers**.

Fuego (Guatemala)

In June 2018, the **Fuego** stratovolcano (Guatemala) suddenly erupted, this volcano is characterised for having a strong explosive activity. Although the Geological Survey of Guatemala (INSIVUMEH) warned about a possible eruption. the authorities did not react to these warnings. This resulted in the displacement of **1.7 million people**, the death of hundreds of people and economic losses around **12.3 million US dollars**. Unfortunately, this is not the only case during Guatemala history.

Even during the Spanish colonial period similar disasters happened, for example, in 1541 the crater collapse of Agua caused the complete destruction of the city of Santiago de los Caballeros. This story is being repeating up to the present.

Estimated effects of the volcanic ash cloud on the airline industry (15–23 April 2010)		
Source	Outcome	
ACIEurope	313 airports	European airports totally disabled (75% of the European Airport Network)
IATA	100,000 flights	Flights cancelled within the EU, to/from the EU and overflying the EU
	19,000 flights	Peak of flights cancelled on 18 and 19 April
EUROCONTROL	10 million passengers 1.2 million passengers 24% (and 9% worldwide) passengers flow reduction	Estimated passengers unable to travel Average of scheduled passengers affected each day Reduction of the within-Europe and Europe-rest of the world passenger flows
Source	Economic impact	
IATA	US\$ 1.7 billion	Revenue loss for airlines during the period 15-21 April
IATA	US\$ 400 million	Per day revenue lost for airlines over the peak period (17–19 April)
AEA	€ 850 million	Loss for airlines including profitability, assistance to passengers, costs for stranded crew, parking and positioning of aircraft and other cost issues (for the period 15–23 April)
ERAA	€ 110 million	Estimated loss for members of ERAA
ELFAA	€ 202 million	Estimated loss for members of ELFAA
IACA	€ 310 million	Estimated loss for members of IACA
ACIEurope	€ 250 million	Overall European airports losses
IAHA	€ 200 million	Direct financial loss for independent handlers pertaining to the IAHA
ANSPs	€ 25 million	Loss per day for Air Traffic Management (ATM)
EC	61%	Fall in air traffic cargo between the scheduled flight per week in the EU-27
Notes: ACI: Airport Council International; IATA: International Air Transport Association; AEA: Association of European Airlines; EUROCONTROL: European Organisation for the Safety of Air Navigation; ERA: European Regions Airline Association; ELFAA: European Low-Fare Airlines Association; IACA: International Air Carrier Association; IAHA: International Aviation Handlers Association; ANSPs: Air Navigation Service Providers and EC: European Commission.		

Figure 3. Detailed economical losses in the aviation sector between 15-23 April 2010 (Mazzochi et al, 2010)

More recent cases are the destruction of El Palmar (Located next to Santa Maria/Santiaguito volcanic complex) in 1983 or the constant floodings of the Samala river that forced the migration of Santa Isabel community in January 2000 (Fuentes and Leon, 2009). The solution to all these cases was the forced displacement of people without any previous study or plan. Forced migration normally causes conflict between different Guatemalan communities (conflicts due to property disputes or land use for agriculture) and consequently, the members of the immigrant community normally return to their previous villages despite the natural hazard remaining. This phenomenon is a consequence of the lack of coordination and communication between the government of Guatemala and different institutions like CONRED (Coordinadora Nacional para la Reduccion de Desastres) or INSIVUMEH (Instituto Nacional de Sismología, Vulcanología, Meteorología e Hidrología). Usually, the advice given by these institutions (See Figures 4 and 5) is not taken into account by the government (Fuentes and Leon, 2009) and consequently, warnings about natural hazards are not transmitted to the local authorities and they do not know how to proceed when a disaster like a volcanic eruption takes place. Then, a forced migration without any planning is done as a belated attempt of a solution by the government. Fuego volcanic activity during June 2018 unfortunately represents, the most recent case of the same story.

Kilauea (USA)

In May 2018, the increasing activity of Kilauea (Hawaii), although it was well monitored, caused several losses of property on the island. Lava flows covered around 3.5 square kilometres, causing the destruction of 700 homes and an economical loss between **3 and 6 millions US dollars**. Lots of building companies have bought lands and built, in zones of very high risk. Even more, there has been constructions in zones invaded by lava flows from previous eruptions. Also, some particulars bought lands situated in high risk zones to sell them for construction and obtain a high benefit. The construction of permanent housing in these sectors should never have occurred, with the obvious (to a geologist) records and visual signs of significant volcanic activity. Cities and residential areas built in areas affected by Mauna Loa (Hawaii), have also the potential risk of being destroyed by volcanic activity because of this feature.

Landslides/Floods

Geomorphology plays a crucial rule in these phenomena, especially in tropical or montaineous areas, where there is a tendency to ignore geomorphological facts and build in unstable sectors resulting in a higher vulnerability of the regional socioeconomical system. In developing countries, where building criteria is poor, vulnerability is even higher. We present here some examples to

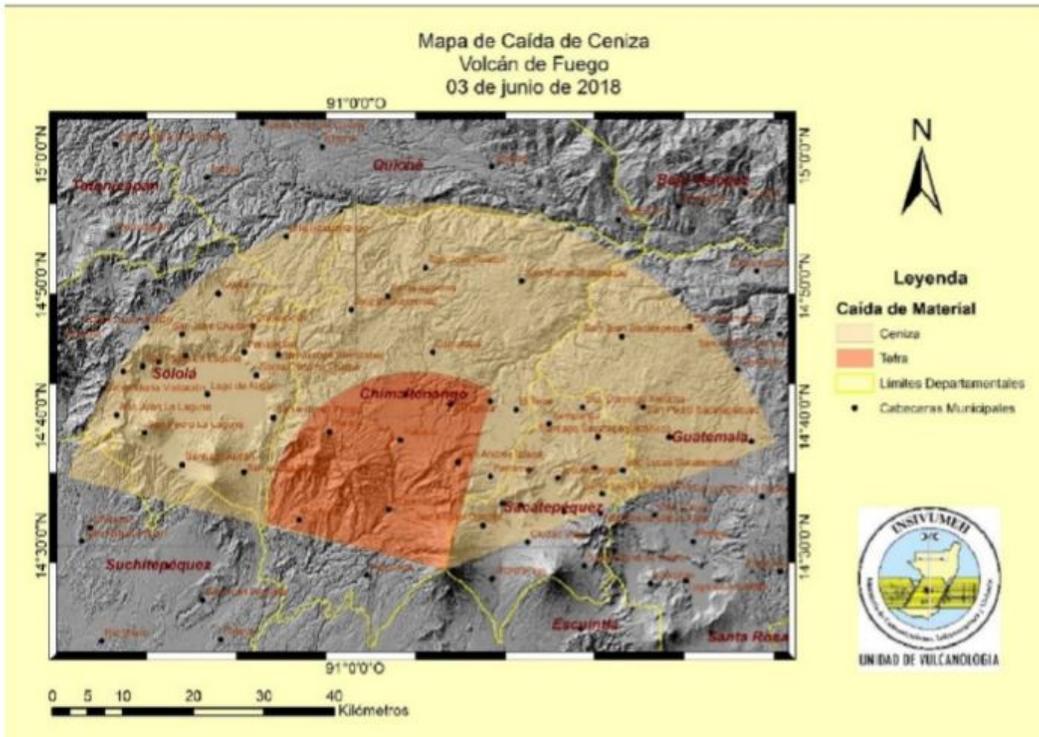


Figure 4. Ash distribution around Fuego stratovolcano on 3 June 2018 (INSIVUMEH)

Por lo anterior, el **INSIVUMEH** recomienda:

A la SE-CONRED: Tomar las precauciones ya que existe la posibilidad de que desciendan lahares fuertes en todas las barrancas principales y otros canales cercanos a estas. No se recomienda permanecer dentro o en las cercanías de las barrancas.

A LA DIRECCIÓN GENERAL DE CAMINOS Y COVIAL: Tomar las precauciones ya que los pasos vehiculares son afectados en las cercanías de las barrancas principales y en las rutas por donde descenden lahares.

Figure 5. Recommendations given by INSIVUMEH according to Fuego activity on 13 October 2018 (INSIVUMEH)

highlight the impact of ignoring geomorphological features.

Landslides associated with El Niño, e.g. the case of Malawi Flooding and Landslides associated with this meteorological phenomenon, are considered the most dangerous ones. El Niño can even affect countries not situated in the Pacific Ocean. As in Malawi, far from the Pacific, was affected by floods and landslides during the 90's and 2000's because of this meteorological phenomenon (Benson et al, 2004), affecting soils used for farming. Since agriculture represents 89 per cent of the national economy. Floods caused a strong impact on the agriculture and therefore on the Malawian economy (Benson et al, 2004), causing big famines during 1993/1994 and 2000/2001 (Benson et al, 2004).

Landslides in mountaineous regions, e.g. the case of Felbertauern (Austria). On May 2013, the landslide of Felbertauern (East-Tyrol, Austria) destroyed 100 metres of road which was the main artery for the region. The authorities considered finally building an alternative road after the total blockage for several weeks. The total economic impact was between 7.7 and 8.6 million euros in the tourism sector of the region, as well as a further 760,000 to 1.4 million euros in order to build the alternative road (Pfurtscheller and Genovese, 2013). This landslide caused a very serious impact especially in the region, where the economy was reduced by 0.6 to 0.8 per cent (Pfurtscheller and Genovese, 2013). However, if we compare with developed countries, this impact was only regional, whereas in the case of a developing country like Malawi it can have a serious impact on the national economy.

A geomorphological study, in which the study of past events, palaeofloods, geomorphology and flood hydrology are considered essential. This work combined with flood simulations, radar imagery and remote sensing is crucial, especially facing recurring events like El Niño (Alcantara Ayala, 2002). This highlights that geologists, especially geomorphologists, are the most qualified to prepare an effective prevention. But also, we note that a good geomorphological study needs the rest of geological disciplines.

As we can appreciate, natural hazards cannot be avoided, but the understanding of the processes and scientific methodologies to predict patterns of behavior of such processes can be a powerful tool in prevention measures (Alcantara Ayala, 2002). Furthermore, taking account of socioeconomic vulnerability will allow prevention measures to be applied more effectively. To reach this goal, we have the responsibility to make politicians aware of the crucial role of geosciences in such areas, so that they do not ignore warnings from their own experts in the future, mainly in developing countries, where those impacts cause many difficulties in the economical development.

Quantum Geology

However, we still cannot fully solve these problems until we have solved our “internal problems”. Geology has further to evolve, in the manner that Physics did from Classical Physics of Newton to Quantum Physics. Looking at the evolution of geology up to today and the Kuhnian concept of scientific revolution can help us to find the key towards "Quantum Geology".

The Kuhnian point of view

Thomas Kuhn, in his book *Structure of Scientific Revolution* (1962, 1970) tried to show the evolution of science through a series of stages using the evolution of physics and chemistry (OHara, 2018).

Starting by what he called immature sciences where several hypotheses (paradigms) existed, one of them would win as time went on. Entering then in the following stages (Ohara, 2018) (Figure 6):

1. Once the hypothesis has been accepted, scientists would start to show that this hypothesis is correct by collecting new data and making new experiments. Any alternative hypothesis is not considered at this stage. This stage is defined as normal science in which scientists are resolving the puzzle.
2. Doing these experiments, anomalies began to appear. However, perhaps by blaming faulty equipment and poor experimentation, they are ignored. Consequently, the first hypothesis remains intact and normal science stage continues. Eventually, new discoveries are made.
3. Anomalies continue appearing more and more until the point that they cannot be explained by the current hypothesis causes the modification of some aspects of it to accommodate the anomalies.
4. More anomalies appear causing a crisis, since the current hypothesis does not explain all the facts, it is no longer acceptable.
5. A new hypothesis is proposed as a solution to the crisis, causing the **scientific revolution**. At this stage, scientists adherents to the old hypothesis enter in conflict with the adherents of the new one (Incommensurability). The new hypothesis must have sufficiently unprecedented achievements and the potential to solve lots of new problems, so that it can be accepted by lots of scientists and have a chance to make a scientific revolution.

6. Once the conflict is solved, the stage of normal science resumes.

Kuhn gave the evolution from Newton physics to Einstein physics as an example of those stages. Looking at geosciences evolution throughout history we are able to appreciate such stages too (OHara, 2018).

Immature science would be geology prior to Lyell, when the debate was still between the scientific hypothesis and the biblical paradigm; and nobody was sure which paradigm was the correct one. Lyell's principles contributed towards the growth of the scientific hypothesis. Those principles, since they explained all the geological processes observed at that moment and were easy to understand, had a lot of supporters (OHara, 2018).

However, Lyell's hypotheses were a priori assumption and there was not enough data to confirm it (OHara, 2018) and the acceptance of those paradigms were made only by faith. Kuhn states that the conversion from an old hypothesis towards the new one can only be made by faith and not by force. In this case, the controversy of catastrophism versus uniformitarianism could have contributed to the rapid acceptance of Lyell's principles.

The building of the Phanerozoic geologic column according to Lyell's principles represents the normal science stage. The Phanerozoic geologic column was accomplished by a group of about ten geologists who worked independently of each other, but following the same principles and having a constant communication between them (OHara, 2018). Apart from a Kuhnian stage of evolution, this also shows, how cooperation helps progress. So, if all geological disciplines are used together ("**The bests geologists have seen the most rocks**"), normal stage of science as well as the Kuhnian crisis can be solved in an easier way (*Union makes the force*).

During this normal science stage, new discoveries were made (New lithological associations and fossils were found). However, anomalies began to appear, especially in tectonics, leading to a crisis that lasted for seventy years (OHara, 2018). Continental Drift was the first attempt to solve it and Plate Tectonics was the second, the latter being the current hypothesis that caused the **Scientific revolution in geology** (OHara, 2018).

The anomalies that led to this crisis were the inadequate criteria to explain several large-scale geological phenomena such as the origin of mountain belts, the nature of the ocean basins or the correlation of similar fossils and similar geologic formations found on different continents. The discovery of radioactivity, the theory of isostasy as an alternative to the contraction theory and the geosyncline concept made by James Hall were also new anomalies that contributed to the crisis of the current hypothesis until they were better understood (OHara, 2018).

The appearance of the Continental Drift paradigm, made by Alfred Wegener, represents the proposal of a new paradigm as a solution to the crisis. However, this hypothesis was mobilist, which was radical at that time (scientists still accepted the fixist principle of Lyell); and no mechanism to explain the theory was understood (The mantle was considered to be completely quiet). Consequently, it did not satisfy the Kuhnian criteria of solutions to a large variety of problems and thus, it did not have a lot of adherents. However, it caused a long debate until the 60's (OHara, 2018).

As experimentation techniques evolved enough to explain more precisely some facts of Continental Drift, as well as new techniques such as paleomagnetic studies, a second hypothesis emerged, **plate tectonics**. This hypothesis was widely accepted because it provided an accurate explanation for all the anomalies listed before. Since it was globally accepted, plate tectonics represents the stage of **scientific revolution** (OHara, 2018). The big acceptance of plate tectonics, minimized the incommensurability phenomena and the stage of normal science appeared again in a short period of time.

According to Kuhn, nowadays, we are in a normal science stage, but there are some aspects that could be anomalies and lead to a new a crisis. Some examples could be the explanation of the origin and the mechanisms of behavior of the "D" Layer (Core-Mantle Boundary), the understanding of the asthenosphere (which is still not very clear at the moment) or why some SLABS (Portion of a tectonic plate that is being subducted) sink deeper than others.

However, some philosophers of science do not share the Kuhnian evolution of science interpretation.

Alternative Interpretations

As, Kuhn's ideas were well accepted in the USA, philosophers and scientists from other countries did not. Even if the acceptance of plate tectonics seem a Kuhnian **scientific revolution** (Mareschal, 1987).

A good example of anti-Kuhnian philosophy is the interpretation by the British philosopher Imre Lakatos, which main objection against the Kuhnian model was that it did not consider the logical way of foundations of scientific theories and the logical reasons for their adoptions (Mareschal, 1987) (As Kuhn believed, the adoption was made by faith).

It used to be thought that scientific knowledge was either empirical or could be derived from empirical evidence; thus, science could grow by accretion or accumulation of new laws. The evolution of astronomy throughout history, shows that science is more than a compilation of experimental facts (Mareschal, 1987).

However, scientific theories have become more and more distant from direct evidence, causing that their logical foundations to be more difficult to establish. We can appreciate this in theoretical physics, as well as in geophysics, where "hard facts" are not the direct result of an experiment but of a complex thought process. For example, we cannot directly measure the age of the earth or the temperature of the core (Mareschal, 1987).

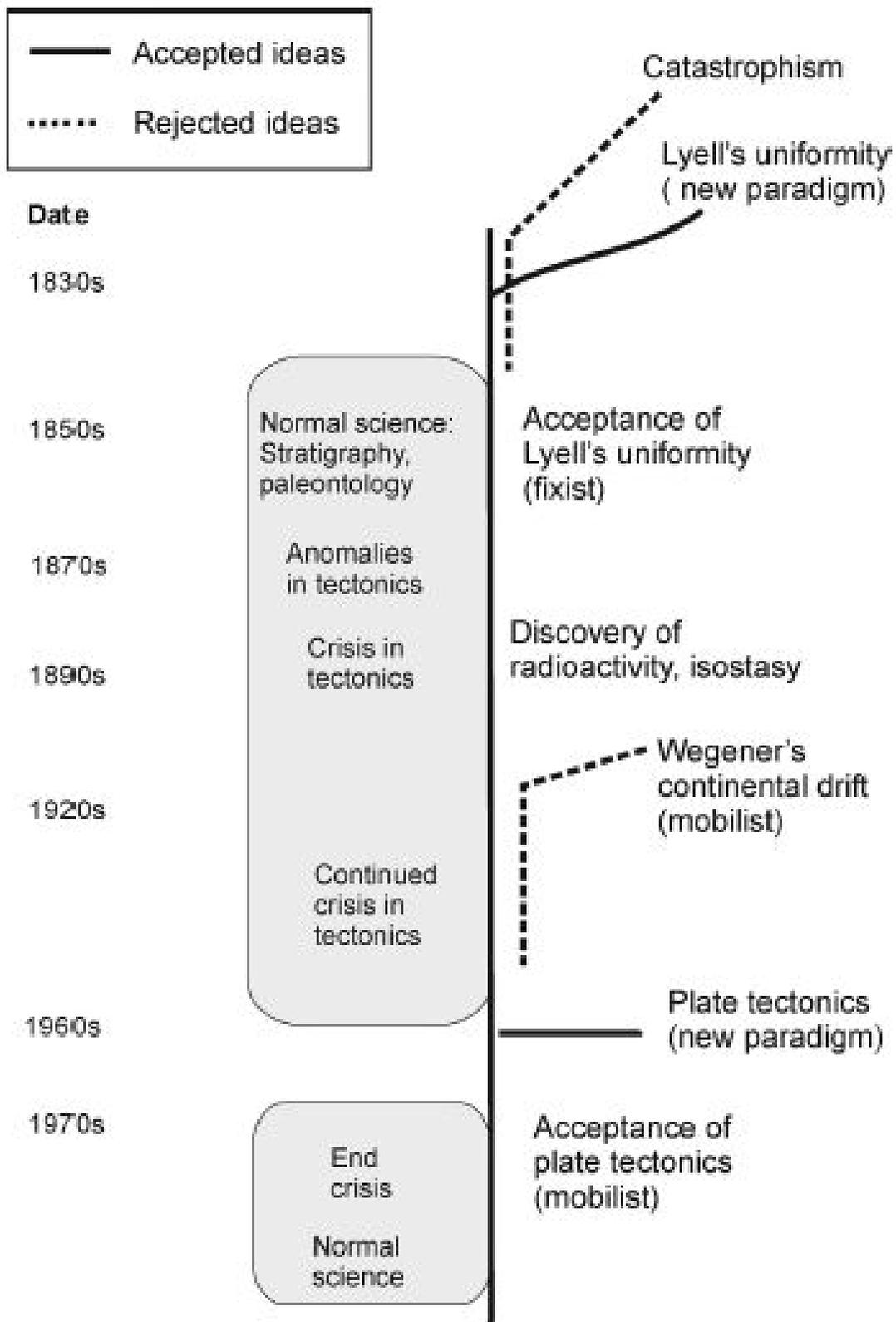


Figure 6. Evolution of Geology through the Kuhnian model (OHara, 2018)

An experiment or a set of experiments cannot prove a scientific theory (If they do so, scientific theories would not need to be revised or rejected). Even more, Karl Popper in 1959 demonstrated that experiments do not increase the probability of a theory's validity, but that they can disprove it (Negative experiments). Nevertheless, negative experiments only lead to a revision of some aspects of the theory and experimental conditions (Mareschal, 1987).

Popper proposed a methodology in this process. The revision of some aspects of a theory giving additional hypothesis represents scientific progress. So, instead of a discontinuous Kuhnian model, where we consider an only unchanging theory, Popper and Lakatos proposed an evolution of a series of theories that comes from a continuous methodology or logic of discovery, instead of a scientific revolution. According to them, a Kuhnian scientific revolution is an attempt to describe the changes that happen when scientific community are making major conceptual revisions (Mareschal, 1987).

Lakatos considers that the essential element of scientific progress is the research programme, which is formed by a core idea composed from the unquestionable hypotheses. This core is surrounded by a 'belt' of a set of auxiliary hypotheses (Mareschal, 1987). According to Lakatos methodology, scientific problems consist of building the belt by improving our empirical and theoretical content. But when theoretical understanding degenerates, it is abandoned by the scientific community. Therefore, scientific progress is a competition of different programmes, where better empirical and theoretical belts constantly replace degenerating ones. The adoption of a new hypothesis is not made by faith but as a result of rational criteria based on the evidence given by the new programme (Mareschal, 1987).

According to Lakatos's interpretation, plate tectonics was accepted because of its great power of explanation, and it was a result of the competition between the Drift Programme (The continents have displaced themselves horizontally with respect to each other), the Permanentist Programme (After the original contraction of continental and oceanic crust in accordance with their density, the oceans and the continents have remained the same) and the Contractionist Programme (Earth has contracted periodically since its formation)(Mareschal, 1987).

Interdisciplinary Science

Both Kuhnian and Non-Kuhnian interpretations are right. If we try to make an interpretation in a geological way, we can conclude that, as in many geological problems, it depends on the scale which you consider. In geology, it is a temporal one. However, the acceptance of a new hypothesis is made more by logic arguments than by faith, even if the scientific community is usually conservative.

If we consider a century scale, we can appreciate that scientific evolution evolves quicker in some specific intervals of time. In this case, a Kuhnian model fits perfectly, and these specific intervals are the Kuhnian scientific revolution stage. But if we study this evolution in detail (year scale, even months), we find the interpretation given by Lakatos.

Going back to geosciences, we can conclude that, Kuhnian or Non-Kuhnian, the origin of the "D" layer or the mechanisms of behaviour of the asthenosphere are keys towards "Quantum Geology".

As outlined earlier, some aspects studied by other sciences (radioactivity, magnetism) have undoubtedly contributed to the evolution of geology. Certainly, evolution in other sciences such as chemistry and physics will help. Communication between professionals, as we have seen in the building of the Phanerozoic geologic column, allows us to make progress towards our quantum theory more easily. However, the more we are specialised, the less we know about the other geological disciplines. Furthermore, our science has been "distracted" by the rest of "earth sciences" which is less interested in pure geological research to improve learning. Consequently our community understands our science very well, but we have not been able to improve key factors, such as predictability or more precise modelling. If we want to contribute to this evolution, all disciplines must work together. Also, we should have a constant communication with members of the scientific community (physicists, chemistry professionals). If we work in this cooperative way, we will find "Quantum Geology" sooner and we will be able to handle better the problems related to education or natural hazards.

Combining Geology with other Disciplines

Combining geological knowledge with other disciplines of science such as Medicine, Biology, etc is a good way of applying our expertise to enhance mutually beneficial solutions.

Medical Geology

The International Medical Geology Association (IMGA), is a good example of such a combination, focused on **Medical Geology**. Medical Geology is the science that deals with the relationship between natural geological factors and the health of living organisms, including humans (Selinus et al, 2013). Since rocks contain the majority of natural elements that are essential to living entities, weathering processes produce the soil in which plants grow up, the water we drink has traveled through different types of rocks and soils which have an influence on its composition (Selinus et al, 2013) and volcanic eruptions can distribute many harmful elements for life such as arsenic or mercury (Selinus et al, 2013). A direct link between geology and human health is obvious (Figure 7).

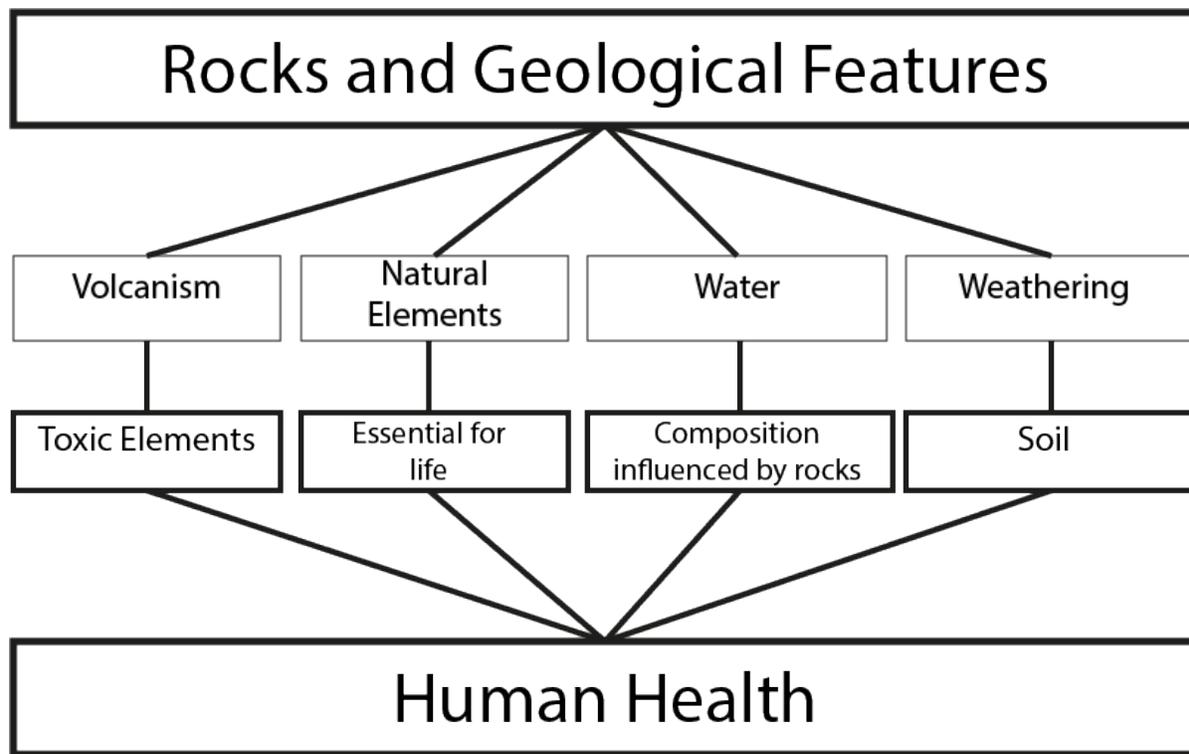


Figure 7. Summary of the link between geology and human health

In nursing, moral obligations about nursing and society are included inside their deontological code, this commitment implies that nurses must detect the harmful events on human health due to environmental causes. One of nurse's duties is to teach about health risks caused by environmental features so that people are more aware about environmental problems. Furthermore, nurses must cooperate with health authorities and participate with multidisciplinary teams which research is mainly focused on how environmental features impact on human health.

The appearance of Lalonde Report in 1974 and the Global Human Health Report made by the World Health Organization in 2000 were steps that contributed to consider the link between health and environment. Even if different international organizations have made different reports that highlight this link, few implement measures have been made. This is the main challenge nowadays. To reach so, different strategies should be planned, including education specially among health professionals. Medical Geology represents a crucial step in this task.

The awareness of the link human health/geological features and the goal of solving health problems caused or aggravated by different geological facts, are the priority goals of medical geology. To reach these goals, bringing together geologists, medicine professionals and general public is the most powerful tool. Working together allow us to reach this goal, moreover, improve human health conditions in ways that without Geology would not have been considered or have been difficult to find.

Some examples of research in medical geology are:

- The study of the effect of toxic components of coal in human health
- The potential of natural dust as a contributor of infections
- Exposure to arsenic via drinking water
- Impact of volcanic eruption on human health

In Figure 8, the measured effects of the Eyjafjallajökull (Iceland) eruption in 2010 on the inhabitants that lived near the volcano, are a good example of applied medical geology.

During the early phases of the eruption, around 250 million tonnes of ash were ejected containing around 8 million tonnes of fine particles (2.8-28 microns), most of them inhalable. Apart from ash, there were pyroclastic falls or lahars. Exposure to volcanic gases is one of the most fatal causes for human health. Short term exposure can aggravate asthma attacks. Long term exposure leads into cardiovascular diseases, chronic bronchitis, eye irritations and respiratory problems (Carlsen et al, 2012).

	All	Men	Women
N (%)		83 (50)	84 (50)
Mean age±SD (years)	52±17	54±18	50±17
BMI±SD (kg/m ²)	30.0±7	29.1±5	30.8±8
Smoking, n (%)			
Never	103 (62)	53 (64)	50 (60)
Former	34 (20)	18 (22)	16 (19)
Current	24 (14)	11 (13)	13 (14)
Self-reported asthma or COPD*, n (%)	28 (17)	10 (12)	18 (21)
Respiratory symptoms, n (%)			
Throat and upper airway irritation or dryness	83 (50)	35 (42)	48 (57)
Cough	58 (35)	28 (34)	30 (35)
Shortness of breath or tightness of chest	43 (26)	20 (24)	23 (27)
Other symptoms, n (%)			
Eye irritation	41 (25)	17 (20)	24 (29)
Headaches	15 (9)	8 (10)	7 (8)
Nausea and stomach aches	12 (7)	7 (8)	5 (6)

Figure 8. Distribution of different symptoms of the inhabitants located near Eyjafjallajökull volcano (Carlsen et al, 2012)

Carlsen et al (2012) ran a study of the affection to human health due to the eruption in the rural areas near the volcano. In this study, a questionnaire survey of the local population was made on their physical condition, respiratory problems, special treatments taken, mental health etc. In this study, there was a 93 per cent participation (Carlsen et al, 2012).

19 per cent of the population was younger than 18 years old. 13 per cent of the adults presented asthma or respiratory symptoms, 39 per cent of them worsened because of the ash. 16 per cent of the adults presented symptoms different to respiratory (Figure 8) and 13 percent of the adults presented mental symptoms (anxiety or depression), especially women (Carlsen et al, 2012). There was no geographical pattern of symptoms distribution and despite these, no hospital admission or fatality due to the eruption was found. The major symptoms were eyes and upper airways irritation. However, the life quality of people with respiratory diseases has severely worsened (Carlsen et al, 2012).

H2020

Horizon 2020 (H2020) is the Research and Innovation programme in which the EU is investing over 80 billion euros between 2014-2020. The main goal of the project is to transfer more discoveries from laboratories to the market, to bring closer research and innovation (especially on industrial leadership, social challenges and science) and to produce a world class science so that private and public sectors can work together and deliver innovation. In geosciences, this is especially centered on raw materials, but there are other projects that apply geosciences in their research, good examples are INoVA (Geochemical Controls on the Ice Nucleating Efficiency of Volcanic Ash) and KINDRA (Knowledge Inventory for Hydrology Research).

Raw Materials

The INTERMIN project is a programme destined to create an effective international network of training centres for professionals, especially in the raw materials field. To reach this goal, there is an involvement of research and educational organizations throughout the European Union and eventually extended to third countries. These organizations are coordinating between them to develop map skills and knowledge about EU and third countries in order to make easier solving gaps and emerging needs. The establishment of common training programmes at an international level is essential in this coordination. The Geoscience University Degree Program Portal (GUIDE) is a good example. GUIDE's main objectives are to integrate all geoscientific master and degrees programmes of EU countries, to provide more information to universities about different training programmes and to support international mobility. First steps have begun in this sector such as EFG Endorsed Training Courses, EuroWorkshops and **EFG International Mentoring Programme**.

INoVA

The aim of this project developed under H2020 is to understand the potential impact of volcanic ash products from explosive eruptions on climate.

Volcanic ash, formed mainly in explosive eruptions, can act as ice-nucleating particles, causing heterogeneous freezing of water located in the eruption plume (vertical and lateral) and in the surrounding atmosphere. In these contexts, ice formation and its relationship with ash is still not well known. Ice formation in these contexts is relevant due to its influence among the dynamic and the electrification of the plume, ash particles aggregation and sedimentation; gas retention; and the hydrological cycle (Maters, 2019). This is especially relevant in large eruptions, in which ash emissions exceed the annual average rate of ash particles present in the atmosphere.

First studies (Maters, 2019), show that ice nucleation depends mainly on the chemical composition, crystallinity and mineralogy of the ash particles. Crystal concentration promotes nucleation, specially alkali feldspar crystals. However, alkaline feldspar is not always enough to nucleate ice effectively, some cases show that plagioclase and orthopyroxene play a crucial role too. Since these phases are controlled by magma composition and ascent/storage conditions, it seems that felsic and intermediate magmas (rich in alkaline feldspar) are the most effective ones on ice nucleation. Apart from phases, crystal relationships within the bulk particle are also important, an abundance of crystal bearing particles having a greater impact than crystal-free glass particles. This fact explains why ignimbritic eruptions have a lower impact on ice nucleation.

Further research is still needed, especially on textural features (phases texture have also a strong influence on ice nucleation) or quantification of different phases (specially alkali feldspar, plagioclase and orthopyroxene which seem to be the most effective nucleating ice) (Maters, 2019).

INoVA is another example of the crucial role of geosciences assessing different challenges. In this case, we can observe the application of volcanology and geochemistry solving a problem relevant to the atmospheric science community.

KINDRA

The main goal of this project is to highlight the crucial role of groundwater, not only in biological or environmental needs but also in urban systems. Being underground and out of sight, groundwater is difficult to study and assess. To progress, an assessment is conducted in several steps. The first one is to create a standard structure in which different research and innovation programmes all along Europe are reported and classified. After that, all existing knowledge on hydrology is embedded in this standardized structure. Once all the information is compiled, the final step is to identify and solve different gaps in hydrogeology research such as the understanding of groundwater-surface water interactions.

Other Solutions

Other effective ways to transmit the importance of geology are:

- Cultural - explain geology to mountain climbers, landscapers or hunters, because they love going to the countryside and have different perceptions about it.
 - Seek to apply the results of specific research to an area where you have worked, so that the area may profit from it (economic or other kind). **How to do so?**
1. During fieldwork, try as much as you can, to invest in the village or different villages of the area (sleep and eat at local hotels/rural houses/restaurants). In this way you will help the economic growth of the area.
 2. Interact with local population (This may also help you during your research). For example, Christian was doing a technical audit of a base metal project in Zimbabwe in 1994 and enjoyed the hospitality of an impromptu bar in the nearby village. The project was a mine in construction and the bar was in a grass-roofed hut. Seating was on logs and the beer was unchilled, as there was neither electricity nor lighting, just an oil lamp. Nevertheless engineers, geologists and other staff enjoyed direct interaction with the community, a good example of simple social intercourse that leads to longer term cooperation and genuine local economic development.
 3. Aim to use your results in order to help the development of that area (Other geoscientists may invest in that area if the results are interesting).

Conclusions

Educational policies related to geology teaching have worsened over the years, affecting all science education in general and geosciences in particular. These policies also have a strong influence on the background of the future teachers, who have almost no formation on geology, removing any motive to teach this important scientific discipline. Apart from the teachers, students prefer to choose other subjects because they are "easier" than geology, aggravating more the disappearance of geology from the curriculum.

However, natural hazards such as earthquakes, volcanic activity, landslides or floods highlight the key role that geology, specially geomorphology, has in the application of preventative measures. Nevertheless, to do a good geomorphological study, we need to use the rest of geological disciplines. Furthermore, considering the socioeconomic systems, including of course its vulnerability, this will certainly add to an effective application of preventative measures. Eyjafjallajökull and Fuego volcanic activity, floods due to El Niño phenomenon, Felbertauern landslide are all good examples that show the enormous impact that natural hazards play on regional and national socioeconomic structures. We have seen in some cases that the authorities, due

to a lack of awareness about geological knowledge, did not consider the advice given by professionals and their own official geological surveys and consequently were not able to handle the situation.

Nowadays, our community has the ability to solve these facts. More geosciences professionals in the educational sector can be a powerful tool, for three main reasons:

1. Geology at schools and high schools will be taught correctly. Since we have more instruction of this scientific discipline, we will have more determination to teach it.
2. We will be able to encourage student to study geology more directly. Not by making the subject easier but helping them understand that our science is hard but worth it.
3. With the help of other members of the scientific community, we will be able to transmit to politicians the crucial role that geology has, especially in dealing with natural disasters and to press them to change educational policies to more accurate ones.

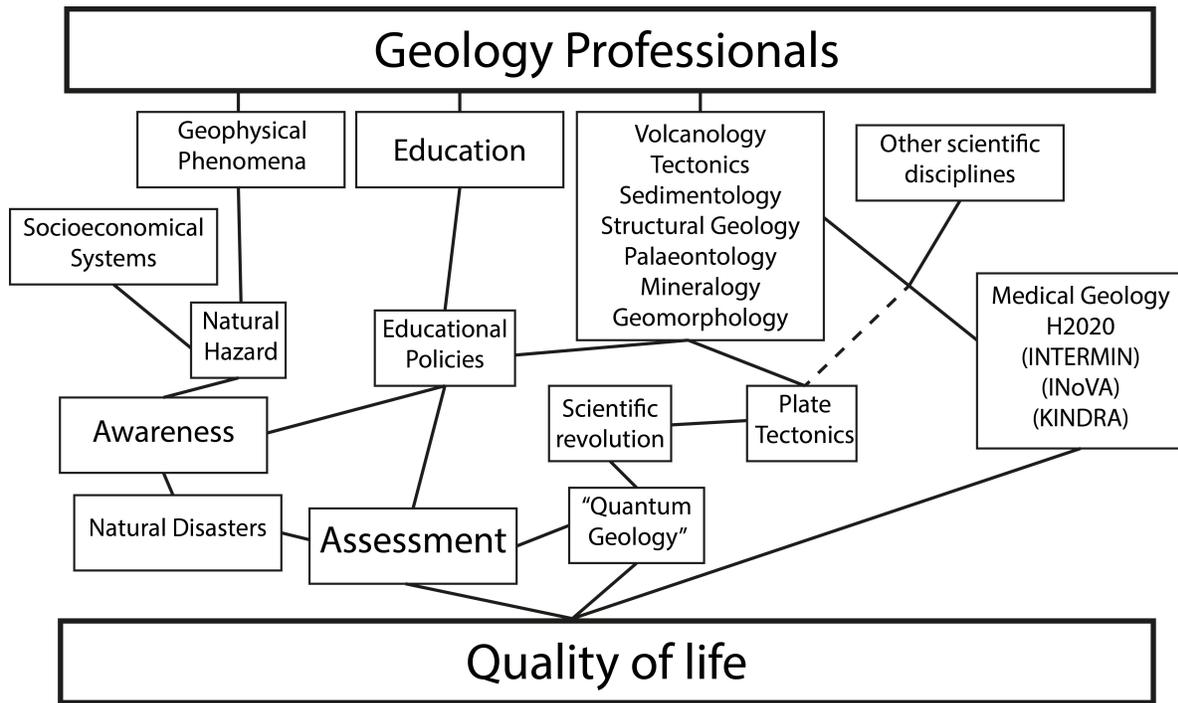


Figure 9. Graphic summary of conclusions

Nevertheless, our science needs to evolve further, like chemistry or physics. Since geology is an interdisciplinary science, it would certainly need its complementary sciences to evolve. Looking at it from the perspective of philosophy, we see that geology, as other sciences evolve through a series of stages (Kuhn) or competition of programmes (Lakatos/Popper), where a series of anomalies/auxiliary hypotheses contribute to the revision of the current hypothesis towards finding a better one. The acceptance of the new hypothesis is made by logical arguments more than by faith, even if the scientific community is usually conservative and despite the possibility of conflict between the supporters of the current hypothesis and the new one. Facts (Anomalies/Auxiliary hypotheses-Belts) that are still not well known and that can lead to a progress in plate tectonics ("**Quantum Geology**"), and in the evolution of geology, are the mechanisms of behavior of the asthenosphere or the origin and behavior of the "D" layer (Core-Mantle Boundary). Even so, this progress cannot be made by focusing only on tectonics but using all disciplines. As we have seen, evolution in different areas (paleontology, stratigraphy) led to the crisis in the tectonic discipline that gave us finally plate tectonics. ("**The best geologists have seen the most rocks**"). Progress towards "Quantum Geology" will certainly develop into a powerful tool to give geology the appreciation that our science deserves and will also help in our task of dealing with education and natural hazard problems.

Combining geology with other disciplines is also a very good tool to achieve this task. Medical Geology (represented by IMGA) shows a direct link between geological features and human health. This combination has improved the quality of life of human and living beings in ways that without geology could not have been found. **Medical geology** is a very good

example of cooperation between different members of the scientific community and it is also a good example of a structure in which geosciences are applicable facing different situations related to human/environmental health or social justice. Apart from medical geology, different projects developed under H2020, such as INTERMIN, INoVA or KINDRA are also good examples of that kind of structure.

All the features explained in this paper shows the application on geosciences in a wide variety of situations and highlight how important is to our daily life.

References

Alcantara-Ayala, I. (2002). Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology*, 47(2-4), 107-124.

Benson, C., Clay, E. (2004). Understanding the economic and financial impacts of natural disasters. The World Bank.

Brusi i Belmonte, D., Bach i Plaza, J., Domingo i Morató, M., Gassiot, X. (1993). La Geología en la enseñanza no universitaria: ¿desaparición o evolución?: la percepción del tema en el marco de la experimentación y perspectivas de aplicación de la Reforma Educativa en Catalunya. *Enseñanza de las ciencias de la tierra*, 1(3), 0134-140.

Carey, M, Jackson, M., Antonello, A. and Rushing, J. (2016) A feminist glaciology framework for global environmental change research. *Progress in Human Geography* vol. 40, 6: pp. 770-793

Carlsen, H. K., Gislason, T., Benediktsdottir, B., Kolbeinsson, T. B., Hauksdottir, A., Thorsteinsson, T., Briem, H. (2012). A survey of early health effects of the Eyjafjallajökull 2010 eruption in Iceland: a population-based study. *BMJ open*, 2(2), e000343. doi: 10.1136/bmjopen-2011-000343

Ellertsdottir, E. (2014). Eyjafjallajökull and the 2010 closure of european airspace: crisis management, economic impact, and tackling future risks.

Fuentes, Y. M., León, J. C. V. D. (2009). Los procesos de traslado forzado debido a desastres naturales: sistematización de experiencias en Guatemala. *Trace. Travaux et recherches dans les Amériques du Centre*, (56), 88-94.

Gaillard, J. C. (2008). Alternative paradigms of volcanic risk perception: the case of Mt. Pinatubo in the Philippines. *Journal of Volcanology and Geothermal Research*, 172(3-4), 315-328.

Greene, M. T. (1985). History of geology. *Osiris*, 1, 97-116.

Langmann, B., Folch, A., Hensch, M., Matthias, V. (2012). Volcanic ash over Europe during the eruption of Eyjafjallajökull on Iceland, April–May 2010. *Atmospheric Environment*, 48, 1-8.

Mareschal, J. C. (1987). Plate tectonics: Scientific revolution or scientific program?. *Eos, Transactions American Geophysical Union*, 68(20), 529-533.

Maters, E. C., Dingwell, D. B., Cimarelli, C., Müller, D., Whale, T. F., and Murray, B. J.: The importance of crystalline phases in ice nucleation by volcanic ash, *Atmos. Chem. Phys. Discuss.*, <https://doi.org/10.5194/acp-2018-1326>, in review, 2019.

Mazzocchi, M., Hansstein, F., Ragona, M. (2010). The 2010 volcanic ash cloud and its financial impact on the European airline industry. In *CESifo Forum* (Vol. 11, No. 2, pp. 92-100). München: ifo Institut für Wirtschaftsforschung an der Universität München.4.

O'Hara, K. D. (2018). *A Brief History of Geology*. Cambridge University Press.

Pfurtscheller, C., Genovese, E. (2013). The Felbertauern landslide of 2013: impact on transport network, regional economy and policy decisions. *Trans Policy*.

Selinus, O., Alloway, B. J. (2013). *Essentials of medical geology* (p. 820). J. A. Centeno, R. B. Finkelman, R. Fuge, U. Lindh, P. Smedley (Eds.). New York, NY, USA:: Springer.

Acknowledgements

We want to extend our special thanks to Gabriel Gutierrez Alonso (Departamento de Geología, Universidad de Salamanca, Spain) for his precious help, especially for Quantum Geology section. To Patricia Martin Sanchez (Nursing service at Hospital Ramon y Cajal, Madrid, Spain) for her view on Medical Geology section. To Elena Maters (School of Earth and Environment, University of Leeds, UK) for providing us references that explain in detail INoVA project and finally to our colleagues at Université Clermont Auvergne (France) for their advice on this topic.

Additional information, Websites recommended

- About EFG Mentoring Programme
- <https://eurogeologists.eu/mentoring/>

- About our cooperation under the EFG Mentoring Programme
- <https://eurogeologists.eu/efg-mentees-and-mentors-have-teamed-up-for-the-geoscience-for->
- About the disappearance of Geology in Educational Plans (The case of Spain)
- <https://www.icog.es/TyT/index.php/2017/11/la-situacion-critica-de-la-geologia-en-el-bach>
- About Volcanology and Society
 1. Eruption of Eyjafjallajkull (Iceland) in 2010
 - https://www.bgs.ac.uk/research/volcanoes/icelandic_ash.html
 - http://www.wikiwand.com/es/Erupci%C3%B3n_del_Eyjafjallaj%C3%B6kull_de_2010
 - <https://www.elmundo.es/mundodinero/2010/04/19/economia/1271680636.html>
 - <https://actualidad.rt.com/economia/view/10423-La-erupci%C3%B3n-del-volcan-island%C3%A9s-causa-graves-da%C3%B1os-econ%C3%B3micos>
 - <http://exploregeography.net/eyjafjallajokull-eruption-2010-iceland/>
 - <http://news.bbc.co.uk/2/hi/8629623.stm>
 - <https://qz.com/251927/icelands-last-giant-volcanic-eruption-cost-the-global-econ>
 2. Eruption of Fuego (Guatemala) in June 2018
 - http://www.insivumeh.gob.gt/?page_id=2816#
 - <https://disasters.nasa.gov/mount-fuego-eruption-2018>
 - <https://www.worldvision.org/disaster-relief-news-stories/guatemala-volcano-erupti>
 - <https://www.bbc.com/news/world-latin-america-46261168>
 - <https://www.bbc.com/news/world-latin-america-44393085>
 - <https://reliefweb.int/report/guatemala/guatemala-volcanic-eruption-situation-repo>
 3. Eruption of Kilauea (Hawaii) in May 2018
 - <https://www.express.co.uk/news/world/974287/hawaii-volcano-eruption-latest-pictur>
 - <https://volcanoes.usgs.gov/volcanoes/kilauea/status.html>
 - <http://blogs.discovermagazine.com/rockyplanet/2018/09/26/the-impact-of-the-2018-kilauea-eruption/#.XArd6XRKjDc>
- About International Medical Geology Association (IMGA)
- https://www.medicalgeology.org/pages/public/imga/page_imga.htm
- <https://www.medicalgeology.org/pages/public/medicalgeology/GLOSSARY.pdf>
- About H2020
- https://www.egu.eu/static/latest/policy/surveys/h2020_report.pdf
- <https://eurogeologists.eu/efg-and-egu-establish-dialogue-with-policy-makers-on-how-the-ge>
- <https://eurogeologists.eu/geoscientists-evaluate-perceived-success-of-horizon-2020-fundi>
- <https://www.inova-eu.com/>
- <http://interminproject.org/about/>
- <https://eurogeologists.eu/wp-content/uploads/2018/06/EFG-Pres.-RFG-Intermin.pdf>
- <http://kindraproject.eu/>