A career in geology?

If you have read this brochure, you probably have a basic interest in science. If you are young and creative, you may consider joining our great scientific adventure for your career – discovering how Nature works and helping to apply geological knowledge to society's benefit. There are plenty of fascinating problems yet to be solved!

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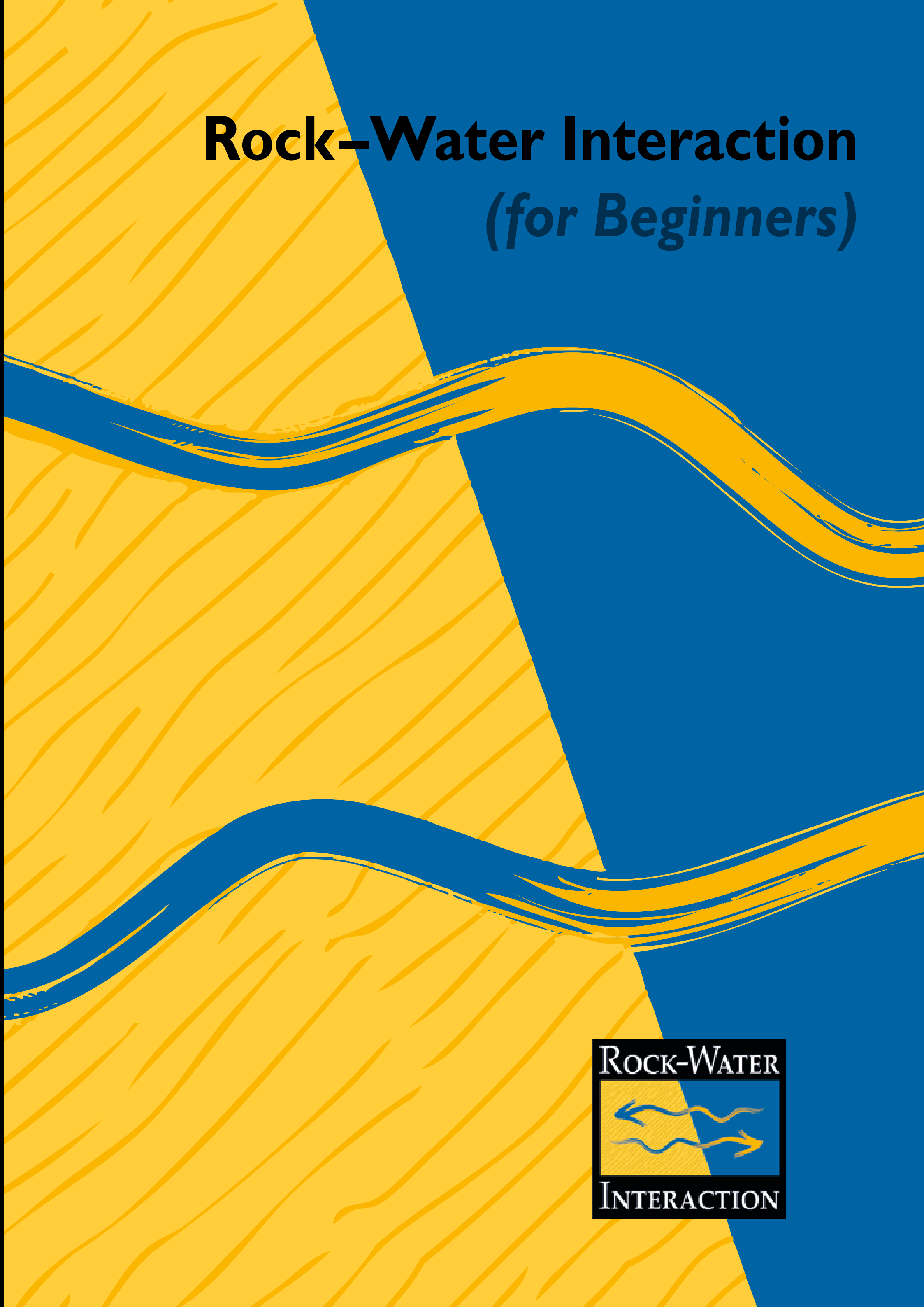

Rock–Water Interaction
(for Beginners)

Rock-Water
Interaction

Rock–Water Interaction *(for Beginners)*

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ROCK-WATER INTERACTION
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Grossus Wasser, Gondo (Photo: L.Diamond)

The term "rock–water interaction" suggests many possible processes in nature, such as riverwater smoothing down rocks over the ages of time, or ocean waves crashing into a rocky shoreline. Within the Geological Sciences, however, the term has a more specific meaning: it refers to the dominantly chemical and thermal exchanges (reactions) that occur between groundwaters and rocks. The logo of our research group (above) symbolizes such exchanges by the double-arrow symbol.

Petroleum deposits
Precious metals
Natural resources
Radioactive waste
Geothermal energy
Environmental protection
Groundwater pollution
Sequestration of atmospheric CO_2

All of the above topics are related by "rock–water interaction". Would you like to know how? In the following we explain exactly what we mean by "rock–water interaction". We also explain what motivates our research into this fascinating field. Perhaps you would like to get involved …

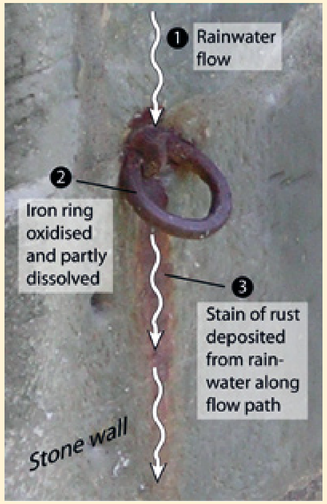
What is rock–water interaction?

We will begin our explanation with an analogy to a simple, well-known phenomenon, that at first sight has little to do with geology. Everybody is familiar with chemical reactions between water and metallic objects. To cite a rather annoying example, rainwater, which is naturally rich in dissolved oxygen, readily reacts with metals to produce the mixture of metal-oxides and hydroxides commonly known as "rust".

With time, the rainwater running over a rusting metallic surface may dissolve the rust itself, weakening the original object (e.g. your car) and rendering it porous. The rusted metal leached away by the rainwater is often redeposited as a colourful stain along the flow path of the rainwater. Common experience shows that such metal–water reactions are faster and more aggressive in warm climates (e.g. in the tropics) and in saline waters (e.g. seawater).

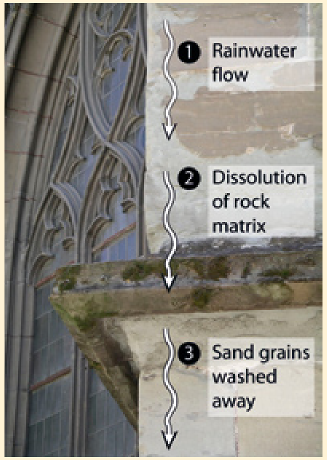
Urban decay

Not so many people realise that rather similar chemical reactions occur wherever water comes into contact with rocks, be the rocks on the Earth's surface or deep within the Earth's Crust. Rock–water reactions are much slower than those which cause pure metals to rust, because most of the minerals that make up rocks are more resistant to dissolution by rain or groundwaters. Yet over the course of centuries the effects of steady corrosion of rocks become quite noticeable, as in the case of decaying facing stones in old buildings.



Nydegg Bridge, Bern (Photo: L.Diamond)

An old iron ring in a stone wall illustrates the essential elements of rock–water interaction: (1) a water flow path: rainwater running over the stone surface, (2) a site of mineral dissolution: iron ring, (3) a downstream site of mineral redeposition: rusty stain.



Bern Cathedral (Photo: L.Diamond)

Decaying sandstone in a medieval cathedral. Rainwater (1) dissolves the minerals that cement the sand grains together within the stone (2). After several centuries of normal weathering (or after a few decades of exposure to industrially acidified rain), the facing stones literally turn to sand (3).

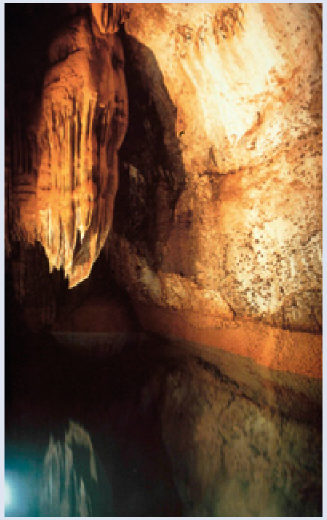


Photo: LAPIS

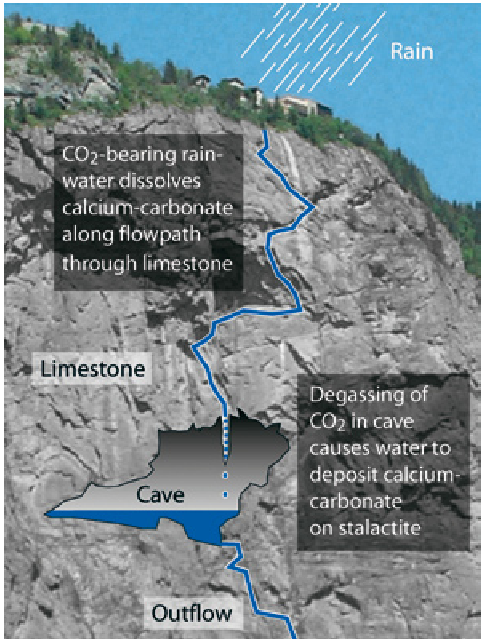
Groundwaters flowing along fractures may dissolve huge pores (caves) in limestone. Later deposition of the dissolved mineral creates stalactites.

Photo: LAPIS

New crystals of calcium carbonate are deposited at the tip of a stalactite.

Underground subversion

A more impressive example of a rock–water reaction is the subterranean dissolution of limestone by carbon-dioxide-enriched groundwaters to create caves. Caves are essentially large-scale equivalents of the pores that form in rusting metal. The dissolved limestone is often redeposited downstream along the flow path of the groundwater, wherever the groundwater makes contact with air and is able to degas. The resulting accumulations (spectacular stalactites or terraces of travertine) are conceptually the equivalents of the stain that flowing rainwater leaves as it runs over rusting metal.



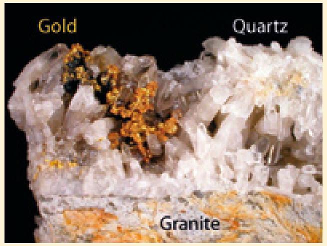
L. Diamond

BOTTLED-UP EVIDENCE

The above examples demonstrate the patient power of flowing water: it can dissolve rocks, it can transport the rock-forming chemical constituents over certain distances, and it can then redeposit the constituents in solid form again. The mineral substances contained in bottled "mineral-water" are further proof of the dissolving power of shallow groundwaters.

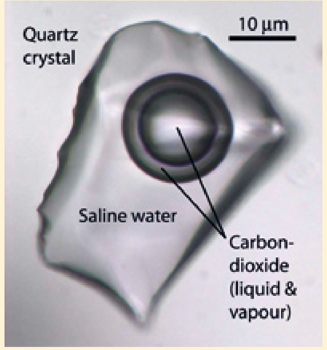
Bottled mineral-water contains both dissolved minerals (salts) and carbon-dioxide gas, which are the products of chemical reactions between subterranean waters and the adjacent rocks.

Thirsty daughter, Bern (Photo: L.Diamond)



Gold-quartz vein, Brusson (Photo J. Megert)

Both the quartz and the gold in this rock enclose tiny droplets of ancient mineral-water known as "fluid inclusions". Such inclusions are proof that metals as inert as gold can be dissolved and redeposited from circulating waters deep in the Earth's Crust.



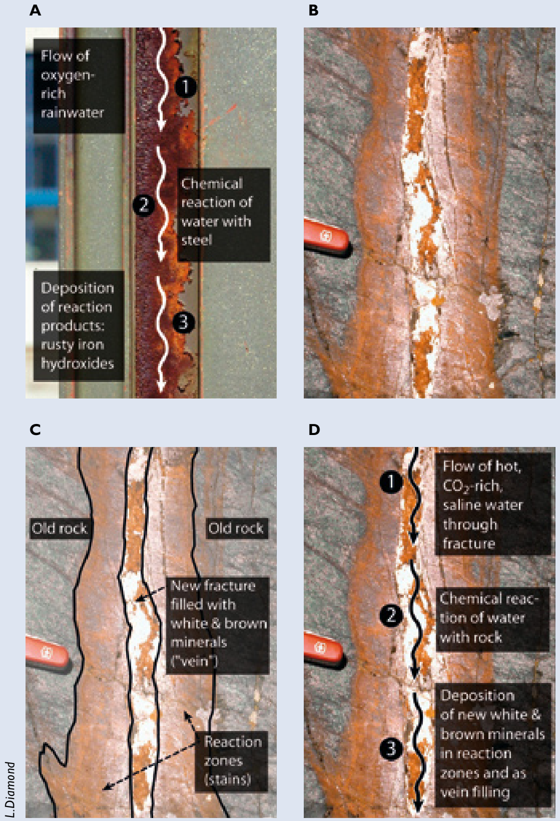
(Photo: L.Diamond)

A natural bottle of mineral-water: a "fluid inclusion" trapped in quartz, viewed through a microscope.

Deep-seated aggression

While tepid rainwater or chilly cavewaters can work wonders with time, the chemical aggressiveness of such waters is trivial compared to the saline, gassy, pressurized, searing-hot waters that circulate deep below the Earth's surface. The scorching geysers and vile vapours that emanate from active volcanoes are surface manifestations of these deep fluids.

At the Earth's surface our favourite bottled mineral water is delicate and agreeable, fizzing in a very satisfying way when the pressure cap is released. If we were to travel deep into the Earth we would encounter large quantities of such water, but with increasing depth it would become more and more aggressive and decidedly unfit for drinking: the increasing temperature and pressure aid its capacity to dissolve minerals, and the increasing mineral content enhances its corrosive power even more. Under the most extreme conditions in the Earth's Crust – at depths of tens of kilometres, under pressures many thousands of times higher than normal atmospheric pressure, at temperatures of up to 800 °C, and with dissolved mineral and gas concentrations of up to 60% by mass – water becomes a supreme solvent, able to dissolve metals as noble as titanium, platinum and gold.



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A *A steel wall that has reacted with cold rainwater to form iron-hydroxides (rust).*

B *A vein in a rock outcrop. The vein consists of patchy white and brown minerals, and it is bordered by a rusty stain.*

C *The lines mark the outlines of the vein, which was initially an open fracture in the old, pre-existing rock. The rusty border zones and the white and brown minerals filling the fracture are products of natural chemical reactions that occurred millions of years ago at high temperature and pressure, deep within the Earth's Crust.*

D *The history of rock–water interaction can be reconstructed as follows: (1) a hot, saline, carbon-dioxide-bearing mineral-water flowed through the fracture; (2) the water reacted with the rock on each side of the fracture; (3) the reaction products (new white and brown minerals) filled the fracture, creating a vein and staining its borders. Thus, the processes that created the vein are rather similar to those that rusted the steel wall in picture* **A***.*

SELF-TEST

You have now acquired enough knowledge of rock–water interaction to conduct a thought experiment as a self-test. The gold reserves of the Swiss National Bank are reputedly stored in secure vaults below the Federal Square in the capital city, Bern. Using the principles of rock–water interaction presented above, devise a flow path that channels deep mineral waters so as to (1) dissolve the walls of the vaults and the gold reserves, (2) pump the gold out of the vault in dissolved form, and (3) redeposit the gold downstream on the surface of your car (thereby preventing unwanted rust).

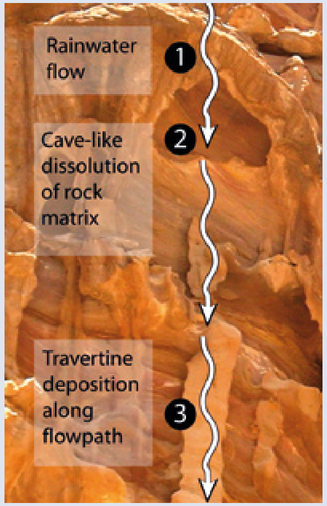
Bundesplatz, Bern (Photo: L.Diamond)

The National Bank of Switzerland is an interesting subject for a "thought experiment" in rock–water interaction.

TIP: Keep your answer to yourself.

Crusty scepticism?

By now, several questions have probably occurred to you: How do we know all these facts about water in the Earth's Crust? Where does all the deep water come from? What mighty forces cause water to move upwards through rocks rather than downwards? How can water circulate through the Crust if the Crust is supposed to be solid? Are the deep rocks that make up the Crust porous and rusty owing to leaching, or are they stained and clogged by mineral deposits? Has rock–water interaction being going on since the Earth was formed or is it only a recent trend? Just what are the consequences of all this deep-seated physical agitation and chemical aggression?



Petra, Jordan (Photo: L.Diamond)

Like decaying cathedrals, sandstone cliffs become cavernous as rainwater dissolves the minerals that cement the sand grains together.

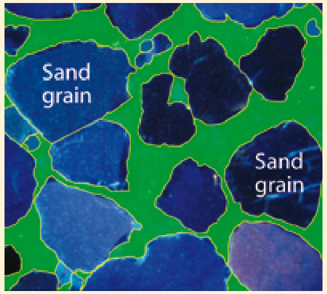
Natural consequences

For all of the above questions, geologists have fascinating, albeit only partial, answers. In fact, these questions are the subject of active research by hundreds of geologists around the world, including those in our institute at the University of Bern. For the moment we shall answer only the last question, because of its direct relevance to modern society. This relevance is illustrated below by examples of the consequences of rock–water interaction. The examples will also make clear why geologists are investing so much effort to answer the other questions!

Rock–Water lab, University of Bern (Photo: L.Diamond)

Highland Valley Mine, British Columbia (L.Diamond)

The shiny metallic rock under the geologist's boot is not gold but it is still a valuable "ore". The rock contains a copper-sulphide, which is the main source of copper for the world's industries. Millions of years ago, an unusual sequence of natural events caused hot mineral-waters to precipitate copper in extremely high concentrations in a small area of what is now British Columbia. By understanding the rock–water interaction that formed this ore deposit, the booted geologist is able to find similar deposits in other localities. These can then be mined to feed the industries that install your copper electrical cables and water pipes.



Haushi Fm. Oman (Photo: L.Diamond)

This colour-enhanced, highly magnified microscope image shows sandstone drilled from 1500 m depth in an oil field. Oil and natural gas can sit within or migrate through the large volume of pores (here rendered visible by green epoxy) between the sand grains (blues).

Formation of metallic ore deposits

Deep waters have circulated through the Earth's Crust since it first formed more than 3 billion years ago. Along the hottest reaches of their flow paths the waters leach metal particles that are normally finely dispersed in the adjacent rocks. Along the coolest stretches of the flow paths, or where chemically reactive rocks are penetrated, the solubility of the metals decreases, causing them to be redeposited in relatively small regions of the Crust, that is, in high concentrations. In their originally dispersed form the metals are worthless, but once concentrated into "ore deposits" by this natural rock–water interaction, the metals become economically attractive. Repeatedly in the history of the Earth, fault movements within the Crust have thrust the ore-bearing rocks close to the Earth's surface, where subsequent erosion has exposed them to view, ready for the prospector's eager hammer. To this favour of Nature we owe most of the accessible resources of metals such copper, iron, zinc, uranium, silver, gold and many more, on which our industrialised society is so dependent. The challenge for geologists is to reconstruct the history of fluid flow, rock–water interaction and rock uplift, so that the location of hitherto unknown deposits can be predicted. This is detective work at its finest!

Formation of oil and natural-gas deposits

Hydrocarbon deposits in the Earth's Crust derive from the decay of plants and marine organisms that have been buried by sand and mud, as rivers dump their load of eroded rock-particles along the ocean shores. Sealed off from free oxygen and subject to the elevated temperature and pressure that accompanies progressive burial, the decaying organic matter slowly transforms into crude oil and methane gas. If these products accumulate in a relatively small region of the crust, then economically exploitable deposits may be formed.

The accumulation process involves migration of the oil and gas, but whereas gas is highly mobile, oil is sticky and it tends to clog in rock pores. This is where rock–water interaction comes into the story: circulating groundwaters flush the oil through porous rocks and thereby drive its upward migration. However, there are circumstances under which these groundwaters partly dissolve the mineral grains in the overlying sediments, enhancing their porosity. This allows the oil and gas to reach the Earth's surface, where the hydrocarbon molecules are broken down by reaction with oxygen or by bacteria. Thus, potentially valuable hydrocarbons are destroyed, without society being able to profit first from the associated release of energy.

Under other circumstances, the circulating groundwaters may deposit minerals in the pores of the overlying sediments, rendering the rocks impermeable and trapping the migrating oil and gas. Subsequent faulting may play a role in sealing or breaching oil and gas reservoirs, and temperature and time are also important factors, altogether making for a rather complex tale.

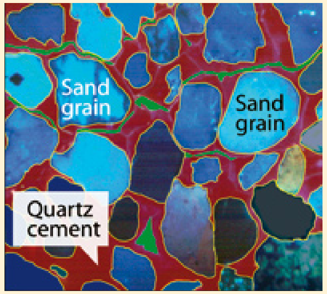
The challenge that geologists face here, just as in the case of metallic ore deposits, is to understand the history of rock–water interaction in sedimentary basins and to predict where economic deposits of oil and gas may lay hidden, ready to be pierced by the drill-bits of oil exploration companies.

Explosive Volcanism

Volcanic eruptions are a major threat to human settlements in some parts of the world, and they are a contributor of atmospheric gases, including carbon-dioxide, throughout the world.

In your travels around the globe you may have noticed that there are two kinds of active volcanoes. First, there are those which disgorge slow-moving rivers of viscous lava or occasionally spit out fiery fountains (specially-clothed volcanologists can approach these lavas and poke sampling rods into them, e.g. on Hawaii or Galapagos). These are nice volcanoes.

Then there are those which are cordoned off from visitors for many kilometres around – these are the ones that blow their tops off in fantastically violent explosions, generating gas-plumes that rise thousands of metres into the atmosphere and throwing a thick blanket of hot ash over large areas of the countryside. These are the bad volcanoes that bury cities (e.g. at Pompeii) and build mountain chains (e.g. the Andes).



Haushi Fm. Oman (Photo: L.Diamond)

This colour-enhanced image shows sandstone drilled from 4000 m depth, far below the oil-field sample displayed on the previous page. As well as being more tightly packed together, the sand grains are cemented by quartz (reddish-brown) that was deposited from circulating groundwaters. Only a small volume of pores remain (green epoxy). Because of the lack of connected pores, this rock can neither store oil nor act as a channelway during oil migration.

Stromboli, Italy. (Photo: M.Mazurek)

In the absence of interaction between water and the magma chamber beneath this volcano, the eruptions are impressive but relatively harmless.

Mt. Saint Helens, Oregon, USA. (Photo: USGS)

Strong interaction between water and the magma chamber beneath this volcano leads to a catastrophic eruption of steam, ash and rock fragments. The fallout from such eruptions can bury hundreds of square kilometres of the surrounding countryside.

(Photo: J. Megert)

A do-it-yourself-experiment in explosive volcanism. Minutes prior to the 1980 eruption of Mt. Saint Helens, Oregon, a landslide on the summit of the volcano suddenly released pressure on the underlying magma, allowing the water and carbon-dioxide gas in the magma to froth out explosively. You can simulate this process by quickly removing the cork in a bottle of "experimental magma".

The difference between the two lies in the extent of the rock–water interaction far below the throats of the volcanoes, in the chambers where Nature brews her magmas. Under the Andean-type volcanoes (Mt. Saint Helens is an example), deep circulating groundwaters are absorbed in the stewing magma (protective clothing will not help you in this environment). The massive pressures at these depths enhance the solubility of water in the molten rock, just as pressure enhances the solubility of carbon-dioxide in water. When the water-bearing magma ascends rapidly into the throat of a volcano, the tremendous drop in pressure reverses the solubility of the water, causing it to froth out instantaneously in an explosive foam of expanding steam.

The power of such eruptions is devastating: both the magma and the vent of the volcano are torn apart, and enormous volumes of rock are thrown into the air. By contrast, under the Hawaiian or Galapagos volcanoes very little water is able to interact with the magma and so little steam escapes from the lava as it erupts. Relatively gentle eruptions are the result.

Geologists around the world are conducting research to understand exactly when and where deep water and other gases interact with magmas to generate explosive volcanic eruptions. Until this understanding is complete, you are advised to visit only the nice volcanoes.

Unnatural consequences

All of the above consequences of rock–water interaction are purely natural phenomena, beyond our control and still only barely within our scientific comprehension. In addition, there are several important processes of rock–water interaction that relate to society‘s use of the Earth‘s surface. Some examples are given below.

Geothermal Energy

The recognition that fossil-fuels are limited and unrenewable has logically steered society‘s attention to alternative energy sources. Among the great energy reservoirs of our planet is the internal heat of the Earth itself. The deeper we drill into the Crust, the hotter the rocks become. This is due to two reasons: on the one hand, the Earth still contains residual heat left over from its hot-tempered birth as a primordial planetary body several billions of years ago. On the other hand, elements such as uranium, thorium and potassium, which are especially enriched in rocks of the Crust, continuously generate new heat via their spontaneous radioactive decay. All this internal heat is slowly diffusing to the Earth‘s surface, but the rate of heat loss to outer space is very slow, guaranteeing us a hot-blooded planet for eons to come.

In many places around the world this free “geothermal” heat is being exploited to generate electricity or to heat buildings. How is the heat extracted? By rock–water interaction, of course. One approach is to drill deep and tap into naturally circulating groundwaters that are heated by the rocks at depth. The hot water (or steam) is extracted through boreholes to the Earth‘s surface where it is used to generate electricity or to heat buildings. Where there is no natural groundwater circulation, surface water can be pumped down drillholes into the hot underground. Once the water is heated by the surrounding rocks it can be recovered in adjacent boreholes. Thus, an artificial flow path is created.

Free geothermal energy sounds like a great deal, but in addition to the extraction costs, there are numerous geological problems associated with its exploitation. Heat flow to the surface is not uniform around the world, and in some areas drilling would have to be undertaken to uneconomic depths to find rocks that are sufficiently hot for heat extraction. Also, as we have learned in the paragraphs above, circulating hot water in the Crust inevitably leads to dissolution, transport and redeposition of minerals. In the case of heat-extraction projects, the pores in the water-bearing rocks may become clogged by mineral deposition, eventually stemming flow. This can limit the productive lifetime of a geothermal region, even though heat may still be available at depth.

Old Faithful, Yellowstone, USA (Photo: USGS)

Geysers are proof that superheated groundwater lies near the Earth‘s surface.

Wairakei, New Zealand (Photo: L. Diamond)

This power station converts the thermal energy in superheated groundwater into electricity. Excess steam escapes like a geyser from the cooling tower.

Photo: NAGRA

Radioactive waste in a metal canister. In view of what we know about the chemical aggressiveness of deep groundwaters, we must carefully evaluate where to bury radioactive and other toxic wastes so that the canisters remain intact far into the future.

Photo: L. Diamond

Anthropogenic emissions of CO_2 are driving global warming and climate change. One way to slow this trend is to pump industrial CO_2 waste into deep geological formations that act as gas traps. Expoited natural-gas reservoirs are a good choice for this purpose.

Current research into rock–water interaction in geothermal fields is directed at ways to enhance energy production and to avoid clogging of the rock pores.

Underground repositories for toxic wastes and greenhouse gases

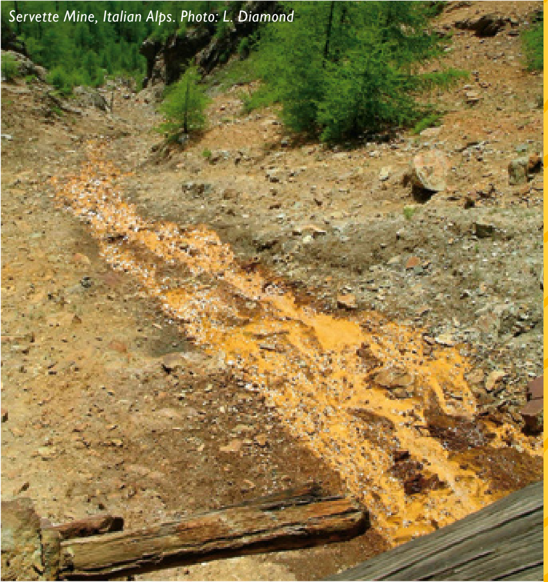
Chemical industries, scientific research institutions, hospitals and nuclear power plants all produce hazardous waste. Often this waste is held in interim storage at the Earth‘s surface, but gradually more of it is being isolated from the biosphere by placement in deep underground repositories.

This disposal concept makes a lot of scientific sense, but there are complications: if enough natural groundwater comes into contact with the waste containers for long enough time, then the protective canisters may dissolve and liberate their hazardous contents. In the worst-case scenario, the migrating groundwater may leach the toxic constituents and carry them up into permeable rock layers from which drinking- or irrigation water is obtained. Our challenge as geologists is to understand where and when such groundwaters may be active and so aid in finding geologically suitable sites for new waste repositories. Modern understanding of rock–water interaction has also triggered a systematic re-evaluation of old waste-disposal sites that may no longer be impermeable to groundwaters.

Most recently, research into rock–water interaction has begun to explore ways to reduce the content of CO_2 and other greenhouse gases in the Earth‘s atmosphere, and so mitigate global warming. Pilot studies are underway to sequester industrial CO_2 in exploited natural-gas reservoirs that we know to have remained gas-tight for millions of years.

Rock–Water Interaction and Society

Above are just some of the interesting examples of rock–water interaction that we could mention. Our research group is particularly interested in natural processes relevant to the exploitation of Earth‘s resources, and to the protection of the environment. We address these fields for two reasons. First, we can apply the same scientific methods of investigation to both cases. You may have noticed how similar the above examples appear once they are described in terms of fluid flow paths, sites of chemical reactions (such as dissolution and precipitation) and so on. We often find that our understanding of one of these fields helps to solve problems in the other. Second, we recognise the dilemma that society faces in achieving sustainable development. On the one hand, society continuously demands new supplies of natural resources, including metals and other minerals, water and energy-sources. Indeed, finding new resources is one of the main applications of the Geological Sciences. On the other hand, exploitation of natural resources almost always affects the local environment. Here too, we can make a unique contribution to ameliorating such impacts, because as geologists we are trained to assess the causes of groundwater contamination. The greatest challenge in applying our geological knowledge is to satisfy both aims simultaneously: to find a sustainable balance between the two necessities of exploiting the Earth‘s resources and protecting the environment.



Servette Mine, Italian Alps. Photo: L. Diamond

The old wooden beams in this photograph support the entrance to a mine that once supplied Italy‘s industries with valuable copper, iron and sulphur. Now long abandoned, the mine is leaking rusty groundwater that is highly acidic and rich in dissolved toxic metals. If this mine were near an urban water supply the pollutants would have to be carefully treated or the mine made impermeable to groundwater. Knowledge of rock–water interaction is the scientific basis for such tasks of environmental protection.