

The Complex Science between Water, Air, and Geology

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Some of what I'm writing here is general knowledge for different people, and other stuff is new research of our research team. What this editorial short article hopes to bring is some interesting facts and examples of geology and its interaction with water and air. It is written for a general audience from high school kids to the academic circles. It is important for everyone to understand how extremely it is to protect Earth to save the long-term future of our species.

All humans are taught the water cycle, and learn from school that we get water from rain, dams, and eventually taps. Water, after breathable air, is the most important substance on Earth (capital E because it is the name of our planet). We see the rain and rivers that run all the way down to the ocean. Water is important to all of us, and we use it for activities such as skiing, swimming, diving, fishing, boat cruises, and more. But most importantly, water makes up organic matter and forms the most vital part of our diets. Water matters most, and most living species abide by the rules of nature and the necessity for air and water. The natural water cycle, that is without human impact, is shown in Figure 1.



Figure 1: This diagram shows the Earth's "Natural" water cycle, omitting the significant impacts of human influences (left bottom corner of the diagram).

Water is important because water, together with air, govern the existence, survival, and evolution of all species. The first oxygen produced by cyanobacteria was isolated in minerals and seawater, but between 2.4 Ga (giga annum = 1 billion years) and 2.5 Ga, cy-anobacteria produced enough oxygen to be stored in the atmosphere of Earth. Through evolution much later ocean animals became multicellular bodies with shells and exoskeletons formed of calcium carbonate (CaCO₃) that eventually formed limestone.

The first oxygen produced by cyanobacteria was isolated in minerals and seawater, but between 2.4 Ga (giga annum = 1 billion years) and 2.5 Ga, cyanobacteria produced enough oxygen to be stored in the atmosphere of Earth. Through evolution, later ocean animals became multicellular bodies with shells and exoskeletons of calcium carbonate (CaCO₃) that eventually formed limestone. The formation of carbonate rocks like limestone and dolomite (CaMg(CO₃)₂) form excellent aquifers by forming underground cavities and caves linked to the surface by springs and sinkholes. These weather easily through dissolution where it dissolves and increases the water's hardness.

Quartz (SiO₂), zircon (ZrSiO₄), rutile (TiO₂), and ilmenite (FeTiO₃) are what you see in beach sand. People mine the last two for titanium, and zircon, when crystallized nicely, is used as a cheaper, but more resistant, substitute for diamond in jewellery. These are the most persistent minerals that do not decompose (change in mineralogy; chemical weathering) in water and contribute the fluvial deposits and the salinity of the ocean. Diamond is carbon and breaks down over time like coal and carbon-based life forms. Quartz is the only common rock-forming mineral that can only disintegrate (break into smaller pieces of the same mineral; physical weathering) and cannot in nature decompose.

Geology is important. As someone said: astronomy gave us distance, and geology gave us time, and it is perfectly true as the universe is roughly 13.8 billion years old, and our planet around 4.56 billion years.

I'm a geologist and I focus on the vadose zone, also known as the unsaturated zone. Below it is the phreatic zone, that is saturated, and referred to as aquifers. In the vadose zone the top part is the soil zone or plant root zone where plant roots and evapotranspiration dominate the surface-to-ground interaction. It is well researched in soil science and is a fundamental part of the water cycle that determines what water returns to the atmosphere or the ocean, and what water infiltrates into the intermediate vadose zone.

People, for drinking and residential use, generally like water from dams because they see it. But they are literally walking on (ground-)water. Surface water is strongly affected by contamination (elevated concentrations) and pollution (contamination with adverse effects), and water losses through evaporation. The vadose zone stores water and transmits it to the phreatic zone, and vadose zones and phreatic zones alternate through the Earth's (capital letter because it's the name of our planet) crust to very deep depths. Hydraulic fracturing (fracking) is a drilling method with which you induce fracturing and permeability to inject and store water, or to extract shale gas.

What people don't know is that the water cycle is complex, and the majority of fresh, liquid water we can't see. 96% of this water is underground, with the other 4% accounted for in the atmosphere and surface water. The hydrological equation describes the relationship with 100% precipitation entering the system, and some being lost on surface through evaporation and transpiration, with evaporation likely removing vast amounts of the surface water. Some of the free surface water form runoff that form streams and rivers that form lakes and eventually reaches the ocean. The hydrological equation is shown in equation (1), where P = precipitation, ET = evapotranspiration (because it's hard to distinguish between evaporation and transpiration), R = runoff, I = infiltration, and ΔS = change in storage.

$P = ET + R + I + \Delta S (1)$

Storage changes by abstraction or drying in unconfined aquifers (those where the water table is in contact with atmospheric air at depth) resulting in lower water and desaturation of the aquifer. This is exacerbated in confined system (those with an overlying low-permeability layer reducing vertical movement substantially) where recharge is limited.

The journey of that 96% is poorly studied and poorly understood. We know what infiltrates, and we know what recharges the aquifer. But the variable flow direction, water content, and travel time make it very difficult to understand these systems. It took our research team many years and a lot of research funding through the Water Research Commission (www.wrc.org.za) to improve the understanding of this complex system. The vadose zone includes the plant root zone, intermediate vadose zone, and capillary fringe, be-

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cause all of this are under negative pore water pressures despite part of the capillary fringe being saturated. This is shown in Figure 2.

The intermediate vadose is complex and we studied it in details. We call the intermediate vadose zone the *Black Box of the Water Cycle* because water infiltrates from surface, and baseflow is seen in the aquifer, but no-one really knows or understands what happens in-between. We also have a LinkedIn group called Intermediate Vadose Zone because there wasn't one. The intermediate vadose zone is currently an in-and-out system bypassed, yet responsible for 96% of all that liquid fresh water, how it is stored, and how it moves. It's importance is exacerbated by it often being estimated or assumed in calculations, models, management, development, engineering, and general water sciences to name a few. This is shown in Figure 3, and with urban impacts in Figure 4.



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Fractured aquifers have continuous sets of intersecting fractures that can become more fractured due to historical tectonic faults that break rock due to rupturing and movement by regional and continental forces. These systems store lots of water for very long periods, and make them reliable for being high yielding and with generally very clean water. Dewatering of mines, excavations, and other infrastructure require proper identification of the long-term mechanical behaviour of the rock, as well as the substantial amount of water that will be released over time and forever, unless the aquifer is mined (excessive use overriding natural recharge of the aquifer causing it to no longer supply water).

Fractured rock is common and often predominant in the intermediate vadose zone. At this depth transported soils such as aeolian and coastal sands can exist to great thicknesses of tens of metres. The critical parameters that influence flow through rock fractures depend on the most important critical fracture characteristic are orientation, aperture, roughness, connectivity or continuity (persistence), and spacing (Jones et al. 2016). Groundwater in fractured systems is dependent on the orientation and intersections as shown in Figure 5, and with photographic examples in Figure 6. Flow in vertical fractures flow faster in rivulets or streams, and flow in horizontal fractures flow slower in films covering the entire surface.

Fracture flow is simplified by the cubic law that is well described in literature. For the purpose of this paper, all that is necessary to know is that the cubic law takes the aperture of the fracture and simplifies it to a set of parallel plates as shown in equation (2) and (3) where K_f represents the fracture hydraulic conductivity as a function of water's kinematic viscosity (υ), density (ρ), and gravitational acceleration (g). The natural and parallel plate fractures are shown with no and different infill materials in Figure 7.

$$K_f = \frac{ge^3}{16\pi^3} = \frac{\rho ge^2}{16\pi^3} \tag{2}$$

$$12vb 12\mu b$$

$$K_f = \frac{ge^2}{12\nu} (3)$$





Figure 6: Left: the water table is in the fractured quartzite and sandstone rock of the Msikaba Formation (Eastern Cape, South Africa); right: vertical joints in sandstone with flowing water of the Clarens Formation (Clarens, South Africa) (© Matthys Dippenaar).



plates; bottom: effects affecting the usability of the parallel plate model (Dippenaar et al. 2022).

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Karst is the landscapes developing due to the dissolution of soluble rock like limestone and dolomite. South Africa has springs supplied the capital city Pretoria, and other places where sinkholes became large water-filled cavity due to continuous weather and erosion. These provides substantial amounts of water that was Pretoria's sole supply for decades and still contribute 8-10% of the city's water supply. Karst systems pose risks for development as sinkholes can form in developed areas. It is also very vulnerable to contamination due to direct water access through sinkholes. Development necessitates very specific regulations to prove that there is low to no risk of sinkholes falling under infrastructure, and recommendations should be made to mitigate those risks. Photos of Wondergat and Grootfontein are shown in Figure 8.



Figure 8: Left: Wondergat (wonder hole) is the biggest natural hole in South Africa, and it is near Lichtenburg; right: collection chamber for Grootfontein (big fountain) that supplies water to Pretoria in South Africa (© Matthys Dippenaar).

Sinkholes can form because there are cavities below land surface that can be filled with water (which is more incompressible that the rock as it is densest in its liquid state) meaning that it is safe. However, when it is dewatered and air enters into the cavity, erosion occurs, and a sinkhole forms on surface. This water can enter through grykes that are enlarged vertical joints that decomposed over time (mature karst), and they are separated by pinnacles as shown in Figure 9, or through epikarst that is younger fractured limestone or dolomite. This has detrimental consequences on the infrastructure and the possible threat to human life.



Figure 9: (a) Mechanisms of sinkhole formation due to erosion of wet or dry soil;
(b) sinkhole due to leaking pipe in Centurion, and (c) in Khutsong (South Africa)
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Humans have enormous impacts on the environment, and most of it is not positive. While many people aim for sustainability, no plastic, saving the Amazon, and environmental awareness, it is not plausible given the overpopulation of Earth, and the drive for fiscal wealth. We must remember that we're part of natural evolution. We are the product of five extinctions and evolution since the Cambrian Explosion roughly 535.8 million years ago. But we are not the only species that matters or that we deem to be in charge. Every living species currently on Earth and that is dying out in a rapid rate due to the activities of mankind (read *The Sixth Extinction: Patterns of Life and the Future of Humankind* by Richard Leaky and Roger Lewin).

Figure 10 shows some impacts on the water cycle. Humans need to listen to scientists and say "I don't trust" or "I don't understand" rather than "I don't believe" because science is not a religion. It is proven and based on many mistakes that is necessary to find the next necessary step. You can have both. Science develops over time, and science is important. And knowing fundamental sciences such as geology that dictates the formation of everything around us is very important. So, let's all put in effort to use and understand science properly.



After reading this you now understand that basic and everyday things like rocks, water, and air are fundamental sciences that developed over a very, very long time.

References

- 1. The karst stuff come from our book "Hazardous Karst" that is under final review at the Groundwater Project at www.gw-project. org.za.
- 2. Dippenaar MA. "Hydrological Heritage Overview: Johannesburg Gold in the Rand, Water from the Land". Water Research Commission (2015).
- 3. Dippenaar MA, Jones BR, Van Rooy JL, Maoyi M and Swart D. "The Vadose Zone: from Theory to Practise". Report K5/2826. Water Research Commission. Pretoria (2022).
- 4. Schirmer M, Leschik S and Musolff A. "Current research in urban hydrogeology A review". Advances in Water Resources 51 (2013): 280-291.
- 5. Jones BR, Brouwers LB, van Tonder WD and Dippenaar MA. "Assessing geotechnical centrifuge modelling in addressing variably saturated flow in soil and fractured rock". Environmental Science and Pollution Research 24 (2018): 13203-13223.

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